Intel Architecture Software Developer's Manual

Volume 2: Instruction Set Reference

NOTE: The *Intel Architecture Software Developer's Manual* consists of three volumes: *Basic Architecture*, Order Number 243190; *Instruction Set Reference*, Order Number 243191; and the *System Programming Guide*, Order Number 243192.
Please refer to all three volumes when evaluating your design needs.

1999

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

1

About This Manual

CHAPTER 1
ABOUT THIS MANUAL

The *Intel Architecture Software Developer's Manual, Volume 2*: *Instruction Set Reference* (Order Number 243191) is part of a three-volume set that describes the architecture and programming environment of all Intel Architecture processors. The other two volumes in this set are:

- The *Intel Architecture Software Developer's Manual, Volume 1: Basic Architecture* (Order Number 243190).
- The *Intel Architecture Software Developer's Manual, Volume 3*: *System Programing Guide* (Order Number 243192).

The *Intel Architecture Software Developer's Manual, Volume 1*, describes the basic architecture and programming environment of an Intel Architecture processor; the *Intel Architecture Software Developer's Manual, Volume 2*, describes the instructions set of the processor and the opcode structure. These two volumes are aimed at application programmers who are writing programs to run under existing operating systems or executives. The *Intel Architecture Software Developer's Manual, Volume 3*, describes the operating-system support environment of an Intel Architecture processor, including memory management, protection, task management, interrupt and exception handling, and system management mode. It also provides Intel Architecture processor compatibility information. This volume is aimed at operating-system and BIOS designers and programmers.

1.1. OVERVIEW OF THE *INTEL ARCHITECTURE SOFTWARE DEVELOPER'S MANUAL, VOLUME 2*: *INSTRUCTION SET REFERENCE*

The contents of this manual are as follows:

Chapter 1 — About This Manual. Gives an overview of all three volumes of the *Intel Architecture Software Developer's Manual.* It also describes the notational conventions in these manuals and lists related Intel manuals and documentation of interest to programmers and hardware designers.

Chapter 2 — Instruction Format. Describes the machine-level instruction format used for all Intel Architecture instructions and gives the allowable encodings of prefixes, the operand-identifier byte (ModR/M byte), the addressing-mode specifier byte (SIB byte), and the displacement and immediate bytes.

Chapter 3 — Instruction Set Reference. Describes each of the Intel Architecture instructions in detail, including an algorithmic description of operations, the effect on flags, the effect of operand- and address-size attributes, and the exceptions that may be generated. The instructions

are arranged in alphabetical order. The FPU, MMX™ Technology instructions, and Streaming SIMD Extensions are included in this chapter.

Appendix A — Opcode Map. Gives an opcode map for the Intel Architecture instruction set.

Appendix B — Instruction Formats and Encodings. Gives the binary encoding of each form of each Intel Architecture instruction.

Appendix C — Compiler Intrinsics and Functional Equivalents. Gives the Intel C/C++ compiler intrinsics and functional equivalents for the MMX™ Technology instructions and Streaming SIMD Extensions.

1.2. OVERVIEW OF THE *INTEL ARCHITECTURE SOFTWARE DEVELOPER'S MANUAL, VOLUME 1*: *BASIC ARCHITECTURE*

The contents of the *Intel Architecture Software Developer's Manual, Volume 1*, are as follows:

Chapter 1 — About This Manual. Gives an overview of all three volumes of the *Intel Architecture Software Developer's Manual*. It also describes the notational conventions in these manuals and lists related Intel manuals and documentation of interest to programmers and hardware designers.

Chapter 2 — Introduction to the Intel Architecture. Introduces the Intel Architecture and the families of Intel processors that are based on this architecture. It also gives an overview of the common features found in these processors and brief history of the Intel Architecture.

Chapter 3 — Basic Execution Environment. Introduces the models of memory organization and describes the register set used by applications.

Chapter 4 — Procedure Calls, Interrupts, and Exceptions. Describes the procedure stack and the mechanisms provided for making procedure calls and for servicing interrupts and exceptions.

Chapter 5 — Data Types and Addressing Modes. Describes the data types and addressing modes recognized by the processor.

Chapter 6 — Instruction Set Summary. Gives an overview of all the Intel Architecture instructions except those executed by the processor's floating-point unit. The instructions are presented in functionally related groups.

Chapter 7 — Floating-Point Unit. Describes the Intel Architecture floating-point unit, including the floating-point registers and data types; gives an overview of the floating-point instruction set; and describes the processor's floating-point exception conditions.

Chapter 8 — Programming with Intel MMX™ Technology. Describes the Intel MMX™ technology, including registers and data types, and gives an overview of the MMX™ technology instruction set.

Chapter 9 — Programming with the Streaming SIMD Extensions. Describes the Intel Streaming SIMD Extensions, including the registers and data types, and gives an overview of the Streaming SIMD Extension set.

Chapter 10— Input/Output. Describes the processor's I/O architecture, including I/O port addressing, the I/O instructions, and the I/O protection mechanism.

Chapter 11 — Processor Identification and Feature Determination. Describes how to determine the CPU type and the features that are available in the processor.

Appendix A — EFLAGS Cross-Reference. Summaries how the Intel Architecture instructions affect the flags in the EFLAGS register.

Appendix B — EFLAGS Condition Codes. Summarizes how the conditional jump, move, and byte set on condition code instructions use the condition code flags (OF, CF, ZF, SF, and PF) in the EFLAGS register.

Appendix C — Floating-Point Exceptions Summary. Summarizes the exceptions that can be raised by floating-point instructions.

Appendix D — Guidelines for Writing FPU and SIMD Extension Exception Handlers. Describes how to design and write MS-DOS* compatible exception-handling facilities for FPU and Streaming SIMD Extension exceptions, including both software and hardware requirements and assembly-language code examples. This appendix also describes general techniques for writing robust FPU exception handlers.

Appendix E— Guidelines for Writing Streaming SIMD Extension Floating-Point Exception Handlers. Provides guidelines for the Streaming SIMD Extension instructions that can generate numeric (floating-point) exceptions, and gives an overview of the necessary support for handling such exceptions.

1.3. OVERVIEW OF THE *INTEL ARCHITECTURE SOFTWARE DEVELOPER'S MANUAL, VOLUME 3*: *SYSTEM PROGRAMMING GUIDE*

The contents of the *Intel Architecture Software Developer's Manual, Volume 3*, are as follows:

Chapter 1 — About This Manual. Gives an overview of all three volumes of the *Intel Architecture Software Developer's Manual.* It also describes the notational conventions in these manuals and lists related Intel manuals and documentation of interest to programmers and hardware designers.

Chapter 2 — System Architecture Overview. Describes the modes of operation of an Intel Architecture processor and the mechanisms provided in the Intel Architecture to support operating systems and executives, including the system-oriented registers and data structures and the system-oriented instructions. The steps necessary for switching between real-address and protected modes are also identified.

Chapter 3 — Protected-Mode Memory Management. Describes the data structures, registers, and instructions that support segmentation and paging and explains how they can be used to implement a “flat” (unsegmented) memory model or a segmented memory model.

Chapter 4 — Protection. Describes the support for page and segment protection provided in the Intel Architecture. This chapter also explains the implementation of privilege rules, stack switching, pointer validation, user and supervisor modes.

Chapter 5 — Interrupt and Exception Handling. Describes the basic interrupt mechanisms defined in the Intel Architecture, shows how interrupts and exceptions relate to protection, and describes how the architecture handles each exception type. Reference information for each Intel Architecture exception is given at the end of this chapter.

Chapter 6 — Task Management. Describes the mechanisms the Intel Architecture provides to support multitasking and inter-task protection.

Chapter 7 — Multiple Processor Management. Describes the instructions and flags that support multiple processors with shared memory, memory ordering, and the advanced programmable interrupt controller (APIC).

Chapter 8 — Processor Management and Initialization. Defines the state of an Intel Architecture processor and its floating-point and SIMD floating-point units after reset initialization. This chapter also explains how to set up an Intel Architecture processor for real-address mode operation and protected- mode operation, and how to switch between modes.

Chapter 9 — Memory Cache Control. Describes the general concept of caching and the caching mechanisms supported by the Intel Architecture. This chapter also describes the memory type range registers (MTRRs) and how they can be used to map memory types of physical memory. MTRRs were introduced into the Intel Architecture with the Pentium® Pro processor. It also presents information on using the new cache control and memory streaming instructions introduced with the Pentium® III processor.

Chapter 10 — MMX™ Technology System Programming. Describes those aspects of the Intel MMX™ technology that must be handled and considered at the system programming level, including task switching, exception handling, and compatibility with existing system environments. The MMX™ technology was introduced into the Intel Architecture with the Pentium® processor.

Chapter 11 — Streaming SIMD Extensions System Programming. Describes those aspects of Streaming SIMD Extensions that must be handled and considered at the system programming level, including task switching, exception handling, and compatibility with existing system environments. Streaming SIMD Extensions were introduced into the Intel Architecture with the Pentium® processor.

Chapter 12 — System Management Mode (SMM). Describes the Intel Architecture’s system management mode (SMM), which can be used to implement power management functions.

Chapter 13 — Machine-Check Architecture. Describes the machine-check architecture, which was introduced into the Intel Architecture with the Pentium® processor.

Chapter 14 — Code Optimization. Discusses general optimization techniques for programming an Intel Architecture processor.

Chapter 15 — Debugging and Performance Monitoring. Describes the debugging registers and other debug mechanism provided in the Intel Architecture. This chapter also describes the time-stamp counter and the performance-monitoring counters.

Chapter 16 — 8086 Emulation. Describes the real-address and virtual-8086 modes of the Intel Architecture.

Chapter 17 — Mixing 16-Bit and 32-Bit Code. Describes how to mix 16-bit and 32-bit code modules within the same program or task.

Chapter 18 — Intel Architecture Compatibility. Describes the programming differences between the Intel 286, Intel386, Intel486, Pentium®, and P6 family processors. The differences among the 32-bit Intel Architecture processors (the Intel386, Intel486, Pentium®, and P6 family processors) are described throughout the three volumes of the *Intel Architecture Software Developer's Manual*, as relevant to particular features of the architecture. This chapter provides a collection of all the relevant compatibility information for all Intel Architecture processors and also describes the basic differences with respect to the 16-bit Intel Architecture processors (the Intel 8086 and Intel 286 processors).

Appendix A — Performance-Monitoring Events. Lists the events that can be counted with the performance-monitoring counters and the codes used to select these events. Both Pentium® processor and P6 family processor events are described.

Appendix B — Model-Specific Registers (MSRs). Lists the MSRs available in the Pentium® and P6 family processors and their functions.

Appendix C — Dual-Processor (DP) Bootup Sequence Example (Specific to Pentium® Processors). Gives an example of how to use the DP protocol to boot two Pentium® processors (a primary processor and a secondary processor) in a DP system and initialize their APICs.

Appendix D — Multiple-Processor (MP) Bootup Sequence Example (Specific to P6 Family Processors). Gives an example of how to use of the MP protocol to boot two P6 family processors in a multiple-processor (MP) system and initialize their APICs.

Appendix E — Programming the LINT0 and LINT1 Inputs. Gives an example of how to program the LINT0 and LINT1 pins for specific interrupt vectors.

1.4. NOTATIONAL CONVENTIONS

This manual uses special notation for data-structure formats, for symbolic representation of instructions, and for hexadecimal numbers. A review of this notation makes the manual easier to read.

1.4.1. Bit and Byte Order

In illustrations of data structures in memory, smaller addresses appear toward the bottom of the figure; addresses increase toward the top. Bit positions are numbered from right to left. The numerical value of a set bit is equal to two raised to the power of the bit position. Intel Archi-

tecture processors is a “little endian” machines; this means the bytes of a word are numbered starting from the least significant byte. Figure 1-1 illustrates these conventions.

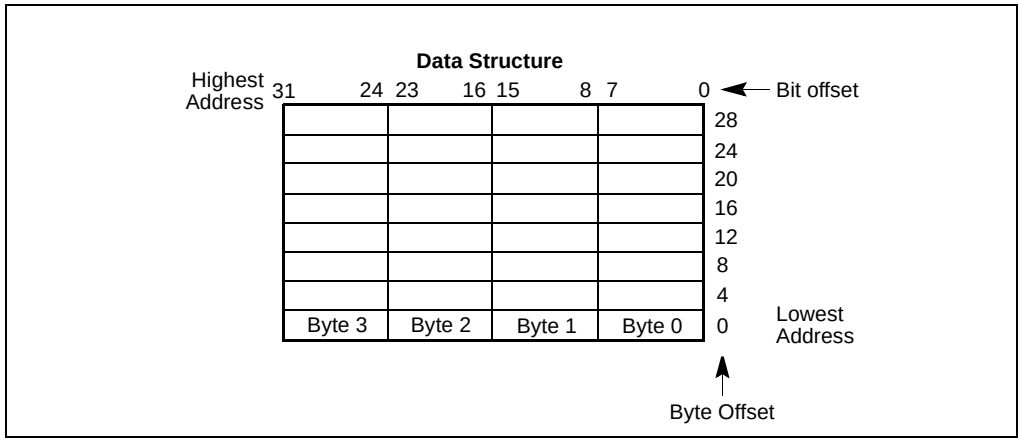


Figure 1-1. Bit and Byte Order

1.4.2. Reserved Bits and Software Compatibility

In many register and memory layout descriptions, certain bits are marked as **reserved**. When bits are marked as reserved, it is essential for compatibility with future processors that software treat these bits as having a future, though unknown, effect. The behavior of reserved bits should be regarded as not only undefined, but unpredictable. Software should follow these guidelines in dealing with reserved bits:

- Do not depend on the states of any reserved bits when testing the values of registers which contain such bits. Mask out the reserved bits before testing.
- Do not depend on the states of any reserved bits when storing to memory or to a register.
- Do not depend on the ability to retain information written into any reserved bits.
- When loading a register, always load the reserved bits with the values indicated in the documentation, if any, or reload them with values previously read from the same register.

NOTE

Avoid any software dependence upon the state of reserved bits in Intel Architecture registers. Depending upon the values of reserved register bits will make software dependent upon the unspecified manner in which the processor handles these bits. Depending upon reserved values risks incompatibility with future processors.

1.4.3. Instruction Operands

When instructions are represented symbolically, a subset of the Intel Architecture assembly language is used. In this subset, an instruction has the following format:

label: mnemonic argument1, argument2, argument3

where:

- A **label** is an identifier which is followed by a colon.
- A **mnemonic** is a reserved name for a class of instruction opcodes which have the same function.
- The operands *argument1*, *argument2*, and *argument3* are optional. There may be from zero to three operands, depending on the opcode. When present, they take the form of either literals or identifiers for data items. Operand identifiers are either reserved names of registers or are assumed to be assigned to data items declared in another part of the program (which may not be shown in the example).

When two operands are present in an arithmetic or logical instruction, the right operand is the source and the left operand is the destination.

For example:

```
LOADREG: MOV EAX, SUBTOTAL
```

In this example LOADREG is a label, MOV is the mnemonic identifier of an opcode, EAX is the destination operand, and SUBTOTAL is the source operand. Some assembly languages put the source and destination in reverse order.

1.4.4. Hexadecimal and Binary Numbers

Base 16 (hexadecimal) numbers are represented by a string of hexadecimal digits followed by the character H (for example, F82EH). A hexadecimal digit is a character from the following set: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, and F.

Base 2 (binary) numbers are represented by a string of 1s and 0s, sometimes followed by the character B (for example, 1010B). The “B” designation is only used in situations where confusion as to the type of number might arise.

1.4.5. Segmented Addressing

The processor uses byte addressing. This means memory is organized and accessed as a sequence of bytes. Whether one or more bytes are being accessed, a byte address is used to locate the byte or bytes of memory. The range of memory that can be addressed is called an **address space**.

The processor also supports segmented addressing. This is a form of addressing where a program may have many independent address spaces, called **segments**. For example, a program can keep its code (instructions) and stack in separate segments. Code addresses would always refer to the code space, and stack addresses would always refer to the stack space. The following notation is used to specify a byte address within a segment:

Segment-register:Byte-address

For example, the following segment address identifies the byte at address FF79H in the segment pointed by the DS register:

DS:FF79H

The following segment address identifies an instruction address in the code segment. The CS register points to the code segment and the EIP register contains the address of the instruction.

CS:EIP

1.4.6. Exceptions

An exception is an event that typically occurs when an instruction causes an error. For example, an attempt to divide by zero generates an exception. However, some exceptions, such as breakpoints, occur under other conditions. Some types of exceptions may provide error codes. An error code reports additional information about the error. An example of the notation used to show an exception and error code is shown below.

#PF(fault code)

This example refers to a page-fault exception under conditions where an error code naming a type of fault is reported. Under some conditions, exceptions which produce error codes may not be able to report an accurate code. In this case, the error code is zero, as shown below for a general-protection exception.

#GP(0)

Refer to Chapter 5, *Interrupt and Exception Handling*, in the *Intel Architecture Software Developer's Manual, Volume 3*, for a list of exception mnemonics and their descriptions.

1.5. RELATED LITERATURE

The following books contain additional material related to Intel processors:

- *Intel Pentium® Pro Processor Specification Update*, Order Number 242689.
- *Intel Pentium® Processor Specification Update*, Order Number 242480.
- AP-485, *Intel Processor Identification and the CPUID Instruction*, Order Number 241618.
- AP-578, *Software and Hardware Considerations for FPU Exception Handlers for Intel Architecture Processors*, Order Number 242415-001.
- *Pentium® Pro Processor Family Developer's Manual, Volume 1: Specifications*, Order Number 242690-001.
- *Pentium® Processor Family Developer's Manual***,** Order Number 241428.
- *Intel486™ Microprocessor Data Book*, Order Number 240440.
- *Intel486™ SX CPU/Intel487™ SX Math Coprocessor Data Book*, Order Number 240950.
- *Intel486™ DX2 Microprocessor Data Book*, Order Number 241245.
- *Intel486™ Microprocessor Product Brief Book*, Order Number 240459.
- *Intel386™ Processor Hardware Reference Manual*, Order Number 231732.
- *Intel386™ Processor System Software Writer's Guide*, Order Number 231499.
- *Intel386™ High-Performance 32-Bit CHMOS Microprocessor with Integrated Memory Management*, Order Number 231630.
- *376 Embedded Processor Programmer's Reference Manual*, Order Number 240314.
- *80387 DX User's Manual Programmer's Reference*, Order Number 231917.
- *376 High-Performance 32-Bit Embedded Processor*, Order Number 240182.
- *Intel386™ SX Microprocessor*, Order Number 240187.
- *Microprocessor and Peripheral Handbook* (Vol. 1), Order Number 230843.
- AP-528, *Optimizations for Intel's 32-Bit Processors*, Order Number 242816-001.

2

Instruction Format

CHAPTER 2
INSTRUCTION FORMAT

This chapter describes the instruction format for all Intel Architecture processors.

2.1. GENERAL INSTRUCTION FORMAT

All Intel Architecture instruction encodings are subsets of the general instruction format shown in Figure 2-1. Instructions consist of optional instruction prefixes (in any order), one or two primary opcode bytes, an addressing-form specifier (if required) consisting of the ModR/M byte and sometimes the SIB (Scale-Index-Base) byte, a displacement (if required), and an immediate data field (if required).

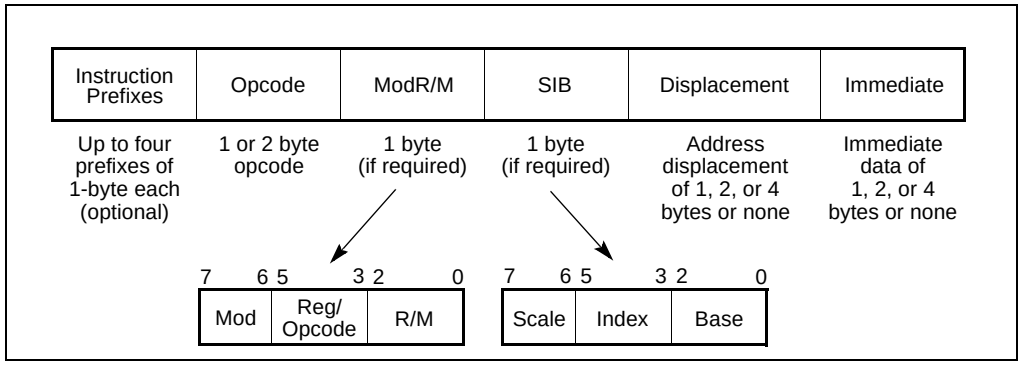


Figure 2-1. Intel Architecture Instruction Format

2.2. INSTRUCTION PREFIXES

The instruction prefixes are divided into four groups, each with a set of allowable prefix codes:

- Lock and repeat prefixes.
  - — F0H—LOCK prefix.
  - — F2H—REPNE/REPNZ prefix (used only with string instructions).
  - — F3H—REP prefix (used only with string instructions and Streaming SIMD Extensions).
  - — F3H—REPE/REPZ prefix (used only with string instructions and Streaming SIMD Extensions).

- Segment override.
  - 2EH—CS segment override prefix.
  - 36H—SS segment override prefix.
  - 3EH—DS segment override prefix.
  - 26H—ES segment override prefix.
  - 64H—FS segment override prefix.
  - 65H—GS segment override prefix.
- Operand-size override, 66H
- Address-size override, 67H

For each instruction, one prefix may be used from each of these groups and be placed in any order. The effect of redundant prefixes (more than one prefix from a group) is undefined and may vary from processor to processor.

- Streaming SIMD Extensions prefix, 0FH

The nature of Streaming SIMD Extensions allows the use of existing instruction formats. Instructions use the ModR/M format and are preceded by the 0F prefix byte. In general, operations are not duplicated to provide two directions (i.e. separate load and store variants). For more information, see Section B.4.1., “Instruction Prefixes” in Appendix B, *Instruction Formats and Encodings*.

2.3. OPCODE

The primary opcode is either 1 or 2 bytes. An additional 3-bit opcode field is sometimes encoded in the ModR/M byte. Smaller encoding fields can be defined within the primary opcode. These fields define the direction of the operation, the size of displacements, the register encoding, condition codes, or sign extension. The encoding of fields in the opcode varies, depending on the class of operation.

2.4. MODR/M AND SIB BYTES

Most instructions that refer to an operand in memory have an addressing-form specifier byte (called the ModR/M byte) following the primary opcode. The ModR/M byte contains three fields of information:

- The *mod* field combines with the r/m field to form 32 possible values: eight registers and 24 addressing modes.
- The *reg/opcode* field specifies either a register number or three more bits of opcode information. The purpose of the reg/opcode field is specified in the primary opcode.
- The *r/m* field can specify a register as an operand or can be combined with the mod field to encode an addressing mode.

Certain encodings of the ModR/M byte require a second addressing byte, the SIB byte, to fully specify the addressing form. The base-plus-index and scale-plus-index forms of 32-bit addressing require the SIB byte. The SIB byte includes the following fields:

- The *scale* field specifies the scale factor.
- The *index* field specifies the register number of the index register.
- The *base* field specifies the register number of the base register.

Refer to Section 2.6. for the encodings of the ModR/M and SIB bytes.

2.5. DISPLACEMENT AND IMMEDIATE BYTES

Some addressing forms include a displacement immediately following either the ModR/M or SIB byte. If a displacement is required, it can be 1, 2, or 4 bytes.

If the instruction specifies an immediate operand, the operand always follows any displacement bytes. An immediate operand can be 1, 2, or 4 bytes.

2.6. ADDRESSING-MODE ENCODING OF MODR/M AND SIB BYTES

The values and the corresponding addressing forms of the ModR/M and SIB bytes are shown in Tables 2-1 through 2-3. The 16-bit addressing forms specified by the ModR/M byte are in Table 2-1, and the 32-bit addressing forms specified by the ModR/M byte are in Table 2-2. Table 2-3 shows the 32-bit addressing forms specified by the SIB byte.

In Tables 2-1 and 2-2, the first column (labeled “Effective Address”) lists 32 different effective addresses that can be assigned to one operand of an instruction by using the Mod and R/M fields of the ModR/M byte. The first 24 give the different ways of specifying a memory location; the last eight (specified by the Mod field encoding 11B) give the ways of specifying the general purpose, MMX™ technology, and SIMD floating-point registers. Each of the register encodings list five possible registers. For example, the first register-encoding (selected by the R/M field encoding of 000B) indicates the general-purpose registers EAX, AX or AL, the MMX™ technology register MM0, or the SIMD floating-point register XMM0. Which of these five registers is used is determined by the opcode byte and the operand-size attribute, which select either the EAX register (32 bits) or AX register (16 bits).

The second and third columns in Tables 2-1 and 2-2 gives the binary encodings of the Mod and R/M fields in the ModR/M byte, respectively, required to obtain the associated effective address listed in the first column. All 32 possible combinations of the Mod and R/M fields are listed.

Across the top of Tables 2-1 and 2-2, the eight possible values of the 3-bit Reg/Opcode field are listed, in decimal (sixth row from top) and in binary (seventh row from top). The seventh row is labeled “REG=”, which represents the use of these three bits to give the location of a second operand, which must be a general-purpose register, an MMX™ technology register, or a SIMD floating-point register. If the instruction does not require a second operand to be specified, then the 3 bits of the Reg/Opcode field may be used as an extension of the opcode, which is repre-

sented by the sixth row, labeled "/digit (Opcode)". The five rows above give the byte, word, and doubleword general-purpose registers; the MMX™ technology registers; the Streaming SIMD Extensions registers; and SIMD floating-point registers that correspond to the register numbers, with the same assignments as for the R/M field when Mod field encoding is 11B. As with the R/M field register options, which of the five possible registers is used is determined by the opcode byte along with the operand-size attribute.

The body of Tables 2-1 and 2-2 (under the label "Value of ModR/M Byte (in Hexadecimal)") contains a 32 by 8 array giving all of the 256 values of the ModR/M byte, in hexadecimal. Bits 3, 4 and 5 are specified by the column of the table in which a byte resides, and the row specifies bits 0, 1 and 2, and also bits 6 and 7.

Table 2-1. 16-Bit Addressing Forms with the ModR/M Byte

r8(/r) r16(/r) r32(/r) mm(/r) xmm(/r) /digit (Opcode) REG =			AL AX EAX MM0 XMM0 0 000	CL CX ECX MM1 XMM1 1 001	DL DX EDX MM2 XMM2 2 010	BL BX EBX MM3 XMM3 3 011	AH SP ESP MM4 XMM4 4 100	CH BP[1] EBP MM5 XMM5 5 101	DH SI ESI MM6 XMM6 6 110	BH DI EDI MM7 XMM7 7 111
Effective Address	**Mod**	**R/M**	**Value of ModR/M Byte (in Hexadecimal)**							
[BX+SI]	00	000	00	08	10	18	20	28	30	38
[BX+DI]		001	01	09	11	19	21	29	31	39
[BP+SI]		010	02	0A	12	1A	22	2A	32	3A
[BP+DI]		011	03	0B	13	1B	23	2B	33	3B
[SI]		100	04	0C	14	1C	24	2C	34	3C
[DI]		101	05	0D	15	1D	25	2D	35	3D
disp16[2]		110	06	0E	16	1E	26	2E	36	3E
[BX]		111	07	0F	17	1F	27	2F	37	3F
[BX+SI]+disp8[3]	01	000	40	48	50	58	60	68	70	78
[BX+DI]+disp8		001	41	49	51	59	61	69	71	79
[BP+SI]+disp8		010	42	4A	52	5A	62	6A	72	7A
[BP+DI]+disp8		011	43	4B	53	5B	63	6B	73	7B
[SI]+disp8		100	44	4C	54	5C	64	6C	74	7C
[DI]+disp8		101	45	4D	55	5D	65	6D	75	7D
[BP]+disp8		110	46	4E	56	5E	66	6E	76	7E
[BX]+disp8		111	47	4F	57	5F	67	6F	77	7F
[BX+SI]+disp16	10	000	80	88	90	98	A0	A8	B0	B8
[BX+DI]+disp16		001	81	89	91	99	A1	A9	B1	B9
[BP+SI]+disp16		010	82	8A	92	9A	A2	AA	B2	BA
[BP+DI]+disp16		011	83	8B	93	9B	A3	AB	B3	BB
[SI]+disp16		100	84	8C	94	9C	A4	AC	B4	BC
[DI]+disp16		101	85	8D	95	9D	A5	AD	B5	BD
[BP]+disp16		110	86	8E	96	9E	A6	AE	B6	BE
[BX]+disp16		111	87	8F	97	9F	A7	AF	B7	BF
EAX/AX/AL/MM0/XMM0	11	000								
ECX/CX/CL/MM1/XMM1		001	C0	C8	D0	D8	E0	E8	F0	F8
EDX/DX/DL/MM2/XMM2		010	C1	C9	D1	D9	EQ	E9	F1	F9
EBX/BX/BL/MM3/XMM3		011	C2	CA	D2	DA	E2	EA	F2	FA
ESP/SP/AHMM4/XMM4		100	C3	CB	D3	DB	E3	EB	F3	FB
EBP/BP/CH/MM5/XMM5		101	C4	CC	D4	DC	E4	EC	F4	FC
ESI/SI/DH/MM6/XMM6		110	C5	CD	D5	DD	E5	ED	F5	FD
EDI/DI/BH/MM7/XMM7		111	C6	CE	D6	DE	E6	EE	F6	FE
			C7	CF	D7	DF	E7	EF	F7	FF

NOTES:

1. The default segment register is SS for the effective addresses containing a BP index, DS for other effective addresses.
2. The “disp16” nomenclature denotes a 16-bit displacement following the ModR/M byte, to be added to the index.
3. The “disp8” nomenclature denotes an 8-bit displacement following the ModR/M byte, to be sign-extended and added to the index.

Table 2-2. 32-Bit Addressing Forms with the ModR/M Byte

r8(/r) r16(/r) r32(/r) mm(/r) xmm(/r) /digit (Opcode) REG =			AL AX EAX MM0 XMM0 0 000	CL CX ECX MM1 XMM1 1 001	DL DX EDX MM2 XMM2 2 010	BL BX EBX MM3 XMM3 3 011	AH SP ESP MM4 XMM4 4 100	CH BP EBP MM5 XMM5 5 101	DH SI ESI MM6 XMM6 6 110	BH DI EDI MM7 XMM7 7 111
Effective Address	**Mod**	**R/M**	**Value of ModR/M Byte (in Hexadecimal)**							
[EAX]	00	000	00	08	10	18	20	28	30	38
[ECX]		001	01	09	11	19	21	29	31	39
[EDX]		010	02	0A	12	1A	22	2A	32	3A
[EBX]		011	03	0B	13	1B	23	2B	33	3B
[--][--][1]		100	04	0C	14	1C	24	2C	34	3C
disp32[2]		101	05	0D	15	1D	25	2D	35	3D
[ESI]		110	06	0E	16	1E	26	2E	36	3E
[EDI]		111	07	0F	17	1F	27	2F	37	3F
disp8[EAX][3]	01	000	40	48	50	58	60	68	70	78
disp8[ECX]		001	41	49	51	59	61	69	71	79
disp8[EDX]		010	42	4A	52	5A	62	6A	72	7A
disp8[EBX];		011	43	4B	53	5B	63	6B	73	7B
disp8[--][--]		100	44	4C	54	5C	64	6C	74	7C
disp8[EBP]		101	45	4D	55	5D	65	6D	75	7D
disp8[ESI]		110	46	4E	56	5E	66	6E	76	7E
disp8[EDI]		111	47	4F	57	5F	67	6F	77	7F
disp32[EAX]	10	000	80	88	90	98	A0	A8	B0	B8
disp32[ECX]		001	81	89	91	99	A1	A9	B1	B9
disp32[EDX]		010	82	8A	92	9A	A2	AA	B2	BA
disp32[EBX]		011	83	8B	93	9B	A3	AB	B3	BB
disp32[--][--]		100	84	8C	94	9C	A4	AC	B4	BC
disp32[EBP]		101	85	8D	95	9D	A5	AD	B5	BD
disp32[ESI]		110	86	8E	96	9E	A6	AE	B6	BE
disp32[EDI]		111	87	8F	97	9F	A7	AF	B7	BF
EAX/AX/AL/MM0/XMM0	11	000	C0	C8	D0	D8	E0	E8	F0	F8
ECX/CX/CL/MM1/XMM1		001	C1	C9	D1	D9	E1	E9	F1	F9
EDX/DX/DL/MM2XMM2		010	C2	CA	D2	DA	E2	EA	F2	FA
EBX/BX/BL/MM3/XMM3		011	C3	CB	D3	DB	E3	EB	F3	FB
ESP/SP/AH/MM4/XMM4		100	C4	CC	D4	DC	E4	EC	F4	FC
EBP/BP/CH/MM5/XMM5		101	C5	CD	D5	DD	E5	ED	F5	FD
ESI/SI/DH/MM6/XMM6		110	C6	CE	D6	DE	E6	EE	F6	FE
EDI/DI/BH/MM7/XMM7		111	C7	CF	D7	DF	E7	EF	F7	FF

NOTES:

1. The [--][--] nomenclature means a SIB follows the ModR/M byte.
2. The disp32 nomenclature denotes a 32-bit displacement following the SIB byte, to be added to the index.
3. The disp8 nomenclature denotes an 8-bit displacement following the SIB byte, to be sign-extended and added to the index.

Table 2-3 is organized similarly to Tables 2-1 and 2-2, except that its body gives the 256 possible values of the SIB byte, in hexadecimal. Which of the 8 general-purpose registers will be used as base is indicated across the top of the table, along with the corresponding values of the base field (bits 0, 1 and 2) in decimal and binary. The rows indicate which register is used as the index (determined by bits 3, 4 and 5) along with the scaling factor (determined by bits 6 and 7).

Table 2-3. 32-Bit Addressing Forms with the SIB Byte

r32 Base = Base =			EAX 0 000	ECX 1 001	EDX 2 010	EBX 3 011	ESP 4 100	[*] 5 101	ESI 6 110	EDI 7 111
Scaled Index	**SS**	**Index**	**Value of SIB Byte (in Hexadecimal)**							
[EAX]	00	000	00	01	02	03	04	05	06	07
[ECX]		001	08	09	0A	0B	0C	0D	0E	0F
[EDX]		010	10	11	12	13	14	15	16	17
[EBX]		011	18	19	1A	1B	1C	1D	1E	1F
none		100	20	21	22	23	24	25	26	27
[EBP]		101	28	29	2A	2B	2C	2D	2E	2F
[ESI]		110	30	31	32	33	34	35	36	37
[EDI]		111	38	39	3A	3B	3C	3D	3E	3F
[EAX*2]	01	000	40	41	42	43	44	45	46	47
[ECX*2]		001	48	49	4A	4B	4C	4D	4E	4F
[EDX*2]		010	50	51	52	53	54	55	56	57
[EBX*2]		011	58	59	5A	5B	5C	5D	5E	5F
none		100	60	61	62	63	64	65	66	67
[EBP*2]		101	68	69	6A	6B	6C	6D	6E	6F
[ESI*2]		110	70	71	72	73	74	75	76	77
[EDI*2]		111	78	79	7A	7B	7C	7D	7E	7F
[EAX*4]	10	000	80	81	82	83	84	85	86	87
[ECX*4]		001	88	89	8A	8B	8C	8D	8E	8F
[EDX*4]		010	90	91	92	93	94	95	96	97
[EBX*4]		011	98	89	9A	9B	9C	9D	9E	9F
none		100	A0	A1	A2	A3	A4	A5	A6	A7
[EBP*4]		101	A8	A9	AA	AB	AC	AD	AE	AF
[ESI*4]		110	B0	B1	B2	B3	B4	B5	B6	B7
[EDI*4]		111	B8	B9	BA	BB	BC	BD	BE	BF
[EAX*8]	11	000	C0	C1	C2	C3	C4	C5	C6	C7
[ECX*8]		001	C8	C9	CA	CB	CC	CD	CE	CF
[EDX*8]		010	D0	D1	D2	D3	D4	D5	D6	D7
[EBX*8]		011	D8	D9	DA	DB	DC	DD	DE	DF
none		100	E0	E1	E2	E3	E4	E5	E6	E7
[EBP*8]		101	E8	E9	EA	EB	EC	ED	EE	EF
[ESI*8]		110	F0	F1	F2	F3	F4	F5	F6	F7
[EDI*8]		111	F8	F9	FA	FB	FC	FD	FE	FF

NOTE:

1. The [*] nomenclature means a disp32 with no base if MOD is 00, [EBP] otherwise. This provides the following addressing modes:

   disp32[index] (MOD=00).
   disp8[EBP][index] (MOD=01).
   disp32[EBP][index] (MOD=10).

3

Instruction Set Reference

CHAPTER 3
INSTRUCTION SET REFERENCE

This chapter describes the complete Intel Architecture instruction set, including the integer, floating-point, MMX™ technology, Streaming SIMD Extensions, and system instructions. The instruction descriptions are arranged in alphabetical order. For each instruction, the forms are given for each operand combination, including the opcode, operands required, and a description. Also given for each instruction are a description of the instruction and its operands, an operational description, a description of the effect of the instructions on flags in the EFLAGS register, and a summary of the exceptions that can be generated.

3.1. INTERPRETING THE INSTRUCTION REFERENCE PAGES

This section describes the information contained in the various sections of the instruction reference pages that make up the majority of this chapter. It also explains the notational conventions and abbreviations used in these sections.

3.1.1. Instruction Format

The following is an example of the format used for each Intel Architecture instruction description in this chapter:

CMC—Complement Carry Flag

Opcode	Instruction	Description
F5	CMC	Complement carry flag

3.1.1.1. OPCODE COLUMN

The “Opcode” column gives the complete object code produced for each form of the instruction. When possible, the codes are given as hexadecimal bytes, in the same order in which they appear in memory. Definitions of entries other than hexadecimal bytes are as follows:

- **/digit**—A digit between 0 and 7 indicates that the ModR/M byte of the instruction uses only the r/m (register or memory) operand. The reg field contains the digit that provides an extension to the instruction's opcode.
- **/r—**Indicates that the ModR/M byte of the instruction contains both a register operand and an r/m operand.
- **cb, cw, cd, cp—**A 1-byte (cb), 2-byte (cw), 4-byte (cd), or 6-byte (cp) value following the opcode that is used to specify a code offset and possibly a new value for the code segment register.
- **ib, iw, id—**A 1-byte (ib), 2-byte (iw), or 4-byte (id) immediate operand to the instruction that follows the opcode, ModR/M bytes or scale-indexing bytes. The opcode determines if the operand is a signed value. All words and doublewords are given with the low-order byte first.
- **+rb, +rw, +rd—**A register code, from 0 through 7, added to the hexadecimal byte given at the left of the plus sign to form a single opcode byte. The register codes are given in Table 3-1.
- **+i—**A number used in floating-point instructions when one of the operands is ST(i) from the FPU register stack. The number i (which can range from 0 to 7) is added to the hexadecimal byte given at the left of the plus sign to form a single opcode byte.

Table 3-1. Register Encodings Associated with the +rb, +rw, and +rd Nomenclature

rb			rw			rd		
AL	=	0	AX	=	0	EAX	=	0
CL	=	1	CX	=	1	ECX	=	1
DL	=	2	DX	=	2	EDX	=	2
BL	=	3	BX	=	3	EBX	=	3
rb			**rw**			**rd**		
AH	=	4	SP	=	4	ESP	=	4
CH	=	5	BP	=	5	EBP	=	5
DH	=	6	SI	=	6	ESI	=	6
BH	=	7	DI	=	7	EDI	=	7

3.1.1.2. INSTRUCTION COLUMN

The “Instruction” column gives the syntax of the instruction statement as it would appear in an ASM386 program. The following is a list of the symbols used to represent operands in the instruction statements:

- **rel8**—A relative address in the range from 128 bytes before the end of the instruction to 127 bytes after the end of the instruction.
- **rel16 and rel32**—A relative address within the same code segment as the instruction assembled. The rel16 symbol applies to instructions with an operand-size attribute of 16 bits; the rel32 symbol applies to instructions with an operand-size attribute of 32 bits.
- **ptr16:16 and ptr16:32**—A far pointer, typically in a code segment different from that of the instruction. The notation *16:16* indicates that the value of the pointer has two parts. The value to the left of the colon is a 16-bit selector or value destined for the code segment register. The value to the right corresponds to the offset within the destination segment. The ptr16:16 symbol is used when the instruction's operand-size attribute is 16 bits; the ptr16:32 symbol is used when the operand-size attribute is 32 bits.
- **r8**—One of the byte general-purpose registers AL, CL, DL, BL, AH, CH, DH, or BH.
- **r16**—One of the word general-purpose registers AX, CX, DX, BX, SP, BP, SI, or DI.
- **r32**—One of the doubleword general-purpose registers EAX, ECX, EDX, EBX, ESP, EBP, ESI, or EDI.
- **imm8**—An immediate byte value. The imm8 symbol is a signed number between –128 and +127 inclusive. For instructions in which imm8 is combined with a word or doubleword operand, the immediate value is sign-extended to form a word or doubleword. The upper byte of the word is filled with the topmost bit of the immediate value.
- **imm16**—An immediate word value used for instructions whose operand-size attribute is 16 bits. This is a number between –32,768 and +32,767 inclusive.

- **imm32**—An immediate doubleword value used for instructions whose operand-size attribute is 32 bits. It allows the use of a number between +2,147,483,647 and –2,147,483,648 inclusive.
- **r/m8**—A byte operand that is either the contents of a byte general-purpose register (AL, BL, CL, DL, AH, BH, CH, and DH), or a byte from memory.
- **r/m16**—A word general-purpose register or memory operand used for instructions whose operand-size attribute is 16 bits. The word general-purpose registers are: AX, BX, CX, DX, SP, BP, SI, and DI. The contents of memory are found at the address provided by the effective address computation.
- **r/m32**—A doubleword general-purpose register or memory operand used for instructions whose operand-size attribute is 32 bits. The doubleword general-purpose registers are: EAX, EBX, ECX, EDX, ESP, EBP, ESI, and EDI. The contents of memory are found at the address provided by the effective address computation.
- **m**—A 16- or 32-bit operand in memory.
- **m8**—A byte operand in memory, usually expressed as a variable or array name, but pointed to by the DS:(E)SI or ES:(E)DI registers. This nomenclature is used only with the string instructions and the XLAT instruction.
- **m16**—A word operand in memory, usually expressed as a variable or array name, but pointed to by the DS:(E)SI or ES:(E)DI registers. This nomenclature is used only with the string instructions.
- **m32**—A doubleword operand in memory, usually expressed as a variable or array name, but pointed to by the DS:(E)SI or ES:(E)DI registers. This nomenclature is used only with the string instructions.
- **m64**—A memory quadword operand in memory. This nomenclature is used only with the CMPXCHG8B instruction.
- **m128**—A memory double quadword operand in memory. This nomenclature is used only with the Streaming SIMD Extensions.
- **m16:16, m16:32**—A memory operand containing a far pointer composed of two numbers. The number to the left of the colon corresponds to the pointer's segment selector. The number to the right corresponds to its offset.
- **m16&32, m16&16, m32&32**—A memory operand consisting of data item pairs whose sizes are indicated on the left and the right side of the ampersand. All memory addressing modes are allowed. The m16&16 and m32&32 operands are used by the BOUND instruction to provide an operand containing an upper and lower bounds for array indices. The m16&32 operand is used by LIDT and LGDT to provide a word with which to load the limit field, and a doubleword with which to load the base field of the corresponding GDTR and IDTR registers.
- **moffs8, moffs16, moffs32**—A simple memory variable (memory offset) of type byte, word, or doubleword used by some variants of the MOV instruction. The actual address is given by a simple offset relative to the segment base. No ModR/M byte is used in the

instruction. The number shown with moffs indicates its size, which is determined by the address-size attribute of the instruction.

- **Sreg**—A segment register. The segment register bit assignments are ES=0, CS=1, SS=2, DS=3, FS=4, and GS=5.
- **m32real, m64real, m80real**—A single-, double-, and extended-real (respectively) floating-point operand in memory.
- **m16int, m32int, m64int**—A word-, short-, and long-integer (respectively) floating-point operand in memory.
- **ST or ST(0)**—The top element of the FPU register stack.
- **ST(i)**—The i^{th} element from the top of the FPU register stack. (i = 0 through 7)
- **mm**—An MMX™ technology register. The 64-bit MMX™ technology registers are: MM0 through MM7.
- **xmm**—A SIMD floating-point register. The 128-bit SIMD floating-point registers are: XMM0 through XMM7.
- **mm/m32**—The low order 32 bits of an MMX™ technology register or a 32-bit memory operand. The 64-bit MMX™ technology registers are: MM0 through MM7. The contents of memory are found at the address provided by the effective address computation.
- **mm/m64**—An MMX™ technology register or a 64-bit memory operand. The 64-bit MMX™ technology registers are: MM0 through MM7. The contents of memory are found at the address provided by the effective address computation.
- **xmm/m32**—A SIMD floating-points register or a 32-bit memory operand. The 128-bit SIMD floating-point registers are XMM0 through XMM7. The contents of memory are found at the address provided by the effective address computation.
- **xmm/m64**—A SIMD floating-point register or a 64-bit memory operand. The 64-bit SIMD floating-point registers are XMM0 through XMM7. The contents of memory are found at the address provided by the effective address computation.
- **xmm/m128**—A SIMD floating-point register or a 128-bit memory operand. The 128-bit SIMD floating-point registers are XMM0 through XMM7. The contents of memory are found at the address provided by the effective address computation.

3.1.1.3. DESCRIPTION COLUMN

The “Description” column following the “Instruction” column briefly explains the various forms of the instruction. The following “Description” and “Operation” sections contain more details of the instruction's operation.

3.1.1.4. DESCRIPTION

The “Description” section describes the purpose of the instructions and the required operands. It also discusses the effect of the instruction on flags.

3.1.2. Operation

The “Operation” section contains an algorithmic description (written in pseudo-code) of the instruction. The pseudo-code uses a notation similar to the Algol or Pascal language. The algorithms are composed of the following elements:

- Comments are enclosed within the symbol pairs “(*” and “*)”.
- Compound statements are enclosed in keywords, such as IF, THEN, ELSE, and FI for an if statement, DO and OD for a do statement, or CASE ... OF and ESAC for a case statement.
- A register name implies the contents of the register. A register name enclosed in brackets implies the contents of the location whose address is contained in that register. For example, ES:[DI] indicates the contents of the location whose ES segment relative address is in register DI. [SI] indicates the contents of the address contained in register SI relative to SI’s default segment (DS) or overridden segment.
- Parentheses around the “E” in a general-purpose register name, such as (E)SI, indicates that an offset is read from the SI register if the current address-size attribute is 16 or is read from the ESI register if the address-size attribute is 32.
- Brackets are also used for memory operands, where they mean that the contents of the memory location is a segment-relative offset. For example, [SRC] indicates that the contents of the source operand is a segment-relative offset.
- A ← B; indicates that the value of B is assigned to A.
- The symbols =, ≠, ≥, and ≤ are relational operators used to compare two values, meaning equal, not equal, greater or equal, less or equal, respectively. A relational expression such as A = B is TRUE if the value of A is equal to B; otherwise it is FALSE.
- The expression “<< COUNT” and “>> COUNT” indicates that the destination operand should be shifted left or right, respectively, by the number of bits indicated by the count operand.

The following identifiers are used in the algorithmic descriptions:

- **OperandSize and AddressSize**—The OperandSize identifier represents the operand-size attribute of the instruction, which is either 16 or 32 bits. The AddressSize identifier represents the address-size attribute, which is either 16 or 32 bits. For example, the following pseudo-code indicates that the operand-size attribute depends on the form of the CMPS instruction used.

```
IF instruction = CMPSW
    THEN OperandSize ← 16;
    ELSE
        IF instruction = CMPSD
            THEN OperandSize ← 32;
        FI;
FI;
```

Refer to Section 3.8., *Operand-Size and Address-Size Attributes* in Chapter 3, *Basic Execution Environment* of the *Intel Architecture Software Developer's Manual, Volume 1*, for general guidelines on how these attributes are determined.

- **StackAddrSize**—Represents the stack address-size attribute associated with the instruction, which has a value of 16 or 32 bits. For more information, refer to Section 4.2.3., *Address-Size Attributes for Stack Accesses* in Chapter 4, *Procedure Calls, Interrupts, and Exceptions* of the *Intel Architecture Software Developer's Manual, Volume 1*.
- **SRC**—Represents the source operand.
- **DEST**—Represents the destination operand.

The following functions are used in the algorithmic descriptions:

- **ZeroExtend(value)**—Returns a value zero-extended to the operand-size attribute of the instruction. For example, if the operand-size attribute is 32, zero extending a byte value of –10 converts the byte from F6H to a doubleword value of 000000F6H. If the value passed to the ZeroExtend function and the operand-size attribute are the same size, ZeroExtend returns the value unaltered.
- **SignExtend(value)**—Returns a value sign-extended to the operand-size attribute of the instruction. For example, if the operand-size attribute is 32, sign extending a byte containing the value –10 converts the byte from F6H to a doubleword value of FFFFFFF6H. If the value passed to the SignExtend function and the operand-size attribute are the same size, SignExtend returns the value unaltered.
- **SaturateSignedWordToSignedByte**—Converts a signed 16-bit value to a signed 8-bit value. If the signed 16-bit value is less than –128, it is represented by the saturated value –128 (80H); if it is greater than 127, it is represented by the saturated value 127 (7FH).
- **SaturateSignedDwordToSignedWord**—Converts a signed 32-bit value to a signed 16-bit value. If the signed 32-bit value is less than –32768, it is represented by the saturated value –32768 (8000H); if it is greater than 32767, it is represented by the saturated value 32767 (7FFFH).
- **SaturateSignedWordToUnsignedByte**—Converts a signed 16-bit value to an unsigned 8-bit value. If the signed 16-bit value is less than zero, it is represented by the saturated value zero (00H); if it is greater than 255, it is represented by the saturated value 255 (FFH).
- **SaturateToSignedByte**—Represents the result of an operation as a signed 8-bit value. If the result is less than –128, it is represented by the saturated value –128 (80H); if it is greater than 127, it is represented by the saturated value 127 (7FH).
- **SaturateToSignedWord**—Represents the result of an operation as a signed 16-bit value. If the result is less than –32768, it is represented by the saturated value –32768 (8000H); if it is greater than 32767, it is represented by the saturated value 32767 (7FFFH).
- **SaturateToUnsignedByte**—Represents the result of an operation as a signed 8-bit value. If the result is less than zero it is represented by the saturated value zero (00H); if it is greater than 255, it is represented by the saturated value 255 (FFH).

- **SaturateToUnsignedWord**—Represents the result of an operation as a signed 16-bit value. If the result is less than zero it is represented by the saturated value zero (00H); if it is greater than 65535, it is represented by the saturated value 65535 (FFFFH).
- **LowOrderWord(DEST * SRC)**—Multiplies a word operand by a word operand and stores the least significant word of the doubleword result in the destination operand.
- **HighOrderWord(DEST * SRC)**—Multiplies a word operand by a word operand and stores the most significant word of the doubleword result in the destination operand.
- **Push(value)**—Pushes a value onto the stack. The number of bytes pushed is determined by the operand-size attribute of the instruction. Refer to the "Operation" section in "PUSH—Push Word or Doubleword Onto the Stack" in this chapter for more information on the push operation.
- **Pop()** removes the value from the top of the stack and returns it. The statement EAX ← Pop(); assigns to EAX the 32-bit value from the top of the stack. Pop will return either a word or a doubleword depending on the operand-size attribute. Refer to the "Operation" section in "POP—Pop a Value from the Stack" in this chapter for more information on the pop operation.
- **PopRegisterStack**—Marks the FPU ST(0) register as empty and increments the FPU register stack pointer (TOP) by 1.
- **Switch-Tasks**—Performs a task switch.
- **Bit(BitBase, BitOffset)**—Returns the value of a bit within a bit string, which is a sequence of bits in memory or a register. Bits are numbered from low-order to high-order within registers and within memory bytes. If the base operand is a register, the offset can be in the range 0..31. This offset addresses a bit within the indicated register. An example, the function Bit[EAX, 21] is illustrated in Figure 3-1.

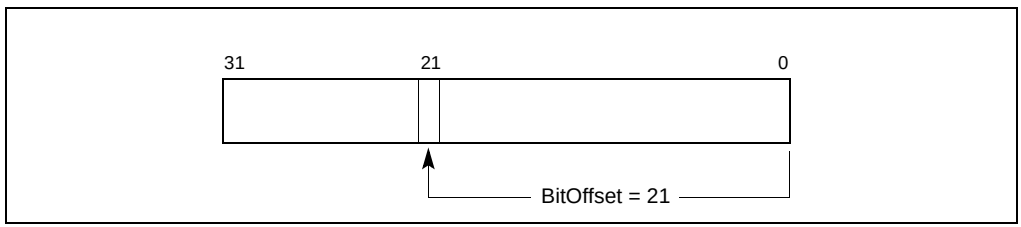


Figure 3-1. Bit Offset for BIT[EAX,21]

If BitBase is a memory address, BitOffset can range from –2 GBits to 2 GBits. The addressed bit is numbered (Offset MOD 8) within the byte at address (BitBase + (BitOffset DIV 8)), where DIV is signed division with rounding towards negative infinity, and MOD returns a positive number. This operation is illustrated in Figure 3-2.

3.1.3. Intel C/C++ Compiler Intrinsics Equivalent

The Pentium® with MMX™ technology, Pentium® II, and Pentium® III processors have characteristics that enable the development of advanced multimedia applications. This section describes the compiler intrinsic equivalents that can be used with the Intel C/C++ Compiler.

Intrinsics are special coding extensions that allow using the syntax of C function calls and C variables instead of hardware registers. Using these intrinsics frees programmers from having to manage registers and assembly programming. Further, the compiler optimizes the instruction scheduling so that executables runs faster.

The following sections discuss the intrinsics API and the MMX™ technology and SIMD floating-point intrinsics. Each intrinsic equivalent is listed with the instruction description. There may be additional intrinsics that do not have an instruction equivalent. It is strongly recommended that the reader reference the compiler documentation for the complete list of supported intrinsics. Please refer to the *Intel C/C++ Compiler User's Guide for Win32* Systems With Streaming SIMD Extension Support* (Order Number 718195-00B). Refer to Appendix C, *Compiler Intrinsics and Functional Equivalents* for more information on using intrinsics.

Most of the intrinsics that use __m64 operands have two different names. If two intrinsic names are shown for the same equivalent, the first name is the intrinsic for Intel C/C++ Compiler versions prior to 4.0 and the second name should be used with the Intel C/C++ Compiler version 4.0 and future versions. The Intel C/C++ Compiler version 4.0 will support the old intrinsic names. Programs written using pre-4.0 intrinsic names will compile with version 4.0. Version 4.0 intrinsic names will not compile on pre-4.0 compilers.

3.1.3.1. THE INTRINSICS API

The benefit of coding with MMX™ technology intrinsics and SIMD floating-point intrinsics is that you can use the syntax of C function calls and C variables instead of hardware registers. This frees you from managing registers and programming assembly. Further, the compiler optimizes the instruction scheduling so that your executable runs faster. For each computational and data manipulation instruction in the new instruction set, there is a corresponding C intrinsic that implements it directly. The intrinsics allow you to specify the underlying implementation (instruction selection) of an algorithm yet leave instruction scheduling and register allocation to the compiler.

3.1.3.2. MMX™ TECHNOLOGY INTRINSICS

The MMX™ technology intrinsics are based on a new __m64 data type to represent the specific contents of an MMX™ technology register. You can specify values in bytes, short integers, 32-bit values, or a 64-bit object. The __m64 data type, however, is not a basic ANSI C data type, and therefore you must observe the following usage restrictions:

- Use __m64 data only on the left-hand side of an assignment, as a return value, or as a parameter. You cannot use it with other arithmetic expressions ("+", ">>", and so on).
- Use __m64 objects in aggregates, such as unions to access the byte elements and structures; the address of an __m64 object may be taken.
- Use __m64 data only with the MMX™ technology intrinsics described in this guide and the *Intel C/C++ Compiler User's Guide for Win32* Systems With Streaming SIMD Extension Support* (Order Number 718195-00B). Refer to Appendix C, *Compiler Intrinsics and Functional Equivalents* for more information on using intrinsics.

3.1.3.3. SIMD FLOATING-POINT INTRINSICS

The __m128 data type is used to represent the contents of an xmm register, which is either four packed single-precision floating-point values or one scalar single-precision number. The __m128 data type is not a basic ANSI C datatype and therefore some restrictions are placed on its usage:

- Use __m128 only on the left-hand side of an assignment, as a return value, or as a parameter. Do not use it in other arithmetic expressions such as "+" and ">>".
- Do not initialize __m128 with literals; there is no way to express 128-bit constants.
- Use __m128 objects in aggregates, such as unions (for example, to access the float elements) and structures. The address of an __m128 object may be taken.
- Use __m128 data only with the intrinsics described in this user's guide. Refer to Appendix C, *Compiler Intrinsics and Functional Equivalents* for more information on using intrinsics.

The compiler aligns __m128 local data to 16B boundaries on the stack. Global __m128 data is also 16B-aligned. (To align float arrays, you can use the alignment declspec described in the following section.) Because the new instruction set treats the SIMD floating-point registers in the same way whether you are using packed or scalar data, there is no __m32 datatype to represent scalar data as you might expect. For scalar operations, you should use the __m128 objects and the "scalar" forms of the intrinsics; the compiler and the processor implement these operations with 32-bit memory references.

The suffixes ps and ss are used to denote "packed single" and "scalar single" precision operations. The packed floats are represented in right-to-left order, with the lowest word (right-most) being used for scalar operations: [z, y, x, w]. To explain how memory storage reflects this, consider the following example.

The operation

```
float a[4] = { 1.0, 2.0, 3.0, 4.0 };
__m128 t = _mm_load_ps(a);
```

produces the same result as follows:

```
__m128 t = _mm_set_ps(4.0, 3.0, 2.0, 1.0);
```

In other words,

```
t = [ 4.0, 3.0, 2.0, 1.0 ]
```

where the “scalar” element is 1.0.

Some intrinsics are “composites” because they require more than one instruction to implement them. You should be familiar with the hardware features provided by the Streaming SIMD Extensions and MMX™ technology when writing programs with the intrinsics.

Keep the following three important issues in mind:

- Certain intrinsics, such as _mm_loadr_ps and _mm_cmpgt_ss, are not directly supported by the instruction set. While these intrinsics are convenient programming aids, be mindful of their implementation cost.
- Floating-point data loaded or stored as __m128 objects must generally be 16-byte-aligned.
- Some intrinsics require that their argument be immediates, that is, constant integers (literals), due to the nature of the instruction.
- The result of arithmetic operations acting on two NaN (Not a Number) arguments is undefined. Therefore, FP operations using NaN arguments will not match the expected behavior of the corresponding assembly instructions.

For a more detailed description of each intrinsic and additional information related to its usage, refer to the *Intel C/C++ Compiler User’s Guide for Win32* Systems With Streaming SIMD Extension Support* (Order Number 718195-00B). Refer to Appendix C, *Compiler Intrinsics and Functional Equivalents* for more information on using intrinsics.

3.1.4. Flags Affected

The “Flags Affected” section lists the flags in the EFLAGS register that are affected by the instruction. When a flag is cleared, it is equal to 0; when it is set, it is equal to 1. The arithmetic and logical instructions usually assign values to the status flags in a uniform manner. For more information, refer to Appendix A, *EFLAGS Cross-Reference*, of the *Intel Architecture Software Developer’s Manual, Volume 1*. Non-conventional assignments are described in the “Operation” section. The values of flags listed as **undefined** may be changed by the instruction in an indeterminate manner. Flags that are not listed are unchanged by the instruction.

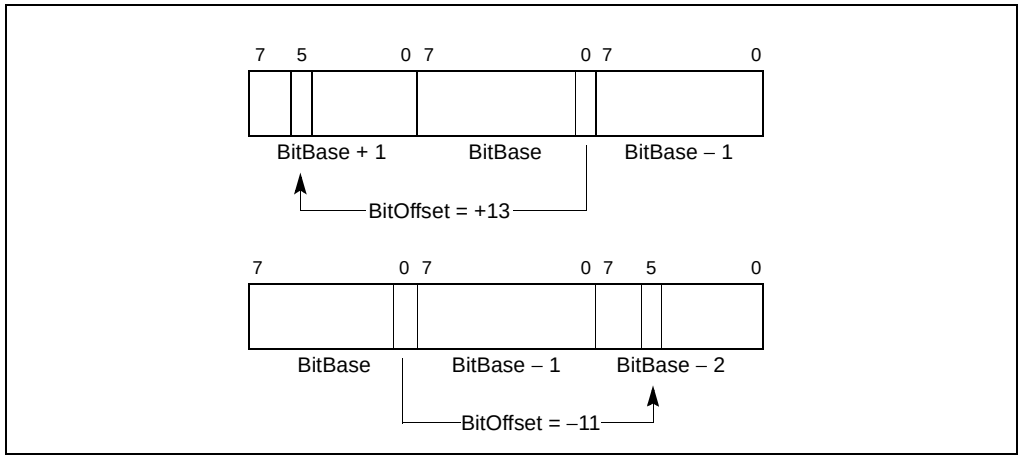


Figure 3-2. Memory Bit Indexing

3.1.5. FPU Flags Affected

The floating-point instructions have an “FPU Flags Affected” section that describes how each instruction can affect the four condition code flags of the FPU status word.

3.1.6. Protected Mode Exceptions

The “Protected Mode Exceptions” section lists the exceptions that can occur when the instruction is executed in protected mode and the reasons for the exceptions. Each exception is given a mnemonic that consists of a pound sign (#) followed by two letters and an optional error code in parentheses. For example, #GP(0) denotes a general protection exception with an error code of 0. Table 3-2 associates each two-letter mnemonic with the corresponding interrupt vector number and exception name. Refer to Chapter 5, *Interrupt and Exception Handling*, of the *Intel Architecture Software Developer's Manual, Volume 3*, for a detailed description of the exceptions.

Application programmers should consult the documentation provided with their operating systems to determine the actions taken when exceptions occur.

3.1.7. Real-Address Mode Exceptions

The “Real-Address Mode Exceptions” section lists the exceptions that can occur when the instruction is executed in real-address mode.

Table 3-2. Exception Mnemonics, Names, and Vector Numbers

Vector No.	Mnemonic	Name	Source
0	#DE	Divide Error	DIV and IDIV instructions.
1	#DB	Debug	Any code or data reference.
3	#BP	Breakpoint	INT 3 instruction.
4	#OF	Overflow	INTO instruction.
5	#BR	BOUND Range Exceeded	BOUND instruction.
6	#UD	Invalid Opcode (Undefined Opcode)	UD2 instruction or reserved opcode.[1]
7	#NM	Device Not Available (No Math Coprocessor)	Floating-point or WAIT/FWAIT instruction.
8	#DF	Double Fault	Any instruction that can generate an exception, an NMI, or an INTR.
10	#TS	Invalid TSS	Task switch or TSS access.
11	#NP	Segment Not Present	Loading segment registers or accessing system segments.
12	#SS	Stack Segment Fault	Stack operations and SS register loads.
13	#GP	General Protection	Any memory reference and other protection checks.
14	#PF	Page Fault	Any memory reference.
16	#MF	Floating-Point Error (Math Fault)	Floating-point or WAIT/FWAIT instruction.
17	#AC	Alignment Check	Any data reference in memory.[2]
18	#MC	Machine Check	Model dependent.[3]
19	#XF	SIMD Floating-Point Numeric Error	Streaming SIMD Extensions

NOTES:

1. The UD2 instruction was introduced in the Pentium® Pro processor.
2. This exception was introduced in the Intel486™ processor.
3. This exception was introduced in the Pentium® processor and enhanced in the Pentium® Pro processor.

3.1.8. Virtual-8086 Mode Exceptions

The “Virtual-8086 Mode Exceptions” section lists the exceptions that can occur when the instruction is executed in virtual-8086 mode.

3.1.9. Floating-Point Exceptions

The "Floating-Point Exceptions" section lists additional exceptions that can occur when a floating-point instruction is executed in any mode. All of these exception conditions result in a floating-point error exception (#MF, vector number 16) being generated. Table 3-3 associates each one- or two-letter mnemonic with the corresponding exception name. Refer to Section 7.8., *Floating-Point Exception Conditions* in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*, for a detailed description of these exceptions.

Table 3-3. Floating-Point Exception Mnemonics and Names

Vector No.	Mnemonic	Name	Source
16	#IS #IA	Floating-point invalid operation: - Stack overflow or underflow - Invalid arithmetic operation	- FPU stack overflow or underflow - Invalid FPU arithmetic operation
16	#Z	Floating-point divide-by-zero	FPU divide-by-zero
16	#D	Floating-point denormalized operation	Attempting to operate on a denormal number
16	#O	Floating-point numeric overflow	FPU numeric overflow
16	#U	Floating-point numeric underflow	FPU numeric underflow
16	#P	Floating-point inexact result (precision)	Inexact result (precision)

3.1.10. SIMD Floating-Point Exceptions - Streaming SIMD Extensions Only

The "SIMD Floating-Point Exceptions" section lists additional exceptions that can occur when a SIMD floating-point instruction is executed in any mode. All of these exception conditions result in a SIMD floating-point error exception (#XF, vector number 19) being generated. Table 3-4 associates each one-or two-letter mnemonic with the corresponding exception name. For a detailed description of these exceptions, refer to Chapter 9, *Programming with the Streaming SIMD Extension*, of the *Intel Architecture Software Developer's Manual, Volume 1.*

Table 3-4. SIMD Floating-Point Exception Mnemonics and Names

Vector No.	Mnemonic	Name	Source
6	#UD	Invalid opcode	Memory access
6	#UD	Invalid opcode	Refer to Note 1 & Table 3-5
7	#NM	Device not available	Refer to Note 1 & Table 3-5
12	#SS	Stack exception	Memory access
13	#GP	General protection	Refer to Note 2
14	#PF	Page fault	Memory access
17	#AC	Alignment check	Refer to Note 3
19	#I	Invalid operation	Refer to Note 4
19	#Z	Divide-by-zero	Refer to Note 4
19	#D	Denormalized operand	Refer to Note 4
19	#O	Numeric overflow	Refer to Note 5
19	#U	Numeric underflow	Refer to Note 5
19	#P	Inexact result	Refer to Note 5

Note 1: These are system exceptions. Table 3-5 lists the causes for Interrupt 6 and Interrupt 7 with Streaming SIMD Extensions.

Note 2: Executing a Streaming SIMD Extension with a misaligned 128-bit memory reference generates a general protection exception; a 128-bit reference within the stack segment, which is not aligned to a 16-byte boundary will also generate a GP fault, not a stack exception (SS). However, the MOVUPS instruction, which performs an unaligned 128-bit load or store, will not generate an exception for data that is not aligned to a 16-byte boundary.

Note 3: This type of alignment check is done for operands which are less than 128-bits in size: 32-bit scalar single and 16-bit/32-bit/64-bit integer MMX™ technology; the exception is the MOVUPS instruction, which performs a 128-bit unaligned load or store, is also covered by this alignment check. There are three conditions that must be true to enable #AC interrupt generation.

Note 4: Invalid, Divide-by-zero and Denormal exceptions are pre-computation exceptions, i.e., they are detected before any arithmetic operation occurs.

Note 5: Underflow, Overflow and Precision exceptions are post-computation exceptions.

Table 3-5. Streaming SIMD Extensions Faults (Interrupts 6 & 7)

CR0.EM	CR0.TS	CR4.OSFXSR	CPUID.XMM	Exception
1	-	-	-	#UD Interrupt 6
0	1	1	1	#NM Interrupt 7
-	-	0	-	#UD Interrupt 6
-	-	-	0	#UD Interrupt 6

3.2. INSTRUCTION REFERENCE

The remainder of this chapter provides detailed descriptions of each of the Intel Architecture instructions.

AAA—ASCII Adjust After Addition

Opcode	Instruction	Description
37	AAA	ASCII adjust AL after addition

Description

This instruction adjusts the sum of two unpacked BCD values to create an unpacked BCD result. The AL register is the implied source and destination operand for this instruction. The AAA instruction is only useful when it follows an ADD instruction that adds (binary addition) two unpacked BCD values and stores a byte result in the AL register. The AAA instruction then adjusts the contents of the AL register to contain the correct 1-digit unpacked BCD result.

If the addition produces a decimal carry, the AH register is incremented by 1, and the CF and AF flags are set. If there was no decimal carry, the CF and AF flags are cleared and the AH register is unchanged. In either case, bits 4 through 7 of the AL register are cleared to 0.

Operation

```
IF ((AL AND 0FH) > 9) OR (AF = 1)
    THEN
        AL ← (AL + 6);
        AH ← AH + 1;
        AF ← 1;
        CF ← 1;
    ELSE
        AF ← 0;
        CF ← 0;
FI;
AL ← AL AND 0FH;
```

Flags Affected

The AF and CF flags are set to 1 if the adjustment results in a decimal carry; otherwise they are cleared to 0. The OF, SF, ZF, and PF flags are undefined.

Exceptions (All Operating Modes)

None.

AAD—ASCII Adjust AX Before Division

Opcode	Instruction	Description
D5 0A	AAD	ASCII adjust AX before division
D5 *ib*	(No mnemonic)	Adjust AX before division to number base *imm8*

Description

This instruction adjusts two unpacked BCD digits (the least-significant digit in the AL register and the most-significant digit in the AH register) so that a division operation performed on the result will yield a correct unpacked BCD value. The AAD instruction is only useful when it precedes a DIV instruction that divides (binary division) the adjusted value in the AX register by an unpacked BCD value.

The AAD instruction sets the value in the AL register to (AL + (10 * AH)), and then clears the AH register to 00H. The value in the AX register is then equal to the binary equivalent of the original unpacked two-digit (base 10) number in registers AH and AL.

The generalized version of this instruction allows adjustment of two unpacked digits of any number base (refer to the "Operation" section below), by setting the *imm8* byte to the selected number base (for example, 08H for octal, 0AH for decimal, or 0CH for base 12 numbers). The AAD mnemonic is interpreted by all assemblers to mean adjust ASCII (base 10) values. To adjust values in another number base, the instruction must be hand coded in machine code (D5 *imm8*).

Operation

```
tempAL ← AL;
tempAH ← AH;
AL ← (tempAL + (tempAH ∗ imm8)) AND FFH; (* imm8 is set to 0AH for the AAD mnemonic *)
AH ← 0
```

The immediate value (*imm8*) is taken from the second byte of the instruction.

Flags Affected

The SF, ZF, and PF flags are set according to the result; the OF, AF, and CF flags are undefined.

Exceptions (All Operating Modes)

None.

AAM—ASCII Adjust AX After Multiply

Opcode	Instruction	Description
D4 0A	AAM	ASCII adjust AX after multiply
D4 *ib*	(No mnemonic)	Adjust AX after multiply to number base *imm8*

Description

This instruction adjusts the result of the multiplication of two unpacked BCD values to create a pair of unpacked (base 10) BCD values. The AX register is the implied source and destination operand for this instruction. The AAM instruction is only useful when it follows an MUL instruction that multiplies (binary multiplication) two unpacked BCD values and stores a word result in the AX register. The AAM instruction then adjusts the contents of the AX register to contain the correct 2-digit unpacked (base 10) BCD result.

The generalized version of this instruction allows adjustment of the contents of the AX to create two unpacked digits of any number base (refer to the "Operation" section below). Here, the *imm8* byte is set to the selected number base (for example, 08H for octal, 0AH for decimal, or 0CH for base 12 numbers). The AAM mnemonic is interpreted by all assemblers to mean adjust to ASCII (base 10) values. To adjust to values in another number base, the instruction must be hand coded in machine code (D4 *imm8*).

Operation

```
tempAL ← AL;
AH ← tempAL / imm8; (* imm8 is set to 0AH for the AAD mnemonic *)
AL ← tempAL MOD imm8;
```

The immediate value (*imm8*) is taken from the second byte of the instruction.

Flags Affected

The SF, ZF, and PF flags are set according to the result. The OF, AF, and CF flags are undefined.

Exceptions (All Operating Modes)

None with the default immediate value of 0AH. If, however, an immediate value of 0 is used, it will cause a #DE (divide error) exception.

AAS—ASCII Adjust AL After Subtraction

Opcode	Instruction	Description
3F	AAS	ASCII adjust AL after subtraction

Description

This instruction adjusts the result of the subtraction of two unpacked BCD values to create a unpacked BCD result. The AL register is the implied source and destination operand for this instruction. The AAS instruction is only useful when it follows a SUB instruction that subtracts (binary subtraction) one unpacked BCD value from another and stores a byte result in the AL register. The AAA instruction then adjusts the contents of the AL register to contain the correct 1-digit unpacked BCD result.

If the subtraction produced a decimal carry, the AH register is decremented by 1, and the CF and AF flags are set. If no decimal carry occurred, the CF and AF flags are cleared, and the AH register is unchanged. In either case, the AL register is left with its top nibble set to 0.

Operation

```
IF ((AL AND 0FH) > 9) OR (AF = 1)
THEN
    AL ← AL – 6;
    AH ← AH – 1;
    AF ← 1;
    CF ← 1;
ELSE
    CF ← 0;
    AF ← 0;
FI;
AL ← AL AND 0FH;
```

Flags Affected

The AF and CF flags are set to 1 if there is a decimal borrow; otherwise, they are cleared to 0. The OF, SF, ZF, and PF flags are undefined.

Exceptions (All Operating Modes)

None.

ADC—Add with Carry

Opcode	Instruction	Description
14 *ib*	ADC AL,*imm8*	Add with carry *imm8* to AL
15 *iw*	ADC AX,*imm16*	Add with carry *imm16* to AX
15 *id*	ADC EAX,*imm32*	Add with carry *imm32* to EAX
80 /2 *ib*	ADC *r/m8*,*imm8*	Add with carry *imm8* to *r/m8*
81 /2 *iw*	ADC *r/m16,imm16*	Add with carry *imm16* to *r/m16*
81 /2 *id*	ADC *r/m32,imm32*	Add with CF *imm32* to *r/m32*
83 /2 *ib*	ADC *r/m16,imm8*	Add with CF sign-extended *imm8* to *r/m16*
83 /2 *ib*	ADC *r/m32,imm8*	Add with CF sign-extended *imm8* into *r/m32*
10 /*r*	ADC *r/m8,r8*	Add with carry byte register to *r/m8*
11 /*r*	ADC *r/m16,r16*	Add with carry *r16* to *r/m16*
11 /*r*	ADC *r/m32,r32*	Add with CF *r32* to *r/m32*
12 /*r*	ADC *r8,r/m8*	Add with carry *r/m8* to byte register
13 /*r*	ADC *r16,r/m16*	Add with carry *r/m16* to *r16*
13 /*r*	ADC *r32,r/m32*	Add with CF *r/m32* to *r32*

Description

This instruction adds the destination operand (first operand), the source operand (second operand), and the carry (CF) flag and stores the result in the destination operand. The destination operand can be a register or a memory location; the source operand can be an immediate, a register, or a memory location. (However, two memory operands cannot be used in one instruction.) The state of the CF flag represents a carry from a previous addition. When an immediate value is used as an operand, it is sign-extended to the length of the destination operand format.

The ADC instruction does not distinguish between signed or unsigned operands. Instead, the processor evaluates the result for both data types and sets the OF and CF flags to indicate a carry in the signed or unsigned result, respectively. The SF flag indicates the sign of the signed result.

The ADC instruction is usually executed as part of a multibyte or multiword addition in which an ADD instruction is followed by an ADC instruction.

Operation

```
DEST ← DEST + SRC + CF;
```

Flags Affected

The OF, SF, ZF, AF, CF, and PF flags are set according to the result.

ADC—Add with Carry (Continued)

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

ADD—Add

Opcode	Instruction	Description
04 *ib*	ADD AL,*imm8*	Add *imm8* to AL
05 *iw*	ADD AX,*imm16*	Add *imm16* to AX
05 *id*	ADD EAX,*imm32*	Add *imm32* to EAX
80 /0 *ib*	ADD *r/m8,imm8*	Add *imm8* to *r/m8*
81 /0 *iw*	ADD *r/m16,imm16*	Add *imm16* to *r/m16*
81 /0 *id*	ADD *r/m32,imm32*	Add *imm32* to *r/m32*
83 /0 *ib*	ADD *r/m16,imm8*	Add sign-extended *imm8* to *r/m16*
83 /0 *ib*	ADD *r/m32,imm8*	Add sign-extended *imm8* to *r/m32*
00 /*r*	ADD *r/m8,r8*	Add *r8* to *r/m8*
01 /*r*	ADD *r/m16,r16*	Add *r16* to *r/m16*
01 /*r*	ADD *r/m32,r32*	Add r32 to *r/m32*
02 /*r*	ADD *r8,r/m8*	Add *r/m8* to *r8*
03 /*r*	ADD *r16,r/m16*	Add *r/m16* to *r16*
03 /*r*	ADD *r32,r/m32*	Add *r/m32* to *r32*

Description

This instruction adds the first operand (destination operand) and the second operand (source operand) and stores the result in the destination operand. The destination operand can be a register or a memory location; the source operand can be an immediate, a register, or a memory location. (However, two memory operands cannot be used in one instruction.) When an immediate value is used as an operand, it is sign-extended to the length of the destination operand format.

The ADD instruction does not distinguish between signed or unsigned operands. Instead, the processor evaluates the result for both data types and sets the OF and CF flags to indicate a carry in the signed or unsigned result, respectively. The SF flag indicates the sign of the signed result.

Operation

DEST ← DEST + SRC;

Flags Affected

The OF, SF, ZF, AF, CF, and PF flags are set according to the result.

ADD—Add (Continued)

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

ADDPS—Packed Single-FP Add

Opcode	Instruction	Description
0F,58,/r	ADDPS *xmm1, xmm2/m128*	Add packed SP FP numbers from *XMM2/Mem* to *XMM1*.

Description

The ADDPS instruction adds the packed SP FP numbers of both their operands.

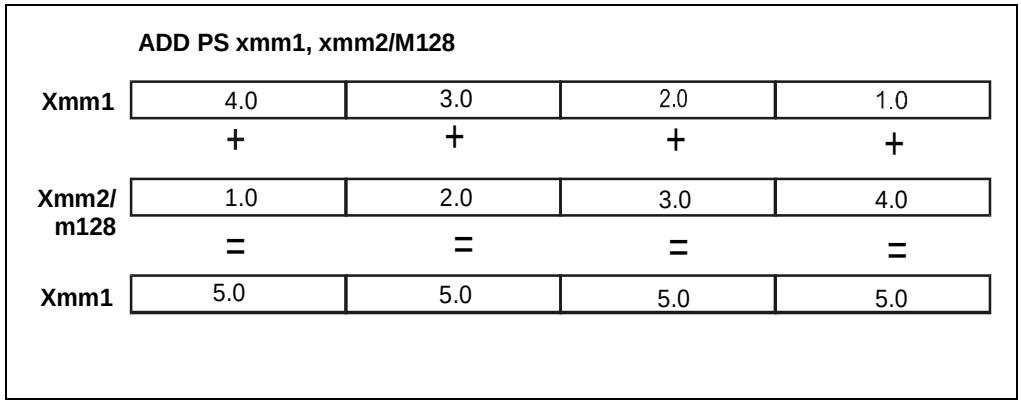


Figure 3-3. Operation of the ADDPS Instruction

Operation

```
DEST[31-0]      = DEST[31-0] + SRC/m128[31-0];
DEST[63-32]     = DEST[63-32] + SRC/m128[63-32];
DEST[95-64]     = DEST[95-64] + SRC/m128[95-64];
DEST[127-96]    = DEST[127-96] + SRC/m128[127-96];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_add_ps(__m128 a, __m128 b)

Adds the four SP FP values of a and b.

ADDPS—Packed Single-FP Add (Continued)

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

Numeric Exceptions

Overflow, Underflow, Invalid, Precision, Denormal.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.

ADDSS—Scalar Single-FP Add

Opcode	Instruction	Description
F3,0F,58, /r	ADDSS *xmm1*, *xmm2/m32*	Add the lower SP FP number from *XMM2/Mem* to *XMM1*.

Description

The ADDSS instruction adds the lower SP FP numbers of both their operands; the upper three fields are passed through from xmm1.

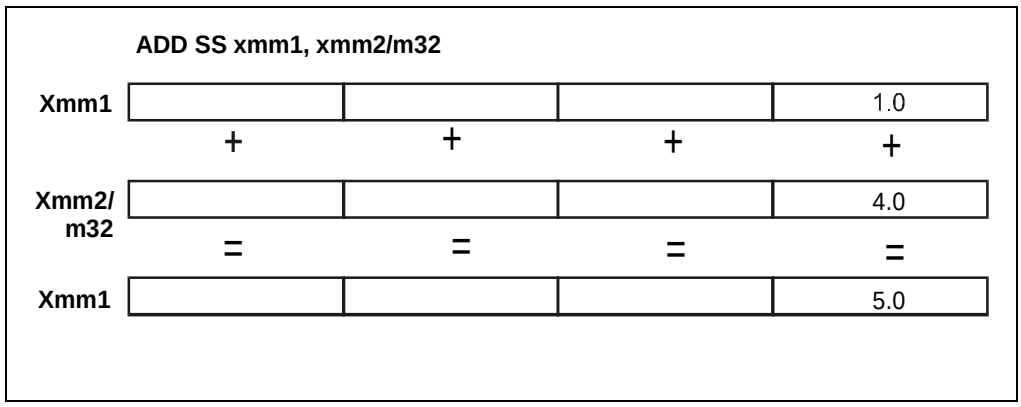


Figure 3-4. Operation of the ADDSS Instruction

Operation

```
DEST[31-0]      = DEST[31-0] + SRC/m32[31-0];
DEST[63-32]     = DEST[63-32];
DEST[95-64]     = DEST[95-64];
DEST[127-96]    = DEST[127-96];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_add_ss(__m128 a, __m128 b)

Adds the lower SP FP (single-precision, floating-point) values of a and b; the upper three SP FP values are passed through from a.

ADDSS—Scalar Single-FP Add (Continued)

Exceptions

None.

Numeric Exceptions

Overflow, Underflow, Invalid, Precision, Denormal.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true (CR0.AM is set; EFLAGS.AC is set; and current CPL is 3).
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

ADDSS—Scalar Single-FP Add (Continued)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

AND—Logical AND

Opcode	Instruction	Description
24 *ib*	AND AL,*imm8*	AL AND *imm8*
25 *iw*	AND AX,*imm16*	AX AND i*mm16*
25 *id*	AND EAX,*imm32*	EAX AND *imm32*
80 /4 *ib*	AND *r/m8,imm8*	*r/m8* AND *imm8*
81 /4 *iw*	AND *r/m16,imm16*	*r/m16* AND *imm16*
81 /4 *id*	AND *r/m32,imm32*	*r/m32* AND *imm32*
83 /4 *ib*	AND *r/m16,imm8*	*r/m16* AND *imm8 (sign-extended)*
83 /4 *ib*	AND *r/m32,imm8*	*r/m32* AND *imm8 (sign-extended)*
20 */r*	AND *r/m8,r8*	*r/m8* AND *r8*
21 /*r*	AND *r/m16,r16*	*r/m16* AND *r16*
21 /*r*	AND *r/m32,r32*	*r/m32* AND *r32*
22 /*r*	AND *r8,r/m8*	*r8* AND *r/m8*
23 /*r*	AND *r16,r/m16*	*r16* AND *r/m16*
23 /*r*	AND *r32,r/m32*	*r32* AND *r/m32*

Description

This instruction performs a bitwise AND operation on the destination (first) and source (second) operands and stores the result in the destination operand location. The source operand can be an immediate, a register, or a memory location; the destination operand can be a register or a memory location. Two memory operands cannot, however, be used in one instruction. Each bit of the instruction result is a 1 if both corresponding bits of the operands are 1; otherwise, it becomes a 0.

Operation

DEST ← DEST AND SRC;

Flags Affected

The OF and CF flags are cleared; the SF, ZF, and PF flags are set according to the result. The state of the AF flag is undefined.

AND—Logical AND (Continued)

Protected Mode Exceptions

#GP(0)	If the destination operand points to a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

ANDNPS—Bit-wise Logical And Not For Single-FP

Opcode	Instruction	Description
0F,55,/r	ANDNPS *xmm1*, *xmm2/m128*	Invert the 128 bits in *XMM1*and then AND the result with 128 bits from *XMM2/Mem*.

Description

The ANDNPS instructions returns a bit-wise logical AND between the complement of XMM1 and XMM2/Mem.

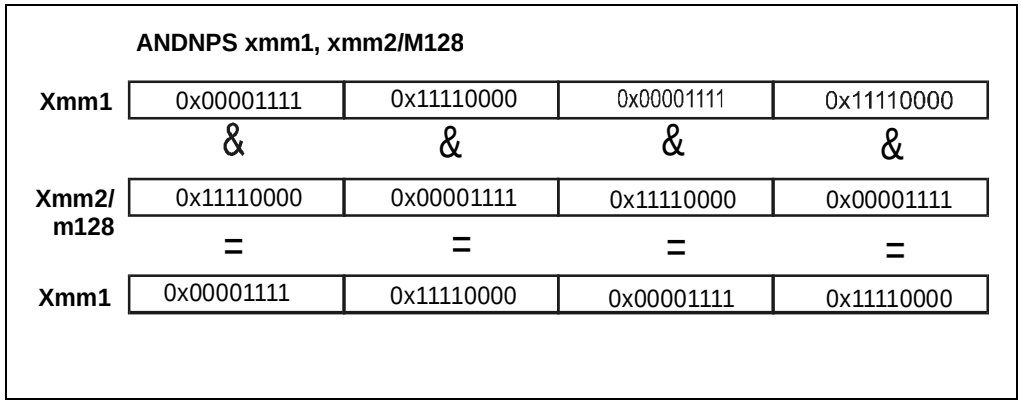


Figure 3-5. Operation of the ANDNPS Instruction

Operation

```
DEST[127-0] = NOT (DEST[127-0]) AND SRC/m128[127-0];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_andnot_ps(__m128 a, __m128 b)

Computes the bitwise AND-NOT of the four SP FP values of a and b.

ANDNPS—Bit-wise Logical And Not for Single-FP (Continued)

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real-Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.

Virtual-8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Comments

The usage of Repeat Prefix (F3H) with ANDNPS is reserved. Different processor implementations may handle this prefix differently. Usage of this prefix with ANDNPS risks incompatibility with future processors.

ANDPS—Bit-wise Logical And For Single FP

Opcode	Instruction	Description
0F,54,/r	ANDPS *xmm1, xmm2/m128*	Logical AND of 128 bits from *XMM2/Mem* to *XMM1* register.

Description

The ANDPS instruction returns a bit-wise logical AND between XMM1 and XMM2/Mem.

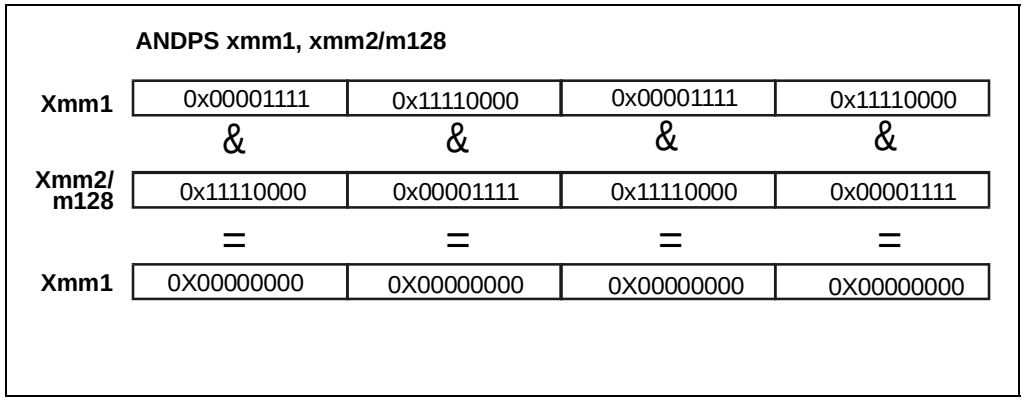


Figure 3-6. Operation of the ANDPS Instruction

Operation

```
DEST[127-0] AND= SRC/m128[127-0];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_and_ps(__m128 a, __m128 b)

Computes the bitwise And of the four SP FP values of a and b.

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

ANDPS—Bit-wise Logical And for Single-FP (Continued)

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real-Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual-8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.

Comments

The usage of Repeat Prefix (F3H) with ANDPS is reserved. Different processor implementations may handle this prefix differently. Usage of this prefix with ANDPS risks incompatibility with future processors.

ARPL—Adjust RPL Field of Segment Selector

Opcode	Instruction	Description
63 /*r*	ARPL *r/m16,r16*	Adjust RPL of *r/m16* to not less than RPL of *r16*

Description

This instruction compares the RPL fields of two segment selectors. The first operand (the destination operand) contains one segment selector and the second operand (source operand) contains the other. (The RPL field is located in bits 0 and 1 of each operand.) If the RPL field of the destination operand is less than the RPL field of the source operand, the ZF flag is set and the RPL field of the destination operand is increased to match that of the source operand. Otherwise, the ZF flag is cleared and no change is made to the destination operand. (The destination operand can be a word register or a memory location; the source operand must be a word register.)

The ARPL instruction is provided for use by operating-system procedures (however, it can also be used by applications). It is generally used to adjust the RPL of a segment selector that has been passed to the operating system by an application program to match the privilege level of the application program. Here the segment selector passed to the operating system is placed in the destination operand and segment selector for the application program's code segment is placed in the source operand. (The RPL field in the source operand represents the privilege level of the application program.) Execution of the ARPL instruction then insures that the RPL of the segment selector received by the operating system is no lower (does not have a higher privilege) than the privilege level of the application program. (The segment selector for the application program's code segment can be read from the stack following a procedure call.)

Refer to Chapter 4.10.4., *Checking Caller Access Privileges (ARPL Instruction)* in Chapter 4, *Protection* of the *Intel Architecture Software Developer's Manual, Volume 3*, for more information about the use of this instruction.

Operation

```
IF DEST(RPL) < SRC(RPL)
THEN
    ZF ← 1;
    DEST(RPL) ← SRC(RPL);
ELSE
    ZF ← 0;
FI;
```

Flags Affected

The ZF flag is set to 1 if the RPL field of the destination operand is less than that of the source operand; otherwise, is cleared to 0.

ARPL—Adjust RPL Field of Segment Selector (Continued)

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#UD	The ARPL instruction is not recognized in real-address mode.

Virtual-8086 Mode Exceptions

#UD	The ARPL instruction is not recognized in virtual-8086 mode.

BOUND—Check Array Index Against Bounds

Opcode	Instruction	Description
62 /*r*	BOUND *r16,m16&16*	Check if *r16* (array index) is within bounds specified by *m16&16*
62 /*r*	BOUND *r32,m32&32*	Check if *r32* (array index) is within bounds specified by *m16&16*

Description

This instruction determines if the first operand (array index) is within the bounds of an array specified the second operand (bounds operand). The array index is a signed integer located in a register. The bounds operand is a memory location that contains a pair of signed doubleword-integers (when the operand-size attribute is 32) or a pair of signed word-integers (when the operand-size attribute is 16). The first doubleword (or word) is the lower bound of the array and the second doubleword (or word) is the upper bound of the array. The array index must be greater than or equal to the lower bound and less than or equal to the upper bound plus the operand size in bytes. If the index is not within bounds, a BOUND range exceeded exception (#BR) is signalled. (When a this exception is generated, the saved return instruction pointer points to the BOUND instruction.)

The bounds limit data structure (two words or doublewords containing the lower and upper limits of the array) is usually placed just before the array itself, making the limits addressable via a constant offset from the beginning of the array. Because the address of the array already will be present in a register, this practice avoids extra bus cycles to obtain the effective address of the array bounds.

Operation

```
IF (ArrayIndex < LowerBound OR ArrayIndex > (UppderBound + OperandSize/8]))
    (* Below lower bound or above upper bound *)
    THEN
        #BR;
FI;
```

Flags Affected

None.

BOUND—Check Array Index Against Bounds (Continued)

Protected Mode Exceptions

#BR	If the bounds test fails.
#UD	If second operand is not a memory location.
#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#BR	If the bounds test fails.
#UD	If second operand is not a memory location.
#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#BR	If the bounds test fails.
#UD	If second operand is not a memory location.
#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

BSF—Bit Scan Forward

Opcode	Instruction	Description
0F BC	BSF *r16,r/m16*	Bit scan forward on *r/m16*
0F BC	BSF *r32,r/m32*	Bit scan forward on *r/m32*

Description

This instruction searches the source operand (second operand) for the least significant set bit (1 bit). If a least significant 1 bit is found, its bit index is stored in the destination operand (first operand). The source operand can be a register or a memory location; the destination operand is a register. The bit index is an unsigned offset from bit 0 of the source operand. If the contents source operand are 0, the contents of the destination operand is undefined.

Operation

```
IF SRC = 0
    THEN
        ZF ← 1;
        DEST is undefined;
    ELSE
        ZF ← 0;
        temp ← 0;
    WHILE Bit(SRC, temp) = 0
    DO
        temp ← temp + 1;
        DEST ← temp;
    OD;
FI;
```

Flags Affected

The ZF flag is set to 1 if all the source operand is 0; otherwise, the ZF flag is cleared. The CF, OF, SF, AF, and PF, flags are undefined.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

BSF—Bit Scan Forward (Continued)

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

BSR—Bit Scan Reverse

Opcode	Instruction	Description
0F BD	BSR *r16,r/m16*	Bit scan reverse on *r/m16*
0F BD	BSR *r32,r/m32*	Bit scan reverse on *r/m32*

Description

This instruction searches the source operand (second operand) for the most significant set bit (1 bit). If a most significant 1 bit is found, its bit index is stored in the destination operand (first operand). The source operand can be a register or a memory location; the destination operand is a register. The bit index is an unsigned offset from bit 0 of the source operand. If the contents source operand are 0, the contents of the destination operand is undefined.

Operation

```
IF SRC = 0
    THEN
        ZF ← 1;
        DEST is undefined;
    ELSE
        ZF ← 0;
        temp ← OperandSize – 1;
    WHILE Bit(SRC, temp) = 0
    DO
        temp ← temp – 1;
        DEST ← temp;
    OD;
FI;
```

Flags Affected

The ZF flag is set to 1 if all the source operand is 0; otherwise, the ZF flag is cleared. The CF, OF, SF, AF, and PF, flags are undefined.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

BSR—Bit Scan Reverse (Continued)

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

BSWAP—Byte Swap

Opcode	Instruction	Description
0F C8+*rd*	BSWAP *r32*	Reverses the byte order of a 32-bit register.

Description

This instruction reverses the byte order of a 32-bit (destination) register: bits 0 through 7 are swapped with bits 24 through 31, and bits 8 through 15 are swapped with bits 16 through 23. This instruction is provided for converting little-endian values to big-endian format and vice versa.

To swap bytes in a word value (16-bit register), use the XCHG instruction. When the BSWAP instruction references a 16-bit register, the result is undefined.

Intel Architecture Compatibility

The BSWAP instruction is not supported on Intel Architecture processors earlier than the Intel486™ processor family. For compatibility with this instruction, include functionally equivalent code for execution on Intel processors earlier than the Intel486™ processor family.

Operation

```
TEMP ← DEST
DEST(7..0) ← TEMP(31..24)
DEST(15..8) ← TEMP(23..16)
DEST(23..16) ← TEMP(15..8)
DEST(31..24) ← TEMP(7..0)
```

Flags Affected

None.

Exceptions (All Operating Modes)

None.

BT—Bit Test

Opcode	Instruction	Description
0F A3	BT *r/m16,r16*	Store selected bit in CF flag
0F A3	BT *r/m32,r32*	Store selected bit in CF flag
0F BA /4 *ib*	BT *r/m16,imm8*	Store selected bit in CF flag
0F BA /4 *ib*	BT *r/m32,imm8*	Store selected bit in CF flag

Description

This instruction selects the bit in a bit string (specified with the first operand, called the bit base) at the bit-position designated by the bit offset operand (second operand) and stores the value of the bit in the CF flag. The bit base operand can be a register or a memory location; the bit offset operand can be a register or an immediate value. If the bit base operand specifies a register, the instruction takes the modulo 16 or 32 (depending on the register size) of the bit offset operand, allowing any bit position to be selected in a 16- or 32-bit register, respectively (refer to Figure 3-1). If the bit base operand specifies a memory location, it represents the address of the byte in memory that contains the bit base (bit 0 of the specified byte) of the bit string (refer to Figure 3-2). The offset operand then selects a bit position within the range -2^{31} to $2^{31} - 1$ for a register offset and 0 to 31 for an immediate offset.

Some assemblers support immediate bit offsets larger than 31 by using the immediate bit offset field in combination with the displacement field of the memory operand. In this case, the low-order three or five bits (three for 16-bit operands, five for 32-bit operands) of the immediate bit offset are stored in the immediate bit offset field, and the high-order bits are shifted and combined with the byte displacement in the addressing mode by the assembler. The processor will ignore the high order bits if they are not zero.

When accessing a bit in memory, the processor may access four bytes starting from the memory address for a 32-bit operand size, using by the following relationship:

Effective Address + (4 ∗ (BitOffset DIV 32))

Or, it may access two bytes starting from the memory address for a 16-bit operand, using this relationship:

Effective Address + (2 ∗ (BitOffset DIV 16))

It may do so even when only a single byte needs to be accessed to reach the given bit. When using this bit addressing mechanism, software should avoid referencing areas of memory close to address space holes. In particular, it should avoid references to memory-mapped I/O registers. Instead, software should use the MOV instructions to load from or store to these addresses, and use the register form of these instructions to manipulate the data.

Operation

CF ← Bit(BitBase, BitOffset)

BT—Bit Test (Continued)

Flags Affected

The CF flag contains the value of the selected bit. The OF, SF, ZF, AF, and PF flags are undefined.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

BTC—Bit Test and Complement

Opcode	Instruction	Description
0F BB	BTC *r/m16,r16*	Store selected bit in CF flag and complement
0F BB	BTC *r/m32,r32*	Store selected bit in CF flag and complement
0F BA /7 *ib*	BTC *r/m16,imm8*	Store selected bit in CF flag and complement
0F BA /7 *ib*	BTC *r/m32,imm8*	Store selected bit in CF flag and complement

Description

This instruction selects the bit in a bit string (specified with the first operand, called the bit base) at the bit-position designated by the bit offset operand (second operand), stores the value of the bit in the CF flag, and complements the selected bit in the bit string. The bit base operand can be a register or a memory location; the bit offset operand can be a register or an immediate value. If the bit base operand specifies a register, the instruction takes the modulo 16 or 32 (depending on the register size) of the bit offset operand, allowing any bit position to be selected in a 16- or 32-bit register, respectively (refer to Figure 3-1). If the bit base operand specifies a memory location, it represents the address of the byte in memory that contains the bit base (bit 0 of the specified byte) of the bit string (refer to Figure 3-2). The offset operand then selects a bit position within the range -2^{31} to $2^{31} - 1$ for a register offset and 0 to 31 for an immediate offset.

Some assemblers support immediate bit offsets larger than 31 by using the immediate bit offset field in combination with the displacement field of the memory operand. Refer to "BT—Bit Test" in this chapter for more information on this addressing mechanism.

Operation

```
CF ← Bit(BitBase, BitOffset)
Bit(BitBase, BitOffset) ← NOT Bit(BitBase, BitOffset);
```

Flags Affected

The CF flag contains the value of the selected bit before it is complemented. The OF, SF, ZF, AF, and PF flags are undefined.

BTC—Bit Test and Complement (Continued)

Protected Mode Exceptions

#GP(0)	If the destination operand points to a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

BTR—Bit Test and Reset

Opcode	Instruction	Description
0F B3	BTR *r/m16,r16*	Store selected bit in CF flag and clear
0F B3	BTR *r/m32,r32*	Store selected bit in CF flag and clear
0F BA /6 *ib*	BTR *r/m16,imm8*	Store selected bit in CF flag and clear
0F BA /6 *ib*	BTR *r/m32,imm8*	Store selected bit in CF flag and clear

Description

This instruction selects the bit in a bit string (specified with the first operand, called the bit base) at the bit-position designated by the bit offset operand (second operand), stores the value of the bit in the CF flag, and clears the selected bit in the bit string to 0. The bit base operand can be a register or a memory location; the bit offset operand can be a register or an immediate value. If the bit base operand specifies a register, the instruction takes the modulo 16 or 32 (depending on the register size) of the bit offset operand, allowing any bit position to be selected in a 16- or 32-bit register, respectively (refer to Figure 3-1). If the bit base operand specifies a memory location, it represents the address of the byte in memory that contains the bit base (bit 0 of the specified byte) of the bit string (refer to Figure 3-2). The offset operand then selects a bit position within the range -2^{31} to $2^{31} - 1$ for a register offset and 0 to 31 for an immediate offset.

Some assemblers support immediate bit offsets larger than 31 by using the immediate bit offset field in combination with the displacement field of the memory operand. Refer to “BT—Bit Test” in this chapter for more information on this addressing mechanism.

Operation

CF ← Bit(BitBase, BitOffset)
Bit(BitBase, BitOffset) ← 0;

Flags Affected

The CF flag contains the value of the selected bit before it is cleared. The OF, SF, ZF, AF, and PF flags are undefined.

BTR—Bit Test and Reset (Continued)

Protected Mode Exceptions

#GP(0)	If the destination operand points to a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

BTS—Bit Test and Set

Opcode	Instruction	Description
0F AB	BTS *r/m16,r16*	Store selected bit in CF flag and set
0F AB	BTS *r/m32,r32*	Store selected bit in CF flag and set
0F BA /5 *ib*	BTS *r/m16,imm8*	Store selected bit in CF flag and set
0F BA /5 *ib*	BTS *r/m32,imm8*	Store selected bit in CF flag and set

Description

This instruction selects the bit in a bit string (specified with the first operand, called the bit base) at the bit-position designated by the bit offset operand (second operand), stores the value of the bit in the CF flag, and sets the selected bit in the bit string to 1. The bit base operand can be a register or a memory location; the bit offset operand can be a register or an immediate value. If the bit base operand specifies a register, the instruction takes the modulo 16 or 32 (depending on the register size) of the bit offset operand, allowing any bit position to be selected in a 16- or 32-bit register, respectively (refer to Figure 3-1). If the bit base operand specifies a memory location, it represents the address of the byte in memory that contains the bit base (bit 0 of the specified byte) of the bit string (refer to Figure 3-2). The offset operand then selects a bit position within the range -2^{31} to $2^{31} - 1$ for a register offset and 0 to 31 for an immediate offset.

Some assemblers support immediate bit offsets larger than 31 by using the immediate bit offset field in combination with the displacement field of the memory operand. Refer to "BT—Bit Test" in this chapter for more information on this addressing mechanism.

Operation

CF ← Bit(BitBase, BitOffset)
Bit(BitBase, BitOffset) ← 1;

Flags Affected

The CF flag contains the value of the selected bit before it is set. The OF, SF, ZF, AF, and PF flags are undefined.

BTS—Bit Test and Set (Continued)

Protected Mode Exceptions

#GP(0)	If the destination operand points to a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

CALL—Call Procedure

Opcode	Instruction	Description
E8 *cw*	CALL *rel16*	Call near, relative, displacement relative to next instruction
E8 *cd*	CALL *rel32*	Call near, relative, displacement relative to next instruction
FF /2	CALL *r/m16*	Call near, absolute indirect, address given in *r/m16*
FF /2	CALL *r/m32*	Call near, absolute indirect, address given in *r/m32*
9A *cd*	CALL *ptr16:16*	Call far, absolute, address given in operand
9A *cp*	CALL *ptr16:32*	Call far, absolute, address given in operand
FF /3	CALL *m16:16*	Call far, absolute indirect, address given in *m16:16*
FF /3	CALL *m16:32*	Call far, absolute indirect, address given in *m16:32*

Description

This instruction saves procedure linking information on the stack and branches to the procedure (called procedure) specified with the destination (target) operand. The target operand specifies the address of the first instruction in the called procedure. This operand can be an immediate value, a general-purpose register, or a memory location.

This instruction can be used to execute four different types of calls:

- Near call—A call to a procedure within the current code segment (the segment currently pointed to by the CS register), sometimes referred to as an intrasegment call.
- Far call—A call to a procedure located in a different segment than the current code segment, sometimes referred to as an intersegment call.
- Inter-privilege-level far call—A far call to a procedure in a segment at a different privilege level than that of the currently executing program or procedure.
- Task switch—A call to a procedure located in a different task.

The latter two call types (inter-privilege-level call and task switch) can only be executed in protected mode. Refer to Section 4.3., *Calling Procedures Using CALL and RET* in Chapter 4, *Procedure Calls, Interrupts, and Exceptions* of the *Intel Architecture Software Developer's Manual, Volume 1*, for additional information on near, far, and inter-privilege-level calls. Refer to Chapter 6, *Task Management,* of the *Intel Architecture Software Developer's Manual, Volume 3*, for information on performing task switches with the CALL instruction.

Near Call. When executing a near call, the processor pushes the value of the EIP register (which contains the offset of the instruction following the CALL instruction) onto the stack (for use later as a return-instruction pointer). The processor then branches to the address in the current code segment specified with the target operand. The target operand specifies either an absolute offset in the code segment (that is an offset from the base of the code segment) or a relative offset (a signed displacement relative to the current value of the instruction pointer in the EIP register, which points to the instruction following the CALL instruction). The CS register is not changed on near calls.

CALL—Call Procedure (Continued)

For a near call, an absolute offset is specified indirectly in a general-purpose register or a memory location (*r/m16* or *r/m32*). The operand-size attribute determines the size of the target operand (16 or 32 bits). Absolute offsets are loaded directly into the EIP register. If the operand-size attribute is 16, the upper two bytes of the EIP register are cleared to 0s, resulting in a maximum instruction pointer size of 16 bits. (When accessing an absolute offset indirectly using the stack pointer [ESP] as a base register, the base value used is the value of the ESP before the instruction executes.)

A relative offset (*rel16* or *rel32*) is generally specified as a label in assembly code, but at the machine code level, it is encoded as a signed, 16- or 32-bit immediate value. This value is added to the value in the EIP register. As with absolute offsets, the operand-size attribute determines the size of the target operand (16 or 32 bits).

Far Calls in Real-Address or Virtual-8086 Mode. When executing a far call in real-address or virtual-8086 mode, the processor pushes the current value of both the CS and EIP registers onto the stack for use as a return-instruction pointer. The processor then performs a "far branch" to the code segment and offset specified with the target operand for the called procedure. Here the target operand specifies an absolute far address either directly with a pointer (*ptr16:16* or *ptr16:32*) or indirectly with a memory location (*m16:16* or *m16:32*). With the pointer method, the segment and offset of the called procedure is encoded in the instruction, using a 4-byte (16-bit operand size) or 6-byte (32-bit operand size) far address immediate. With the indirect method, the target operand specifies a memory location that contains a 4-byte (16-bit operand size) or 6-byte (32-bit operand size) far address. The operand-size attribute determines the size of the offset (16 or 32 bits) in the far address. The far address is loaded directly into the CS and EIP registers. If the operand-size attribute is 16, the upper two bytes of the EIP register are cleared to 0s.

Far Calls in Protected Mode. When the processor is operating in protected mode, the CALL instruction can be used to perform the following three types of far calls:

- Far call to the same privilege level.
- Far call to a different privilege level (inter-privilege level call).
- Task switch (far call to another task).

In protected mode, the processor always uses the segment selector part of the far address to access the corresponding descriptor in the GDT or LDT. The descriptor type (code segment, call gate, task gate, or TSS) and access rights determine the type of call operation to be performed.

If the selected descriptor is for a code segment, a far call to a code segment at the same privilege level is performed. (If the selected code segment is at a different privilege level and the code segment is non-conforming, a general-protection exception is generated.) A far call to the same privilege level in protected mode is very similar to one carried out in real-address or virtual-8086 mode. The target operand specifies an absolute far address either directly with a pointer (*ptr16:16* or *ptr16:32*) or indirectly with a memory location (*m16:16* or *m16:32*). The operand-size attribute determines the size of the offset (16 or 32 bits) in the far address. The new code segment selector and its descriptor are loaded into CS register, and the offset from the instruction is loaded into the EIP register.

CALL—Call Procedure (Continued)

Note that a call gate (described in the next paragraph) can also be used to perform far call to a code segment at the same privilege level. Using this mechanism provides an extra level of indirection and is the preferred method of making calls between 16-bit and 32-bit code segments.

When executing an inter-privilege-level far call, the code segment for the procedure being called must be accessed through a call gate. The segment selector specified by the target operand identifies the call gate. Here again, the target operand can specify the call gate segment selector either directly with a pointer (*ptr16:16* or *ptr16:32*) or indirectly with a memory location (*m16:16* or *m16:32*). The processor obtains the segment selector for the new code segment and the new instruction pointer (offset) from the call gate descriptor. (The offset from the target operand is ignored when a call gate is used.) On inter-privilege-level calls, the processor switches to the stack for the privilege level of the called procedure. The segment selector for the new stack segment is specified in the TSS for the currently running task. The branch to the new code segment occurs after the stack switch. (Note that when using a call gate to perform a far call to a segment at the same privilege level, no stack switch occurs.) On the new stack, the processor pushes the segment selector and stack pointer for the calling procedure's stack, an (optional) set of parameters from the calling procedures stack, and the segment selector and instruction pointer for the calling procedure's code segment. (A value in the call gate descriptor determines how many parameters to copy to the new stack.) Finally, the processor branches to the address of the procedure being called within the new code segment.

Executing a task switch with the CALL instruction, is somewhat similar to executing a call through a call gate. Here the target operand specifies the segment selector of the task gate for the task being switched to (and the offset in the target operand is ignored.) The task gate in turn points to the TSS for the task, which contains the segment selectors for the task's code and stack segments. The TSS also contains the EIP value for the next instruction that was to be executed before the task was suspended. This instruction pointer value is loaded into EIP register so that the task begins executing again at this next instruction.

The CALL instruction can also specify the segment selector of the TSS directly, which eliminates the indirection of the task gate. Refer to Chapter 6, *Task Management*, of the *Intel Architecture Software Developer's Manual, Volume 3*, for detailed information on the mechanics of a task switch.

Note that when you execute at task switch with a CALL instruction, the nested task flag (NT) is set in the EFLAGS register and the new TSS's previous task link field is loaded with the old tasks TSS selector. Code is expected to suspend this nested task by executing an IRET instruction, which, because the NT flag is set, will automatically use the previous task link to return to the calling task. Refer to Section 6.4., *Task Linking* in Chapter 6, *Task Management* of the *Intel Architecture Software Developer's Manual, Volume 3*, for more information on nested tasks. Switching tasks with the CALL instruction differs in this regard from the JMP instruction which does not set the NT flag and therefore does not expect an IRET instruction to suspend the task.

CALL—Call Procedure (Continued)

Mixing 16-Bit and 32-Bit Calls. When making far calls between 16-bit and 32-bit code segments, the calls should be made through a call gate. If the far call is from a 32-bit code segment to a 16-bit code segment, the call should be made from the first 64 KBytes of the 32-bit code segment. This is because the operand-size attribute of the instruction is set to 16, so only a 16-bit return address offset is saved. Also, the call should be made using a 16-bit call gate so that 16-bit values will be pushed on the stack. Refer to Chapter 16, *Mixing 16-Bit and 32-Bit Code*, of the *Intel Architecture Software Developer's Manual, Volume 3*, for more information on making calls between 16-bit and 32-bit code segments.

Operation

```
IF near call
    THEN IF near relative call
        IF the instruction pointer is not within code segment limit THEN #GP(0); FI;
        THEN IF OperandSize = 32
            THEN
                IF stack not large enough for a 4-byte return address THEN #SS(0); FI;
                Push(EIP);
                EIP ← EIP + DEST; (* DEST is rel32 *)
            ELSE (* OperandSize = 16 *)
                IF stack not large enough for a 2-byte return address THEN #SS(0); FI;
                Push(IP);
                EIP ← (EIP + DEST) AND 0000FFFFH; (* DEST is rel16 *)
        FI;
    FI;
    ELSE (* near absolute call *)
        IF the instruction pointer is not within code segment limit THEN #GP(0); FI;
        IF OperandSize = 32
            THEN
                IF stack not large enough for a 4-byte return address THEN #SS(0); FI;
                Push(EIP);
                EIP ← DEST; (* DEST is r/m32 *)
            ELSE (* OperandSize = 16 *)
                IF stack not large enough for a 2-byte return address THEN #SS(0); FI;
                Push(IP);
                EIP ← DEST AND 0000FFFFH; (* DEST is r/m16 *)
        FI;
    FI:
FI;

IF far call AND (PE = 0 OR (PE = 1 AND VM = 1)) (* real-address or virtual-8086 mode *)
    THEN
        IF OperandSize = 32
            THEN
                IF stack not large enough for a 6-byte return address THEN #SS(0); FI;
                IF the instruction pointer is not within code segment limit THEN #GP(0); FI;
```

CALL—Call Procedure (Continued)

```
                    Push(CS); (* padded with 16 high-order bits *)
                    Push(EIP);
                    CS ← DEST[47:32]; (* DEST is ptr16:32 or [m16:32] *)
                    EIP ← DEST[31:0]; (* DEST is ptr16:32 or [m16:32] *)
                ELSE (* OperandSize = 16 *)
                    IF stack not large enough for a 4-byte return address THEN #SS(0); FI;
                    IF the instruction pointer is not within code segment limit THEN #GP(0); FI;
                    Push(CS);
                    Push(IP);
                    CS ← DEST[31:16]; (* DEST is ptr16:16 or [m16:16] *)
                    EIP ← DEST[15:0]; (* DEST is ptr16:16 or [m16:16] *)
                    EIP ← EIP AND 0000FFFFH; (* clear upper 16 bits *)
            FI;
FI;

IF far call AND (PE = 1 AND VM = 0) (* Protected mode, not virtual-8086 mode *)
    THEN
        IF segment selector in target operand null THEN #GP(0); FI;
        IF segment selector index not within descriptor table limits
            THEN #GP(new code segment selector);
        FI;
        Read type and access rights of selected segment descriptor;
        IF segment type is not a conforming or nonconforming code segment, call gate,
            task gate, or TSS THEN #GP(segment selector); FI;
        Depending on type and access rights
            GO TO CONFORMING-CODE-SEGMENT;
            GO TO NONCONFORMING-CODE-SEGMENT;
            GO TO CALL-GATE;
            GO TO TASK-GATE;
            GO TO TASK-STATE-SEGMENT;
FI;

CONFORMING-CODE-SEGMENT:
    IF DPL > CPL THEN #GP(new code segment selector); FI;
    IF segment not present THEN #NP(new code segment selector); FI;
    IF OperandSize = 32
        THEN
            IF stack not large enough for a 6-byte return address THEN #SS(0); FI;
            IF the instruction pointer is not within code segment limit THEN #GP(0); FI;
            Push(CS); (* padded with 16 high-order bits *)
            Push(EIP);
            CS ← DEST(NewCodeSegmentSelector);
            (* segment descriptor information also loaded *)
            CS(RPL) ← CPL
            EIP ← DEST(offset);
```

CALL—Call Procedure (Continued)

```
        ELSE (* OperandSize = 16 *)
            IF stack not large enough for a 4-byte return address THEN #SS(0); FI;
            IF the instruction pointer is not within code segment limit THEN #GP(0); FI;
            Push(CS);
            Push(IP);
            CS ← DEST(NewCodeSegmentSelector);
            (* segment descriptor information also loaded *)
            CS(RPL) ← CPL
            EIP ← DEST(offset) AND 0000FFFFH; (* clear upper 16 bits *)
    FI;
END;

NONCONFORMING-CODE-SEGMENT:
    IF (RPL > CPL) OR (DPL ≠ CPL) THEN #GP(new code segment selector); FI;
    IF segment not present THEN #NP(new code segment selector); FI;
    IF stack not large enough for return address THEN #SS(0); FI;
    tempEIP ← DEST(offset)
    IF OperandSize=16
        THEN
            tempEIP ← tempEIP AND 0000FFFFH; (* clear upper 16 bits *)
    FI;
    IF tempEIP outside code segment limit THEN #GP(0); FI;
    IF OperandSize = 32
        THEN
            Push(CS); (* padded with 16 high-order bits *)
            Push(EIP);
            CS ← DEST(NewCodeSegmentSelector);
            (* segment descriptor information also loaded *)
            CS(RPL) ← CPL;
            EIP ← tempEIP;
        ELSE (* OperandSize = 16 *)
            Push(CS);
            Push(IP);
            CS ← DEST(NewCodeSegmentSelector);
            (* segment descriptor information also loaded *)
            CS(RPL) ← CPL;
            EIP ← tempEIP;
    FI;
END;

CALL-GATE:
    IF call gate DPL < CPL or RPL THEN #GP(call gate selector); FI;
    IF call gate not present THEN #NP(call gate selector); FI;
    IF call gate code-segment selector is null THEN #GP(0); FI;
```

CALL—Call Procedure (Continued)

```
    IF call gate code-segment selector index is outside descriptor table limits
        THEN #GP(code segment selector); FI;
    Read code segment descriptor;
    IF code-segment segment descriptor does not indicate a code segment
    OR code-segment segment descriptor DPL > CPL
        THEN #GP(code segment selector); FI;
    IF code segment not present THEN #NP(new code segment selector); FI;
    IF code segment is non-conforming AND DPL < CPL
        THEN go to MORE-PRIVILEGE;
        ELSE go to SAME-PRIVILEGE;
    FI;
END;

MORE-PRIVILEGE:
    IF current TSS is 32-bit TSS
        THEN
            TSSstackAddress ← new code segment (DPL ∗ 8) + 4
            IF (TSSstackAddress + 7) > TSS limit
                THEN #TS(current TSS selector); FI;
            newSS ← TSSstackAddress + 4;
            newESP ← stack address;
        ELSE (* TSS is 16-bit *)
            TSSstackAddress ← new code segment (DPL ∗ 4) + 2
            IF (TSSstackAddress + 4) > TSS limit
                THEN #TS(current TSS selector); FI;
            newESP ← TSSstackAddress;
            newSS ← TSSstackAddress + 2;
    FI;
    IF stack segment selector is null THEN #TS(stack segment selector); FI;
    IF stack segment selector index is not within its descriptor table limits
        THEN #TS(SS selector); FI
    Read code segment descriptor;
    IF stack segment selector's RPL ≠ DPL of code segment
        OR stack segment DPL ≠ DPL of code segment
        OR stack segment is not a writable data segment
            THEN #TS(SS selector); FI
    IF stack segment not present THEN #SS(SS selector); FI;
    IF CallGateSize = 32
        THEN
            IF stack does not have room for parameters plus 16 bytes
                THEN #SS(SS selector); FI;
            IF CallGate(InstructionPointer) not within code segment limit THEN #GP(0); FI;
            SS ← newSS;
            (* segment descriptor information also loaded *)
```

CALL—Call Procedure (Continued)

```
                ESP ← newESP;
                CS:EIP ← CallGate(CS:InstructionPointer);
                (* segment descriptor information also loaded *)
                Push(oldSS:oldESP); (* from calling procedure *)
                temp ← parameter count from call gate, masked to 5 bits;
                Push(parameters from calling procedure's stack, temp)
                Push(oldCS:oldEIP); (* return address to calling procedure *)
            ELSE (* CallGateSize = 16 *)
                IF stack does not have room for parameters plus 8 bytes
                    THEN #SS(SS selector); FI;
                IF (CallGate(InstructionPointer) AND FFFFH) not within code segment limit
                    THEN #GP(0); FI;
                SS ← newSS;
                (* segment descriptor information also loaded *)
                ESP ← newESP;
                CS:IP ← CallGate(CS:InstructionPointer);
                (* segment descriptor information also loaded *)
                Push(oldSS:oldESP); (* from calling procedure *)
                temp ← parameter count from call gate, masked to 5 bits;
                Push(parameters from calling procedure's stack, temp)
                Push(oldCS:oldEIP); (* return address to calling procedure *)
        FI;
        CPL ← CodeSegment(DPL)
        CS(RPL) ← CPL
END;

SAME-PRIVILEGE:
        IF CallGateSize = 32
            THEN
                IF stack does not have room for 8 bytes
                    THEN #SS(0); FI;
                IF EIP not within code segment limit then #GP(0); FI;
                CS:EIP ← CallGate(CS:EIP) (* segment descriptor information also loaded *)
                Push(oldCS:oldEIP); (* return address to calling procedure *)
            ELSE (* CallGateSize = 16 *)
                IF stack does not have room for parameters plus 4 bytes
                    THEN #SS(0); FI;
                IF IP not within code segment limit THEN #GP(0); FI;
                CS:IP ← CallGate(CS:instruction pointer)
                (* segment descriptor information also loaded *)
                Push(oldCS:oldIP); (* return address to calling procedure *)
        FI;
        CS(RPL) ← CPL
END;
```

CALL—Call Procedure (Continued)

```
TASK-GATE:
    IF task gate DPL < CPL or RPL
        THEN #GP(task gate selector);
    FI;
    IF task gate not present
        THEN #NP(task gate selector);
    FI;
    Read the TSS segment selector in the task-gate descriptor;
    IF TSS segment selector local/global bit is set to local
        OR index not within GDT limits
            THEN #GP(TSS selector);
    FI;
    Access TSS descriptor in GDT;

    IF TSS descriptor specifies that the TSS is busy (low-order 5 bits set to 00001)
            THEN #GP(TSS selector);
    FI;
    IF TSS not present
        THEN #NP(TSS selector);
    FI;
    SWITCH-TASKS (with nesting) to TSS;
    IF EIP not within code segment limit
        THEN #GP(0);
    FI;
END;

TASK-STATE-SEGMENT:
    IF TSS DPL < CPL or RPL
    OR TSS descriptor indicates TSS not available
        THEN #GP(TSS selector);
    FI;
    IF TSS is not present
        THEN #NP(TSS selector);
    FI;
    SWITCH-TASKS (with nesting) to TSS
    IF EIP not within code segment limit
        THEN #GP(0);
    FI;
END;
```

Flags Affected

All flags are affected if a task switch occurs; no flags are affected if a task switch does not occur.

CALL—Call Procedure (Continued)

Protected Mode Exceptions

#GP(0)	If target offset in destination operand is beyond the new code segment limit.
	If the segment selector in the destination operand is null.
	If the code segment selector in the gate is null.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#GP(selector)	If code segment or gate or TSS selector index is outside descriptor table limits.
	If the segment descriptor pointed to by the segment selector in the destination operand is not for a conforming-code segment, nonconforming-code segment, call gate, task gate, or task state segment.
	If the DPL for a nonconforming-code segment is not equal to the CPL or the RPL for the segment's segment selector is greater than the CPL.
	If the DPL for a conforming-code segment is greater than the CPL.
	If the DPL from a call-gate, task-gate, or TSS segment descriptor is less than the CPL or than the RPL of the call-gate, task-gate, or TSS's segment selector.
	If the segment descriptor for a segment selector from a call gate does not indicate it is a code segment.
	If the segment selector from a call gate is beyond the descriptor table limits.
	If the DPL for a code-segment obtained from a call gate is greater than the CPL.
	If the segment selector for a TSS has its local/global bit set for local.
	If a TSS segment descriptor specifies that the TSS is busy or not available.
#SS(0)	If pushing the return address, parameters, or stack segment pointer onto the stack exceeds the bounds of the stack segment, when no stack switch occurs.
	If a memory operand effective address is outside the SS segment limit.
#SS(selector)	If pushing the return address, parameters, or stack segment pointer onto the stack exceeds the bounds of the stack segment, when a stack switch occurs.

CALL—Call Procedure (Continued)

	If the SS register is being loaded as part of a stack switch and the segment pointed to is marked not present.
	If stack segment does not have room for the return address, parameters, or stack segment pointer, when stack switch occurs.
#NP(selector)	If a code segment, data segment, stack segment, call gate, task gate, or TSS is not present.
#TS(selector)	If the new stack segment selector and ESP are beyond the end of the TSS.
	If the new stack segment selector is null.
	If the RPL of the new stack segment selector in the TSS is not equal to the DPL of the code segment being accessed.
	If DPL of the stack segment descriptor for the new stack segment is not equal to the DPL of the code segment descriptor.
	If the new stack segment is not a writable data segment.
	If segment-selector index for stack segment is outside descriptor table limits.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory access occurs when the CPL is 3 and alignment checking is enabled.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the target offset is beyond the code segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the target offset is beyond the code segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory access occurs when alignment checking is enabled.

CBW/CWDE—Convert Byte to Word/Convert Word to Doubleword

Opcode	Instruction	Description
98	CBW	AX ← sign-extend of AL
98	CWDE	EAX ← sign-extend of AX

Description

These instructions double the size of the source operand by means of sign extension (refer to Figure 6-5 in Chapter 6, *Instruction Set Summary* of the *Intel Architecture Software Developer's Manual, Volume 1*). The CBW (convert byte to word) instruction copies the sign (bit 7) in the source operand into every bit in the AH register. The CWDE (convert word to doubleword) instruction copies the sign (bit 15) of the word in the AX register into the higher 16 bits of the EAX register.

The CBW and CWDE mnemonics reference the same opcode. The CBW instruction is intended for use when the operand-size attribute is 16 and the CWDE instruction for when the operand-size attribute is 32. Some assemblers may force the operand size to 16 when CBW is used and to 32 when CWDE is used. Others may treat these mnemonics as synonyms (CBW/CWDE) and use the current setting of the operand-size attribute to determine the size of values to be converted, regardless of the mnemonic used.

The CWDE instruction is different from the CWD (convert word to double) instruction. The CWD instruction uses the DX:AX register pair as a destination operand; whereas, the CWDE instruction uses the EAX register as a destination.

Operation

```
IF OperandSize = 16 (* instruction = CBW *)
    THEN AX ← SignExtend(AL);
    ELSE (* OperandSize = 32, instruction = CWDE *)
        EAX ← SignExtend(AX);
FI;
```

Flags Affected

None.

Exceptions (All Operating Modes)

None.

CDQ—Convert Double to Quad

Refer to entry for CWD/CDQ — Convert Word to Doubleword/Convert Doubleword to Quadword.

CLC—Clear Carry Flag

Opcode	Instruction	Description
F8	CLC	Clear CF flag

Description

This instruction clears the CF flag in the EFLAGS register.

Operation

CF ← 0;

Flags Affected

The CF flag is cleared to 0. The OF, ZF, SF, AF, and PF flags are unaffected.

Exceptions (All Operating Modes)

None.

CLD—Clear Direction Flag

Opcode	Instruction	Description
FC	CLD	Clear DF flag

Description

This instruction clears the DF flag in the EFLAGS register. When the DF flag is set to 0, string operations increment the index registers (ESI and/or EDI).

Operation

DF ← 0;

Flags Affected

The DF flag is cleared to 0. The CF, OF, ZF, SF, AF, and PF flags are unaffected.

Exceptions (All Operating Modes)

None.

CLI—Clear Interrupt Flag

Opcode	Instruction	Description
FA	CLI	Clear interrupt flag; interrupts disabled when interrupt flag cleared

Description

This instruction clears the IF flag in the EFLAGS register. No other flags are affected. Clearing the IF flag causes the processor to ignore maskable external interrupts. The IF flag and the CLI and STI instruction have no affect on the generation of exceptions and NMI interrupts.

The following decision table indicates the action of the CLI instruction (bottom of the table) depending on the processor's mode of operating and the CPL and IOPL of the currently running program or procedure (top of the table).

PE =	0	1	1	1	1
VM =	X	0	X	0	1
CPL	X	≤ IOPL	X	> IOPL	X
IOPL	X	X	= 3	X	< 3
IF ← 0	Y	Y	Y	N	N
#GP(0)	N	N	N	Y	Y

NOTES:

X Don't care

N Action in column 1 not taken

Y Action in column 1 taken

CLI—Clear Interrupt Flag (Continued)

Operation

```
IF PE = 0 (* Executing in real-address mode *)
    THEN
        IF ← 0;
    ELSE
        IF VM = 0   (* Executing in protected mode *)
            THEN
                IF CPL ≤ IOPL
                    THEN
                        IF ← 0;
                    ELSE
                        #GP(0);
                FI;
        FI;
            ELSE  (* Executing in Virtual-8086 mode  *)
                IF IOPL = 3
                    THEN
                        IF  ← 0
                    ELSE
                        #GP(0);
                FI;
        FI;
FI;
```

Flags Affected

The IF is cleared to 0 if the CPL is equal to or less than the IOPL; otherwise, it is not affected. The other flags in the EFLAGS register are unaffected.

Protected Mode Exceptions

#GP(0)	If the CPL is greater (has less privilege) than the IOPL of the current program or procedure.

Real-Address Mode Exceptions

None.

Virtual-8086 Mode Exceptions

#GP(0)	If the CPL is greater (has less privilege) than the IOPL of the current program or procedure.

CLTS—Clear Task-Switched Flag in CR0

Opcode	Instruction	Description
0F 06	CLTS	Clears TS flag in CR0

Description

This instruction clears the task-switched (TS) flag in the CR0 register. This instruction is intended for use in operating-system procedures. It is a privileged instruction that can only be executed at a CPL of 0. It is allowed to be executed in real-address mode to allow initialization for protected mode.

The processor sets the TS flag every time a task switch occurs. The flag is used to synchronize the saving of FPU context in multitasking applications. Refer to the description of the TS flag in Section 2.5., *Control Registers* in Chapter 2, *System Architecture Overview* of the *Intel Architecture Software Developer's Manual, Volume 3*, for more information about this flag.

Operation

CR0(TS) ← 0;

Flags Affected

The TS flag in CR0 register is cleared.

Protected Mode Exceptions

#GP(0) If the CPL is greater than 0.

Real-Address Mode Exceptions

None.

Virtual-8086 Mode Exceptions

#GP(0) If the CPL is greater than 0.

CMC—Complement Carry Flag

Opcode	Instruction	Description
F5	CMC	Complement CF flag

Description

This instruction complements the CF flag in the EFLAGS register.

Operation

CF ← NOT CF;

Flags Affected

The CF flag contains the complement of its original value. The OF, ZF, SF, AF, and PF flags are unaffected.

Exceptions (All Operating Modes)

None.

CMOV*cc*—Conditional Move

Opcode	Instruction	Description
0F 47 */r*	CMOVA *r16, r/m16*	Move if above (CF=0 and ZF=0)
0F 47 */r*	CMOVA *r32, r/m32*	Move if above (CF=0 and ZF=0)
0F 43 */r*	CMOVAE *r16, r/m16*	Move if above or equal (CF=0)
0F 43 */r*	CMOVAE *r32, r/m32*	Move if above or equal (CF=0)
0F 42 */r*	CMOVB *r16, r/m16*	Move if below (CF=1)
0F 42 */r*	CMOVB *r32, r/m32*	Move if below (CF=1)
0F 46 */r*	CMOVBE *r16, r/m16*	Move if below or equal (CF=1 or ZF=1)
0F 46 */r*	CMOVBE *r32, r/m32*	Move if below or equal (CF=1 or ZF=1)
0F 42 */r*	CMOVC *r16, r/m16*	Move if carry (CF=1)
0F 42 */r*	CMOVC *r32, r/m32*	Move if carry (CF=1)
0F 44 */r*	CMOVE *r16, r/m16*	Move if equal (ZF=1)
0F 44 */r*	CMOVE *r32, r/m32*	Move if equal (ZF=1)
0F 4F */r*	CMOVG *r16, r/m16*	Move if greater (ZF=0 and SF=OF)
0F 4F */r*	CMOVG *r32, r/m32*	Move if greater (ZF=0 and SF=OF)
0F 4D */r*	CMOVGE *r16, r/m16*	Move if greater or equal (SF=OF)
0F 4D */r*	CMOVGE *r32, r/m32*	Move if greater or equal (SF=OF)
0F 4C */r*	CMOVL *r16, r/m16*	Move if less (SF<>OF)
0F 4C */r*	CMOVL *r32, r/m32*	Move if less (SF<>OF)
0F 4E */r*	CMOVLE *r16, r/m16*	Move if less or equal (ZF=1 or SF<>OF)
0F 4E */r*	CMOVLE *r32, r/m32*	Move if less or equal (ZF=1 or SF<>OF)
0F 46 */r*	CMOVNA *r16, r/m16*	Move if not above (CF=1 or ZF=1)
0F 46 */r*	CMOVNA *r32, r/m32*	Move if not above (CF=1 or ZF=1)
0F 42 */r*	CMOVNAE *r16, r/m16*	Move if not above or equal (CF=1)
0F 42 */r*	CMOVNAE *r32, r/m32*	Move if not above or equal (CF=1)
0F 43 */r*	CMOVNB *r16, r/m16*	Move if not below (CF=0)
0F 43 */r*	CMOVNB *r32, r/m32*	Move if not below (CF=0)
0F 47 */r*	CMOVNBE *r16, r/m16*	Move if not below or equal (CF=0 and ZF=0)
0F 47 */r*	CMOVNBE *r32, r/m32*	Move if not below or equal (CF=0 and ZF=0)
0F 43 */r*	CMOVNC *r16, r/m16*	Move if not carry (CF=0)
0F 43 */r*	CMOVNC *r32, r/m32*	Move if not carry (CF=0)
0F 45 */r*	CMOVNE *r16, r/m16*	Move if not equal (ZF=0)
0F 45 */r*	CMOVNE *r32, r/m32*	Move if not equal (ZF=0)
0F 4E */r*	CMOVNG *r16, r/m16*	Move if not greater (ZF=1 or SF<>OF)
0F 4E */r*	CMOVNG *r32, r/m32*	Move if not greater (ZF=1 or SF<>OF)
0F 4C */r*	CMOVNGE *r16, r/m16*	Move if not greater or equal (SF<>OF)
0F 4C */r*	CMOVNGE *r32, r/m32*	Move if not greater or equal (SF<>OF)
0F 4D */r*	CMOVNL *r16, r/m16*	Move if not less (SF=OF)
0F 4D */r*	CMOVNL *r32, r/m32*	Move if not less (SF=OF)
0F 4F */r*	CMOVNLE *r16, r/m16*	Move if not less or equal (ZF=0 and SF=OF)
0F 4F */r*	CMOVNLE *r32, r/m32*	Move if not less or equal (ZF=0 and SF=OF)

CMOV*cc*—Conditional Move (Continued)

Opcode	Instruction	Description
0F 41 */r*	CMOVNO *r16, r/m16*	Move if not overflow (OF=0)
0F 41 */r*	CMOVNO *r32, r/m32*	Move if not overflow (OF=0)
0F 4B */r*	CMOVNP *r16, r/m16*	Move if not parity (PF=0)
0F 4B */r*	CMOVNP *r32, r/m32*	Move if not parity (PF=0)
0F 49 */r*	CMOVNS *r16, r/m16*	Move if not sign (SF=0)
0F 49 */r*	CMOVNS *r32, r/m32*	Move if not sign (SF=0)
0F 45 */r*	CMOVNZ *r16, r/m16*	Move if not zero (ZF=0)
0F 45 */r*	CMOVNZ *r32, r/m32*	Move if not zero (ZF=0)
0F 40 */r*	CMOVO *r16, r/m16*	Move if overflow (OF=0)
0F 40 */r*	CMOVO *r32, r/m32*	Move if overflow (OF=0)
0F 4A */r*	CMOVP *r16, r/m16*	Move if parity (PF=1)
0F 4A */r*	CMOVP *r32, r/m32*	Move if parity (PF=1)
0F 4A */r*	CMOVPE *r16, r/m16*	Move if parity even (PF=1)
0F 4A */r*	CMOVPE *r32, r/m32*	Move if parity even (PF=1)
0F 4B */r*	CMOVPO *r16, r/m16*	Move if parity odd (PF=0)
0F 4B */r*	CMOVPO *r32, r/m32*	Move if parity odd (PF=0)
0F 48 */r*	CMOVS *r16, r/m16*	Move if sign (SF=1)
0F 48 */r*	CMOVS *r32, r/m32*	Move if sign (SF=1)
0F 44 */r*	CMOVZ *r16, r/m16*	Move if zero (ZF=1)
0F 44 */r*	CMOVZ *r32, r/m32*	Move if zero (ZF=1)

Description

The CMOV*cc* instructions check the state of one or more of the status flags in the EFLAGS register (CF, OF, PF, SF, and ZF) and perform a move operation if the flags are in a specified state (or condition). A condition code (*cc*) is associated with each instruction to indicate the condition being tested for. If the condition is not satisfied, a move is not performed and execution continues with the instruction following the CMOV*cc* instruction.

These instructions can move a 16- or 32-bit value from memory to a general-purpose register or from one general-purpose register to another. Conditional moves of 8-bit register operands are not supported.

The conditions for each CMOV*cc* mnemonic is given in the description column of the above table. The terms “less” and “greater” are used for comparisons of signed integers and the terms “above” and “below” are used for unsigned integers.

Because a particular state of the status flags can sometimes be interpreted in two ways, two mnemonics are defined for some opcodes. For example, the CMOVA (conditional move if above) instruction and the CMOVNBE (conditional move if not below or equal) instruction are alternate mnemonics for the opcode 0F 47H.

CMOV*cc*—Conditional Move (Continued)

The CMOV*cc* instructions are new for the Pentium® Pro processor family; however, they may not be supported by all the processors in the family. Software can determine if the CMOV*cc* instructions are supported by checking the processor's feature information with the CPUID instruction (refer to "COMISS—Scalar Ordered Single-FP Compare and Set EFLAGS" in this chapter).

Operation

```
temp ← DEST
IF condition TRUE
    THEN
        DEST ← SRC
    ELSE
        DEST ← temp
FI;
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

CMOV*cc*—Conditional Move (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

CMP—Compare Two Operands

Opcode	Instruction	Description
3C *ib*	CMP AL, *imm8*	Compare *imm8* with AL
3D *iw*	CMP AX, *imm16*	Compare *imm16* with AX
3D *id*	CMP EAX, *imm32*	Compare *imm32* with EAX
80 /7 *ib*	CMP *r/m8, imm8*	Compare *imm8* with *r/m8*
81 /7 *iw*	CMP *r/m16, imm16*	Compare *imm16* with *r/m16*
81 /7 *id*	CMP *r/m32,imm32*	Compare *imm32* with *r/m32*
83 /7 *ib*	CMP *r/m16,imm8*	Compare *imm8* with *r/m16*
83 /7 *ib*	CMP *r/m32,imm8*	Compare *imm8* with *r/m32*
38 /*r*	CMP *r/m8,r8*	Compare *r8* with *r/m8*
39 /*r*	CMP *r/m16,r16*	Compare *r16* with *r/m16*
39 /*r*	CMP *r/m32,r32*	Compare *r32* with *r/m32*
3A /*r*	CMP *r8,r/m8*	Compare *r/m8* with *r8*
3B /*r*	CMP *r16,r/m16*	Compare *r/m16* with *r16*
3B /*r*	CMP *r32,r/m32*	Compare *r/m32* with *r32*

Description

This instruction compares the first source operand with the second source operand and sets the status flags in the EFLAGS register according to the results. The comparison is performed by subtracting the second operand from the first operand and then setting the status flags in the same manner as the SUB instruction. When an immediate value is used as an operand, it is sign-extended to the length of the first operand.

The CMP instruction is typically used in conjunction with a conditional jump (J*cc*), condition move (CMOV*cc*), or SET*cc* instruction. The condition codes used by the J*cc*, CMOV*cc*, and SET*cc* instructions are based on the results of a CMP instruction. Appendix B, *EFLAGS Condition Codes*, in the *Intel Architecture Software Developer's Manual, Volume 1*, shows the relationship of the status flags and the condition codes.

Operation

```
temp ← SRC1 – SignExtend(SRC2);
ModifyStatusFlags; (* Modify status flags in the same manner as the SUB instruction*)
```

Flags Affected

The CF, OF, SF, ZF, AF, and PF flags are set according to the result.

CMP—Compare Two Operands (Continued)

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

CMPPS—Packed Single-FP Compare

Opcode	Instruction	Description
0F,C2,/r,ib	CMPPS *xmm1, xmm2/m128, imm8*	Compare packed SP FP numbers from *XMM2/Mem* to packed SP FP numbers in *XMM1* register using *imm8* as predicate.

Description

For each individual pair of SP FP numbers, the CMPPS instruction returns an all "1" 32-bit mask or an all "0" 32-bit mask, using the comparison predicate specified by imm8.

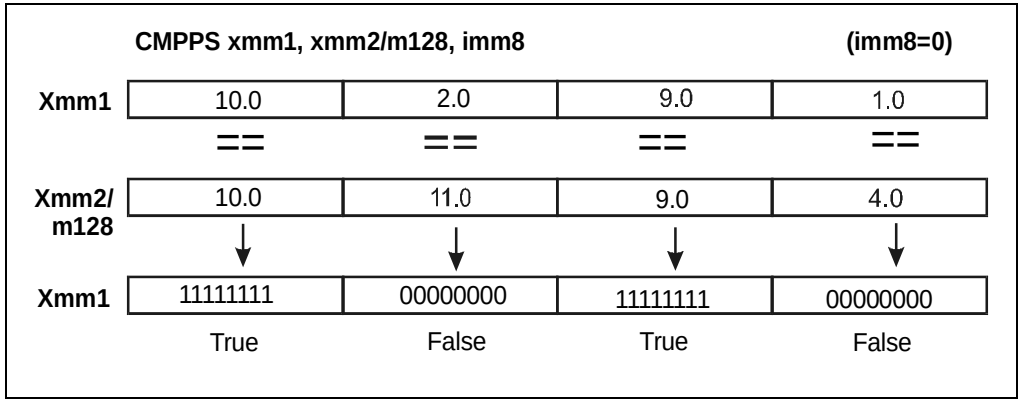


Figure 3-7. Operation of the CMPPS (Imm8=0) Instruction

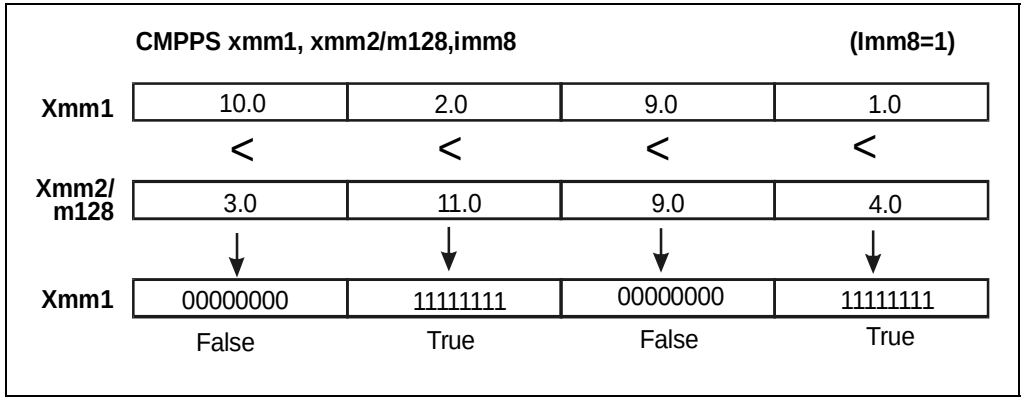


Figure 3-8. Operation of the CMPPS (Imm8=1) Instruction

CMPPS—Packed Single-FP Compare (Continued)

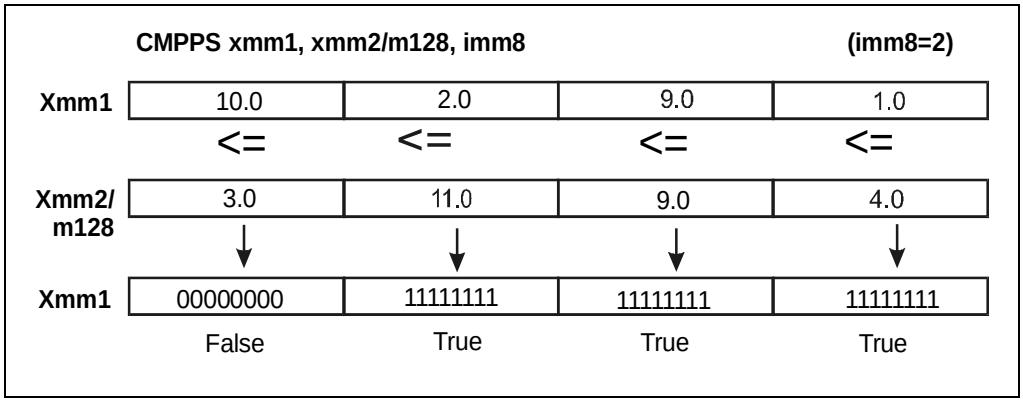


Figure 3-9. Operation of the CMPPS (Imm8=2) Instruction

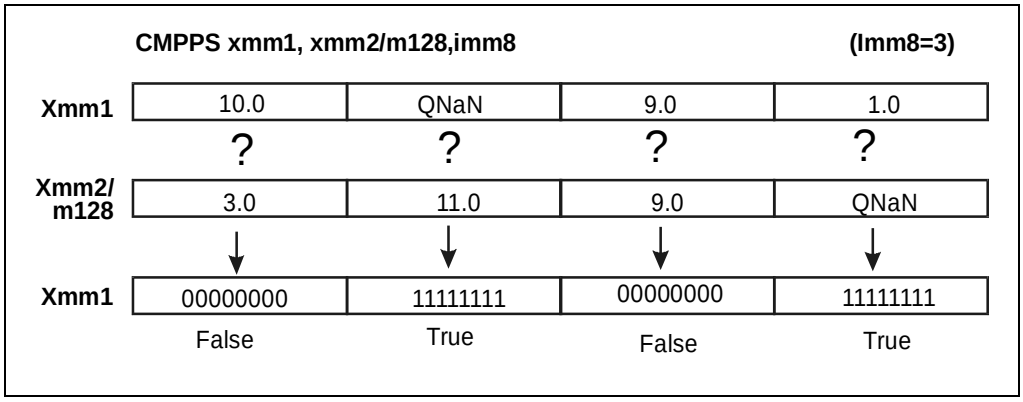


Figure 3-10. Operation of the CMPPS (Imm8=3) Instruction

CMPPS—Packed Single-FP Compare (Continued)

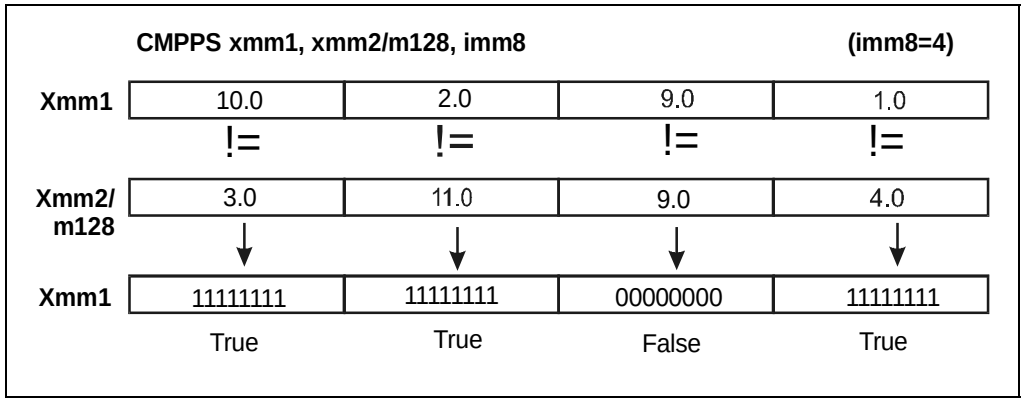


Figure 3-11. Operation of the CMPPS (Imm8=4) Instruction

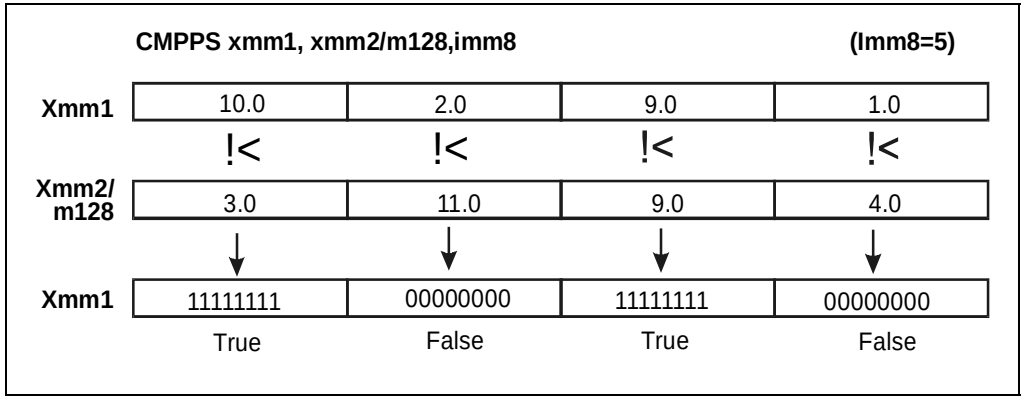


Figure 3-12. Operation of the CMPPS (Imm8=5) Instruction

CMPPS—Packed Single-FP Compare (Continued)

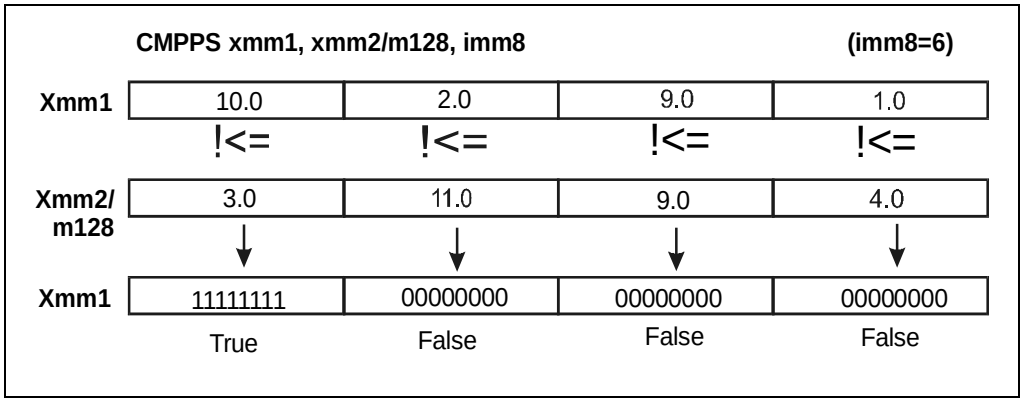


Figure 3-13. Operation of the CMPPS (Imm8=6) Instruction

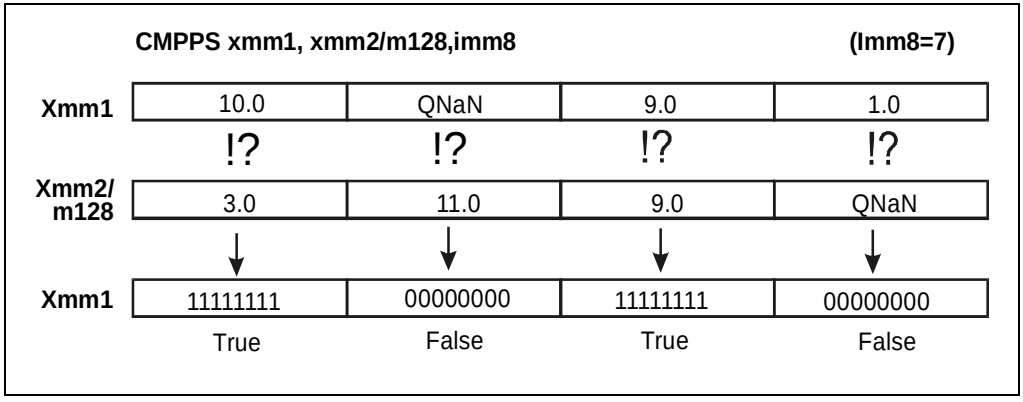


Figure 3-14. Operation of the CMPPS (Imm8=7) Instruction

CMPPS—Packed Single-FP Compare (Continued)

Note that a subsequent computational instruction which uses this mask as an input operand will not generate a fault, since a mask of all "0's" corresponds to an FP value of +0.0 and a mask of all "1's" corresponds to an FP value of -qNaN. Some of the comparisons can be achieved only through software emulation. For these comparisons the programmer must swap the operands, copying registers when necessary to protect the data that will now be in the destination, and then perform the compare using a different predicate. The predicate to be used for these emulations is listed in the table under the heading "Emulation". The following table shows the different comparison types:

Predicate	Description	Relation	Emulation	imm8 Encoding	Result if NaN Operand	Q/SNaN Operand Signals Invalid
eq	equal	xmm1 == xmm2		000B	False	No
lt	less-than	xmm1 < xmm2		001B	False	Yes
le	less-than-or-equal	xmm1 <= xmm2		010B	False	Yes
	greater than	xmm1 > xmm2	swap, protect, lt		False	Yes
	greater-than-or-equal	xmm1 >= xmm2	swap protect, le		False	Yes
unord	unordered	xmm1 ? xmm2		011B	True	No
neq	not-equal	!(xmm1 == xmm2)		100B	True	No
nlt	not-less-than	!(xmm1 < xmm2)		101B	True	Yes
nle	not-less-than-or-equal	!(xmm1 <= xmm2)		110B	True	Yes
	not-greater-than	!(xmm1 > xmm2)	swap, protect, nlt		True	Yes
	not-greater-than-or-equal	!(xmm1 >= xmm2)	swap, protect, nle		True	Yes
ord	ordered	!(xmm1 ? xmm2)		111B	False	No

NOTE:

The greater-than, greater-than-or-equal, not-greater-than, and not-greater-than-or-equal relations are not directly implemented in hardware.

CMPPS—Packed Single-FP Compare (Continued)

Operation

```
IF (imm8 = 0) THEN
    OP = "EQ";
ELSE
    IF (imm8 = 1) THEN
        OP = "LT";
    ELSE
        IF (imm8 = 2) THEN
            OP = "LE";
        ELSE
            IF (imm8 = 3) THEN
                OP = "UNORD";
            ELSE
                IF (imm8 = 4) THEN
                    OP = "NE";
                ELSE
                    IF (imm8 = 5) THEN
                        OP = "NLT";
                    ELSE
                        IF (imm8 = 6) THEN
                            OP = "NLE";
                        ELSE
                            IF (imm8 = 7) THEN
                     OP = "ORD";
                            FI
                        FI
                    FI
                FI
            FI
        FI
    FI
FI

CMP0 = DEST[31-0]  OP  SRC/m128[31-0];
CMP1 = DEST[63-32]  OP  SRC/m128[63-32];
CMP2 = DEST [95-64]  OP  SRC/m128[95-64];
CMP3 = DEST[127-96]  OP  SRC/m128[127-96];

IF (CMP0 = TRUE) THEN
    DEST[31-0] = 0XFFFFFFFF;
    DEST[63-32] = 0XFFFFFFFF;
    DEST[95-64] = 0XFFFFFFFF;
    DEST[127-96] = 0XFFFFFFFF;
```

CMPPS—Packed Single-FP Compare (Continued)

```
ELSE
    DEST[31-0] = 0X00000000;
    DEST[63-32] = 0X00000000;
    DEST[95-64] = 0X00000000;
    DEST[127-96] = 0X00000000;
FI
```

Intel C/C++ Compiler Intrinsic Equivalents

__m128 _mm_cmpeq_ps(__m128 a, __m128 b)

Compare for equality.

__m128 _mm_cmplt_ps(__m128 a, __m128 b)

Compare for less-than.

__m128 _mm_cmple_ps(__m128 a, __m128 b)

Compare for less-than-or-equal.

__m128 _mm_cmpgt_ps(__m128 a, __m128 b)

Compare for greater-than.

__m128 _mm_cmpge_ps(__m128 a, __m128 b)

Compare for greater-than-or-equal.

__m128 _mm_cmpneq_ps(__m128 a, __m128 b)

Compare for inequality.

__m128 _mm_cmpnlt_ps(__m128 a, __m128 b)

Compare for not-less-than.

__m128 _mm_cmpngt_ps(__m128 a, __m128 b)

Compare for not-greater-than.

__m128 _mm_cmpnge_ps(__m128 a, __m128 b)

Compare for not-greater-than-or-equal.

__m128 _mm_cmpord_ps(__m128 a, __m128 b)

Compare for ordered.

__m128 _mm_cmpunord_ps(__m128 a, __m128 b)

Compare for unordered.

__m128 _mm_cmpnle_ps(__m128 a, __m128 b)

Compare for not-less-than-or-equal.

CMPPS—Packed Single-FP Compare (Continued)

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

Numeric Exceptions

Invalid, if sNaN operands, denormal.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

CMPPS—Packed Single-FP Compare (Continued)

Virtual Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code) For a page fault.

Comments

Compilers and assemblers should implement the following 2-operand pseudo-ops in addition to the 3-operand CMPPS instruction:

Pseudo-Op	Implementation
CMPEQPS xmm1, xmm2	CMPPS xmm1,xmm2, 0
CMPLTPS xmm1, xmm2	CMPPS xmm1,xmm2, 1
CMPLEPS xmm1, xmm2	CMPPS xmm1,xmm2, 2
CMPUNORDPS xmm1, xmm2	CMPPS xmm1,xmm2, 3
CMPNEQPS xmm1, xmm2	CMPPS xmm1,xmm2, 4
CMPNLTPS xmm1, xmm2	CMPPS xmm1,xmm2, 5
CMPNLEPS xmm1, xmm2	CMPPS xmm1,xmm2, 6
CMPORDPS xmm1, xmm2	CMPPS xmm1,xmm2, 7

The greater-than relations not implemented in hardware require more than one instruction to emulate in software and therefore should not be implemented as pseudo-ops. (For these, the programmer should reverse the operands of the corresponding less than relations and use move instructions to ensure that the mask is moved to the correct destination register and that the source operand is left intact.)

Bits 7-4 of the immediate field are reserved. Different processors may handle them differently. Usage of these bits risks incompatibility with future processors.

CMPS/CMPSB/CMPSW/CMPSD—Compare String Operands

Opcode	Instruction	Description
A6	CMPS *m8, m8*	Compares byte at address DS:(E)SI with byte at address ES:(E)DI and sets the status flags accordingly
A7	CMPS *m16, m16*	Compares word at address DS:(E)SI with word at address ES:(E)DI and sets the status flags accordingly
A7	CMPS *m32, m32*	Compares doubleword at address DS:(E)SI with doubleword at address ES:(E)DI and sets the status flags accordingly
A6	CMPSB	Compares byte at address DS:(E)SI with byte at address ES:(E)DI and sets the status flags accordingly
A7	CMPSW	Compares word at address DS:(E)SI with word at address ES:(E)DI and sets the status flags accordingly
A7	CMPSD	Compares doubleword at address DS:(E)SI with doubleword at address ES:(E)DI and sets the status flags accordingly

Description

This instruction compares the byte, word, or double word specified with the first source operand with the byte, word, or double word specified with the second source operand and sets the status flags in the EFLAGS register according to the results. Both the source operands are located in memory. The address of the first source operand is read from either the DS:ESI or the DS:SI registers (depending on the address-size attribute of the instruction, 32 or 16, respectively). The address of the second source operand is read from either the ES:EDI or the ES:DI registers (again depending on the address-size attribute of the instruction). The DS segment may be overridden with a segment override prefix, but the ES segment cannot be overridden.

At the assembly-code level, two forms of this instruction are allowed: the “explicit-operands” form and the “no-operands” form. The explicit-operands form (specified with the CMPS mnemonic) allows the two source operands to be specified explicitly. Here, the source operands should be symbols that indicate the size and location of the source values. This explicit-operands form is provided to allow documentation; however, note that the documentation provided by this form can be misleading. That is, the source operand symbols must specify the correct **type** (size) of the operands (bytes, words, or doublewords), but they do not have to specify the correct **location**. The locations of the source operands are always specified by the DS:(E)SI and ES:(E)DI registers, which must be loaded correctly before the compare string instruction is executed.

The no-operands form provides “short forms” of the byte, word, and doubleword versions of the CMPS instructions. Here also the DS:(E)SI and ES:(E)DI registers are assumed by the processor to specify the location of the source operands. The size of the source operands is selected with the mnemonic: CMPSB (byte comparison), CMPSW (word comparison), or CMPSD (doubleword comparison).

CMPS/CMPSB/CMPSW/CMPSD—Compare String Operands (Continued)

After the comparison, the (E)SI and (E)DI registers are incremented or decremented automatically according to the setting of the DF flag in the EFLAGS register. (If the DF flag is 0, the (E)SI and (E)DI register are incremented; if the DF flag is 1, the (E)SI and (E)DI registers are decremented.) The registers are incremented or decremented by one for byte operations, by two for word operations, or by four for doubleword operations.

The CMPS, CMPSB, CMPSW, and CMPSD instructions can be preceded by the REP prefix for block comparisons of ECX bytes, words, or doublewords. More often, however, these instructions will be used in a LOOP construct that takes some action based on the setting of the status flags before the next comparison is made. Refer to "REP/REPE/REPZ/REPNE /REPNZ—Repeat String Operation Prefix" in this chapter for a description of the REP prefix.

Operation

```
temp ←SRC1 – SRC2;
SetStatusFlags(temp);
IF (byte comparison)
    THEN IF DF = 0
        THEN
            (E)SI ← (E)SI + 1;
            (E)DI ← (E)DI + 1;
        ELSE
            (E)SI ← (E)SI – 1;
            (E)DI ← (E)DI – 1;
        FI;
    ELSE IF (word comparison)
        THEN IF DF = 0
            (E)SI ← (E)SI + 2;
            (E)DI ← (E)DI + 2;
        ELSE
            (E)SI ← (E)SI – 2;
            (E)DI ← (E)DI – 2;
        FI;
    ELSE (* doubleword comparison*)
        THEN IF DF = 0
            (E)SI ← (E)SI + 4;
            (E)DI ← (E)DI + 4;
        ELSE
            (E)SI ← (E)SI – 4;
            (E)DI ← (E)DI – 4;
        FI;
FI;
```

CMPS/CMPSB/CMPSW/CMPSD—Compare String Operands (Continued)

Flags Affected

The CF, OF, SF, ZF, AF, and PF flags are set according to the temporary result of the comparison.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

CMPSS—Scalar Single-FP Compare

Opcode	Instruction	Description
F3,0F,C2,/r,ib	CMPSS *xmm1, xmm2/m32, imm8*	Compare lowest SP FP number from *XMM2/Mem* to lowest SP FP number in *XMM1* register using imm8 as predicate.

Description

For the lowest pair of SP FP numbers, the CMPSS instruction returns an all "1" 32-bit mask or an all "0" 32-bit mask, using the comparison predicate specified by imm8. The values for the upper three pairs of SP FP numbers are not compared. Note that a subsequent computational instruction, which uses this mask as an input operand, will not generate a fault, since a mask of all "0"s corresponds to an FP value of +0.0, and a mask of all "1's" corresponds to an FP value of -qNaN. Some comparisons can be achieved only through software emulation. For those comparisons, the programmer must swap the operands, copying registers when necessary to protect the data that will now be in the destination, and then perform the compare using a different predicate. The predicate to be used for these emulations is listed under the heading "Emulation."

CMPSS—Scalar Single-FP Compare (Continued)

The following table shows the different comparison types:

Predi-cate	Description	Relation	Emulation	imm8 Encoding	Result if NaN Operand	qNaN Operand Signals Invalid
eq	equal	xmm1 == xmm2		000B	False	No
lt	less-than	xmm1 < xmm2		001B	False	Yes
le	less-than-or-equal	xmm1 <= xmm2		010B	False	Yes
	greater than	xmm1 > xmm2	swap, protect, lt		False	Yes
	greater-than-or-equal	xmm1 >= xmm2	swap protect, le		False	Yes
unord	unordered	xmm1 ? xmm2		011B	True	No
neq	not-equal	!(xmm1 == xmm2)		100B	True	No
nlt	not-less-than	!(xmm1 < xmm2)		101B	True	Yes
nle	not-less-than-or-equal	!(xmm1 <= xmm2)		110B	True	Yes
	not-greater-than	!(xmm1 > xmm2)	swap, protect, nlt		True	Yes
	not-greater-than-or-equal	!(xmm1 >= xmm2)	swap, protect, nle		True	Yes
ord	ordered	!(xmm1 ? xmm2)		111B	False	No

NOTE:

* The greater-than, greater-than-or-equal, not-greater-than, and not-greater-than-or-equal relations are not directly implemented in hardware.

CMPSS—Scalar Single-FP Compare (Continued)

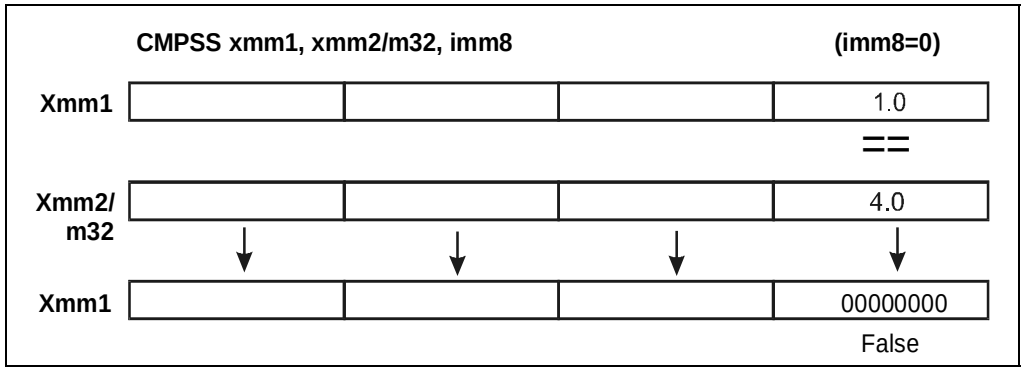


Figure 3-15. Operation of the CMPSS (Imm8=0) Instruction

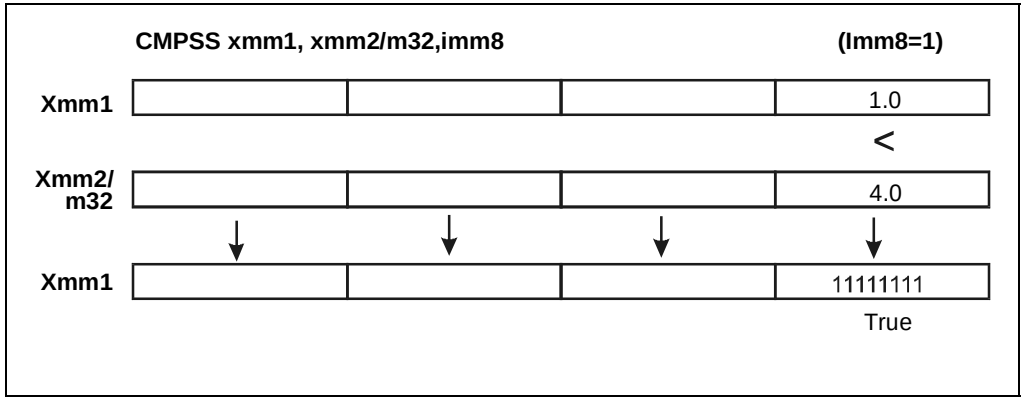


Figure 3-16. Operation of the CMPSS (Imm8=1) Instruction

CMPSS—Scalar Single-FP Compare (Continued)

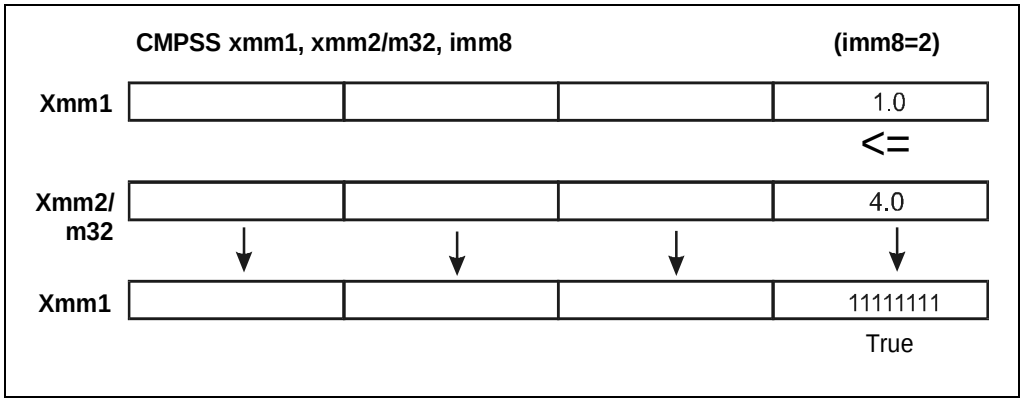


Figure 3-17. Operation of the CMPSS (Imm8=2) Instruction

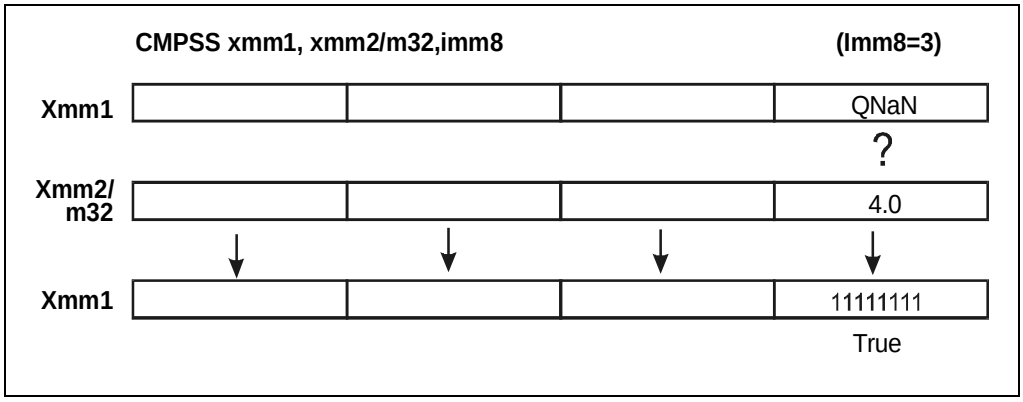


Figure 3-18. Operation of the CMPSS (Imm8=3) Instruction

CMPSS—Scalar Single-FP Compare (Continued)

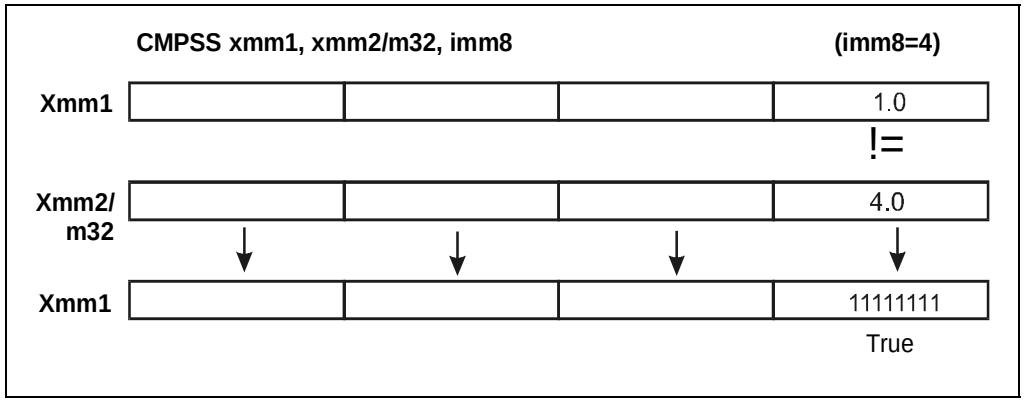


Figure 3-19. Operation of the CMPSS (Imm8=4) Instruction

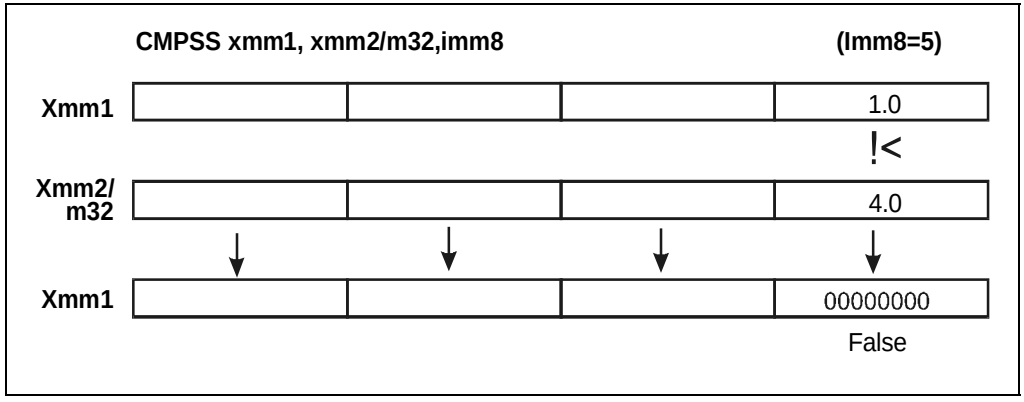


Figure 3-20. Operation of the CMPSS (Imm8=5) Instruction

CMPSS—Scalar Single-FP Compare (Continued)

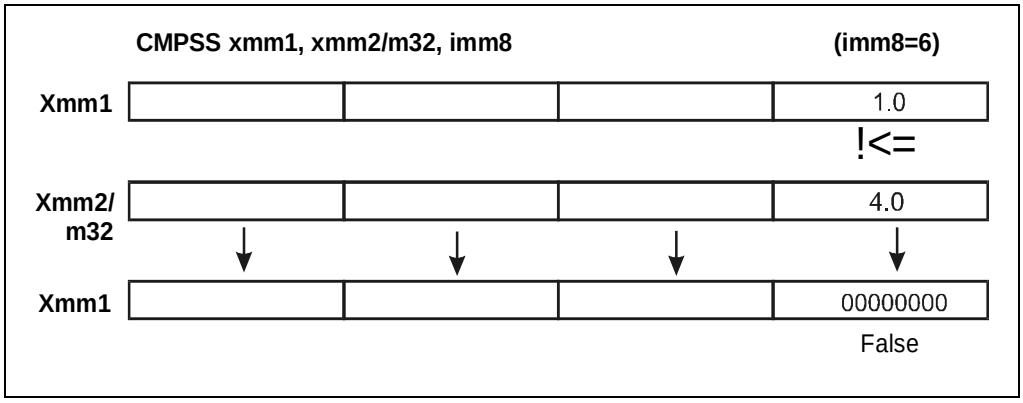


Figure 3-21. Operation of the CMPSS (Imm8=6) Instruction

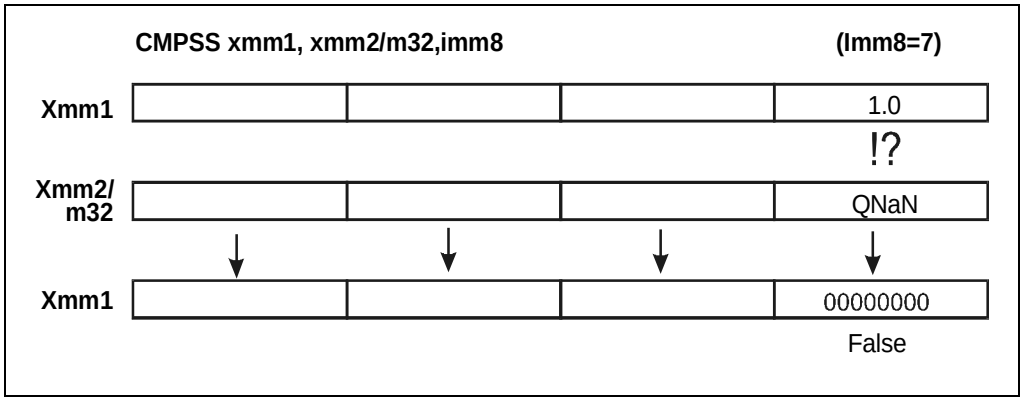


Figure 3-22. Operation of the CMPSS (Imm8=7) Instruction

CMPSS—Scalar Single-FP Compare (Continued)

Operation

```
IF (imm8 = 0) THEN
    OP = "EQ";
ELSE
    IF (imm8 = 1) THEN
        OP = "LT";
    ELSE
        IF (imm8 = 2) THEN
            OP = "LE";
        ELSE
            IF (imm8 = 3) THEN
                OP = "UNORD";
            ELSE
                IF (imm8 = 4) THEN
                    OP = "NE";
                ELSE
                    IF (imm8 = 5) THEN
                        OP = "NLT";
                    ELSE
                        IF (imm8 = 6) THEN
                            OP = "NLE";
                        ELSE
                            IF (imm8 = 7) THEN
                     OP = "ORD";
                            FI
                        FI
                    FI
                FI
            FI
        FI
    FI
FI
CMP0 = DEST[31-0]  OP  SRC/m128[31-0];

IF (CMP0 = TRUE) THEN
    DEST[31-0] = 0XFFFFFFFF;
    DEST[63-32] = DEST[63-32];
    DEST[95-64] = DEST[95-64];
    DEST[127-96] = DEST[127-96];
ELSE
    DEST[31-0] = 0X00000000;
    DEST[63-32] = DEST[63-32];
    DEST[95-64] = DEST[95-64];
    DEST[127-96] = DEST[127-96];
FI
```

CMPSS—Scalar Single-FP Compare (Continued)

Intel C/C++ Compiler Intrinsic Equivalents

__m128 _mm_cmpeq_ss(__m128 a, __m128 b)

Compare for equality.

__m128 _mm_cmplt_ss(__m128 a, __m128 b)

Compare for less-than.

__m128 _mm_cmple_ss(__m128 a, __m128 b)

Compare for less-than-or-equal.

__m128 _mm_cmpgt_ss(__m128 a, __m128 b)

Compare for greater-than.

__m128 _mm_cmpge_ss(__m128 a, __m128 b)

Compare for greater-than-or-equal.

__m128 _mm_cmpneq_ss(__m128 a, __m128 b)

Compare for inequality.

__m128 _mm_cmpnlt_ss(__m128 a, __m128 b)

Compare for not-less-than.

__m128 _mm_cmpnle_ss(__m128 a, __m128 b)

Compare for not-less-than-or-equal.

__m128 _mm_cmpngt_ss(__m128 a, __m128 b)

Compare for not-greater-than.

__m128 _mm_cmpnge_ss(__m128 a, __m128 b)

Compare for not-greater-than-or-equal.

__m128 _mm_cmpord_ss(__m128 a, __m128 b)

Compare for ordered.

__m128 _mm_cmpunord_ss(__m128 a, __m128 b)

Compare for unordered.

CMPSS—Scalar Single-FP Compare (Continued)

Exceptions

None.

Numeric Exceptions

Invalid if sNaN operand, invalid if qNaN and predicate as listed in above table, denormal.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true (CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

CMPSS—Scalar Single-FP Compare (Continued)

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

Comments

Compilers and assemblers should implement the following 2-operand pseudo-ops in addition to the 3-operand CMPSS instruction.

Pseudo-Op	Implementation
CMPEQSS xmm1, xmm2	CMPSS xmm1,xmm2, 0
CMPLTSS xmm1, xmm2	CMPSS xmm1,xmm2, 1
CMPLESS xmm1, xmm2	CMPSS xmm1,xmm2, 2
CMPUNORDSS xmm1, xmm2	CMPSS xmm1,xmm2, 3
CMPNEQSS xmm1, xmm2	CMPSS xmm1,xmm2, 4
CMPNLTSS xmm1, xmm2	CMPSS xmm1,xmm2, 5
CMPNLESS xmm1, xmm2	CMPSS xmm1,xmm2, 6
CMPORDSS xmm1, xmm2	CMPSS xmm1,xmm2, 7

The greater-than relations not implemented in hardware require more than one instruction to emulate in software and therefore should not be implemented as pseudo-ops. (For these, the programmer should reverse the operands of the corresponding less than relations and use move instructions to ensure that the mask is moved to the correct destination register and that the source operand is left intact.)

Bits 7-4 of the immediate field are reserved. Different processors may handle them differently. Usage of these bits risks incompatibility with future processors.

CMPXCHG—Compare and Exchange

Opcode	Instruction	Description
0F B0/*r*	CMPXCHG *r/m8,r8*	Compare AL with *r/m8*. If equal, ZF is set and *r8* is loaded into *r/m8*. Else, clear ZF and load *r/m8* into AL.
0F B1/*r*	CMPXCHG *r/m16,r16*	Compare AX with *r/m16*. If equal, ZF is set and *r16* is loaded into *r/m16*. Else, clear ZF and load *r/m16* into AL
0F B1/*r*	CMPXCHG *r/m32,r32*	Compare EAX with *r/m32*. If equal, ZF is set and *r32* is loaded into *r/m32*. Else, clear ZF and load *r/m32* into AL

Description

This instruction compares the value in the AL, AX, or EAX register (depending on the size of the operand) with the first operand (destination operand). If the two values are equal, the second operand (source operand) is loaded into the destination operand. Otherwise, the destination operand is loaded into the AL, AX, or EAX register.

This instruction can be used with a LOCK prefix to allow the instruction to be executed atomically. To simplify the interface to the processor's bus, the destination operand receives a write cycle without regard to the result of the comparison. The destination operand is written back if the comparison fails; otherwise, the source operand is written into the destination. (The processor never produces a locked read without also producing a locked write.)

Intel Architecture Compatibility

This instruction is not supported on Intel processors earlier than the Intel486™ processors.

Operation

```
(* accumulator = AL, AX, or EAX, depending on whether *)
(* a byte, word, or doubleword comparison is being performed*)
IF accumulator = DEST
    THEN
        ZF ← 1
        DEST ← SRC
    ELSE
        ZF ← 0
        accumulator ← DEST
FI;
```

Flags Affected

The ZF flag is set if the values in the destination operand and register AL, AX, or EAX are equal; otherwise it is cleared. The CF, PF, AF, SF, and OF flags are set according to the results of the comparison operation.

CMPXCHG—Compare and Exchange (Continued)

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

CMPXCHG8B—Compare and Exchange 8 Bytes

Opcode	Instruction	Description
0F C7 /1 m64	CMPXCHG8B *m64*	Compare EDX:EAX with *m64.* If equal, set ZF and load ECX:EBX into *m64.* Else, clear ZF and load *m64* into EDX:EAX.

Description

This instruction compares the 64-bit value in EDX:EAX with the operand (destination operand). If the values are equal, the 64-bit value in ECX:EBX is stored in the destination operand. Otherwise, the value in the destination operand is loaded into EDX:EAX. The destination operand is an 8-byte memory location. For the EDX:EAX and ECX:EBX register pairs, EDX and ECX contain the high-order 32 bits and EAX and EBX contain the low-order 32 bits of a 64-bit value.

This instruction can be used with a LOCK prefix to allow the instruction to be executed atomically. To simplify the interface to the processor's bus, the destination operand receives a write cycle without regard to the result of the comparison. The destination operand is written back if the comparison fails; otherwise, the source operand is written into the destination. (The processor never produces a locked read without also producing a locked write.)

Intel Architecture Compatibility

This instruction is not supported on Intel processors earlier than the Pentium® processors.

Operation

```
IF (EDX:EAX = DEST)
    ZF ← 1
    DEST ← ECX:EBX
ELSE
    ZF ← 0
    EDX:EAX ← DEST
```

Flags Affected

The ZF flag is set if the destination operand and EDX:EAX are equal; otherwise it is cleared. The CF, PF, AF, SF, and OF flags are unaffected.

CMPXCHG8B—Compare and Exchange 8 Bytes (Continued)

Protected Mode Exceptions

#UD	If the destination operand is not a memory location.
#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#UD	If the destination operand is not a memory location.
#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#UD	If the destination operand is not a memory location.
#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

COMISS—Scalar Ordered Single-FP Compare and Set EFLAGS

Opcode	Instruction	Description
0F,2F,/r	COMISS *xmm1, xmm2/m32*	Compare lower SP FP number in *XMM1* register with lower SP FP number in *XMM2/Mem* and set the status flags accordingly

Description

The COMISS instruction compares two SP FP numbers and sets the ZF,PF,CF bits in the EFLAGS register as described above. Although the data type is packed single-FP, only the lower SP numbers are compared. In addition, the OF, SF, and AF bits in the EFLAGS register are zeroed out. The unordered predicate is returned if either input is a NaN (qNaN or sNaN).

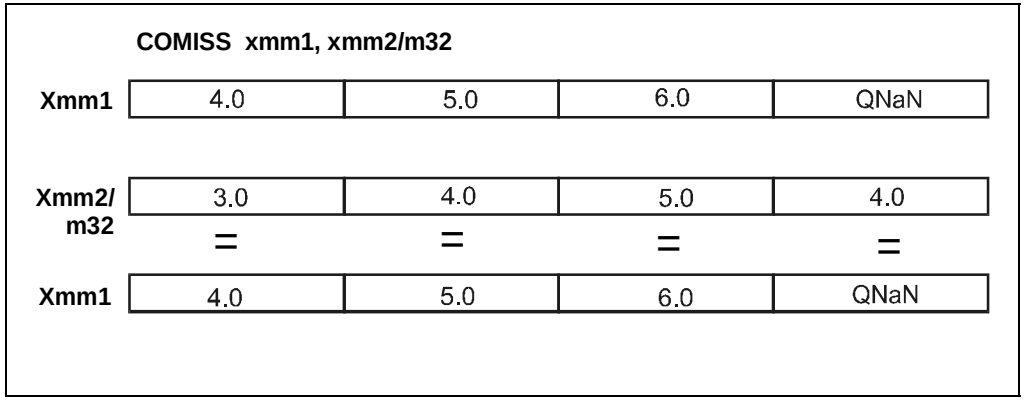


Figure 3-23. Operation of the COMISS Instruction, Condition One

EFLAGS: OF,SF,AF=000
EFLAGS: ZF,PF,CF=111
MXCSR flags: Invalid flag is set

COMISS—Scalar Ordered Single-FP Compare And Set EFLAGS (Continued)

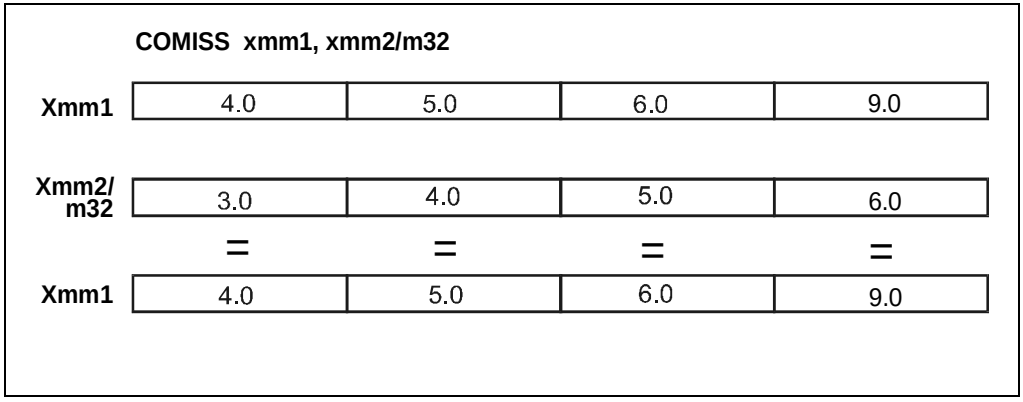


Figure 3-24. Operation of the COMISS Instruction, Condition Two

EFLAGS: OF,SF,AF=000
EFLAGS: ZF,PF,CF=000
MXCSR flags: Invalid flag is set

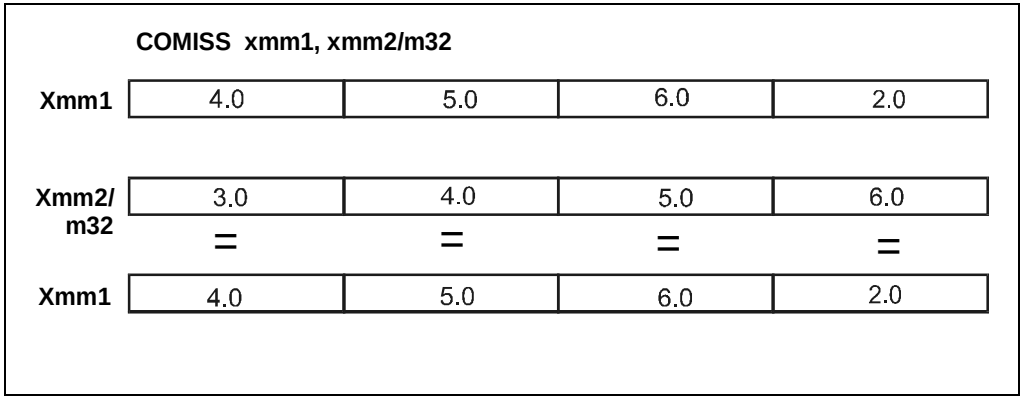


Figure 3-25. Operation of the COMISS Instruction, Condition Three

EFLAGS: OF,SF,AF=000
EFLAGS: ZF,PF,CF=001
MXCSR flags: Invalid flag is set

COMISS—Scalar Ordered Single-FP Compare And Set EFLAGS (Continued)

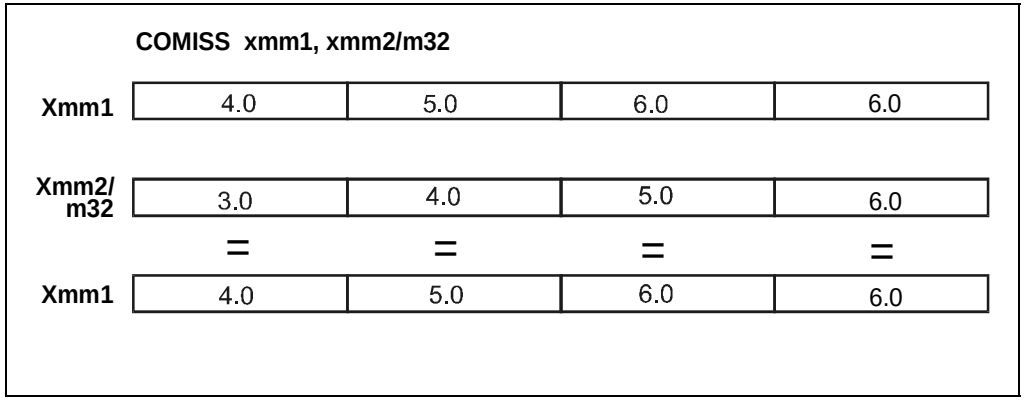


Figure 3-26. Operation of the COMISS Instruction, Condition Four

EFLAGS: OF,SF,AF=000
EFLAGS: ZF,PF,CF=100
MXCSR flags: Invalid flag is set

COMISS—Scalar Ordered Single-FP Compare And Set EFLAGS (Continued)

Operation

```
OF = 0;
SF = 0;
AF = 0;

IF ((DEST[31-0]  UNORD SRC/m32[31-0]) = TRUE) THEN
    ZF = 1;
    PF = 1;
    CF = 1;
ELSE
    IF ((DEST[31-0] GTRTHAN SRC/m32[31-0]) = TRUE)THEN
        ZF = 0;
        PF = 0;
        CF = 0;
    ELSE
        IF ((DEST[31-0] LESSTHAN SRC/m32[31-0]) = TRUE THEN
            ZF = 0;
            PF = 0;
            CF = 1;
        ELSE
            ZF = 1;
            PF = 0;
            CF = 0;
        FI
    FI
FI
```

COMISS—Scalar Ordered Single-FP Compare And Set EFLAGS (Continued)

Intel C/C++ Compiler Intrinsic Equivalents

int_mm_comieq_ss(__m128 a, __m128 b)

Compares the lower SP FP value of a and b for a equal to b. If a and b are equal, 1 is returned. Otherwise 0 is returned.

int_mm_comilt_ss(__m128 a, __m128 b)

Compares the lower SP FP value of a and b for a less than b. If a is less than b, 1 is returned. Otherwise 0 is returned.

int_mm_comile_ss(__m128 a, __m128 b)

Compares the lower SP FP value of a and b for a less than or equal to b. If a is less than or equal to b, 1 is returned. Otherwise 0 is returned.

int_mm_comigt_ss(__m128 a, __m128 b)

Compares the lower SP FP value of a and b for a greater than b. If a is greater than b are equal, 1 is returned. Otherwise 0 is returned.

int_mm_comige_ss(__m128 a, __m128 b)

Compares the lower SP FP value of a and b for a greater than or equal to b. If a is greater than or equal to b, 1 is returned. Otherwise 0 is returned.

int_mm_comineq_ss(__m128 a, __m128 b)

Compares the lower SP FP value of a and b for a not equal to b. If a and b are not equal, 1 is returned. Otherwise 0 is returned.

Exceptions

None.

COMISS—Scalar Ordered Single-FP Compare And Set EFLAGS (Continued)

Numeric Exceptions

Invalid (if sNaN or qNaN operands), Denormal. Integer EFLAGS values will not be updated in the presence of unmasked numeric exceptions.

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

COMISS—Scalar Ordered Single-FP Compare And Set EFLAGS (Continued)

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

Comments

COMISS differs from UCOMISS and COMISS in that it signals an invalid numeric exception when a source operand is either a qNaN or an sNaN operand; UCOMISS signals invalid only a source operand is an sNaN.

The usage of Repeat (F2H, F3H) and Operand-Size (66H) prefixes with COMISS is reserved. Different processor implementations may handle this prefix differently. Usage of this prefix with COMISS risks incompatibility with future processors.

CPUID—CPU Identification

Opcode	Instruction	Description
0F A2	CPUID	EAX ← Processor identification information

Description

This instruction provides processor identification information in registers EAX, EBX, ECX, and EDX. This information identifies Intel as the vendor, gives the family, model, and stepping of processor, feature information, and cache information. An input value loaded into the EAX register determines what information is returned, as shown in Table 3-6.

Table 3-6. Information Returned by CPUID Instruction

Initial EAX Value	Information Provided about the Processor	
0	EAX	Maximum CPUID Input Value (2 for the Pentium® Pro processor and 1 for the Pentium® processor and the later versions of Intel486™ processor that support the CPUID instruction).
	EBX	"Genu"
	ECX	"ntel"
	EDX	"inel"
1	EAX	Version Information (Type, Family, Model, and Stepping ID)
	EBX	Reserved
	ECX	Reserved
	EDX	Feature Information
2	EAX	Cache and TLB Information
	EBX	Cache and TLB Information
	ECX	Cache and TLB Information
	EDX	Cache and TLB Information

The CPUID instruction can be executed at any privilege level to serialize instruction execution. Serializing instruction execution guarantees that any modifications to flags, registers, and memory for previous instructions are completed before the next instruction is fetched and executed. For more information, refer to Section 7.4., *Serializing Instructions* in Chapter 7, *Multiple-Processor Management* of the *Intel Architecture Software Developer's Manual, Volume 3*.

When the input value in register EAX is 0, the processor returns the highest value the CPUID instruction recognizes in the EAX register (refer to Table 3-6). A vendor identification string is returned in the EBX, EDX, and ECX registers. For Intel processors, the vendor identification string is "GenuineIntel" as follows:

```
EBX ← 756e6547h (* "Genu", with G in the low nibble of BL *)
EDX ← 49656e69h (* "inel", with i in the low nibble of DL *)
ECX ← 6c65746eh (* "ntel", with n in the low nibble of CL *)
```

CPUID—CPU Identification (Continued)

When the input value is 1, the processor returns version information in the EAX register and feature information in the EDX register (refer to Figure 3-27).

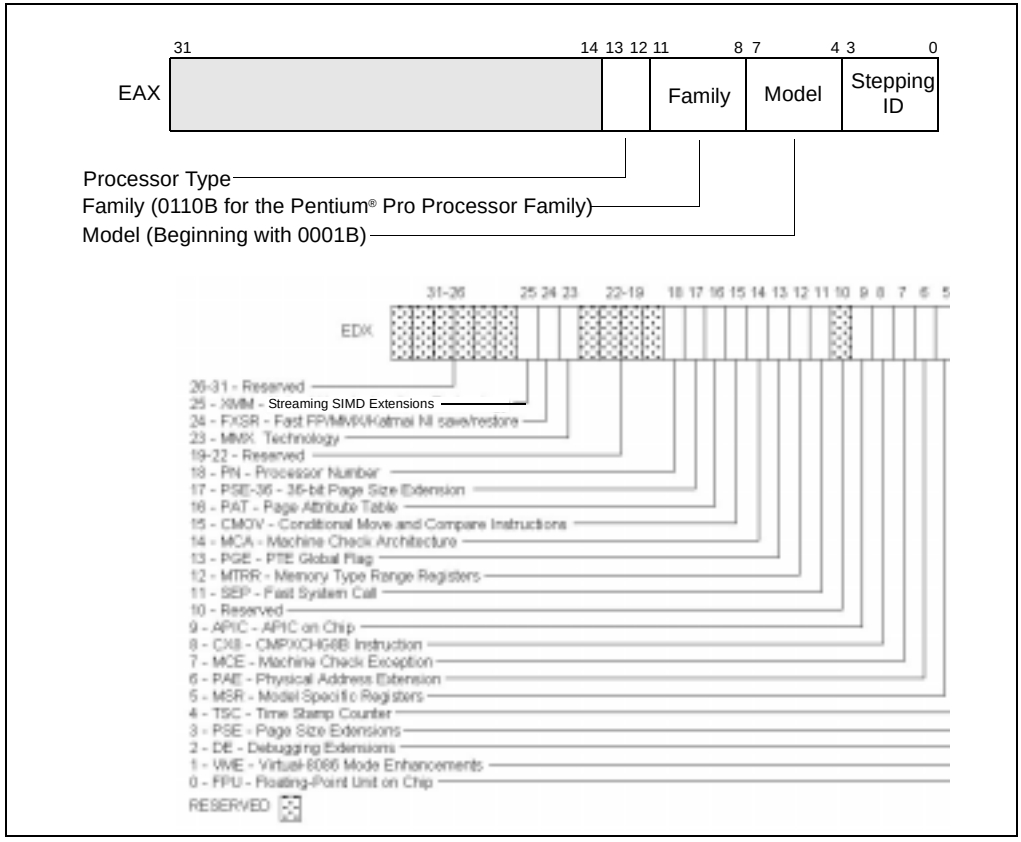


Figure 3-27. Version and Feature Information in Registers EAX and EDX

The version information consists of an Intel Architecture family identifier, a model identifier, a stepping ID, and a processor type. The model, family, and processor type for the first processor in the Intel Pentium® Pro family is as follows:

- Model—0001B
- Family—0110B
- Processor Type—00B

CPUID—CPU Identification (Continued)

Refer to AP-485, *Intel Processor Identification and the CPUID Instruction* (Order Number 241618), the *Intel Pentium® Pro Processor Specification Update* (Order Number 242689), and the *Intel Pentium® Processor Specification Update* (Order Number 242480) for more information on identifying earlier Intel Architecture processors.

The available processor types are given in Table 3-7. Intel releases information on stepping IDs as needed.

Table 3-7. Processor Type Field

Type	Encoding
Original OEM Processor	00B
Intel OverDrive® Processor	01B
Dual processor*	10B
Intel reserved.	11B

* Not applicable to Intel386™ and Intel486™ processors.

CPUID—CPU Identification (Continued)

Table 3-8 shows the encoding of the feature flags in the EDX register. A feature flag set to 1 indicates the corresponding feature is supported. Software should identify Intel as the vendor to properly interpret the feature flags.

Table 3-8. Feature Flags Returned in EDX Register

Bit	Feature	Description
0	FPU—Floating-Point Unit on Chip	Processor contains an FPU and executes the Intel 387 instruction set.
1	VME—Virtual-8086 Mode Enhancements	Processor supports the following virtual-8086 mode enhancements: • CR4.VME bit enables virtual-8086 mode extensions. • CR4.PVI bit enables protected-mode virtual interrupts. • Expansion of the TSS with the software indirection bitmap. • EFLAGS.VIF bit (virtual interrupt flag). • EFLAGS.VIP bit (virtual interrupt pending flag).
2	DE—Debugging Extensions	Processor supports I/O breakpoints, including the CR4.DE bit for enabling debug extensions and optional trapping of access to the DR4 and DR5 registers.
3	PSE—Page Size Extensions	Processor supports 4-Mbyte pages, including the CR4.PSE bit for enabling page size extensions, the modified bit in page directory entries (PDEs), page directory entries, and page table entries (PTEs).
4	TSC—Time Stamp Counter	Processor supports the RDTSC (read time stamp counter) instruction, including the CR4.TSD bit that, along with the CPL, controls whether the time stamp counter can be read.
5	MSR—Model Specific Registers	Processor supports the RDMSR (read model-specific register) and WRMSR (write model-specific register) instructions.
6	PAE—Physical Address Extension	Processor supports physical addresses greater than 32 bits, the extended page-table-entry format, an extra level in the page translation tables, and 2-MByte pages. The CR4.PAE bit enables this feature. The number of address bits is implementation specific. The Pentium® Pro processor supports 36 bits of addressing when the PAE bit is set.
7	MCE—Machine Check Exception	Processor supports the CR4.MCE bit, enabling machine check exceptions. However, this feature does not define the model-specific implementations of machine-check error logging, reporting, or processor shutdowns. Machine-check exception handlers might have to check the processor version to do model-specific processing of the exception or check for presence of the machine-check feature.
8	CX8—CMPXCHG 8B Instruction	Processor supports the CMPXCHG8B (compare and exchange 8 bytes) instruction.
9	APIC	Processor contains an on-chip Advanced Programmable Interrupt Controller (APIC) and it has been enabled and is available for use.
10	Reserved	

CPUID—CPU Identification (Continued)

Bit	Feature	Description
11	SEP—Fast System Call	Indicates whether the processor supports the Fast System Call instructions, SYSENTER and SYSEXIT.
12	MTRR—Memory Type Range Registers	Processor supports machine-specific memory-type range registers (MTRRs). The MTRRs contains bit fields that indicate the processor's MTRR capabilities, including which memory types the processor supports, the number of variable MTRRs the processor supports, and whether the processor supports fixed MTRRs.
13	PGE—PTE Global Flag	Processor supports the CR4.PGE flag enabling the global bit in both PTDEs and PTEs. These bits are used to indicate translation lookaside buffer (TLB) entries that are common to different tasks and need not be flushed when control register CR3 is written.
14	MCA—Machine Check Architecture	Processor supports the MCG_CAP (machine check global capability) MSR. The MCG_CAP register indicates how many banks of error reporting MSRs the processor supports.
15	CMOV—Conditional Move and Compare Instructions	Processor supports the CMOV*cc* instruction and, if the FPU feature flag (bit 0) is also set, supports the FCMOV*cc* and FCOMI instructions.
16	FGPAT—Page Attribute Table	Processor supports CMOVcc, and if the FPU feature flag (bit 0) is also set, supports the FMOVCC and FCOMI instructions.
17	PSE-36—36-bit Page Size Extension	Processor supports 4MB pages with 36 bit physical addresses.
18	PN—Processor Number	Processor supports the 96-bit Processor Number feature, and the feature is enabled
19-22	Reserved	
23	MMX™ Technology	Processor supports the MMX™ instruction set. These instructions operate in parallel on multiple data elements (8 bytes, 4 words, or 2 doublewords) packed into quadword registers or memory locations.
24	FXSR—Fast FP/MMX™ Technology/Streaming SIMD Extensions save/restore	Indicates whether the processor supports the FXSAVE and FXRSTOR instructions for fast save and restore of the floating point context. Presence of this bit also indicates that CR4.OSFXSR is available for an operating system to indicate that it uses the fast save/restore instructions.
25	XMM—Streaming SIMD Extensions	Processor supports the Streaming SIMD Extensions instruction set.
26-31	Reserved	

CPUID—CPU Identification (Continued)

When the input value is 2, the processor returns information about the processor's internal caches and TLBs in the EAX, EBX, ECX, and EDX registers. The encoding of these registers is as follows:

- The least-significant byte in register EAX (register AL) indicates the number of times the CPUID instruction must be executed with an input value of 2 to get a complete description of the processor's caches and TLBs. The Pentium® Pro family of processors will return a 1.
- The most significant bit (bit 31) of each register indicates whether the register contains valid information (cleared to 0) or is reserved (set to 1).
- If a register contains valid information, the information is contained in one-byte descriptors. Table 3-9 shows the encoding of these descriptors.

Table 3-9. Encoding of Cache and TLB Descriptors

Descriptor Value	Cache or TLB Description
00H	Null descriptor
01H	Instruction TLB: 4K-Byte Pages, 4-way set associative, 32 entries
02H	Instruction TLB: 4M-Byte Pages, fully associative, two entries
03H	Data TLB: 4K-Byte Pages, 4-way set associative, 64 entries
04H	Data TLB: 4M-Byte Pages, 4-way set associative, eight entries
06H	Instruction cache: 8K Bytes, 4-way set associative, 32 byte line size
08H	Instruction cache: 16K Bytes, 4-way set associative, 32 byte line size
0AH	Data cache: 8K Bytes, 2-way set associative, 32 byte line size
0CH	Data cache: 16K Bytes, 2-way or 4-way set associative, 32 byte line size
40H	No L2 Cache
41H	L2 Unified cache: 128K Bytes, 4-way set associative, 32 byte line size
42H	L2 Unified cache: 256K Bytes, 4-way set associative, 32 byte line size
43H	L2 Unified cache: 512K Bytes, 4-way set associative, 32 byte line size
44H	L2 Unified cache: 1M Byte, 4-way set associative, 32 byte line size
45H	L2 Unified cache: 2M Byte, 4-way set associative, 32 byte line size

CPUID—CPU Identification (Continued)

The first member of the Pentium® Pro processor family will return the following information about caches and TLBs when the CPUID instruction is executed with an input value of 2:

EAX	03 02 01 01H
EBX	0H
ECX	0H
EDX	06 04 0A 42H

These values are interpreted as follows:

- The least-significant byte (byte 0) of register EAX is set to 01H, indicating that the CPUID instruction needs to be executed only once with an input value of 2 to retrieve complete information about the processor's caches and TLBs.
- The most-significant bit of all four registers (EAX, EBX, ECX, and EDX) is set to 0, indicating that each register contains valid 1-byte descriptors.
- Bytes 1, 2, and 3 of register EAX indicate that the processor contains the following:
  - 01H—A 32-entry instruction TLB (4-way set associative) for mapping 4-KByte pages.
  - 02H—A 2-entry instruction TLB (fully associative) for mapping 4-MByte pages.
  - 03H—A 64-entry data TLB (4-way set associative) for mapping 4-KByte pages.
- The descriptors in registers EBX and ECX are valid, but contain null descriptors.
- Bytes 0, 1, 2, and 3 of register EDX indicate that the processor contains the following:
  - 42H—A 256-KByte unified cache (the L2 cache), 4-way set associative, with a 32-byte cache line size.
  - 0AH—An 8-KByte data cache (the L1 data cache), 2-way set associative, with a 32-byte cache line size.
  - 04H—An 8-entry data TLB (4-way set associative) for mapping 4M-byte pages.
  - 06H—An 8-KByte instruction cache (the L1 instruction cache), 4-way set associative, with a 32-byte cache line size.

Intel Architecture Compatibility

The CPUID instruction is not supported in early models of the Intel486™ processor or in any Intel Architecture processor earlier than the Intel486™ processor. The ID flag in the EFLAGS register can be used to determine if this instruction is supported. If a procedure is able to set or clear this flag, the CPUID is supported by the processor running the procedure.

CPUID—CPU Identification (Continued)

Operation

```
CASE (EAX) OF
    EAX = 0:
        EAX ← highest input value understood by CPUID; (* 2 for Pentium® Pro processor *)
        EBX ← Vendor identification string;
        EDX ← Vendor identification string;
        ECX ← Vendor identification string;
    BREAK;
    EAX = 1:
        EAX[3:0] ← Stepping ID;
        EAX[7:4] ← Model;
        EAX[11:8] ← Family;
        EAX[13:12] ← Processor type;
        EAX[31:12] ← Reserved;
        EBX ← Reserved;ECX ← Reserved;
        EDX ← Feature flags;  (* Refer to Figure 3-27 *)
    BREAK;
    EAX = 2:
        EAX ← Cache and TLB information;
        EBX ← Cache and TLB information;
        ECX ← Cache and TLB information;
        EDX ← Cache and TLB information;
    BREAK;
    DEFAULT: (* EAX > highest value recognized by CPUID *)
        EAX ← reserved, undefined;
        EBX ← reserved, undefined;
        ECX ← reserved, undefined;
        EDX ← reserved, undefined;
    BREAK;
ESAC;
```

Flags Affected

None.

Exceptions (All Operating Modes)

None.

CVTPI2PS—Packed Signed INT32 to Packed Single-FP Conversion

Opcode	Instruction	Description
0F,2A,/r	CVTPI2PS *xmm*, *mm*/*m64*	Convert two 32-bit signed integers from *MM*/*Mem* to two SP FP.

Description

The CVTPI2PS instruction converts signed 32-bit integers to SP FP numbers. When the conversion is inexact, rounding is done according to MXCSR. A #MF fault is signalled if there is a pending x87 fault.

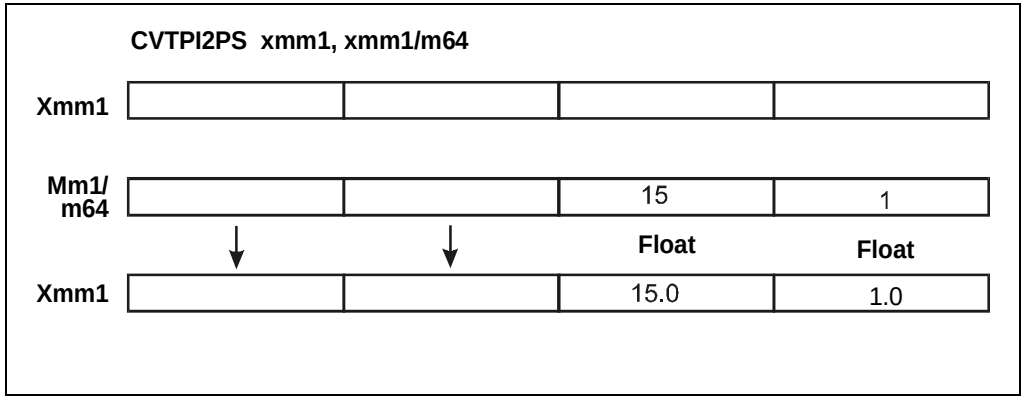


Figure 3-28. Operation of the CVTPI2PS Instruction

Operation

```
DEST[31-0]    = (float) (SRC/m64[31-0]);
DEST[63-32]   = (float) (SRC/m64[63-32]);
DEST[95-64]   = DEST[95-64];
DEST[127-96]  = DEST[127-96];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_cvt_pi2ps(__m128 a, __m64 b)

__m128 _mm_cvtpi32_ps(__m128 a, __m64 b)

Convert the two 32-bit integer values in packed form in b to two SP FP values; the upper two SP FP values are passed through from a.

CVTPI2PS—Packed Signed INT32 to Packed Single-FP Conversion (Continued)

Exceptions

None.

Numeric Exceptions

Precision.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

CVTPI2PS—Packed Signed INT32 to Packed Single-FP Conversion (Continued)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#AC	For unaligned memory reference.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

CVTPI2PS—Packed Signed INT32 to Packed Single-FP Conversion (Continued)

Comments

This instruction behaves identically to original MMX™ instructions, in the presence of x87-FP instructions:

- Transition from x87-FP to MMX™ technology (TOS=0, FP valid bits set to all valid).
- MMX™ instructions write ones (1s) to the exponent part of the corresponding x87-FP register.

However, the use of a memory source operand with this instruction will not result in the above transition from x87-FP to MMX™ technology.

Prioritizing for fault and assist behavior for CVTPI2PS is as follows:

Memory source

1. Invalid opcode (CR0.EM=1)
2. DNA (CR0.TS=1)
3. #SS or #GP, for limit violation
4. #PF, page fault
5. Streaming SIMD Extensions numeric fault (i.e., precision)

Register source

1. Invalid opcode (CR0.EM=1)
2. DNA (CR0.TS=1)
3. #MF, pending x87-FP fault signalled
4. After returning from #MF, x87-FP->MMX™ technology transition
5. Streaming SIMD Extensions numeric fault (i.e., precision)

CVTPS2PI—Packed Single-FP to Packed INT32 Conversion

Opcode	Instruction	Description
0F,2D,/r	CVTPS2PI *mm, xmm/m64*	Convert lower two SP FP from *XMM/Mem* to two 32-bit signed integers in *MM* using rounding specified by MXCSR.

Description

The CVTPS2PI instruction converts the lower two SP FP numbers in *xmm/m64* to signed 32-bit integers in *mm.* When the conversion is inexact, the value rounded according to the MXCSR is returned. If the converted result(s) is/are larger than the maximum signed 32 bit value, the Integer Indefinite value (0x80000000) will be returned.

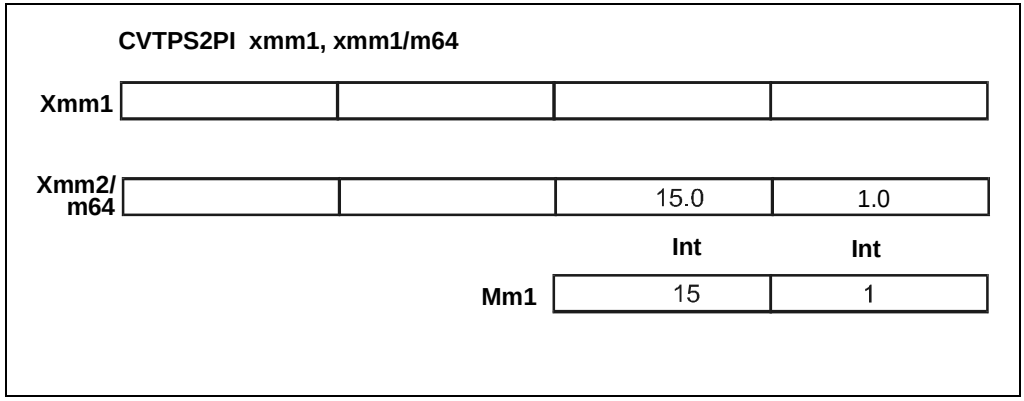


Figure 3-29. Operation of the CVTPS2PI Instruction

Operation

```
DEST[31-0] = (int) (SRC/m64[31-0]);
DEST[63-32]= (int) (SRC/m64[63-32]);
```

Intel C/C++ Compiler Intrinsic Equivalent

__m64 _mm_cvt_ps2pi(__m128 a)

__m64 _mm_cvtps_pi32(__m128 a)

Convert the two lower SP FP values of a to two 32-bit integers with truncation, returning the integers in packed form.

CVTPS2PI—Packed Single-FP to Packed INT32 Conversion (Continued)

Exceptions

None.

Numeric Exceptions

Invalid, Precision.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

CVTPS2PI—Packed Single-FP to Packed INT32 Conversion (Continued)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

CVTPS2PI—Packed Single-FP to Packed INT32 Conversion (Continued)

Comments

This instruction behaves identically to original MMX™ instructions, in the presence of x87-FP instructions:

- Transition from x87-FP to MMX™ technology (TOS=0, FP valid bits set to all valid).
- MMX™ instructions write ones (1s) to the exponent part of the corresponding x87-FP register.

Prioritizing for fault and assist behavior for CVTPS2PI is as follows:

Memory source

1. Invalid opcode (CR0.EM=1)
2. DNA (CR0.TS=1)
3. #MF, pending x87-FP fault signalled
4. After returning from #MF, x87-FP->MMX™ technology transition
5. #SS or #GP, for limit violation
6. #PF, page fault
7. Streaming SIMD Extensions numeric fault (i.e., invalid, precision)

Register source

1. Invalid opcode (CR0.EM=1)
2. DNA (CR0.TS=1)
3. #MF, pending x87-FP fault signalled
4. After returning from #MF, x87-FP->MMX™ technology transition
5. Streaming SIMD Extensions numeric fault (i.e., precision)

CVTSI2SS—Scalar Signed INT32 to Single-FP Conversion

Opcode	Instruction	Description
F3,0F,2A,/r	CVTSI2SS *xmm*, r/*m32*	Convert one 32-bit signed integer from Integer Reg/*Mem* to one SP FP.

Description

The CVTSI2SS instruction converts a signed 32-bit integer from memory or from a 32-bit integer register to an SP FP number. When the conversion is inexact, rounding is done according to the MXCSR.

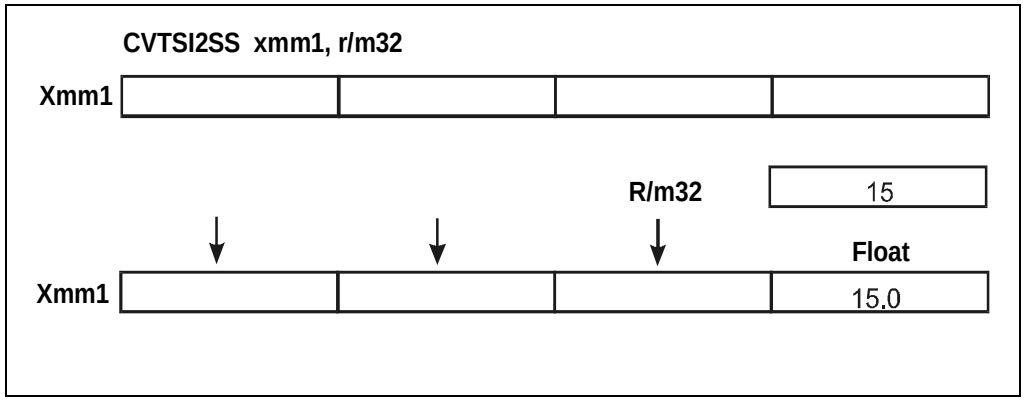


Figure 3-30. Operation of the CVTSI2SS Instruction

Operation

```
DEST[31-0]      = (float) (R/m32);
DEST[63-32]     = DEST[63-32];
DEST[95-64]     = DEST[95-64];
DEST[127-96]    = DEST[127-96];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_cvt_si2ss(__m128 a, int b)

__m128 _mm_cvtsi32_ss(__m128 a, int b)

Convert the 32-bit integer value b to an SP FP value; the upper three SP FP values are passed through from a.

CVTSI2SS—Scalar Signed INT32 to Single-FP Conversion (Continued)

Exceptions

None.

Numeric Exceptions

Precision.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

CVTSI2SS—Scalar Signed INT32 to Single-FP Conversion (Continued)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

CVTSS2SI—Scalar Single-FP to Signed INT32 Conversion

Opcode	Instruction	Description
F3,0F,2D,/r	CVTSS2SI r32, *xmm/m32*	Convert one SP FP from *XMM*/*Mem* to one 32 bit signed integer using rounding mode specified by MXCSR, and move the result to an integer register.

Description

The CVTSS2SI instruction converts an SP FP number to a signed 32-bit integer and returns it in the 32-bit integer register. When the conversion is inexact, the rounded value according to the MXCSR is returned. If the converted result is larger than the maximum signed 32 bit integer, the Integer Indefinite value (0x80000000) will be returned.

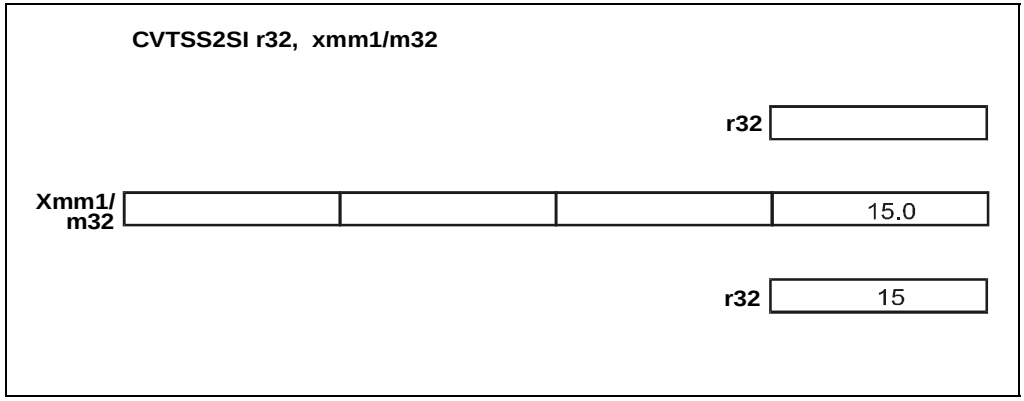


Figure 3-31. Operation of the CVTSS2SI Instruction

Operation

```
r32 = (int) (SRC/m32[31-0]);
```

Intel C/C++ Compiler Intrinsic Equivalent

int_mm_cvt_ss2si(__m128 a)

int_mm_cvtss_si32(__m128 a)

Convert the lower SP FP value of a to a 32-bit integer according to the current rounding mode.

CVTSS2SI—Scalar Single-FP to Signed INT32 Conversion (Continued)

Exceptions

None.

Numeric Exceptions

Invalid, Precision.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference.To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT = 0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

CVTSS2SI—Scalar Single-FP to Signed INT32 Conversion (Continued)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

CVTTPS2PI—PackedSingle-FPtoPackedINT32Conversion(Truncate)

Opcode	Instruction	Description
0F,2C,/r	CVTTPS2PI *mm*, *xmm/m64*	Convert lower two SP FP from *XMM*/*Mem* to two 32-bit signed integers in *MM* using truncate.

Description

The CVTTPS2PI instruction converts the lower two SP FP numbers in *xmm*/*m64* to two 32-bit signed integers in mm. If the conversion is inexact, the truncated result is returned. If the converted result(s) is/are larger than the maximum signed 32 bit value, the Integer Indefinite value (0x80000000) will be returned.

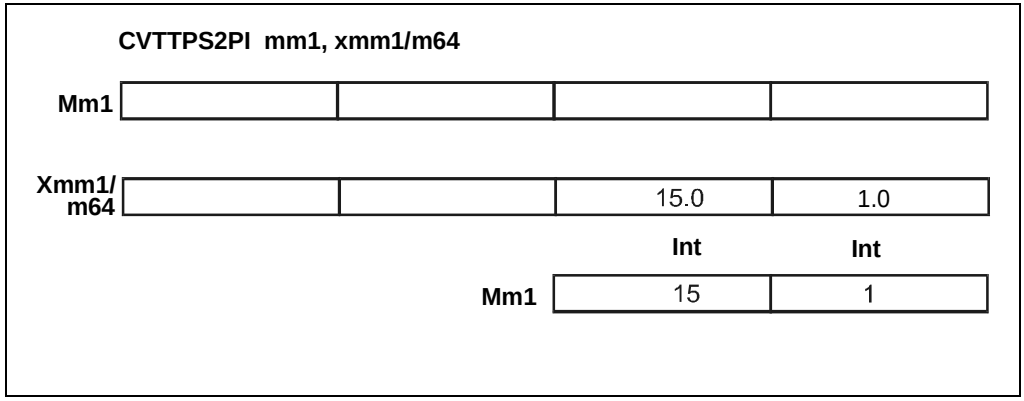


Figure 3-32. Operation of the CVTTPS2PI Instruction

Operation

```
DEST[31-0] = (int) (SRC/m64[31-0]);
DEST[63-32]= (int) (SRC/m64[63-32]);
```

CVTTPS2PI—Packed Single-FP to Packed INT32 Conversion (Truncate) (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

__m64 _mm_cvtt_ps2pi(__m128 a)

__m64 _mm_cvttps_pi32(__m128 a)

Convert the two lower SP FP values of a to two 32-bit integers according to the current rounding mode, returning the integers in packed form.

Exceptions

None.

Numeric Exceptions

Invalid, Precision.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

CVTTPS2PI—Packed Single-FP to Packed INT32 Conversion (Truncate) (Continued)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

CVTTPS2PI—Packed Single-FP to Packed INT32 Conversion (Truncate) (Continued)

Comments

This instruction behaves identically to original MMX™ instructions, in the presence of x87-FP instructions, including:

- Transition from x87-FP to MMX™ technology (TOS=0, FP valid bits set to all valid).
- MMX™ instructions write ones (1s) to the exponent part of the corresponding x87-FP register.

Prioritizing for fault and assist behavior for CVTTPS2PI is as follows:

Memory source

1. Invalid opcode (CR0.EM=1)
2. DNA (CR0.TS=1)
3. #MF, pending x87-FP fault signalled
4. After returning from #MF, x87-FP->MMX™ technology transition
5. #SS or #GP, for limit violation
6. #PF, page fault
7. Streaming SIMD Extensions numeric fault (i.e., precision)

Register source

1. Invalid opcode (CR0.EM=1)
2. DNA (CR0.TS=1)
3. #MF, pending x87-FP fault signalled
4. After returning from #MF, x87-FP->MMX™ technology transition
5. Streaming SIMD Extensions numeric fault (i.e., precision)

CVTTSS2SI—Scalar Single-FP to Signed INT32 Conversion (Truncate)

Opcode	Instruction	Description
F3,0F,2C,/r	CVTTSS2SI r32, *xmm/m32*	Convert lowest SP FP from *XMM/Mem* to one 32 bit signed integer using truncate, and move the result to an integer register.

Description

The CVTTSS2SI instruction converts an SP FP number to a signed 32-bit integer and returns it in the 32-bit integer register. If the conversion is inexact, the truncated result is returned. If the converted result is larger than the maximum signed 32 bit value, the Integer Indefinite value (0x80000000) will be returned.

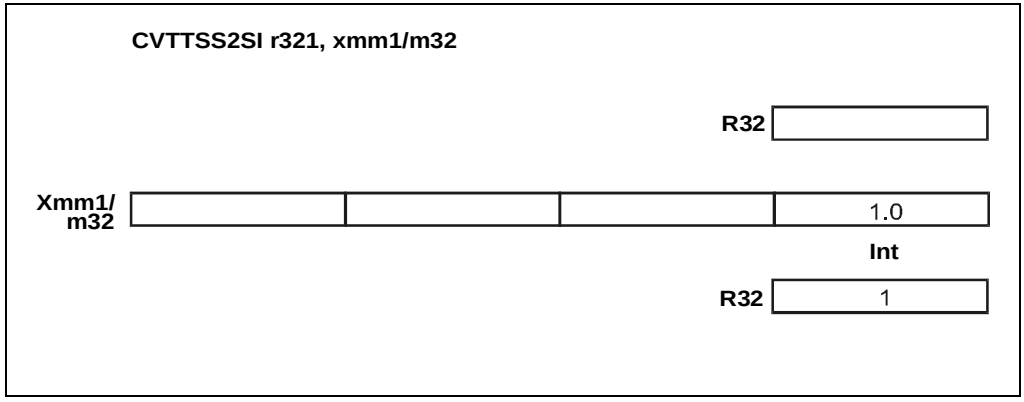


Figure 3-33. Operation of the CVTTSS2SI Instruction

Operation

```
r32 = (INT) (SRC/m32[31-0]);
```

CVTTSS2SI—Scalar Single-FP to Signed INT32 Conversion (Truncate) (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

Version 4.0 and later Intel C/C++ Compiler intrinsic:

int_mm_cvtt_ss2si(__m128 a)

int_mm_cvttss_si32(__m128 a)

Convert the lower SP FP value of a to a 32-bit integer according to the current rounding mode.

Pre-4.0 Intel C/C++ Compiler intrinsic:

_m64_m_from_int(int_i)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

_m64_mm_cvttsi32_si64(int_i)

Convert the integer object i to a 64-bit __m64 object. The integer value is zero extended to 64 bits.

Pre-4.0 Intel C/C++ Compiler intrinsic:

int_m_to_int(__m64_m)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

int_mm_cvtsi64_si32(__m64_m)

Convert the lower 32 bits of the __m64 object m to an integer.

Exceptions

None.

Numeric Exceptions

Invalid, Precision.

CVTTSS2SI—Scalar Single-FP to Signed INT32 Conversion (Truncate) (Continued)

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

CVTTSS2SI—Scalar Single-FP to Signed INT32 Conversion (Truncate) (Continued)

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

CWD/CDQ—Convert Word to Doubleword/Convert Doubleword to Quadword

Opcode	Instruction	Description
99	CWD	DX:AX ← sign-extend of AX
99	CDQ	EDX:EAX ← sign-extend of EAX

Description

These instructions double the size of the operand in register AX or EAX (depending on the operand size) by means of sign extension and stores the result in registers DX:AX or EDX:EAX, respectively. The CWD instruction copies the sign (bit 15) of the value in the AX register into every bit position in the DX register. For more information, refer to Figure 6-5 in Chapter 6, *Instruction Set Summary*of the *Intel Architecture Software Developer's Manual, Volume 1*. The CDQ instruction copies the sign (bit 31) of the value in the EAX register into every bit position in the EDX register.

The CWD instruction can be used to produce a doubleword dividend from a word before a word division, and the CDQ instruction can be used to produce a quadword dividend from a doubleword before doubleword division.

The CWD and CDQ mnemonics reference the same opcode. The CWD instruction is intended for use when the operand-size attribute is 16 and the CDQ instruction for when the operand-size attribute is 32. Some assemblers may force the operand size to 16 when CWD is used and to 32 when CDQ is used. Others may treat these mnemonics as synonyms (CWD/CDQ) and use the current setting of the operand-size attribute to determine the size of values to be converted, regardless of the mnemonic used.

Operation

```
IF OperandSize = 16 (* CWD instruction *)
    THEN DX ← SignExtend(AX);
    ELSE (* OperandSize = 32, CDQ instruction *)
        EDX ← SignExtend(EAX);
FI;
```

Flags Affected

None.

Exceptions (All Operating Modes)

None.

CWDE—Convert Word to Doubleword

Refer to entry for CBW/CWDE—Convert Byte to Word/Convert Word to Doubleword.

DAA—Decimal Adjust AL after Addition

Opcode	Instruction	Description
27	DAA	Decimal adjust AL after addition

Description

This instruction adjusts the sum of two packed BCD values to create a packed BCD result. The AL register is the implied source and destination operand. The DAA instruction is only useful when it follows an ADD instruction that adds (binary addition) two 2-digit, packed BCD values and stores a byte result in the AL register. The DAA instruction then adjusts the contents of the AL register to contain the correct 2-digit, packed BCD result. If a decimal carry is detected, the CF and AF flags are set accordingly.

Operation

```
IF (((AL AND 0FH) > 9) or AF = 1)
    THEN
        AL ← AL + 6;
        CF ← CF OR CarryFromLastAddition; (* CF OR carry from AL ← AL + 6 *)
        AF ← 1;
    ELSE
        AF ← 0;
FI;
IF ((AL AND F0H) > 90H) or CF = 1)
    THEN
        AL ←  AL + 60H;
        CF  ← 1;
    ELSE
        CF ← 0;
FI;
```

Example

```
ADD AL, BL      Before: AL=79H  BL=35H EFLAGS(OSZAPC)=XXXXXX
                After:  AL=AEH  BL=35H EFLAGS(0SZAPC)=110000
DAA             Before: AL=2EH  BL=35H EFLAGS(OSZAPC)=110000
                After:  AL=04H  BL=35H EFLAGS(0SZAPC)=X00101
```

DAA—Decimal Adjust AL after Addition (Continued)

Flags Affected

The CF and AF flags are set if the adjustment of the value results in a decimal carry in either digit of the result (refer to the “Operation” section above). The SF, ZF, and PF flags are set according to the result. The OF flag is undefined.

Exceptions (All Operating Modes)

None.

DAS—Decimal Adjust AL after Subtraction

Opcode	Instruction	Description
2F	DAS	Decimal adjust AL after subtraction

Description

This instruction adjusts the result of the subtraction of two packed BCD values to create a packed BCD result. The AL register is the implied source and destination operand. The DAS instruction is only useful when it follows a SUB instruction that subtracts (binary subtraction) one 2-digit, packed BCD value from another and stores a byte result in the AL register. The DAS instruction then adjusts the contents of the AL register to contain the correct 2-digit, packed BCD result. If a decimal borrow is detected, the CF and AF flags are set accordingly.

Operation

```
IF (AL AND 0FH) > 9 OR AF = 1
    THEN
        AL ← AL – 6;
        CF ← CF OR BorrowFromLastSubtraction; (* CF OR borrow from AL ← AL – 6 *)
        AF ← 1;
    ELSE AF ← 0;
FI;
IF ((AL > 9FH) or CF = 1)
    THEN
        AL ← AL – 60H;
        CF ← 1;
    ELSE CF ← 0;
FI;
```

Example

```
SUB AL, BL      Before: AL=35H  BL=47H EFLAGS(OSZAPC)=XXXXXX
                After:  AL=EEH  BL=47H EFLAGS(0SZAPC)=010111
DAA             Before: AL=EEH  BL=47H EFLAGS(OSZAPC)=010111
                After:  AL=88H  BL=47H EFLAGS(0SZAPC)=X10111
```

Flags Affected

The CF and AF flags are set if the adjustment of the value results in a decimal borrow in either digit of the result (refer to the “Operation” section above). The SF, ZF, and PF flags are set according to the result. The OF flag is undefined.

Exceptions (All Operating Modes)

None.

DEC—Decrement by 1

Opcode	Instruction	Description
FE /1	DEC *r/m8*	Decrement *r/m8* by 1
FF /1	DEC *r/m16*	Decrement *r/m16* by 1
FF /1	DEC *r/m32*	Decrement *r/m32* by 1
48+rw	DEC *r16*	Decrement *r16* by 1
48+rd	DEC *r32*	Decrement *r32* by 1

Description

This instruction subtracts one from the destination operand, while preserving the state of the CF flag. The destination operand can be a register or a memory location. This instruction allows a loop counter to be updated without disturbing the CF flag. (To perform a decrement operation that updates the CF flag, use a SUB instruction with an immediate operand of 1.)

Operation

DEST ← DEST – 1;

Flags Affected

The CF flag is not affected. The OF, SF, ZF, AF, and PF flags are set according to the result.

Protected Mode Exceptions

#GP(0)	If the destination operand is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

DEC—Decrement by 1 (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

DIV—Unsigned Divide

Opcode	Instruction	Description
F6 /6	DIV *r/m8*	Unsigned divide AX by *r/m8*; AL ← Quotient, AH ← Remainder
F7 /6	DIV *r/m16*	Unsigned divide DX:AX by *r/m16*; AX ← Quotient, DX ← Remainder
F7 /6	DIV *r/m32*	Unsigned divide EDX:EAX by *r/m32* doubleword; EAX ← Quotient, EDX ← Remainder

Description

This instruction divides (unsigned) the value in the AX register, DX:AX register pair, or EDX:EAX register pair (dividend) by the source operand (divisor) and stores the result in the AX (AH:AL), DX:AX, or EDX:EAX registers. The source operand can be a general-purpose register or a memory location. The action of this instruction depends on the operand size, as shown in the following table:

Operand Size	Dividend	Divisor	Quotient	Remainder	Maximum Quotient
Word/byte	AX	r/m8	AL	AH	255
Doubleword/word	DX:AX	r/m16	AX	DX	65,535
Quadword/doubleword	EDX:EAX	r/m32	EAX	EDX	$2^{32} - 1$

Non-integral results are truncated (chopped) towards 0. The remainder is always less than the divisor in magnitude. Overflow is indicated with the #DE (divide error) exception rather than with the CF flag.

DIV—Unsigned Divide (Continued)

Operation

```
IF SRC = 0
    THEN #DE; (* divide error *)
FI;
IF OpernadSize = 8 (* word/byte operation *)
    THEN
        temp ← AX / SRC;
        IF temp > FFH
            THEN #DE; (* divide error *) ;
            ELSE
                AL ← temp;
                AH ← AX MOD SRC;
        FI;
    ELSE
        IF OperandSize = 16 (* doubleword/word operation *)
            THEN
                temp ← DX:AX / SRC;

                IF temp > FFFFH
                    THEN #DE; (* divide error *) ;
                    ELSE
                        AX ← temp;
                        DX ← DX:AX MOD SRC;
                FI;
            ELSE (* quadword/doubleword operation *)
                temp ← EDX:EAX / SRC;
                IF temp > FFFFFFFFH
                    THEN #DE; (* divide error *) ;
                    ELSE
                        EAX ← temp;
                        EDX ← EDX:EAX MOD SRC;
                FI;
        FI;
FI;
```

Flags Affected

The CF, OF, SF, ZF, AF, and PF flags are undefined.

DIV—Unsigned Divide (Continued)

Protected Mode Exceptions

#DE	If the source operand (divisor) is 0
	If the quotient is too large for the designated register.
#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#DE	If the source operand (divisor) is 0.
	If the quotient is too large for the designated register.
#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#DE	If the source operand (divisor) is 0.
	If the quotient is too large for the designated register.
#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

DIVPS—Packed Single-FP Divide

Opcode	Instruction	Description
0F,5E,/r	DIVPS *xmm1*, *xmm2/m128*	Divide packed SP FP numbers in *XMM1* by *XMM2/Mem*

Description

The DIVPS instruction divides the packed SP FP numbers of both their operands.

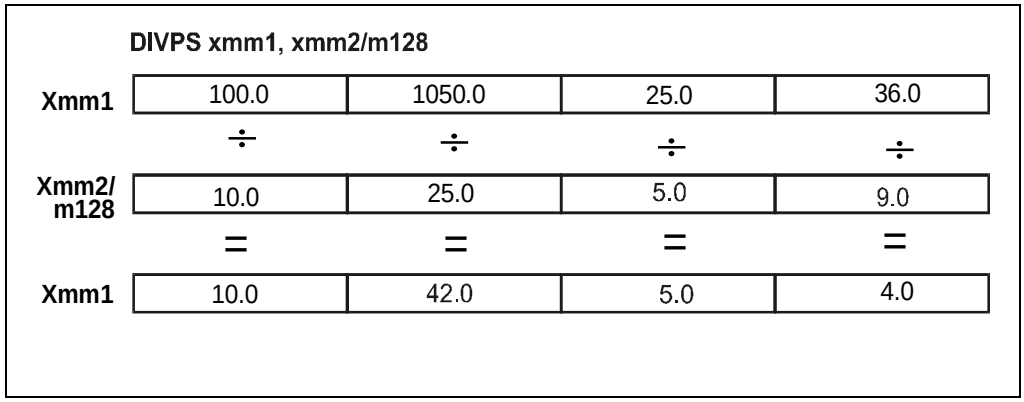


Figure 3-34. Operation of the DIVPS Instruction

Operation

```
DEST[31-0]      = DEST[31-0] / (SRC/m128[31-0]);
DEST[63-32]     = DEST[63-32] / (SRC/m128[63-32]);
DEST[95-64]     = DEST[95-64] / (SRC/m128[95-64]);
DEST[127-96]    = DEST[127-96] / (SRC/m128[127-96]);
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_div_ps(__m128 a, __m128 b)

Divides the four SP FP values of a and b.

DIVPS—Packed Single-FP Divide (Continued)

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

Numeric Exceptions

Overflow, Underflow, Invalid, Divide by Zero, Precision, Denormal.

Protected Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#GP	(0) for an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS	(0) for an illegal address in the SS segment.
#PF	(fault-code) for a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1)
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

DIVPS—Packed Single-FP Divide (Continued)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code).	If a page fault occurs.

DIVSS—Scalar Single-FP Divide

Opcode	Instruction	Description
F3,0F,5E,/r	DIVSS *xmm1*, *xmm2/m32*	Divide lower SP FP numbers in *XMM1* by *XMM2/Mem*

Description

The DIVSS instructions divide the lowest SP FP numbers of both operands; the upper three fields are passed through from xmm1.

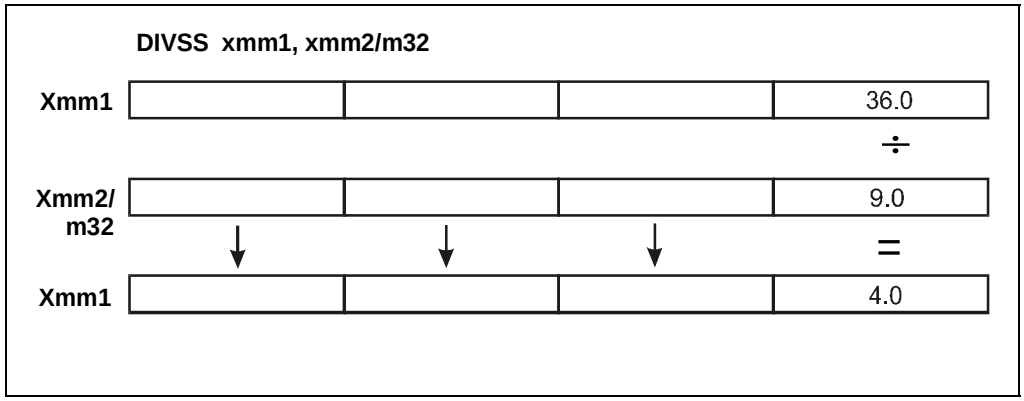


Figure 3-35. Operation of the DIVSS Instruction

Operation

```
DEST[31-0]    = DEST[31-0] / (SRC/m32[31-0]);
DEST[63-32]   = DEST[63-32];
DEST[95-64]   = DEST[95-64];
DEST[127-96]  = DEST[127-96];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_div_ss(__m128 a, __m128 b)

Divides the lower SP FP values of a and b; the upper three SP FP values are passed through from a.

Exceptions

None. Overflow, Underflow, Invalid, Divide by Zero, Precision, Denormal.

DIVSS—Scalar Single-FP Divide (Continued)

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

EMMS—Empty MMX™ State

Opcode	Instruction	Description
0F 77	EMMS	Set the FP tag word to empty.

Description

This instruction sets the values of all the tags in the FPU tag word to empty (all ones). This operation marks the MMX™ technology registers as available, so they can subsequently be used by floating-point instructions. Refer to Figure 7-11 in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*, for the format of the FPU tag word. All other MMX™ instructions (other than the EMMS instruction) set all the tags in FPU tag word to valid (all zeroes).

The EMMS instruction must be used to clear the MMX™ technology state at the end of all MMX™ technology routines and before calling other procedures or subroutines that may execute floating-point instructions. If a floating-point instruction loads one of the registers in the FPU register stack before the FPU tag word has been reset by the EMMS instruction, a floating-point stack overflow can occur that will result in a floating-point exception or incorrect result.

Operation

```
FPUTagWord ← FFFF
```

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

void_m_empty()

Version 4.0 and later Intel C/C++ Compiler intrinsic:

void_mm_empty()

Clears the MMX™ technology state.

Flags Affected

None.

Protected Mode Exceptions

#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

EMMS—Empty MMX™ State (Continued)

Real-Address Mode Exceptions

#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

ENTER—Make Stack Frame for Procedure Parameters

Opcode	Instruction	Description
C8 *iw* 00	ENTER *imm16*,0	Create a stack frame for a procedure
C8 *iw* 01	ENTER *imm16*,1	Create a nested stack frame for a procedure
C8 *iw* ib	ENTER *imm16,imm8*	Create a nested stack frame for a procedure

Description

This instruction creates a stack frame for a procedure. The first operand (size operand) specifies the size of the stack frame (that is, the number of bytes of dynamic storage allocated on the stack for the procedure). The second operand (nesting level operand) gives the lexical nesting level (0 to 31) of the procedure. The nesting level determines the number of stack frame pointers that are copied into the “display area” of the new stack frame from the preceding frame. Both of these operands are immediate values.

The stack-size attribute determines whether the BP (16 bits) or EBP (32 bits) register specifies the current frame pointer and whether SP (16 bits) or ESP (32 bits) specifies the stack pointer.

The ENTER and companion LEAVE instructions are provided to support block structured languages. The ENTER instruction (when used) is typically the first instruction in a procedure and is used to set up a new stack frame for a procedure. The LEAVE instruction is then used at the end of the procedure (just before the RET instruction) to release the stack frame.

If the nesting level is 0, the processor pushes the frame pointer from the EBP register onto the stack, copies the current stack pointer from the ESP register into the EBP register, and loads the ESP register with the current stack-pointer value minus the value in the size operand. For nesting levels of one or greater, the processor pushes additional frame pointers on the stack before adjusting the stack pointer. These additional frame pointers provide the called procedure with access points to other nested frames on the stack. Refer to Section 4.5., *Procedure Calls for Block-Structured Languages* in Chapter 4, *Procedure Calls, Interrupts, and Exceptions* of the *Intel Architecture Software Developer's Manual, Volume 1*, for more information about the actions of the ENTER instruction.

ENTER—Make Stack Frame for Procedure Parameters (Continued)

Operation

```
NestingLevel ← NestingLevel MOD 32
IF StackSize = 32
    THEN
        Push(EBP) ;
        FrameTemp ← ESP;
    ELSE (* StackSize = 16*)
        Push(BP);
        FrameTemp ← SP;
FI;
IF NestingLevel = 0
    THEN GOTO CONTINUE;
FI;
IF (NestingLevel > 0)
    FOR i ← 1 TO (NestingLevel – 1)
        DO
            IF OperandSize = 32
                THEN
                    IF StackSize = 32
                        EBP ← EBP – 4;
                        Push([EBP]); (* doubleword push *)
                    ELSE (* StackSize = 16*)
                        BP ← BP – 4;
                        Push([BP]); (* doubleword push *)
                    FI;
                ELSE (* OperandSize = 16 *)
                    IF StackSize = 32
                        THEN
                            EBP ← EBP – 2;
                            Push([EBP]); (* word push *)
                        ELSE (* StackSize = 16*)
                            BP ← BP – 2;
                            Push([BP]); (* word push *)
                    FI;
            FI;
    OD;
    IF OperandSize = 32
        THEN
            Push(FrameTemp); (* doubleword push *)
        ELSE (* OperandSize = 16 *)
            Push(FrameTemp); (* word push *)
    FI;
    GOTO CONTINUE;
FI;
```

ENTER—Make Stack Frame for Procedure Parameters (Continued)

```
CONTINUE:
IF StackSize = 32
    THEN
        EBP ← FrameTemp
        ESP ← EBP – Size;
    ELSE (* StackSize = 16*)
        BP ← FrameTemp
        SP ← BP – Size;
FI;
END;
```

Flags Affected

None.

Protected Mode Exceptions

#SS(0)	If the new value of the SP or ESP register is outside the stack segment limit.
#PF(fault-code)	If a page fault occurs.

Real-Address Mode Exceptions

#SS(0)	If the new value of the SP or ESP register is outside the stack segment limit.

Virtual-8086 Mode Exceptions

#SS(0)	If the new value of the SP or ESP register is outside the stack segment limit.
#PF(fault-code)	If a page fault occurs.

F2XM1—Compute 2^x-1

Opcode	Instruction	Description
D9 F0	F2XM1	Replace ST(0) with $(2^{ST(0)} - 1)$

Description

This instruction calculates the exponential value of 2 to the power of the source operand minus 1. The source operand is located in register ST(0) and the result is also stored in ST(0). The value of the source operand must lie in the range –1.0 to +1.0. If the source value is outside this range, the result is undefined.

The following table shows the results obtained when computing the exponential value of various classes of numbers, assuming that neither overflow nor underflow occurs.

ST(0) SRC	ST(0) DEST
–1.0 to –0	–0.5 to –0
–0	–0
+0	+0
+0 to +1.0	+0 to 1.0

Values other than 2 can be exponentiated using the following formula:

$x^y = 2^{(y * \log_2 x)}$

Operation

$ST(0) \leftarrow (2^{ST(0)} - 1);$

FPU Flags Affected

C1 — Set to 0 if stack underflow occurred.

Indicates rounding direction if the inexact-result exception (#P) is generated: 0 = not roundup; 1 = roundup.

C0, C2, C3 — Undefined.

F2XM1—Compute 2^x-1 (Continued)

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Source operand is an sNaN value or unsupported format.
#D	Result is a denormal value.
#U	Result is too small for destination format.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FABS—Absolute Value

Opcode	Instruction	Description
D9 E1	FABS	Replace ST with its absolute value.

Description

This instruction clears the sign bit of ST(0) to create the absolute value of the operand. The following table shows the results obtained when creating the absolute value of various classes of numbers.

ST(0) SRC	ST(0) DEST
–∞	+∞
–F	+F
–0	+0
+0	+0
+F	+F
+∞	+∞
NaN	NaN

NOTE:
F Means finite-real number.

Operation

ST(0) ← |ST(0)|

FPU Flags Affected

C1	Set to 0 if stack underflow occurred; otherwise, cleared to 0.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

FABS—Absolute Value (Continued)

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FADD/FADDP/FIADD—Add

Opcode	Instruction	Description
D8 /0	FADD *m32 real*	Add *m32real* to ST(0) and store result in ST(0)
DC /0	FADD *m64real*	Add *m64real* to ST(0) and store result in ST(0)
D8 C0+i	FADD ST(0), ST(i)	Add ST(0) to ST(i) and store result in ST(0)
DC C0+i	FADD ST(i), ST(0)	Add ST(i) to ST(0) and store result in ST(i)
DE C0+i	FADDP ST(i), ST(0)	Add ST(0) to ST(i), store result in ST(i), and pop the register stack
DE C1	FADDP	Add ST(0) to ST(1), store result in ST(1), and pop the register stack
DA /0	FIADD *m32int*	Add *m32int* to ST(0) and store result in ST(0)
DE /0	FIADD *m16int*	Add *m16int* to ST(0) and store result in ST(0)

Description

This instruction adds the destination and source operands and stores the sum in the destination location. The destination operand is always an FPU register; the source operand can be a register or a memory location. Source operands in memory can be in single-real, double-real, word-integer, or short-integer formats.

The no-operand version of the instruction adds the contents of the ST(0) register to the ST(1) register. The one-operand version adds the contents of a memory location (either a real or an integer value) to the contents of the ST(0) register. The two-operand version, adds the contents of the ST(0) register to the ST(i) register or vice versa. The value in ST(0) can be doubled by coding:

```
FADD ST(0), ST(0);
```

The FADDP instructions perform the additional operation of popping the FPU register stack after storing the result. To pop the register stack, the processor marks the ST(0) register as empty and increments the stack pointer (TOP) by 1. (The no-operand version of the floating-point add instructions always results in the register stack being popped. In some assemblers, the mnemonic for this instruction is FADD rather than FADDP.)

The FIADD instructions convert an integer source operand to extended-real format before performing the addition.

The table on the following page shows the results obtained when adding various classes of numbers, assuming that neither overflow nor underflow occurs.

When the sum of two operands with opposite signs is 0, the result is +0, except for the round toward $-\infty$ mode, in which case the result is –0. When the source operand is an integer 0, it is treated as a +0.

When both operand are infinities of the same sign, the result is ∞ of the expected sign. If both operands are infinities of opposite signs, an invalid-operation exception is generated.

FADD/FADDP/FIADD—Add (Continued)

SRC \ DEST	–∞	–F	–0	+0	+F	+∞	NaN
-∞	-∞	-∞	-∞	-∞	-∞	*	NaN
–F or –I	-∞	–F	SRC	SRC	±F or ±0	+∞	NaN
–0	-∞	DEST	–0	±0	DEST	+∞	NaN
+0	-∞	DEST	±0	+0	DEST	+∞	NaN
+F or +I	-∞	±F or ±0	SRC	SRC	+F	+∞	NaN
+∞	*	+∞	+∞	+∞	+∞	+∞	NaN
NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

NOTES:

F Means finite-real number.

I Means integer.

* Indicates floating-point invalid-arithmetic-operand (#IA) exception.

Operation

```
IF instruction is FIADD
    THEN
        DEST ← DEST + ConvertExtendedReal(SRC);
    ELSE (* source operand is real number *)
        DEST ← DEST + SRC;
FI;
IF instruction = FADDP
    THEN
        PopRegisterStack;
FI;
```

FPU Flags Affected

C1	Set to 0 if stack underflow occurred. Indicates rounding direction if the inexact-result exception (#P) is generated: 0 = not roundup; 1 = roundup.
C0, C2, C3	Undefined.

FADD/FADDP/FIADD—Add (Continued)

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Operand is an sNaN value or unsupported format.
	Operands are infinities of unlike sign.
#D	Source operand is a denormal value.
#U	Result is too small for destination format.
#O	Result is too large for destination format.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

FADD/FADDP/FIADD—Add (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FBLD—Load Binary Coded Decimal

Opcode	Instruction	Description
DF /4	FBLD *m80 dec*	Convert BCD value to real and push onto the FPU stack.

Description

This instruction converts the BCD source operand into extended-real format and pushes the value onto the FPU stack. The source operand is loaded without rounding errors. The sign of the source operand is preserved, including that of –0.

The packed BCD digits are assumed to be in the range 0 through 9; the instruction does not check for invalid digits (AH through FH). Attempting to load an invalid encoding produces an undefined result.

Operation

```
TOP ← TOP – 1;
ST(0) ← ExtendedReal(SRC);
```

FPU Flags Affected

C1	Set to 1 if stack overflow occurred; otherwise, cleared to 0.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack overflow occurred.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

FBLD—Load Binary Coded Decimal (Continued)

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FBSTP—Store BCD Integer and Pop

Opcode	Instruction	Description
DF /6	FBSTP m80bcd	Store ST(0) in m80bcd and pop ST(0).

Description

This instruction converts the value in the ST(0) register to an 18-digit packed BCD integer, stores the result in the destination operand, and pops the register stack. If the source value is a non-integral value, it is rounded to an integer value, according to rounding mode specified by the RC field of the FPU control word. To pop the register stack, the processor marks the ST(0) register as empty and increments the stack pointer (TOP) by 1.

The destination operand specifies the address where the first byte destination value is to be stored. The BCD value (including its sign bit) requires 10 bytes of space in memory.

The following table shows the results obtained when storing various classes of numbers in packed BCD format.

ST(0)	DEST
-∞	*
–F < –1	–D
–1 < –F < –0	**
–0	–0
+0	+0
+0 < +F < +1	**
+F > +1	+D
+∞	*
NaN	*

NOTES:

F Means finite-real number.

D Means packed-BCD number.

* Indicates floating-point invalid-operation (#IA) exception.

** ±0 or ±1, depending on the rounding mode.

If the source value is too large for the destination format and the invalid-operation exception is not masked, an invalid-operation exception is generated and no value is stored in the destination operand. If the invalid-operation exception is masked, the packed BCD indefinite value is stored in memory.

If the source value is a quiet NaN, an invalid-operation exception is generated. Quiet NaNs do not normally cause this exception to be generated.

FBSTP—Store BCD Integer and Pop (Continued)

Operation

```
DEST ← BCD(ST(0));
PopRegisterStack;
```

FPU Flags Affected

C1	Set to 0 if stack underflow occurred.
	Indicates rounding direction if the inexact exception (#P) is generated: 0 = not roundup; 1 = roundup.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Source operand is empty; contains a NaN, ±∞, or unsupported format; or contains value that exceeds 18 BCD digits in length.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#GP(0)	If a segment register is being loaded with a segment selector that points to a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

FBSTP—Store BCD Integer and Pop (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FCHS—Change Sign

Opcode	Instruction	Description
D9 E0	FCHS	Complements sign of ST(0)

Description

This instruction complements the sign bit of ST(0). This operation changes a positive value into a negative value of equal magnitude or vice versa. The following table shows the results obtained when changing the sign of various classes of numbers.

ST(0) SRC	ST(0) DEST
–∞	+∞
–F	+F
–0	+0
+0	–0
+F	–F
+∞	–∞
NaN	NaN

NOTE:

F Means finite-real number.

Operation

SignBit(ST(0)) ← NOT (SignBit(ST(0)))

FPU Flags Affected

C1 Set to 0 if stack underflow occurred; otherwise, cleared to 0.

C0, C2, C3 Undefined.

Floating-Point Exceptions

#IS Stack underflow occurred.

Protected Mode Exceptions

#NM EM or TS in CR0 is set.

FCHS—Change Sign (Continued)

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FCLEX/FNCLEX—Clear Exceptions

Opcode	Instruction	Description
9B DB E2	FCLEX	Clear floating-point exception flags after checking for pending unmasked floating-point exceptions.
DB E2	FNCLEX*	Clear floating-point exception flags without checking for pending unmasked floating-point exceptions.

NOTE:

* Refer to “Intel Architecture Compatibility” below.

Description

This instruction clears the floating-point exception flags (PE, UE, OE, ZE, DE, and IE), the exception summary status flag (ES), the stack fault flag (SF), and the busy flag (B) in the FPU status word. The FCLEX instruction checks for and handles any pending unmasked floating-point exceptions before clearing the exception flags; the FNCLEX instruction does not.

Intel Architecture Compatibility

When operating a Pentium® or Intel486™ processor in MS-DOS compatibility mode, it is possible (under unusual circumstances) for an FNCLEX instruction to be interrupted prior to being executed to handle a pending FPU exception. Refer to Section D.2.1.3., *No-Wait FPU Instructions Can Get FPU Interrupt in Window* in Appendix D, *Guidelines for Writing FPU and Streaming SIMD Extension Exception Handlers* of the *Intel Architecture Software Developer's Manual, Volume 1*, for a description of these circumstances. An FNCLEX instruction cannot be interrupted in this way on a Pentium® Pro processor.

On a Pentium® III processor, the FCLEX/FNCLEX instructions operate the same as on a Pentium® II processor. They have no effect on the Pentium® III processor SIMD floating-point functional unit or control/status register.

Operation

```
FPUStatusWord[0..7] ← 0;
FPUStatusWord[15] ← 0;
```

FPU Flags Affected

The PE, UE, OE, ZE, DE, IE, ES, SF, and B flags in the FPU status word are cleared. The C0, C1, C2, and C3 flags are undefined.

Floating-Point Exceptions

None.

FCLEX/FNCLEX—Clear Exceptions (Continued)

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FCMOV*cc*—Floating-Point Conditional Move

Opcode	Instruction	Description
DA C0+i	FCMOVB ST(0), ST(i)	Move if below (CF=1)
DA C8+i	FCMOVE ST(0), ST(i)	Move if equal (ZF=1)
DA D0+i	FCMOVBE ST(0), ST(i)	Move if below or equal (CF=1 or ZF=1)
DA D8+i	FCMOVU ST(0), ST(i)	Move if unordered (PF=1)
DB C0+i	FCMOVNB ST(0), ST(i)	Move if not below (CF=0)
DB C8+i	FCMOVNE ST(0), ST(i)	Move if not equal (ZF=0)
DB D0+i	FCMOVNBE ST(0), ST(i)	Move if not below or equal (CF=0 and ZF=0)
DB D8+i	FCMOVNU ST(0), ST(i)	Move if not unordered (PF=0)

Description

This instruction tests the status flags in the EFLAGS register and moves the source operand (second operand) to the destination operand (first operand) if the given test condition is true. The conditions for each mnemonic are given in the Description column above and in Table 6-4 in Chapter 6, *Instruction Set Summary* of the *Intel Architecture Software Developer's Manual, Volume 1*. The source operand is always in the ST(i) register and the destination operand is always ST(0).

The FCMOV*cc* instructions are useful for optimizing small IF constructions. They also help eliminate branching overhead for IF operations and the possibility of branch mispredictions by the processor.

A processor may not support the FCMOV*cc* instructions. Software can check if the FCMOV*cc* instructions are supported by checking the processor's feature information with the CPUID instruction (refer to "COMISS—Scalar Ordered Single-FP Compare and Set EFLAGS" in this chapter). If both the CMOV and FPU feature bits are set, the FCMOV*cc* instructions are supported.

Intel Architecture Compatibility

The FCMOVcc instructions were introduced to the Intel Architecture in the Pentium® Pro processor family and is not available in earlier Intel Architecture processors.

Operation

```
IF condition TRUE
    ST(0) ← ST(i)
FI;
```

FPU Flags Affected

C1	Set to 0 if stack underflow occurred.
C0, C2, C3	Undefined.

FCMOV*cc*—Floating-Point Conditional Move (Continued)

Floating-Point Exceptions

#IS	Stack underflow occurred.

Integer Flags Affected

None.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FCOM/FCOMP/FCOMPP—Compare Real

Opcode	Instruction	Description
D8 /2	FCOM *m32real*	Compare ST(0) with *m32real*.
DC /2	FCOM *m64real*	Compare ST(0) with *m64real*.
D8 D0+i	FCOM ST(i)	Compare ST(0) with ST(i).
D8 D1	FCOM	Compare ST(0) with ST(1).
D8 /3	FCOMP *m32real*	Compare ST(0) with *m32real* and pop register stack.
DC /3	FCOMP *m64real*	Compare ST(0) with m64real and pop register stack.
D8 D8+i	FCOMP ST(i)	Compare ST(0) with ST(i) and pop register stack.
D8 D9	FCOMP	Compare ST(0) with ST(1) and pop register stack.
DE D9	FCOMPP	Compare ST(0) with ST(1) and pop register stack twice.

Description

These instructions compare the contents of register ST(0) and source value and sets condition code flags C0, C2, and C3 in the FPU status word according to the results (refer to the table below). The source operand can be a data register or a memory location. If no source operand is given, the value in ST(0) is compared with the value in ST(1). The sign of zero is ignored, so that –0.0 = +0.0.

Condition	C3	C2	C0
ST(0) > SRC	0	0	0
ST(0) < SRC	0	0	1
ST(0) = SRC	1	0	0
Unordered*	1	1	1

NOTE:

* Flags not set if unmasked invalid-arithmetic-operand (#IA) exception is generated.

This instruction checks the class of the numbers being compared (refer to “FXAM—Examine” in this chapter). If either operand is a NaN or is in an unsupported format, an invalid-arithmetic-operand exception (#IA) is raised and, if the exception is masked, the condition flags are set to “unordered.” If the invalid-arithmetic-operand exception is unmasked, the condition code flags are not set.

The FCOMP instruction pops the register stack following the comparison operation and the FCOMPP instruction pops the register stack twice following the comparison operation. To pop the register stack, the processor marks the ST(0) register as empty and increments the stack pointer (TOP) by 1.

FCOM/FCOMP/FCOMPP—Compare Real (Continued)

The FCOM instructions perform the same operation as the FUCOM instructions. The only difference is how they handle qNaN operands. The FCOM instructions raise an invalid-arithmetic-operand exception (#IA) when either or both of the operands is a NaN value or is in an unsupported format. The FUCOM instructions perform the same operation as the FCOM instructions, except that they do not generate an invalid-arithmetic-operand exception for qNaNs.

Operation

```
CASE (relation of operands) OF
    ST > SRC:       C3, C2, C0 ← 000;
    ST < SRC:       C3, C2, C0 ← 001;
    ST = SRC:       C3, C2, C0 ← 100;
ESAC;
IF ST(0) or SRC = NaN or unsupported format
    THEN
        #IA
        IF FPUControlWord.IM = 1
            THEN
                C3, C2, C0 ← 111;
        FI;
FI;
IF instruction = FCOMP
    THEN
        PopRegisterStack;
FI;
IF instruction = FCOMPP
    THEN
        PopRegisterStack;
        PopRegisterStack;
FI;
```

FPU Flags Affected

C1	Set to 0 if stack underflow occurred; otherwise, cleared to 0.
C0, C2, C3	Refer to table on previous page.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	One or both operands are NaN values or have unsupported formats.
	Register is marked empty.
#D	One or both operands are denormal values.

FCOM/FCOMP/FCOMPP—Compare Real (Continued)

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FCOMI/FCOMIP/FUCOMI/FUCOMIP—Compare Real and Set EFLAGS

Opcode	Instruction	Description
DB F0+i	FCOMI ST, ST(i)	Compare ST(0) with ST(i) and set status flags accordingly
DF F0+i	FCOMIP ST, ST(i)	Compare ST(0) with ST(i), set status flags accordingly, and pop register stack
DB E8+i	FUCOMI ST, ST(i)	Compare ST(0) with ST(i), check for ordered values, and set status flags accordingly
DF E8+i	FUCOMIP ST, ST(i)	Compare ST(0) with ST(i), check for ordered values, set status flags accordingly, and pop register stack

Description

These instructions compare the contents of register ST(0) and ST(i) and sets the status flags ZF, PF, and CF in the EFLAGS register according to the results (refer to the table below). The sign of zero is ignored for comparisons, so that –0.0 = +0.0.

Comparison Results	ZF	PF	CF
ST0 > ST(i)	0	0	0
ST0 < ST(i)	0	0	1
ST0 = ST(i)	1	0	0
Unordered*	1	1	1

NOTE:

* Flags are set regardless, whether there is an unmasked invalid-arithmetic-operand (#IA) exception generated or not.

The FCOMI/FCOMIP instructions perform the same operation as the FUCOMI/FUCOMIP instructions. The only difference is how they handle qNaN operands. The FCOMI/FCOMIP instructions set the status flags to “unordered” and generate an invalid-arithmetic-operand exception (#IA) when either or both of the operands is a NaN value (sNaN or qNaN) or is in an unsupported format.

The FUCOMI/FUCOMIP instructions perform the same operation as the FCOMI/FCOMIP instructions, except that they do not generate an invalid-arithmetic-operand exception for qNaNs. Refer to “FXAM—Examine” in this chapter for additional information on unordered comparisons.

If invalid-operation exception is unmasked, the status flags are not set if the invalid-arithmetic-operand exception is generated.

The FCOMIP and FUCOMIP instructions also pop the register stack following the comparison operation. To pop the register stack, the processor marks the ST(0) register as empty and increments the stack pointer (TOP) by 1.

FCOMI/FCOMIP/FUCOMI/FUCOMIP—Compare Real and Set EFLAGS (Continued)

Intel Architecture Compatibility

The FCOMI/FCOMIP/FUCOMI/FUCOMIP instructions were introduced to the Intel Architecture in the Pentium® Pro processor family and are not available in earlier Intel Architecture processors.

Operation

```
CASE (relation of operands) OF
    ST(0) > ST(i):      ZF, PF, CF ← 000;
    ST(0) < ST(i):      ZF, PF, CF ← 001;
    ST(0) = ST(i):      ZF, PF, CF ← 100;
ESAC;
IF instruction is FCOMI or FCOMIP
    THEN
        IF ST(0) or ST(i) = NaN or unsupported format
            THEN
                #IA
                IF FPUControlWord.IM = 1
                    THEN
                        ZF, PF, CF ← 111;
                FI;
        FI;
FI;
IF instruction is FUCOMI or FUCOMIP
    THEN
        IF ST(0) or ST(i) = QNaN, but not SNaN or unsupported format
            THEN
                ZF, PF, CF ← 111;
            ELSE (* ST(0) or ST(i) is SNaN or unsupported format *)
                 #IA;
                IF FPUControlWord.IM = 1
                    THEN
                        ZF, PF, CF ← 111;
                FI;
        FI;
FI;
IF instruction is FCOMIP or FUCOMIP
    THEN
        PopRegisterStack;
FI;
```

FCOMI/FCOMIP/FUCOMI/FUCOMIP—Compare Real and Set EFLAGS (Continued)

FPU Flags Affected

C1	Set to 0 if stack underflow occurred; otherwise, cleared to 0.
C0, C2, C3	Not affected.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	(FCOMI or FCOMIP instruction) One or both operands are NaN values or have unsupported formats. (FUCOMI or FUCOMIP instruction) One or both operands are sNaN values (but not qNaNs) or have undefined formats. Detection of a qNaN value does not raise an invalid-operand exception.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FCOS—Cosine

Opcode	Instruction	Description
D9 FF	FCOS	Replace ST(0) with its cosine

Description

This instruction calculates the cosine of the source operand in register ST(0) and stores the result in ST(0). The source operand must be given in radians and must be within the range -2^{63} to $+2^{63}$. The following table shows the results obtained when taking the cosine of various classes of numbers, assuming that neither overflow nor underflow occurs.

ST(0) SRC	ST(0) DEST
–∞	*
–F	–1 to +1
–0	+1
+0	+1
+F	–1 to +1
+∞	*
NaN	NaN

NOTES:

F Means finite-real number.

* Indicates floating-point invalid-arithmetic-operand (#IA) exception.

If the source operand is outside the acceptable range, the C2 flag in the FPU status word is set, and the value in register ST(0) remains unchanged. The instruction does not raise an exception when the source operand is out of range. It is up to the program to check the C2 flag for out-of-range conditions. Source values outside the range -2^{63} to $+2^{63}$ can be reduced to the range of the instruction by subtracting an appropriate integer multiple of 2π or by using the FPREM instruction with a divisor of 2π. Refer to Section 7.5.8., *Pi* in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*, for a discussion of the proper value to use for π in performing such reductions.

Operation

```
IF |ST(0)| < 2^63
THEN
    C2 ← 0;
    ST(0) ← cosine(ST(0));
ELSE (*source operand is out-of-range *)
    C2 ← 1;
FI;
```

FCOS—Cosine (Continued)

FPU Flags Affected

C1	Set to 0 if stack underflow occurred.
	Indicates rounding direction if the inexact-result exception (#P) is generated: 0 = not roundup; 1 = roundup.
	Undefined if C2 is 1.
C2	Set to 1 if source operand is outside the range -2^{63} to $+2^{63}$; otherwise, cleared to 0.
C0, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Source operand is an sNaN value, ∞, or unsupported format.
#D	Result is a denormal value.
#U	Result is too small for destination format.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FDECSTP—Decrement Stack-Top Pointer

Opcode	Instruction	Description
D9 F6	FDECSTP	Decrement TOP field in FPU status word.

Description

Description

This instruction subtracts one from the TOP field of the FPU status word (decrements the top-of-stack pointer). If the TOP field contains a 0, it is set to 7. The effect of this instruction is to rotate the stack by one position. The contents of the FPU data registers and tag register are not affected.

Operation

```
IF TOP = 0
    THEN TOP ← 7;
    ELSE TOP ← TOP – 1;
FI;
```

FPU Flags Affected

The C1 flag is set to 0; otherwise, cleared to 0. The C0, C2, and C3 flags are undefined.

Floating-Point Exceptions

None.

Protected Mode Exceptions

#NM EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM EM or TS in CR0 is set.

FDIV/FDIVP/FIDIV—Divide

Opcode	Instruction	Description
D8 /6	FDIV *m32real*	Divide ST(0) by *m32real* and store result in ST(0)
DC /6	FDIV *m64real*	Divide ST(0) by *m64real* and store result in ST(0)
D8 F0+i	FDIV ST(0), ST(i)	Divide ST(0) by ST(i) and store result in ST(0)
DC F8+i	FDIV ST(i), ST(0)	Divide ST(i) by ST(0) and store result in ST(i)
DE F8+i	FDIVP ST(i), ST(0)	Divide ST(i) by ST(0), store result in ST(i), and pop the register stack
DE F9	FDIVP	Divide ST(1) by ST(0), store result in ST(1), and pop the register stack
DA /6	FIDIV *m32int*	Divide ST(0) by *m32int* and store result in ST(0)
DE /6	FIDIV *m16int*	Divide ST(0) by *m16int* and store result in ST(0)

Description

These instructions divide the destination operand by the source operand and stores the result in the destination location. The destination operand (dividend) is always in an FPU register; the source operand (divisor) can be a register or a memory location. Source operands in memory can be in single-real, double-real, word-integer, or short-integer formats.

The no-operand version of the instruction divides the contents of the ST(1) register by the contents of the ST(0) register. The one-operand version divides the contents of the ST(0) register by the contents of a memory location (either a real or an integer value). The two-operand version, divides the contents of the ST(0) register by the contents of the ST(i) register or vice versa.

The FDIVP instructions perform the additional operation of popping the FPU register stack after storing the result. To pop the register stack, the processor marks the ST(0) register as empty and increments the stack pointer (TOP) by 1. The no-operand version of the floating-point divide instructions always results in the register stack being popped. In some assemblers, the mnemonic for this instruction is FDIV rather than FDIVP.

The FIDIV instructions convert an integer source operand to extended-real format before performing the division. When the source operand is an integer 0, it is treated as a +0.

If an unmasked divide by zero exception (#Z) is generated, no result is stored; if the exception is masked, an ∞ of the appropriate sign is stored in the destination operand.

The following table shows the results obtained when dividing various classes of numbers, assuming that neither overflow nor underflow occurs.

FDIV/FDIVP/FIDIV—Divide (Continued)

		DEST						
		–∞	–F	–0	+0	+F	+∞	NaN
SRC	-∞	*	+0	+0	–0	–0	*	NaN
	–F	+∞	+F	+0	–0	–F	–∞	NaN
	–I	+∞	+F	+0	–0	–F	–∞	NaN
	–0	+∞	**	*	*	**	–∞	NaN
	+0	–∞	**	*	*	**	+∞	NaN
	+I	–∞	–F	–0	+0	+F	+∞	NaN
	+F	–∞	–F	–0	+0	+F	+∞	NaN
	+∞	*	–0	–0	+0	+0	*	NaN
	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

NOTES:

F Means finite-real number.

I Means integer.

* Indicates floating-point invalid-arithmetic-operand (#IA) exception.

** Indicates floating-point zero-divide (#Z) exception.

Operation

```
IF SRC = 0
    THEN
        #Z
    ELSE
        IF instruction is FIDIV
            THEN
                DEST ← DEST / ConvertExtendedReal(SRC);
            ELSE (* source operand is real number *)
                DEST ← DEST / SRC;
        FI;
FI;
IF instruction = FDIVP
    THEN
        PopRegisterStack
FI;
```

FDIV/FDIVP/FIDIV—Divide (Continued)

FPU Flags Affected

C1	Set to 0 if stack underflow occurred.
	Indicates rounding direction if the inexact-result exception (#P) is generated: 0 = not roundup; 1 = roundup.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Operand is an sNaN value or unsupported format.
	$\pm\infty$ / $\pm\infty$; ±0 / ±0
#D	Result is a denormal value.
#Z	DEST / ±0, where DEST is not equal to ±0.
#U	Result is too small for destination format.
#O	Result is too large for destination format.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

FDIV/FDIVP/FIDIV—Divide (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FDIVR/FDIVRP/FIDIVR—Reverse Divide

Opcode	Instruction	Description
D8 /7	FDIVR *m32real*	Divide *m32real* by ST(0) and store result in ST(0)
DC /7	FDIVR *m64real*	Divide *m64real* by ST(0) and store result in ST(0)
D8 F8+i	FDIVR ST(0), ST(i)	Divide ST(i) by ST(0) and store result in ST(0)
DC F0+i	FDIVR ST(i), ST(0)	Divide ST(0) by ST(i) and store result in ST(i)
DE F0+i	FDIVRP ST(i), ST(0)	Divide ST(0) by ST(i), store result in ST(i), and pop the register stack
DE F1	FDIVRP	Divide ST(0) by ST(1), store result in ST(1), and pop the register stack
DA /7	FIDIVR *m32int*	Divide *m32int* by ST(0) and store result in ST(0)
DE /7	FIDIVR *m16int*	Divide *m16int* by ST(0) and store result in ST(0)

Description

These instructions divide the source operand by the destination operand and stores the result in the destination location. The destination operand (divisor) is always in an FPU register; the source operand (dividend) can be a register or a memory location. Source operands in memory can be in single-real, double-real, word-integer, or short-integer formats.

These instructions perform the reverse operations of the FDIV, FDIVP, and FIDIV instructions. They are provided to support more efficient coding.

The no-operand version of the instruction divides the contents of the ST(0) register by the contents of the ST(1) register. The one-operand version divides the contents of a memory location (either a real or an integer value) by the contents of the ST(0) register. The two-operand version, divides the contents of the ST(i) register by the contents of the ST(0) register or vice versa.

The FDIVRP instructions perform the additional operation of popping the FPU register stack after storing the result. To pop the register stack, the processor marks the ST(0) register as empty and increments the stack pointer (TOP) by 1. The no-operand version of the floating-point divide instructions always results in the register stack being popped. In some assemblers, the mnemonic for this instruction is FDIVR rather than FDIVRP.

The FIDIVR instructions convert an integer source operand to extended-real format before performing the division.

If an unmasked divide by zero exception (#Z) is generated, no result is stored; if the exception is masked, an ∞ of the appropriate sign is stored in the destination operand.

The following table shows the results obtained when dividing various classes of numbers, assuming that neither overflow nor underflow occurs.

FDIVR/FDIVRP/FIDIVR—Reverse Divide (Continued)

		DEST						
		–∞	–F	–0	+0	+F	+∞	NaN
SRC	–∞	*	+∞	+∞	–∞	–∞	*	NaN
	–F	+0	+F	**	**	-F	–0	NaN
	–I	+0	+F	**	**	-F	–0	NaN
	–0	+0	+0	*	*	–0	–0	NaN
	+0	–0	–0	*	*	+0	+0	NaN
	+I	–0	-F	**	**	+F	+0	NaN
	+F	–0	-F	**	**	+F	+0	NaN
	+∞	*	–∞	–∞	+∞	+∞	*	NaN
	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

NOTES:

F Means finite-real number.

I Means integer.

* Indicates floating-point invalid-arithmetic-operand (#IA) exception.

** Indicates floating-point zero-divide (#Z) exception.

When the source operand is an integer 0, it is treated as a +0.

Operation

```
IF DEST = 0
    THEN
        #Z
    ELSE
        IF instruction is FIDIVR
            THEN
                DEST ← ConvertExtendedReal(SRC) / DEST;
            ELSE (* source operand is real number *)
                DEST ← SRC / DEST;
        FI;
FI;
IF instruction = FDIVRP
    THEN
        PopRegisterStack
FI;
```

FDIVR/FDIVRP/FIDIVR—Reverse Divide (Continued)

FPU Flags Affected

C1	Set to 0 if stack underflow occurred.
	Indicates rounding direction if the inexact-result exception (#P) is generated: 0 = not roundup; 1 = roundup.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Operand is an sNaN value or unsupported format.
	$\pm\infty$ / $\pm\infty$; ±0 / ±0
#D	Result is a denormal value.
#Z	SRC / ±0, where SRC is not equal to ±0.
#U	Result is too small for destination format.
#O	Result is too large for destination format.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

FDIVR/FDIVRP/FIDIVR—Reverse Divide (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FFREE—Free Floating-Point Register

Opcode	Instruction	Description
DD C0+i	FFREE ST(i)	Sets tag for ST(i) to empty

Description

This instruction sets the tag in the FPU tag register associated with register ST(i) to empty (11B). The contents of ST(i) and the FPU stack-top pointer (TOP) are not affected.

Operation

TAG(i) ← 11B;

FPU Flags Affected

C0, C1, C2, C3 undefined.

Floating-Point Exceptions

None.

Protected Mode Exceptions

#NM EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM EM or TS in CR0 is set.

FICOM/FICOMP—Compare Integer

Opcode	Instruction	Description
DE /2	FICOM *m16int*	Compare ST(0) with *m16int*
DA /2	FICOM *m32int*	Compare ST(0) with *m32int*
DE /3	FICOMP *m16int*	Compare ST(0) with *m16int* and pop stack register
DA /3	FICOMP *m32int*	Compare ST(0) with *m32int* and pop stack register

Description

These instruction compare the value in ST(0) with an integer source operand and sets the condition code flags C0, C2, and C3 in the FPU status word according to the results (refer to table below). The integer value is converted to extended-real format before the comparison is made.

Condition	C3	C2	C0
ST(0) > SRC	0	0	0
ST(0) < SRC	0	0	1
ST(0) = SRC	1	0	0
Unordered	1	1	1

These instructions perform an “unordered comparison.” An unordered comparison also checks the class of the numbers being compared (refer to “FXAM—Examine” in this chapter). If either operand is a NaN or is in an undefined format, the condition flags are set to “unordered.”

The sign of zero is ignored, so that –0.0 = +0.0.

The FICOMP instructions pop the register stack following the comparison. To pop the register stack, the processor marks the ST(0) register empty and increments the stack pointer (TOP) by 1.

Operation

```
CASE (relation of operands) OF
    ST(0) > SRC:    C3, C2, C0 ← 000;
    ST(0) < SRC:    C3, C2, C0 ← 001;
    ST(0) = SRC:    C3, C2, C0 ← 100;
    Unordered:      C3, C2, C0 ← 111;
ESAC;
IF instruction = FICOMP
    THEN
        PopRegisterStack;
FI;
```

FICOM/FICOMP—Compare Integer (Continued)

FPU Flags Affected

C1	Set to 0 if stack underflow occurred; otherwise, set to 0.
C0, C2, C3	Refer to table on previous page.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	One or both operands are NaN values or have unsupported formats.
#D	One or both operands are denormal values.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FILD—Load Integer

Opcode	Instruction	Description
DF /0	FILD *m16int*	Push *m16int* onto the FPU register stack.
DB /0	FILD *m32int*	Push *m32int* onto the FPU register stack.
DF /5	FILD *m64int*	Push *m64int* onto the FPU register stack.

Description

This instruction converts the signed-integer source operand into extended-real format and pushes the value onto the FPU register stack. The source operand can be a word, short, or long integer value. It is loaded without rounding errors. The sign of the source operand is preserved.

Operation

```
TOP ← TOP – 1;
ST(0) ← ExtendedReal(SRC);
```

FPU Flags Affected

C1	Set to 1 if stack overflow occurred; cleared to 0 otherwise.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack overflow occurred.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

FILD—Load Integer (Continued)

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FINCSTP—Increment Stack-Top Pointer

Opcode	Instruction	Description
D9 F7	FINCSTP	Increment the TOP field in the FPU status register

Description

This instruction adds one to the TOP field of the FPU status word (increments the top-of-stack pointer). If the TOP field contains a 7, it is set to 0. The effect of this instruction is to rotate the stack by one position. The contents of the FPU data registers and tag register are not affected. This operation is not equivalent to popping the stack, because the tag for the previous top-of-stack register is not marked empty.

Operation

```
IF TOP = 7
    THEN TOP ← 0;
    ELSE TOP ← TOP + 1;
FI;
```

FPU Flags Affected

The C1 flag is set to 0; otherwise, cleared to 0. The C0, C2, and C3 flags are undefined.

Floating-Point Exceptions

None.

Protected Mode Exceptions

#NM EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM EM or TS in CR0 is set.

FINIT/FNINIT—Initialize Floating-Point Unit

Opcode	Instruction	Description
9B DB E3	FINIT	Initialize FPU after checking for pending unmasked floating-point exceptions.
DB E3	FNINIT*	Initialize FPU without checking for pending unmasked floating-point exceptions.

NOTE:

* Refer to “Intel Architecture Compatibility” below.

Description

These instructions set the FPU control, status, tag, instruction pointer, and data pointer registers to their default states. The FPU control word is set to 037FH (round to nearest, all exceptions masked, 64-bit precision). The status word is cleared (no exception flags set, TOP is set to 0). The data registers in the register stack are left unchanged, but they are all tagged as empty (11B). Both the instruction and data pointers are cleared.

The FINIT instruction checks for and handles any pending unmasked floating-point exceptions before performing the initialization; the FNINIT instruction does not.

Intel Architecture Compatibility

When operating a Pentium® or Intel486™ processor in MS-DOS compatibility mode, it is possible (under unusual circumstances) for an FNINIT instruction to be interrupted prior to being executed to handle a pending FPU exception. Refer to Section D.2.1.3., *No-Wait FPU Instructions Can Get FPU Interrupt in Window* in Appendix D, *Guidelines for Writing FPU and Streaming SIMD Extension Exception Handlers* of the *Intel Architecture Software Developer's Manual, Volume 1*, for a description of these circumstances. An FNINIT instruction cannot be interrupted in this way on a Pentium® Pro processor.

In the Intel387 math coprocessor, the FINIT/FNINIT instruction does not clear the instruction and data pointers.

On a Pentium® III processor, the FINIT/FNINT instructions operate the same as on a Pentium® II processor. They have no effect on the Pentium® III processor SIMD floating-point functional unit or control/status register.

Operation

```
FPUControlWord ← 037FH;
FPUStatusWord ← 0;
FPUTagWord ← FFFFH;
FPUDataPointer ← 0;
FPUInstructionPointer ← 0;
FPULastInstructionOpcode ← 0;
```

FINIT/FNINIT—Initialize Floating-Point Unit (Continued)

FPU Flags Affected

C0, C1, C2, C3 cleared to 0.

Floating-Point Exceptions

None.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

Comments

This instruction has no effect on the state of SIMD floating-point registers.

FIST/FISTP—Store Integer

Opcode	Instruction	Description
DF /2	FIST *m16int*	Store ST(0) in *m16int*
DB /2	FIST *m32int*	Store ST(0) in *m32int*
DF /3	FISTP *m16int*	Store ST(0) in *m16int* and pop register stack
DB /3	FISTP *m32int*	Store ST(0) in *m32int* and pop register stack
DF /7	FISTP *m64int*	Store ST(0) in *m64int* and pop register stack

Description

The FIST instruction converts the value in the ST(0) register to a signed integer and stores the result in the destination operand. Values can be stored in word- or short-integer format. The destination operand specifies the address where the first byte of the destination value is to be stored.

The FISTP instruction performs the same operation as the FIST instruction and then pops the register stack. To pop the register stack, the processor marks the ST(0) register as empty and increments the stack pointer (TOP) by 1. The FISTP instruction can also stores values in long-integer format.

The following table shows the results obtained when storing various classes of numbers in integer format.

ST(0)	DEST
–∞	*
–F < –1	–I
–1 < –F < –0	**
–0	0
+0	0
+0 < +F < +1	**
+F > +1	+I
+∞	*
NaN	*

NOTES:

F Means finite-real number.

I Means integer.

* Indicates floating-point invalid-operation (#IA) exception.

** 0 or ±1, depending on the rounding mode.

FIST/FISTP—Store Integer (Continued)

If the source value is a non-integral value, it is rounded to an integer value, according to the rounding mode specified by the RC field of the FPU control word.

If the value being stored is too large for the destination format, is an ∞, is a NaN, or is in an unsupported format and if the invalid-arithmetic-operand exception (#IA) is unmasked, an invalid-operation exception is generated and no value is stored in the destination operand. If the invalid-operation exception is masked, the integer indefinite value is stored in the destination operand.

Operation

```
DEST ← Integer(ST(0));
IF instruction = FISTP
    THEN
        PopRegisterStack;
FI;
```

FPU Flags Affected

C1	Set to 0 if stack underflow occurred.
	Indicates rounding direction of if the inexact exception (#P) is generated: 0 = not roundup; 1 = roundup.
	Cleared to 0 otherwise.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Source operand is too large for the destination format
	Source operand is a NaN value or unsupported format.
#P	Value cannot be represented exactly in destination format.

FIST/FISTP—Store Integer (Continued)

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FLD—Load Real

Opcode	Instruction	Description
D9 /0	FLD *m32real*	Push *m32real* onto the FPU register stack.
DD /0	FLD *m64real*	Push *m64real* onto the FPU register stack.
DB /5	FLD *m80real*	Push *m80real* onto the FPU register stack.
D9 C0+i	FLD ST(i)	Push ST(i) onto the FPU register stack.

Description

This instruction pushes the source operand onto the FPU register stack. If the source operand is in single- or double-real format, it is automatically converted to the extended-real format before being pushed on the stack.

The FLD instruction can also push the value in a selected FPU register [ST(i)] onto the stack. Here, pushing register ST(0) duplicates the stack top.

Operation

```
IF SRC is ST(i)
    THEN
        temp ← ST(i)
TOP ← TOP – 1;
IF SRC is memory-operand
    THEN
        ST(0) ← ExtendedReal(SRC);
    ELSE (* SRC is ST(i) *)
        ST(0) ← temp;
```

FPU Flags Affected

C1	Set to 1 if stack overflow occurred; otherwise, cleared to 0.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack overflow occurred.
#IA	Source operand is an sNaN value or unsupported format.
#D	Source operand is a denormal value. Does not occur if the source operand is in extended-real format.

FLD—Load Real (Continued)

Protected Mode Exceptions

#GP(0)	If destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FLD1/FLDL2T/FLDL2E/FLDPI/FLDLG2/FLDLN2/FLDZ—Load Constant

Opcode	Instruction	Description
D9 E8	FLD1	Push +1.0 onto the FPU register stack.
D9 E9	FLDL2T	Push $\log_2 10$ onto the FPU register stack.
D9 EA	FLDL2E	Push $\log_2 e$ onto the FPU register stack.
D9 EB	FLDPI	Push π onto the FPU register stack.
D9 EC	FLDLG2	Push $\log_{10} 2$ onto the FPU register stack.
D9 ED	FLDLN2	Push $\log_e 2$ onto the FPU register stack.
D9 EE	FLDZ	Push +0.0 onto the FPU register stack.

Description

These instructions push one of seven commonly used constants (in extended-real format) onto the FPU register stack. The constants that can be loaded with these instructions include +1.0, +0.0, $\log_2 10$, $\log_2 e$, π, $\log_{10} 2$, and $\log_e 2$. For each constant, an internal 66-bit constant is rounded (as specified by the RC field in the FPU control word) to external-real format. The inexact-result exception (#P) is not generated as a result of the rounding. Refer to Section 7.5.8., *Pi* in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*, for a description of the π constant.

Operation

```
TOP ← TOP – 1;
ST(0) ← CONSTANT;
```

FPU Flags Affected

C1	Set to 1 if stack overflow occurred; otherwise, cleared to 0.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack overflow occurred.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

FLD1/FLDL2T/FLDL2E/FLDPI/FLDLG2/FLDLN2/FLDZ—Load Constant (Continued)

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

Intel Architecture Compatibility

When the RC field is set to round-to-nearest, the FPU produces the same constants that is produced by the Intel 8087 and Intel287 math coprocessors.

FLDCW—Load Control Word

Opcode	Instruction	Description
D9 /5	FLDCW m2byte	Load FPU control word from *m2byte.*

Description

This instruction loads the 16-bit source operand into the FPU control word. The source operand is a memory location. This instruction is typically used to establish or change the FPU's mode of operation.

If one or more exception flags are set in the FPU status word prior to loading a new FPU control word and the new control word unmasks one or more of those exceptions, a floating-point exception will be generated upon execution of the next floating-point instruction (except for the no-wait floating-point instructions. For more information, refer to Section 7.7.3., *Software Exception Handling* in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*). To avoid raising exceptions when changing FPU operating modes, clear any pending exceptions (using the FCLEX or FNCLEX instruction) before loading the new control word.

Intel Architecture Compatibility

On a Pentium® III processor, the FLDCW instruction operates the same as on a Pentium® II processor. It has no effect on the Pentium® III processor SIMD floating-point functional unit or control/status register.

Operation

```
FPUControlWord ← SRC;
```

FPU Flags Affected

C0, C1, C2, C3 undefined.

Floating-Point Exceptions

None; however, this operation might unmask a pending exception in the FPU status word. That exception is then generated upon execution of the next "waiting" floating-point instruction.

FLDCW—Load Control Word (Continued)

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FLDENV—Load FPU Environment

Opcode	Instruction	Description
D9 /4	FLDENV *m14/28byte*	Load FPU environment from *m14byte* or *m28byte*.

Description

This instruction loads the complete FPU operating environment from memory into the FPU registers. The source operand specifies the first byte of the operating-environment data in memory. This data is typically written to the specified memory location by a FSTENV or FNSTENV instruction.

The FPU operating environment consists of the FPU control word, status word, tag word, instruction pointer, data pointer, and last opcode. Figures 7-13 through Figure 7-16 in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*, show the layout in memory of the loaded environment, depending on the operating mode of the processor (protected or real) and the current operand-size attribute (16-bit or 32-bit). In virtual-8086 mode, the real mode layouts are used.

The FLDENV instruction should be executed in the same operating mode as the corresponding FSTENV/FNSTENV instruction.

If one or more unmasked exception flags are set in the new FPU status word, a floating-point exception will be generated upon execution of the next floating-point instruction (except for the no-wait floating-point instructions. or more information, refer to Section 7.7.3., *Software Exception Handling* in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*). To avoid generating exceptions when loading a new environment, clear all the exception flags in the FPU status word that is being loaded.

Intel Architecture Compatibility

On a Pentium® III processor, the FLDENV instruction operates the same as on a Pentium® II processor. It has no effect on the Pentium® III processor SIMD floating-point functional unit or control/status register.

Operation

```
FPUControlWord ← SRC(FPUControlWord);
FPUStatusWord ← SRC(FPUStatusWord);
FPUTagWord ← SRC(FPUTagWord);
FPUDataPointer ← SRC(FPUDataPointer);
FPUInstructionPointer ← SRC(FPUInstructionPointer);
FPULastInstructionOpcode ← SRC(FPULastInstructionOpcode);
```

FPU Flags Affected

The C0, C1, C2, C3 flags are loaded.

FLDENV—Load FPU Environment (Continued)

Floating-Point Exceptions

None; however, if an unmasked exception is loaded in the status word, it is generated upon execution of the next “waiting” floating-point instruction.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FMUL/FMULP/FIMUL—Multiply

Opcode	Instruction	Description
D8 /1	FMUL *m32real*	Multiply ST(0) by *m32real* and store result in ST(0)
DC /1	FMUL *m64real*	Multiply ST(0) by *m64real* and store result in ST(0)
D8 C8+i	FMUL ST(0), ST(i)	Multiply ST(0) by ST(i) and store result in ST(0)
DC C8+i	FMUL ST(i), ST(0)	Multiply ST(i) by ST(0) and store result in ST(i)
DE C8+i	FMULP ST(i), ST(0)	Multiply ST(i) by ST(0), store result in ST(i), and pop the register stack
DE C9	FMULP	Multiply ST(1) by ST(0), store result in ST(1), and pop the register stack
DA /1	FIMUL *m32int*	Multiply ST(0) by *m32int* and store result in ST(0)
DE /1	FIMUL *m16int*	Multiply ST(0) by *m16int* and store result in ST(0)

Description

These instructions multiply the destination and source operands and stores the product in the destination location. The destination operand is always an FPU data register; the source operand can be an FPU data register or a memory location. Source operands in memory can be in single-real, double-real, word-integer, or short-integer formats.

The no-operand version of the instruction multiplies the contents of the ST(1) register by the contents of the ST(0) register and stores the product in the ST(1) register. The one-operand version multiplies the contents of the ST(0) register by the contents of a memory location (either a real or an integer value) and stores the product in the ST(0) register. The two-operand version, multiplies the contents of the ST(0) register by the contents of the ST(i) register, or vice versa, with the result being stored in the register specified with the first operand (the destination operand).

The FMULP instructions perform the additional operation of popping the FPU register stack after storing the product. To pop the register stack, the processor marks the ST(0) register as empty and increments the stack pointer (TOP) by 1. The no-operand version of the floating-point multiply instructions always results in the register stack being popped. In some assemblers, the mnemonic for this instruction is FMUL rather than FMULP.

The FIMUL instructions convert an integer source operand to extended-real format before performing the multiplication.

The sign of the result is always the exclusive-OR of the source signs, even if one or more of the values being multiplied is 0 or ∞. When the source operand is an integer 0, it is treated as a +0.

The following table shows the results obtained when multiplying various classes of numbers, assuming that neither overflow nor underflow occurs.

FMUL/FMULP/FIMUL—Multiply (Continued)

		DEST						
		–∞	–F	–0	+0	+F	+∞	NaN
SRC	–∞	+∞	+∞	*	*	–∞	–∞	NaN
	–F	+∞	+F	+0	–0	–F	–∞	NaN
	–I	+∞	+F	+0	–0	–F	–∞	NaN
	–0	*	+0	+0	–0	–0	*	NaN
	+0	*	–0	–0	+0	+0	*	NaN
	+I	–∞	–F	–0	+0	+F	+∞	NaN
	+F	–∞	–F	–0	+0	+F	+∞	NaN
	+∞	–∞	–∞	*	*	+∞	+∞	NaN
	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

NOTES:

F Means finite-real number.

I Means Integer.

* Indicates invalid-arithmetic-operand (#IA) exception.

Operation

```
IF instruction is FIMUL
    THEN
        DEST ← DEST ∗ ConvertExtendedReal(SRC);
    ELSE (* source operand is real number *)
        DEST ← DEST ∗ SRC;
FI;
IF instruction = FMULP
    THEN
        PopRegisterStack
FI;
```

FPU Flags Affected

C1	Set to 0 if stack underflow occurred. Indicates rounding direction if the inexact-result exception (#P) fault is generated: 0 = not roundup; 1 = roundup.
C0, C2, C3	Undefined.

FMUL/FMULP/FIMUL—Multiply (Continued)

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Operand is an sNaN value or unsupported format.
	One operand is ±0 and the other is ±∞.
#D	Source operand is a denormal value.
#U	Result is too small for destination format.
#O	Result is too large for destination format.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

FMUL/FMULP/FIMUL—Multiply (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FNOP—No Operation

Opcode	Instruction	Description
D9 D0	FNOP	No operation is performed.

Description

This instruction performs no FPU operation. This instruction takes up space in the instruction stream but does not affect the FPU or machine context, except the EIP register.

FPU Flags Affected

C0, C1, C2, C3 undefined.

Floating-Point Exceptions

None.

Protected Mode Exceptions

#NM EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM EM or TS in CR0 is set.

FPATAN—Partial Arctangent

Opcode	Instruction	Description
D9 F3	FPATAN	Replace ST(1) with arctan(ST(1)/ST(0)) and pop the register stack

Description

This instruction computes the arctangent of the source operand in register ST(1) divided by the source operand in register ST(0), stores the result in ST(1), and pops the FPU register stack. The result in register ST(0) has the same sign as the source operand ST(1) and a magnitude less than $+\pi$.

The FPATAN instruction returns the angle between the X axis and the line from the origin to the point (X,Y), where Y (the ordinate) is ST(1) and X (the abscissa) is ST(0). The angle depends on the sign of X and Y independently, not just on the sign of the ratio Y/X. This is because a point ($-$X,Y) is in the second quadrant, resulting in an angle between $\pi/2$ and π, while a point (X,$-$Y) is in the fourth quadrant, resulting in an angle between 0 and $-\pi/2$. A point ($-$X,$-$Y) is in the third quadrant, giving an angle between $-\pi/2$ and $-\pi$.

The following table shows the results obtained when computing the arctangent of various classes of numbers, assuming that underflow does not occur.

ST(1) \ ST(0)	$-\infty$	$-$F	-0	$+0$	+F	$+\infty$	NaN
$-\infty$	$-3\pi/4$*	$-\pi/2$	$-\pi/2$	$-\pi/2$	$-\pi/2$	$-\pi/4$*	NaN
$-$F	$-\pi$	$-\pi$ to $-\pi/2$	$-\pi/2$	$-\pi/2$	$-\pi/2$ to -0	-0	NaN
-0	$-\pi$	$-\pi$	$-\pi$*	-0*	-0	-0	NaN
$+0$	$+\pi$	$+\pi$	$+\pi$*	$+0$*	+0	+0	NaN
+F	$+\pi$	$+\pi$ to $+\pi/2$	$+\pi/2$	$+\pi/2$	$+\pi/2$ to +0	+0	NaN
$+\infty$	$+3\pi/4$*	$+\pi/2$	$+\pi/2$	$+\pi/2$	$+\pi/2$	$+\pi/4$*	NaN
NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

NOTES:

F Means finite-real number.

* Table 7-20 in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*, specifies that the ratios 0/0 and ∞/∞ generate the floating-point invalid arithmetic-operation exception and, if this exception is masked, the real indefinite value is returned. With the FPATAN instruction, the 0/0 or ∞/∞ value is actually not calculated using division. Instead, the arctangent of the two variables is derived from a common mathematical formulation that is generalized to allow complex numbers as arguments. In this complex variable formulation, arctangent(0,0) etc. has well defined values. These values are needed to develop a library to compute transcendental functions with complex arguments, based on the FPU functions that only allow real numbers as arguments.

There is no restriction on the range of source operands that FPATAN can accept.

FPATAN—Partial Arctangent (Continued)

Intel Architecture Compatibility

The source operands for this instruction are restricted for the 80287 math coprocessor to the following range:

$0 \leq |ST(1)| < |ST(0)| < +\infty$

Operation

```
ST(1) ← arctan(ST(1) / ST(0));
PopRegisterStack;
```

FPU Flags Affected

C1	Set to 0 if stack underflow occurred.
	Indicates rounding direction if the inexact-result exception (#P) is generated: 0 = not roundup; 1 = roundup.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Source operand is an sNaN value or unsupported format.
#D	Source operand is a denormal value.
#U	Result is too small for destination format.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FPREM—Partial Remainder

Opcode	Instruction	Description
D9 F8	FPREM	Replace ST(0) with the remainder obtained from dividing ST(0) by ST(1)

Description

This instruction computes the remainder obtained from dividing the value in the ST(0) register (the dividend) by the value in the ST(1) register (the divisor or **modulus**), and stores the result in ST(0). The remainder represents the following value:

Remainder = ST(0) – (Q ∗ ST(1))

Here, Q is an integer value that is obtained by truncating the real-number quotient of [ST(0) / ST(1)] toward zero. The sign of the remainder is the same as the sign of the dividend. The magnitude of the remainder is less than that of the modulus, unless a partial remainder was computed (as described below).

This instruction produces an exact result; the precision (inexact) exception does not occur and the rounding control has no effect. The following table shows the results obtained when computing the remainder of various classes of numbers, assuming that underflow does not occur.

		ST(1)						
		–∞	–F	–0	+0	+F	+∞	NaN
ST(0)	–∞	*	*	*	*	*	*	NaN
	–F	ST(0)	–F or –0	**	**	–F or –0	ST(0)	NaN
	–0	–0	–0	*	*	–0	–0	NaN
	+0	+0	+0	*	*	+0	+0	NaN
	+F	ST(0)	+F or +0	**	**	+F or +0	ST(0)	NaN
	+∞	*	*	*	*	*	*	NaN
	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

NOTES:

F Means finite-real number.

* Indicates floating-point invalid-arithmetic-operand (#IA) exception.

** Indicates floating-point zero-divide (#Z) exception.

When the result is 0, its sign is the same as that of the dividend. When the modulus is ∞, the result is equal to the value in ST(0).

FPREM—Partial Remainder (Continued)

The FPREM instruction gets its name “partial remainder” because of the way it computes the remainder. This instructions arrives at a remainder through iterative subtraction. It can, however, reduce the exponent of ST(0) by no more than 63 in one execution of the instruction. If the instruction succeeds in producing a remainder that is less than the modulus, the operation is complete and the C2 flag in the FPU status word is cleared. Otherwise, C2 is set, and the result in ST(0) is called the **partial remainder**. The exponent of the partial remainder will be less than the exponent of the original dividend by at least 32. Software can re-execute the instruction (using the partial remainder in ST(0) as the dividend) until C2 is cleared. (Note that while executing such a remainder-computation loop, a higher-priority interrupting routine that needs the FPU can force a context switch in-between the instructions in the loop.)

An important use of the FPREM instruction is to reduce the arguments of periodic functions. When reduction is complete, the instruction stores the three least-significant bits of the quotient in the C3, C1, and C0 flags of the FPU status word. This information is important in argument reduction for the tangent function (using a modulus of $\pi/4$), because it locates the original angle in the correct one of eight sectors of the unit circle.

Operation

```
D ← exponent(ST(0)) – exponent(ST(1));
IF D < 64
    THEN
        Q ← Integer(TruncateTowardZero(ST(0) / ST(1)));
        ST(0) ← ST(0) – (ST(1) * Q);
        C2 ← 0;
        C0, C3, C1 ← LeastSignificantBits(Q); (* Q2, Q1, Q0 *)
    ELSE
        C2 ← 1;
        N ← an implementation-dependent number between 32 and 63;
        QQ ← Integer(TruncateTowardZero((ST(0) / ST(1)) / 2^(D – N)));
        ST(0) ← ST(0) – (ST(1) * QQ * 2^(D – N));
FI;
```

FPU Flags Affected

C0	Set to bit 2 (Q2) of the quotient.
C1	Set to 0 if stack underflow occurred; otherwise, set to least significant bit of quotient (Q0).
C2	Set to 0 if reduction complete; set to 1 if incomplete.
C3	Set to bit 1 (Q1) of the quotient.

FPREM—Partial Remainder (Continued)

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Source operand is an sNaN value, modulus is 0, dividend is ∞, or unsupported format.
#D	Source operand is a denormal value.
#U	Result is too small for destination format.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FPREM1—Partial Remainder

Opcode	Instruction	Description
D9 F5	FPREM1	Replace ST(0) with the IEEE remainder obtained from dividing ST(0) by ST(1)

Description

This instruction computes the IEEE remainder obtained from dividing the value in the ST(0) register (the dividend) by the value in the ST(1) register (the divisor or **modulus**), and stores the result in ST(0). The remainder represents the following value:

Remainder = ST(0) – (Q ∗ ST(1))

Here, Q is an integer value that is obtained by rounding the real-number quotient of [ST(0) / ST(1)] toward the nearest integer value. The magnitude of the remainder is less than half the magnitude of the modulus, unless a partial remainder was computed (as described below).

This instruction produces an exact result; the precision (inexact) exception does not occur and the rounding control has no effect. The following table shows the results obtained when computing the remainder of various classes of numbers, assuming that underflow does not occur.

		ST(1)						
		–∞	–F	–0	+0	+F	+∞	NaN
ST(0)	–∞	*	*	*	*	*	*	NaN
	–F	ST(0)	±F or –0	**	**	±F or –0	ST(0)	NaN
	–0	–0	–0	*	*	–0	–0	NaN
	+0	+0	+0	*	*	+0	+0	NaN
	+F	ST(0)	±F or +0	**	**	±F or +0	ST(0)	NaN
	+∞	*	*	*	*	*	*	NaN
	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

NOTES:

F Means finite-real number.

* Indicates floating-point invalid-arithmetic-operand (#IA) exception.

** Indicates floating-point zero-divide (#Z) exception.

When the result is 0, its sign is the same as that of the dividend. When the modulus is ∞, the result is equal to the value in ST(0).

The FPREM1 instruction computes the remainder specified in IEEE Std 754. This instruction operates differently from the FPREM instruction in the way that it rounds the quotient of ST(0) divided by ST(1) to an integer (refer to the “Operation” section below).

FPREM1—Partial Remainder (Continued)

Like the FPREM instruction, the FPREM1 computes the remainder through iterative subtraction, but can reduce the exponent of ST(0) by no more than 63 in one execution of the instruction. If the instruction succeeds in producing a remainder that is less than one half the modulus, the operation is complete and the C2 flag in the FPU status word is cleared. Otherwise, C2 is set, and the result in ST(0) is called the **partial remainder**. The exponent of the partial remainder will be less than the exponent of the original dividend by at least 32. Software can re-execute the instruction (using the partial remainder in ST(0) as the dividend) until C2 is cleared. (Note that while executing such a remainder-computation loop, a higher-priority interrupting routine that needs the FPU can force a context switch in-between the instructions in the loop.)

An important use of the FPREM1 instruction is to reduce the arguments of periodic functions. When reduction is complete, the instruction stores the three least-significant bits of the quotient in the C3, C1, and C0 flags of the FPU status word. This information is important in argument reduction for the tangent function (using a modulus of $\pi/4$), because it locates the original angle in the correct one of eight sectors of the unit circle.

Operation

```
D ← exponent(ST(0)) – exponent(ST(1));
IF D < 64
    THEN
        Q ← Integer(RoundTowardNearestInteger(ST(0) / ST(1)));
        ST(0) ← ST(0) – (ST(1) ∗ Q);
        C2 ← 0;
        C0, C3, C1 ← LeastSignificantBits(Q); (* Q2, Q1, Q0 *)
    ELSE
        C2 ← 1;
        N ← an implementation-dependent number between 32 and 63;
        QQ ← Integer(TruncateTowardZero((ST(0) / ST(1)) / 2^(D – N)));
        ST(0) ← ST(0) – (ST(1) ∗ QQ ∗ 2^(D – N));
FI;
```

FPU Flags Affected

C0	Set to bit 2 (Q2) of the quotient.
C1	Set to 0 if stack underflow occurred; otherwise, set to least significant bit of quotient (Q0).
C2	Set to 0 if reduction complete; set to 1 if incomplete.
C3	Set to bit 1 (Q1) of the quotient.

FPREM1—Partial Remainder (Continued)

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Source operand is an sNaN value, modulus (divisor) is 0, dividend is ∞, or unsupported format.
#D	Source operand is a denormal value.
#U	Result is too small for destination format.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FPTAN—Partial Tangent

Opcode	Instruction	Clocks	Description
D9 F2	FPTAN	17-173	Replace ST(0) with its tangent and push 1 onto the FPU stack.

Description

This instruction computes the tangent of the source operand in register ST(0), stores the result in ST(0), and pushes a 1.0 onto the FPU register stack. The source operand must be given in radians and must be less than $\pm 2^{63}$. The following table shows the unmasked results obtained when computing the partial tangent of various classes of numbers, assuming that underflow does not occur.

ST(0) SRC	ST(0) DEST
–∞	*
–F	–F to +F
–0	–0
+0	+0
+F	–F to +F
+∞	*
NaN	NaN

NOTES:

F Means finite-real number.

* Indicates floating-point invalid-arithmetic-operand (#IA) exception.

If the source operand is outside the acceptable range, the C2 flag in the FPU status word is set, and the value in register ST(0) remains unchanged. The instruction does not raise an exception when the source operand is out of range. It is up to the program to check the C2 flag for out-of-range conditions. Source values outside the range -2^{63} to $+2^{63}$ can be reduced to the range of the instruction by subtracting an appropriate integer multiple of 2π or by using the FPREM instruction with a divisor of 2π. Refer to Section 7.5.8., *Pi* in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*, for a discussion of the proper value to use for π in performing such reductions.

The value 1.0 is pushed onto the register stack after the tangent has been computed to maintain compatibility with the Intel 8087 and Intel287 math coprocessors. This operation also simplifies the calculation of other trigonometric functions. For instance, the cotangent (which is the reciprocal of the tangent) can be computed by executing a FDIVR instruction after the FPTAN instruction.

FPTAN—Partial Tangent (Continued)

Operation

```
IF ST(0) < 2^63
THEN
    C2 ← 0;
    ST(0) ← tan(ST(0));
    TOP ← TOP – 1;
    ST(0) ← 1.0;
ELSE (*source operand is out-of-range *)
    C2 ← 1;
FI;
```

FPU Flags Affected

C1	Set to 0 if stack underflow occurred; set to 1 if stack overflow occurred. Indicates rounding direction if the inexact-result exception (#P) is generated: 0 = not roundup; 1 = roundup.
C2	Set to 1 if source operand is outside the range -2^{63} to $+2^{63}$; otherwise, cleared to 0.
C0, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Source operand is an sNaN value, ∞, or unsupported format.
#D	Source operand is a denormal value.
#U	Result is too small for destination format.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FRNDINT—Round to Integer

Opcode	Instruction	Description
D9 FC	FRNDINT	Round ST(0) to an integer.

Description

This instruction rounds the source value in the ST(0) register to the nearest integral value, depending on the current rounding mode (setting of the RC field of the FPU control word), and stores the result in ST(0).

If the source value is ∞, the value is not changed. If the source value is not an integral value, the floating-point inexact-result exception (#P) is generated.

Operation

```
ST(0) ← RoundToIntegralValue(ST(0));
```

FPU Flags Affected

C1	Set to 0 if stack underflow occurred.
	Indicates rounding direction if the inexact-result exception (#P) is generated: 0 = not roundup; 1 = roundup.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Source operand is an sNaN value or unsupported format.
#D	Source operand is a denormal value.
#P	Source operand is not an integral value.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FRSTOR—Restore FPU State

Opcode	Instruction	Description
DD /4	FRSTOR *m94/108byte*	Load FPU state from *m94byte* or *m108byte*.

Description

This instruction loads the FPU state (operating environment and register stack) from the memory area specified with the source operand. This state data is typically written to the specified memory location by a previous FSAVE/FNSAVE instruction.

The FPU operating environment consists of the FPU control word, status word, tag word, instruction pointer, data pointer, and last opcode. Figures 7-13 through Figure 7-16 in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*, show the layout in memory of the stored environment, depending on the operating mode of the processor (protected or real) and the current operand-size attribute (16-bit or 32-bit). In virtual-8086 mode, the real mode layouts are used. The contents of the FPU register stack are stored in the 80 bytes immediately follow the operating environment image.

The FRSTOR instruction should be executed in the same operating mode as the corresponding FSAVE/FNSAVE instruction.

Intel Architecture Compatibility

On a Pentium® III processor, the FRSTOR instruction operates the same as on a Pentium® II processor. It has no effect on the SIMD floating-point functional unit or control/status register, i.e., it does not restore the SIMD floating-point processor state.

Operation

```
FPUControlWord ← SRC(FPUControlWord);
FPUStatusWord ← SRC(FPUStatusWord);
FPUTagWord ← SRC(FPUTagWord);
FPUDataPointer ← SRC(FPUDataPointer);
FPUInstructionPointer ← SRC(FPUInstructionPointer);
FPULastInstructionOpcode ← SRC(FPULastInstructionOpcode);
ST(0) ← SRC(ST(0));
ST(1) ← SRC(ST(1));
ST(2) ← SRC(ST(2));
ST(3) ← SRC(ST(3));
ST(4) ← SRC(ST(4));
ST(5) ← SRC(ST(5));
ST(6) ← SRC(ST(6));
ST(7) ← SRC(ST(7));
```

FRSTOR—Restore FPU State (Continued)

FPU Flags Affected

The C0, C1, C2, C3 flags are loaded.

Floating-Point Exceptions

None; however, this operation might unmask an existing exception that has been detected but not generated, because it was masked. Here, the exception is generated at the completion of the instruction.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

FRSTOR—Restore FPU State (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

Comments

This instruction has no effect on the state of SIMD floating-point registers.

FSAVE/FNSAVE—Store FPU State

Opcode	Instruction	Description
9B DD /6	FSAVE *m94/108byte*	Store FPU state to *m94byte* or *m108byte* after checking for pending unmasked floating-point exceptions. Then re-initialize the FPU.
DD /6	FNSAVE* *m94/108byte*	Store FPU environment to *m94byte* or *m108byte* without checking for pending unmasked floating-point exceptions. Then re-initialize the FPU.

NOTE:

* Refer to “Intel Architecture Compatibility” below.

Description

These instructions store the current FPU state (operating environment and register stack) at the specified destination in memory, and then re-initializes the FPU. The FSAVE instruction checks for and handles pending unmasked floating-point exceptions before storing the FPU state; the FNSAVE instruction does not.

The FPU operating environment consists of the FPU control word, status word, tag word, instruction pointer, data pointer, and last opcode. Figures 7-13 through Figures 7-16 in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1* show the layout in memory of the stored environment, depending on the operating mode of the processor (protected or real) and the current operand-size attribute (16-bit or 32-bit). In virtual-8086 mode, the real mode layouts are used. The contents of the FPU register stack are stored in the 80 bytes immediately follow the operating environment image.

The saved image reflects the state of the FPU after all floating-point instructions preceding the FSAVE/FNSAVE instruction in the instruction stream have been executed.

After the FPU state has been saved, the FPU is reset to the same default values it is set to with the FINIT/FNINIT instructions (refer to “FINIT/FNINIT—Initialize Floating-Point Unit” in this chapter).

The FSAVE/FNSAVE instructions are typically used when the operating system needs to perform a context switch, an exception handler needs to use the FPU, or an application program needs to pass a “clean” FPU to a procedure.

Intel Architecture Compatibility

For Intel math coprocessors and FPUs prior to the Intel Pentium® processor, an FWAIT instruction should be executed before attempting to read from the memory image stored with a prior FSAVE/FNSAVE instruction. This FWAIT instruction helps insure that the storage operation has been completed.

On a Pentium® III processor, the FSAVE/FNSAVE instructions operate the same as on a Pentium® II processor. They have no effect on the Pentium® III processor SIMD floating-point functional unit or control/status register, i.e., they do not save the SIMD floating-point processor state.

FSAVE/FNSAVE—Store FPU State (Continued)

When operating a Pentium® or Intel486™ processor in MS-DOS compatibility mode, it is possible (under unusual circumstances) for an FNSAVE instruction to be interrupted prior to being executed to handle a pending FPU exception.

Refer to Section D.2.1.3., *No-Wait FPU Instructions Can Get FPU Interrupt in Window* in Appendix D, *Guidelines for Writing FPU and Streaming SIMD Extension Exception Handlers* of the *Intel Architecture Software Developer's Manual, Volume 1* for a description of these circumstances. An FNSAVE instruction cannot be interrupted in this way on a Pentium® Pro processor.

Operation

```
(* Save FPU State and Registers *)
DEST(FPUControlWord) ← FPUControlWord;
DEST(FPUStatusWord) ← FPUStatusWord;
DEST(FPUTagWord) ← FPUTagWord;
DEST(FPUDataPointer) ← FPUDataPointer;
DEST(FPUInstructionPointer) ← FPUInstructionPointer;
DEST(FPULastInstructionOpcode) ← FPULastInstructionOpcode;
DEST(ST(0)) ← ST(0);
DEST(ST(1)) ← ST(1);
DEST(ST(2)) ← ST(2);
DEST(ST(3)) ← ST(3);
DEST(ST(4)) ← ST(4);
DEST(ST(5)) ← ST(5);
DEST(ST(6)) ← ST(6);
DEST(ST(7)) ← ST(7);
(* Initialize FPU *)
FPUControlWord ← 037FH;
FPUStatusWord ← 0;
FPUTagWord ← FFFFH;
FPUDataPointer ← 0;
FPUInstructionPointer ← 0;
FPULastInstructionOpcode ← 0;
```

FPU Flags Affected

The C0, C1, C2, and C3 flags are saved and then cleared.

Floating-Point Exceptions

None.

FSAVE/FNSAVE—Store FPU State (Continued)

Protected Mode Exceptions

#GP(0)	If destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

Comments

This instruction has no effect on the state of SIMD floating-point registers.

FSCALE—Scale

Opcode	Instruction	Description
D9 FD	FSCALE	Scale ST(0) by ST(1).

Description

This instruction multiplies the destination operand by 2 to the power of the source operand and stores the result in the destination operand. The destination operand is a real value that is located in register ST(0). The source operand is the nearest integer value that is smaller than the value in the ST(1) register (that is, the value in register ST(1) is truncated toward 0 to its nearest integer value to form the source operand). This instruction provides rapid multiplication or division by integral powers of 2 because it is implemented by simply adding an integer value (the source operand) to the exponent of the value in register ST(0). The following table shows the results obtained when scaling various classes of numbers, assuming that neither overflow nor underflow occurs.

		ST(1)		
		–N	0	+N
ST(0)	–∞	–∞	–∞	–∞
	–F	–F	–F	–F
	–0	–0	–0	–0
	+0	+0	+0	+0
	+F	+F	+F	+F
	+∞	+∞	+∞	+∞
	NaN	NaN	NaN	NaN

NOTES:

F Means finite-real number.

N Means integer.

In most cases, only the exponent is changed and the mantissa (significand) remains unchanged. However, when the value being scaled in ST(0) is a denormal value, the mantissa is also changed and the result may turn out to be a normalized number. Similarly, if overflow or underflow results from a scale operation, the resulting mantissa will differ from the source's mantissa.

The FSCALE instruction can also be used to reverse the action of the FXTRACT instruction, as shown in the following example:

```
FXTRACT;
FSCALE;
FSTP ST(1);
```

FSCALE—Scale (Continued)

In this example, the FXTRACT instruction extracts the significand and exponent from the value in ST(0) and stores them in ST(0) and ST(1) respectively. The FSCALE then scales the significand in ST(0) by the exponent in ST(1), recreating the original value before the FXTRACT operation was performed. The FSTP ST(1) instruction overwrites the exponent (extracted by the FXTRACT instruction) with the recreated value, which returns the stack to its original state with only one register [ST(0)] occupied.

Operation

$ST(0) \leftarrow ST(0) * 2^{ST(1)}$;

FPU Flags Affected

C1	Set to 0 if stack underflow occurred.
	Indicates rounding direction if the inexact-result exception (#P) is generated: 0 = not roundup; 1 = roundup.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Source operand is an sNaN value or unsupported format.
#D	Source operand is a denormal value.
#U	Result is too small for destination format.
#O	Result is too large for destination format.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FSIN—Sine

Opcode	Instruction	Description
D9 FE	FSIN	Replace ST(0) with its sine.

Description

This instruction calculates the sine of the source operand in register ST(0) and stores the result in ST(0). The source operand must be given in radians and must be within the range -2^{63} to $+2^{63}$. The following table shows the results obtained when taking the sine of various classes of numbers, assuming that underflow does not occur.

SRC (ST(0))	DEST (ST(0))
–∞	*
–F	–1 to +1
–0	–0
+0	+0
+F	–1 to +1
+∞	*
NaN	NaN

NOTES:

F Means finite-real number.

* Indicates floating-point invalid-arithmetic-operand (#IA) exception.

If the source operand is outside the acceptable range, the C2 flag in the FPU status word is set, and the value in register ST(0) remains unchanged. The instruction does not raise an exception when the source operand is out of range. It is up to the program to check the C2 flag for out-of-range conditions. Source values outside the range -2^{63} to $+2^{63}$ can be reduced to the range of the instruction by subtracting an appropriate integer multiple of 2π or by using the FPREM instruction with a divisor of 2π. Refer to Section 7.5.8., *Pi* in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*, for a discussion of the proper value to use for π in performing such reductions.

Operation

```
IF ST(0) < 2^63
THEN
    C2 ← 0;
    ST(0) ← sin(ST(0));
ELSE (* source operand out of range *)
    C2 ← 1;
FI:
```

FSIN—Sine (Continued)

FPU Flags Affected

C1	Set to 0 if stack underflow occurred. Indicates rounding direction if the inexact-result exception (#P) is generated: 0 = not roundup; 1 = roundup.
C2	Set to 1 if source operand is outside the range -2^{63} to $+2^{63}$; otherwise, cleared to 0.
C0, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Source operand is an sNaN value, ∞, or unsupported format.
#D	Source operand is a denormal value.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FSINCOS—Sine and Cosine

Opcode	Instruction	Description
D9 FB	FSINCOS	Compute the sine and cosine of ST(0); replace ST(0) with the sine, and push the cosine onto the register stack.

Description

This instruction computes both the sine and the cosine of the source operand in register ST(0), stores the sine in ST(0), and pushes the cosine onto the top of the FPU register stack. (This instruction is faster than executing the FSIN and FCOS instructions in succession.)

The source operand must be given in radians and must be within the range -2^{63} to $+2^{63}$. The following table shows the results obtained when taking the sine and cosine of various classes of numbers, assuming that underflow does not occur.

SRC	DEST	
ST(0)	ST(1) Cosine	ST(0) Sine
–∞	*	*
–F	–1 to +1	–1 to +1
–0	+1	–0
+0	+1	+0
+F	–1 to +1	–1 to +1
+∞	*	*
NaN	NaN	NaN

NOTES:

F Means finite-real number.

* Indicates floating-point invalid-arithmetic-operand (#IA) exception.

If the source operand is outside the acceptable range, the C2 flag in the FPU status word is set, and the value in register ST(0) remains unchanged. The instruction does not raise an exception when the source operand is out of range. It is up to the program to check the C2 flag for out-of-range conditions. Source values outside the range -2^{63} to $+2^{63}$ can be reduced to the range of the instruction by subtracting an appropriate integer multiple of 2π or by using the FPREM instruction with a divisor of 2π. Refer to Section 7.5.8., *Pi* in Chapter 7.5.8., *Pi* of the *Intel Architecture Software Developer's Manual, Volume 1*, for a discussion of the proper value to use for π in performing such reductions.

FSINCOS—Sine and Cosine (Continued)

Operation

```
IF ST(0) < 2^63
THEN
    C2 ← 0;
    TEMP ← cosine(ST(0));
    ST(0) ← sine(ST(0));

    TOP ← TOP – 1;
    ST(0) ← TEMP;
ELSE (* source operand out of range *)
    C2 ← 1;
FI:
```

FPU Flags Affected

C1	Set to 0 if stack underflow occurred; set to 1 of stack overflow occurs. Indicates rounding direction if the exception (#P) is generated: 0 = not roundup; 1 = roundup.
C2	Set to 1 if source operand is outside the range -2^{63} to $+2^{63}$; otherwise, cleared to 0.
C0, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Source operand is an sNaN value, ∞, or unsupported format.
#D	Source operand is a denormal value.
#U	Result is too small for destination format.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FSQRT—Square Root

Opcode	Instruction	Description
D9 FA	FSQRT	Calculates square root of ST(0) and stores the result in ST(0)

Description

This instruction calculates the square root of the source value in the ST(0) register and stores the result in ST(0).

The following table shows the results obtained when taking the square root of various classes of numbers, assuming that neither overflow nor underflow occurs.

SRC (ST(0))	DEST (ST(0))
–∞	*
–F	*
–0	–0
+0	+0
+F	+F
+∞	+∞
NaN	NaN

NOTES:

F Means finite-real number.

* Indicates floating-point invalid-arithmetic-operand (#IA) exception.

Operation

ST(0) ← SquareRoot(ST(0));

FPU Flags Affected

C1 — Set to 0 if stack underflow occurred.

Indicates rounding direction if inexact-result exception (#P) is generated: 0 = not roundup; 1 = roundup.

C0, C2, C3 — Undefined.

FSQRT—Square Root (Continued)

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Source operand is an sNaN value or unsupported format.
	Source operand is a negative value (except for –0).
#D	Source operand is a denormal value.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FST/FSTP—Store Real

Opcode	Instruction	Description
D9 /2	FST *m32real*	Copy ST(0) to *m32real*
DD /2	FST *m64real*	Copy ST(0) to *m64real*
DD D0+i	FST ST(i)	Copy ST(0) to ST(i)
D9 /3	FSTP *m32real*	Copy ST(0) to *m32real* and pop register stack
DD /3	FSTP *m64real*	Copy ST(0) to *m64real* and pop register stack
DB /7	FSTP *m80real*	Copy ST(0) to *m80real* and pop register stack
DD D8+i	FSTP ST(i)	Copy ST(0) to ST(i) and pop register stack

Description

The FST instruction copies the value in the ST(0) register to the destination operand, which can be a memory location or another register in the FPU register stack. When storing the value in memory, the value is converted to single- or double-real format.

The FSTP instruction performs the same operation as the FST instruction and then pops the register stack. To pop the register stack, the processor marks the ST(0) register as empty and increments the stack pointer (TOP) by 1. The FSTP instruction can also store values in memory in extended-real format.

If the destination operand is a memory location, the operand specifies the address where the first byte of the destination value is to be stored. If the destination operand is a register, the operand specifies a register in the register stack relative to the top of the stack.

If the destination size is single- or double-real, the significand of the value being stored is rounded to the width of the destination (according to rounding mode specified by the RC field of the FPU control word), and the exponent is converted to the width and bias of the destination format. If the value being stored is too large for the destination format, a numeric overflow exception (#O) is generated and, if the exception is unmasked, no value is stored in the destination operand. If the value being stored is a denormal value, the denormal exception (#D) is not generated. This condition is simply signalled as a numeric underflow exception (#U) condition.

If the value being stored is ±0, ±∞, or a NaN, the least-significant bits of the significand and the exponent are truncated to fit the destination format. This operation preserves the value's identity as a 0, ∞, or NaN.

If the destination operand is a non-empty register, the invalid-operation exception is not generated.

Operation

```
DEST ← ST(0);
IF instruction = FSTP
    THEN
        PopRegisterStack;
FI;
```

FST/FSTP—Store Real (Continued)

FPU Flags Affected

C1	Set to 0 if stack underflow occurred.
	Indicates rounding direction of if the floating-point inexact exception (#P) is generated: 0 = not roundup; 1 = roundup.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Source operand is an sNaN value or unsupported format.
#U	Result is too small for the destination format.
#O	Result is too large for the destination format.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

FST/FSTP—Store Real (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FSTCW/FNSTCW—Store Control Word

Opcode	Instruction	Description
9B D9 /7	FSTCW *m2byte*	Store FPU control word to *m2byte* after checking for pending unmasked floating-point exceptions.
D9 /7	FNSTCW* *m2byte*	Store FPU control word to *m2byte* without checking for pending unmasked floating-point exceptions.

NOTE:

* Refer to “Intel Architecture Compatibility” below.

Description

These instructions store the current value of the FPU control word at the specified destination in memory. The FSTCW instruction checks for and handles pending unmasked floating-point exceptions before storing the control word; the FNSTCW instruction does not.

Intel Architecture Compatibility

When operating a Pentium® or Intel486™ processor in MS-DOS compatibility mode, it is possible (under unusual circumstances) for an FNSTCW instruction to be interrupted prior to being executed to handle a pending FPU exception. Refer to Section D.2.1.3., *No-Wait FPU Instructions Can Get FPU Interrupt in Window* in Appendix D, *Guidelines for Writing FPU and Streaming SIMD Extension Exception Handlers* of the *Intel Architecture Software Developer's Manual, Volume 1*, for a description of these circumstances. An FNSTCW instruction cannot be interrupted in this way on a Pentium® Pro processor.

On a Pentium® III processor, the FSTCW/FNSTCW instructions operate the same as on a Pentium® II processor. They have no effect on the Pentium® III processor SIMD floating-point functional unit or control/status register.

Operation

```
DEST ← FPUControlWord;
```

FPU Flags Affected

The C0, C1, C2, and C3 flags are undefined.

Floating-Point Exceptions

None.

FSTCW/FNSTCW—Store Control Word (Continued)

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FSTENV/FNSTENV—Store FPU Environment

Opcode	Instruction	Description
9B D9 /6	FSTENV *m14/28byte*	Store FPU environment to *m14byte* or *m28byte* after checking for pending unmasked floating-point exceptions. Then mask all floating-point exceptions.
D9 /6	FNSTENV* *m14/28byte*	Store FPU environment to *m14byte* or *m28byte* without checking for pending unmasked floating-point exceptions. Then mask all floating-point exceptions.

NOTE:

* Refer to “Intel Architecture Compatibility” below.

Description

These instructions save the current FPU operating environment at the memory location specified with the destination operand, and then masks all floating-point exceptions. The FPU operating environment consists of the FPU control word, status word, tag word, instruction pointer, data pointer, and last opcode. Figures 7-13 through Figure 7-16 in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer’s Manual, Volume 1* show the layout in memory of the stored environment, depending on the operating mode of the processor (protected or real) and the current operand-size attribute (16-bit or 32-bit). In virtual-8086 mode, the real mode layouts are used.

The FSTENV instruction checks for and handles any pending unmasked floating-point exceptions before storing the FPU environment; the FNSTENV instruction does not.The saved image reflects the state of the FPU after all floating-point instructions preceding the FSTENV/FNSTENV instruction in the instruction stream have been executed.

These instructions are often used by exception handlers because they provide access to the FPU instruction and data pointers. The environment is typically saved in the stack. Masking all exceptions after saving the environment prevents floating-point exceptions from interrupting the exception handler.

Intel Architecture Compatibility

When operating a Pentium® or Intel486™ processor in MS-DOS compatibility mode, it is possible (under unusual circumstances) for an FNSTENV instruction to be interrupted prior to being executed to handle a pending FPU exception. Refer to Section D.2.1.3., *No-Wait FPU Instructions Can Get FPU Interrupt in Window* in Appendix D, *Guidelines for Writing FPU and Streaming SIMD Extension Exception Handlers* of the *Intel Architecture Software Developer’s Manual, Volume 1*, for a description of these circumstances. An FNSTENV instruction cannot be interrupted in this way on a Pentium® Pro processor.

On a Pentium® III processor, the FSTENV/FNSTENV instructions operate the same as on a Pentium® II processor. They have no effect on the Pentium® III processor SIMD floating-point functional unit or control/status register.

FSTENV/FNSTENV—Store FPU Environment (Continued)

Operation

```
DEST(FPUControlWord) ← FPUControlWord;
DEST(FPUStatusWord) ← FPUStatusWord;
DEST(FPUTagWord) ← FPUTagWord;
DEST(FPUDataPointer) ← FPUDataPointer;
DEST(FPUInstructionPointer) ← FPUInstructionPointer;
DEST(FPULastInstructionOpcode) ← FPULastInstructionOpcode;
```

FPU Flags Affected

The C0, C1, C2, and C3 are undefined.

Floating-Point Exceptions

None.

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

FSTENV/FNSTENV—Store FPU Environment (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FSTSW/FNSTSW—Store Status Word

Opcode	Instruction	Description
9B DD /7	FSTSW *m2byte*	Store FPU status word at *m2byte* after checking for pending unmasked floating-point exceptions.
9B DF E0	FSTSW AX	Store FPU status word in AX register after checking for pending unmasked floating-point exceptions.
DD /7	FNSTSW* *m2byte*	Store FPU status word at *m2byte* without checking for pending unmasked floating-point exceptions.
DF E0	FNSTSW* AX	Store FPU status word in AX register without checking for pending unmasked floating-point exceptions.

NOTE:

* Refer to “Intel Architecture Compatibility” below.

Description

These instructions store the current value of the FPU status word in the destination location. The destination operand can be either a two-byte memory location or the AX register. The FSTSW instruction checks for and handles pending unmasked floating-point exceptions before storing the status word; the FNSTSW instruction does not.

The FNSTSW AX form of the instruction is used primarily in conditional branching (for instance, after an FPU comparison instruction or an FPREM, FPREM1, or FXAM instruction), where the direction of the branch depends on the state of the FPU condition code flags. Refer to Section 7.3.3., *Branching and Conditional Moves on FPU Condition Codes* in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*. This instruction can also be used to invoke exception handlers (by examining the exception flags) in environments that do not use interrupts. When the FNSTSW AX instruction is executed, the AX register is updated before the processor executes any further instructions. The status stored in the AX register is thus guaranteed to be from the completion of the prior FPU instruction.

Intel Architecture Compatibility

When operating a Pentium® or Intel486™ processor in MS-DOS compatibility mode, it is possible (under unusual circumstances) for an FNSTSW instruction to be interrupted prior to being executed to handle a pending FPU exception. Refer to Section D.2.1.3., *No-Wait FPU Instructions Can Get FPU Interrupt in Window* in Appendix D, *Guidelines for Writing FPU and Streaming SIMD Extension Exception Handlers* of the *Intel Architecture Software Developer's Manual, Volume 1*, for a description of these circumstances. An FNSTSW instruction cannot be interrupted in this way on a Pentium® Pro processor.

On a Pentium® III processor, the FSTSW/FNSTSW instructions operate the same as on a Pentium® II processor. They have no effect on the Pentium® III processor SIMD floating-point functional unit or control/status register.

FSTSW/FNSTSW—Store Status Word (Continued)

Operation

```
DEST ← FPUStatusWord;
```

FPU Flags Affected

The C0, C1, C2, and C3 are undefined.

Floating-Point Exceptions

None.

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

FSTSW/FNSTSW—Store Status Word (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FSUB/FSUBP/FISUB—Subtract

Opcode	Instruction	Description
D8 /4	FSUB *m32real*	Subtract *m32real* from ST(0) and store result in ST(0)
DC /4	FSUB *m64real*	Subtract *m64real* from ST(0) and store result in ST(0)
D8 E0+i	FSUB ST(0), ST(i)	Subtract ST(i) from ST(0) and store result in ST(0)
DC E8+i	FSUB ST(i), ST(0)	Subtract ST(0) from ST(i) and store result in ST(i)
DE E8+i	FSUBP ST(i), ST(0)	Subtract ST(0) from ST(i), store result in ST(i), and pop register stack
DE E9	FSUBP	Subtract ST(0) from ST(1), store result in ST(1), and pop register stack
DA /4	FISUB *m32int*	Subtract *m32int* from ST(0) and store result in ST(0)
DE /4	FISUB *m16int*	Subtract *m16int* from ST(0) and store result in ST(0)

Description

These instructions subtract the source operand from the destination operand and stores the difference in the destination location. The destination operand is always an FPU data register; the source operand can be a register or a memory location. Source operands in memory can be in single-real, double-real, word-integer, or short-integer formats.

The no-operand version of the instruction subtracts the contents of the ST(0) register from the ST(1) register and stores the result in ST(1). The one-operand version subtracts the contents of a memory location (either a real or an integer value) from the contents of the ST(0) register and stores the result in ST(0). The two-operand version, subtracts the contents of the ST(0) register from the ST(i) register or vice versa.

The FSUBP instructions perform the additional operation of popping the FPU register stack following the subtraction. To pop the register stack, the processor marks the ST(0) register as empty and increments the stack pointer (TOP) by 1. The no-operand version of the floating-point subtract instructions always results in the register stack being popped. In some assemblers, the mnemonic for this instruction is FSUB rather than FSUBP.

The FISUB instructions convert an integer source operand to extended-real format before performing the subtraction.

The following table shows the results obtained when subtracting various classes of numbers from one another, assuming that neither overflow nor underflow occurs. Here, the SRC value is subtracted from the DEST value (DEST − SRC = result).

When the difference between two operands of like sign is 0, the result is +0, except for the round toward −∞ mode, in which case the result is −0. This instruction also guarantees that +0 − (−0) = +0, and that −0 − (+0) = −0. When the source operand is an integer 0, it is treated as a +0.

When one operand is ∞, the result is ∞ of the expected sign. If both operands are ∞ of the same sign, an invalid-operation exception is generated.

FSUB/FSUBP/FISUB—Subtract (Continued)

DEST \ SRC	–∞	–F or –I	–0	+0	+F or +I	+∞	NaN
–∞	*	–∞	–∞	–∞	–∞	–∞	NaN
–F	+∞	±F or ±0	DEST	DEST	–F	–∞	NaN
–0	+∞	–SRC	±0	–0	–SRC	–∞	NaN
+0	+∞	–SRC	+0	±0	–SRC	–∞	NaN
+F	+∞	+F	DEST	DEST	±F or ±0	–∞	NaN
+∞	+∞	+∞	+∞	+∞	+∞	*	NaN
NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

NOTES:

F Means finite-real number.

I Means integer.

* Indicates floating-point invalid-arithmetic-operand (#IA) exception.

Operation

```
IF instruction is FISUB
    THEN
        DEST ← DEST – ConvertExtendedReal(SRC);
    ELSE (* source operand is real number *)
        DEST ← DEST – SRC;
FI;
IF instruction is FSUBP
    THEN
        PopRegisterStack
FI;
```

FPU Flags Affected

C1	Set to 0 if stack underflow occurred. Indicates rounding direction if the inexact-result exception (#P) fault is generated: 0 = not roundup; 1 = roundup.
C0, C2, C3	Undefined.

FSUB/FSUBP/FISUB—Subtract (Continued)

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Operand is an sNaN value or unsupported format.
	Operands are infinities of like sign.
#D	Source operand is a denormal value.
#U	Result is too small for destination format.
#O	Result is too large for destination format.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

FSUB/FSUBP/FISUB—Subtract (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FSUBR/FSUBRP/FISUBR—Reverse Subtract

Opcode	Instruction	Description
D8 /5	FSUBR *m32real*	Subtract ST(0) from *m32real* and store result in ST(0)
DC /5	FSUBR *m64real*	Subtract ST(0) from *m64real* and store result in ST(0)
D8 E8+i	FSUBR ST(0), ST(i)	Subtract ST(0) from ST(i) and store result in ST(0)
DC E0+i	FSUBR ST(i), ST(0)	Subtract ST(i) from ST(0) and store result in ST(i)
DE E0+i	FSUBRP ST(i), ST(0)	Subtract ST(i) from ST(0), store result in ST(i), and pop register stack
DE E1	FSUBRP	Subtract ST(1) from ST(0), store result in ST(1), and pop register stack
DA /5	FISUBR *m32int*	Subtract ST(0) from *m32int* and store result in ST(0)
DE /5	FISUBR *m16int*	Subtract ST(0) from *m16int* and store result in ST(0)

Description

These instructions subtract the destination operand from the source operand and stores the difference in the destination location. The destination operand is always an FPU register; the source operand can be a register or a memory location. Source operands in memory can be in single-real, double-real, word-integer, or short-integer formats.

These instructions perform the reverse operations of the FSUB, FSUBP, and FISUB instructions. They are provided to support more efficient coding.

The no-operand version of the instruction subtracts the contents of the ST(1) register from the ST(0) register and stores the result in ST(1). The one-operand version subtracts the contents of the ST(0) register from the contents of a memory location (either a real or an integer value) and stores the result in ST(0). The two-operand version, subtracts the contents of the ST(i) register from the ST(0) register or vice versa.

The FSUBRP instructions perform the additional operation of popping the FPU register stack following the subtraction. To pop the register stack, the processor marks the ST(0) register as empty and increments the stack pointer (TOP) by 1. The no-operand version of the floating-point reverse subtract instructions always results in the register stack being popped. In some assemblers, the mnemonic for this instruction is FSUBR rather than FSUBRP.

The FISUBR instructions convert an integer source operand to extended-real format before performing the subtraction.

The following table shows the results obtained when subtracting various classes of numbers from one another, assuming that neither overflow nor underflow occurs. Here, the DEST value is subtracted from the SRC value (SRC – DEST = result).

When the difference between two operands of like sign is 0, the result is +0, except for the round toward –∞ mode, in which case the result is –0. This instruction also guarantees that +0 – (–0) = +0, and that –0 – (+0) = –0. When the source operand is an integer 0, it is treated as a +0.

When one operand is ∞, the result is ∞ of the expected sign. If both operands are ∞ of the same sign, an invalid-operation exception is generated.

FSUBR/FSUBRP/FISUBR—Reverse Subtract (Continued)

DEST \ SRC	–∞	–F or –I	–0	+0	+F or +I	+∞	NaN
–∞	*	+∞	+∞	+∞	+∞	+∞	NaN
–F	–∞	±F or ±0	–DEST	–DEST	+F	+∞	NaN
–0	–∞	SRC	±0	+0	SRC	+∞	NaN
+0	–∞	SRC	–0	±0	SRC	+∞	NaN
+F	–∞	–F	–DEST	–DEST	±F or ±0	+∞	NaN
+∞	–∞	–∞	–∞	–∞	–∞	*	NaN
NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

NOTES:

F Means finite-real number.

I Means integer.

* Indicates floating-point invalid-arithmetic-operand (#IA) exception.

Operation

```
IF instruction is FISUBR
    THEN
        DEST ← ConvertExtendedReal(SRC) – DEST;
    ELSE (* source operand is real number *)
        DEST ← SRC – DEST;
FI;
IF instruction = FSUBRP
    THEN
        PopRegisterStack
FI;
```

FPU Flags Affected

C1	Set to 0 if stack underflow occurred. Indicates rounding direction if the inexact-result exception (#P) fault is generated: 0 = not roundup; 1 = roundup.
C0, C2, C3	Undefined.

FSUBR/FSUBRP/FISUBR—Reverse Subtract (Continued)

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Operand is an sNaN value or unsupported format.
	Operands are infinities of like sign.
#D	Source operand is a denormal value.
#U	Result is too small for destination format.
#O	Result is too large for destination format.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.

FSUBR/FSUBRP/FISUBR—Reverse Subtract (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NM	EM or TS in CR0 is set.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

FTST—TEST

Opcode	Instruction	Description
D9 E4	FTST	Compare ST(0) with 0.0.

Description

This instruction compares the value in the ST(0) register with 0.0 and sets the condition code flags C0, C2, and C3 in the FPU status word according to the results (refer to the table below).

Condition	C3	C2	C0
ST(0) > 0.0	0	0	0
ST(0) < 0.0	0	0	1
ST(0) = 0.0	1	0	0
Unordered	1	1	1

This instruction performs an "unordered comparison." An unordered comparison also checks the class of the numbers being compared (refer to "FXAM—Examine" in this chapter). If the value in register ST(0) is a NaN or is in an undefined format, the condition flags are set to "unordered" and the invalid operation exception is generated.

The sign of zero is ignored, so that –0.0 = +0.0.

Operation

```
CASE (relation of operands) OF
    Not comparable:  C3, C2, C0 ← 111;
    ST(0) > 0.0:     C3, C2, C0 ← 000;
    ST(0) < 0.0:     C3, C2, C0 ← 001;
    ST(0) = 0.0:     C3, C2, C0 ← 100;
ESAC;
```

FPU Flags Affected

C1	Set to 0 if stack underflow occurred; otherwise, cleared to 0.
C0, C2, C3	Refer to above table.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	The source operand is a NaN value or is in an unsupported format.
#D	The source operand is a denormal value.

FTST—TEST (Continued)

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FUCOM/FUCOMP/FUCOMPP—Unordered Compare Real

Opcode	Instruction	Description
DD E0+i	FUCOM ST(i)	Compare ST(0) with ST(i)
DD E1	FUCOM	Compare ST(0) with ST(1)
DD E8+i	FUCOMP ST(i)	Compare ST(0) with ST(i) and pop register stack
DD E9	FUCOMP	Compare ST(0) with ST(1) and pop register stack
DA E9	FUCOMPP	Compare ST(0) with ST(1) and pop register stack twice

Description

These instructions perform an unordered comparison of the contents of register ST(0) and ST(i) and sets condition code flags C0, C2, and C3 in the FPU status word according to the results (refer to the table below). If no operand is specified, the contents of registers ST(0) and ST(1) are compared. The sign of zero is ignored, so that –0.0 = +0.0.

Comparison Results	C3	C2	C0
ST0 > ST(i)	0	0	0
ST0 < ST(i)	0	0	1
ST0 = ST(i)	1	0	0
Unordered	1	1	1

NOTE:

* Flags not set if unmasked invalid-arithmetic-operand (#IA) exception is generated.

An unordered comparison checks the class of the numbers being compared (refer to "FXAM—Examine" in this chapter). The FUCOM instructions perform the same operations as the FCOM instructions. The only difference is that the FUCOM instructions raise the invalid-arithmetic-operand exception (#IA) only when either or both operands are an sNaN or are in an unsupported format; qNaNs cause the condition code flags to be set to unordered, but do not cause an exception to be generated. The FCOM instructions raise an invalid-operation exception when either or both of the operands are a NaN value of any kind or are in an unsupported format.

As with the FCOM instructions, if the operation results in an invalid-arithmetic-operand exception being raised, the condition code flags are set only if the exception is masked.

The FUCOMP instruction pops the register stack following the comparison operation and the FUCOMPP instruction pops the register stack twice following the comparison operation. To pop the register stack, the processor marks the ST(0) register as empty and increments the stack pointer (TOP) by 1.

FUCOM/FUCOMP/FUCOMPP—Unordered Compare Real (Continued)

Operation

```
CASE (relation of operands) OF
    ST > SRC:       C3, C2, C0 ← 000;
    ST < SRC:       C3, C2, C0 ← 001;
    ST = SRC:       C3, C2, C0 ← 100;
ESAC;
IF ST(0) or SRC = QNaN, but not SNaN or unsupported format
    THEN
        C3, C2, C0 ← 111;
    ELSE (* ST(0) or SRC is SNaN or unsupported format *)
         #IA;
        IF FPUControlWord.IM = 1
            THEN
                C3, C2, C0 ← 111;
        FI;
FI;
IF instruction = FUCOMP
    THEN
        PopRegisterStack;
FI;
IF instruction = FUCOMPP
    THEN
        PopRegisterStack;
        PopRegisterStack;
FI;
```

FPU Flags Affected

C1	Set to 0 if stack underflow occurred.
C0, C2, C3	Refer to table on previous page.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	One or both operands are sNaN values or have unsupported formats. Detection of a qNaN value in and of itself does not raise an invalid-operand exception.
#D	One or both operands are denormal values.

FUCOM/FUCOMP/FUCOMPP—Unordered Compare Real (Continued)

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FWAIT—Wait

Refer to entry for WAIT/FWAIT—Wait.

FXAM—Examine

Opcode	Instruction	Description
D9 E5	FXAM	Classify value or number in ST(0)

Description

This instruction examines the contents of the ST(0) register and sets the condition code flags C0, C2, and C3 in the FPU status word to indicate the class of value or number in the register (refer to the table below).

Class	C3	C2	C0
Unsupported	0	0	0
NaN	0	0	1
Normal finite number	0	1	0
Infinity	0	1	1
Zero	1	0	0
Empty	1	0	1
Denormal number	1	1	0

The C1 flag is set to the sign of the value in ST(0), regardless of whether the register is empty or full.

Operation

```
C1 ← sign bit of ST; (* 0 for positive, 1 for negative *)
CASE (class of value or number in ST(0)) OF
    Unsupported:C3, C2, C0 ← 000;
    NaN:        C3, C2, C0 ← 001;
    Normal:     C3, C2, C0 ← 010;
    Infinity:   C3, C2, C0 ← 011;
    Zero:       C3, C2, C0 ← 100;
    Empty:      C3, C2, C0 ← 101;
    Denormal:   C3, C2, C0 ← 110;
ESAC;
```

FPU Flags Affected

C1	Sign of value in ST(0).
C0, C2, C3	Refer to table above.

FXAM—Examine (Continued)

Floating-Point Exceptions

None.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FXCH—Exchange Register Contents

Opcode	Instruction	Description
D9 C8+i	FXCH ST(i)	Exchange the contents of ST(0) and ST(i)
D9 C9	FXCH	Exchange the contents of ST(0) and ST(1)

Description

This instruction exchanges the contents of registers ST(0) and ST(i). If no source operand is specified, the contents of ST(0) and ST(1) are exchanged.

This instruction provides a simple means of moving values in the FPU register stack to the top of the stack [ST(0)], so that they can be operated on by those floating-point instructions that can only operate on values in ST(0). For example, the following instruction sequence takes the square root of the third register from the top of the register stack:

```
FXCH ST(3);
FSQRT;
FXCH ST(3);
```

Operation

```
IF number-of-operands is 1
    THEN
        temp ← ST(0);
        ST(0) ← SRC;
        SRC ← temp;
    ELSE
        temp ← ST(0);
        ST(0) ← ST(1);
        ST(1) ← temp;
```

FPU Flags Affected

C1	Set to 0 if stack underflow occurred; otherwise, cleared to 0.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

FXCH—Exchange Register Contents (Continued)

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FXRSTOR—Restore FP and MMX™ State and Streaming SIMD Extension State

Opcode	Instruction	Description
0F,AE,/1	FXRSTOR m512byte	Load FP and MMX™ technology and Streaming SIMD Extension state from m512byte.

Description

The FXRSTOR instruction reloads the FP and MMX™ technology state, and the Streaming SIMD Extension state (environment and registers), from the memory area defined by m512byte. This data should have been written by a previous FXSAVE.

The floating-point, MMX™ technology, and Streaming SIMD Extension environment and registers consist of the following data structure (little-endian byte order as arranged in memory, with byte offset into row described by right column):

FXRSTOR—Restore FP And MMX™ State and Streaming SIMD Extension State (Continued)

15 14	13 12	11 10 9 8	7 6	5 4	3 2	1 0	
Rsrvd	CS	IP	FOP	FTW	FSW	FCW	**0**
Reserved		MXCSR	Rsrvd	DS	DP		**16**
Reserved		ST0/MM0					**32**
Reserved		ST1/MM1					**48**
Reserved		ST2/MM2					**64**
Reserved		ST3/MM3					**80**
Reserved		ST4/MM4					**96**
Reserved		ST5/MM5					**112**
Reserved		ST6/MM6					**128**
Reserved		ST7/MM7					**144**
XMM0							**160**
XMM1							**176**
XMM2							**192**
XMM3							**208**
XMM4							**224**
XMM5							**240**
XMM6							**256**
XMM7							**272**
Reserved							**288**
Reserved							**304**
Reserved							**320**
Reserved							**336**
Reserved							**352**
Reserved							**368**
Reserved							**384**
Reserved							**400**
Reserved							**416**
Reserved							**432**
Reserved							**448**
Reserved							**464**
Reserved							**480**
Reserved							**496**

FXRSTOR—Restore FP And MMX™ State And Streaming SIMD Extension State (Continued)

Three fields in the floating-point save area contain reserved bits that are not indicated in the table:

FOP — The lower 11-bits contain the opcode, upper 5-bits are reserved.

IP & DP — 32-bit mode: 32-bit IP-offset.

16-bit mode: lower 16 bits are IP-offset and upper 16 bits are reserved.

If the MXCSR state contains an unmasked exception with a corresponding status flag also set, loading it will not result in a floating-point error condition being asserted. Only the next occurrence of this unmasked exception will result in the error condition being asserted.

Some bits of MXCSR (bits 31-16 and bit 6) are defined as reserved and cleared; attempting to write a non-zero value to these bits will result in a general protection exception.

FXRSTOR does not flush pending x87-FP exceptions, unlike FRSTOR. To check and raise exceptions when loading a new operating environment, use FWAIT after FXRSTOR.

The Streaming SIMD Extension fields in the save image (XMM0-XMM7 and MXCSR) will not be loaded into the processor if the CR4.OSFXSR bit is not set. This CR4 bit must be set in order to enable execution of Streaming SIMD Extension.

Operation

```
FP and MMX™ technology state and Streaming SIMD Extension state = m512byte;
```

Exceptions

#AC — If exception detection is disabled, a general protection exception is signalled if the address is not aligned on 16-byte boundary. Note that if #AC is enabled (and CPL is 3), signalling of #AC is not guaranteed and may vary with implementation. In all implementations where #AC is not signalled, a general protection fault will instead be signalled. In addition, the width of the alignment check when #AC is enabled may also vary with implementation; for instance, for a given implementation, #AC might be signalled for a 2-byte misalignment, whereas #GP might be signalled for all other misalignments (4-/8-/16-byte). Invalid opcode exception if instruction is preceded by a LOCK override prefix. General protection fault if reserved bits of MXCSR are loaded with non-zero values.

Numeric Exceptions

None.

FXRSTOR—Restore FP And MMX™ State And Streaming SIMD Extension State (Continued)

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments, or if an attempt is made to load non-zero values to reserved bits in the MXCSR field.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#NM	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#NM	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

Comments

State saved with FXSAVE and restored with FRSTOR, and state saved with FSAVE and restored with FXRSTOR, will result in incorrect restoration of state in the processor. The address size prefix will have the usual effect on address calculation, but will have no effect on the format of the FXRSTOR image.

The use of Repeat (F2H, F3H) and Operand-size (66H) prefixes with FXRSTOR is reserved. Different processor implementations may handle these prefixes differently. Usage of these prefixes with FXRSTOR risks incompatibility with future processors.

FXSAVE—Store FP and MMX™ State and Streaming SIMD Extension State

Opcode	Instruction	Description
0F,AE,/0	FXSAVE *m512byte*	Store FP and MMX™ technology state and Streaming SIMD Extension state to *m512byte*.

Description

The FXSAVE instruction writes the current FP and MMX™ technology state, and Streaming SIMD Extension state (environment and registers), to the specified destination defined by m512byte. It does this without checking for pending unmasked floating-point exceptions (similar to the operation of FNSAVE). Unlike the FSAVE/FNSAVE instructions, the processor retains the contents of the FP and MMX™ technology state and Streaming SIMD Extension state in the processor after the state has been saved. This instruction has been optimized to maximize floating-point save performance. The save data structure is as follows (little-endian byte order as arranged in memory, with byte offset into row described by right column):

FXSAVE—Store FP and MMX™ State And Streaming SIMD Extension State (Continued)

15 14	13 12	11 10 9 8	7 6	5 4	3 2	1 0	
Rsrvd	CS	IP	FOP	FTW	FSW	FCW	0
Reserved		MXCSR	Rsrvd	DS	DP		16
Reserved		ST0/MM0					32
Reserved		ST1/MM1					48
Reserved		ST2/MM2					64
Reserved		ST3/MM3					80
Reserved		ST4/MM4					96
Reserved		ST5/MM5					112
Reserved		ST6/MM6					128
Reserved		ST7/MM7					144
XMM0							160
XMM1							176
XMM2							192
XMM3							208
XMM4							224
XMM5							240
XMM6							256
XMM7							272
Reserved							288
Reserved							304
Reserved							320
Reserved							336
Reserved							352
Reserved							368
Reserved							384
Reserved							400
Reserved							416
Reserved							432
Reserved							448
Reserved							464
Reserved							480
Reserved							496

FXSAVE—Store FP and MMX™ State And Streaming SIMD Extension State (Continued)

Three fields in the floating-point save area contain reserved bits that are not indicated in the table:

FOP: The lower 11-bits contain the opcode, upper 5-bits are reserved.

IP & DP: 32-bit mode: 32-bit IP-offset.

16-bit mode: lower 16 bits are IP-offset and upper 16 bits are reserved.

The FXSAVE instruction is used when an operating system needs to perform a context switch or when an exception handler needs to use the floating-point, MMX™ technology, and Streaming SIMD Extension units. It cannot be used by an application program to pass a "clean" FP state to a procedure, since it retains the current state. An application must explicitly execute an FINIT instruction after FXSAVE to provide for this functionality.

All of the x87-FP fields retain the same internal format as in FSAVE except for FTW.

Unlike FSAVE, FXSAVE saves only the FTW valid bits rather than the entire x87-FP FTW field. The FTW bits are saved in a non-TOS relative order, which means that FR0 is always saved first, followed by FR1, FR2 and so forth. As an example, if TOS=4 and only ST0, ST1 and ST2 are valid, FSAVE saves the FTW field in the following format:

ST3	ST2	ST1	ST0	ST7	ST6	ST5	ST4 (TOS=4)
FR7	FR6	FR5	FR4	FR3	FR2	FR1	FR0
11	xx	xx	xx	11	11	11	11

where xx is one of (00, 01, 10). (11) indicates an empty stack elements, and the 00, 01, and 10 indicate Valid, Zero, and Special, respectively. In this example, FXSAVE would save the following vector:

FR7	FRits6	FR5	FR4	FR3	FR2	FR1	FR0
0	1	1	1	0	0	0	0

FXSAVE—Store FP and MMX™ State And Streaming SIMD Extension State (Continued)

The FSAVE format for FTW can be recreated from the FTW valid bits and the stored 80-bit FP data (assuming the stored data was not the contents of MMX™ technology registers) using the following table:

Exponent all 1's	Exponent all 0's	Fraction all 0's	J and M bits	FTW valid bit	x87 FTW	
0	0	0	0x	1	Special	10
0	0	0	1x	1	Valid	00
0	0	1	00	1	Special	10
0	0	1	10	1	Valid	00
0	1	0	0x	1	Special	10
0	1	0	1x	1	Special	10
0	1	1	00	1	Zero	01
0	1	1	10	1	Special	10
1	0	0	1x	1	Special	10
1	0	0	1x	1	Special	10
1	0	1	00	1	Special	10
1	0	1	10	1	Special	10
For all legal combinations above				0	Empty	11

The J-bit is defined to be the 1-bit binary integer to the left of the decimal place in the significand. The M-bit is defined to be the most significant bit of the fractional portion of the significand (i.e., the bit immediately to the right of the decimal place).

When the M- bit is the most significant bit of the fractional portion of the significand, it must be 0 if the fraction is all 0's.

If the FXSAVE instruction is immediately preceded by an FP instruction which does not use a memory operand, then the FXSAVE instruction does not write/update the DP field, in the FXSAVE image.

MXCSR holds the contents of the SIMD floating-point Control/Status Register. Refer to the LDMXCSR instruction for a full description of this field.

The fields XMM0-XMM7 contain the content of registers XMM0-XMM7 in exactly the same format as they exist in the registers.

FXSAVE—Store FP and MMX™ State And Streaming SIMD Extension State (Continued)

The Streaming SIMD Extension fields in the save image (XMM0-XMM7 and MXCSR) may not be loaded into the processor if the CR4.OSFXSR bit is not set. This CR4 bit must be set in order to enable execution of Streaming SIMD Extensions.

The destination m512byte is assumed to be aligned on a 16-byte boundary. If m512byte is not aligned on a 16-byte boundary, FXSAVE generates a general protection exception.

Operation

m512byte = FP and MMX™ technology state and Streaming SIMD Extension state;

Exceptions

#AC	If exception detection is disabled, a general protection exception is signalled if the address is not aligned on 16-byte boundary. Note that if #AC is enabled (and CPL is 3), signalling of #AC is not guaranteed and may vary with implementation. In all implementations where #AC is not signalled, a general protection fault will instead be signalled. In addition, the width of the alignment check when #AC is enabled may also vary with implementation; for instance, for a given implementation, #AC might be signalled for a 2-byte misalignment, whereas #GP might be signalled for all other misalignments (4-/8-/16-byte). Invalid opcode exception if instruction is preceded by a LOCK override prefix.

Numeric Exceptions

Invalid, Precision.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#NM	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).

FXSAVE—Store FP and MMX™ State And Streaming SIMD Extension State (Continued)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#NM	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

Comments

State saved with FXSAVE and restored with FRSTOR, and state saved with FSAVE and restored with FXRSTOR, will result in incorrect restoration of state in the processor. The address size prefix will have the usual effect on address calculation, but will have no effect on the format of the FXSAVE image.

The use of Repeat (F2H, F3H) and Operand-size (66H) prefixes with FXSAVE is reserved. Different processor implementations may handle these prefixes differently. Usage of these prefixes with FXSAVE risks incompatibility with future processors.

FXTRACT—Extract Exponent and Significand

Opcode	Instruction	Description
D9 F4	FXTRACT	Separate value in ST(0) into exponent and significand, store exponent in ST(0), and push the significand onto the register stack.

Description

This instruction separates the source value in the ST(0) register into its exponent and significand, stores the exponent in ST(0), and pushes the significand onto the register stack. Following this operation, the new top-of-stack register ST(0) contains the value of the original significand expressed as a real number. The sign and significand of this value are the same as those found in the source operand, and the exponent is 3FFFH (biased value for a true exponent of zero). The ST(1) register contains the value of the original operand's true (unbiased) exponent expressed as a real number. (The operation performed by this instruction is a superset of the IEEE-recommended logb(*x*) function.)

This instruction and the F2XM1 instruction are useful for performing power and range scaling operations. The FXTRACT instruction is also useful for converting numbers in extended-real format to decimal representations (e.g., for printing or displaying).

If the floating-point zero-divide exception (#Z) is masked and the source operand is zero, an exponent value of –∞ is stored in register ST(1) and 0 with the sign of the source operand is stored in register ST(0).

Operation

```
TEMP ← Significand(ST(0));
ST(0) ← Exponent(ST(0));
TOP← TOP – 1;
ST(0) ← TEMP;
```

FPU Flags Affected

C1	Set to 0 if stack underflow occurred; set to 1 if stack overflow occurred.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.
	Stack overflow occurred.
#IA	Source operand is an sNaN value or unsupported format.
#Z	ST(0) operand is ±0.
#D	Source operand is a denormal value.

FXTRACT—Extract Exponent and Significand (Continued)

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FYL2X—Compute y ∗ $\log_2$x

Opcode	Instruction	Description
D9 F1	FYL2X	Replace ST(1) with (ST(1) ∗ $\log_2$ST(0)) and pop the register stack

Description

This instruction calculates (ST(1) ∗ $\log_2$ (ST(0))), stores the result in resister ST(1), and pops the FPU register stack. The source operand in ST(0) must be a non-zero positive number.

The following table shows the results obtained when taking the log of various classes of numbers, assuming that neither overflow nor underflow occurs.

		ST(0)							
		−∞	−F	±0	+0 < +F < +1	+1	+F > +1	+∞	NaN
ST(1)	−∞	*	*	+∞	+∞	*	−∞	−∞	NaN
	−F	*	*	**	+F	−0	−F	−∞	NaN
	−0	*	*	*	+0	−0	−0	*	NaN
	+0	*	*	*	−0	+0	+0	*	NaN
	+F	*	*	**	−F	+0	+F	+∞	NaN
	+∞	*	*	−∞	−∞	∗	+∞	+∞	NaN
	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

NOTES:

F Means finite-real number.

* Indicates floating-point invalid-operation (#IA) exception.

** Indicates floating-point zero-divide (#Z) exception.

If the divide-by-zero exception is masked and register ST(0) contains ±0, the instruction returns ∞ with a sign that is the opposite of the sign of the source operand in register ST(1).

The FYL2X instruction is designed with a built-in multiplication to optimize the calculation of logarithms with an arbitrary positive base (b):

$\log_b x = (\log_2 b)^{-1} * \log_2 x$

Operation

ST(1) ← ST(1) ∗ $\log_2$ST(0);
PopRegisterStack;

FYL2X—Compute y ∗ $\log_2$x (Continued)

FPU Flags Affected

C1	Set to 0 if stack underflow occurred.
	Indicates rounding direction if the inexact-result exception (#P) is generated: 0 = not roundup; 1 = roundup.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Either operand is an sNaN or unsupported format.
	Source operand in register ST(0) is a negative finite value (not –0).
#Z	Source operand in register ST(0) is ±0.
#D	Source operand is a denormal value.
#U	Result is too small for destination format.
#O	Result is too large for destination format.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

FYL2XP1—Compute y ∗ $\log_2$(x +1)

Opcode	Instruction	Description
D9 F9	FYL2XP1	Replace ST(1) with ST(1) ∗ $\log_2$(ST(0) + 1.0) and pop the register stack

Description

This instruction calculates the log epsilon (ST(1) ∗ $\log_2$(ST(0) + 1.0)), stores the result in register ST(1), and pops the FPU register stack. The source operand in ST(0) must be in the range:

$$-(1-\sqrt{2}/2))\text{to}(1-\sqrt{2}/2)$$

The source operand in ST(1) can range from –∞ to +∞. If the ST(0) operand is outside of its acceptable range, the result is undefined and software should not rely on an exception being generated. Under some circumstances exceptions may be generated when ST(0) is out of range, but this behavior is implementation specific and not guaranteed.

The following table shows the results obtained when taking the log epsilon of various classes of numbers, assuming that underflow does not occur.

		ST(0)				
		–(1 – ($\sqrt{2}/2$)) to –0	–0	+0	+0 to +(1 – ($\sqrt{2}/2$))	NaN
ST(1)	–∞	+∞	*	*	–∞	NaN
	–F	+F	+0	–0	–F	NaN
	–0	+0	+0	–0	–0	NaN
	+0	–0	–0	+0	+0	NaN
	+F	–F	–0	+0	+F	NaN
	+∞	–∞	*	*	+∞	NaN
	NaN	NaN	NaN	NaN	NaN	NaN

NOTES:

F Means finite-real number.

* Indicates floating-point invalid-operation (#IA) exception.

This instruction provides optimal accuracy for values of epsilon [the value in register ST(0)] that are close to 0. When the epsilon value (ε) is small, more significant digits can be retained by using the FYL2XP1 instruction than by using (ε+1) as an argument to the FYL2X instruction. The (ε+1) expression is commonly found in compound interest and annuity calculations. The result can be simply converted into a value in another logarithm base by including a scale factor in the ST(1) source operand. The following equation is used to calculate the scale factor for a particular logarithm base, where n is the logarithm base desired for the result of the FYL2XP1 instruction: scale factor = $\log_n 2$

FYL2XP1—Compute y ∗ $\log_2$(x +1) (Continued)

Operation

ST(1) ← ST(1) ∗ $\log_2$(ST(0) + 1.0);
PopRegisterStack;

FPU Flags Affected

C1	Set to 0 if stack underflow occurred.
	Indicates rounding direction if the inexact-result exception (#P) is generated: 0 = not roundup; 1 = roundup.
C0, C2, C3	Undefined.

Floating-Point Exceptions

#IS	Stack underflow occurred.
#IA	Either operand is an sNaN value or unsupported format.
#D	Source operand is a denormal value.
#U	Result is too small for destination format.
#O	Result is too large for destination format.
#P	Value cannot be represented exactly in destination format.

Protected Mode Exceptions

#NM	EM or TS in CR0 is set.

Real-Address Mode Exceptions

#NM	EM or TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM	EM or TS in CR0 is set.

HLT—Halt

Opcode	Instruction	Description
F4	HLT	Halt

Description

This instruction stops instruction execution and places the processor in a HALT state. An enabled interrupt, NMI, or a reset will resume execution. If an interrupt (including NMI) is used to resume execution after a HLT instruction, the saved instruction pointer (CS:EIP) points to the instruction following the HLT instruction.

The HLT instruction is a privileged instruction. When the processor is running in protected or virtual-8086 mode, the privilege level of a program or procedure must be 0 to execute the HLT instruction.

Operation

```
Enter Halt state;
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the current privilege level is not 0.

Real-Address Mode Exceptions

None.

Virtual-8086 Mode Exceptions

#GP(0)	If the current privilege level is not 0.

IDIV—Signed Divide

Opcode	Instruction	Description
F6 /7	IDIV *r/m8*	Signed divide AX (where AH must contain sign-extension of AL) by *r/m* byte. (Results: AL=Quotient, AH=Remainder)
F7 /7	IDIV *r/m16*	Signed divide DX:AX (where DX must contain sign-extension of AX) by *r/m* word. (Results: AX=Quotient, DX=Remainder)
F7 /7	IDIV *r/m32*	Signed divide EDX:EAX (where EDX must contain sign-extension of EAX) by *r/m* doubleword. (Results: EAX=Quotient, EDX=Remainder)

Description

This instruction divides (signed) the value in the AL, AX, or EAX register by the source operand and stores the result in the AX, DX:AX, or EDX:EAX registers. The source operand can be a general-purpose register or a memory location. The action of this instruction depends on the operand size, as shown in the following table:

Operand Size	Dividend	Divisor	Quotient	Remainder	Quotient Range
Word/byte	AX	r/m8	AL	AH	–128 to +127
Doubleword/word	DX:AX	r/m16	AX	DX	–32,768 to +32,767
Quadword/doubleword	EDX:EAX	r/m32	EAX	EDX	-2^{31} to $2^{32} - 1$

Non-integral results are truncated (chopped) towards 0. The sign of the remainder is always the same as the sign of the dividend. The absolute value of the remainder is always less than the absolute value of the divisor. Overflow is indicated with the #DE (divide error) exception rather than with the OF (overflow) flag.

Operation

```
IF SRC = 0
    THEN #DE; (* divide error *)
FI;
IF OpernadSize = 8 (* word/byte operation *)
    THEN
        temp ← AX / SRC; (* signed division *)
        IF (temp > 7FH) OR (temp < 80H)
        (* if a positive result is greater than 7FH or a negative result is less than 80H *)
            THEN #DE; (* divide error *) ;
            ELSE
                AL ← temp;
                AH ← AX SignedModulus SRC;
        FI;
```

IDIV—Signed Divide (Continued)

```
    ELSE
        IF OpernadSize = 16 (* doubleword/word operation *)
            THEN
                temp ← DX:AX / SRC; (* signed division *)
                IF (temp > 7FFFH) OR (temp < 8000H)
                (* if a positive result is greater than 7FFFH *)
                (* or a negative result is less than 8000H *)
                    THEN #DE; (* divide error *) ;
                    ELSE
                        AX ← temp;
                        DX ← DX:AX SignedModulus SRC;
                FI;
            ELSE (* quadword/doubleword operation *)
                temp ← EDX:EAX / SRC; (* signed division *)
                IF (temp > 7FFFFFFFH) OR (temp < 80000000H)
                (* if a positive result is greater than 7FFFFFFFH *)
                (* or a negative result is less than 80000000H *)
                    THEN #DE; (* divide error *) ;
                    ELSE
                        EAX ← temp;
                        EDX ← EDXE:AX SignedModulus SRC;
                FI;
        FI;
FI;
```

Flags Affected

The CF, OF, SF, ZF, AF, and PF flags are undefined.

Protected Mode Exceptions

#DE	If the source operand (divisor) is 0.
	The signed result (quotient) is too large for the destination.
#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

IDIV—Signed Divide (Continued)

Real-Address Mode Exceptions

#DE	If the source operand (divisor) is 0.
	The signed result (quotient) is too large for the destination.
#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#DE	If the source operand (divisor) is 0.
	The signed result (quotient) is too large for the destination.
#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

IMUL—Signed Multiply

Opcode	Instruction	Description
F6 /5	IMUL *r/m8*	AX← AL ∗ *r/m* byte
F7 /5	IMUL *r/m16*	DX:AX ← AX ∗ *r/m* word
F7 /5	IMUL *r/m32*	EDX:EAX ← EAX ∗ *r/m* doubleword
0F AF /*r*	IMUL *r16,r/m16*	word register ← word register ∗ *r/m* word
0F AF /*r*	IMUL *r32,r/m32*	doubleword register ← doubleword register ∗ *r/m* doubleword
6B /*r ib*	IMUL *r16,r/m16,imm8*	word register ← *r/m16* ∗ sign-extended immediate byte
6B /*r ib*	IMUL *r32,r/m32,imm8*	doubleword register ← *r/m32* ∗ sign-extended immediate byte
6B /*r ib*	IMUL *r16,imm8*	word register ← word register ∗ sign-extended immediate byte
6B /*r ib*	IMUL *r32,imm8*	doubleword register ← doubleword register ∗ sign-extended immediate byte
69 /*r iw*	IMUL *r16,r/m16,imm16*	word register ← *r/m16* ∗ immediate word
69 /*r id*	IMUL *r32,r/m32,imm32*	doubleword register ← *r/m32* ∗ immediate doubleword
69 /*r iw*	IMUL *r16,imm16*	word register ← *r/m16* ∗ immediate word
69 /*r id*	IMUL *r32,imm32*	doubleword register ← *r/m32* ∗ immediate doubleword

Description

This instruction performs a signed multiplication of two operands. This instruction has three forms, depending on the number of operands.

- **One-operand form.** This form is identical to that used by the MUL instruction. Here, the source operand (in a general-purpose register or memory location) is multiplied by the value in the AL, AX, or EAX register (depending on the operand size) and the product is stored in the AX, DX:AX, or EDX:EAX registers, respectively.
- **Two-operand form.** With this form the destination operand (the first operand) is multiplied by the source operand (second operand). The destination operand is a general-purpose register and the source operand is an immediate value, a general-purpose register, or a memory location. The product is then stored in the destination operand location.
- **Three-operand form.** This form requires a destination operand (the first operand) and two source operands (the second and the third operands). Here, the first source operand (which can be a general-purpose register or a memory location) is multiplied by the second source operand (an immediate value). The product is then stored in the destination operand (a general-purpose register).

When an immediate value is used as an operand, it is sign-extended to the length of the destination operand format.

IMUL—Signed Multiply (Continued)

The CF and OF flags are set when significant bits are carried into the upper half of the result. The CF and OF flags are cleared when the result fits exactly in the lower half of the result.

The three forms of the IMUL instruction are similar in that the length of the product is calculated to twice the length of the operands. With the one-operand form, the product is stored exactly in the destination. With the two- and three- operand forms, however, result is truncated to the length of the destination before it is stored in the destination register. Because of this truncation, the CF or OF flag should be tested to ensure that no significant bits are lost.

The two- and three-operand forms may also be used with unsigned operands because the lower half of the product is the same regardless if the operands are signed or unsigned. The CF and OF flags, however, cannot be used to determine if the upper half of the result is non-zero.

IMUL—Signed Multiply (Continued)

Operation

```
IF (NumberOfOperands = 1)
    THEN IF (OperandSize = 8)
        THEN
            AX ← AL ∗ SRC  (* signed multiplication *)
            IF ((AH = 00H) OR (AH = FFH))
                THEN CF = 0; OF = 0;
                ELSE CF = 1; OF = 1;
            FI;
        ELSE IF OperandSize = 16
            THEN
                DX:AX ← AX ∗ SRC  (* signed multiplication *)
                IF ((DX = 0000H) OR (DX = FFFFH))
                    THEN CF = 0; OF = 0;
                    ELSE CF = 1; OF = 1;
                FI;
            ELSE (* OperandSize = 32 *)
                EDX:EAX ← EAX ∗ SRC  (* signed multiplication *)
                IF ((EDX = 00000000H) OR (EDX = FFFFFFFFH))
                    THEN CF = 0; OF = 0;
                    ELSE CF = 1; OF = 1;
                FI;
        FI;
    ELSE IF (NumberOfOperands = 2)
        THEN
            temp ← DEST ∗ SRC    (* signed multiplication; temp is double DEST size*)
            DEST ← DEST ∗ SRC  (* signed multiplication *)
            IF temp ≠ DEST
                THEN CF = 1; OF = 1;
                ELSE CF = 0; OF = 0;
            FI;
        ELSE (* NumberOfOperands = 3 *)
            DEST ← SRC1 ∗ SRC2   (* signed multiplication *)
            temp ← SRC1 ∗ SRC2     (* signed multiplication; temp is double SRC1 size *)
            IF temp ≠ DEST
                THEN CF = 1; OF = 1;
                ELSE CF = 0; OF = 0;
            FI;
    FI;
FI;
```

IMUL—Signed Multiply (Continued)

Flags Affected

For the one operand form of the instruction, the CF and OF flags are set when significant bits are carried into the upper half of the result and cleared when the result fits exactly in the lower half of the result. For the two- and three-operand forms of the instruction, the CF and OF flags are set when the result must be truncated to fit in the destination operand size and cleared when the result fits exactly in the destination operand size. The SF, ZF, AF, and PF flags are undefined.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

IN—Input from Port

Opcode	Instruction	Description
E4 *ib*	IN AL,*imm8*	Input byte from *imm8* I/O port address into AL
E5 *ib*	IN AX,*imm8*	Input byte from *imm8* I/O port address into AX
E5 *ib*	IN EAX,*imm8*	Input byte from *imm8* I/O port address into EAX
EC	IN AL,DX	Input byte from I/O port in DX into AL
ED	IN AX,DX	Input word from I/O port in DX into AX
ED	IN EAX,DX	Input doubleword from I/O port in DX into EAX

Description

This instruction copies the value from the I/O port specified with the second operand (source operand) to the destination operand (first operand). The source operand can be a byte-immediate or the DX register; the destination operand can be register AL, AX, or EAX, depending on the size of the port being accessed (8, 16, or 32 bits, respectively). Using the DX register as a source operand allows I/O port addresses from 0 to 65,535 to be accessed; using a byte immediate allows I/O port addresses 0 to 255 to be accessed.

When accessing an 8-bit I/O port, the opcode determines the port size; when accessing a 16- and 32-bit I/O port, the operand-size attribute determines the port size.

At the machine code level, I/O instructions are shorter when accessing 8-bit I/O ports. Here, the upper eight bits of the port address will be 0.

This instruction is only useful for accessing I/O ports located in the processor's I/O address space. Refer to Chapter 10, *Input/Output* of the *Intel Architecture Software Developer's Manual, Volume 1*, for more information on accessing I/O ports in the I/O address space.

Operation

```
IF ((PE = 1) AND ((CPL > IOPL) OR (VM = 1)))
    THEN (* Protected mode with CPL > IOPL or virtual-8086 mode *)
        IF (Any I/O Permission Bit for I/O port being accessed = 1)
            THEN (* I/O operation is not allowed *)
                #GP(0);
            ELSE ( * I/O operation is allowed *)
                DEST ← SRC; (* Reads from selected I/O port *)
        FI;
    ELSE (Real Mode or Protected Mode with CPL ≤ IOPL *)
        DEST ← SRC; (* Reads from selected I/O port *)
FI;
```

Flags Affected

None.

IN—Input from Port (Continued)

Protected Mode Exceptions

#GP(0)	If the CPL is greater than (has less privilege) the I/O privilege level (IOPL) and any of the corresponding I/O permission bits in TSS for the I/O port being accessed is 1.

Real-Address Mode Exceptions

None.

Virtual-8086 Mode Exceptions

#GP(0)	If any of the I/O permission bits in the TSS for the I/O port being accessed is 1.

INC—Increment by 1

Opcode	Instruction	Description
FE /0	INC *r/m8*	Increment *r/m* byte by 1
FF /0	INC *r/m16*	Increment *r/m* word by 1
FF /0	INC *r/m32*	Increment *r/m* doubleword by 1
40+ *rw*	INC *r16*	Increment word register by 1
40+ *rd*	INC *r32*	Increment doubleword register by 1

Description

This instruction adds one to the destination operand, while preserving the state of the CF flag. The destination operand can be a register or a memory location. This instruction allows a loop counter to be updated without disturbing the CF flag. (Use a ADD instruction with an immediate operand of 1 to perform an increment operation that does updates the CF flag.)

Operation

DEST ← DEST +1;

Flags Affected

The CF flag is not affected. The OF, SF, ZF, AF, and PF flags are set according to the result.

Protected Mode Exceptions

#GP(0)	If the destination operand is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

INC—Increment by 1 (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

INS/INSB/INSW/INSD—Input from Port to String

Opcode	Instruction	Description
6C	INS m8, DX	Input byte from I/O port specified in DX into memory location specified in ES:(E)DI
6D	INS m16, DX	Input word from I/O port specified in DX into memory location specified in ES:(E)DI
6D	INS m32, DX	Input doubleword from I/O port specified in DX into memory location specified in ES:(E)DI
6C	INSB	Input byte from I/O port specified in DX into memory location specified with ES:(E)DI
6D	INSW	Input word from I/O port specified in DX into memory location specified in ES:(E)DI
6D	INSD	Input doubleword from I/O port specified in DX into memory location specified in ES:(E)DI

Description

These instructions copy the data from the I/O port specified with the source operand (second operand) to the destination operand (first operand). The source operand is an I/O port address (from 0 to 65,535) that is read from the DX register. The destination operand is a memory location, the address of which is read from either the ES:EDI or the ES:DI registers (depending on the address-size attribute of the instruction, 32 or 16, respectively). The ES segment cannot be overridden with a segment override prefix. The size of the I/O port being accessed (that is, the size of the source and destination operands) is determined by the opcode for an 8-bit I/O port or by the operand-size attribute of the instruction for a 16- or 32-bit I/O port.

At the assembly-code level, two forms of this instruction are allowed: the “explicit-operands” form and the “no-operands” form. The explicit-operands form (specified with the INS mnemonic) allows the source and destination operands to be specified explicitly. Here, the source operand must be “DX,” and the destination operand should be a symbol that indicates the size of the I/O port and the destination address. This explicit-operands form is provided to allow documentation; however, note that the documentation provided by this form can be misleading. That is, the destination operand symbol must specify the correct **type** (size) of the operand (byte, word, or doubleword), but it does not have to specify the correct **location**. The location is always specified by the ES:(E)DI registers, which must be loaded correctly before the INS instruction is executed.

The no-operands form provides “short forms” of the byte, word, and doubleword versions of the INS instructions. Here also DX is assumed by the processor to be the source operand and ES:(E)DI is assumed to be the destination operand. The size of the I/O port is specified with the choice of mnemonic: INSB (byte), INSW (word), or INSD (doubleword).

After the byte, word, or doubleword is transfer from the I/O port to the memory location, the (E)DI register is incremented or decremented automatically according to the setting of the DF flag in the EFLAGS register. (If the DF flag is 0, the (E)DI register is incremented; if the DF flag is 1, the (E)DI register is decremented.) The (E)DI register is incremented or decremented by one for byte operations, by two for word operations, or by four for doubleword operations.

INS/INSB/INSW/INSD—Input from Port to String (Continued)

The INS, INSB, INSW, and INSD instructions can be preceded by the REP prefix for block input of ECX bytes, words, or doublewords. Refer to "REP/REPE/REPZ/REPNE /REPNZ—Repeat String Operation Prefix" in this chapter for a description of the REP prefix.

These instructions are only useful for accessing I/O ports located in the processor's I/O address space. Refer to Chapter 10, *Input/Output* of the *Intel Architecture Software Developer's Manual, Volume 1*, for more information on accessing I/O ports in the I/O address space.

Operation

```
IF ((PE = 1) AND ((CPL > IOPL) OR (VM = 1)))
    THEN (* Protected mode with CPL > IOPL or virtual-8086 mode *)
        IF (Any I/O Permission Bit for I/O port being accessed = 1)
            THEN (* I/O operation is not allowed *)
                #GP(0);
            ELSE ( * I/O operation is allowed *)
                DEST ← SRC; (* Reads from I/O port *)
        FI;
    ELSE (Real Mode or Protected Mode with CPL ≤ IOPL *)
        DEST ← SRC; (* Reads from I/O port *)
FI;
IF (byte transfer)
    THEN IF DF = 0
        THEN (E)DI ← (E)DI + 1;
        ELSE (E)DI ← (E)DI – 1;
    FI;
    ELSE IF (word transfer)
        THEN IF DF = 0
            THEN (E)DI ← (E)DI + 2;
            ELSE (E)DI ← (E)DI – 2;
        FI;
        ELSE (* doubleword transfer *)
            THEN IF DF = 0
                THEN (E)DI ← (E)DI + 4;
                ELSE (E)DI ← (E)DI – 4;
            FI;
    FI;
FI;
```

Flags Affected

None.

INS/INSB/INSW/INSD—Input from Port to String (Continued)

Protected Mode Exceptions

#GP(0)	If the CPL is greater than (has less privilege) the I/O privilege level (IOPL) and any of the corresponding I/O permission bits in TSS for the I/O port being accessed is 1.
	If the destination is located in a nonwritable segment.
	If an illegal memory operand effective address in the ES segments is given.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If any of the I/O permission bits in the TSS for the I/O port being accessed is 1.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

INT *n*/INTO/INT 3—Call to Interrupt Procedure

Opcode	Instruction	Description
CC	INT 3	Interrupt 3—trap to debugger
CD *ib*	INT *imm8*	Interrupt vector number specified by immediate byte
CE	INTO	Interrupt 4—if overflow flag is 1

Description

The INT *n* instruction generates a call to the interrupt or exception handler specified with the destination operand. For more information, refer to Section 4.4., *Interrupts and Exceptions* in Chapter 4, *Procedure Calls, Interrupts, and Exceptions* of the *Intel Architecture Software Developer's Manual, Volume 1*. The destination operand specifies an interrupt vector number from 0 to 255, encoded as an 8-bit unsigned intermediate value. Each interrupt vector number provides an index to a gate descriptor in the IDT. The first 32 interrupt vector numbers are reserved by Intel for system use. Some of these interrupts are used for internally generated exceptions.

The INT *n* instruction is the general mnemonic for executing a software-generated call to an interrupt handler. The INTO instruction is a special mnemonic for calling overflow exception (#OF), interrupt vector number 4. The overflow interrupt checks the OF flag in the EFLAGS register and calls the overflow interrupt handler if the OF flag is set to 1.

The INT 3 instruction generates a special one byte opcode (CC) that is intended for calling the debug exception handler. (This one byte form is valuable because it can be used to replace the first byte of any instruction with a breakpoint, including other one byte instructions, without over-writing other code). To further support its function as a debug breakpoint, the interrupt generated with the CC opcode also differs from the regular software interrupts as follows:

- Interrupt redirection does not happen when in VME mode; the interrupt is handled by a protected-mode handler.
- The virtual-8086 mode IOPL checks do not occur. The interrupt is taken without faulting at any IOPL level.

Note that the "normal" 2-byte opcode for INT 3 (CD03) does not have these special features. Intel and Microsoft assemblers will not generate the CD03 opcode from any mnemonic, but this opcode can be created by direct numeric code definition or by self-modifying code.

The action of the INT *n* instruction (including the INTO and INT 3 instructions) is similar to that of a far call made with the CALL instruction. The primary difference is that with the INT *n* instruction, the EFLAGS register is pushed onto the stack before the return address. (The return address is a far address consisting of the current values of the CS and EIP registers.) Returns from interrupt procedures are handled with the IRET instruction, which pops the EFLAGS information and return address from the stack.

INT *n*/INTO/INT 3—Call to Interrupt Procedure (Continued)

The interrupt vector number specifies an interrupt descriptor in the interrupt descriptor table (IDT); that is, it provides index into the IDT. The selected interrupt descriptor in turn contains a pointer to an interrupt or exception handler procedure. In protected mode, the IDT contains an array of 8-byte descriptors, each of which is an interrupt gate, trap gate, or task gate. In real-address mode, the IDT is an array of 4-byte far pointers (2-byte code segment selector and a 2-byte instruction pointer), each of which point directly to a procedure in the selected segment. (Note that in real-address mode, the IDT is called the **interrupt vector table**, and it's pointers are called interrupt vectors.)

The following decision table indicates which action in the lower portion of the table is taken given the conditions in the upper portion of the table. Each Y in the lower section of the decision table represents a procedure defined in the "Operation" section for this instruction (except #GP).

PE	0	1	1	1	1	1	1	1
VM	–	–	–	–	–	0	1	1
IOPL	–	–	–	–	–	–	<3	=3
DPL/CPL RELATIONSHIP	–	DPL< CPL	–	DPL> CPL	DPL= CPL or C	DPL< CPL & NC	–	–
INTERRUPT TYPE	–	S/W	–	–	–	–	–	–
GATE TYPE	–	–	Task	Trap or Interrupt	Trap or Interrupt	Trap or Interrupt	Trap or Interrupt	Trap or Interrupt
REAL-ADDRESS-MODE	Y							
PROTECTED-MODE		Y	Y	Y	Y	Y	Y	Y
TRAP-OR-INTERRUPT-GATE				Y	Y	Y	Y	Y
INTER-PRIVILEGE-LEVEL-INTERRUPT						Y		
INTRA-PRIVILEGE-LEVEL-INTERRUPT					Y			
INTERRUPT-FROM-VIRTUAL-8086-MODE								Y
TASK-GATE			Y					
#GP		Y		Y			Y	

NOTES:

– Don't Care.

Y Yes, Action Taken.

Blank Action Not Taken.

INT *n*/INTO/INT 3—Call to Interrupt Procedure (Continued)

When the processor is executing in virtual-8086 mode, the IOPL determines the action of the INT *n* instruction. If the IOPL is less than 3, the processor generates a general protection exception (#GP); if the IOPL is 3, the processor executes a protected mode interrupt to privilege level 0. The interrupt gate's DPL must be set to three and the target CPL of the interrupt handler procedure must be 0 to execute the protected mode interrupt to privilege level 0.

The interrupt descriptor table register (IDTR) specifies the base linear address and limit of the IDT. The initial base address value of the IDTR after the processor is powered up or reset is 0.

Operation

The following operational description applies not only to the INT *n* and INTO instructions, but also to external interrupts and exceptions.

```
IF PE=0
    THEN
        GOTO REAL-ADDRESS-MODE;
    ELSE (* PE=1 *)
        IF (VM=1 AND IOPL < 3 AND INT n)
            THEN
                #GP(0);
            ELSE (* protected mode or virtual-8086 mode interrupt *)
                GOTO PROTECTED-MODE;
        FI;
FI;

REAL-ADDRESS-MODE:
    IF ((DEST ∗ 4) + 3) is not within IDT limit THEN #GP; FI;
    IF stack not large enough for a 6-byte return information THEN #SS; FI;
    Push (EFLAGS[15:0]);
    IF ← 0; (* Clear interrupt flag *)
    TF ← 0; (* Clear trap flag *)
    AC ← 0; (*Clear AC flag*)
    Push(CS);
    Push(IP);
    (* No error codes are pushed *)
    CS ← IDT(Descriptor (vector_number ∗ 4), selector));
    EIP ← IDT(Descriptor (vector_number ∗ 4), offset)); (* 16-bit offset AND 0000FFFFH *)
END;

PROTECTED-MODE:
    IF ((DEST ∗ 8) + 7) is not within IDT limits
        OR selected IDT descriptor is not an interrupt-, trap-, or task-gate type
            THEN #GP((DEST ∗ 8) + 2 + EXT);
            (* EXT is bit 0 in error code *)
    FI;
```

INT *n*/INTO/INT 3—Call to Interrupt Procedure (Continued)

```
    IF software interrupt (* generated by INT n, INT 3, or INTO *)
        THEN
            IF gate descriptor DPL < CPL
                THEN #GP((vector_number * 8) + 2 );
                (* PE=1, DPL<CPL, software interrupt *)
            FI;
    FI;
    IF gate not present THEN #NP((vector_number * 8) + 2 + EXT); FI;
    IF task gate (* specified in the selected interrupt table descriptor *)
        THEN GOTO TASK-GATE;
        ELSE GOTO TRAP-OR-INTERRUPT-GATE; (* PE=1, trap/interrupt gate *)
    FI;
END;

TASK-GATE: (* PE=1, task gate *)
    Read segment selector in task gate (IDT descriptor);
        IF local/global bit is set to local
            OR index not within GDT limits
                THEN #GP(TSS selector);
        FI;
        Access TSS descriptor in GDT;
        IF TSS descriptor specifies that the TSS is busy (low-order 5 bits set to 00001)
            THEN #GP(TSS selector);
        FI;
        IF TSS not present
            THEN #NP(TSS selector);
        FI;
    SWITCH-TASKS (with nesting) to TSS;
    IF interrupt caused by fault with error code
        THEN
            IF stack limit does not allow push of error code
                THEN #SS(0);
            FI;
            Push(error code);
    FI;
    IF EIP not within code segment limit
        THEN #GP(0);
    FI;
END;
TRAP-OR-INTERRUPT-GATE
    Read segment selector for trap or interrupt gate (IDT descriptor);
    IF segment selector for code segment is null
        THEN #GP(0H + EXT); (* null selector with EXT flag set *)
    FI;
```

INT *n*/INTO/INT 3—Call to Interrupt Procedure (Continued)

```
    IF segment selector is not within its descriptor table limits
        THEN #GP(selector + EXT);
    FI;
    Read trap or interrupt handler descriptor;
    IF descriptor does not indicate a code segment
        OR code segment descriptor DPL > CPL
            THEN #GP(selector + EXT);
    FI;
    IF trap or interrupt gate segment is not present,
        THEN #NP(selector + EXT);
    FI;
    IF code segment is non-conforming AND DPL < CPL
        THEN IF VM=0
            THEN
                GOTO INTER-PRIVILEGE-LEVEL-INTERRUPT;
                (* PE=1, interrupt or trap gate, nonconforming *)
                (* code segment, DPL<CPL, VM=0 *)
            ELSE (* VM=1 *)
                IF code segment DPL ≠ 0 THEN #GP(new code segment selector); FI;
                GOTO INTERRUPT-FROM-VIRTUAL-8086-MODE;
                (* PE=1, interrupt or trap gate, DPL<CPL, VM=1 *)
        FI;
        ELSE (* PE=1, interrupt or trap gate, DPL ≥ CPL *)
            IF VM=1 THEN #GP(new code segment selector); FI;
            IF code segment is conforming OR code segment DPL = CPL
                THEN
                    GOTO INTRA-PRIVILEGE-LEVEL-INTERRUPT;
                ELSE
                    #GP(CodeSegmentSelector + EXT);
                    (* PE=1, interrupt or trap gate, nonconforming *)
                    (* code segment, DPL>CPL *)
            FI;
    FI;
END;

INTER-PREVILEGE-LEVEL-INTERRUPT
    (* PE=1, interrupt or trap gate, non-conforming code segment, DPL<CPL *)
    (* Check segment selector and descriptor for stack of new privilege level in current TSS *)
    IF current TSS is 32-bit TSS
        THEN
            TSSstackAddress ← (new code segment DPL * 8) + 4
            IF (TSSstackAddress + 7) > TSS limit
                THEN #TS(current TSS selector); FI;
            NewSS ← TSSstackAddress + 4;
            NewESP ← stack address;
```

INT *n*/INTO/INT 3—Call to Interrupt Procedure (Continued)

```
        ELSE (* TSS is 16-bit *)
            TSSstackAddress ← (new code segment DPL ∗ 4) + 2
            IF (TSSstackAddress + 4) > TSS limit
                THEN #TS(current TSS selector); FI;
            NewESP ← TSSstackAddress;
            NewSS ← TSSstackAddress + 2;
    FI;
    IF segment selector is null THEN #TS(EXT); FI;
    IF segment selector index is not within its descriptor table limits
        OR segment selector's RPL ≠ DPL of code segment,
            THEN #TS(SS selector + EXT);
    FI;
Read segment descriptor for stack segment in GDT or LDT;
    IF stack segment DPL ≠ DPL of code segment,
        OR stack segment does not indicate writable data segment,
            THEN #TS(SS selector + EXT);
    FI;
    IF stack segment not present THEN #SS(SS selector+EXT); FI;
    IF 32-bit gate
        THEN
            IF new stack does not have room for 24 bytes (error code pushed)
                OR 20 bytes (no error code pushed)
                    THEN #SS(segment selector + EXT);
            FI;
        ELSE (* 16-bit gate *)
            IF new stack does not have room for 12 bytes (error code pushed)
                OR 10 bytes (no error code pushed);
                    THEN #SS(segment selector + EXT);
            FI;
    FI;
    IF instruction pointer is not within code segment limits THEN #GP(0); FI;
    SS:ESP ← TSS(NewSS:NewESP) (* segment descriptor information also loaded *)
    IF 32-bit gate
        THEN
            CS:EIP ← Gate(CS:EIP); (* segment descriptor information also loaded *)
        ELSE (* 16-bit gate *)
            CS:IP ← Gate(CS:IP); (* segment descriptor information also loaded *)
    FI;
    IF 32-bit gate
        THEN
            Push(far pointer to old stack); (* old SS and ESP, 3 words padded to 4 *);
            Push(EFLAGS);
            Push(far pointer to return instruction); (* old CS and EIP, 3 words padded to 4*);
            Push(ErrorCode); (* if needed, 4 bytes *)
```

INT *n*/INTO/INT 3—Call to Interrupt Procedure (Continued)

```
        ELSE(* 16-bit gate *)
            Push(far pointer to old stack); (* old SS and SP, 2 words *);
            Push(EFLAGS(15..0));
            Push(far pointer to return instruction); (* old CS and IP, 2 words *);
            Push(ErrorCode); (* if needed, 2 bytes *)
    FI;
    CPL ← CodeSegmentDescriptor(DPL);
    CS(RPL) ← CPL;
    IF interrupt gate
        THEN IF ← 0 (* interrupt flag to 0 (disabled) *); FI;
    TF ← 0;
    VM ← 0;
    RF ← 0;
    NT ← 0;
    END;

INTERRUPT-FROM-VIRTUAL-8086-MODE:
    (* Check segment selector and descriptor for privilege level 0 stack in current TSS *)
    IF current TSS is 32-bit TSS
        THEN
            TSSstackAddress ← (new code segment DPL * 8) + 4
            IF (TSSstackAddress + 7) > TSS limit
                THEN #TS(current TSS selector); FI;
            NewSS ← TSSstackAddress + 4;
            NewESP ← stack address;
        ELSE (* TSS is 16-bit *)
            TSSstackAddress ← (new code segment DPL * 4) + 2
            IF (TSSstackAddress + 4) > TSS limit
                THEN #TS(current TSS selector); FI;
            NewESP ← TSSstackAddress;
            NewSS ← TSSstackAddress + 2;
    FI;
        IF segment selector is null THEN #TS(EXT); FI;
        IF segment selector index is not within its descriptor table limits
            OR segment selector's RPL ≠ DPL of code segment,
                THEN #TS(SS selector + EXT);
        FI;
    Access segment descriptor for stack segment in GDT or LDT;
    IF stack segment DPL ≠ DPL of code segment,
        OR stack segment does not indicate writable data segment,
            THEN #TS(SS selector + EXT);
    FI;
    IF stack segment not present THEN #SS(SS selector+EXT); FI;
```

INT *n*/INTO/INT 3—Call to Interrupt Procedure (Continued)

```
    IF 32-bit gate
        THEN
            IF new stack does not have room for 40 bytes (error code pushed)
                OR 36 bytes (no error code pushed);
                    THEN #SS(segment selector + EXT);
            FI;
        ELSE (* 16-bit gate *)
            IF new stack does not have room for 20 bytes (error code pushed)
                OR 18 bytes (no error code pushed);
                    THEN #SS(segment selector + EXT);
            FI;
    FI;
    IF instruction pointer is not within code segment limits THEN #GP(0); FI;
    tempEFLAGS ← EFLAGS;
    VM ← 0;
    TF ← 0;
    RF ← 0;
    IF service through interrupt gate THEN IF ← 0; FI;
    TempSS ← SS;
    TempESP ← ESP;
    SS:ESP ← TSS(SS0:ESP0); (* Change to level 0 stack segment *)
    (* Following pushes are 16 bits for 16-bit gate and 32 bits for 32-bit gates *)
    (* Segment selector pushes in 32-bit mode are padded to two words *)
    Push(GS);
    Push(FS);
    Push(DS);
    Push(ES);
    Push(TempSS);
    Push(TempESP);
    Push(TempEFlags);
    Push(CS);
    Push(EIP);
    GS ← 0; (*segment registers nullified, invalid in protected mode *)
    FS ← 0;
    DS ← 0;
    ES ← 0;
    CS ← Gate(CS);
    IF OperandSize=32
        THEN
            EIP ← Gate(instruction pointer);
        ELSE (* OperandSize is 16 *)
            EIP ← Gate(instruction pointer) AND 0000FFFFH;
    FI;
    (* Starts execution of new routine in Protected Mode *)
END;
```

INT *n*/INTO/INT 3—Call to Interrupt Procedure (Continued)

```
INTRA-PRIVILEGE-LEVEL-INTERRUPT:
    (* PE=1, DPL = CPL or conforming segment *)
    IF 32-bit gate
        THEN
            IF current stack does not have room for 16 bytes (error code pushed)
                OR 12 bytes (no error code pushed); THEN #SS(0);
            FI;
        ELSE (* 16-bit gate *)
            IF current stack does not have room for 8 bytes (error code pushed)
                OR 6 bytes (no error code pushed); THEN #SS(0);
            FI;
    IF instruction pointer not within code segment limit THEN #GP(0); FI;
    IF 32-bit gate
        THEN
            Push (EFLAGS);
            Push (far pointer to return instruction); (* 3 words padded to 4 *)
            CS:EIP ← Gate(CS:EIP); (* segment descriptor information also loaded *)
            Push (ErrorCode); (* if any *)
        ELSE (* 16-bit gate *)
            Push (FLAGS);
            Push (far pointer to return location); (* 2 words *)
            CS:IP ← Gate(CS:IP); (* segment descriptor information also loaded *)
            Push (ErrorCode); (* if any *)
    FI;
    CS(RPL) ← CPL;
    IF interrupt gate
        THEN
            IF ← 0; FI;
            TF ← 0;
            NT ← 0;
            VM ← 0;
            RF ← 0;
    FI;
END;
```

Flags Affected

The EFLAGS register is pushed onto the stack. The IF, TF, NT, AC, RF, and VM flags may be cleared, depending on the mode of operation of the processor when the INT instruction is executed (refer to the “Operation” section). If the interrupt uses a task gate, any flags may be set or cleared, controlled by the EFLAGS image in the new task’s TSS.

INT *n*/INTO/INT 3—Call to Interrupt Procedure (Continued)

Protected Mode Exceptions

#GP(0)	If the instruction pointer in the IDT or in the interrupt-, trap-, or task gate is beyond the code segment limits.
#GP(selector)	If the segment selector in the interrupt-, trap-, or task gate is null.
	If a interrupt-, trap-, or task gate, code segment, or TSS segment selector index is outside its descriptor table limits.
	If the interrupt vector number is outside the IDT limits.
	If an IDT descriptor is not an interrupt-, trap-, or task-descriptor.
	If an interrupt is generated by the INT *n*, INT 3, or INTO instruction and the DPL of an interrupt-, trap-, or task-descriptor is less than the CPL.
	If the segment selector in an interrupt- or trap-gate does not point to a segment descriptor for a code segment.
	If the segment selector for a TSS has its local/global bit set for local.
	If a TSS segment descriptor specifies that the TSS is busy or not available.
#SS(0)	If pushing the return address, flags, or error code onto the stack exceeds the bounds of the stack segment and no stack switch occurs.
#SS(selector)	If the SS register is being loaded and the segment pointed to is marked not present.
	If pushing the return address, flags, error code, or stack segment pointer exceeds the bounds of the new stack segment when a stack switch occurs.
#NP(selector)	If code segment, interrupt-, trap-, or task gate, or TSS is not present.
#TS(selector)	If the RPL of the stack segment selector in the TSS is not equal to the DPL of the code segment being accessed by the interrupt or trap gate.
	If DPL of the stack segment descriptor pointed to by the stack segment selector in the TSS is not equal to the DPL of the code segment descriptor for the interrupt or trap gate.
	If the stack segment selector in the TSS is null.
	If the stack segment for the TSS is not a writable data segment.
	If segment-selector index for stack segment is outside descriptor table limits.
#PF(fault-code)	If a page fault occurs.

INT *n*/INTO/INT 3—Call to Interrupt Procedure (Continued)

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the interrupt vector number is outside the IDT limits.
#SS	If stack limit violation on push.
	If pushing the return address, flags, or error code onto the stack exceeds the bounds of the stack segment.

INT *n*/INTO/INT 3—Call to Interrupt Procedure (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	(For INT *n*, INTO, or BOUND instruction) If the IOPL is less than 3 or the DPL of the interrupt-, trap-, or task-gate descriptor is not equal to 3.
	If the instruction pointer in the IDT or in the interrupt-, trap-, or task gate is beyond the code segment limits.
#GP(selector)	If the segment selector in the interrupt-, trap-, or task gate is null.
	If a interrupt-, trap-, or task gate, code segment, or TSS segment selector index is outside its descriptor table limits.
	If the interrupt vector number is outside the IDT limits.
	If an IDT descriptor is not an interrupt-, trap-, or task-descriptor.
	If an interrupt is generated by the INT *n* instruction and the DPL of an interrupt-, trap-, or task-descriptor is less than the CPL.
	If the segment selector in an interrupt- or trap-gate does not point to a segment descriptor for a code segment.
	If the segment selector for a TSS has its local/global bit set for local.
#SS(selector)	If the SS register is being loaded and the segment pointed to is marked not present.
	If pushing the return address, flags, error code, stack segment pointer, or data segments exceeds the bounds of the stack segment.
#NP(selector)	If code segment, interrupt-, trap-, or task gate, or TSS is not present.
#TS(selector)	If the RPL of the stack segment selector in the TSS is not equal to the DPL of the code segment being accessed by the interrupt or trap gate.
	If DPL of the stack segment descriptor for the TSS's stack segment is not equal to the DPL of the code segment descriptor for the interrupt or trap gate.
	If the stack segment selector in the TSS is null.
	If the stack segment for the TSS is not a writable data segment.
	If segment-selector index for stack segment is outside descriptor table limits.
#PF(fault-code)	If a page fault occurs.
#BP	If the INT 3 instruction is executed.
#OF	If the INTO instruction is executed and the OF flag is set.

INVD—Invalidate Internal Caches

Opcode	Instruction	Description
0F 08	INVD	Flush internal caches; initiate flushing of external caches.

Description

This instruction invalidates (flushes) the processor's internal caches and issues a special-function bus cycle that directs external caches to also flush themselves. Data held in internal caches is not written back to main memory.

After executing this instruction, the processor does not wait for the external caches to complete their flushing operation before proceeding with instruction execution. It is the responsibility of hardware to respond to the cache flush signal.

The INVD instruction is a privileged instruction. When the processor is running in protected mode, the CPL of a program or procedure must be 0 to execute this instruction.

Use this instruction with care. Data cached internally and not written back to main memory will be lost. Unless there is a specific requirement or benefit to flushing caches without writing back modified cache lines (for example, testing or fault recovery where cache coherency with main memory is not a concern), software should use the WBINVD instruction.

Intel Architecture Compatibility

The INVD instruction is implementation dependent, and its function may be implemented differently on future Intel Architecture processors. This instruction is not supported on Intel Architecture processors earlier than the Intel486™ processor.

Operation

```
Flush(InternalCaches);
SignalFlush(ExternalCaches);
Continue (* Continue execution);
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the current privilege level is not 0.

INVD—Invalidate Internal Caches (Continued)

Real-Address Mode Exceptions

None.

Virtual-8086 Mode Exceptions

#GP(0)	The INVD instruction cannot be executed in virtual-8086 mode.

INVLPG—Invalidate TLB Entry

Opcode	Instruction	Description
0F 01/7	INVLPG m	Invalidate TLB Entry for page that contains *m*

Description

This instruction invalidates (flushes) the translation lookaside buffer (TLB) entry specified with the source operand. The source operand is a memory address. The processor determines the page that contains that address and flushes the TLB entry for that page.

The INVLPG instruction is a privileged instruction. When the processor is running in protected mode, the CPL of a program or procedure must be 0 to execute this instruction.

The INVLPG instruction normally flushes the TLB entry only for the specified page; however, in some cases, it flushes the entire TLB. Refer to "MOV—Move to/from Control Registers" in this chapter for further information on operations that flush the TLB.

Intel Architecture Compatibility

The INVLPG instruction is implementation dependent, and its function may be implemented differently on future Intel Architecture processors. This instruction is not supported on Intel Architecture processors earlier than the Intel486™ processor.

Operation

```
Flush(RelevantTLBEntries);
Continue (* Continue execution);
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the current privilege level is not 0.
#UD	Operand is a register.

Real-Address Mode Exceptions

#UD	Operand is a register.

Virtual-8086 Mode Exceptions

#GP(0)	The INVLPG instruction cannot be executed at the virtual-8086 mode.

IRET/IRETD—Interrupt Return

Opcode	Instruction	Description
CF	IRET	Interrupt return (16-bit operand size)
CF	IRETD	Interrupt return (32-bit operand size)

Description

These instructions return program control from an exception or interrupt handler to a program or procedure that was interrupted by an exception, an external interrupt, or a software-generated interrupt. These instructions are also used to perform a return from a nested task. (A nested task is created when a CALL instruction is used to initiate a task switch or when an interrupt or exception causes a task switch to an interrupt or exception handler.) Refer to Section 6.4., *Task Linking* in Chapter 6, *Task Management* of the *Intel Architecture Software Developer's Manual, Volume 3*.

IRET and IRETD are mnemonics for the same opcode. The IRETD mnemonic (interrupt return double) is intended for use when returning from an interrupt when using the 32-bit operand size; however, most assemblers use the IRET mnemonic interchangeably for both operand sizes.

In Real-Address Mode, the IRET instruction preforms a far return to the interrupted program or procedure. During this operation, the processor pops the return instruction pointer, return code segment selector, and EFLAGS image from the stack to the EIP, CS, and EFLAGS registers, respectively, and then resumes execution of the interrupted program or procedure.

In Protected Mode, the action of the IRET instruction depends on the settings of the NT (nested task) and VM flags in the EFLAGS register and the VM flag in the EFLAGS image stored on the current stack. Depending on the setting of these flags, the processor performs the following types of interrupt returns:

- Return from virtual-8086 mode.
- Return to virtual-8086 mode.
- Intra-privilege level return.
- Inter-privilege level return.
- Return from nested task (task switch).

If the NT flag (EFLAGS register) is cleared, the IRET instruction performs a far return from the interrupt procedure, without a task switch. The code segment being returned to must be equally or less privileged than the interrupt handler routine (as indicated by the RPL field of the code segment selector popped from the stack). As with a real-address mode interrupt return, the IRET instruction pops the return instruction pointer, return code segment selector, and EFLAGS image from the stack to the EIP, CS, and EFLAGS registers, respectively, and then resumes execution of the interrupted program or procedure. If the return is to another privilege level, the IRET instruction also pops the stack pointer and SS from the stack, before resuming program execution. If the return is to virtual-8086 mode, the processor also pops the data segment registers from the stack.

IRET/IRETD—Interrupt Return (Continued)

If the NT flag is set, the IRET instruction performs a task switch (return) from a nested task (a task called with a CALL instruction, an interrupt, or an exception) back to the calling or interrupted task. The updated state of the task executing the IRET instruction is saved in its TSS. If the task is re-entered later, the code that follows the IRET instruction is executed.

Operation

```
IF PE = 0
    THEN
        GOTO REAL-ADDRESS-MODE:;
    ELSE
        GOTO PROTECTED-MODE;
FI;

REAL-ADDRESS-MODE;
    IF OperandSize = 32
        THEN
            IF top 12 bytes of stack not within stack limits THEN #SS; FI;
            IF instruction pointer not within code segment limits THEN #GP(0); FI;
            EIP ← Pop();
            CS ← Pop(); (* 32-bit pop, high-order 16 bits discarded *)
            tempEFLAGS ← Pop();
            EFLAGS ← (tempEFLAGS AND 257FD5H) OR (EFLAGS AND 1A0000H);
        ELSE (* OperandSize = 16 *)
            IF top 6 bytes of stack are not within stack limits THEN #SS; FI;
            IF instruction pointer not within code segment limits THEN #GP(0); FI;
            EIP ← Pop();
            EIP ← EIP AND 0000FFFFH;
            CS ← Pop(); (* 16-bit pop *)
            EFLAGS[15:0] ← Pop();
    FI;
END;

PROTECTED-MODE:
    IF VM = 1 (* Virtual-8086 mode: PE=1, VM=1 *)
        THEN
            GOTO RETURN-FROM-VIRTUAL-8086-MODE; (* PE=1, VM=1 *)
    FI;
    IF NT = 1
        THEN
            GOTO TASK-RETURN;( *PE=1, VM=0, NT=1 *)
    FI;
    IF OperandSize=32
        THEN
            IF top 12 bytes of stack not within stack limits
                THEN #SS(0)
```

IRET/IRETD—Interrupt Return (Continued)

```
            FI;
            tempEIP ← Pop();
            tempCS ← Pop();
            tempEFLAGS ← Pop();
        ELSE (* OperandSize = 16 *)
            IF top 6 bytes of stack are not within stack limits
                THEN #SS(0);
            FI;
            tempEIP ← Pop();
            tempCS ← Pop();
            tempEFLAGS ← Pop();
            tempEIP ← tempEIP AND FFFFH;
            tempEFLAGS ← tempEFLAGS AND FFFFH;
    FI;
    IF tempEFLAGS(VM) = 1 AND CPL=0
        THEN
            GOTO RETURN-TO-VIRTUAL-8086-MODE;
            (* PE=1, VM=1 in EFLAGS image *)
        ELSE
            GOTO PROTECTED-MODE-RETURN;
            (* PE=1, VM=0 in EFLAGS image *)
    FI;

RETURN-FROM-VIRTUAL-8086-MODE:
(* Processor is in virtual-8086 mode when IRET is executed and stays in virtual-8086 mode *)
    IF IOPL=3 (* Virtual mode: PE=1, VM=1, IOPL=3 *)
        THEN IF OperandSize = 32
            THEN
                IF top 12 bytes of stack not within stack limits THEN #SS(0); FI;
                IF instruction pointer not within code segment limits THEN #GP(0); FI;
                EIP ← Pop();
                CS ← Pop(); (* 32-bit pop, high-order 16 bits discarded *)
                EFLAGS ← Pop();
                (*VM,IOPL,VIP,and VIF EFLAGS bits are not modified by pop *)
            ELSE (* OperandSize = 16 *)
                IF top 6 bytes of stack are not within stack limits THEN #SS(0); FI;
                IF instruction pointer not within code segment limits THEN #GP(0); FI;
                EIP ← Pop();
                EIP ← EIP AND 0000FFFFH;
                CS ← Pop(); (* 16-bit pop *)
                EFLAGS[15:0] ← Pop(); (* IOPL in EFLAGS is not modified by pop *)
            FI;
        ELSE
            #GP(0); (* trap to virtual-8086 monitor: PE=1, VM=1, IOPL<3 *)
    FI;
```

IRET/IRETD—Interrupt Return (Continued)

```
END;

RETURN-TO-VIRTUAL-8086-MODE:
(* Interrupted procedure was in virtual-8086 mode: PE=1, VM=1 in flags image *)
    IF top 24 bytes of stack are not within stack segment limits
        THEN #SS(0);
    FI;
    IF instruction pointer not within code segment limits
        THEN #GP(0);
    FI;
    CS ← tempCS;
    EIP ← tempEIP;
    EFLAGS ← tempEFLAGS
    TempESP ← Pop();
    TempSS ← Pop();
    ES ← Pop(); (* pop 2 words; throw away high-order word *)
    DS ← Pop(); (* pop 2 words; throw away high-order word *)
    FS ← Pop(); (* pop 2 words; throw away high-order word *)
    GS ← Pop(); (* pop 2 words; throw away high-order word *)
    SS:ESP ← TempSS:TempESP;
    (* Resume execution in Virtual-8086 mode *)
END;

TASK-RETURN: (* PE=1, VM=0, NT=1 *)
    Read segment selector in link field of current TSS;
    IF local/global bit is set to local
        OR index not within GDT limits
            THEN #GP(TSS selector);
    FI;
    Access TSS for task specified in link field of current TSS;
    IF TSS descriptor type is not TSS or if the TSS is marked not busy
        THEN #GP(TSS selector);
    FI;
    IF TSS not present
        THEN #NP(TSS selector);
    FI;
    SWITCH-TASKS (without nesting) to TSS specified in link field of current TSS;
    Mark the task just abandoned as NOT BUSY;
    IF EIP is not within code segment limit
        THEN #GP(0);
    FI;
END;

PROTECTED-MODE-RETURN: (* PE=1, VM=0 in flags image *)
    IF return code segment selector is null THEN GP(0); FI;
    IF return code segment selector addrsses descriptor beyond descriptor table limit
```

IRET/IRETD—Interrupt Return (Continued)

```
        THEN GP(selector; FI;
    Read segment descriptor pointed to by the return code segment selector
    IF return code segment descriptor is not a code segment THEN #GP(selector); FI;
    IF return code segment selector RPL < CPL THEN #GP(selector); FI;
    IF return code segment descriptor is conforming
        AND return code segment DPL > return code segment selector RPL
            THEN #GP(selector); FI;
    IF return code segment descriptor is not present THEN #NP(selector); FI:
    IF return code segment selector RPL > CPL
        THEN GOTO RETURN-OUTER-PRIVILEGE-LEVEL;
        ELSE GOTO RETURN-TO-SAME-PRIVILEGE-LEVEL
    FI;
END;

RETURN-TO-SAME-PRIVILEGE-LEVEL: (* PE=1, VM=0 in flags image, RPL=CPL *)
    IF EIP is not within code segment limits THEN #GP(0); FI;
    EIP ← tempEIP;
    CS ← tempCS; (* segment descriptor information also loaded *)
    EFLAGS (CF, PF, AF, ZF, SF, TF, DF, OF, NT) ← tempEFLAGS;
    IF OperandSize=32
        THEN
            EFLAGS(RF, AC, ID) ← tempEFLAGS;
    FI;
    IF CPL ≤ IOPL
        THEN
            EFLAGS(IF) ← tempEFLAGS;
    FI;
    IF CPL = 0
        THEN
            EFLAGS(IOPL) ← tempEFLAGS;
            IF OperandSize=32
                THEN EFLAGS(VM, VIF, VIP) ← tempEFLAGS;
            FI;
    FI;
END;

RETURN-TO-OUTER-PRIVILGE-LEVEL:
    IF OperandSize=32
        THEN
            IF top 8 bytes on stack are not within limits THEN #SS(0); FI;
        ELSE (* OperandSize=16 *)
            IF top 4 bytes on stack are not within limits THEN #SS(0); FI;
    FI;
    Read return segment selector;
    IF stack segment selector is null THEN #GP(0); FI;
    IF return stack segment selector index is not within its descriptor table limits
```

IRET/IRETD—Interrupt Return (Continued)

```
            THEN #GP(SSselector); FI;
    Read segment descriptor pointed to by return segment selector;
    IF stack segment selector RPL ≠ RPL of the return code segment selector
        IF stack segment selector RPL ≠ RPL of the return code segment selector
        OR the stack segment descriptor does not indicate a a writable data segment;
        OR stack segment DPL ≠ RPL of the return code segment selector
                THEN #GP(SS selector);
        FI;
        IF stack segment is not present THEN #SS(SS selector); FI;
    IF tempEIP is not within code segment limit THEN #GP(0); FI;
    EIP ← tempEIP;
    CS ← tempCS;
    EFLAGS (CF, PF, AF, ZF, SF, TF, DF, OF, NT) ← tempEFLAGS;
    IF OperandSize=32
        THEN
            EFLAGS(RF, AC, ID) ← tempEFLAGS;
    FI;
    IF CPL ≤ IOPL
        THEN
            EFLAGS(IF) ← tempEFLAGS;
    FI;
    IF CPL = 0
        THEN
            EFLAGS(IOPL) ← tempEFLAGS;
            IF OperandSize=32
                THEN EFLAGS(VM, VIF, VIP) ← tempEFLAGS;
            FI;
    FI;
    CPL ← RPL of the return code segment selector;
    FOR each of segment register (ES, FS, GS, and DS)
        DO;
            IF segment register points to data or non-conforming code segment
            AND CPL > segment descriptor DPL (* stored in hidden part of segment register *)
                THEN (* segment register invalid *)
                    SegmentSelector ← 0; (* null segment selector *)
            FI;
        OD;
END:
```

Flags Affected

All the flags and fields in the EFLAGS register are potentially modified, depending on the mode of operation of the processor. If performing a return from a nested task to a previous task, the EFLAGS register will be modified according to the EFLAGS image stored in the previous task's TSS.

IRET/IRETD—Interrupt Return (Continued)

Protected Mode Exceptions

#GP(0)	If the return code or stack segment selector is null.
	If the return instruction pointer is not within the return code segment limit.
#GP(selector)	If a segment selector index is outside its descriptor table limits.
	If the return code segment selector RPL is greater than the CPL.
	If the DPL of a conforming-code segment is greater than the return code segment selector RPL.
	If the DPL for a nonconforming-code segment is not equal to the RPL of the code segment selector.
	If the stack segment descriptor DPL is not equal to the RPL of the return code segment selector.
	If the stack segment is not a writable data segment.
	If the stack segment selector RPL is not equal to the RPL of the return code segment selector.
	If the segment descriptor for a code segment does not indicate it is a code segment.
	If the segment selector for a TSS has its local/global bit set for local.
	If a TSS segment descriptor specifies that the TSS is busy or not available.
#SS(0)	If the top bytes of stack are not within stack limits.
#NP(selector)	If the return code or stack segment is not present.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory reference occurs when the CPL is 3 and alignment checking is enabled.

Real-Address Mode Exceptions

#GP	If the return instruction pointer is not within the return code segment limit.
#SS	If the top bytes of stack are not within stack limits.

IRET/IRETD—Interrupt Return (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If the return instruction pointer is not within the return code segment limit.
	IF IOPL not equal to 3
#PF(fault-code)	If a page fault occurs.
#SS(0)	If the top bytes of stack are not within stack limits.
#AC(0)	If an unaligned memory reference occurs and alignment checking is enabled.

J*cc*—Jump if Condition Is Met

Opcode	Instruction	Description
77 *cb*	JA *rel8*	Jump short if above (CF=0 and ZF=0)
73 *cb*	JAE *rel8*	Jump short if above or equal (CF=0)
72 *cb*	JB *rel8*	Jump short if below (CF=1)
76 *cb*	JBE *rel8*	Jump short if below or equal (CF=1 or ZF=1)
72 *cb*	JC *rel8*	Jump short if carry (CF=1)
E3 *cb*	JCXZ *rel8*	Jump short if CX register is 0
E3 *cb*	JECXZ *rel8*	Jump short if ECX register is 0
74 *cb*	JE *rel8*	Jump short if equal (ZF=1)
7F *cb*	JG *rel8*	Jump short if greater (ZF=0 and SF=OF)
7D *cb*	JGE *rel8*	Jump short if greater or equal (SF=OF)
7C *cb*	JL *rel8*	Jump short if less (SF<>OF)
7E *cb*	JLE *rel8*	Jump short if less or equal (ZF=1 or SF<>OF)
76 *cb*	JNA *rel8*	Jump short if not above (CF=1 or ZF=1)
72 *cb*	JNAE *rel8*	Jump short if not above or equal (CF=1)
73 *cb*	JNB *rel8*	Jump short if not below (CF=0)
77 *cb*	JNBE *rel8*	Jump short if not below or equal (CF=0 and ZF=0)
73 *cb*	JNC *rel8*	Jump short if not carry (CF=0)
75 *cb*	JNE *rel8*	Jump short if not equal (ZF=0)
7E *cb*	JNG *rel8*	Jump short if not greater (ZF=1 or SF<>OF)
7C *cb*	JNGE *rel8*	Jump short if not greater or equal (SF<>OF)
7D *cb*	JNL *rel8*	Jump short if not less (SF=OF)
7F *cb*	JNLE *rel8*	Jump short if not less or equal (ZF=0 and SF=OF)
71 *cb*	JNO *rel8*	Jump short if not overflow (OF=0)
7B *cb*	JNP *rel8*	Jump short if not parity (PF=0)
79 *cb*	JNS *rel8*	Jump short if not sign (SF=0)
75 *cb*	JNZ *rel8*	Jump short if not zero (ZF=0)
70 *cb*	JO *rel8*	Jump short if overflow (OF=1)
7A *cb*	JP *rel8*	Jump short if parity (PF=1)
7A *cb*	JPE *rel8*	Jump short if parity even (PF=1)
7B *cb*	JPO *rel8*	Jump short if parity odd (PF=0)
78 *cb*	JS *rel8*	Jump short if sign (SF=1)
74 *cb*	JZ *rel8*	Jump short if zero (ZF = 1)
0F 87 *cw/cd*	JA *rel16/32*	Jump near if above (CF=0 and ZF=0)
0F 83 *cw/cd*	JAE *rel16/32*	Jump near if above or equal (CF=0)
0F 82 *cw/cd*	JB *rel16/32*	Jump near if below (CF=1)
0F 86 *cw/cd*	JBE *rel16/32*	Jump near if below or equal (CF=1 or ZF=1)
0F 82 *cw/cd*	JC *rel16/32*	Jump near if carry (CF=1)

J*cc*—Jump if Condition Is Met (Continued)

Opcode	Instruction	Description
0F 84 *cw/cd*	JE *rel16/32*	Jump near if equal (ZF=1)
0F 8F *cw/cd*	JG *rel16/32*	Jump near if greater (ZF=0 and SF=OF)
0F 8D *cw/cd*	JGE *rel16/32*	Jump near if greater or equal (SF=OF)
0F 8C *cw/cd*	JL *rel16/32*	Jump near if less (SF<>OF)
0F 8E *cw/cd*	JLE *rel16/32*	Jump near if less or equal (ZF=1 or SF<>OF)
0F 86 *cw/cd*	JNA *rel16/32*	Jump near if not above (CF=1 or ZF=1)
0F 82 *cw/cd*	JNAE *rel16/32*	Jump near if not above or equal (CF=1)
0F 83 *cw/cd*	JNB *rel16/32*	Jump near if not below (CF=0)
0F 87 *cw/cd*	JNBE *rel16/32*	Jump near if not below or equal (CF=0 and ZF=0)
0F 83 *cw/cd*	JNC *rel16/32*	Jump near if not carry (CF=0)
0F 85 *cw/cd*	JNE *rel16/32*	Jump near if not equal (ZF=0)
0F 8E *cw/cd*	JNG *rel16/32*	Jump near if not greater (ZF=1 or SF<>OF)
0F 8C *cw/cd*	JNGE *rel16/32*	Jump near if not greater or equal (SF<>OF)
0F 8D *cw/cd*	JNL *rel16/32*	Jump near if not less (SF=OF)
0F 8F *cw/cd*	JNLE *rel16/32*	Jump near if not less or equal (ZF=0 and SF=OF)
0F 81 *cw/cd*	JNO *rel16/32*	Jump near if not overflow (OF=0)
0F 8B *cw/cd*	JNP *rel16/32*	Jump near if not parity (PF=0)
0F 89 *cw/cd*	JNS *rel16/32*	Jump near if not sign (SF=0)
0F 85 *cw/cd*	JNZ *rel16/32*	Jump near if not zero (ZF=0)
0F 80 *cw/cd*	JO *rel16/32*	Jump near if overflow (OF=1)
0F 8A *cw/cd*	JP *rel16/32*	Jump near if parity (PF=1)
0F 8A *cw/cd*	JPE *rel16/32*	Jump near if parity even (PF=1)
0F 8B *cw/cd*	JPO *rel16/32*	Jump near if parity odd (PF=0)
0F 88 *cw/cd*	JS *rel16/32*	Jump near if sign (SF=1)
0F 84 *cw/cd*	JZ *rel16/32*	Jump near if 0 (ZF=1)

Description

This instruction checks the state of one or more of the status flags in the EFLAGS register (CF, OF, PF, SF, and ZF) and, if the flags are in the specified state (condition), performs a jump to the target instruction specified by the destination operand. A condition code (*cc*) is associated with each instruction to indicate the condition being tested for. If the condition is not satisfied, the jump is not performed and execution continues with the instruction following the J*cc* instruction.

J*cc*—Jump if Condition Is Met (Continued)

The target instruction is specified with a relative offset (a signed offset relative to the current value of the instruction pointer in the EIP register). A relative offset (*rel8*, *rel16*, or *rel32*) is generally specified as a label in assembly code, but at the machine code level, it is encoded as a signed, 8-bit or 32-bit immediate value, which is added to the instruction pointer. Instruction coding is most efficient for offsets of –128 to +127. If the operand-size attribute is 16, the upper two bytes of the EIP register are cleared to 0s, resulting in a maximum instruction pointer size of 16 bits.

The conditions for each J*cc* mnemonic are given in the "Description" column of the table on the preceding page. The terms "less" and "greater" are used for comparisons of signed integers and the terms "above" and "below" are used for unsigned integers.

Because a particular state of the status flags can sometimes be interpreted in two ways, two mnemonics are defined for some opcodes. For example, the JA (jump if above) instruction and the JNBE (jump if not below or equal) instruction are alternate mnemonics for the opcode 77H.

The J*cc* instruction does not support far jumps (jumps to other code segments). When the target for the conditional jump is in a different segment, use the opposite condition from the condition being tested for the J*cc* instruction, and then access the target with an unconditional far jump (JMP instruction) to the other segment. For example, the following conditional far jump is illegal:

```
JZ FARLABEL;
```

To accomplish this far jump, use the following two instructions:

```
JNZ BEYOND;
JMP FARLABEL;
BEYOND:
```

The JECXZ and JCXZ instructions differs from the other J*cc* instructions because they do not check the status flags. Instead they check the contents of the ECX and CX registers, respectively, for 0. Either the CX or ECX register is chosen according to the address-size attribute. These instructions are useful at the beginning of a conditional loop that terminates with a conditional loop instruction (such as LOOPNE). They prevent entering the loop when the ECX or CX register is equal to 0, which would cause the loop to execute 2^{32} or 64K times, respectively, instead of zero times.

All conditional jumps are converted to code fetches of one or two cache lines, regardless of jump address or cacheability.

J*cc*—Jump if Condition Is Met (Continued)

Operation

```
IF condition
    THEN
         EIP ← EIP + SignExtend(DEST);
        IF OperandSize = 16
            THEN
                EIP ← EIP AND 0000FFFFH;
        FI;
FI;
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the offset being jumped to is beyond the limits of the CS segment.

Real-Address Mode Exceptions

#GP	If the offset being jumped to is beyond the limits of the CS segment or is outside of the effective address space from 0 to FFFFH. This condition can occur if 32-address size override prefix is used.

Virtual-8086 Mode Exceptions

#GP(0)	If the offset being jumped to is beyond the limits of the CS segment or is outside of the effective address space from 0 to FFFFH. This condition can occur if 32-address size override prefix is used.

JMP—Jump

Opcode	Instruction	Description
EB *cb*	JMP *rel8*	Jump short, relative, displacement relative to next instruction
E9 *cw*	JMP *rel16*	Jump near, relative, displacement relative to next instruction
E9 *cd*	JMP *rel32*	Jump near, relative, displacement relative to next instruction
FF /4	JMP *r/m16*	Jump near, absolute indirect, address given in *r/m16*
FF /4	JMP *r/m32*	Jump near, absolute indirect, address given in *r/m32*
EA *cd*	JMP *ptr16:16*	Jump far, absolute, address given in operand
EA *cp*	JMP *ptr16:32*	Jump far, absolute, address given in operand
FF /5	JMP *m16:16*	Jump far, absolute indirect, address given in *m16:16*
FF /5	JMP *m16:32*	Jump far, absolute indirect, address given in *m16:32*

Description

This instruction transfers program control to a different point in the instruction stream without recording return information. The destination (target) operand specifies the address of the instruction being jumped to. This operand can be an immediate value, a general-purpose register, or a memory location.

This instruction can be used to execute four different types of jumps:

- Near jump—A jump to an instruction within the current code segment (the segment currently pointed to by the CS register), sometimes referred to as an intrasegment jump.
- Short jump—A near jump where the jump range is limited to –128 to +127 from the current EIP value.
- Far jump—A jump to an instruction located in a different segment than the current code segment but at the same privilege level, sometimes referred to as an intersegment jump.
- Task switch—A jump to an instruction located in a different task.

A task switch can only be executed in protected mode. Refer to Chapter 6, *Task Management*, of the *Intel Architecture Software Developer's Manual, Volume 3*, for information on performing task switches with the JMP instruction.

Near and Short Jumps. When executing a near jump, the processor jumps to the address (within the current code segment) that is specified with the target operand. The target operand specifies either an absolute offset (that is an offset from the base of the code segment) or a relative offset (a signed displacement relative to the current value of the instruction pointer in the EIP register). A near jump to a relative offset of 8-bits (*rel8*) is referred to as a short jump. The CS register is not changed on near and short jumps.

An absolute offset is specified indirectly in a general-purpose register or a memory location (*r/m16* or *r/m32*). The operand-size attribute determines the size of the target operand (16 or 32 bits). Absolute offsets are loaded directly into the EIP register. If the operand-size attribute is 16, the upper two bytes of the EIP register are cleared to 0s, resulting in a maximum instruction pointer size of 16 bits.

JMP—Jump (Continued)

A relative offset (*rel8*, *rel16*, or *rel32*) is generally specified as a label in assembly code, but at the machine code level, it is encoded as a signed 8-, 16-, or 32-bit immediate value. This value is added to the value in the EIP register. (Here, the EIP register contains the address of the instruction following the JMP instruction). When using relative offsets, the opcode (for short vs. near jumps) and the operand-size attribute (for near relative jumps) determines the size of the target operand (8, 16, or 32 bits).

Far Jumps in Real-Address or Virtual-8086 Mode. When executing a far jump in real-address or virtual-8086 mode, the processor jumps to the code segment and offset specified with the target operand. Here the target operand specifies an absolute far address either directly with a pointer (*ptr16:16* or *ptr16:32*) or indirectly with a memory location (*m16:16* or *m16:32*). With the pointer method, the segment and address of the called procedure is encoded in the instruction, using a 4-byte (16-bit operand size) or 6-byte (32-bit operand size) far address immediate. With the indirect method, the target operand specifies a memory location that contains a 4-byte (16-bit operand size) or 6-byte (32-bit operand size) far address. The far address is loaded directly into the CS and EIP registers. If the operand-size attribute is 16, the upper two bytes of the EIP register are cleared to 0s.

Far Jumps in Protected Mode. When the processor is operating in protected mode, the JMP instruction can be used to perform the following three types of far jumps:

- A far jump to a conforming or non-conforming code segment.
- A far jump through a call gate.
- A task switch.

(The JMP instruction cannot be used to perform interprivilege level far jumps.)

In protected mode, the processor always uses the segment selector part of the far address to access the corresponding descriptor in the GDT or LDT. The descriptor type (code segment, call gate, task gate, or TSS) and access rights determine the type of jump to be performed.

If the selected descriptor is for a code segment, a far jump to a code segment at the same privilege level is performed. (If the selected code segment is at a different privilege level and the code segment is non-conforming, a general-protection exception is generated.) A far jump to the same privilege level in protected mode is very similar to one carried out in real-address or virtual-8086 mode. The target operand specifies an absolute far address either directly with a pointer (*ptr16:16* or *ptr16:32*) or indirectly with a memory location (*m16:16* or *m16:32*). The operand-size attribute determines the size of the offset (16 or 32 bits) in the far address. The new code segment selector and its descriptor are loaded into CS register, and the offset from the instruction is loaded into the EIP register. Note that a call gate (described in the next paragraph) can also be used to perform far call to a code segment at the same privilege level. Using this mechanism provides an extra level of indirection and is the preferred method of making jumps between 16-bit and 32-bit code segments.

JMP—Jump (Continued)

When executing a far jump through a call gate, the segment selector specified by the target operand identifies the call gate. (The offset part of the target operand is ignored.) The processor then jumps to the code segment specified in the call gate descriptor and begins executing the instruction at the offset specified in the call gate. No stack switch occurs. Here again, the target operand can specify the far address of the call gate either directly with a pointer (*ptr16:16* or *ptr16:32*) or indirectly with a memory location (*m16:16* or *m16:32*).

Executing a task switch with the JMP instruction, is somewhat similar to executing a jump through a call gate. Here the target operand specifies the segment selector of the task gate for the task being switched to (and the offset part of the target operand is ignored). The task gate in turn points to the TSS for the task, which contains the segment selectors for the task's code and stack segments. The TSS also contains the EIP value for the next instruction that was to be executed before the task was suspended. This instruction pointer value is loaded into EIP register so that the task begins executing again at this next instruction.

The JMP instruction can also specify the segment selector of the TSS directly, which eliminates the indirection of the task gate. Refer to Chapter 6, *Task Management*, of the *Intel Architecture Software Developer's Manual, Volume 3*, for detailed information on the mechanics of a task switch.

Note that when you execute at task switch with a JMP instruction, the nested task flag (NT) is not set in the EFLAGS register and the new TSS's previous task link field is not loaded with the old task's TSS selector. A return to the previous task can thus not be carried out by executing the IRET instruction. Switching tasks with the JMP instruction differs in this regard from the CALL instruction which does set the NT flag and save the previous task link information, allowing a return to the calling task with an IRET instruction.

JMP—Jump (Continued)

Operation

```
IF near jump
    THEN IF near relative jump
        THEN
            tempEIP ← EIP + DEST; (* EIP is instruction following JMP instruction*)
        ELSE (* near absolute jump *)
            tempEIP ← DEST;
    FI;
    IF tempEIP is beyond code segment limit THEN #GP(0); FI;
    IF OperandSize = 32
        THEN
            EIP ← tempEIP;
        ELSE (* OperandSize=16 *)
            EIP ← tempEIP AND 0000FFFFH;
    FI;
FI:

IF far jump AND (PE = 0 OR (PE = 1 AND VM = 1)) (* real-address or virtual-8086 mode *)
    THEN
        tempEIP ← DEST(offset); (* DEST is ptr16:32 or [m16:32] *)
        IF tempEIP is beyond code segment limit THEN #GP(0); FI;
        CS ← DEST(segment selector); (* DEST is ptr16:32 or [m16:32] *)
        IF OperandSize = 32
            THEN
                EIP ← tempEIP; (* DEST is ptr16:32 or [m16:32] *)
            ELSE (* OperandSize = 16 *)
                EIP ← tempEIP AND 0000FFFFH; (* clear upper 16 bits *)
        FI;
FI;
IF far jump AND (PE = 1 AND VM = 0) (* Protected mode, not virtual-8086 mode *)
    THEN
        IF effective address in the CS, DS, ES, FS, GS, or SS segment is illegal
            OR segment selector in target operand null
            THEN #GP(0);
        FI;
        IF segment selector index not within descriptor table limits
            THEN #GP(new selector);
        FI;
        Read type and access rights of segment descriptor;
        IF segment type is not a conforming or nonconforming code segment, call gate,
            task gate, or TSS THEN #GP(segment selector); FI;
        Depending on type and access rights
            GO TO CONFORMING-CODE-SEGMENT;
            GO TO NONCONFORMING-CODE-SEGMENT;
```

JMP—Jump (Continued)

```
                GO TO CALL-GATE;
                GO TO TASK-GATE;
                GO TO TASK-STATE-SEGMENT;
    ELSE
        #GP(segment selector);
FI;

CONFORMING-CODE-SEGMENT:
    IF DPL > CPL THEN #GP(segment selector); FI;
    IF segment not present THEN #NP(segment selector); FI;
    tempEIP ← DEST(offset);
    IF OperandSize=16
        THEN tempEIP ← tempEIP AND 0000FFFFH;
    FI;
    IF tempEIP not in code segment limit THEN #GP(0); FI;
    CS ← DEST(SegmentSelector); (* segment descriptor information also loaded *)
    CS(RPL) ← CPL
    EIP ← tempEIP;
END;

NONCONFORMING-CODE-SEGMENT:
    IF (RPL > CPL) OR (DPL ≠ CPL) THEN #GP(code segment selector); FI;

    IF segment not present THEN #NP(segment selector); FI;
    IF instruction pointer outside code segment limit THEN #GP(0); FI;
    tempEIP ← DEST(offset);
    IF OperandSize=16
        THEN tempEIP ← tempEIP AND 0000FFFFH;
    FI;
    IF tempEIP not in code segment limit THEN #GP(0); FI;
    CS ← DEST(SegmentSelector); (* segment descriptor information also loaded *)
    CS(RPL) ← CPL
    EIP ← tempEIP;
END;

CALL-GATE:
    IF call gate DPL < CPL
        OR call gate DPL < call gate segment-selector RPL
            THEN #GP(call gate selector); FI;
    IF call gate not present THEN #NP(call gate selector); FI;
    IF call gate code-segment selector is null THEN #GP(0); FI;
    IF call gate code-segment selector index is outside descriptor table limits
        THEN #GP(code segment selector); FI;
    Read code segment descriptor;
```

JMP—Jump (Continued)

```
    IF code-segment segment descriptor does not indicate a code segment
        OR code-segment segment descriptor is conforming and DPL > CPL
        OR code-segment segment descriptor is non-conforming and DPL ≠ CPL
            THEN #GP(code segment selector); FI;
    IF code segment is not present THEN #NP(code-segment selector); FI;
    IF instruction pointer is not within code-segment limit THEN #GP(0); FI;
    tempEIP ← DEST(offset);
    IF GateSize=16
        THEN tempEIP ← tempEIP AND 0000FFFFH;
    FI;
    IF tempEIP not in code segment limit THEN #GP(0); FI;
    CS ← DEST(SegmentSelector); (* segment descriptor information also loaded *)
    CS(RPL) ← CPL
    EIP ← tempEIP;
END;

TASK-GATE:
    IF task gate DPL < CPL
        OR task gate DPL < task gate segment-selector RPL
            THEN #GP(task gate selector); FI;
    IF task gate not present THEN #NP(gate selector); FI;
    Read the TSS segment selector in the task-gate descriptor;
    IF TSS segment selector local/global bit is set to local
        OR index not within GDT limits
        OR TSS descriptor specifies that the TSS is busy
            THEN #GP(TSS selector); FI;
    IF TSS not present THEN #NP(TSS selector); FI;
    SWITCH-TASKS to TSS;
    IF EIP not within code segment limit THEN #GP(0); FI;
END;

TASK-STATE-SEGMENT:
    IF TSS DPL < CPL
        OR TSS DPL < TSS segment-selector RPL
        OR TSS descriptor indicates TSS not available
            THEN #GP(TSS selector); FI;
    IF TSS is not present THEN #NP(TSS selector); FI;
    SWITCH-TASKS to TSS
    IF EIP not within code segment limit THEN #GP(0); FI;
END;
```

Flags Affected

All flags are affected if a task switch occurs; no flags are affected if a task switch does not occur.

JMP—Jump (Continued)

Protected Mode Exceptions

#GP(0)	If offset in target operand, call gate, or TSS is beyond the code segment limits.
	If the segment selector in the destination operand, call gate, task gate, or TSS is null.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#GP(selector)	If segment selector index is outside descriptor table limits.
	If the segment descriptor pointed to by the segment selector in the destination operand is not for a conforming-code segment, nonconforming-code segment, call gate, task gate, or task state segment.
	If the DPL for a nonconforming-code segment is not equal to the CPL
	(When not using a call gate.) If the RPL for the segment's segment selector is greater than the CPL.
	If the DPL for a conforming-code segment is greater than the CPL.
	If the DPL from a call-gate, task-gate, or TSS segment descriptor is less than the CPL or than the RPL of the call-gate, task-gate, or TSS's segment selector.
	If the segment descriptor for selector in a call gate does not indicate it is a code segment.
	If the segment descriptor for the segment selector in a task gate does not indicate available TSS.
	If the segment selector for a TSS has its local/global bit set for local.
	If a TSS segment descriptor specifies that the TSS is busy or not available.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NP (selector)	If the code segment being accessed is not present.
	If call gate, task gate, or TSS not present.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3. (Only occurs when fetching target from memory.)

JMP—Jump (Continued)

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If the target operand is beyond the code segment limits.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made. (Only occurs when fetching target from memory.)

LAHF—Load Status Flags into AH Register

Opcode	Instruction	Description
9F	LAHF	Load: AH = EFLAGS(SF:ZF:0:AF:0:PF:1:CF)

Description

This instruction moves the low byte of the EFLAGS register (which includes status flags SF, ZF, AF, PF, and CF) to the AH register. Reserved bits 1, 3, and 5 of the EFLAGS register are set in the AH register as shown in the “Operation” section below.

Operation

AH ← EFLAGS(SF:ZF:0:AF:0:PF:1:CF);

Flags Affected

None (that is, the state of the flags in the EFLAGS register is not affected).

Exceptions (All Operating Modes)

None.

LAR—Load Access Rights Byte

Opcode	Instruction	Description
0F 02 /*r*	LAR *r16,r/m16*	*r16* ← *r/m16* masked by FF00H
0F 02 /*r*	LAR *r32,r/m32*	*r32* ← *r/m32* masked by 00FxFF00H

Description

This instruction loads the access rights from the segment descriptor specified by the second operand (source operand) into the first operand (destination operand) and sets the ZF flag in the EFLAGS register. The source operand (which can be a register or a memory location) contains the segment selector for the segment descriptor being accessed. The destination operand is a general-purpose register.

The processor performs access checks as part of the loading process. Once loaded in the destination register, software can perform additional checks on the access rights information.

When the operand size is 32 bits, the access rights for a segment descriptor include the type and DPL fields and the S, P, AVL, D/B, and G flags, all of which are located in the second doubleword (bytes 4 through 7) of the segment descriptor. The doubleword is masked by 00FXFF00H before it is loaded into the destination operand. When the operand size is 16 bits, the access rights include the type and DPL fields. Here, the two lower-order bytes of the doubleword are masked by FF00H before being loaded into the destination operand.

This instruction performs the following checks before it loads the access rights in the destination register:

- Checks that the segment selector is not null.
- Checks that the segment selector points to a descriptor that is within the limits of the GDT or LDT being accessed
- Checks that the descriptor type is valid for this instruction. All code and data segment descriptors are valid for (can be accessed with) the LAR instruction. The valid system segment and gate descriptor types are given in the following table.
- If the segment is not a conforming code segment, it checks that the specified segment descriptor is visible at the CPL (that is, if the CPL and the RPL of the segment selector are less than or equal to the DPL of the segment selector).

If the segment descriptor cannot be accessed or is an invalid type for the instruction, the ZF flag is cleared and no access rights are loaded in the destination operand.

The LAR instruction can only be executed in protected mode.

LAR—Load Access Rights Byte (Continued)

Type	Name	Valid
0	Reserved	No
1	Available 16-bit TSS	Yes
2	LDT	Yes
3	Busy 16-bit TSS	Yes
4	16-bit call gate	Yes
5	16-bit/32-bit task gate	Yes
6	16-bit interrupt gate	No
7	16-bit trap gate	No
8	Reserved	No
9	Available 32-bit TSS	Yes
A	Reserved	No
B	Busy 32-bit TSS	Yes
C	32-bit call gate	Yes
D	Reserved	No
E	32-bit interrupt gate	No
F	32-bit trap gate	No

Operation

```
IF SRC(Offset) > descriptor table limit THEN ZF ← 0; FI;
Read segment descriptor;
IF SegmentDescriptor(Type) ≠ conforming code segment
    AND (CPL > DPL) OR (RPL > DPL)
    OR Segment type is not valid for instruction
        THEN
            ZF ← 0
        ELSE
            IF OperandSize = 32
                THEN
                    DEST ← [SRC] AND 00FxFF00H;
                ELSE (*OperandSize = 16*)
                    DEST ← [SRC] AND FF00H;
            FI;
FI;
```

LAR—Load Access Rights Byte (Continued)

Flags Affected

The ZF flag is set to 1 if the access rights are loaded successfully; otherwise, it is cleared to 0.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3. (Only occurs when fetching target from memory.)

Real-Address Mode Exceptions

#UD	The LAR instruction is not recognized in real-address mode.

Virtual-8086 Mode Exceptions

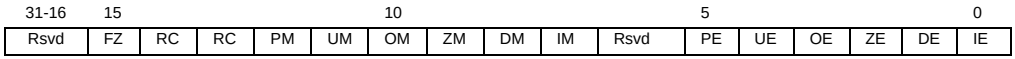
#UD	The LAR instruction cannot be executed in virtual-8086 mode.

LDMXCSR—Load Streaming SIMD Extension Control/Status

Opcode	Instruction	Description
0F,AE,/2	LDMXCSR m32	Load Streaming SIMD Extension control/status word from m32.

Description

The MXCSR control/status register is used to enable masked/unmasked exception handling, to set rounding modes, to set flush-to-zero mode, and to view exception status flags. The following figure shows the format and encoding of the fields in MXCSR



The default MXCSR value at reset is 0x1f80.

Bits 5-0 indicate whether a Streaming SIMD Extension numerical exception has been detected. They are “sticky” flags, and can be cleared by using the LDMXCSR instruction to write zeroes to these fields. If an LDMXCSR instruction clears a mask bit and sets the corresponding exception flag bit, an exception will not be immediately generated. The exception will occur only upon the next Streaming SIMD Extension to cause this type of exception. Streaming SIMD Extension uses only one exception flag for each exception. There is no provision for individual exception reporting within a packed data type. In situations where multiple identical exceptions occur within the same instruction, the associated exception flag is updated and indicates that at least one of these conditions happened. These flags are cleared upon reset.

Bits 12-7 configure numerical exception masking. An exception type is masked if the corresponding bit is set, and unmasked if the bit is clear. These enables are set upon reset, meaning that all numerical exceptions are masked.

Bits 14-13 encode the rounding-control, which provides for the common round-to-nearest mode, as well as directed rounding and true chop. Rounding control affects the arithmetic instructions and certain conversion instructions. The encoding for RC is as follows:

LDMXCSR—Load Streaming SIMD Extension Control/Status (Continued)

Rounding Mode	RC Field	Description
Round to nearest (even)	00B	Rounded result is the closest to the infinitely precise result. If two values are equally close, the result is the even value (that is, the one with the least-significant bit of zero).
Round down (to minus infinity)	01B	Rounded result is close to but no greater than the infinitely precise result
Round up (toward positive infinity)	10B	Rounded result is close to but no less than the infinitely precise result.
Round toward zero (truncate)	11B	Rounded result is close to but no greater in absolute value than the infinitely precise result.

The rounding-control is set to round to nearest upon reset.

Bit 15 (FZ) is used to turn on the Flush To Zero mode (bit is set). Turning on the Flush To Zero mode has the following effects during underflow situations:

- zero results are returned with the sign of the true result
- precision and underflow exception flags are set

The IEEE mandated masked response to underflow is to deliver the denormalized result (i.e., gradual underflow); consequently, the flush to zero mode is not compatible with IEEE Std. 754. It is provided primarily for performance reasons. At the cost of a slight precision loss, faster execution can be achieved for applications where underflows are common. Unmasking the underflow exception takes precedence over Flush To Zero mode. This arrangement means that an exception handler will be invoked for a Streaming SIMD Extension that generates an underflow condition while this exception is unmasked, regardless of whether flush to zero is enabled.

The other bits of MXCSR (bits 31-16 and bit 6) are defined as reserved and cleared; attempting to write a non-zero value to these bits, using either the FXRSTOR or LDMXCSR instructions, will result in a general protection exception.

The linear address corresponds to the address of the least-significant byte of the referenced memory data.

Operation

```
MXCSR = m32;
```

LDMXCSR—Load Streaming SIMD Extension Control/Status (Continued)

C/C++ Compiler Intrinsic Equivalent

_mm_setcsr(unsigned int i)

Sets the control register to the value specified.

Exceptions

General protection fault if reserved bits are loaded with non-zero values.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set. #AC for unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

LDMXCSR—Load Streaming SIMD Extension Control/Status (Continued)

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.
#AC	For unaligned memory reference.

Comments

The usage of Repeat Prefix (F3H) with LDMXCSR is reserved. Different processor implementations may handle this prefix differently. Usage of this prefix with LDMXCSR risks incompatibility with future processors.

LDS/LES/LFS/LGS/LSS—Load Far Pointer

Opcode	Instruction	Description
C5 /*r*	LDS *r16,m16:16*	Load DS:*r16* with far pointer from memory
C5 /*r*	LDS *r32,m16:32*	Load DS:*r32* with far pointer from memory
0F B2 /*r*	LSS *r16,m16:16*	Load SS:*r16* with far pointer from memory
0F B2 /*r*	LSS *r32,m16:32*	Load SS:*r32* with far pointer from memory
C4 /*r*	LES *r16,m16:16*	Load ES:*r16* with far pointer from memory
C4 /*r*	LES *r32,m16:32*	Load ES:*r32* with far pointer from memory
0F B4 /*r*	LFS *r16,m16:16*	Load FS:*r16* with far pointer from memory
0F B4 /*r*	LFS *r32,m16:32*	Load FS:*r32* with far pointer from memory
0F B5 /*r*	LGS *r16,m16:16*	Load GS:*r16* with far pointer from memory
0F B5 /*r*	LGS *r32,m16:32*	Load GS:*r32* with far pointer from memory

Description

These instructions load a far pointer (segment selector and offset) from the second operand (source operand) into a segment register and the first operand (destination operand). The source operand specifies a 48-bit or a 32-bit pointer in memory depending on the current setting of the operand-size attribute (32 bits or 16 bits, respectively). The instruction opcode and the destination operand specify a segment register/general-purpose register pair. The 16-bit segment selector from the source operand is loaded into the segment register specified with the opcode (DS, SS, ES, FS, or GS). The 32-bit or 16-bit offset is loaded into the register specified with the destination operand.

If one of these instructions is executed in protected mode, additional information from the segment descriptor pointed to by the segment selector in the source operand is loaded in the hidden part of the selected segment register.

Also in protected mode, a null selector (values 0000 through 0003) can be loaded into DS, ES, FS, or GS registers without causing a protection exception. (Any subsequent reference to a segment whose corresponding segment register is loaded with a null selector, causes a general-protection exception (#GP) and no memory reference to the segment occurs.)

LDS/LES/LFS/LGS/LSS—Load Far Pointer (Continued)

Operation

```
IF Protected Mode
    THEN IF SS is loaded
        THEN IF SegementSelector = null
            THEN #GP(0);
        FI;
        ELSE IF Segment selector index is not within descriptor table limits
        OR Segment selector RPL ≠ CPL
        OR Access rights indicate nonwritable data segment
        OR DPL ≠ CPL
            THEN #GP(selector);
        FI;
        ELSE IF Segment marked not present
            THEN #SS(selector);
        FI;
        SS ← SegmentSelector(SRC);
        SS ← SegmentDescriptor([SRC]);
    ELSE IF DS, ES, FS, or GS is loaded with non-null segment selector
        THEN IF Segment selector index is not within descriptor table limits
        OR Access rights indicate segment neither data nor readable code segment
        OR (Segment is data or nonconforming-code segment
            AND both RPL and CPL > DPL)
            THEN #GP(selector);
        FI;
        ELSE IF Segment marked not present
            THEN #NP(selector);
        FI;
        SegmentRegister ← SegmentSelector(SRC) AND RPL;
        SegmentRegister ← SegmentDescriptor([SRC]);
    ELSE IF DS, ES, FS or GS is loaded with a null selector:
        SegmentRegister ← NullSelector;
        SegmentRegister(DescriptorValidBit) ← 0; (*hidden flag; not accessible by software*)
    FI;
FI;
IF (Real-Address or Virtual-8086 Mode)
    THEN
        SegmentRegister ← SegmentSelector(SRC);
FI;
DEST ← Offset(SRC);
```

LDS/LES/LFS/LGS/LSS—Load Far Pointer (Continued)

Flags Affected

None.

Protected Mode Exceptions

#UD	If source operand is not a memory location.
#GP(0)	If a null selector is loaded into the SS register.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#GP(selector)	If the SS register is being loaded and any of the following is true: the segment selector index is not within the descriptor table limits, the segment selector RPL is not equal to CPL, the segment is a nonwritable data segment, or DPL is not equal to CPL.
	If the DS, ES, FS, or GS register is being loaded with a non-null segment selector and any of the following is true: the segment selector index is not within descriptor table limits, the segment is neither a data nor a readable code segment, or the segment is a data or nonconforming-code segment and both RPL and CPL are greater than DPL.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#SS(selector)	If the SS register is being loaded and the segment is marked not present.
#NP(selector)	If DS, ES, FS, or GS register is being loaded with a non-null segment selector and the segment is marked not present.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#UD	If source operand is not a memory location.

LDS/LES/LFS/LGS/LSS—Load Far Pointer (Continued)

Virtual-8086 Mode Exceptions

#UD	If source operand is not a memory location.
#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

LEA—Load Effective Address

Opcode	Instruction	Description
8D /*r*	LEA *r16,m*	Store effective address for *m* in register *r16*
8D /*r*	LEA *r32,m*	Store effective address for *m* in register *r32*

Description

This instruction computes the effective address of the second operand (the source operand) and stores it in the first operand (destination operand). The source operand is a memory address (offset part) specified with one of the processors addressing modes; the destination operand is a general-purpose register. The address-size and operand-size attributes affect the action performed by this instruction, as shown in the following table. The operand-size attribute of the instruction is determined by the chosen register; the address-size attribute is determined by the attribute of the code segment.

Operand Size	Address Size	Action Performed
16	16	16-bit effective address is calculated and stored in requested 16-bit register destination.
16	32	32-bit effective address is calculated. The lower 16 bits of the address are stored in the requested 16-bit register destination.
32	16	16-bit effective address is calculated. The 16-bit address is zero-extended and stored in the requested 32-bit register destination.
32	32	32-bit effective address is calculated and stored in the requested 32-bit register destination.

Different assemblers may use different algorithms based on the size attribute and symbolic reference of the source operand.

LEA—Load Effective Address (Continued)

Operation

```
IF OperandSize = 16 AND AddressSize = 16
    THEN
        DEST ← EffectiveAddress(SRC); (* 16-bit address *)
    ELSE IF OperandSize = 16 AND AddressSize = 32
        THEN
            temp ← EffectiveAddress(SRC); (* 32-bit address *)
            DEST ← temp[0..15]; (* 16-bit address *)
    ELSE IF OperandSize = 32 AND AddressSize = 16
        THEN
            temp ← EffectiveAddress(SRC); (* 16-bit address *)
            DEST ← ZeroExtend(temp); (* 32-bit address *)
    ELSE IF OperandSize = 32 AND AddressSize = 32
        THEN
            DEST ← EffectiveAddress(SRC); (* 32-bit address *)
    FI;
FI;
```

Flags Affected

None.

Protected Mode Exceptions

#UD	If source operand is not a memory location.

Real-Address Mode Exceptions

#UD	If source operand is not a memory location.

Virtual-8086 Mode Exceptions

#UD	If source operand is not a memory location.

LEAVE—High Level Procedure Exit

Opcode	Instruction	Description
C9	LEAVE	Set SP to BP, then pop BP
C9	LEAVE	Set ESP to EBP, then pop EBP

Description

This instruction releases the stack frame set up by an earlier ENTER instruction. The LEAVE instruction copies the frame pointer (in the EBP register) into the stack pointer register (ESP), which releases the stack space allocated to the stack frame. The old frame pointer (the frame pointer for the calling procedure that was saved by the ENTER instruction) is then popped from the stack into the EBP register, restoring the calling procedure's stack frame.

A RET instruction is commonly executed following a LEAVE instruction to return program control to the calling procedure.

Refer to Section 4.5., *Procedure Calls for Block-Structured Languages* in Chapter 4, *Procedure Calls, Interrupts, and Exceptions* of the *Intel Architecture Software Developer's Manual, Volume 1*, for detailed information on the use of the ENTER and LEAVE instructions.

Operation

```
IF StackAddressSize = 32
    THEN
        ESP ← EBP;
    ELSE (* StackAddressSize = 16*)
        SP ← BP;
FI;
IF OperandSize = 32
    THEN
        EBP ← Pop();
    ELSE (* OperandSize = 16*)
        BP ← Pop();
FI;
```

Flags Affected

None.

LEAVE—High Level Procedure Exit (Continued)

Protected Mode Exceptions

#SS(0)	If the EBP register points to a location that is not within the limits of the current stack segment.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If the EBP register points to a location outside of the effective address space from 0 to 0FFFFH.

Virtual-8086 Mode Exceptions

#GP(0)	If the EBP register points to a location outside of the effective address space from 0 to 0FFFFH.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

LES—Load Full Pointer

Refer to entry for LDS/LES/LFS/LGS/LSS—Load Far Pointer.

LFS—Load Full Pointer

Refer to entry for LDS/LES/LFS/LGS/LSS—Load Far Pointer.

LGDT/LIDT—Load Global/Interrupt Descriptor Table Register

Opcode	Instruction	Description
0F 01 /2	LGDT *m16&32*	Load *m* into GDTR
0F 01 /3	LIDT *m16&32*	Load *m* into IDTR

Description

These instructions load the values in the source operand into the global descriptor table register (GDTR) or the interrupt descriptor table register (IDTR). The source operand specifies a 6-byte memory location that contains the base address (a linear address) and the limit (size of table in bytes) of the global descriptor table (GDT) or the interrupt descriptor table (IDT). If operand-size attribute is 32 bits, a 16-bit limit (lower two bytes of the 6-byte data operand) and a 32-bit base address (upper four bytes of the data operand) are loaded into the register. If the operand-size attribute is 16 bits, a 16-bit limit (lower two bytes) and a 24-bit base address (third, fourth, and fifth byte) are loaded. Here, the high-order byte of the operand is not used and the high-order byte of the base address in the GDTR or IDTR is filled with zeroes.

The LGDT and LIDT instructions are used only in operating-system software; they are not used in application programs. They are the only instructions that directly load a linear address (that is, not a segment-relative address) and a limit in protected mode. They are commonly executed in real-address mode to allow processor initialization prior to switching to protected mode.

Refer to “SFENCE—Store Fence” in this chapter for information on storing the contents of the GDTR and IDTR.

Operation

```
IF instruction is LIDT
    THEN
        IF OperandSize = 16
            THEN
                IDTR(Limit) ← SRC[0:15];
                IDTR(Base) ← SRC[16:47] AND 00FFFFFFH;
            ELSE (* 32-bit Operand Size *)
                IDTR(Limit) ← SRC[0:15];
                IDTR(Base) ← SRC[16:47];
        FI;
    ELSE (* instruction is LGDT *)
        IF OperandSize = 16
            THEN
                GDTR(Limit) ← SRC[0:15];
                GDTR(Base) ← SRC[16:47] AND 00FFFFFFH;
            ELSE (* 32-bit Operand Size *)
                GDTR(Limit) ← SRC[0:15];
                GDTR(Base) ← SRC[16:47];
        FI; FI;
```

LGDT/LIDT—Load Global/Interrupt Descriptor Table Register (Continued)

Flags Affected

None.

Protected Mode Exceptions

#UD	If source operand is not a memory location.
#GP(0)	If the current privilege level is not 0.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.

Real-Address Mode Exceptions

#UD	If source operand is not a memory location.
#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.

LGS—Load Full Pointer

Refer to entry for LDS/LES/LFS/LGS/LSS—Load Far Pointer.

LLDT—Load Local Descriptor Table Register

Opcode	Instruction	Description
0F 00 /2	LLDT *r/m16*	Load segment selector *r/m16* into LDTR

Description

This instruction loads the source operand into the segment selector field of the local descriptor table register (LDTR). The source operand (a general-purpose register or a memory location) contains a segment selector that points to a local descriptor table (LDT). After the segment selector is loaded in the LDTR, the processor uses to segment selector to locate the segment descriptor for the LDT in the global descriptor table (GDT). It then loads the segment limit and base address for the LDT from the segment descriptor into the LDTR. The segment registers DS, ES, SS, FS, GS, and CS are not affected by this instruction, nor is the LDTR field in the task state segment (TSS) for the current task.

If the source operand is 0, the LDTR is marked invalid and all references to descriptors in the LDT (except by the LAR, VERR, VERW or LSL instructions) cause a general protection exception (#GP).

The operand-size attribute has no effect on this instruction.

The LLDT instruction is provided for use in operating-system software; it should not be used in application programs. Also, this instruction can only be executed in protected mode.

Operation

```
IF SRC(Offset) > descriptor table limit THEN #GP(segment selector); FI;
Read segment descriptor;
IF SegmentDescriptor(Type) ≠ LDT THEN #GP(segment selector); FI;
IF segment descriptor is not present THEN #NP(segment selector);
LDTR(SegmentSelector) ← SRC;
LDTR(SegmentDescriptor) ← GDTSegmentDescriptor;
```

Flags Affected

None.

LLDT—Load Local Descriptor Table Register (Continued)

Protected Mode Exceptions

#GP(0)	If the current privilege level is not 0.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#GP(selector)	If the selector operand does not point into the Global Descriptor Table or if the entry in the GDT is not a Local Descriptor Table.
	Segment selector is beyond GDT limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#NP(selector)	If the LDT descriptor is not present.
#PF(fault-code)	If a page fault occurs.

Real-Address Mode Exceptions

#UD	The LLDT instruction is not recognized in real-address mode.

Virtual-8086 Mode Exceptions

#UD	The LLDT instruction is recognized in virtual-8086 mode.

LIDT—Load Interrupt Descriptor Table Register

Refer to entry for LGDT/LIDT—Load Global/Interrupt Descriptor Table Register.

LMSW—Load Machine Status Word

Opcode	Instruction	Description
0F 01 /6	LMSW *r/m16*	Loads *r/m16* in machine status word of CR0

Description

This instruction loads the source operand into the machine status word, bits 0 through 15 of register CR0. The source operand can be a 16-bit general-purpose register or a memory location. Only the low-order four bits of the source operand (which contains the PE, MP, EM, and TS flags) are loaded into CR0. The PG, CD, NW, AM, WP, NE, and ET flags of CR0 are not affected. The operand-size attribute has no effect on this instruction.

If the PE flag of the source operand (bit 0) is set to 1, the instruction causes the processor to switch to protected mode. While in protected mode, the LMSW instruction cannot be used clear the PE flag and force a switch back to real-address mode.

The LMSW instruction is provided for use in operating-system software; it should not be used in application programs. In protected or virtual-8086 mode, it can only be executed at CPL 0.

This instruction is provided for compatibility with the Intel 286 processor; programs and procedures intended to run on the P6 family, Intel486™, and Intel386™ processors should use the MOV (control registers) instruction to load the whole CR0 register. The MOV CR0 instruction can be used to set and clear the PE flag in CR0, allowing a procedure or program to switch between protected and real-address modes.

This instruction is a serializing instruction.

Operation

```
CR0[0:3] ← SRC[0:3];
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the current privilege level is not 0.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.

LMSW—Load Machine Status Word (Continued)

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If the current privilege level is not 0.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.

LOCK—Assert LOCK# Signal Prefix

Opcode	Instruction	Description
F0	LOCK	Asserts LOCK# signal for duration of the accompanying instruction

Description

This instruction causes the processor's LOCK# signal to be asserted during execution of the accompanying instruction (turns the instruction into an atomic instruction). In a multiprocessor environment, the LOCK# signal insures that the processor has exclusive use of any shared memory while the signal is asserted.

Note that in later Intel Architecture processors (such as the Pentium® Pro processor), locking may occur without the LOCK# signal being asserted. Refer to Intel Architecture Compatibility below.

The LOCK prefix can be prepended only to the following instructions and to those forms of the instructions that use a memory operand: ADD, ADC, AND, BTC, BTR, BTS, CMPXCHG, DEC, INC, NEG, NOT, OR, SBB, SUB, XOR, XADD, and XCHG. An undefined opcode exception will be generated if the LOCK prefix is used with any other instruction. The XCHG instruction always asserts the LOCK# signal regardless of the presence or absence of the LOCK prefix.

The LOCK prefix is typically used with the BTS instruction to perform a read-modify-write operation on a memory location in shared memory environment.

The integrity of the LOCK prefix is not affected by the alignment of the memory field. Memory locking is observed for arbitrarily misaligned fields.

Intel Architecture Compatibility

Beginning with the Pentium® Pro processor, when the LOCK prefix is prefixed to an instruction and the memory area being accessed is cached internally in the processor, the LOCK# signal is generally not asserted. Instead, only the processor's cache is locked. Here, the processor's cache coherency mechanism insures that the operation is carried out atomically with regards to memory. Refer to Section 7.1.4., *Effects of a LOCK Operation on Internal Processor Caches* in Chapter 7, *Multiple-Processor Management* of the *Intel Architecture Software Developer's Manual, Volume 3*, the for more information on locking of caches.

Operation

```
AssertLOCK#(DurationOfAccompaningInstruction)
```

Flags Affected

None.

LOCK—Assert LOCK# Signal Prefix (Continued)

Protected Mode Exceptions

#UD	If the LOCK prefix is used with an instruction not listed in the “Description” section above. Other exceptions can be generated by the instruction that the LOCK prefix is being applied to.

Real-Address Mode Exceptions

#UD	If the LOCK prefix is used with an instruction not listed in the “Description” section above. Other exceptions can be generated by the instruction that the LOCK prefix is being applied to.

Virtual-8086 Mode Exceptions

#UD	If the LOCK prefix is used with an instruction not listed in the “Description” section above. Other exceptions can be generated by the instruction that the LOCK prefix is being applied to.

LODS/LODSB/LODSW/LODSD—Load String

Opcode	Instruction	Description
AC	LODS m8	Load byte at address DS:(E)SI into AL
AD	LODS m16	Load word at address DS:(E)SI into AX
AD	LODS m32	Load doubleword at address DS:(E)SI into EAX
AC	LODSB	Load byte at address DS:(E)SI into AL
AD	LODSW	Load word at address DS:(E)SI into AX
AD	LODSD	Load doubleword at address DS:(E)SI into EAX

Description

These instructions load a byte, word, or doubleword from the source operand into the AL, AX, or EAX register, respectively. The source operand is a memory location, the address of which is read from the DS:EDI or the DS:SI registers (depending on the address-size attribute of the instruction, 32 or 16, respectively). The DS segment may be overridden with a segment override prefix.

At the assembly-code level, two forms of this instruction are allowed: the “explicit-operands” form and the “no-operands” form. The explicit-operands form (specified with the LODS mnemonic) allows the source operand to be specified explicitly. Here, the source operand should be a symbol that indicates the size and location of the source value. The destination operand is then automatically selected to match the size of the source operand (the AL register for byte operands, AX for word operands, and EAX for doubleword operands). This explicit-operands form is provided to allow documentation; however, note that the documentation provided by this form can be misleading. That is, the source operand symbol must specify the correct **type** (size) of the operand (byte, word, or doubleword), but it does not have to specify the correct **location**. The location is always specified by the DS:(E)SI registers, which must be loaded correctly before the load string instruction is executed.

The no-operands form provides “short forms” of the byte, word, and doubleword versions of the LODS instructions. Here also DS:(E)SI is assumed to be the source operand and the AL, AX, or EAX register is assumed to be the destination operand. The size of the source and destination operands is selected with the mnemonic: LODSB (byte loaded into register AL), LODSW (word loaded into AX), or LODSD (doubleword loaded into EAX).

After the byte, word, or doubleword is transferred from the memory location into the AL, AX, or EAX register, the (E)SI register is incremented or decremented automatically according to the setting of the DF flag in the EFLAGS register. (If the DF flag is 0, the (E)SI register is incremented; if the DF flag is 1, the ESI register is decremented.) The (E)SI register is incremented or decremented by one for byte operations, by two for word operations, or by four for doubleword operations.

LODS/LODSB/LODSW/LODSD—Load String (Continued)

The LODS, LODSB, LODSW, and LODSD instructions can be preceded by the REP prefix for block loads of ECX bytes, words, or doublewords. More often, however, these instructions are used within a LOOP construct because further processing of the data moved into the register is usually necessary before the next transfer can be made. Refer to "REP/REPE/REPZ/REPNE /REPNZ—Repeat String Operation Prefix" in this chapter for a description of the REP prefix.

Operation

```
IF (byte load)
    THEN
        AL ← SRC; (* byte load *)
            THEN IF DF = 0
                THEN (E)SI ← (E)SI + 1;
                ELSE (E)SI ← (E)SI – 1;
            FI;
    ELSE IF (word load)
        THEN
            AX ← SRC; (* word load *)
                THEN IF DF = 0
                    THEN (E)SI ← (E)SI + 2;
                    ELSE (E)SI ← (E)SI – 2;
                FI;
        ELSE (* doubleword transfer *)
            EAX ← SRC; (* doubleword load *)
                THEN IF DF = 0
                    THEN (E)SI ← (E)SI + 4;
                    ELSE (E)SI ← (E)SI – 4;
                FI;
    FI;
FI;
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

LODS/LODSB/LODSW/LODSD—Load String (Continued)

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

LOOP/LOOP*cc*—Loop According to ECX Counter

Opcode	Instruction	Description
E2 *cb*	LOOP *rel8*	Decrement count; jump short if count ≠ 0
E1 *cb*	LOOPE *rel8*	Decrement count; jump short if count ≠ 0 and ZF=1
E1 *cb*	LOOPZ *rel8*	Decrement count; jump short if count ≠ 0 and ZF=1
E0 *cb*	LOOPNE *rel8*	Decrement count; jump short if count ≠ 0 and ZF=0
E0 *cb*	LOOPNZ *rel8*	Decrement count; jump short if count ≠ 0 and ZF=0

Description

These instructions perform a loop operation using the ECX or CX register as a counter. Each time the LOOP instruction is executed, the count register is decremented, then checked for 0. If the count is 0, the loop is terminated and program execution continues with the instruction following the LOOP instruction. If the count is not zero, a near jump is performed to the destination (target) operand, which is presumably the instruction at the beginning of the loop. If the address-size attribute is 32 bits, the ECX register is used as the count register; otherwise the CX register is used.

The target instruction is specified with a relative offset (a signed offset relative to the current value of the instruction pointer in the EIP register). This offset is generally specified as a label in assembly code, but at the machine code level, it is encoded as a signed, 8-bit immediate value, which is added to the instruction pointer. Offsets of –128 to +127 are allowed with this instruction.

Some forms of the loop instruction (LOOP*cc*) also accept the ZF flag as a condition for terminating the loop before the count reaches zero. With these forms of the instruction, a condition code (*cc*) is associated with each instruction to indicate the condition being tested for. Here, the LOOP*cc* instruction itself does not affect the state of the ZF flag; the ZF flag is changed by other instructions in the loop.

LOOP/LOOP*cc*—Loop According to ECX Counter (Continued)

Operation

```
IF AddressSize = 32
    THEN
        Count is ECX;
    ELSE (* AddressSize = 16 *)
        Count is CX;
FI;
Count ← Count – 1;

IF instruction is not LOOP
    THEN
        IF (instruction = LOOPE) OR (instruction = LOOPZ)
            THEN
                IF (ZF =1) AND (Count ≠ 0)
                    THEN BranchCond ← 1;
                    ELSE BranchCond ← 0;
                FI;
        FI;
        IF (instruction = LOOPNE) OR (instruction = LOOPNZ)
            THEN
                IF (ZF =0 ) AND (Count ≠ 0)
                    THEN BranchCond ← 1;
                    ELSE BranchCond ← 0;
                FI;
        FI;
    ELSE (* instruction = LOOP *)
        IF (Count ≠ 0)
            THEN BranchCond ← 1;
            ELSE BranchCond ← 0;
        FI;
FI;
IF BranchCond = 1
    THEN
         EIP ← EIP + SignExtend(DEST);
        IF OperandSize = 16
            THEN
                EIP ← EIP AND 0000FFFFH;
        FI;
    ELSE
        Terminate loop and continue program execution at EIP;
FI;
```

LOOP/LOOP*cc*—Loop According to ECX Counter (Continued)

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the offset jumped to is beyond the limits of the code segment.

Real-Address Mode Exceptions

None.

Virtual-8086 Mode Exceptions

None.

LSL—Load Segment Limit

Opcode	Instruction	Description
0F 03 /*r*	LSL *r16,r/m16*	Load: *r16* ← segment limit, selector *r/m16*
0F 03 /*r*	LSL *r32,r/m32*	Load: *r32* ← segment limit, selector *r/m32*)

Description

This instruction loads the unscrambled segment limit from the segment descriptor specified with the second operand (source operand) into the first operand (destination operand) and sets the ZF flag in the EFLAGS register. The source operand (which can be a register or a memory location) contains the segment selector for the segment descriptor being accessed. The destination operand is a general-purpose register.

The processor performs access checks as part of the loading process. Once loaded in the destination register, software can compare the segment limit with the offset of a pointer.

The segment limit is a 20-bit value contained in bytes 0 and 1 and in the first four bits of byte 6 of the segment descriptor. If the descriptor has a byte granular segment limit (the granularity flag is set to 0), the destination operand is loaded with a byte granular value (byte limit). If the descriptor has a page granular segment limit (the granularity flag is set to 1), the LSL instruction will translate the page granular limit (page limit) into a byte limit before loading it into the destination operand. The translation is performed by shifting the 20-bit “raw” limit left 12 bits and filling the low-order 12 bits with 1s.

When the operand size is 32 bits, the 32-bit byte limit is stored in the destination operand. When the operand size is 16 bits, a valid 32-bit limit is computed; however, the upper 16 bits are truncated and only the low-order 16 bits are loaded into the destination operand.

This instruction performs the following checks before it loads the segment limit into the destination register:

- Checks that the segment selector is not null.
- Checks that the segment selector points to a descriptor that is within the limits of the GDT or LDT being accessed
- Checks that the descriptor type is valid for this instruction. All code and data segment descriptors are valid for (can be accessed with) the LSL instruction. The valid special segment and gate descriptor types are given in the following table.
- If the segment is not a conforming code segment, the instruction checks that the specified segment descriptor is visible at the CPL (that is, if the CPL and the RPL of the segment selector are less than or equal to the DPL of the segment selector).

If the segment descriptor cannot be accessed or is an invalid type for the instruction, the ZF flag is cleared and no value is loaded in the destination operand.

LSL—Load Segment Limit (Continued)

Type	Name	Valid
0	Reserved	No
1	Available 16-bit TSS	Yes
2	LDT	Yes
3	Busy 16-bit TSS	Yes
4	16-bit call gate	No
5	16-bit/32-bit task gate	No
6	16-bit interrupt gate	No
7	16-bit trap gate	No
8	Reserved	No
9	Available 32-bit TSS	Yes
A	Reserved	No
B	Busy 32-bit TSS	Yes
C	32-bit call gate	No
D	Reserved	No
E	32-bit interrupt gate	No
F	32-bit trap gate	No

LSL—Load Segment Limit (Continued)

Operation

```
IF SRC(Offset) > descriptor table limit
    THEN ZF ← 0; FI;
Read segment descriptor;
IF SegmentDescriptor(Type) ≠ conforming code segment
    AND (CPL > DPL) OR (RPL > DPL)
    OR Segment type is not valid for instruction
        THEN
            ZF ← 0
        ELSE
            temp ← SegmentLimit([SRC]);
            IF (G = 1)
                THEN
                    temp ← ShiftLeft(12, temp) OR 00000FFFH;
            FI;
            IF OperandSize = 32
                THEN
                    DEST ← temp;
                ELSE (*OperandSize = 16*)
                    DEST ← temp AND FFFFH;
            FI;
FI;
```

Flags Affected

The ZF flag is set to 1 if the segment limit is loaded successfully; otherwise, it is cleared to 0.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

LSL—Load Segment Limit (Continued)

Real-Address Mode Exceptions

#UD	The LSL instruction is not recognized in real-address mode.

Virtual-8086 Mode Exceptions

#UD	The LSL instruction is not recognized in virtual-8086 mode.

LSS—Load Full Pointer

Refer to entry for LDS/LES/LFS/LGS/LSS—Load Far Pointer.

LTR—Load Task Register

Opcode	Instruction	Description
0F 00 /3	LTR *r/m16*	Load *r/m16* into task register

Description

This instruction loads the source operand into the segment selector field of the task register. The source operand (a general-purpose register or a memory location) contains a segment selector that points to a task state segment (TSS). After the segment selector is loaded in the task register, the processor uses the segment selector to locate the segment descriptor for the TSS in the global descriptor table (GDT). It then loads the segment limit and base address for the TSS from the segment descriptor into the task register. The task pointed to by the task register is marked busy, but a switch to the task does not occur.

The LTR instruction is provided for use in operating-system software; it should not be used in application programs. It can only be executed in protected mode when the CPL is 0. It is commonly used in initialization code to establish the first task to be executed.

The operand-size attribute has no effect on this instruction.

Operation

```
IF SRC(Offset) > descriptor table limit OR IF SRC(type) ≠ global
    THEN #GP(segment selector);
FI;
Read segment descriptor;
IF segment descriptor is not for an available TSS THEN #GP(segment selector); FI;
IF segment descriptor is not present THEN #NP(segment selector);
TSSsegmentDescriptor(busy) ← 1;
(* Locked read-modify-write operation on the entire descriptor when setting busy flag *)
TaskRegister(SegmentSelector) ← SRC;
TaskRegister(SegmentDescriptor) ← TSSSegmentDescriptor;
```

Flags Affected

None.

LTR—Load Task Register (Continued)

Protected Mode Exceptions

#GP(0)	If the current privilege level is not 0.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#GP(selector)	If the source selector points to a segment that is not a TSS or to one for a task that is already busy.
	If the selector points to LDT or is beyond the GDT limit.
#NP(selector)	If the TSS is marked not present.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.

Real-Address Mode Exceptions

#UD	The LTR instruction is not recognized in real-address mode.

Virtual-8086 Mode Exceptions

#UD	The LTR instruction is not recognized in virtual-8086 mode.

MASKMOVQ—Byte Mask Write

Opcode	Instruction	Description
0F,F7,/r	MASKMOVQ *mm1*, *mm2*	Move 64-bits representing integer data from *MM1* register to memory location specified by the edi register, using the byte mask in *MM2* register.

Description

Data is stored from the mm1 register to the location specified by the di/edi register (using DS segment). The size of the store depends on the address-size attribute. The most significant bit in each byte of the mask register mm2 is used to selectively write the data (0 = no write, 1 = write) on a per-byte basis. Behavior with a mask of all zeroes is as follows:

- No data will be written to memory. However, transition from FP to MMX™ technology state (if necessary) will occur, irrespective of the value of the mask.
- For memory references, a zero byte mask does not prevent addressing faults (i.e., #GP, #SS) from being signalled.
- Signalling of page faults (#PG) is implementation-specific.
- #UD, #NM, #MF, and #AC faults are signalled irrespective of the value of the mask.
- Signalling of breakpoints (code or data) is not guaranteed; different processor implementations may signal or not signal these breakpoints.
- If the destination memory region is mapped as UC or WP, enforcement of associated semantics for these memory types is not guaranteed (i.e., is reserved) and is implementation-specific. Dependence on the behavior of a specific implementation in this case is not recommended, and may lead to future incompatibility.

The Mod field of the ModR/M byte must be 11, or an Invalid Opcode Exception will result.

MASKMOVQ—Byte Mask Write (Continued)

Operation

```
IF (SRC[7] = 1) THEN
    m64[EDI] = DEST[7-0];
ELSE
    M64[EDI] = 0X0;

IF (SRC[15] = 1) THEN
    m64[EDI] = DEST[15-8];
ELSE
    M64[EDI] = 0X0;

IF (SRC[23] = 1) THEN
    m64[EDI] = DEST[23-16];
ELSE
    M64[EDI] = 0X0;

IF (SRC[31] = 1) THEN
    m64[EDI] = DEST[31-24];
ELSE
    M64[EDI] = 0X0;

IF (SRC[39] = 1) THEN
    m64[EDI] = DEST[39-32];
ELSE
    M64[EDI] = 0X0;

IF (SRC[47] = 1) THEN
    m64[EDI] = DEST[47-40];
ELSE
    M64[EDI] = 0X0;

IF (SRC[55] = 1) THEN
    m64[EDI] = DEST[55-48];
ELSE
    M64[EDI] = 0X0;

IF (SRC[63] = 1) THEN
    m64[EDI] = DEST[63-56];
ELSE
    M64[EDI] = 0X0;
```

MASKMOVQ—Byte Mask Write (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

void_m_maskmovq(__m64d, __m64n, char * p)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

void_mm_maskmove_si64(__m64d, __m64n, char * p)

Conditionally store byte elements of d to address p. The high bit of each byte in the selector n determines whether the corresponding byte in d will be stored.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.

MASKMOVQ—Byte Mask Write (Continued)

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

MASKMOVQ—Byte Mask Write (Continued)

Comments

MASKMOVQ can be used to improve performance for algorithms which need to merge data on a byte granularity. MASKMOVQ should not cause a read for ownership; doing so generates unnecessary bandwidth since data is to be written directly using the byte-mask without allocating old data prior to the store. Similar to the Streaming SIMD Extension non-temporal store instructions, MASKMOVQ minimizes pollution of the cache hierarchy. MASKMOVQ implicitly uses weakly-ordered, write-combining stores (WC). Refer to Section 9.3.9., *Cacheability Control Instructions* in Chapter 9, *Programming with the Streaming SIMD Extension* of the *Intel Architecture Software Developer's Manual, Volume 1*, for further information about non-temporal stores.

As a consequence of the resulting weakly-ordered memory consistency model, a fencing operation such as SFENCE should be used if multiple processors may use different memory types to read/write the same memory location specified by edi.

This instruction behaves identically to MMX™ instructions, in the presence of x87-FP instructions: transition from x87-FP to MMX™ technology (TOS=0, FP valid bits set to all valid).

MASMOVQ ignores the value of CR4.OSFXSR. Since it does not affect the new Streaming SIMD Extension state, they will not generate an invalid exception if CR4.OSFXSR = 0.

MAXPS—Packed Single-FP Maximum

Opcode	Instruction	Description
0F,5F,/r	MAXPS *xmm1*, *xmm2/m128*	Return the maximum SP FP numbers between *XMM2/Mem* and *XMM1.*

Description

The MAXPS instruction returns the maximum SP FP numbers from XMM1 and XMM2/Mem. If the values being compared are both zeroes, source2 (xmm2/m128) would be returned. If source2 (xmm2/m128) is an sNaN, this sNaN is forwarded unchanged to the destination (i.e., a quieted version of the sNaN is not returned).

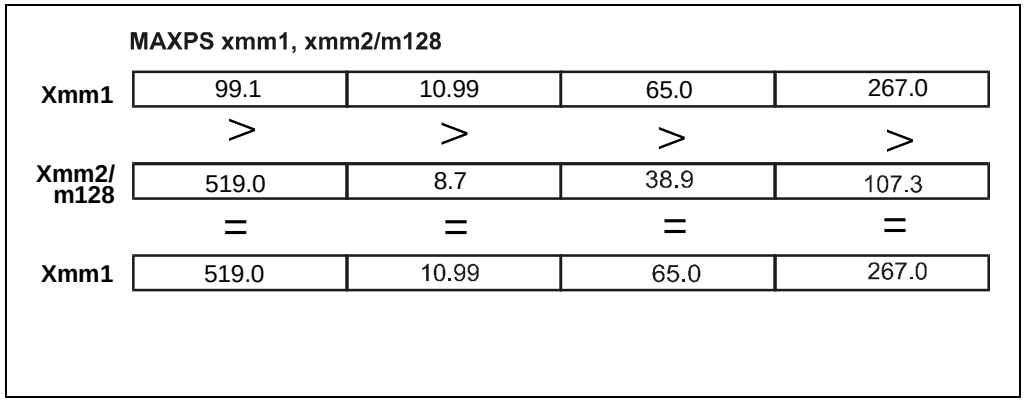


Figure 3-36. Operation of the MAXPS Instruction

Operation

```
IF (DEST[31-0]=NaN) THEN
    DEST[31-0] = SRC[31-0];
ELSE
    IF (SRC[31-0] = NaN) THEN
        DEST[31-0] = SRC[31-0];
    ELSE
        IF (DEST[31-0] > SRC/m128[31-0]) THEN
            DEST[31-0] = DEST[31-0];
        ELSE
            DEST[31-0] = SRC/m128[31-0];
        FI
    FI
FI
```

MAXPS—Packed Single-FP Maximum (Continued)

```
IF (DEST[63-32]=NaN) THEN
    DEST[63-32] = SRC[63-32];
ELSE
    IF (SRC[63-32] = NaN) THEN
        DEST[63-32] = SRC[63-32];
    ELSE
        IF (DEST[63-32] > SRC/m128[63-32]) THEN
            DEST[63-32] = DEST[63-32];
        ELSE
            DEST[63-32] = SRC/m128[63-32];
        FI
    FI
FI
IF (DEST[95-64]=NaN) THEN
    DEST[95-64] = SRC[95-64];
ELSE
    IF (SRC[95-64] = NaN) THEN
        DEST[95-64] = SRC[95-64];
    ELSE
        IF (DEST[95-64] > SRC/m128[95-64]) THEN
            DEST[95-64] = DEST[95-64];
        ELSE
            DEST[95-64] = SRC/m128[95-64];
        FI
    FI
FI
IF (DEST[127-96]=NaN) THEN
    DEST[127-96] = SRC[127-96];
ELSE
    IF (SRC[127-96] = NaN) THEN
        DEST[127-96] = SRC[127-96];
    ELSE
        IF (DEST[127-96] > SRC/m128[127-96]) THEN
            DEST[127-96] = DEST[127-96];
        ELSE
            DEST[127-96] = SRC/m128[127-96];
        FI
    FI
FI
```

MAXPS—Packed Single-FP Maximum (Continued)

Exceptions

General protection exception if not aligned on 16-byte boundary, including unaligned reference within the stack segment.

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_max_ps(__m128 a, __m128 b)

Computes the maximums of the four SP FP values of a and b.

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

Numeric Exceptions

Invalid (including qNaN source operand), Denormal.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

MAXPS—Packed Single-FP Maximum (Continued)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.

Comments

Note that if only one source is a NaN for these instructions, the Src2 operand (either NaN or real value) is written to the result; this differs from the behavior for other instructions as defined in Table 7-9 in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*, which is to always write the NaN to the result, regardless of which source operand contains the NaN. This approach for MAXPS allows compilers to use the MAXPS instruction for common C conditional constructs. If instead of this behavior, it is required that the NaN source operand be returned, the min/max functionality can be emulated using a sequence of instructions: comparison followed by AND, ANDN, and OR.

MAXSS—Scalar Single-FP Maximum

Opcode	Instruction	Description
F3,0F,5F,/r	MAXSS *xmm1*, *xmm2/m32*	Return the maximum SP FP number between the lower SP FP numbers from *XMM2/Mem* and *XMM1.*

Description

The MAXSS instruction returns the maximum SP FP number from the lower SP FP numbers of XMM1 and XMM2/Mem; the upper three fields are passed through from xmm1. If the values being compared are both zeroes, source2 (xmm2/m128) will be returned. If source2 (xmm2/m128) is an sNaN, this sNaN is forwarded unchanged to the destination (i.e., a quieted version of the sNaN is not returned).

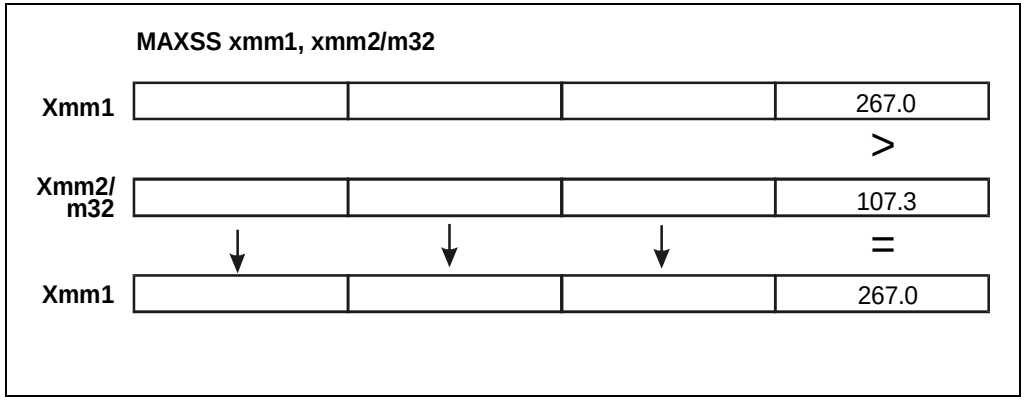


Figure 3-37. Operation of the MAXSS Instruction

MAXSS—Scalar Single-FP Maximum (Continued)

Operation

```
IF (DEST[31-0]=NaN) THEN
    DEST[31-0] = SRC[31-0];
ELSE
    IF (SRC[31-0] = NaN) THEN
        DEST[31-0] = SRC[31-0];
    ELSE
        IF (DEST[31-0] > SRC/m128[31-0]) THEN
            DEST[31-0] = DEST[31-0];
        ELSE
            DEST[31-0] = SRC/m128[31-0];
        FI
    FI
FI
DEST[63-32]=   DEST[63-32];
DEST[95-64]=   DEST[95-64];
DEST[127-96]=  DEST[127-96];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_max_ss(__m128 a, __m128 b)

Computes the maximum of the lower SP FP values of a and b; the upper three SP FP values are passed through from a.

Exceptions

None.

Numeric Exceptions

Invalid (including qNaN source operand), Denormal.

MAXSS—Scalar Single-FP Maximum (Continued)

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

MAXSS—Scalar Single-FP Maximum (Continued)

Comments

Note that if only one source is a NaN for these instructions, the Src2 operand (either NaN or real value) is written to the result; this differs from the behavior for other instructions as defined in Table 7-9 in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*, which is to always write the NaN to the result, regardless of which source operand contains the NaN. The upper three operands are still bypassed from the src1 operand, as in all other scalar operations. This approach for MAXSS allows compilers to use the MAXSS instruction for common C conditional constructs. If instead of this behavior, it is required that the NaN source operand be returned, the min/max functionality can be emulated using a sequence of instructions: comparison followed by AND, ANDN, and OR.

MINPS—Packed Single-FP Minimum

Opcode	Instruction	Description
0F,5D,/r	MINPS *xmm1*, *xmm2/m128*	Return the minimum SP numbers between *XMM2/Mem* and *XMM1*.

Description

The MINPS instruction returns the minimum SP FP numbers from XMM1 and XMM2/Mem. If the values being compared are both zeroes, source2 (xmm2/m128) would be returned. If source2 (xmm2/m128) is an sNaN, this sNaN is forwarded unchanged to the destination (i.e., a quieted version of the sNaN is not returned).

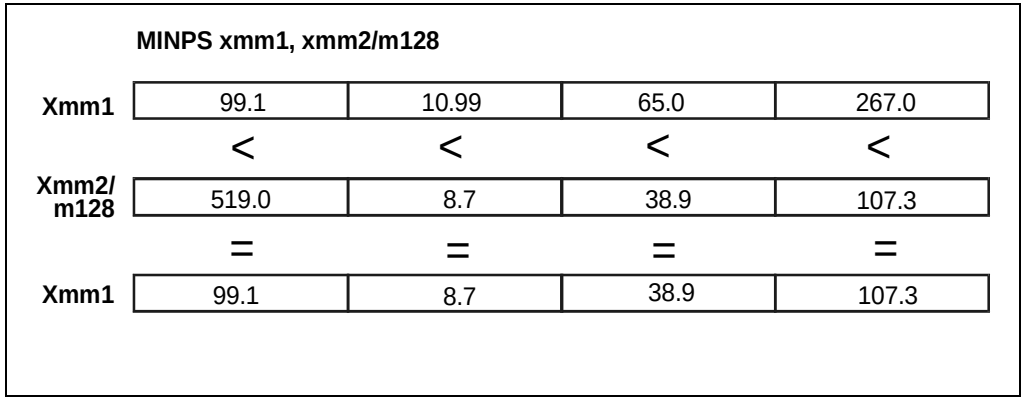


Figure 3-38. Operation of the MINPS Instruction

Operation

```
IF (DEST[31-0]=NaN) THEN
    DEST[31-0] = SRC[31-0];
ELSE
    IF (SRC[31-0] = NaN) THEN
        DEST[31-0] = SRC[31-0];
    ELSE
        IF (DEST[31-0] < SRC/m128[31-0]) THEN
            DEST[31-0] = DEST[31-0];
        ELSE
            DEST[31-0] = SRC/m128[31-0];
        FI
    FI
FI
```

MINPS—Packed Single-FP Minimum (Continued)

```
IF (DEST[63-32]=NaN) THEN
    DEST[63-32] = SRC[63-32];
ELSE
    IF (SRC[63-32] = NaN) THEN
        DEST[63-32] = SRC[63-32];
    ELSE
        IF (DEST[63-32] < SRC/m128[63-32]) THEN
            DEST[63-32] = DEST[63-32];
        ELSE
            DEST[63-32] = SRC/m128[63-32];
        FI
    FI
FI
IF (DEST[95-64]=NaN) THEN
    DEST[95-64] = SRC[95-64];
ELSE
    IF (SRC[95-64] = NaN) THEN
        DEST[95-64] = SRC[95-64];
    ELSE
        IF (DEST[95-64] < SRC/m128[95-64]) THEN
            DEST[95-64] = DEST[95-64];
        ELSE
            DEST[95-64] = SRC/m128[95-64];
        FI
    FI
FI
IF (DEST[127-96]=NaN) THEN
    DEST[127-96] = SRC[127-96];
ELSE
    IF (SRC[127-96] = NaN) THEN
        DEST[127-96] = SRC[127-96];
    ELSE
        IF (DEST[127-96] < SRC/m128[127-96]) THEN
            DEST[127-96] = DEST[127-96];
        ELSE
            DEST[127-96] = SRC/m128[127-96];
        FI
    FI
FI
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_min_ps(__m128 a, __m128 b)

Computes the minimums of the four SP FP values of a and b.

MINPS—Packed Single-FP Minimum (Continued)

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

Numeric Exceptions

Invalid (including qNaN source operand), Denormal.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

MINPS—Packed Single-FP Minimum (Continued)

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code) For a page fault.

Comments

Note that if only one source is a NaN for these instructions, the Src2 operand (either NaN or real value) is written to the result; this differs from the behavior for other instructions as defined in Table 7-9 in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*, which is to always write the NaN to the result, regardless of which source operand contains the NaN. This approach for MINPS allows compilers to use the MINPS instruction for common C conditional constructs. If instead of this behavior, it is required that the NaN source operand be returned, the min/max functionality can be emulated using a sequence of instructions: comparison followed by AND, ANDN, and OR.

MINSS—Scalar Single-FP Minimum

Opcode	Instruction	Description
0F,5D,/r	MINSS *xmm1*, *xmm2/m32*	Return the minimum SP FP number between the lowest SP FP numbers from *XMM2/Mem* and *XMM1*.

Description

The MINSS instruction returns the minimum SP FP number from the lower SP FP numbers from XMM1 and XMM2/Mem; the upper three fields are passed through from xmm1. If the values being compared are both zeroes, source2 (xmm2/m128) would be returned. If source2 (xmm2/m128) is an sNaN, this sNaN is forwarded unchanged to the destination (i.e., a quieted version of the sNaN is not returned).

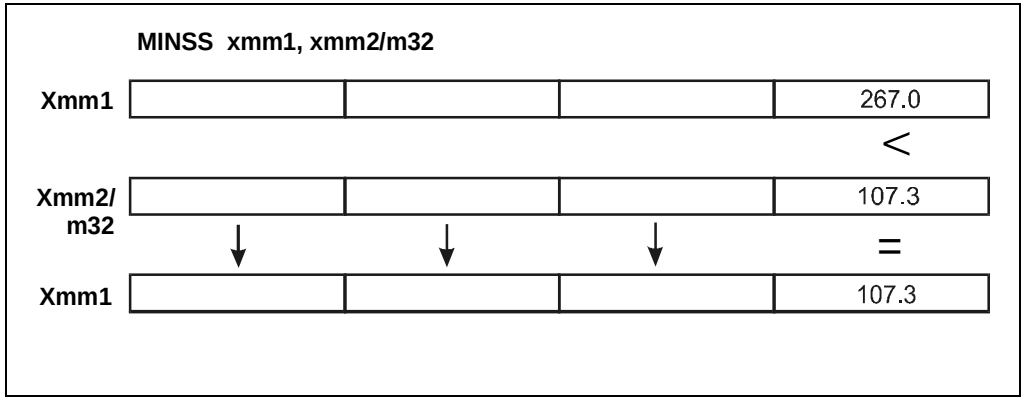


Figure 3-39. Operation of the MINSS Instruction

MINSS—Scalar Single-FP Minimum (Continued)

Operation

```
IF (DEST[31-0]=NaN) THEN
    DEST[31-0] = SRC[31-0];
ELSE
    IF (SRC[31-0] = NaN) THEN
        DEST[31-0] = SRC[31-0];
    ELSE
        IF (DEST[31-0] < SRC/m128[31-0]) THEN
            DEST[31-0] = DEST[31-0];
        ELSE
            DEST[31-0] = SRC/m128[31-0];
        FI
    FI
FI
DEST[63-32]=   DEST[63-32];
DEST[95-64]=   DEST[95-64];
DEST[127-96]=  DEST[127-96];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_min_ss(__m128 a, __m128 b)

Computes the minimum of the lower SP FP values of a and b; the upper three SP FP values are passed through from a.

Exceptions

None.

Numeric Exceptions

Invalid (including qNaN source operand), Denormal.

MINSS—Scalar Single-FP Minimum (Continued)

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

MINSS—Scalar Single-FP Minimum (Continued)

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF (fault-code)	For a page fault.
#AC	For unaligned memory references.

Comments

Note that if only one source is a NaN for these instructions, the Src2 operand (either NaN or real value) is written to the result; this differs from the behavior for other instructions as defined in Table 7-9 in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*, which is to always write the NaN to the result, regardless of which source operand contains the NaN. The upper three operands are still bypassed from the src1 operand, as in all other scalar operations. This approach for MINSS allows compilers to use the MINSS instruction for common C conditional constructs. If instead of this behavior, it is required that the NaN source operand be returned, the min/max functionality can be emulated using a sequence of instructions: comparison followed by AND, ANDN, and OR.

MOV—Move

Opcode	Instruction	Description
88 /*r*	MOV *r/m8,r8*	Move *r8* to *r/m8*
89 /*r*	MOV *r/m16,r16*	Move *r16* to *r/m16*
89 /*r*	MOV *r/m32,r32*	Move *r32* to *r/m32*
8A /*r*	MOV *r8,r/m8*	Move *r/m8* to *r8*
8B /*r*	MOV *r16,r/m16*	Move *r/m16* to *r16*
8B /*r*	MOV *r32,r/m32*	Move *r/m32* to *r32*
8C /*r*	MOV *r/m16,Sreg***	Move segment register to *r/m16*
8E /*r*	MOV *Sreg,r/m16***	Move *r/m16* to segment register
A0	MOV AL,*moffs8**	Move byte at (*seg:offset*) to AL
A1	MOV AX,*moffs16**	Move word at (*seg:offset*) to AX
A1	MOV EAX,*moffs32**	Move doubleword at (*seg:offset*) to EAX
A2	MOV *moffs8**,AL	Move AL to (*seg:offset*)
A3	MOV *moffs16**,AX	Move AX to (*seg:offset*)
A3	MOV *moffs32**,EAX	Move EAX to (*seg:offset*)
B0+ *rb*	MOV *r8,imm8*	Move *imm8* to *r8*
B8+ *rw*	MOV *r16,imm16*	Move *imm16* to *r16*
B8+ *rd*	MOV *r32,imm32*	Move *imm32* to *r32*
C6 /*0*	MOV *r/m8,imm8*	Move *imm8* to *r/m8*
C7 /*0*	MOV *r/m16,imm16*	Move *imm16* to *r/m16*
C7 /*0*	MOV *r/m32,imm32*	Move *imm32* to *r/m32*

NOTES:

* The *moffs8*, *moffs16*, and *moffs32* operands specify a simple offset relative to the segment base, where 8, 16, and 32 refer to the size of the data. The address-size attribute of the instruction determines the size of the offset, either 16 or 32 bits.

** In 32-bit mode, the assembler may insert the 16-bit operand-size prefix with this instruction (refer to the following “Description” section for further information).

Description

This instruction copies the second operand (source operand) to the first operand (destination operand). The source operand can be an immediate value, general-purpose register, segment register, or memory location; the destination register can be a general-purpose register, segment register, or memory location. Both operands must be the same size, which can be a byte, a word, or a doubleword.

The MOV instruction cannot be used to load the CS register. Attempting to do so results in an invalid opcode exception (#UD). To load the CS register, use the far JMP, CALL, or RET instruction.

MOV—Move (Continued)

If the destination operand is a segment register (DS, ES, FS, GS, or SS), the source operand must be a valid segment selector. In protected mode, moving a segment selector into a segment register automatically causes the segment descriptor information associated with that segment selector to be loaded into the hidden (shadow) part of the segment register. While loading this information, the segment selector and segment descriptor information is validated (refer to the "Operation" algorithm below). The segment descriptor data is obtained from the GDT or LDT entry for the specified segment selector.

A null segment selector (values 0000-0003) can be loaded into the DS, ES, FS, and GS registers without causing a protection exception. However, any subsequent attempt to reference a segment whose corresponding segment register is loaded with a null value causes a general protection exception (#GP) and no memory reference occurs.

Loading the SS register with a MOV instruction inhibits all interrupts until after the execution of the next instruction. This operation allows a stack pointer to be loaded into the ESP register with the next instruction (MOV ESP, **stack-pointer value**) before an interrupt occurs[1]. The LSS instruction offers a more efficient method of loading the SS and ESP registers.

When operating in 32-bit mode and moving data between a segment register and a general-purpose register, the Intel Architecture 32-bit family of processors do not require the use of the 16-bit operand-size prefix (a byte with the value 66H) with this instruction, but most assemblers will insert it if the typical form of the instruction is used (for example, MOV DS, AX). The processor will execute this instruction correctly, but it will usually require an extra clock. With most assemblers, using the instruction form MOV DS, EAX will avoid this unneeded 66H prefix. When the processor executes the instruction with a 32-bit general-purpose register, it assumes that the 16 least-significant bits of the general-purpose register are the destination or source operand. If the register is a destination operand, the resulting value in the two high-order bytes of the register is implementation dependent. For the Pentium® Pro processor, the two high-order bytes are filled with zeroes; for earlier 32-bit Intel Architecture processors, the two high order bytes are undefined.

1. Note that in a sequence of instructions that individually delay interrupts past the following instruction, only the first instruction in the sequence is guaranteed to delay the interrupt, but subsequent interrupt-delaying instructions may not delay the interrupt. Thus, in the following instruction sequence:
   STI
   MOV SS, EAX
   MOV ESP, EBP
   interrupts may be recognized before MOV ESP, EBP executes, because STI also delays interrupts for one instruction.

MOV—Move (Continued)

Operation

DEST ← SRC;

Loading a segment register while in protected mode results in special checks and actions, as described in the following listing. These checks are performed on the segment selector and the segment descriptor it points to.

```
IF SS is loaded;
    THEN
        IF segment selector is null
            THEN #GP(0);
        FI;
        IF segment selector index is outside descriptor table limits
            OR segment selector's RPL ≠ CPL
            OR segment is not a writable data segment
            OR DPL ≠ CPL
                THEN #GP(selector);
        FI;
        IF segment not marked present
            THEN #SS(selector);
    ELSE
        SS ← segment selector;
        SS ← segment descriptor;
    FI;
FI;
IF DS, ES, FS or GS is loaded with non-null selector;
THEN
    IF segment selector index is outside descriptor table limits
        OR segment is not a data or readable code segment
        OR ((segment is a data or nonconforming code segment)
            AND (both RPL and CPL > DPL))
                THEN #GP(selector);
        IF segment not marked present
            THEN #NP(selector);
    ELSE
        SegmentRegister ← segment selector;
        SegmentRegister ← segment descriptor;
    FI;
FI;
IF DS, ES, FS or GS is loaded with a null selector;
    THEN
        SegmentRegister ← segment selector;
        SegmentRegister ← segment descriptor;
FI;
```

MOV—Move (Continued)

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If attempt is made to load SS register with null segment selector.
	If the destination operand is in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#GP(selector)	If segment selector index is outside descriptor table limits.
	If the SS register is being loaded and the segment selector's RPL and the segment descriptor's DPL are not equal to the CPL.
	If the SS register is being loaded and the segment pointed to is a nonwritable data segment.
	If the DS, ES, FS, or GS register is being loaded and the segment pointed to is not a data or readable code segment.
	If the DS, ES, FS, or GS register is being loaded and the segment pointed to is a data or nonconforming code segment, but both the RPL and the CPL are greater than the DPL.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#SS(selector)	If the SS register is being loaded and the segment pointed to is marked not present.
#NP	If the DS, ES, FS, or GS register is being loaded and the segment pointed to is marked not present.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.
#UD	If attempt is made to load the CS register.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
#UD	If attempt is made to load the CS register.

MOV—Move (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.
#UD	If attempt is made to load the CS register.

MOV—Move to/from Control Registers

Opcode	Instruction	Description
0F 22 /*r*	MOV CR0,*r32*	Move *r32* to CR0
0F 22 /*r*	MOV CR2,*r32*	Move *r32* to CR2
0F 22 /*r*	MOV CR3,*r32*	Move *r32* to CR3
0F 22 /*r*	MOV CR4,*r32*	Move *r32* to CR4
0F 20 /*r*	MOV *r32*,CR0	Move CR0 to *r32*
0F 20 /*r*	MOV *r32*,CR2	Move CR2 to *r32*
0F 20 /*r*	MOV *r32*,CR3	Move CR3 to *r32*
0F 20 /*r*	MOV *r32*,CR4	Move CR4 to *r32*

Description

This instruction moves the contents of a control register (CR0, CR2, CR3, or CR4) to a general-purpose register or vice versa. The operand size for these instructions is always 32 bits, regardless of the operand-size attribute. Refer to Section 2.5., *Control Registers* in Chapter 2, *System Architecture Overview* of the *Intel Architecture Software Developer's Manual, Volume 3*, for a detailed description of the flags and fields in the control registers.

When loading a control register, a program should not attempt to change any of the reserved bits; that is, always set reserved bits to the value previously read.

At the opcode level, the *reg* field within the ModR/M byte specifies which of the control registers is loaded or read. The two bits in the *mod* field are always 11B. The *r/m* field specifies the general-purpose register loaded or read.

These instructions have the following side effects:

- When writing to control register CR3, all non-global TLB entries are flushed. Refer to Section 3.7., *Translation Lookaside Buffers (TLBs)* in Chapter 3, *Protected-Mode Memory Management* of the *Intel Architecture Software Developer's Manual, Volume 3*, for a detailed description of the flags and fields in the control registers.

MOV—Move to/from Control Registers (Continued)

The following side effects are implementation specific for the Pentium® Pro processors. Software should not depend on this functionality in future Intel Architecture processors:

- When modifying any of the paging flags in the control registers (PE and PG in register CR0 and PGE, PSE, and PAE in register CR4), all TLB entries are flushed, including global entries.
- If the PG flag is set to 1 and control register CR4 is written to set the PAE flag to 1 (to enable the physical address extension mode), the pointers (PDPTRs) in the page-directory pointers table will be loaded into the processor (into internal, non-architectural registers).
- If the PAE flag is set to 1 and the PG flag set to 1, writing to control register CR3 will cause the PDPTRs to be reloaded into the processor.
- If the PAE flag is set to 1 and control register CR0 is written to set the PG flag, the PDPTRs are reloaded into the processor.

Operation

DEST ← SRC;

Flags Affected

The OF, SF, ZF, AF, PF, and CF flags are undefined.

Protected Mode Exceptions

#GP(0)	If the current privilege level is not 0.
	If an attempt is made to write invalid bit combinations in CR0 (such as setting the PG flag to 1 when the PE flag is set to 0, or setting the CD flag to 0 when the NE flag is set to 1).
	If an attempt is made to write a 1 to any reserved bit in CR4.
	If an attempt is made to write reserved bits in the page-directory pointers table (used in the extended physical addressing mode) when the PAE flag in control register CR4 and the PG flag in control register CR0 are set to 1.

Real-Address Mode Exceptions

#GP	If an attempt is made to write a 1 to any reserved bit in CR4.

Virtual-8086 Mode Exceptions

#GP(0)	These instructions cannot be executed in virtual-8086 mode.

MOV—Move to/from Debug Registers

Opcode	Instruction	Description
0F 21/*r*	MOV *r32*, DR0-DR7	Move debug register to *r32*
0F 23 /*r*	MOV DR0-DR7,*r32*	Move *r32* to debug register

Description

This instruction moves the contents of a debug register (DR0, DR1, DR2, DR3, DR4, DR5, DR6, or DR7) to a general-purpose register or vice versa. The operand size for these instructions is always 32 bits, regardless of the operand-size attribute. Refer to Chapter 14, *Debugging and Performance Monitoring* of the *Intel Architecture Software Developer's Manual, Volume 3*, for a detailed description of the flags and fields in the debug registers.

The instructions must be executed at privilege level 0 or in real-address mode.

When the debug extension (DE) flag in register CR4 is clear, these instructions operate on debug registers in a manner that is compatible with Intel386™ and Intel486™ processors. In this mode, references to DR4 and DR5 refer to DR6 and DR7, respectively. When the DE set in CR4 is set, attempts to reference DR4 and DR5 result in an undefined opcode (#UD) exception. (The CR4 register was added to the Intel Architecture beginning with the Pentium® processor.)

At the opcode level, the *reg* field within the ModR/M byte specifies which of the debug registers is loaded or read. The two bits in the *mod* field are always 11. The *r/m* field specifies the general-purpose register loaded or read.

Operation

```
IF ((DE = 1)  and (SRC or DEST = DR4 or DR5))
THEN
    #UD;
ELSE
    DEST ← SRC;
```

Flags Affected

The OF, SF, ZF, AF, PF, and CF flags are undefined.

Protected Mode Exceptions

#GP(0)	If the current privilege level is not 0.
#UD	If the DE (debug extensions) bit of CR4 is set and a MOV instruction is executed involving DR4 or DR5.
#DB	If any debug register is accessed while the GD flag in debug register DR7 is set.

MOV—Move to/from Debug Registers (Continued)

Real-Address Mode Exceptions

#UD	If the DE (debug extensions) bit of CR4 is set and a MOV instruction is executed involving DR4 or DR5.
#DB	If any debug register is accessed while the GD flag in debug register DR7 is set.

Virtual-8086 Mode Exceptions

#GP(0)	The debug registers cannot be loaded or read when in virtual-8086 mode.

MOVAPS—Move Aligned Four Packed Single-FP

Opcode	Instruction	Description
0F,28,/r	MOVAPS *xmm1*, xmm2/m128	Move 128 bits representing four packed SP data from *XMM2/Mem* to *XMM1* register.
0F,29,/r	MOVAPS *xmm2/m128*, *xmm1*	Move 128 bits representing four packed SP from *XMM1* register to *XMM2/Mem*.

Description

The linear address corresponds to the address of the least-significant byte of the referenced memory data. When a memory address is indicated, the 16 bytes of data at memory location m128 are loaded or stored. When the register-register form of this operation is used, the content of the 128-bit source register is copied into the 128-bit destination register.

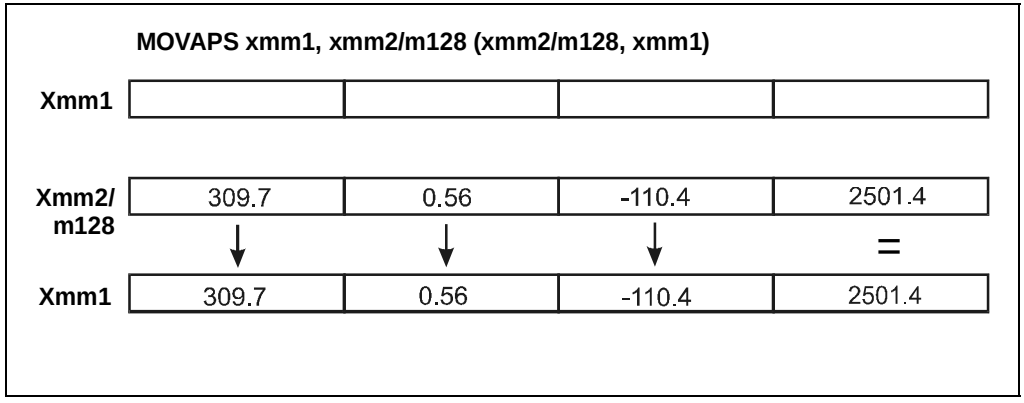


Figure 3-40. Operation of the MOVAPS Instruction

MOVAPS—Move Aligned Four Packed Single-FP (Continued)

Operation

```
IF (destination = DEST) THEN
    IF (SRC = m128)THEN (* load instruction *)
        DEST[127-0] = m128;
    ELSE(* move instruction *)
        DEST[127=0] = SRC[127-0];
    FI;
ELSE
    IF (destination = m128)THEN (* store instruction *)
        m128 = SRC[127-0];
    ELSE(* move instruction *)
        DEST[127-0] = SRC[127-0];
    FI;
FI;
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_load_ps(float * p)

Loads four SP FP values. The address must be 16-byte-aligned.

void_mm_store_ps(float *p, __m128 a)

Stores four SP FP values. The address must be 16-byte-aligned.

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

Numeric Exceptions

None.

MOVAPS—Move Aligned Four Packed Single-FP (Continued)

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.

Comments

MOVAPS should be used when dealing with 16-byte aligned SP FP numbers. If the data is not known to be aligned, MOVUPS should be used instead of MOVAPS. The usage of this instruction should be limited to the cases where the aligned restriction is easy to meet. Processors that support Streaming SIMD Extension will provide optimal aligned performance for the MOVAPS instruction.

The usage of Repeat Prefix (F3H) with MOVAPS is reserved. Different processor implementations may handle this prefix differently. Usage of this prefix with MOVAPS risks incompatibility with future processors.

MOVD—Move 32 Bits

Opcode	Instruction	Description
0F 6E /r	MOVD *mm, r/m32*	Move doubleword from *r/m32* to *mm.*
0F 7E /r	MOVD *r/m32, mm*	Move doubleword from *mm* to *r/m32.*

Description

This instruction copies doubleword from source operand (second operand) to destination operand (first operand). Source and destination operands can be MMX™ technology registers, memory locations, or 32-bit general-purpose registers; however, data cannot be transferred from an MMX™ technology register to another MMX™ technology register, from one memory location to another memory location, or from one general-purpose register to another general-purpose register.

When the destination operand is an MMX™ technology register, the 32-bit source value is written to the low-order 32 bits of the 64-bit MMX™ technology register and zero-extended to 64 bits (refer to Figure 3-41). When the source operand is an MMX™ technology register, the low-order 32 bits of the MMX™ technology register are written to the 32-bit general-purpose register or 32-bit memory location selected with the destination operand.

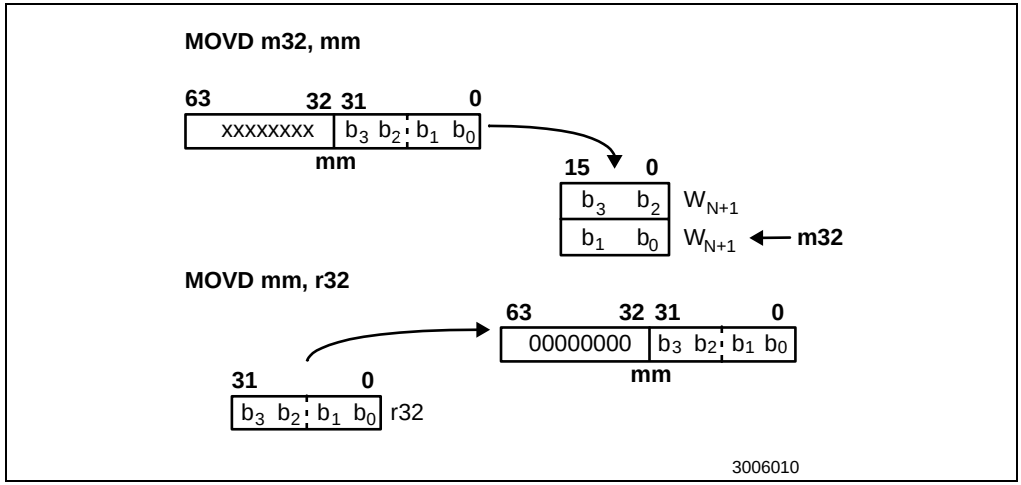


Figure 3-41. Operation of the MOVD Instruction

MOVD—Move 32 Bits (Continued)

Operation

```
IF DEST is MMX™ technology register
    THEN
        DEST ← ZeroExtend(SRC);
    ELSE (* SRC is MMX™ technology register *)
        DEST ← LowOrderDoubleword(SRC);
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the destination operand is in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

MOVD—Move 32 Bits (Continued)

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

MOVHLPS— High to Low Packed Single-FP

Opcode	Instruction	Description
OF,12,/r	MOVHLPS *xmm1, xmm2*	Move 64 bits representing higher two SP operands from *xmm2* to lower two fields of *xmm1* register.

Description

The upper 64-bits of the source register xmm2 are loaded into the lower 64-bits of the 128-bit register xmm1, and the upper 64-bits of xmm1 are left unchanged.

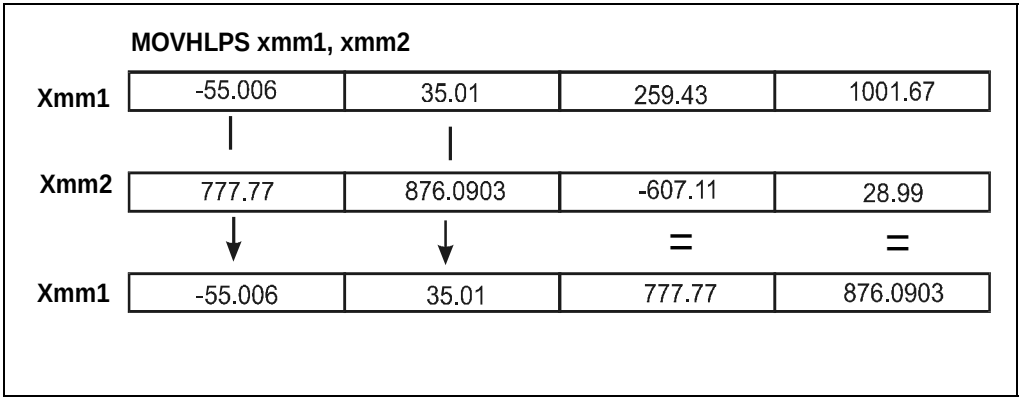


Figure 3-42. Operation of the MOVHLPS Instruction

Operation

```
DEST[127-64] = DEST[127-64];
DEST[63-0] = SRC[127-64];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_movehl_ps(__m128 a, __m128 b)

Moves the upper 2 SP FP values of b to the lower 2 SP FP values of the result. The upper 2 SP FP values of a are passed through to the result.

MOVHLPS— High to Low Packed Single-FP (Continued)

Exceptions

None

Numeric Exceptions

None.

Protected Mode Exceptions

#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

Comments

The usage of Repeat (F2H, F3H) and Operand Size (66H) prefixes with MOVHLPS is reserved. Different processor implementations may handle these prefixes differently. Usage of these prefixes with MOVHLPS risks incompatibility with future processors.

MOVHPS—Move High Packed Single-FP

Opcode	Instruction	Description
0F,16,/r	MOVHPS *xmm*, *m64*	Move 64 bits representing two SP operands from *Mem* to upper two fields of *XMM* register.
0F,17,/r	MOVHPS *m64*, *xmm*	Move 64 bits representing two SP operands from upper two fields of *XMM* register to *Mem*.

Description

The linear address corresponds to the address of the least-significant byte of the referenced memory data. When the load form of this operation is used, m64 is loaded into the upper 64-bits of the 128-bit register xmm, and the lower 64-bits are left unchanged.

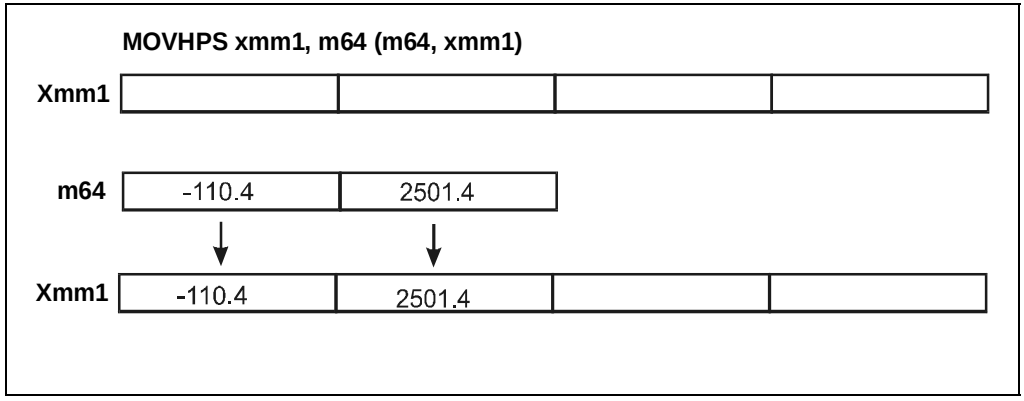


Figure 3-43. Operation of the MOVHPS Instruction

MOVHPS—Move High Packed Single-FP (Continued)

Operation

```
IF (destination = DEST) THEN(* load instruction *)
    DEST[127-64] = m64;
    DEST[31-0] = DEST[31-0];
    DEST[63-32] = DEST[63-32];
ELSE (* store instruction *)
    m64 = SRC[127-64];
FI;
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_loadh_pi(__m128 a, __m64 * p)

Sets the upper two SP FP values with 64 bits of data loaded from the address p; the lower two values are passed through from a.

void_mm_storeh_pi(__m64 * p, __m128 a)

Stores the upper two SP FP values of a to the address p.

Exceptions

None.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#UD	If CR4.OSFXSR(bit 9) = 0
#UD	If CPUID.XMM(EDX bit 25) = 0.

MOVHPS—Move High Packed Single-FP (Continued)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF (fault-code)	For a page fault.
#AC	For unaligned memory reference if the current privilege level is 3.

Comments

The usage of Repeat Prefixes (F2H, F3H) with MOVHPS is reserved. Different processor implementations may handle these prefixes differently. Usage of these prefixes with MOVHPS risks incompatibility with future processors.

MOVLHPS—Move Low to High Packed Single-FP

Opcode	Instruction	Description
OF,16,/r	MOVLHPS *xmm1, xmm2*	Move 64 bits representing lower two SP operands from *xmm2* to upper two fields of *xmm1* register.

Description

The lower 64-bits of the source register xmm2 are loaded into the upper 64-bits of the 128-bit register xmm1, and the lower 64-bits of xmm1 are left unchanged.

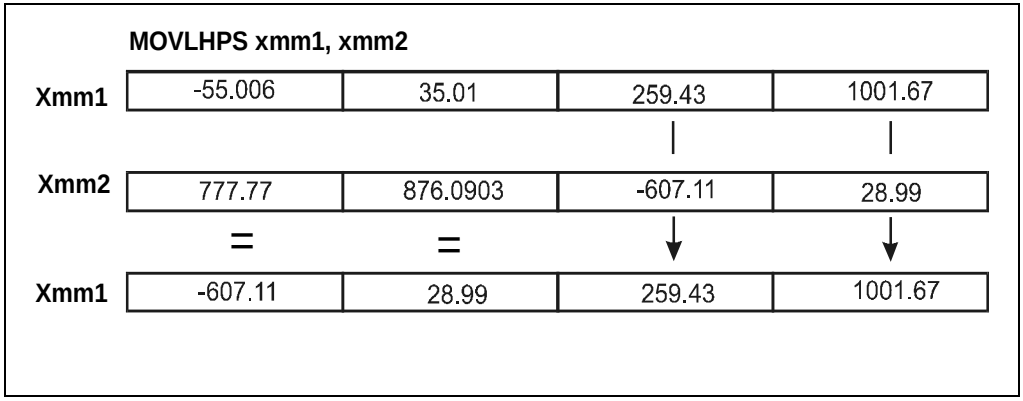


Figure 3-44. Operation of the MOVLHPS Instruction

Operation

```
DEST[127-64] = SRC[63-0];
DEST[63-0] = DEST[63-0];
```

MOVLHPS—Move Low to High Packed Single-FP (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_movelh_ps (__m128 a, __m128 b)

Moves the lower 2 SP FP values of b to the upper 2 SP FP values of the result. The lower 2 SP FP values of a are passed through to the result.

Exceptions

None.

Numeric Exceptions

None.

Protected Mode Exceptions

#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

Comments

The usage of Repeat (F2H, F3H) and Operand Size (66H) prefixes with MOVLHPS is reserved. Different processor implementations may handle these prefixes differently. Usage of these prefixes with MOVLHPS risks incompatibility with future processors.

MOVLPS—Move Low Packed Single-FP

Opcode	Instruction	Description
0F,12,/r	MOVLPS *xmm*, *m64*	Move 64 bits representing two SP operands from *Mem* to lower two fields of *XMM* register.
0F,13,/r	MOVLPS *m64*, *xmm*	Move 64 bits representing two SP operands from lower two fields of *XMM* register to *Mem*.

Description

The linear address corresponds to the address of the least-significant byte of the referenced memory data. When the load form of this operation is used, m64 is loaded into the lower 64-bits of the 128-bit register xmm, and the upper 64-bits are left unchanged.

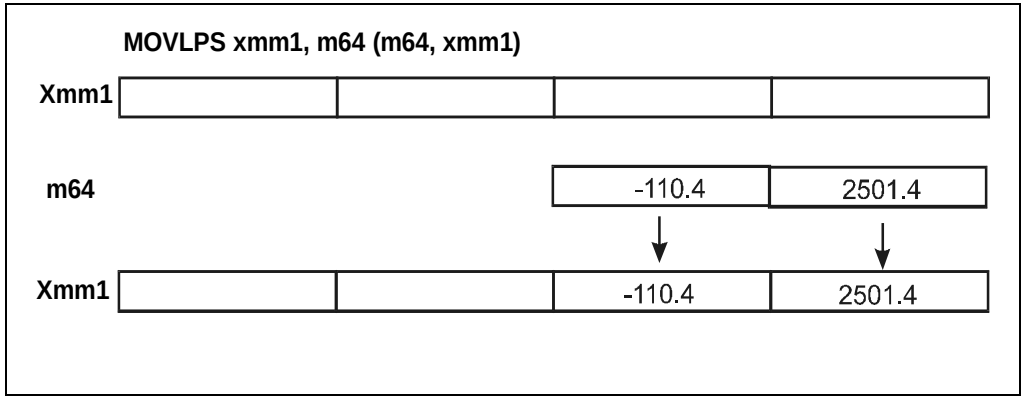


Figure 3-45. Operation of the MOVLPS Instruction

MOVLPS—Move Low Packed Single-FP (Continued)

Operation

```
IF (destination = DEST) THEN(* load instruction *)
    DEST[63-0] = m64;
    DEST[95-64] = DEST[95-64];
    DEST[127-96] = DEST[127-96];
ELSE(* store instruction *)
    m64 = DEST[63-0];
FI
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_loadl_pi(__m128 a, __m64 *p)

Sets the lower two SP FP values with 64 bits of data loaded from the address p; the upper two values are passed through from a.

void_mm_storel_pi(__m64 * p, __m128 a)

Stores the lower two SP FP values of a to the address p.

Exceptions

None.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

MOVLPS—Move Low Packed Single-FP (Continued)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF (fault-code)	For a page fault.
#AC	For unaligned memory reference if the current privilege level is 3.

Comments

The usage of Repeat Prefix (F3H) with MOVLPS is reserved. Different processor implementations may handle this prefix differently. Usage of this prefix with MOVLPS risks incompatibility with future processors.

MOVMSKPS—Move Mask To Integer

Opcode	Instruction	Description
0F,50,/r	MOVMSKPS r32, *xmm*	Move the single mask to r32.

Description

The MOVMSKPS instruction returns to the integer register r32 a 4-bit mask formed of the most significant bits of each SP FP number of its operand.

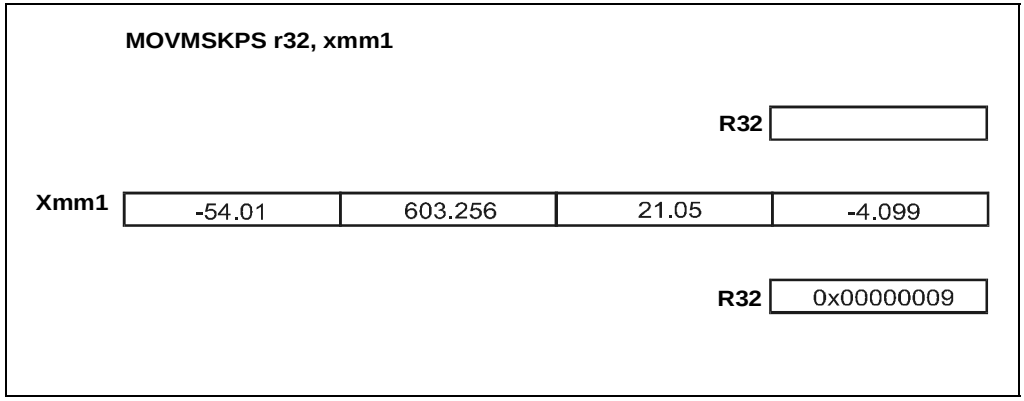


Figure 3-46. Operation of the MOVMSKPS Instruction

Operation

```
r32[0]      = SRC[31];
r32[1]      = SRC[63];
r32[2]      = SRC[95];
r32[3]      = SRC[127];
r32[7-4]    = 0X0;
r32[15-8]   = 0X00;
r32[31-16]  = 0X0000;
```

MOVMSKPS—Move Mask To Integer (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

int_mm_movemask_ps(__m128 a)

Creates a 4-bit mask from the most significant bits of the four SP FP values.

Exceptions

None.

Numeric Exceptions

None.

Protected Mode Exceptions

#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

Comments

The usage of Repeat Prefix (F3H) with MOVMSKPS is reserved. Different process implementations may handle this prefix differently. Usage of this prefix with MOVMSKPS risks incompatibility with future processors.

MOVNTPS—Move Aligned Four Packed Single-FP Non Temporal

Opcode	Instruction	Description
0F,2B, /r	MOVNTPS *m128*, *xmm*	Move 128 bits representing four packed SP FP data from *XMM* register to Mem, minimizing pollution in the cache hierarchy.

Description

The linear address corresponds to the address of the least-significant byte of the referenced memory data. This store instruction minimizes cache pollution.

Operation

```
m128 = SRC;
```

C/C++ Compiler Intrinsic Equivalent

void_mm_stream_ps(float * p, __m128 a)

Stores the data in a to the address p without polluting the caches. The address must be 16-byte-aligned.

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

MOVNTPS—Move Aligned Four Packed Single-FP Non Temporal (Continued)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.

Comments

MOVTNPS should be used when dealing with 16-byte aligned single-precision FP numbers. MOVNTPS minimizes pollution in the cache hierarchy. As a consequence of the resulting weakly-ordered memory consistency model, a fencing operation should be used if multiple processors may use different memory types to read/write the memory location. Refer to Section 9.3.9., *Cacheability Control Instructions* in Chapter 9, *Programming with the Streaming SIMD Extension* of the *Intel Architecture Software Developer's Manual, Volume 1*, for further information about non-temporal stores.

The usage of Repeat Prefix (F3H) with MOVNTPS is reserved. Different processor implementations may handle this prefix differently. Usage of this prefix with MOVNTPS risks incompatibility with future processors.

MOVNTQ—Move 64 Bits Non Temporal

Opcode	Instruction	Description
0F,E7,/r	MOVNTQ *m64, mm*	Move 64 bits representing integer operands (8b, 16b, 32b) from *MM* register to memory, minimizing pollution within cache hierarchy.

Description

The linear address corresponds to the address of the least-significant byte of the referenced memory data. This store instruction minimizes cache pollution.

Operation

```
m64 = SRC;
```

C/C++ Compiler Intrinsic Equivalent

void_mm_stream_pi(__m64 * p, __m64 a)

Stores the data in a to the address p without polluting the caches.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true (CR0.AM is set; EFLAGS.AC is set; current CPL is 3)

MOVNTQ—Move 64 Bits Non Temporal (Continued)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

Comments

MOVNTQ minimizes pollution in the cache hierarchy. As a consequence of the resulting weakly-ordered memory consistency model, a fencing operation should be used if multiple processors may use different memory types to read/write the memory location. Refer to Section 9.3.9., *Cacheability Control Instructions* in Chapter 9, *Programming with the Streaming SIMD Extension* of the *Intel Architecture Software Developer's Manual, Volume 1*, for further information about non-temporal stores.

MOVNTQ ignores the value of CR4.OSFXSR. Since it does not affect the new Streaming SIMD Extension state, MOVNTQ will not generate an invalid exception if CR4.OSFXSR = 0.

MOVQ—Move 64 Bits

Opcode	Instruction	Description
0F 6F /r	MOVQ *mm, mm/m64*	Move quadword from *mm/m64* to *mm*.
0F 7F /r	MOVQ *mm/m64, mm*	Move quadword from *mm* to *mm/m64*.

Description

This instruction copies quadword from the source operand (second operand) to the destination operand (first operand) (refer to Figure 3-47). A source or destination operand can be either an MMX™ technology register or a memory location; however, data cannot be transferred from one memory location to another memory location. Data can be transferred from one MMX™ technology register to another MMX™ technology register.

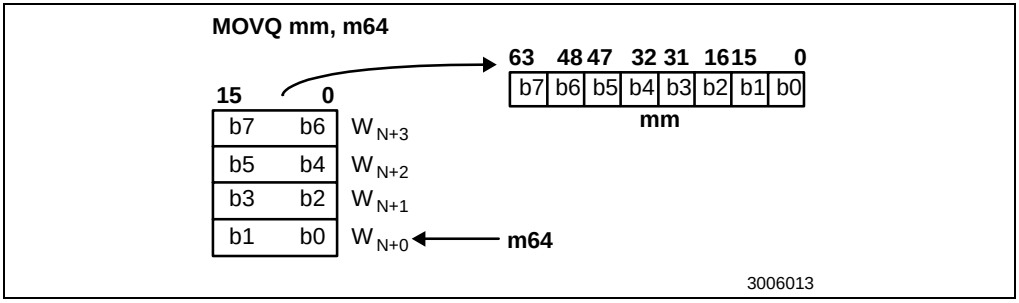


Figure 3-47. Operation of the MOVQ Instructions

Operation

DEST ← SRC;

Flags Affected

None.

MOVQ—Move 64 Bits (Continued)

Protected Mode Exceptions

#GP(0)	If the destination operand is in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

MOVS/MOVSB/MOVSW/MOVSD—Move Data from String to String

Opcode	Instruction	Description
A4	MOVS *m8, m8*	Move byte at address DS:(E)SI to address ES:(E)DI
A5	MOVS *m16, m16*	Move word at address DS:(E)SI to address ES:(E)DI
A5	MOVS *m32, m32*	Move doubleword at address DS:(E)SI to address ES:(E)DI
A4	MOVSB	Move byte at address DS:(E)SI to address ES:(E)DI
A5	MOVSW	Move word at address DS:(E)SI to address ES:(E)DI
A5	MOVSD	Move doubleword at address DS:(E)SI to address ES:(E)DI

Description

These instructions move the byte, word, or doubleword specified with the second operand (source operand) to the location specified with the first operand (destination operand). Both the source and destination operands are located in memory. The address of the source operand is read from the DS:ESI or the DS:SI registers (depending on the address-size attribute of the instruction, 32 or 16, respectively). The address of the destination operand is read from the ES:EDI or the ES:DI registers (again depending on the address-size attribute of the instruction). The DS segment may be overridden with a segment override prefix, but the ES segment cannot be overridden.

At the assembly-code level, two forms of this instruction are allowed: the “explicit-operands” form and the “no-operands” form. The explicit-operands form (specified with the MOVS mnemonic) allows the source and destination operands to be specified explicitly. Here, the source and destination operands should be symbols that indicate the size and location of the source value and the destination, respectively. This explicit-operands form is provided to allow documentation; however, note that the documentation provided by this form can be misleading. That is, the source and destination operand symbols must specify the correct **type** (size) of the operands (bytes, words, or doublewords), but they do not have to specify the correct **location**. The locations of the source and destination operands are always specified by the DS:(E)SI and ES:(E)DI registers, which must be loaded correctly before the move string instruction is executed.

The no-operands form provides “short forms” of the byte, word, and doubleword versions of the MOVS instructions. Here also DS:(E)SI and ES:(E)DI are assumed to be the source and destination operands, respectively. The size of the source and destination operands is selected with the mnemonic: MOVSB (byte move), MOVSW (word move), or MOVSD (doubleword move).

After the move operation, the (E)SI and (E)DI registers are incremented or decremented automatically according to the setting of the DF flag in the EFLAGS register. (If the DF flag is 0, the (E)SI and (E)DI register are incremented; if the DF flag is 1, the (E)SI and (E)DI registers are decremented.) The registers are incremented or decremented by one for byte operations, by two for word operations, or by four for doubleword operations.

MOVS/MOVSB/MOVSW/MOVSD—Move Data from String to String (Continued)

The MOVS, MOVSB, MOVSW, and MOVSD instructions can be preceded by the REP prefix (refer to "REP/REPE/REPZ/REPNE /REPNZ—Repeat String Operation Prefix" in this chapter) for block moves of ECX bytes, words, or doublewords.

Operation

```
DEST ←SRC;
IF (byte move)
    THEN IF DF = 0
        THEN
            (E)SI ← (E)SI + 1;
            (E)DI ← (E)DI + 1;
        ELSE
            (E)SI ← (E)SI – 1;
            (E)DI ← (E)DI – 1;
        FI;
    ELSE IF (word move)
        THEN IF DF = 0
            (E)SI ← (E)SI + 2;
            (E)DI ← (E)DI + 2;
        ELSE
            (E)SI ← (E)SI – 2;
            (E)DI ← (E)DI – 2;
        FI;
    ELSE (* doubleword move*)
        THEN IF DF = 0
            (E)SI ← (E)SI + 4;
            (E)DI ← (E)DI + 4;
        ELSE
            (E)SI ← (E)SI – 4;
            (E)DI ← (E)DI – 4;
        FI;
FI;
```

Flags Affected

None.

MOVS/MOVSB/MOVSW/MOVSD—Move Data from String to String (Continued)

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

MOVSS—Move Scalar Single-FP

Opcode	Instruction	Description
F3,0F,10,/r	MOVSS *xmm1, xmm2/m32*	Move 32 bits representing one scalar SP operand from *XMM2/Mem* to *XMM1* register.
F3,0F,11,/r	MOVSS *xmm2/m32, xmm1*	Move 32 bits representing one scalar SP operand from *XMM1* register to *XMM2/Mem*.

Description

The linear address corresponds to the address of the least-significant byte of the referenced memory data. When a memory address is indicated, the four bytes of data at memory location m32 are loaded or stored. When the load form of this operation is used, the 32 bits from memory are copied into the lower 32 bits of the 128-bit register xmm, the 96 most significant bits being cleared.

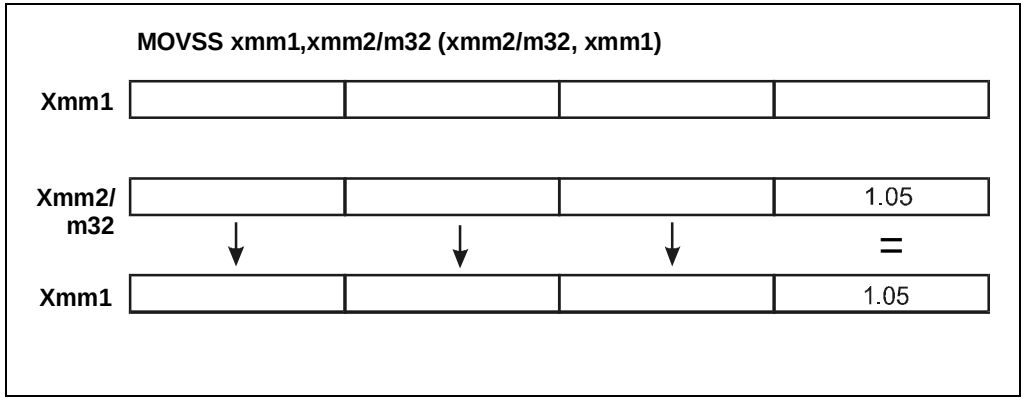


Figure 3-48. Operation of the MOVSS Instruction

MOVSS—Move Scalar Single-FP (Continued)

Operation

```
IF (destination = DEST) THEN
    IF (SRC == m32) THEN(* load instruction *)
        DEST[31-0] = m32;
        DEST [63-32] = 0X00000000;
        DEST [95-64] = 0X00000000;
        DEST [127-96] = 0X00000000;
    ELSE(* move instruction *)
        DEST [31-0] = SRC[31-0];
        DEST [63-32] = DEST [63-32];
        DEST [95-64] = DEST [95-64];
        DEST [127-96] = DEST [127-96];
    FI
ELSE
    IF (destination = m32) THEN(* store instruction *)
        m32 = SRC[31-0];
    ELSE     (* move instruction *)
        DEST [31-0] = SRC[31-0]
        DEST [63-32] = DEST[63-32];
        DEST [95-64] = DEST [95-64];
        DEST [127-96] = DEST [127-96];
    FI
FI
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_load_ss(float * p)

Loads an SP FP value into the low word and clears the upper three words.

void_mm_store_ss(float * p, __m128 a)

Stores the lower SP FP value.

__m128 _mm_move_ss(__m128 a, __m128 b)

Sets the low word to the SP FP value of b. The upper 3 SP FP values are passed through from a.

Exceptions

None.

Numeric Exceptions

None.

MOVSS—Move Scalar Single-FP (Continued)

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference.To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

MOVSX—Move with Sign-Extension

Opcode	Instruction	Description
0F BE /*r*	MOVSX *r16,r/m8*	Move byte to word with sign-extension
0F BE /*r*	MOVSX *r32,r/m8*	Move byte to doubleword, sign-extension
0F BF /*r*	MOVSX *r32,r/m16*	Move word to doubleword, sign-extension

Description

This instruction copies the contents of the source operand (register or memory location) to the destination operand (register) and sign extends the value to 16 or 32 bits. For more information, refer to Section 6-5, *Sign Extension* in Chapter 6, *Instruction Set Summary* of the *Intel Architecture Software Developer's Manual, Volume 1*. The size of the converted value depends on the operand-size attribute.

Operation

DEST ← SignExtend(SRC);

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

MOVSX—Move with Sign-Extension (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.

MOVUPS—Move Unaligned Four Packed Single-FP

Opcode	Instruction	Description
0F,10,/r	MOVUPS *xmm1, xmm2/m128*	Move 128 bits representing four SP data from *XMM2/Mem* to *XMM1* register.
0F,11,/r	MOVUPS *xmm2/m128, xmm1*	Move 128 bits representing four SP data from *XMM1* register to *XMM2/Mem.*

Description

The linear address corresponds to the address of the least-significant byte of the referenced memory data. When a memory address is indicated, the 16 bytes of data at memory location m128 are loaded to the 128-bit multimedia register xmm or stored from the 128-bit multimedia register xmm. When the register-register form of this operation is used, the content of the 128-bit source register is copied into 128-bit register xmm. No assumption is made about alignment.

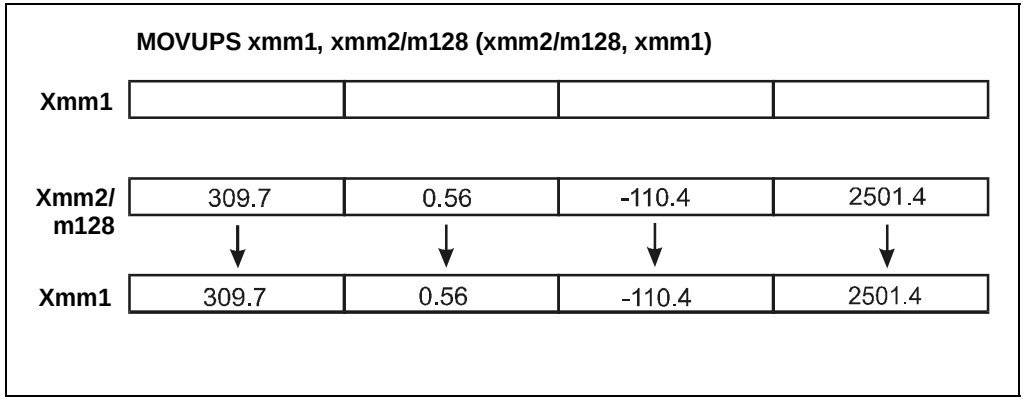


Figure 3-49. Operation of the MOVUPS Instruction

MOVUPS—Move Unaligned Four Packed Single-FP (Continued)

Operation

```
IF (destination = xmm) THEN
    IF (SRC = m128)THEN(* load instruction *)
        DEST[127-0] = m128;
    ELSE (* move instruction *)
        DEST[127-0] = SRC[127-0];
    FI
ELSE
    IF (destination = m128) THEN(* store instruction *)
        m128 = SRC[127-0];
    ELSE   (* move instruction *)
        DEST[127-0] = SRC[127-0];
    FI
FI
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_loadu_ps(float * p)

Loads four SP FP values. The address need not be 16-byte-aligned.

void_mm_storeu_ps(float *p, __m128 a)

Stores four SP FP values. The address need not be 16-byte-aligned.

Exceptions

None.

Numeric Exceptions

None.

MOVUPS—Move Unaligned Four Packed Single-FP (Continued)

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code	For a page fault.
#UD	If CR0.EM = 1.
#AC	For unaligned memory reference if the current privilege level is 3.
#NM	If TS bit in CR0 is set.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

Comments

MOVUPS should be used with SP FP numbers when that data is known to be unaligned.The usage of this instruction should be limited to the cases where the aligned restriction is hard or impossible to meet. Streaming SIMD Extension implementations guarantee optimum unaligned support for MOVUPS. Efficient Streaming SIMD Extension applications should mainly rely on MOVAPS, not MOVUPS, when dealing with aligned data.

The usage of Repeat-NE (F2H) and Operand Size (66H) prefixes is reserved. Different processor implementations may handle these prefixes differently. Usage of these prefixes with MOVUPS risks incompatibility with future processors.

A linear address of the 128 bit data access, while executing in 16-bit mode, that overlaps the end of a 16-bit segment is not allowed and is defined as reserved behavior. Different processor implementations may/may not raise a GP fault in this case if the segment limit has been exceeded. Additionally, the address that spans the end of the segment may/may not wrap around to the beginning of the segment.

MOVZX—Move with Zero-Extend

Opcode	Instruction	Description
0F B6 /*r*	MOVZX *r16,r/m8*	Move byte to word with zero-extension
0F B6 /*r*	MOVZX *r32,r/m8*	Move byte to doubleword, zero-extension
0F B7 /*r*	MOVZX *r32,r/m16*	Move word to doubleword, zero-extension

Description

This instruction copies the contents of the source operand (register or memory location) to the destination operand (register) and zero extends the value to 16 or 32 bits. The size of the converted value depends on the operand-size attribute.

Operation

DEST ← ZeroExtend(SRC);

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

MOVZX—Move with Zero-Extend (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

MUL—Unsigned Multiply

Opcode	Instruction	Description
F6 /4	MUL *r/m8*	Unsigned multiply (AX ← AL ∗ *r/m8*)
F7 /4	MUL *r/m16*	Unsigned multiply (DX:AX ← AX ∗ *r/m16*)
F7 /4	MUL *r/m32*	Unsigned multiply (EDX:EAX ← EAX ∗ *r/m32*)

Description

This instruction performs an unsigned multiplication of the first operand (destination operand) and the second operand (source operand) and stores the result in the destination operand. The destination operand is an implied operand located in register AL, AX or EAX (depending on the size of the operand); the source operand is located in a general-purpose register or a memory location. The action of this instruction and the location of the result depends on the opcode and the operand size as shown in the following table.

Operand Size	Source 1	Source 2	Destination
Byte	AL	r/m8	AX
Word	AX	r/m16	DX:AX
Doubleword	EAX	r/m32	EDX:EAX

The result is stored in register AX, register pair DX:AX, or register pair EDX:EAX (depending on the operand size), with the high-order bits of the product contained in register AH, DX, or EDX, respectively. If the high-order bits of the product are 0, the CF and OF flags are cleared; otherwise, the flags are set.

Operation

```
IF byte operation
    THEN
        AX ← AL ∗ SRC
    ELSE (* word or doubleword operation *)
        IF OperandSize = 16
            THEN
                DX:AX ← AX ∗ SRC
            ELSE (* OperandSize = 32 *)
                EDX:EAX ← EAX ∗ SRC
        FI;
FI;
```

Flags Affected

The OF and CF flags are cleared to 0 if the upper half of the result is 0; otherwise, they are set to 1. The SF, ZF, AF, and PF flags are undefined.

MUL—Unsigned Multiply (Continued)

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

MULPS—Packed Single-FP Multiply

Opcode	Instruction	Description
0F,59,/r	MULPS xmm1, xmm2/m128	Multiply packed SP FP numbers in XMM2/Mem to XMM1.

Description

The MULPS instructions multiply the packed SP FP numbers of both their operands.

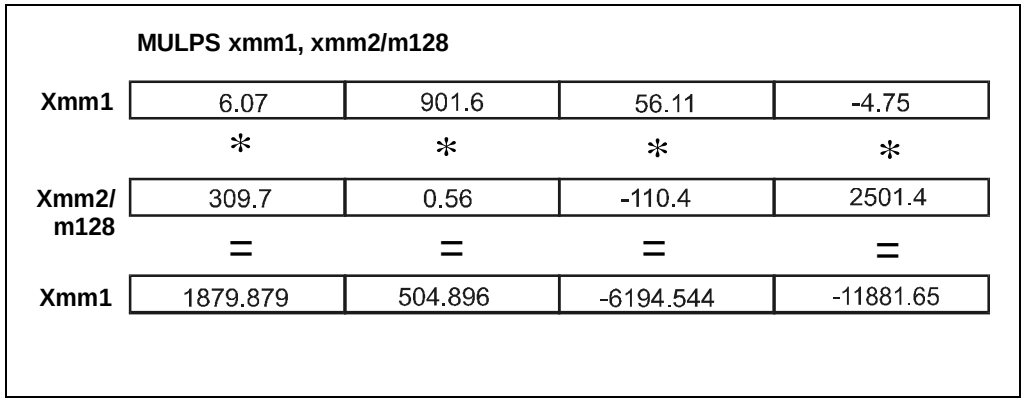


Figure 3-50. Operation of the MULPS Instruction

Operation

```
DEST[31-0] = DEST[31-0] * SRC/m128[31-0];
DEST[63-32] = DEST[63-32] * SRC/m128[63-32];
DEST[95-64] = DEST[95-64] * SRC/m128[95-64];
DEST[127-96] = DEST[127-96] * SRC/m128[127-96];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_mul_ps(__m128 a, __m128 b)

Multiplies the four SP FP values of a and b.

MULPS—Packed Single-FP Multiply (Continued)

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

Numeric Exceptions

Overflow, Underflow, Invalid, Precision, Denormal.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.

MULSS—Scalar Single-FP Multiply

Opcode	Instruction	Description
F3,0F,59,/r	MULSS xmm1 xmm2/m32	Multiply the lowest SP FP number in XMM2/Mem to XMM1.

Description

The MULSS instructions multiply the lowest SP FP numbers of both their operands; the upper three fields are passed through from xmm1.

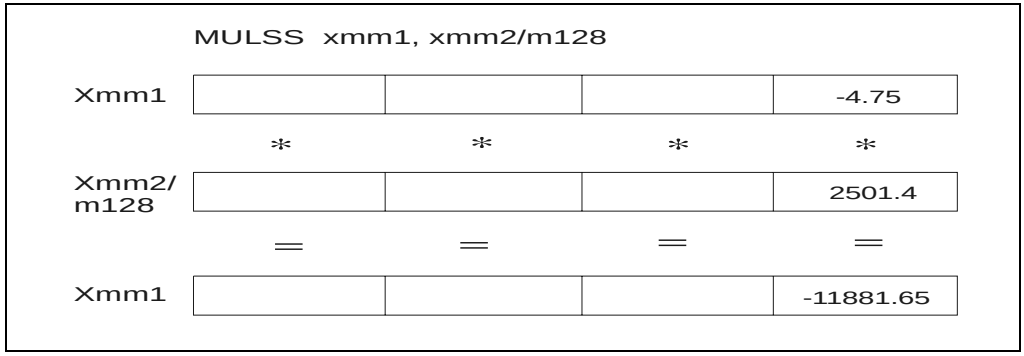


Figure 3-51. Operation of the MULSS Instruction

Operation

```
DEST[31-0] = DEST[31-0] * SRC/m32[31-0];
DEST[63-32] = DEST[63-32];
DEST[95-64] = DEST[95-64];
DEST[127-96] = DEST[127-96];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_mul_ss(__m128 a, __m128 b)

Multiplies the lower SP FP values of a and b; the upper three SP FP values are passed through from a.

Exceptions

None.

Numeric Exceptions

Overflow, Underflow, Invalid, Precision, Denormal.

MULSS—Scalar Single-FP Multiply (Continued)

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

NEG—Two's Complement Negation

Opcode	Instruction	Description
F6 /3	NEG *r/m8*	Two's complement negate *r/m8*
F7 /3	NEG *r/m16*	Two's complement negate *r/m16*
F7 /3	NEG *r/m32*	Two's complement negate *r/m32*

Description

This instruction replaces the value of operand (the destination operand) with its two's complement. (This operation is equivalent to subtracting the operand from 0.) The destination operand is located in a general-purpose register or a memory location.

Operation

```
IF DEST = 0
    THEN CF ← 0
    ELSE CF ← 1;
FI;
DEST ←  – (DEST)
```

Flags Affected

The CF flag cleared to 0 if the source operand is 0; otherwise it is set to 1. The OF, SF, ZF, AF, and PF flags are set according to the result.

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

NEG—Two's Complement Negation (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

NOP—No Operation

Opcode	Instruction	Description
90	NOP	No operation

Description

This instruction performs no operation. This instruction is a one-byte instruction that takes up space in the instruction stream but does not affect the machine context, except the EIP register.

The NOP instruction is an alias mnemonic for the XCHG (E)AX, (E)AX instruction.

Flags Affected

None.

Exceptions (All Operating Modes)

None.

NOT—One's Complement Negation

Opcode	Instruction	Description
F6 /2	NOT *r/m8*	Reverse each bit of *r/m8*
F7 /2	NOT *r/m16*	Reverse each bit of *r/m16*
F7 /2	NOT *r/m32*	Reverse each bit of *r/m32*

Description

This instruction performs a bitwise NOT operation (each 1 is cleared to 0, and each 0 is set to 1) on the destination operand and stores the result in the destination operand location. The destination operand can be a register or a memory location.

Operation

DEST ← NOT DEST;

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the destination operand points to a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

NOT—One's Complement Negation (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

OR—Logical Inclusive OR

Opcode	Instruction	Description
0C *ib*	OR AL,*imm8*	AL OR *imm8*
0D *iw*	OR AX,*imm16*	AX OR *imm16*
0D *id*	OR EAX,*imm32*	EAX OR *imm32*
80 /1 *ib*	OR *r/m8,imm8*	*r/m8* OR *imm8*
81 /1 *iw*	OR *r/m16,imm16*	*r/m16* OR *imm16*
81 /1 *id*	OR *r/m32,imm32*	*r/m32* OR *imm32*
83 /1 *ib*	OR *r/m16,imm8*	*r/m16* OR *imm8 (sign-extended)*
83 /1 *ib*	OR *r/m32,imm8*	*r/m32* OR *imm8 (sign-extended)*
08 /*r*	OR *r/m8,r8*	*r/m8* OR *r8*
09 /*r*	OR *r/m16,r16*	*r/m16* OR *r16*
09 /*r*	OR *r/m32,r32*	*r/m32* OR *r32*
0A /*r*	OR *r8,r/m8*	*r8* OR *r/m8*
0B /*r*	OR *r16,r/m16*	*r16* OR *r/m16*
0B /*r*	OR *r32,r/m32*	*r32* OR *r/m32*

Description

This instruction performs a bitwise inclusive OR operation between the destination (first) and source (second) operands and stores the result in the destination operand location. The source operand can be an immediate, a register, or a memory location; the destination operand can be a register or a memory location. (However, two memory operands cannot be used in one instruction.) Each bit of the result of the OR instruction is 0 if both corresponding bits of the operands are 0; otherwise, each bit is 1.

Operation

DEST ← DEST OR SRC;

Flags Affected

The OF and CF flags are cleared; the SF, ZF, and PF flags are set according to the result. The state of the AF flag is undefined.

OR—Logical Inclusive OR (Continued)

Protected Mode Exceptions

#GP(0)	If the destination operand points to a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

ORPS—Bit-wise Logical OR for Single-FP Data

Opcode	Instruction	Description
0F,56,/r	ORPS *xmm1, xmm2/m128*	OR 128 bits from *XMM2/Mem* to *XMM1* register.

Description

The ORPS instructions return a bit-wise logical OR between xmm1 and xmm2/mem.

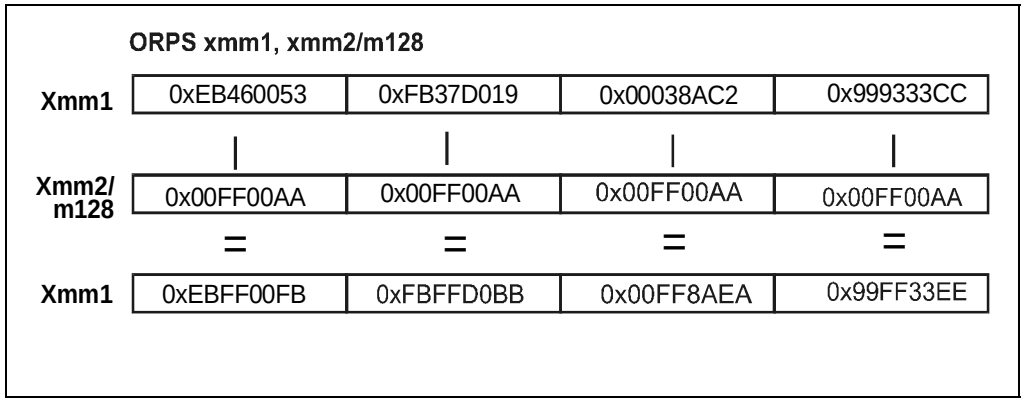


Figure 3-52. Operation of the ORPS Instruction

Operation

```
DEST[127-0] |= SRC/m128[127-0];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_or_ps(__m128 a, __m128 b)

Computes the bitwise OR of the four SP FP values of a and b.

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

ORPS—Bit-wise Logical OR for Single-FP Data (Continued)

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.

Comments

The usage of Repeat Prefix (F3H) with ORPS is reserved. Different processor implementations may handle this prefix differently. Usage of this prefix with ORPS risks incompatibility with future processors.

OUT—Output to Port

Opcode	Instruction	Description
E6 *ib*	OUT *imm8*, AL	Output byte in AL to I/O port address *imm8*
E7 *ib*	OUT *imm8*, AX	Output word in AX to I/O port address *imm8*
E7 *ib*	OUT *imm8*, EAX	Output doubleword in EAX to I/O port address *imm8*
EE	OUT DX, AL	Output byte in AL to I/O port address in DX
EF	OUT DX, AX	Output word in AX to I/O port address in DX
EF	OUT DX, EAX	Output doubleword in EAX to I/O port address in DX

Description

This instruction copies the value from the second operand (source operand) to the I/O port specified with the destination operand (first operand). The source operand can be register AL, AX, or EAX, depending on the size of the port being accessed (8, 16, or 32 bits, respectively); the destination operand can be a byte-immediate or the DX register. Using a byte immediate allows I/O port addresses 0 to 255 to be accessed; using the DX register as a source operand allows I/O ports from 0 to 65,535 to be accessed.

The size of the I/O port being accessed is determined by the opcode for an 8-bit I/O port or by the operand-size attribute of the instruction for a 16- or 32-bit I/O port.

At the machine code level, I/O instructions are shorter when accessing 8-bit I/O ports. Here, the upper eight bits of the port address will be 0.

This instruction is only useful for accessing I/O ports located in the processor's I/O address space. Refer to Chapter 10, *Input/Output* of the *Intel Architecture Software Developer's Manual, Volume 1*, for more information on accessing I/O ports in the I/O address space.

Intel Architecture Compatibility

After executing an OUT instruction, the Pentium® processor insures that the EWBE# pin has been sampled active before it begins to execute the next instruction. (Note that the instruction can be prefetched if EWBE# is not active, but it will not be executed until the EWBE# pin is sampled active.) Only the P6 family of processors has the EWBE# pin; the other Intel Architecture processors do not.

OUT—Output to Port (Continued)

Operation

```
IF ((PE = 1) AND ((CPL > IOPL) OR (VM = 1)))
    THEN (* Protected mode with CPL > IOPL or virtual-8086 mode *)
        IF (Any I/O Permission Bit for I/O port being accessed = 1)
            THEN (* I/O operation is not allowed *)
                #GP(0);
            ELSE ( * I/O operation is allowed *)
                DEST ← SRC; (* Writes to selected I/O port *)
        FI;
    ELSE (Real Mode or Protected Mode with CPL ≤ IOPL *)
        DEST ← SRC; (* Writes to selected I/O port *)
FI;
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the CPL is greater than (has less privilege) the I/O privilege level (IOPL) and any of the corresponding I/O permission bits in TSS for the I/O port being accessed is 1.

Real-Address Mode Exceptions

None.

Virtual-8086 Mode Exceptions

#GP(0)	If any of the I/O permission bits in the TSS for the I/O port being accessed is 1.

OUTS/OUTSB/OUTSW/OUTSD—Output String to Port

Opcode	Instruction	Description
6E	OUTS DX, *m8*	Output byte from memory location specified in DS:(E)SI to I/O port specified in DX
6F	OUTS DX, *m16*	Output word from memory location specified in DS:(E)SI to I/O port specified in DX
6F	OUTS DX, *m32*	Output doubleword from memory location specified in DS:(E)SI to I/O port specified in DX
6E	OUTSB	Output byte from memory location specified in DS:(E)SI to I/O port specified in DX
6F	OUTSW	Output word from memory location specified in DS:(E)SI to I/O port specified in DX
6F	OUTSD	Output doubleword from memory location specified in DS:(E)SI to I/O port specified in DX

Description

These instructions copy data from the source operand (second operand) to the I/O port specified with the destination operand (first operand). The source operand is a memory location, the address of which is read from either the DS:EDI or the DS:DI registers (depending on the address-size attribute of the instruction, 32 or 16, respectively). The DS segment may be overridden with a segment override prefix. The destination operand is an I/O port address (from 0 to 65,535) that is read from the DX register. The size of the I/O port being accessed (that is, the size of the source and destination operands) is determined by the opcode for an 8-bit I/O port or by the operand-size attribute of the instruction for a 16- or 32-bit I/O port.

At the assembly-code level, two forms of this instruction are allowed: the “explicit-operands” form and the “no-operands” form. The explicit-operands form (specified with the OUTS mnemonic) allows the source and destination operands to be specified explicitly. Here, the source operand should be a symbol that indicates the size of the I/O port and the source address, and the destination operand must be DX. This explicit-operands form is provided to allow documentation; however, note that the documentation provided by this form can be misleading. That is, the source operand symbol must specify the correct **type** (size) of the operand (byte, word, or doubleword), but it does not have to specify the correct **location**. The location is always specified by the DS:(E)SI registers, which must be loaded correctly before the OUTS instruction is executed.

The no-operands form provides “short forms” of the byte, word, and doubleword versions of the OUTS instructions. Here also DS:(E)SI is assumed to be the source operand and DX is assumed to be the destination operand. The size of the I/O port is specified with the choice of mnemonic: OUTSB (byte), OUTSW (word), or OUTSD (doubleword).

After the byte, word, or doubleword is transferred from the memory location to the I/O port, the (E)SI register is incremented or decremented automatically according to the setting of the DF flag in the EFLAGS register. (If the DF flag is 0, the (E)SI register is incremented; if the DF flag is 1, the (E)SI register is decremented.) The (E)SI register is incremented or decremented by ne for byte operations, by two for word operations, or by four for doubleword operations.

OUTS/OUTSB/OUTSW/OUTSD—Output String to Port (Continued)

The OUTS, OUTSB, OUTSW, and OUTSD instructions can be preceded by the REP prefix for block input of ECX bytes, words, or doublewords. Refer to "REP/REPE/REPZ/REPNE /REPNZ—Repeat String Operation Prefix" in this chapter for a description of the REP prefix.

This instruction is only useful for accessing I/O ports located in the processor's I/O address space. Refer to Chapter 10, *Input/Output* of the *Intel Architecture Software Developer's Manual, Volume 1*, for more information on accessing I/O ports in the I/O address space.

Intel Architecture Compatibility

After executing an OUTS, OUTSB, OUTSW, or OUTSD instruction, the Pentium® processor insures that the EWBE# pin has been sampled active before it begins to execute the next instruction. (Note that the instruction can be prefetched if EWBE# is not active, but it will not be executed until the EWBE# pin is sampled active.) Only the P6 family of processors has the EWBE# pin. For the P6 family processors, upon execution of an OUTS, OUTSB, OUTSW, or OUTSD instruction, the P6 family of processor will not execute the next instruction until the data phase of the transaction is complete.

OUTS/OUTSB/OUTSW/OUTSD—Output String to Port (Continued)

Operation

```
IF ((PE = 1) AND ((CPL > IOPL) OR (VM = 1)))
    THEN (* Protected mode with CPL > IOPL or virtual-8086 mode *)
        IF (Any I/O Permission Bit for I/O port being accessed = 1)
            THEN (* I/O operation is not allowed *)
                #GP(0);
            ELSE ( * I/O operation is allowed *)
                DEST ← SRC; (* Writes to I/O port *)
        FI;
    ELSE (Real Mode or Protected Mode with CPL ≤ IOPL *)
        DEST ← SRC; (* Writes to I/O port *)
FI;
IF (byte transfer)
    THEN IF DF = 0
        THEN (E)SI ← (E)SI + 1;
        ELSE (E)SI ← (E)SI – 1;
    FI;
    ELSE IF (word transfer)
        THEN IF DF = 0
            THEN (E)SI ← (E)SI + 2;
            ELSE (E)SI ← (E)SI – 2;
        FI;
        ELSE (* doubleword transfer *)
            THEN IF DF = 0
                THEN (E)SI ← (E)SI + 4;
                ELSE (E)SI ← (E)SI – 4;
            FI;
    FI;
FI;
```

Flags Affected

None.

OUTS/OUTSB/OUTSW/OUTSD—Output String to Port (Continued)

Protected Mode Exceptions

#GP(0)	If the CPL is greater than (has less privilege) the I/O privilege level (IOPL) and any of the corresponding I/O permission bits in TSS for the I/O port being accessed is 1.
	If a memory operand effective address is outside the limit of the CS, DS, ES, FS, or GS segment.
	If the segment register contains a null segment selector.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If any of the I/O permission bits in the TSS for the I/O port being accessed is 1.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PACKSSWB/PACKSSDW—Pack with Signed Saturation

Opcode	Instruction	Description
0F 63 /r	PACKSSWB *mm, mm/m64*	Packs and saturate pack four signed words from *mm* and four signed words from *mm/m64* into eight signed bytes in *mm*.
0F 6B /r	PACKSSDW *mm, mm/m64*	Pack and saturate two signed doublewords from *mm* and two signed doublewords from *mm/m64* into four signed words in *mm*.

Description

These instructions pack and saturate signed words into bytes (PACKSSWB) or signed doublewords into words (PACKSSDW). The PACKSSWB instruction packs four signed words from the destination operand (first operand) and four signed words from the source operand (second operand) into eight signed bytes in the destination operand. If the signed value of a word is beyond the range of a signed byte (that is, greater than 7FH or less than 80H), the saturated byte value of 7FH or 80H, respectively, is stored into the destination.

The PACKSSDW instruction packs two signed doublewords from the destination operand (first operand) and two signed doublewords from the source operand (second operand) into four signed words in the destination operand (refer to Figure 3-53). If the signed value of a doubleword is beyond the range of a signed word (that is, greater than 7FFFH or less than 8000H), the saturated word value of 7FFFH or 8000H, respectively, is stored into the destination.

The destination operand for either the PACKSSWB or PACKSSDW instruction must be an MMX™ technology register; the source operand may be either an MMX™ technology register or a quadword memory location.

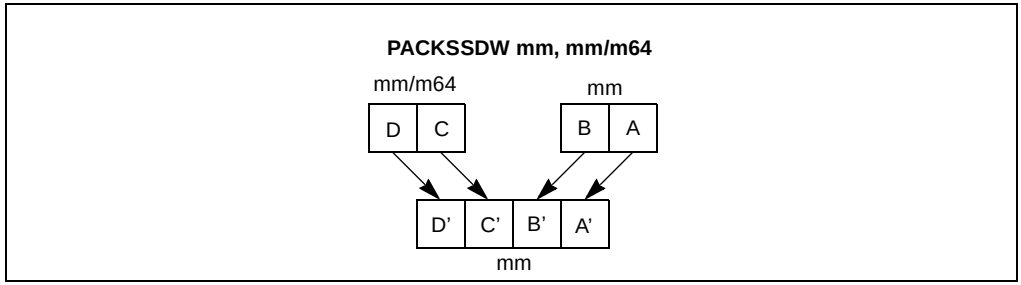


Figure 3-53. Operation of the PACKSSDW Instruction

PACKSSWB/PACKSSDW—Pack with Signed Saturation (Continued)

Operation

```
IF instruction is PACKSSWB
    THEN
        DEST(7..0) ← SaturateSignedWordToSignedByte DEST(15..0);
        DEST(15..8) ← SaturateSignedWordToSignedByte DEST(31..16);
        DEST(23..16) ← SaturateSignedWordToSignedByte DEST(47..32);
        DEST(31..24) ← SaturateSignedWordToSignedByte DEST(63..48);
        DEST(39..32) ← SaturateSignedWordToSignedByte SRC(15..0);
        DEST(47..40) ← SaturateSignedWordToSignedByte SRC(31..16);
        DEST(55..48) ← SaturateSignedWordToSignedByte SRC(47..32);
        DEST(63..56) ← SaturateSignedWordToSignedByte SRC(63..48);
    ELSE (* instruction is PACKSSDW *)
        DEST(15..0) ← SaturateSignedDoublewordToSignedWord DEST(31..0);
        DEST(31..16) ← SaturateSignedDoublewordToSignedWord DEST(63..32);
        DEST(47..32) ← SaturateSignedDoublewordToSignedWord SRC(31..0);
        DEST(63..48) ← SaturateSignedDoublewordToSignedWord SRC(63..32);
FI;
```

Intel C/C++ Compiler Intrinsic Equivalents

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_packsswb (__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_packs_pi16(__m64 m1, __m64 m2)

Pack the four 16-bit values from m1 into the lower four 8-bit values of the result with signed saturation, and pack the four 16-bit values from m2 into the upper four 8-bit values of the result with signed saturation.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_packssdw (__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_packs_pi32 (__m64 m1, __m64 m2)

Pack the two 32-bit values from m1 into the lower two 16-bit values of the result with signed saturation, and pack the two 32-bit values from m2 into the upper two 16-bit values of the result with signed saturation.

Flags Affected

None.

PACKSSWB/PACKSSDW—Pack with Signed Saturation (Continued)

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PACKUSWB—Pack with Unsigned Saturation

Opcode	Instruction	Description
0F 67 /r	PACKUSWB *mm, mm/m64*	Pack and saturate four signed words from *mm* and four signed words from *mm/m64* into eight unsigned bytes in *mm.*

Description

This instruction packs and saturates four signed words from the destination operand (first operand) and four signed words from the source operand (second operand) into eight unsigned bytes in the destination operand (refer to Figure 3-54). If the signed value of a word is beyond the range of an unsigned byte (that is, greater than FFH or less than 00H), the saturated byte value of FFH or 00H, respectively, is stored into the destination.

The destination operand must be an MMX™ technology register; the source operand may be either an MMX™ technology register or a quadword memory location.

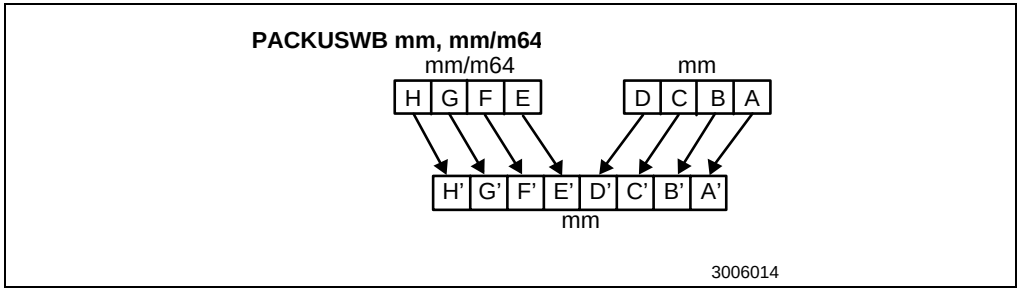


Figure 3-54. Operation of the PACKUSWB Instruction

Operation

```
DEST(7..0) ← SaturateSignedWordToUnsignedByte DEST(15..0);
DEST(15..8) ← SaturateSignedWordToUnsignedByte DEST(31..16);
DEST(23..16) ← SaturateSignedWordToUnsignedByte DEST(47..32);
DEST(31..24) ← SaturateSignedWordToUnsignedByte DEST(63..48);
DEST(39..32) ← SaturateSignedWordToUnsignedByte SRC(15..0);
DEST(47..40) ← SaturateSignedWordToUnsignedByte SRC(31..16);
DEST(55..48) ← SaturateSignedWordToUnsignedByte SRC(47..32);
DEST(63..56) ← SaturateSignedWordToUnsignedByte SRC(63..48);
```

PACKUSWB—Pack with Unsigned Saturation (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_packuswb(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_packs_pu16(__m64 m1, __m64 m2)

Pack the four 16-bit values from m1 into the lower four 8-bit values of the result with unsigned saturation, and pack the four 16-bit values from m2 into the upper four 8-bit values of the result with unsigned saturation.

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

PACKUSWB—Pack with Unsigned Saturation (Continued)

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PADDB/PADDW/PADDD—Packed Add

Opcode	Instruction	Description
0F FC /r	PADDB *mm, mm/m64*	Add packed bytes from *mm/m64* to packed bytes in *mm.*
0F FD /r	PADDW *mm, mm/m64*	Add packed words from *mm/m64* to packed words in *mm.*
0F FE /r	PADDD *mm, mm/m64*	Add packed doublewords from *mm/m64* to packed doublewords in *mm.*

Description

These instructions add the individual data elements (bytes, words, or doublewords) of the source operand (second operand) to the individual data elements of the destination operand (first operand) (refer to Figure 3-55). If the result of an individual addition exceeds the range for the specified data type (overflows), the result is wrapped around, meaning that the result is truncated so that only the lower (least significant) bits of the result are returned (that is, the carry is ignored).

The destination operand must be an MMX™ technology register; the source operand can be either an MMX™ technology register or a quadword memory location.

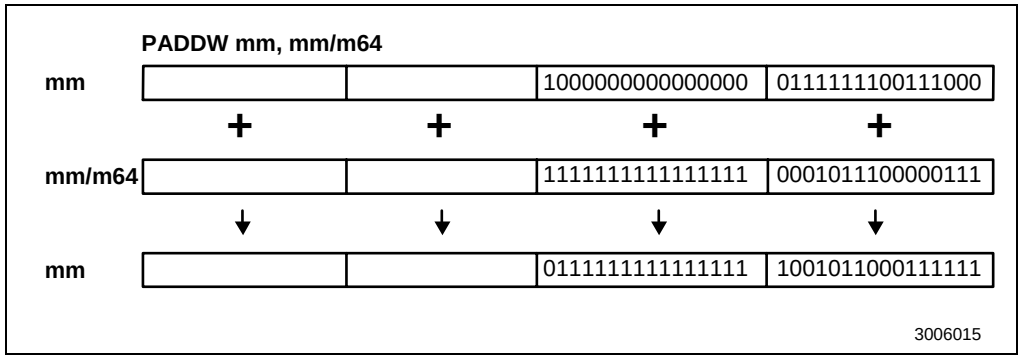


Figure 3-55. Operation of the PADDW Instruction

The PADDB instruction adds the bytes of the source operand to the bytes of the destination operand and stores the results to the destination operand. When an individual result is too large to be represented in eight bits, the lower eight bits of the result are written to the destination operand and therefore the result wraps around.

The PADDW instruction adds the words of the source operand to the words of the destination operand and stores the results to the destination operand. When an individual result is too large to be represented in 16 bits, the lower 16 bits of the result are written to the destination operand and therefore the result wraps around.

PADDB/PADDW/PADDD—Packed Add (Continued)

The PADDD instruction adds the doublewords of the source operand to the doublewords of the destination operand and stores the results to the destination operand. When an individual result is too large to be represented in 32 bits, the lower 32 bits of the result are written to the destination operand and therefore the result wraps around.

Note that like the integer ADD instruction, the PADDB, PADDW, and PADDD instructions can operate on either unsigned or signed (two's complement notation) packed integers. Unlike the integer instructions, none of the MMX™ instructions affect the EFLAGS register. With MMX™ instructions, there are no carry or overflow flags to indicate when overflow has occurred, so the software must control the range of values or else use the "with saturation" MMX™ instructions.

Operation

```
IF instruction is PADDB
    THEN
        DEST(7..0) ← DEST(7..0) + SRC(7..0);
        DEST(15..8) ← DEST(15..8) + SRC(15..8);
        DEST(23..16) ← DEST(23..16)+ SRC(23..16);
        DEST(31..24) ← DEST(31..24) + SRC(31..24);
        DEST(39..32) ← DEST(39..32) + SRC(39..32);
        DEST(47..40) ← DEST(47..40)+ SRC(47..40);
        DEST(55..48) ← DEST(55..48) + SRC(55..48);
        DEST(63..56) ← DEST(63..56) + SRC(63..56);
ELSEIF instruction is PADDW
    THEN
        DEST(15..0) ← DEST(15..0) + SRC(15..0);
        DEST(31..16) ← DEST(31..16) + SRC(31..16);
        DEST(47..32) ← DEST(47..32) + SRC(47..32);
        DEST(63..48) ← DEST(63..48) + SRC(63..48);
    ELSE (* instruction is PADDD *)
        DEST(31..0) ← DEST(31..0) + SRC(31..0);
        DEST(63..32) ← DEST(63..32) + SRC(63..32);
FI;
```

PADDB/PADDW/PADDD—Packed Add (Continued)

Intel C/C++ Compiler Intrinsic Equivalents

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_paddb(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_add_pi8(__m64 m1, __m64 m2)

Add the eight 8-bit values in m1 to the eight 8-bit values in m2.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_paddw(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_addw_pi16(__m64 m1, __m64 m2)

Add the four 16-bit values in m1 to the four 16-bit values in m2.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_paddd(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_add_pi32(__m64 m1, __m64 m2)

Add the two 32-bit values in m1 to the two 32-bit values in m2.

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

PADDB/PADDW/PADDD—Packed Add (Continued)

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PADDSB/PADDSW—Packed Add with Saturation

Opcode	Instruction	Description
0F EC /r	PADDSB *mm, mm/m64*	Add signed packed bytes from *mm/m64* to signed packed bytes in *mm* and saturate.
0F ED /r	PADDSW *mm, mm/m64*	Add signed packed words from *mm/m64* to signed packed words in *mm* and saturate.

Description

These instructions add the individual signed data elements (bytes or words) of the source operand (second operand) to the individual signed data elements of the destination operand (first operand) (refer to Figure 3-56). If the result of an individual addition exceeds the range for the specified data type, the result is saturated. The destination operand must be an MMX™ technology register; the source operand can be either an MMX™ technology register or a quadword memory location.

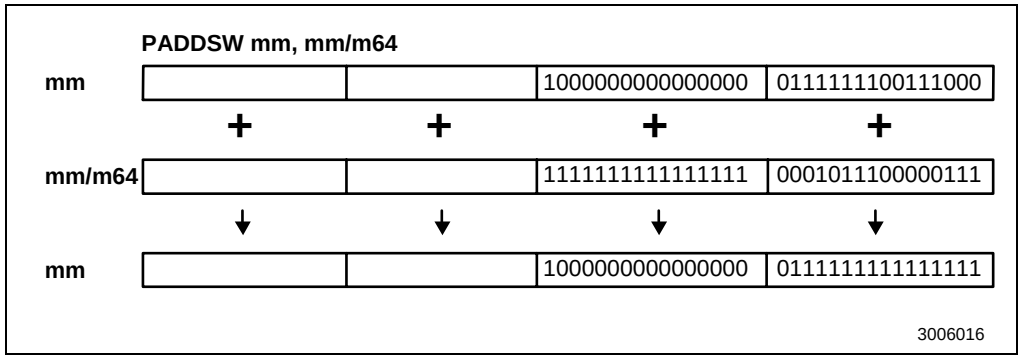


Figure 3-56. Operation of the PADDSW Instruction

The PADDSB instruction adds the signed bytes of the source operand to the signed bytes of the destination operand and stores the results to the destination operand. When an individual result is beyond the range of a signed byte (that is, greater than 7FH or less than 80H), the saturated byte value of 7FH or 80H, respectively, is written to the destination operand.

The PADDSW instruction adds the signed words of the source operand to the signed words of the destination operand and stores the results to the destination operand. When an individual result is beyond the range of a signed word (that is, greater than 7FFFH or less than 8000H), the saturated word value of 7FFFH or 8000H, respectively, is written to the destination operand.

PADDSB/PADDSW—Packed Add with Saturation (Continued)

Operation

```
IF instruction is PADDSB
    THEN
        DEST(7..0) ← SaturateToSignedByte(DEST(7..0) + SRC (7..0)) ;
        DEST(15..8) ← SaturateToSignedByte(DEST(15..8) + SRC(15..8) );
        DEST(23..16) ← SaturateToSignedByte(DEST(23..16)+ SRC(23..16) );
        DEST(31..24) ← SaturateToSignedByte(DEST(31..24) + SRC(31..24) );
        DEST(39..32) ← SaturateToSignedByte(DEST(39..32) + SRC(39..32) );
        DEST(47..40) ← SaturateToSignedByte(DEST(47..40)+ SRC(47..40) );
        DEST(55..48) ← SaturateToSignedByte(DEST(55..48) + SRC(55..48) );
        DEST(63..56) ← SaturateToSignedByte(DEST(63..56) + SRC(63..56) );
    ELSE { (* instruction is PADDSW *)
        DEST(15..0) ← SaturateToSignedWord(DEST(15..0) + SRC(15..0) );
        DEST(31..16) ← SaturateToSignedWord(DEST(31..16) + SRC(31..16) );
        DEST(47..32) ← SaturateToSignedWord(DEST(47..32) + SRC(47..32) );
        DEST(63..48) ← SaturateToSignedWord(DEST(63..48) + SRC(63..48) );
FI;
```

Intel C/C++ Compiler Intrinsic Equivalents

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_paddsb(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_adds_pi8(__m64 m1, __m64 m2)

Add the eight signed 8-bit values in m1 to the eight signed 8-bit values in m2 and saturate.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_paddsw(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_adds_pi16(__m64 m1, __m64 m2)

Add the four signed 16-bit values in m1 to the four signed 16-bit values in m2 and saturate.

Flags Affected

None.

PADDSB/PADDSW—Packed Add with Saturation (Continued)

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PADDUSB/PADDUSW—Packed Add Unsigned with Saturation

Opcode	Instruction	Description
0F DC /r	PADDUSB *mm, mm/m64*	Add unsigned packed bytes from *mm/m64* to unsigned packed bytes in *mm* and saturate.
0F DD /r	PADDUSW *mm, mm/m64*	Add unsigned packed words from *mm/m64* to unsigned packed words in *mm* and saturate.

Description

These instructions add the individual unsigned data elements (bytes or words) of the packed source operand (second operand) to the individual unsigned data elements of the packed destination operand (first operand) (refer to Figure 3-57). If the result of an individual addition exceeds the range for the specified unsigned data type, the result is saturated. The destination operand must be an MMX™ technology register; the source operand can be either an MMX™ technology register or a quadword memory location.

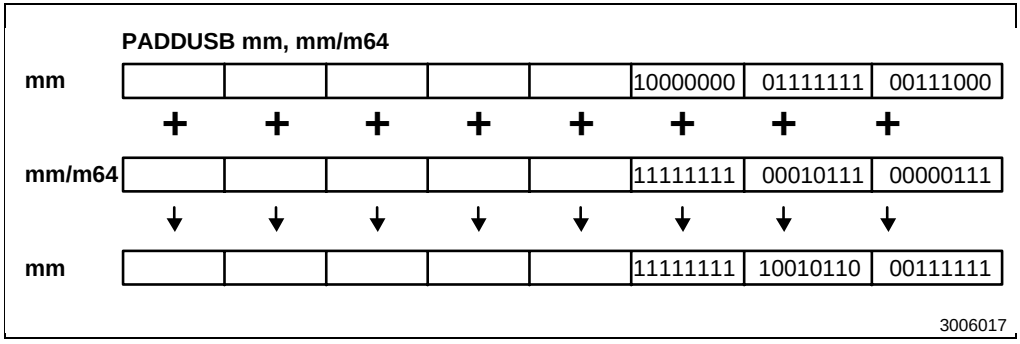


Figure 3-57. Operation of the PADDUSB Instruction

The PADDUSB instruction adds the unsigned bytes of the source operand to the unsigned bytes of the destination operand and stores the results to the destination operand. When an individual result is beyond the range of an unsigned byte (that is, greater than FFH), the saturated unsigned byte value of FFH is written to the destination operand.

The PADDUSW instruction adds the unsigned words of the source operand to the unsigned words of the destination operand and stores the results to the destination operand. When an individual result is beyond the range of an unsigned word (that is, greater than FFFFH), the saturated unsigned word value of FFFFH is written to the destination operand.

PADDUSB/PADDUSW—Packed Add Unsigned with Saturation (Continued)

Operation

```
IF instruction is PADDUSB
    THEN
        DEST(7..0) ← SaturateToUnsignedByte(DEST(7..0) + SRC (7..0) );
        DEST(15..8) ← SaturateToUnsignedByte(DEST(15..8) + SRC(15..8) );
        DEST(23..16) ← SaturateToUnsignedByte(DEST(23..16)+ SRC(23..16) );
        DEST(31..24) ← SaturateToUnsignedByte(DEST(31..24) + SRC(31..24) );
        DEST(39..32) ← SaturateToUnsignedByte(DEST(39..32) + SRC(39..32) );
        DEST(47..40) ← SaturateToUnsignedByte(DEST(47..40)+ SRC(47..40) );
        DEST(55..48) ← SaturateToUnsignedByte(DEST(55..48) + SRC(55..48) );
        DEST(63..56) ← SaturateToUnsignedByte(DEST(63..56) + SRC(63..56) );
    ELSE { (* instruction is PADDUSW *)
        DEST(15..0) ← SaturateToUnsignedWord(DEST(15..0) + SRC(15..0) );
        DEST(31..16) ← SaturateToUnsignedWord(DEST(31..16) + SRC(31..16) );
        DEST(47..32) ← SaturateToUnsignedWord(DEST(47..32) + SRC(47..32) );
        DEST(63..48) ← SaturateToUnsignedWord(DEST(63..48) + SRC(63..48) );
FI;
```

Intel C/C++ Compiler Intrinsic Equivalents

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_paddusb(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_adds_pu8(__m64 m1, __m64 m2)

Add the eight unsigned 8-bit values in m1 to the eight unsigned 8-bit values in m2 and saturate.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_paddusw(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_adds_pu16(__m64 m1, __m64 m2)

Add the four unsigned 16-bit values in m1 to the four unsigned 16-bit values in m2 and saturate.

Flags Affected

None.

PADDUSB/PADDUSW—Packed Add Unsigned with Saturation (Continued)

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PAND—Logical AND

Opcode	Instruction	Description
0F DB /r	PAND *mm, mm/m64*	AND quadword from *mm/m64* to quadword in mm.

Description

This instruction performs a bitwise logical AND operation on the quadword source (second) and destination (first) operands and stores the result in the destination operand location (refer to Figure 3-58). The source operand can be an MMX™ technology register or a quadword memory location; the destination operand must be an MMX™ technology register. Each bit of the result of the PAND instruction is set to 1 if the corresponding bits of the operands are both 1; otherwise it is made zero

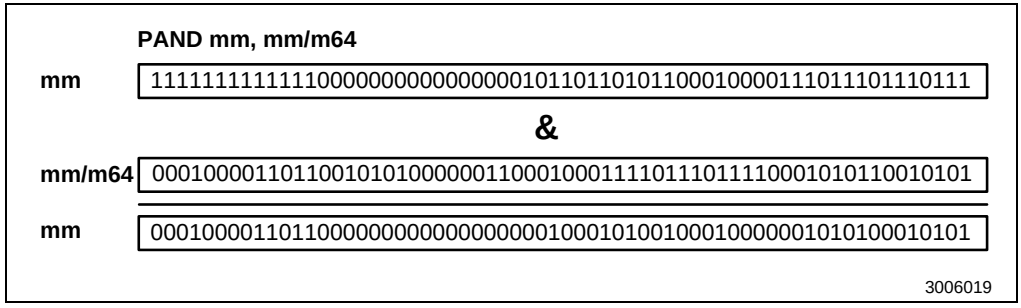


Figure 3-58. Operation of the PAND Instruction

Operation

DEST ← DEST AND SRC;

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pand(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_and_si64(__m64 m1, __m64 m2)

Perform a bitwise AND of the 64-bit value in m1 with the 64-bit value in m2.

Flags Affected

None.

PAND—Logical AND (Continued)

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PANDN—Logical AND NOT

Opcode	Instruction	Description
0F DF /r	PANDN *mm, mm/m64*	AND quadword from *mm/m64* to NOT quadword in *mm.*

Description

This instruction performs a bitwise logical NOT on the quadword destination operand (first operand). Then, the instruction performs a bitwise logical AND operation on the inverted destination operand and the quadword source operand (second operand) (refer to Figure 3-59). Each bit of the result of the AND operation is set to one if the corresponding bits of the source and inverted destination bits are one; otherwise it is set to zero. The result is stored in the destination operand location.

The source operand can be an MMX™ technology register or a quadword memory location; the destination operand must be an MMX™ technology register.

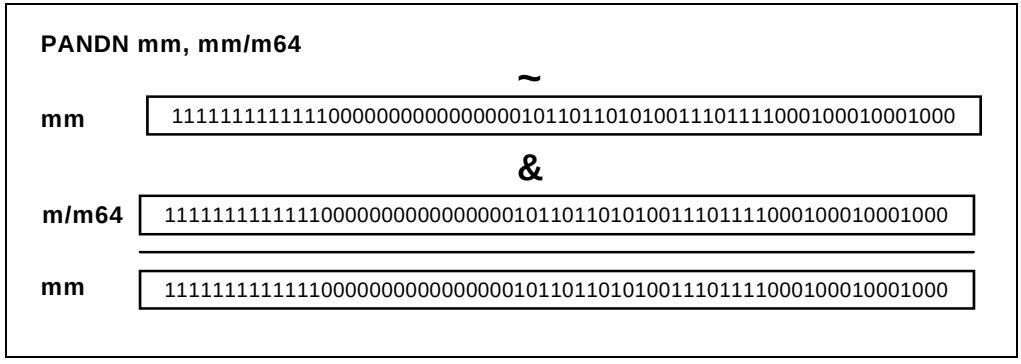


Figure 3-59. Operation of the PANDN Instruction

Operation

DEST ← (NOT DEST) AND SRC;

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pandn(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_andnot_si64(__m64 m1, __m64 m2)

Perform a logical NOT on the 64-bit value in m1 and use the result in a bitwise AND with the 64-bit value in m2.

PANDN—Logical AND NOT (Continued)

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PAVGB/PAVGW—Packed Average

Opcode	Instruction	Description
0F,E0, /r	PAVGB *mm1,mm2/m64*	Average with rounding packed unsigned bytes from MM2/Mem to packed bytes in MM1 register.
0F,E3, /r	PAVGW *mm1, mm2/m64*	Average with rounding packed unsigned words from MM2/Mem to packed words in MM1 register.

Description

The PAVG instructions add the unsigned data elements of the source operand to the unsigned data elements of the destination register, along with a carry-in. The results of the add are then each independently right-shifted by one bit position. The high order bits of each element are filled with the carry bits of the corresponding sum.

The destination operand is an MMX™ technology register. The source operand can either be an MMX™ technology register or a 64-bit memory operand.

The PAVGB instruction operates on packed unsigned bytes, and the PAVGW instruction operates on packed unsigned words.

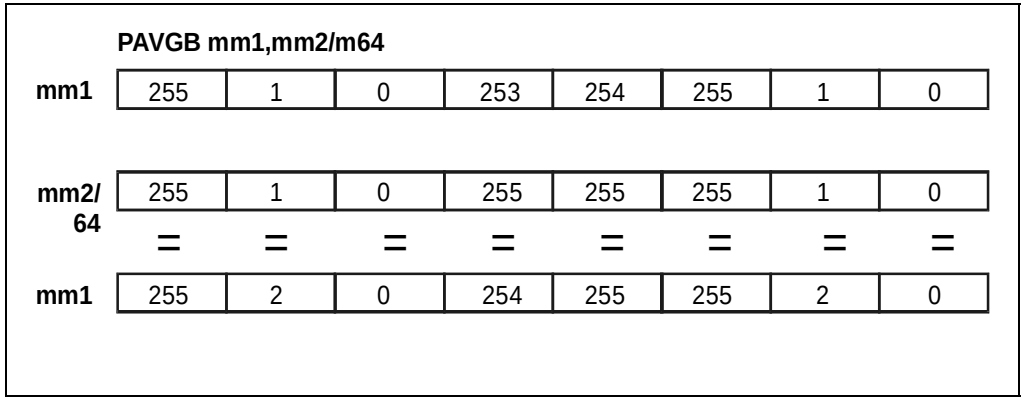


Figure 3-60. Operation of the PAVGB/PAVGW Instruction

PAVGB/PAVGW—Packed Average (Continued)

Operation

```
IF (* instruction = PAVGB *) THEN
    X[0] = DEST[7-0];
    Y[0] = SRC/m64[7-0];
    X[1] = DEST[15-8];
    Y[1] = SRC/m64[15-8];
    X[2] = DEST[23-16];
    Y[2] = SRC/m64[23-16];
    X[3] = DEST[31-24];
    Y[3] = SRC/m64[31-24];
    X[4] = DEST[39-32];
    Y[4] = SRC/m64[39-32];
    X[5] = DEST[47-40];
    Y[5] = SRC/m64[47-40];
    X[6] = DEST[55-48];
    Y[6] = SRC/m64[55-48];
    X[7] = DEST[63-56];
    Y[7] = SRC/m64[63-56];

WHILE (I < 8)
    TEMP[I] = ZERO_EXT(X[I], 8) + ZERO_EXT{Y[I], 8);
    RES[I] = (TEMP[I] + 1) >> 1;
ENDWHILE

DEST[7-0] = RES[0];
DEST[15-8] = RES[1];
DEST[23-16] = RES[2];
DEST[31-24] = RES[3];
DEST[39-32] = RES[4];
DEST[47-40] = RES[5];
DEST[55-48] = RES[6];
DEST[63-56] = RES[7];

ELSE IF (* instruction  PAVGW *)THEN
    X[0] = DEST[15-0];
    Y[0] = SRC/m64[15-0];
    X[1] = DEST[31-16];
    Y[1] = SRC/m64[31-16];
    X[2] = DEST[47-32];
    Y[2] = SRC/m64[47-32];
    X[3] = DEST[63-48];
    Y[3] = SRC/m64[63-48];
```

PAVGB/PAVGW—Packed Average (Continued)

```
WHILE (I < 4)
    TEMP[I] = ZERO_EXT(X[I], 16) + ZERO_EXT{Y[I], 16);
    RES[I] = (TEMP[I] + 1) >> 1;
ENDWHILE

    DEST[15-0] = RES[0];
    DEST[31-16] = RES[1];
    DEST[47-32] = RES[2];
    DEST[63-48] = RES[3];

FI;
```

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64_mm_pavgb(__m64 a, __m64 b)

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64_mm_avg_pu8(__m64 a, __m64 b)

Performs the packed average on the eight 8-bit values of the two operands.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64_mm_pavgw(__m64 a, __m64 b)

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64_mm_avg_pu16(__m64 a, __m64 b)

Performs the packed average on the four 16-bit values of the two operands.

Numeric Exceptions

None.

PAVGB/PAVGW—Packed Average (Continued)

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.
#AC	For unaligned memory references (if the current privilege level is 3).

PCMPEQB/PCMPEQW/PCMPEQD—Packed Compare for Equal

Opcode	Instruction	Description
0F 74 /r	PCMPEQB *mm, mm/m64*	Compare packed bytes in *mm/m64* with packed bytes in *mm* for equality.
0F 75 /r	PCMPEQW *mm, mm/m64*	Compare packed words in *mm/m64* with packed words in *mm* for equality.
0F 76 /r	PCMPEQD *mm, mm/m64*	Compare packed doublewords in *mm/m64* with packed doublewords in *mm* for equality.

Description

These instructions compare the individual data elements (bytes, words, or doublewords) in the destination operand (first operand) to the corresponding data elements in the source operand (second operand) (refer to Figure 3-61). If a pair of data elements are equal, the corresponding data element in the destination operand is set to all ones; otherwise, it is set to all zeroes. The destination operand must be an MMX™ technology register; the source operand may be either an MMX™ technology register or a 64-bit memory location.

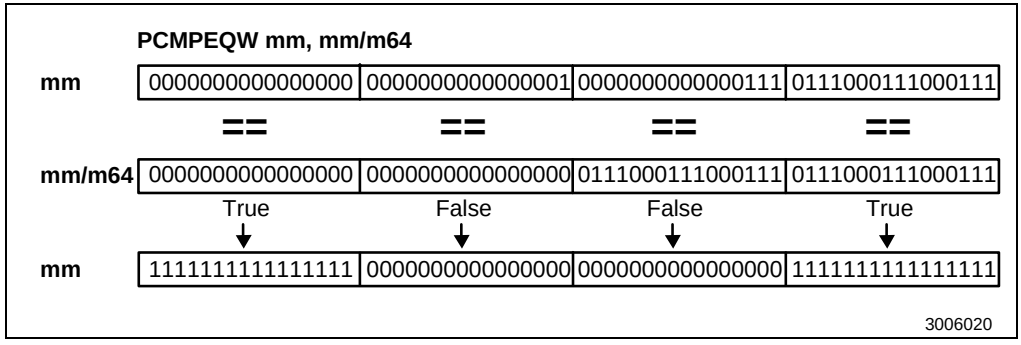


Figure 3-61. Operation of the PCMPEQW Instruction

The PCMPEQB instruction compares the bytes in the destination operand to the corresponding bytes in the source operand, with the bytes in the destination operand being set according to the results.

The PCMPEQW instruction compares the words in the destination operand to the corresponding words in the source operand, with the words in the destination operand being set according to the results.

The PCMPEQD instruction compares the doublewords in the destination operand to the corresponding doublewords in the source operand, with the doublewords in the destination operand being set according to the results.

PCMPEQB/PCMPEQW/PCMPEQD—Packed Compare for Equal (Continued)

Operation

```
IF instruction is PCMPEQB
    THEN
        IF DEST(7..0) = SRC(7..0)
            THEN DEST(7  0) ← FFH;
            ELSE DEST(7..0) ← 0;
        * Continue comparison of second through seventh bytes in DEST and SRC *
        IF DEST(63..56) = SRC(63..56)
            THEN DEST(63..56) ← FFH;
            ELSE DEST(63..56) ← 0;
ELSE IF instruction is PCMPEQW
    THEN
        IF DEST(15..0) = SRC(15..0)
            THEN DEST(15..0) ← FFFFH;
            ELSE DEST(15..0) ← 0;
        * Continue comparison of second and third words in DEST and SRC *
        IF DEST(63..48) = SRC(63..48)
            THEN DEST(63..48) ← FFFFH;
            ELSE DEST(63..48) ← 0;
    ELSE (* instruction is PCMPEQD *)
        IF DEST(31..0) = SRC(31..0)
            THEN DEST(31..0) ← FFFFFFFFH;
            ELSE DEST(31..0) ← 0;
        IF DEST(63..32) = SRC(63..32)
            THEN DEST(63..32) ← FFFFFFFFH;
            ELSE DEST(63..32) ← 0;
FI;
```

PCMPEQB/PCMPEQW/PCMPEQD—Packed Compare for Equal (Continued)

Intel C/C++ Compiler Intrinsic Equivalents

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pcmpeqb (__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_cmpeq_pi8 (__m64 m1, __m64 m2)

If the respective 8-bit values in m1 are equal to the respective 8-bit values in m2 set the respective 8-bit resulting values to all ones, otherwise set them to all zeroes.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pcmpeqw (__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_cmpeq_pi16 (__m64 m1, __m64 m2)

If the respective 16-bit values in m1 are equal to the respective 16-bit values in m2 set the respective 16-bit resulting values to all ones, otherwise set them to all zeroes.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pcmpeqd (__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_cmpeq_pi32 (__m64 m1, __m64 m2)

If the respective 32-bit values in m1 are equal to the respective 32-bit values in m2 set the respective 32-bit resulting values to all ones, otherwise set them to all zeroes.

Flags Affected

None:

PCMPEQB/PCMPEQW/PCMPEQD—Packed Compare for Equal (Continued)

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PCMPGTB/PCMPGTW/PCMPGTD—Packed Compare for Greater Than

Opcode	Instruction	Description
0F 64 /r	PCMPGTB *mm, mm/m64*	Compare packed bytes in *mm* with packed bytes in *mm/m64* for greater value.
0F 65 /r	PCMPGTW *mm, mm/m64*	Compare packed words in *mm* with packed words in *mm/m64* for greater value.
0F 66 /r	PCMPGTD *mm, mm/m64*	Compare packed doublewords in *mm* with packed doublewords in *mm/m64* for greater value.

Description

These instructions compare the individual signed data elements (bytes, words, or doublewords) in the destination operand (first operand) to the corresponding signed data elements in the source operand (second operand) (refer to Figure 3-62). If a data element in the destination operand is greater than its corresponding data element in the source operand, the data element in the destination operand is set to all ones; otherwise, it is set to all zeroes. The destination operand must be an MMX™ technology register; the source operand may be either an MMX™ technology register or a 64-bit memory location.

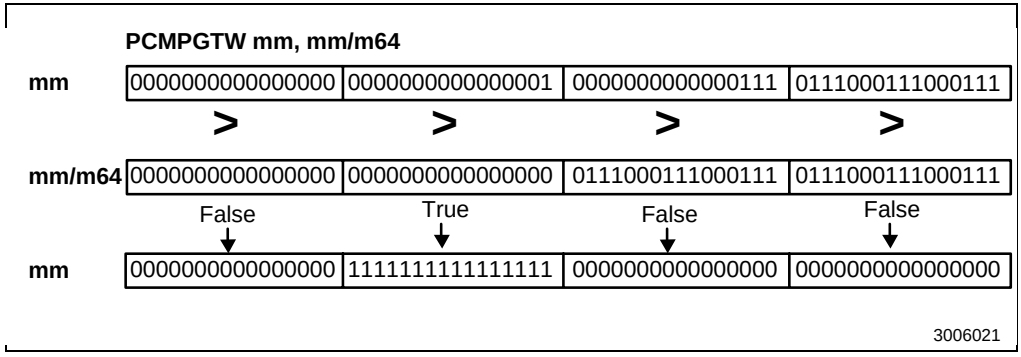


Figure 3-62. Operation of the PCMPGTW Instruction

The PCMPGTB instruction compares the signed bytes in the destination operand to the corresponding signed bytes in the source operand, with the bytes in the destination operand being set according to the results.

The PCMPGTW instruction compares the signed words in the destination operand to the corresponding signed words in the source operand, with the words in the destination operand being set according to the results.

The PCMPGTD instruction compares the signed doublewords in the destination operand to the corresponding signed doublewords in the source operand, with the doublewords in the destination operand being set according to the results.

PCMPGTB/PCMPGTW/PCMPGTD—Packed Compare for Greater Than (Continued)

Operation

```
IF instruction is PCMPGTB
    THEN
        IF DEST(7..0) > SRC(7..0)
            THEN DEST(7  0) ← FFH;
            ELSE DEST(7..0) ← 0;
        * Continue comparison of second through seventh bytes in DEST and SRC *
        IF DEST(63..56) > SRC(63..56)
            THEN DEST(63..56) ← FFH;
            ELSE DEST(63..56) ← 0;
ELSE IF instruction is PCMPGTW
    THEN
        IF DEST(15..0) > SRC(15..0)
            THEN DEST(15..0) ← FFFFH;
            ELSE DEST(15..0) ←0;
        * Continue comparison of second and third bytes in DEST and SRC *
        IF DEST(63..48) > SRC(63..48)
            THEN DEST(63..48) ← FFFFH;
            ELSE DEST(63..48) ← 0;
    ELSE { (* instruction is PCMPGTD *)
        IF DEST(31..0) > SRC(31..0)
            THEN DEST(31..0) ← FFFFFFFFH;
            ELSE DEST(31..0) ← 0;
        IF DEST(63..32) > SRC(63..32)
            THEN DEST(63..32) ← FFFFFFFFH;
            ELSE DEST(63..32) ← 0;
FI;
```

PCMPGTB/PCMPGTW/PCMPGTD—Packed Compare for Greater Than (Continued)

Intel C/C++ Compiler Intrinsic Equivalents

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pcmpgtb (__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_cmpgt_pi8 (__m64 m1, __m64 m2)

If the respective 8-bit values in m1 are greater than the respective 8-bit values in m2 set the respective 8-bit resulting values to all ones, otherwise set them to all zeroes.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pcmpgtw (__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_pcmpgt_pi16 (__m64 m1, __m64 m2)

If the respective 16-bit values in m1 are greater than the respective 16-bit values in m2 set the respective 16-bit resulting values to all ones, otherwise set them to all zeroes.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pcmpgtd (__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_pcmpgt_pi32 (__m64 m1, __m64 m2)

If the respective 32-bit values in m1 are greater than the respective 32-bit values in m2 set the respective 32-bit resulting values to all ones, otherwise set them all to zeroes.

Flags Affected

None.

PCMPGTB/PCMPGTW/PCMPGTD—Packed Compare for Greater Than (Continued)

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PEXTRW—Extract Word

Opcode	Instruction	Description
0F,C5, /r, ib	PEXTRW r32, mm, imm8	Extract the word pointed to by imm8 from MM and move it to a 32-bit integer register.

Description

The PEXTRW instruction moves the word in MM (selected by the two least significant bits of imm8) to the lower half of a 32-bit integer register.

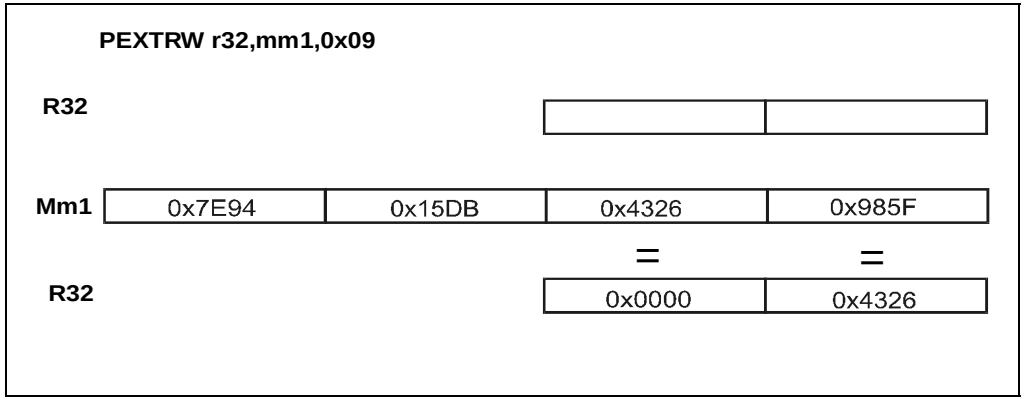


Figure 3-63. Operation of the PEXTRW Instruction

Operation

```
SEL = imm8 AND 0X3;
MM_TEMP = (SRC >> (SEL * 16)) AND 0XFFFF;
r32[15-0] = MM_TEMP[15-0];
r32[31-16] = 0X0000;
```

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

int_m_pextrw(__m64 a, int n)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

int_mm_extract_pi16(__m64 a, int n)

Extracts one of the four words of a. The selector n must be an immediate.

PEXTRW—Extract Word (Continued)

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.

PINSRW—Insert Word

Opcode	Instruction	Description
0F,C4,/r,ib	PINSRW *mm*, r32/*m16*, *imm8*	Insert the word from the lower half of r32 or from *Mem16* into the position in *MM* pointed to by *imm8* without touching the other words.

Description

The PINSRW instruction loads a word from the lower half of a 32-bit integer register (or from memory) and inserts it in the MM destination register, at a position defined by the two least significant bits of the imm8 constant. The insertion is done in such a way that the three other words from the destination register are left untouched.

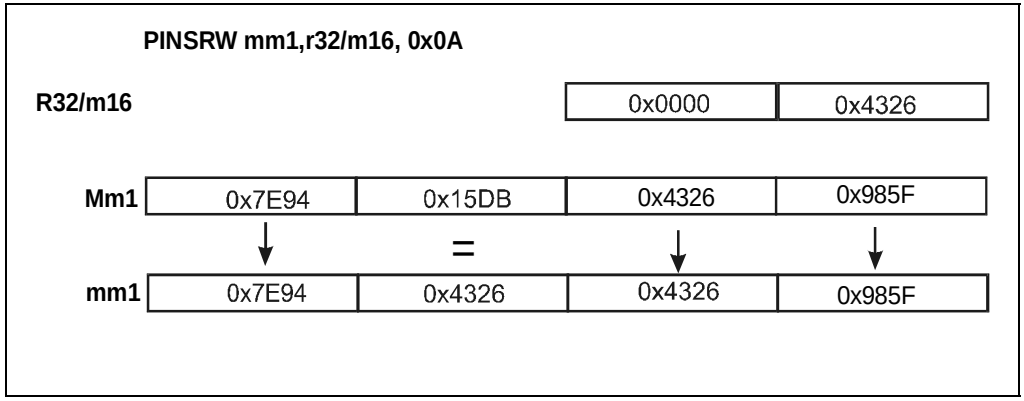


Figure 3-64. Operation of the PINSRW Instruction

Operation

```
SEL = imm8 AND 0X3;
IF(SEL = 0) THEN
    MASK=0X000000000000FFFF;
ELSE
    IF(SEL = 1) THEN
        MASK=0X00000000FFFF0000 :
    ELSE
        IF(SEL = 2) THEN
            MASK=0XFFFF000000000000;
        FI
    FI
FI
DEST = (DEST AND NOT MASK) OR ((m16/r32[15-0] << (SEL * 16)) AND MASK);
```

PINSRW—Insert Word (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pinsrw(__m64 a, int d, int n)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_insert_pi16(__m64 a, int d, int n)

Inserts word d into one of four words of a. The selector n must be an immediate.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

PMADDWD—Packed Multiply and Add

Opcode	Instruction	Description
0F F5 /r	PMADDWD *mm, mm/m64*	Multiply the packed words in *mm* by the packed words in *mm/m64*. Add the 32-bit pairs of results and store in *mm* as doubleword

Description

This instruction multiplies the individual signed words of the destination operand by the corresponding signed words of the source operand, producing four signed, doubleword results (refer to Figure 3-65). The two doubleword results from the multiplication of the high-order words are added together and stored in the upper doubleword of the destination operand; the two doubleword results from the multiplication of the low-order words are added together and stored in the lower doubleword of the destination operand. The destination operand must be an MMX™ technology register; the source operand may be either an MMX™ technology register or a 64-bit memory location.

The PMADDWD instruction wraps around to 80000000H only when all four words of both the source and destination operands are 8000H.

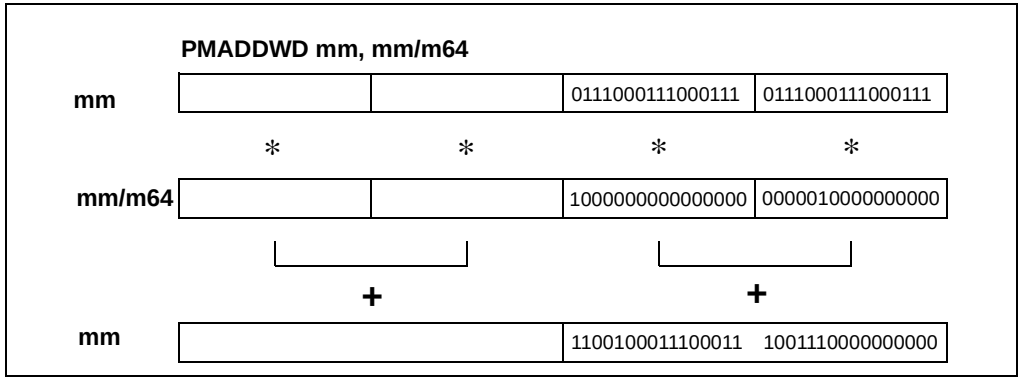


Figure 3-65. Operation of the PMADDWD Instruction

Operation

DEST(31..0) ← (DEST(15..0) ∗ SRC(15..0)) + (DEST(31..16) ∗ SRC(31..16));
DEST(63..32) ← (DEST(47..32) ∗ SRC(47..32)) + (DEST(63..48) ∗ SRC(63..48));

PMADDWD—Packed Multiply and Add (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pmaddwd(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_madd_pi16(__m64 m1, __m64 m2)

Multiply four 16-bit values in m1 by four 16-bit values in m2 producing four 32-bit intermediate results, which are then summed by pairs to produce two 32-bit results.

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

PMADDWD—Packed Multiply and Add (Continued)

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PMAXSW—Packed Signed Integer Word Maximum

Opcode	Instruction	Description
0F,EE, /r	PMAXSW *mm1, mm2/m64*	Return the maximum words between *MM2/Mem* and *MM1*.

Description

The PMAXSW instruction returns the maximum between the four signed words in MM1 and MM2/Mem.

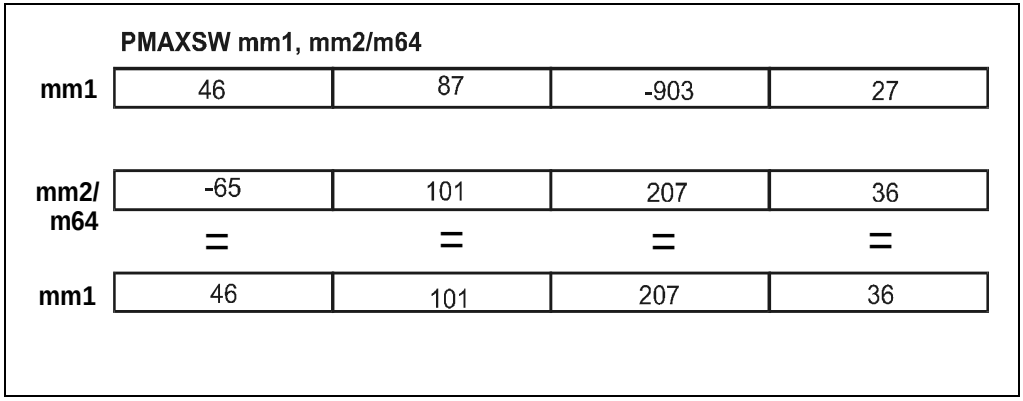


Figure 3-66. Operation of the PMAXSW Instruction

PMAXSW—Packed Signed Integer Word Maximum (Continued)

Operation

```
IF DEST[15-0] > SRC/m64[15-0]) THEN
    (DEST[15-0] = DEST[15-0];
ELSE
    (DEST[15-0] = SRC/m64[15-0];
FI
IF DEST[31-16] > SRC/m64[31-16]) THEN
    (DEST[31-16] = DEST[31-16];
ELSE
    (DEST[31-16] = SRC/m64[31-16];
FI
IF DEST[47-32] > SRC/m64[47-32]) THEN
    (DEST[47-32] = DEST[47-32];
ELSE
    (DEST[47-32] SRC/m64[47-32];
FI
IF DEST[63-48] > SRC/m64[63-48]) THEN
    (DEST[63-48] = DEST[63-48];
ELSE
    (DEST[63-48] = SRC/m64[63-48];
FI
```

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pmaxsw(__m64 a, __m64 b)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_max_pi16(__m64 a, __m64 b)

Computes the element-wise maximum of the words in a and b.

Numeric Exceptions

None.

PMAXSW—Packed Signed Integer Word Maximum (Continued)

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.
#AC	For unaligned memory reference if the current privilege level is 3.

PMAXUB—Packed Unsigned Integer Byte Maximum

Opcode	Instruction	Description
0F,DE, /r	PMAXUB *mm1, mm2/m64*	Return the maximum bytes between *MM2/Mem* and *MM1*.

Description

The PMAXUB instruction returns the maximum between the eight unsigned words in MM1 and MM2/Mem.

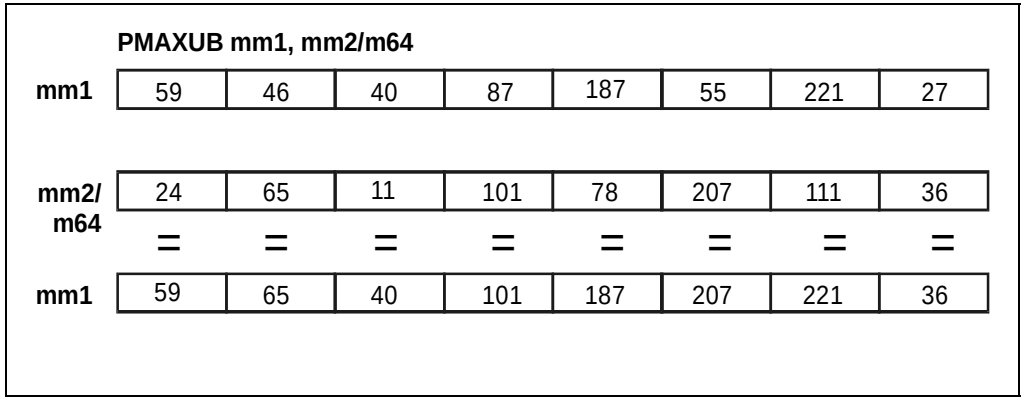


Figure 3-67. Operation of the PMAXUB Instruction

PMAXUB—Packed Unsigned Integer Byte Maximum (Continued)

Operation

```
IF DEST[7-0] > SRC/m64[7-0]) THEN
    (DEST[7-0] = DEST[7-0];
ELSE
    (DEST[7-0] = SRC/m64[7-0];
FI
IF DEST[15-8] > SRC/m64[15-8]) THEN
    (DEST[15-8] = DEST[15-8];
ELSE
    (DEST[15-8] = SRC/m64[15-8];
FI
IF DEST[23-16] > SRC/m64[23-16]) THEN
    (DEST[23-16] = DEST[23-16];
ELSE
    (DEST[23-16] = SRC/m64[23-16];
FI
IF DEST[31-24] > SRC/m64[31-24]) THEN
    (DEST[31-24] = DEST[31-24];
ELSE
    (DEST[31-24] = SRC/m64[31-24];
FI
IF DEST[39-32] > SRC/m64[39-32]) THEN
    (DEST[39-32] = DEST[39-32];
ELSE
    (DEST[39-32] = SRC/m64[39-32];
FI
IF DEST[47-40] > SRC/m64[47-40]) THEN
    (DEST[47-40] = DEST[47-40];
ELSE
    (DEST[47-40] = SRC/m64[47-40];
FI
IF DEST[55-48] > SRC/m64[55-48]) THEN
    (DEST[55-48] = DEST[55-48];
ELSE
    (DEST[55-48] = SRC/m64[55-48];
FI
IF DEST[63-56] > SRC/m64[63-56]) THEN
    (DEST[63-56] = DEST[63-56];
ELSE
    (DEST[63-56] = SRC/m64[63-56];
FI
```

PMAXUB—Packed Unsigned Integer Byte Maximum (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pmaxub(__m64 a, __m64 b)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_max_pu8(__m64 a, __m64 b)

Computes the element-wise maximum of the unsigned bytes in a and b.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.
#AC	For unaligned memory reference if the current privilege level is 3.

PMINSW—Packed Signed Integer Word Minimum

Opcode	Instruction	Description
0F,EA, /r	PMINSW *mm1, mm2/m64*	Return the minimum words between *MM2/Mem* and *MM1*.

Description

The PMINSW instruction returns the minimum between the four signed words in MM1 and MM2/Mem.

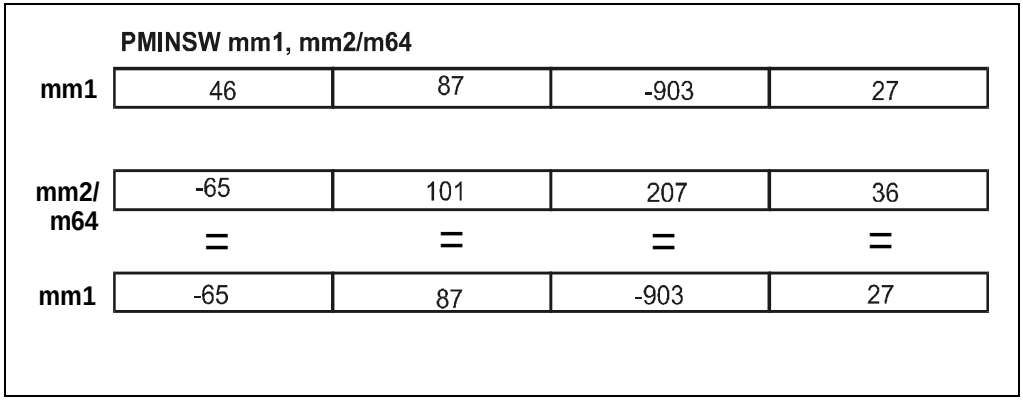


Figure 3-68. Operation of the PMINSW Instruction

PMINSW—Packed Signed Integer Word Minimum (Continued)

Operation

```
IF DEST[15-0] < SRC/m64[15-0]) THEN
    (DEST[15-0] = DEST[15-0];
ELSE
    (DEST[15-0] = SRC/m64[15-0];
FI
IF DEST[31-16] < SRC/m64[31-16]) THEN
    (DEST[31-16] = DEST[31-16];
ELSE
    (DEST[31-16] = SRC/m64[31-16];
FI
IF DEST[47-32] < SRC/m64[47-32]) THEN
    (DEST[47-32] = DEST[47-32];
ELSE
    (DEST[47-32] SRC/m64[47-32];
FI
IF DEST[63-48] < SRC/m64[63-48]) THEN
    (DEST[63-48] = DEST[63-48];
ELSE
    (DEST[63-48] = SRC/m64[63-48];
FI
```

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pminsw(__m64 a, __m64 b)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_min_pi16(__m64 a, __m64 b)

Computes the element-wise minimum of the words in a and b.

Numeric Exceptions

None.

PMINSW—Packed Signed Integer Word Minimum (Continued)

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.
#AC	For unaligned memory reference if the current privilege level is 3.

PMINUB—Packed Unsigned Integer Byte Minimum

Opcode	Instruction	Description
0F,DA, /r	PMINUB *mm1, mm2/m64*	Return the minimum bytes between *MM2/Mem* and *MM1*.

Description

The PMINUB instruction returns the minimum between the eight unsigned words in MM1 and MM2/Mem.

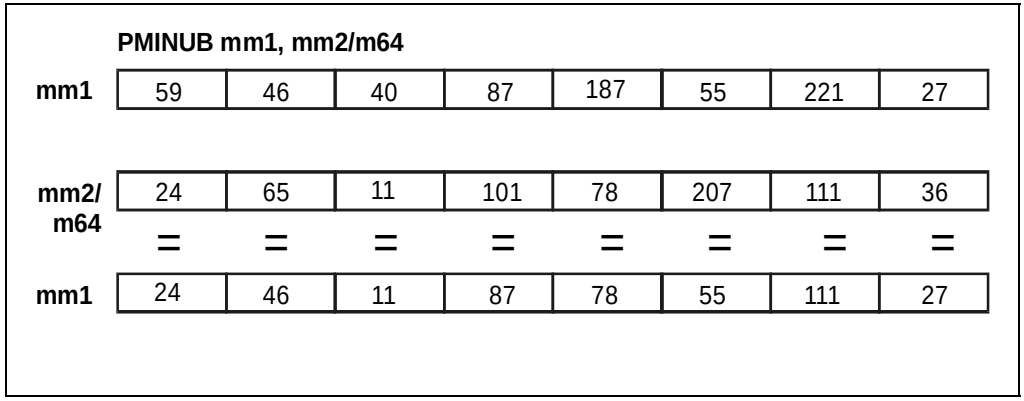


Figure 3-69. Operation of the PMINUB Instruction

PMINUB—Packed Unsigned Integer Byte Minimum (Continued)

Operation

```
IF DEST[7-0] < SRC/m64[7-0]) THEN
    (DEST[7-0] = DEST[7-0];
ELSE
    (DEST[7-0] = SRC/m64[7-0];
FI
IF DEST[15-8] < SRC/m64[15-8]) THEN
    (DEST[15-8] = DEST[15-8];
ELSE
    (DEST[15-8] = SRC/m64[15-8];
FI
IF DEST[23-16] < SRC/m64[23-16]) THEN
    (DEST[23-16] = DEST[23-16];
ELSE
    (DEST[23-16] = SRC/m64[23-16];
FI
IF DEST[31-24] < SRC/m64[31-24]) THEN
    (DEST[31-24] = DEST[31-24];
ELSE
    (DEST[31-24] = SRC/m64[31-24];
FI
IF DEST[39-32] < SRC/m64[39-32]) THEN
    (DEST[39-32] = DEST[39-32];
ELSE
    (DEST[39-32] = SRC/m64[39-32];
FI
IF DEST[47-40] < SRC/m64[47-40]) THEN
    (DEST[47-40] = DEST[47-40];
ELSE
    (DEST[47-40] = SRC/m64[47-40];
FI
IF DEST[55-48] < SRC/m64[55-48]) THEN
    (DEST[55-48] = DEST[55-48];
ELSE
    (DEST[55-48] = SRC/m64[55-48];
FI
IF DEST[63-56] < SRC/m64[63-56]) THEN
    (DEST[63-56] = DEST[63-56];
ELSE
    (DEST[63-56] = SRC/m64[63-56];
FI
```

PMINUB—Packed Unsigned Integer Byte Minimum (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pminub(__m64 a, __m64 b)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _m_min_pu8(__m64 a, __m64 b)

Computes the element-wise minimum of the unsigned bytes in a and b.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.
#AC	For unaligned memory reference if the current privilege level is 3.

PMOVMSKB—Move Byte Mask To Integer

Opcode	Instruction	Description
0F,D7,/r	PMOVMSKB r32, *mm*	Move the byte mask of *MM* to r32.

Description

The PMOVMSKB instruction returns an 8-bit mask formed of the most significant bits of each byte of its source operand.

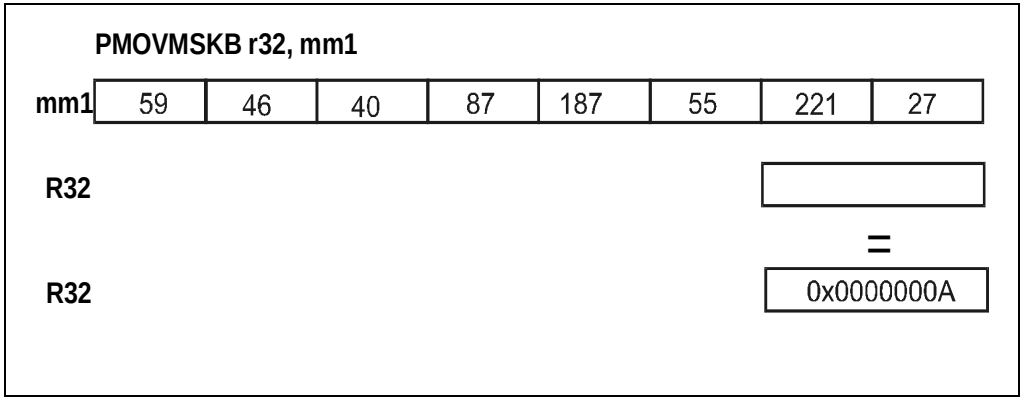


Figure 3-70. Operation of the PMOVMSKB Instruction

Operation

```
r32[7] = SRC[63]; r32[6] = SRC[55];
r32[5] = SRC[47]; r32[4] = SRC[39];
r32[3] = SRC[31]; r32[2] = SRC[23];
r32[1] = SRC[15]; r32[0] = SRC[7];
r32[31-8] = 0X000000;
```

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

int_m_pmovmskb(__m64 a)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

int_mm_movemask_pi8(__m64 a)

Creates an 8-bit mask from the most significant bits of the bytes in a.

PMOVMSKB—Move Byte Mask To Integer (Continued)

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF (fault-code)	For a page fault.
#AC	For unaligned memory reference if the current privilege level is 3.

PMULHUW—Packed Multiply High Unsigned

Opcode	Instruction	Description
0F,E4,/r	PMULHUW *mm1*, *mm2/m64*	Multiply the packed unsigned words in *MM1* register with the packed unsigned words in *MM2/Mem*, then store the high-order 16 bits of the results in *MM1*.

Description

The PMULHUW instruction multiplies the four unsigned words in the destination operand with the four unsigned words in the source operand. The high-order 16 bits of the 32-bit intermediate results are written to the destination operand.

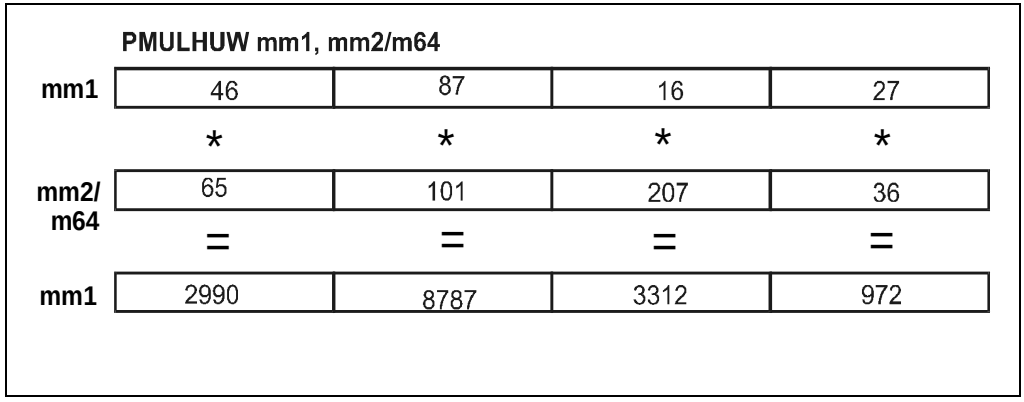


Figure 3-71. Operation of the PMULHUW Instruction

Operation

```
DEST[15-0] = (DEST[15-0] * SRC/m64[15-0])[31-16];
DEST[31-16] = (DEST[31-16] * SRC/m64[31-16])[31-16];
DEST[47-32] = (DEST[47-32] * SRC/m64[47-32])[31-16];
DEST[63-48] = (DEST[63-48] * SRC/m64[63-48])[31-16];
```

PMULHUW—Packed Multiply High Unsigned (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pmulhuw(__m64 a, __m64 b)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_mulhi_pu16(__m64 a, __m64 b)

Multiplies the unsigned words in a and b, returning the upper 16 bits of the 32-bit intermediate results.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.

PMULHUW—Packed Multiply High Unsigned (Continued)

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.
#AC	For unaligned memory reference if the current privilege level is 3.

PMULHW—Packed Multiply High

Opcode	Instruction	Description
0F E5 /r	PMULHW *mm, mm/m64*	Multiply the signed packed words in *mm* by the signed packed words in *mm/m64*, then store the high-order word of each doubleword result in *mm*.

Description

This instruction multiplies the four signed words of the source operand (second operand) by the four signed words of the destination operand (first operand), producing four signed, doubleword, intermediate results (refer to Figure 3-72). The high-order word of each intermediate result is then written to its corresponding word location in the destination operand. The destination operand must be an MMX™ technology register; the source operand may be either an MMX™ technology register or a 64-bit memory location.

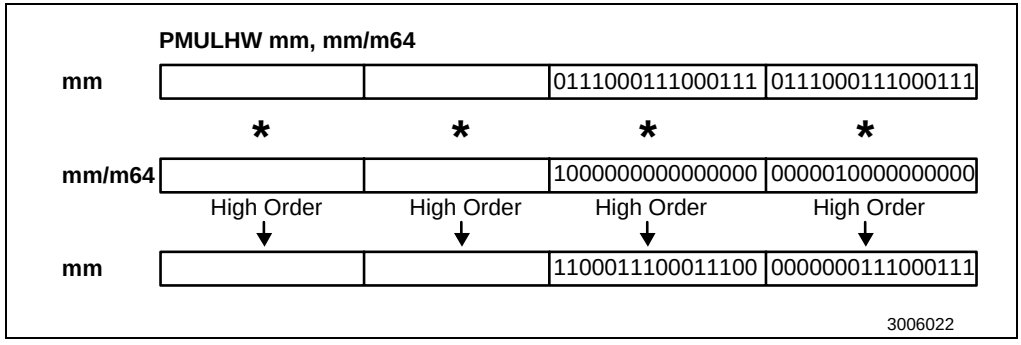


Figure 3-72. Operation of the PMULHW Instruction

Operation

```
DEST(15..0) ← HighOrderWord(DEST(15..0) * SRC(15..0));
DEST(31..16) ← HighOrderWord(DEST(31..16) * SRC(31..16));
DEST(47..32) ← HighOrderWord(DEST(47..32) * SRC(47..32));
DEST(63..48) ← HighOrderWord(DEST(63..48) * SRC(63..48));
```

PMULHW—Packed Multiply High (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pmulhw(__m64 m1, __m64 m2)

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _mM_mulhi_pi16(__m64 m1, __m64 m2)

Multiply four signed 16-bit values in m1 by four signed 16-bit values in m2 and produce the high 16 bits of the four results.

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

PMULHW—Packed Multiply High (Continued)

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PMULLW—Packed Multiply Low

Opcode	Instruction	Description
0F D5 /r	PMULLW *mm, mm/m64*	Multiply the packed words in *mm* with the packed words in *mm/m64*, then store the low-order word of each doubleword result in *mm*.

Description

This instruction multiplies the four signed or unsigned words of the source operand (second operand) with the four signed or unsigned words of the destination operand (first operand), producing four doubleword, intermediate results (refer to Figure 3-73). The low-order word of each intermediate result is then written to its corresponding word location in the destination operand. The destination operand must be an MMX™ technology register; the source operand may be either an MMX™ technology register or a 64-bit memory location.

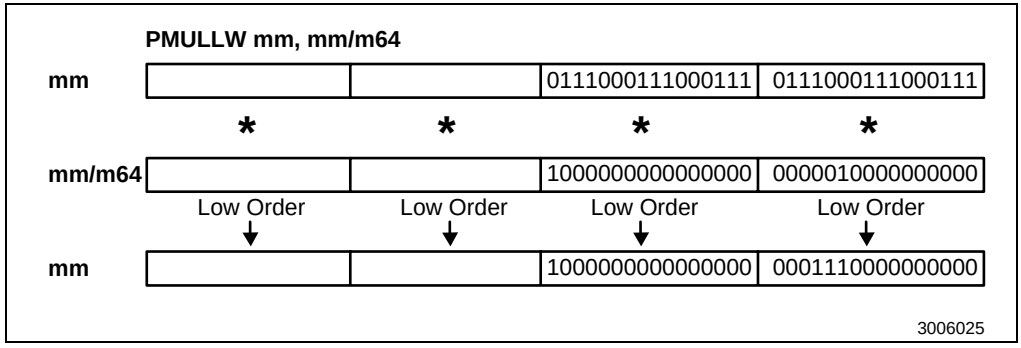


Figure 3-73. Operation of the PMULLW Instruction

Operation

```
DEST(15..0) ← LowOrderWord(DEST(15..0) * SRC(15..0));
DEST(31..16) ← LowOrderWord(DEST(31..16) * SRC(31..16));
DEST(47..32) ← LowOrderWord(DEST(47..32) * SRC(47..32));
DEST(63..48) ← LowOrderWord(DEST(63..48) * SRC(63..48));
```

PMULLW—Packed Multiply Low (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pmullw(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_mullo_pi16(__m64 m1, __m64 m2)

Multiply four 16-bit values in m1 by four 16-bit values in m2 and produce the low 16 bits of the four results.

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

PMULLW—Packed Multiply Low (Continued)

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

POP—Pop a Value from the Stack

Opcode	Instruction	Description
8F /0	POP *m16*	Pop top of stack into *m16*; increment stack pointer
8F /0	POP *m32*	Pop top of stack into *m32*; increment stack pointer
58+ *rw*	POP *r16*	Pop top of stack into *r16*; increment stack pointer
58+ *rd*	POP *r32*	Pop top of stack into *r32*; increment stack pointer
1F	POP DS	Pop top of stack into DS; increment stack pointer
07	POP ES	Pop top of stack into ES; increment stack pointer
17	POP SS	Pop top of stack into SS; increment stack pointer
0F A1	POP FS	Pop top of stack into FS; increment stack pointer
0F A9	POP GS	Pop top of stack into GS; increment stack pointer

Description

This instruction loads the value from the top of the stack to the location specified with the destination operand and then increments the stack pointer. The destination operand can be a general-purpose register, memory location, or segment register.

The current operand-size attribute of the stack segment determines the stack pointer size (16 bits or 32 bits—the source address size), and the operand-size attribute of the current code segment determines the amount the stack pointer is incremented (two bytes or four bytes). For example, if these address- and operand-size attributes are 32, the 32-bit ESP register (stack pointer) is incremented by four and, if they are 16, the 16-bit SP register is incremented by two. (The B flag in the stack segment's segment descriptor determines the stack's address-size attribute, and the D flag in the current code segment's segment descriptor, along with prefixes, determines the operand-size attribute and also the address-size attribute of the destination operand.)

If the destination operand is one of the segment registers DS, ES, FS, GS, or SS, the value loaded into the register must be a valid segment selector. In protected mode, popping a segment selector into a segment register automatically causes the descriptor information associated with that segment selector to be loaded into the hidden (shadow) part of the segment register and causes the selector and the descriptor information to be validated (refer to the "Operation" section below).

A null value (0000-0003) may be popped into the DS, ES, FS, or GS register without causing a general protection fault. However, any subsequent attempt to reference a segment whose corresponding segment register is loaded with a null value causes a general protection exception (#GP). In this situation, no memory reference occurs and the saved value of the segment register is null.

The POP instruction cannot pop a value into the CS register. To load the CS register from the stack, use the RET instruction.

If the ESP register is used as a base register for addressing a destination operand in memory, the POP instruction computes the effective address of the operand after it increments the ESP register. For the case of a 16-bit stack where ESP wraps to 0h as a result of the POP instruction, the resulting location of the memory write is processor-family-specific.

POP—Pop a Value from the Stack (Continued)

The POP ESP instruction increments the stack pointer (ESP) before data at the old top of stack is written into the destination.

A POP SS instruction inhibits all interrupts, including the NMI interrupt, until after execution of the next instruction. This action allows sequential execution of POP SS and MOV ESP, EBP instructions without the danger of having an invalid stack during an interrupt[1]. However, use of the LSS instruction is the preferred method of loading the SS and ESP registers.

Operation

```
IF StackAddrSize = 32
    THEN
        IF OperandSize = 32
            THEN
                DEST ← SS:ESP; (* copy a doubleword *)
                ESP ← ESP + 4;
            ELSE (* OperandSize = 16*)
                DEST ← SS:ESP; (* copy a word *)
            ESP ← ESP + 2;
        FI;
    ELSE (* StackAddrSize = 16* )
        IF OperandSize = 16
            THEN
                DEST ← SS:SP; (* copy a word *)
                SP ← SP + 2;
            ELSE (* OperandSize = 32 *)
                DEST ← SS:SP; (* copy a doubleword *)
                SP ← SP + 4;
        FI;
FI;
```

Loading a segment register while in protected mode results in special checks and actions, as described in the following listing. These checks are performed on the segment selector and the segment descriptor it points to.

```
IF SS is loaded;
    THEN
        IF segment selector is null
            THEN #GP(0);
```

1. Note that in a sequence of instructions that individually delay interrupts past the following instruction, only the first instruction in the sequence is guaranteed to delay the interrupt, but subsequent interrupt-delaying instructions may not delay the interrupt. Thus, in the following instruction sequence:
   ```
   STI
   POP SS
   POP ESP
   ```
   interrupts may be recognized before the POP ESP executes, because STI also delays interrupts for one instruction.

POP—Pop a Value from the Stack (Continued)

```
        FI;
        IF segment selector index is outside descriptor table limits
            OR segment selector's RPL ≠ CPL
            OR segment is not a writable data segment
            OR DPL ≠ CPL
                THEN #GP(selector);
        FI;
        IF segment not marked present
            THEN #SS(selector);
    ELSE
        SS ← segment selector;
        SS ← segment descriptor;
    FI;
FI;
IF DS, ES, FS or GS is loaded with non-null selector;
THEN
    IF segment selector index is outside descriptor table limits
        OR segment is not a data or readable code segment
        OR ((segment is a data or nonconforming code segment)
            AND (both RPL and CPL > DPL))
                THEN #GP(selector);
        IF segment not marked present
            THEN #NP(selector);
    ELSE
        SegmentRegister ← segment selector;
        SegmentRegister ← segment descriptor;
    FI;
FI;
IF DS, ES, FS or GS is loaded with a null selector;
    THEN
        SegmentRegister ← segment selector;
        SegmentRegister ← segment descriptor;
FI;
```

Flags Affected

None.

POP—Pop a Value from the Stack (Continued)

Protected Mode Exceptions

#GP(0)	If attempt is made to load SS register with null segment selector.
	If the destination operand is in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#GP(selector)	If segment selector index is outside descriptor table limits.
	If the SS register is being loaded and the segment selector's RPL and the segment descriptor's DPL are not equal to the CPL.
	If the SS register is being loaded and the segment pointed to is a nonwritable data segment.
	If the DS, ES, FS, or GS register is being loaded and the segment pointed to is not a data or readable code segment.
	If the DS, ES, FS, or GS register is being loaded and the segment pointed to is a data or nonconforming code segment, but both the RPL and the CPL are greater than the DPL.
#SS(0)	If the current top of stack is not within the stack segment.
	If a memory operand effective address is outside the SS segment limit.
#SS(selector)	If the SS register is being loaded and the segment pointed to is marked not present.
#NP	If the DS, ES, FS, or GS register is being loaded and the segment pointed to is marked not present.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory reference is made while the current privilege level is 3 and alignment checking is enabled.

POP—Pop a Value from the Stack (Continued)

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory reference is made while alignment checking is enabled.

POPA/POPAD—Pop All General-Purpose Registers

Opcode	Instruction	Description
61	POPA	Pop DI, SI, BP, BX, DX, CX, and AX
61	POPAD	Pop EDI, ESI, EBP, EBX, EDX, ECX, and EAX

Description

These instructions pop doublewords (POPAD) or words (POPA) from the stack into the general-purpose registers. The registers are loaded in the following order: EDI, ESI, EBP, EBX, EDX, ECX, and EAX (if the operand-size attribute is 32) and DI, SI, BP, BX, DX, CX, and AX (if the operand-size attribute is 16). These instructions reverse the operation of the PUSHA/PUSHAD instructions. The value on the stack for the ESP or SP register is ignored. Instead, the ESP or SP register is incremented after each register is loaded.

The POPA (pop all) and POPAD (pop all double) mnemonics reference the same opcode. The POPA instruction is intended for use when the operand-size attribute is 16 and the POPAD instruction for when the operand-size attribute is 32. Some assemblers may force the operand size to 16 when POPA is used and to 32 when POPAD is used (using the operand-size override prefix [66H] if necessary). Others may treat these mnemonics as synonyms (POPA/POPAD) and use the current setting of the operand-size attribute to determine the size of values to be popped from the stack, regardless of the mnemonic used. (The D flag in the current code segment's segment descriptor determines the operand-size attribute.)

Operation

```
IF OperandSize = 32 (* instruction = POPAD *)
THEN
    EDI ← Pop();
    ESI ← Pop();
    EBP ← Pop();
    increment ESP by 4 (* skip next 4 bytes of stack *)
    EBX ← Pop();
    EDX ← Pop();
    ECX ← Pop();
    EAX ← Pop();
ELSE (* OperandSize = 16, instruction = POPA *)
    DI ← Pop();
    SI ← Pop();
    BP ← Pop();
    increment ESP by 2 (* skip next 2 bytes of stack *)
    BX ← Pop();
    DX ← Pop();
    CX ← Pop();
    AX ← Pop();
FI;
```

POPA/POPAD—Pop All General-Purpose Registers (Continued)

Flags Affected

None.

Protected Mode Exceptions

#SS(0)	If the starting or ending stack address is not within the stack segment.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory reference is made while the current privilege level is 3 and alignment checking is enabled.

Real-Address Mode Exceptions

#SS	If the starting or ending stack address is not within the stack segment.

Virtual-8086 Mode Exceptions

#SS(0)	If the starting or ending stack address is not within the stack segment.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory reference is made while alignment checking is enabled.

POPF/POPFD—Pop Stack into EFLAGS Register

Opcode	Instruction	Description
9D	POPF	Pop top of stack into lower 16 bits of EFLAGS
9D	POPFD	Pop top of stack into EFLAGS

Description

These instructions pop a doubleword (POPFD) from the top of the stack (if the current operand-size attribute is 32) and stores the value in the EFLAGS register, or pops a word from the top of the stack (if the operand-size attribute is 16) and stores it in the lower 16 bits of the EFLAGS register (that is, the FLAGS register). These instructions reverse the operation of the PUSHF/PUSHFD instructions.

The POPF (pop flags) and POPFD (pop flags double) mnemonics reference the same opcode. The POPF instruction is intended for use when the operand-size attribute is 16 and the POPFD instruction for when the operand-size attribute is 32. Some assemblers may force the operand size to 16 when POPF is used and to 32 when POPFD is used. Others may treat these mnemonics as synonyms (POPF/POPFD) and use the current setting of the operand-size attribute to determine the size of values to be popped from the stack, regardless of the mnemonic used.

The effect of the POPF/POPFD instructions on the EFLAGS register changes slightly, depending on the mode of operation of the processor. When the processor is operating in protected mode at privilege level 0 (or in real-address mode, which is equivalent to privilege level 0), all the non-reserved flags in the EFLAGS register except the VIP, VIF, and VM flags can be modified. The VIP and VIF flags are cleared, and the VM flag is unaffected.

When operating in protected mode, with a privilege level greater than 0, but less than or equal to IOPL, all the flags can be modified except the IOPL field and the VIP, VIF, and VM flags. Here, the IOPL flags are unaffected, the VIP and VIF flags are cleared, and the VM flag is unaffected. The interrupt flag (IF) is altered only when executing at a level at least as privileged as the IOPL. If a POPF/POPFD instruction is executed with insufficient privilege, an exception does not occur, but the privileged bits do not change.

When operating in virtual-8086 mode, the I/O privilege level (IOPL) must be equal to 3 to use POPF/POPFD instructions and the VM, RF, IOPL, VIP, and VIF flags are unaffected. If the IOPL is less than 3, the POPF/POPFD instructions cause a general-protection exception (#GP).

Refer to Section 3.6.3. in Chapter 3, *Basic Execution Environment* of the *Intel Architecture Software Developer's Manual, Volume 1*, for information about the EFLAGS registers.

Operation

```
IF VM=0 (* Not in Virtual-8086 Mode *)
    THEN IF CPL=0
        THEN
            IF OperandSize = 32;
                THEN
```

POPF/POPFD—Pop Stack into EFLAGS Register (Continued)

```
                    EFLAGS ← Pop();
                    (* All non-reserved flags except VIP, VIF, and VM can be modified; *)
                    (* VIP and VIF are cleared; VM is unaffected*)
                ELSE (* OperandSize = 16 *)
                    EFLAGS[15:0] ← Pop(); (* All non-reserved flags can be modified; *)
            FI;
        ELSE (* CPL > 0 *)
            IF OperandSize = 32;
                THEN
                    EFLAGS ← Pop()
                    (* All non-reserved bits except IOPL, VIP, and VIF can be modified; *)
                    (* IOPL is unaffected; VIP and VIF are cleared; VM is unaffected *)
                ELSE (* OperandSize = 16 *)
                    EFLAGS[15:0] ← Pop();
                    (* All non-reserved bits except IOPL can be modified *)
                    (* IOPL is unaffected *)
            FI;
    FI;
    ELSE  (* In Virtual-8086 Mode *)
        IF IOPL=3
            THEN IF OperandSize=32
                THEN
                    EFLAGS ← Pop()
                    (* All non-reserved bits except VM, RF, IOPL, VIP, and VIF *)
                    (* can be modified; VM, RF, IOPL, VIP, and VIF are unaffected *)
                ELSE
                    EFLAGS[15:0] ← Pop()
                    (* All non-reserved bits except IOPL can be modified *)
                    (* IOPL is unaffected *)
            FI;
            ELSE (* IOPL < 3 *)
                #GP(0);  (* trap to virtual-8086 monitor *)
        FI;
    FI;
FI;
```

Flags Affected

All flags except the reserved bits and the VM bit.

POPF/POPFD—Pop Stack into EFLAGS Register (Continued)

Protected Mode Exceptions

#SS(0)	If the top of stack is not within the stack segment.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory reference is made while the current privilege level is 3 and alignment checking is enabled.

Real-Address Mode Exceptions

#SS	If the top of stack is not within the stack segment.

Virtual-8086 Mode Exceptions

#GP(0)	If the I/O privilege level is less than 3. If an attempt is made to execute the POPF/POPFD instruction with an operand-size override prefix.
#SS(0)	If the top of stack is not within the stack segment.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory reference is made while alignment checking is enabled.

POR—Bitwise Logical OR

Opcode	Instruction	Description
0F EB /r	POR *mm, mm/m64*	OR quadword from mm/m64 to quadword in mm.

Description

This instruction performs a bitwise logical OR operation on the quadword source (second) and destination (first) operands and stores the result in the destination operand location (refer to Figure 3-74). The source operand can be an MMX™ technology register or a quadword memory location; the destination operand must be an MMX™ technology register. Each bit of the result is made 0 if the corresponding bits of both operands are 0; otherwise the bit is set to 1.

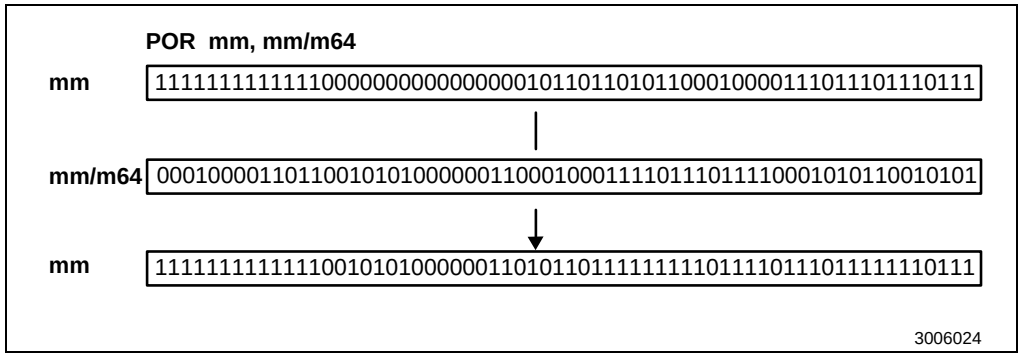


Figure 3-74. Operation of the POR Instruction.

Operation

DEST ← DEST OR SRC;

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_por(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_or_si64(__m64 m1, __m64 m2)

Perform a bitwise OR of the 64-bit value in m1 with the 64-bit value in m2.

Flags Affected

None.

POR—Bitwise Logical OR (Continued)

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PREFETCH—Prefetch

Opcode	Instruction	Description
0F,18,/1	PREFETCHT0 *m8*	Move data specified by address closer to the processor using the t0 hint.
0F,18,/2	PREFETCHT1 *m8*	Move data specified by address closer to the processor using the t1 hint.
0F,18,/3	PREFETCHT2 *m8*	Move data specified by address closer to the processor using the t2 hint.
0F,18,/0	PREFETCHNTA *m8*	Move data specified by address closer to the processor using the nta hint.

Description

If there are no excepting conditions, the prefetch instruction fetches the line containing the addresses byte to a location in the cache hierarchy specified by a locality hint. If the line is already present in the cache hierarchy at a level closer to the processor, no data movement occurs. The bits 5:3 of the ModR/M byte specify locality hints as follows:

- temporal data(t0) - prefetch data into all cache levels.
- temporal with respect to first level cache (t1) - prefetch data in all cache levels except 0th cache level
- temporal with respect to second level cache (t2) - prefetch data in all cache levels, except 0th and 1st cache levels.
- non temporal with respect to all cache levels (nta) - prefetch data into non-temporal cache structure.

The architectural implementation of this instruction in no way effects the function of a program. Locality hints are processor implementation-dependent, and can be overloaded or ignored by a processor implementation. The prefetch instruction does not cause any exceptions (except for code breakpoints), does not affect program behavior, and may be ignored by the processor implementation. The amount of data prefetched is processor implementation-dependent. It will, however, be a minimum of 32 bytes. Prefetches to uncacheable or WC memory (UC or WCF memory types) will be ignored. Additional ModRM encodings, besides those specified above, are defined to be reserved, and the use of reserved encodings risks future incompatibility. Use of any ModRM value other than the specified ones will lead to unpredictable behavior.

Operation

```
FETCH (m8);
```

PREFETCH—Prefetch (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

void_mm_prefetch(char *p, int i)

Loads one cache line of data from address p to a location "closer" to the processor. The value i specifies the type of prefetch operation. The value i specifies the type of prefetch operation: the constants _MM_HINT_T0, _MM_HINT_T1, _MM_HINT_T2, and _MM_HINT_NTA should be used, corresponding to the type of prefetch instruction.

Numeric Exceptions

None.

Protected Mode Exceptions

None.

Real Address Mode Exceptions

None.

Virtual 8086 Mode Exceptions

None.

Comments

This instruction is merely a hint. If executed, this instruction moves data closer to the processor in anticipation of future use. The performance of these instructions in application code can be implementation specific. To achieve maximum speedup, code tuning might be necessary for each implementation. The non temporal hint also minimizes pollution of useful cache data.

PREFETCH instructions ignore the value of CR4.OSFXSR. Since they do not affect the new Streaming SIMD Extension state, they will not generate an invalid exception if CR4.OSFXSR = 0.

If the PTE is not in the TLB, the prefetch is ignored.

PSADBW—Packed Sum of Absolute Differences

Opcode	Instruction	Description
0F,F6, /r	PSADBW *mm1,mm2/m64*	Absolute difference of packed unsigned bytes from *MM2 /Mem* and *MM1*; these differences are then summed to produce a word result.

Description

The PSADBW instruction computes the absolute value of the difference of unsigned bytes for mm1 and mm2/m64. These differences are then summed to produce a word result in the lower 16-bit field; the upper three words are cleared.

The destination operand is an MMX™ technology register. The source operand can either be an MMX™ technology register or a 64-bit memory operand.

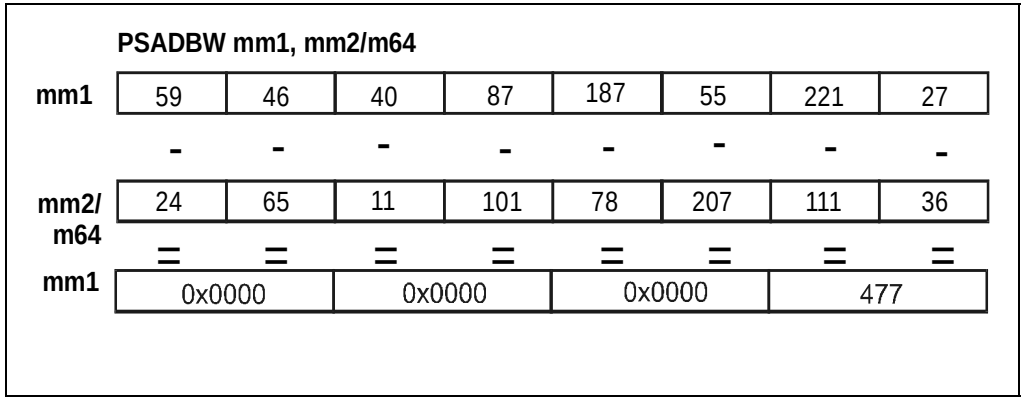


Figure 3-75. Operation of the PSADBW Instruction

PSADBW—Packed Sum of Absolute Differences (Continued)

Operation

```
TEMP1 = abs(DEST[7-0] - SRC/m64[7-0]);
TEMP2 = abs(DEST[15-8] - SRC/m64[15-8]);
TEMP3 = abs(DEST[23-16] - SRC/m64[23-16]);
TEMP4 = abs(DEST[31-24] - SRC/m64[31-24]);
TEMP5 = abs(DEST[39-32] - SRC/m64[39-32]);
TEMP6 = abs(DEST[47-40] - SRC/m64[47-40]);
TEMP7 = abs(DEST[55-48] - SRC/m64[55-48]);
TEMP8 = abs(DEST[63-56] - SRC/m64[63-56]);

DEST[15:0] = TEMP1 + TEMP2 + TEMP3 + TEMP4 + TEMP5 + TEMP6 + TEMP7 + TEMP8;
DEST[31:16] = 0X00000000;
DEST[47:32] = 0X00000000;
DEST[63:48] = 0X00000000;
```

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64_m_psadbw(__m64 a,__m64 b)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64_mm_sad_pu8(__m64 a,__m64 b)

Computes the sum of the absolute differences of the unsigned bytes in a and b, returning the value in the lower word. The upper three words are cleared.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).

PSADBW—Packed Sum of Absolute Differences (Continued)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.

PSHUFW—Packed Shuffle Word

Opcode	Instruction	Description
0F,70,/r,ib	PSHUFW *mm1, mm2/m64, imm8*	Shuffle the words in *MM2/Mem* based on the encoding in *imm8* and store in *MM1*.

Description

The PSHUF instruction uses the imm8 operand to select which of the four words in MM2/Mem will be placed in each of the words in MM1. Bits 1 and 0 of imm8 encode the source for destination word 0 (MM1[15-0]), bits 3 and 2 encode for word 1, bits 5 and 4 encode for word 2, and bits 7 and 6 encode for word 3 (MM1[63-48]). Similarly, the two-bit encoding represents which source word is to be used, e.g., a binary encoding of 10 indicates that source word 2 (MM2/Mem[47-32]) will be used.

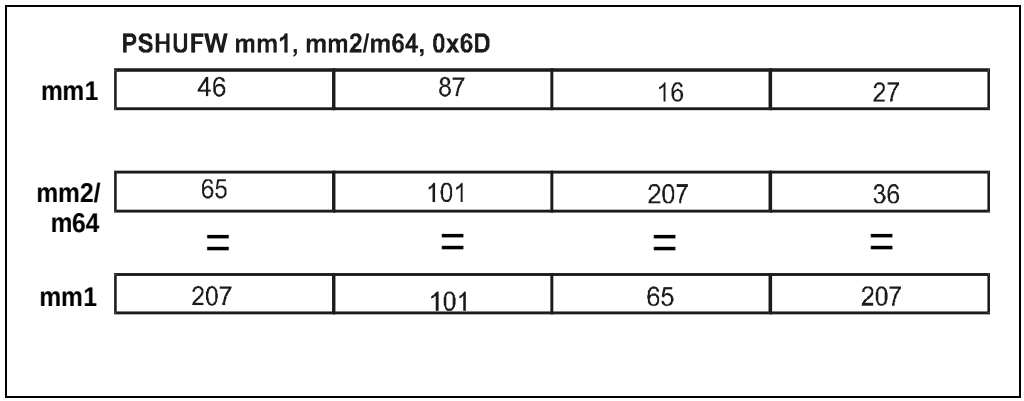


Figure 3-76. Operation of the PSHUFW Instruction

Operation

```
DEST[15-0] = (SRC/m64 >> (imm8[1-0] * 16) )[15-0]
DEST[31-16] = (SRC/m64 >> (imm8[3-2] * 16) )[15-0]
DEST[47-32] = (SRC/m64 >> (imm8[5-4] * 16) )[15-0]
DEST[63-48] = (SRC/m64 >> (imm8[7-6] * 16) )[15-0]
```

PSHUFW—Packed Shuffle Word (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pshufw(__m64 a, int n)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_shuffle_pi16(__m64 a, int n)

Returns a combination of the four words of a. The selector n must be an immediate.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.
#AC	For unaligned memory reference if the current privilege level is 3.

PSLLW/PSLLD/PSLLQ—Packed Shift Left Logical

Opcode	Instruction	Description
0F F1 /r	PSLLW *mm, mm/m64*	Shift words in *mm* left by amount specified in *mm/m64*, while shifting in zeroes.
0F 71 /6, ib	PSLLW *mm, imm8*	Shift words in *mm* left by *imm8*, while shifting in zeroes.
0F F2 /r	PSLLD *mm, mm/m64*	Shift doublewords in *mm* left by amount specified in *mm/m64*, while shifting in zeroes.
0F 72 /6 ib	PSLLD *mm, imm8*	Shift doublewords in *mm* by *imm8*, while shifting in zeroes.
0F F3 /r	PSLLQ *mm, mm/m64*	Shift *mm* left by amount specified in *mm/m64*, while shifting in zeroes.
0F 73 /6 ib	PSLLQ *mm, imm8*	Shift *mm* left by Imm8, while shifting in zeroes.

Description

These instructions shift the bits in the data elements (words, doublewords, or quadword) in the destination operand (first operand) to the left by the number of bits specified in the unsigned count operand (second operand) (refer to Figure 3-77). The result of the shift operation is written to the destination operand. As the bits in the data elements are shifted left, the empty low-order bits are cleared (set to zero). If the value specified by the count operand is greater than 15 (for words), 31 (for doublewords), or 63 (for a quadword), then the destination operand is set to all zeroes.

The destination operand must be an MMX™ technology register; the count operand can be either an MMX™ technology register, a 64-bit memory location, or an 8-bit immediate.

The PSLLW instruction shifts each of the four words of the destination operand to the left by the number of bits specified in the count operand; the PSLLD instruction shifts each of the two doublewords of the destination operand; and the PSLLQ instruction shifts the 64-bit quadword in the destination operand. As the individual data elements are shifted left, the empty low-order bit positions are filled with zeroes.

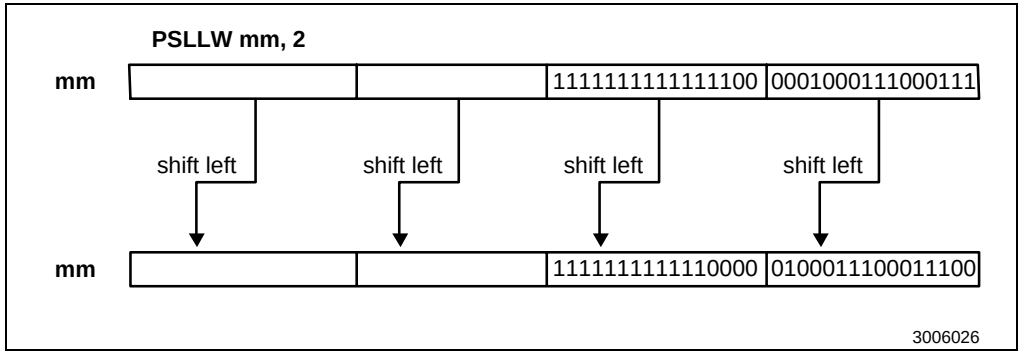


Figure 3-77. Operation of the PSLLW Instruction

PSLLW/PSLLD/PSLLQ—Packed Shift Left Logical (Continued)

Operation

```
IF instruction is PSLLW
    THEN
        DEST(15..0) ← DEST(15..0) << COUNT;
        DEST(31..16) ← DEST(31..16) << COUNT;
        DEST(47..32) ← DEST(47..32) << COUNT;
        DEST(63..48) ← DEST(63..48) << COUNT;
    ELSE IF instruction is PSLLD
        THEN {
            DEST(31..0) ← DEST(31..0) << COUNT;
            DEST(63..32) ← DEST(63..32) << COUNT;
        ELSE  (* instruction is PSLLQ *)
            DEST ← DEST << COUNT;
FI;
```

PSLLW/PSLLD/PSLLQ—Packed Shift Left Logical (Continued)

Intel C/C++ Compiler Intrinsic Equivalents

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psllw (__m64 m, __m64 count)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_sll_pi16 (__m64 m, __m64 count)

Shifts four 16-bit values in m left the amount specified by count while shifting in zeroes.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psllwi (__m64 m, int count)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_slli_pi16 (__m64 m, int count)

Shifts four 16-bit values in m left the amount specified by count while shifting in zeroes. For the best performance, count should be a constant.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pslld (__m64 m, __m64 count)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_sll_pi32 (__m64 m, __m64 count)

Shifts two 32-bit values in m left the amount specified by count while shifting in zeroes.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pslldi (__m64 m, int count)

Shifts two 32-bit values in m left the amount specified by count while shifting in zeroes. For the best performance, count should be a constant.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psllq (__m64 m, __m64 count)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_sll_si64 (__m64 m, __m64 count)

Shifts the 64-bit value in m left the amount specified by count while shifting in zeroes.

PSLLW/PSLLD/PSLLQ—Packed Shift Left Logical (Continued)

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psllqi (__m64 m, int count)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_slli_si64 (__m64 m, int count)

Shifts the 64-bit value in m left the amount specified by count while shifting in zeroes. For the best performance, count should be a constant.

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

PSLLW/PSLLD/PSLLQ—Packed Shift Left Logical (Continued)

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PSRAW/PSRAD—Packed Shift Right Arithmetic

Opcode	Instruction	Description
0F E1 /r	PSRAW *mm, mm/m64*	Shift words in *mm* right by amount specified in *mm/m64* while shifting in sign bits.
0F 71 /4 ib	PSRAW *mm, imm8*	Shift words in *mm* right by *imm8* while shifting in sign bits
0F E2 /r	PSRAD *mm, mm/m64*	Shift doublewords in *mm* right by amount specified in *mm/m64* while shifting in sign bits.
0F 72 /4 ib	PSRAD *mm, imm8*	Shift doublewords in *mm* right by *imm8* while shifting in sign bits.

Description

These instructions shift the bits in the data elements (words or doublewords) in the destination operand (first operand) to the right by the amount of bits specified in the unsigned count operand (second operand) (refer to Figure 3-78). The result of the shift operation is written to the destination operand. The empty high-order bits of each element are filled with the initial value of the sign bit of the data element. If the value specified by the count operand is greater than 15 (for words) or 31 (for doublewords), each destination data element is filled with the initial value of the sign bit of the element.

The destination operand must be an MMX™ technology register; the count operand (source operand) can be either an MMX™ technology register, a 64-bit memory location, or an 8-bit immediate.

The PSRAW instruction shifts each of the four words in the destination operand to the right by the number of bits specified in the count operand; the PSRAD instruction shifts each of the two doublewords in the destination operand. As the individual data elements are shifted right, the empty high-order bit positions are filled with the sign value.

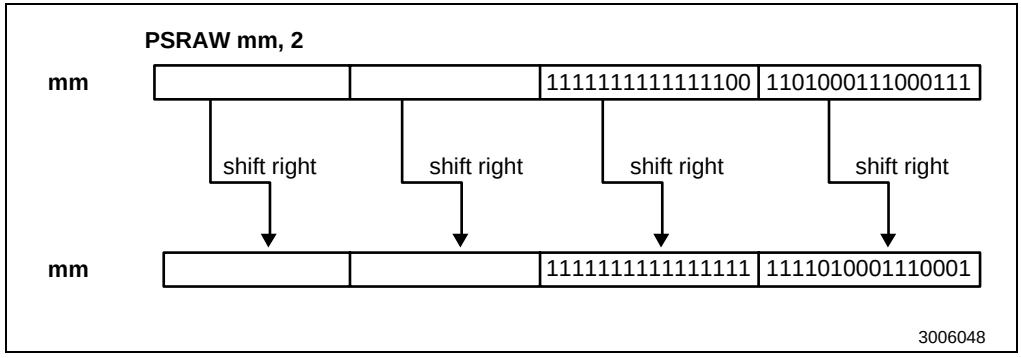


Figure 3-78. Operation of the PSRAW Instruction

PSRAW/PSRAD—Packed Shift Right Arithmetic (Continued)

Operation

```
IF instruction is PSRAW
    THEN
        DEST(15..0) ← SignExtend (DEST(15..0) >> COUNT);
        DEST(31..16) ← SignExtend (DEST(31..16) >> COUNT);
        DEST(47..32) ← SignExtend (DEST(47..32) >> COUNT);
        DEST(63..48) ← SignExtend (DEST(63..48) >> COUNT);
    ELSE { (*instruction is PSRAD *)
        DEST(31..0) ← SignExtend (DEST(31..0) >> COUNT);
        DEST(63..32) ← SignExtend (DEST(63..32) >> COUNT);
FI;
```

Intel C/C++ Compiler Intrinsic Equivalents

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psraw (__m64 m, __m64 count)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_sraw_pi16 (__m64 m, __m64 count)

Shifts four 16-bit values in m right the amount specified by count while shifting in the sign bit.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psrawi (__m64 m, int count)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_srai_pi16 (__m64 m, int count)

Shifts four 16-bit values in m right the amount specified by count while shifting in the sign bit. For the best performance, count should be a constant.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psrad (__m64 m, __m64 count)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_sra_pi32 (__m64 m, __m64 count)

Shifts two 32-bit values in m right the amount specified by count while shifting in the sign bit.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psradi (__m64 m, int count)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_srai_pi32 (__m64 m, int count)

Shifts two 32-bit values in m right the amount specified by count while shifting in the sign bit. For the best performance, count should be a constant.

PSRAW/PSRAD—Packed Shift Right Arithmetic (Continued)

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PSRLW/PSRLD/PSRLQ—Packed Shift Right Logical

Opcode	Instruction	Description
0F D1 /r	PSRLW *mm, mm/m64*	Shift words in *mm* right by amount specified in *mm/m64* while shifting in zeroes.
0F 71 /2 ib	PSRLW *mm, imm8*	Shift words in *mm* right by *imm8.*
0F D2 /r	PSRLD *mm, mm/m64*	Shift doublewords in *mm* right by amount specified in *mm/m64* while shifting in zeroes.
0F 72 /2 ib	PSRLD *mm, imm8*	Shift doublewords in *mm* right by *imm8.*
0F D3 /r	PSRLQ *mm, mm/m64*	Shift *mm* right by amount specified in *mm/m64* while shifting in zeroes.
0F 73 /2 ib	PSRLQ *mm, imm8*	Shift *mm* right by *imm8* while shifting in zeroes.

Description

These instructions shift the bits in the data elements (words, doublewords, or quadword) in the destination operand (first operand) to the right by the number of bits specified in the unsigned count operand (second operand) (refer to Figure 3-79). The result of the shift operation is written to the destination operand. As the bits in the data elements are shifted right, the empty high-order bits are cleared (set to zero). If the value specified by the count operand is greater than 15 (for words), 31 (for doublewords), or 63 (for a quadword), then the destination operand is set to all zeroes.

The destination operand must be an MMX™ technology register; the count operand can be either an MMX™ technology register, a 64-bit memory location, or an 8-bit immediate.

The PSRLW instruction shifts each of the four words of the destination operand to the right by the number of bits specified in the count operand; the PSRLD instruction shifts each of the two doublewords of the destination operand; and the PSRLQ instruction shifts the 64-bit quadword in the destination operand. As the individual data elements are shifted right, the empty high-order bit positions are filled with zeroes.

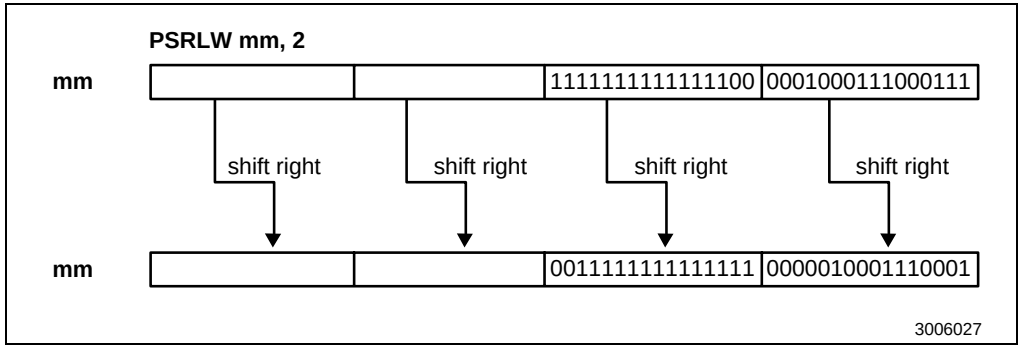


Figure 3-79. Operation of the PSRLW Instruction

PSRLW/PSRLD/PSRLQ—Packed Shift Right Logical (Continued)

Operation

```
IF instruction is PSRLW
    THEN {
        DEST(15..0) ← DEST(15..0) >> COUNT;
        DEST(31..16) ← DEST(31..16) >> COUNT;
        DEST(47..32) ← DEST(47..32) >> COUNT;
        DEST(63..48) ← DEST(63..48) >> COUNT;
ELSE IF instruction is PSRLD
    THEN {
        DEST(31..0) ← DEST(31..0) >> COUNT;
        DEST(63..32) ← DEST(63..32) >> COUNT;
    ELSE  (* instruction is PSRLQ *)
        DEST ← DEST >> COUNT;
FI;
```

PSRLW/PSRLD/PSRLQ—Packed Shift Right Logical (Continued)

Intel C/C++ Compiler Intrinsic Equivalents

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psrlw (__m64 m, __m64 count)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_srl_pi16 (__m64 m, __m64 count)

Shifts four 16-bit values in m right the amount specified by count while shifting in zeroes.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psrlwi (__m64 m, int count)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_srli_pi16 (__m64 m, int count)

Shifts four 16-bit values in m right the amount specified by count while shifting in zeroes. For the best performance, count should be a constant.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psrld (__m64 m, __m64 count)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_sri_pi32 (__m64 m, __m64 count)

Shifts two 32-bit values in m right the amount specified by count while shifting in zeroes.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psrldi (__m64 m, int count)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_srli_pi32 (__m64 m, int count)

Shifts two 32-bit values in m right the amount specified by count while shifting in zeroes. For the best performance, count should be a constant.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psrlq (__m64 m, __m64 count)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_srl_si64 (__m64 m, __m64 count)

Shifts the 64-bit value in m right the amount specified by count while shifting in zeroes.

PSRLW/PSRLD/PSRLQ—Packed Shift Right Logical (Continued)

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psrlqi (__m64 m, int count)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_srli_si64 (__m64 m, int count)

Shifts the 64-bit value in m right the amount specified by count while shifting in zeroes. For the best performance, count should be a constant.

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

PSRLW/PSRLD/PSRLQ—Packed Shift Right Logical (Continued)

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PSUBB/PSUBW/PSUBD—Packed Subtract

Opcode	Instruction	Description
0F F8 /r	PSUBB *mm, mm/m64*	Subtract packed bytes in *mm/m64* from packed bytes in *mm*.
0F F9 /r	PSUBW *mm, mm/m64*	Subtract packed words in*mm/m64* from packed words in *mm*.
0F FA /r	PSUBD *mm, mm/m64*	Subtract packed doublewords in *mm/m64* from packed doublewords in *mm*.

Description

These instructions subtract the individual data elements (bytes, words, or doublewords) of the source operand (second operand) from the individual data elements of the destination operand (first operand) (refer to Figure 3-80). If the result of a subtraction exceeds the range for the specified data type (overflows), the result is wrapped around, meaning that the result is truncated so that only the lower (least significant) bits of the result are returned (that is, the carry is ignored).

The destination operand must be an MMX™ technology register; the source operand can be either an MMX™ technology register or a quadword memory location.

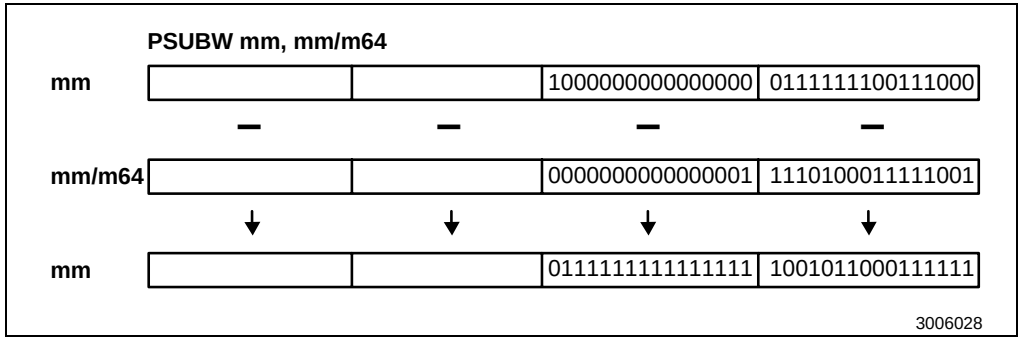


Figure 3-80. Operation of the PSUBW Instruction

The PSUBB instruction subtracts the bytes of the source operand from the bytes of the destination operand and stores the results to the destination operand. When an individual result is too large to be represented in eight bits, the lower eight bits of the result are written to the destination operand and therefore the result wraps around.

The PSUBW instruction subtracts the words of the source operand from the words of the destination operand and stores the results to the destination operand. When an individual result is too large to be represented in 16 bits, the lower 16 bits of the result are written to the destination operand and therefore the result wraps around.

PSUBB/PSUBW/PSUBD—Packed Subtract (Continued)

The PSUBD instruction subtracts the doublewords of the source operand from the doublewords of the destination operand and stores the results to the destination operand. When an individual result is too large to be represented in 32 bits, the lower 32 bits of the result are written to the destination operand and therefore the result wraps around.

Note that like the integer SUB instruction, the PSUBB, PSUBW, and PSUBD instructions can operate on either unsigned or signed (two's complement notation) packed integers. Unlike the integer instructions, none of the MMX™ instructions affect the EFLAGS register. With MMX™ instructions, there are no carry or overflow flags to indicate when overflow has occurred, so the software must control the range of values or else use the "with saturation" MMX™ instructions.

Operation

```
IF instruction is PSUBB
    THEN
        DEST(7..0) ← DEST(7..0) – SRC(7..0);
        DEST(15..8) ← DEST(15..8) – SRC(15..8);
        DEST(23..16) ← DEST(23..16) – SRC(23..16);
        DEST(31..24) ← DEST(31..24) – SRC(31..24);
        DEST(39..32) ← DEST(39..32) – SRC(39..32);
        DEST(47..40) ← DEST(47..40) – SRC(47..40);
        DEST(55..48) ← DEST(55..48) – SRC(55..48);
        DEST(63..56) ← DEST(63..56) – SRC(63..56);
ELSEIF instruction is PSUBW
    THEN
        DEST(15..0) ← DEST(15..0) – SRC(15..0);
        DEST(31..16) ← DEST(31..16) – SRC(31..16);
        DEST(47..32) ← DEST(47..32) – SRC(47..32);
        DEST(63..48) ← DEST(63..48) – SRC(63..48);
    ELSE { (* instruction is PSUBD *)
        DEST(31..0) ← DEST(31..0) – SRC(31..0);
        DEST(63..32) ← DEST(63..32) – SRC(63..32);
FI;
```

PSUBB/PSUBW/PSUBD—Packed Subtract (Continued)

Intel C/C++ Compiler Intrinsic Equivalents

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psubb(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_sub_pi8(__m64 m1, __m64 m2)

Subtract the eight 8-bit values in m2 from the eight 8-bit values in m1.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psubw(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_sub_pi16(__m64 m1, __m64 m2)

Subtract the four 16-bit values in m2 from the four 16-bit values in m1.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psubd(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_sub_pi32(__m64 m1, __m64 m2)

Subtract the two 32-bit values in m2 from the two 32-bit values in m1.

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

PSUBB/PSUBW/PSUBD—Packed Subtract (Continued)

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PSUBSB/PSUBSW—Packed Subtract with Saturation

Opcode	Instruction	Description
0F E8 /r	PSUBSB *mm, mm/m64*	Subtract signed packed bytes in *mm/m64* from signed packed bytes in *mm* and saturate.
0F E9 /r	PSUBSW *mm, mm/m64*	Subtract signed packed words in *mm/m64* from signed packed words in *mm* and saturate.

Description

These instructions subtract the individual signed data elements (bytes or words) of the source operand (second operand) from the individual signed data elements of the destination operand (first operand) (refer to Figure 3-81). If the result of a subtraction exceeds the range for the specified data type, the result is saturated. The destination operand must be an MMX™ technology register; the source operand can be either an MMX™ technology register or a quadword memory location.

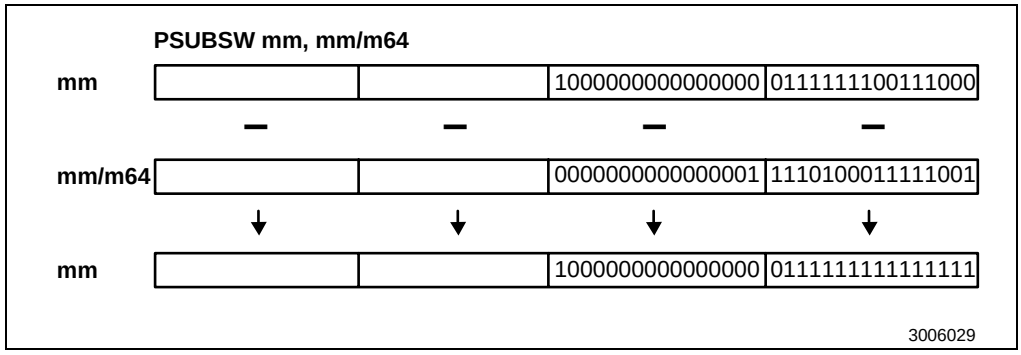


Figure 3-81. Operation of the PSUBSW Instruction

The PSUBSB instruction subtracts the signed bytes of the source operand from the signed bytes of the destination operand and stores the results to the destination operand. When an individual result is beyond the range of a signed byte (that is, greater than 7FH or less than 80H), the saturated byte value of 7FH or 80H, respectively, is written to the destination operand.

The PSUBSW instruction subtracts the signed words of the source operand from the signed words of the destination operand and stores the results to the destination operand. When an individual result is beyond the range of a signed word (that is, greater than 7FFFH or less than 8000H), the saturated word value of 7FFFH or 8000H, respectively, is written to the destination operand.

PSUBSB/PSUBSW—Packed Subtract with Saturation (Continued)

Operation

```
IF instruction is PSUBSB
    THEN
        DEST(7..0) ← SaturateToSignedByte(DEST(7..0) – SRC (7..0));
        DEST(15..8) ← SaturateToSignedByte(DEST(15..8) – SRC(15..8));
        DEST(23..16) ← SaturateToSignedByte(DEST(23..16) – SRC(23..16));
        DEST(31..24) ← SaturateToSignedByte(DEST(31..24) – SRC(31..24));
        DEST(39..32) ← SaturateToSignedByte(DEST(39..32) – SRC(39..32));
        DEST(47..40) ← SaturateToSignedByte(DEST(47..40) – SRC(47..40));
        DEST(55..48) ← SaturateToSignedByte(DEST(55..48) – SRC(55..48));
        DEST(63..56) ← SaturateToSignedByte(DEST(63..56) – SRC(63..56))
    ELSE (* instruction is PSUBSW *)
        DEST(15..0) ← SaturateToSignedWord(DEST(15..0) – SRC(15..0));
        DEST(31..16) ← SaturateToSignedWord(DEST(31..16) – SRC(31..16));
        DEST(47..32) ← SaturateToSignedWord(DEST(47..32) – SRC(47..32));
        DEST(63..48) ← SaturateToSignedWord(DEST(63..48) – SRC(63..48));
FI;
```

Intel C/C++ Compiler Intrinsic Equivalents

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psubsb(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_subs_pi8(__m64 m1, __m64 m2)

Subtract the eight signed 8-bit values in m2 from the eight signed 8-bit values in m1 and saturate.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psubsw(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_subs_pi16(__m64 m1, __m64 m2)

Subtract the four signed 16-bit values in m2 from the four signed 16-bit values in m1 and saturate.

Flags Affected

None.

PSUBSB/PSUBSW—Packed Subtract with Saturation (Continued)

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PSUBUSB/PSUBUSW—Packed Subtract Unsigned with Saturation

Opcode	Instruction	Description
0F D8 /r	PSUBUSB *mm, mm/m64*	Subtract unsigned packed bytes in *mm/m64* from unsigned packed bytes in *mm* and saturate.
0F D9 /r	PSUBUSW *mm, mm/m64*	Subtract unsigned packed words in *mm/m64* from unsigned packed words in *mm* and saturate.

Description

These instructions subtract the individual unsigned data elements (bytes or words) of the source operand (second operand) from the individual unsigned data elements of the destination operand (first operand) (refer to Figure 3-82). If the result of an individual subtraction exceeds the range for the specified unsigned data type, the result is saturated. The destination operand musts be an MMX™ technology register; the source operand can be either an MMX™ technology register or a quadword memory location.

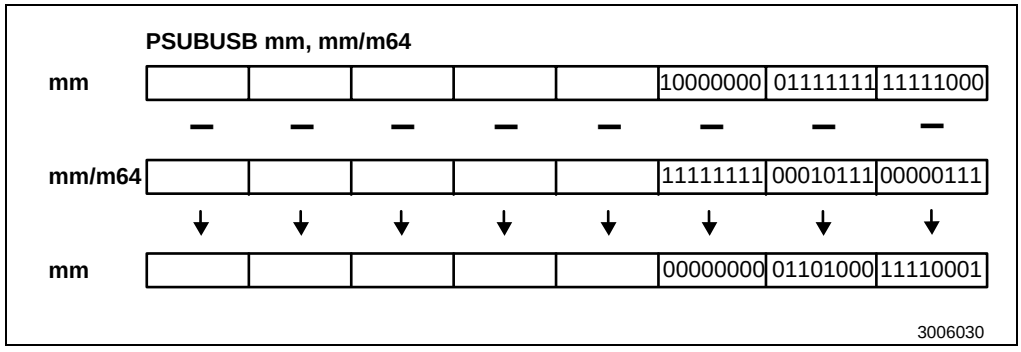


Figure 3-82. Operation of the PSUBUSB Instruction

The PSUBUSB instruction subtracts the unsigned bytes of the source operand from the unsigned bytes of the destination operand and stores the results to the destination operand. When an individual result is less than zero (a negative value), the saturated unsigned byte value of 00H is written to the destination operand.

The PSUBUSW instruction subtracts the unsigned words of the source operand from the unsigned words of the destination operand and stores the results to the destination operand. When an individual result is less than zero (a negative value), the saturated unsigned word value of 0000H is written to the destination operand.

PSUBUSB/PSUBUSW—Packed Subtract Unsigned with Saturation (Continued)

Operation

```
IF instruction is PSUBUSB
    THEN
        DEST(7..0) ← SaturateToUnsignedByte (DEST(7..0 – SRC (7..0) );
        DEST(15..8) ← SaturateToUnsignedByte ( DEST(15..8) – SRC(15..8) );
        DEST(23..16) ← SaturateToUnsignedByte (DEST(23..16) – SRC(23..16) );
        DEST(31..24) ← SaturateToUnsignedByte (DEST(31..24) – SRC(31..24) );
        DEST(39..32) ← SaturateToUnsignedByte (DEST(39..32) – SRC(39..32) );
        DEST(47..40) ← SaturateToUnsignedByte (DEST(47..40) – SRC(47..40) );
        DEST(55..48) ← SaturateToUnsignedByte (DEST(55..48) – SRC(55..48) );
        DEST(63..56) ← SaturateToUnsignedByte (DEST(63..56) – SRC(63..56) );
    ELSE { (* instruction is PSUBUSW *)
        DEST(15..0) ← SaturateToUnsignedWord (DEST(15..0) – SRC(15..0) );
        DEST(31..16) ← SaturateToUnsignedWord (DEST(31..16) – SRC(31..16) );
        DEST(47..32) ← SaturateToUnsignedWord (DEST(47..32) – SRC(47..32) );
        DEST(63..48) ← SaturateToUnsignedWord (DEST(63..48) – SRC(63..48) );
FI;
```

Intel C/C++ Compiler Intrinsic Equivalents

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psubusb(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_sub_pu8(__m64 m1, __m64 m2)

Subtract the eight unsigned 8-bit values in m2 from the eight unsigned 8-bit values in m1 and saturate.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_psubusw(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_sub_pu16(__m64 m1, __m64 m2)

Subtract the four unsigned 16-bit values in m2 from the four unsigned 16-bit values in m1 and saturate.

Flags Affected

None.

PSUBUSB/PSUBUSW—Packed Subtract Unsigned with Saturation (Continued)

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PUNPCKHBW/PUNPCKHWD/PUNPCKHDQ—Unpack High Packed Data

Opcode	Instruction	Description
0F 68 /r	PUNPCKHBW *mm, mm/m64*	Interleave high-order bytes from *mm* and *mm/m64* into *mm*.
0F 69 /r	PUNPCKHWD *mm, mm/m64*	Interleave high-order words from *mm* and *mm/m64* into *mm*.
0F 6A /r	PUNPCKHDQ *mm, mm/m64*	Interleave high-order doublewords from *mm* and *mm/m64* into *mm*.

Description

These instructions unpack and interleave the high-order data elements (bytes, words, or doublewords) of the destination operand (first operand) and source operand (second operand) into the destination operand (refer to Figure 3-83). The low-order data elements are ignored. The destination operand must be an MMX™ technology register; the source operand may be either an MMX™ technology register or a 64-bit memory location. When the source data comes from a memory operand, the full 64-bit operand is accessed from memory, but the instruction uses only the high-order 32 bits.

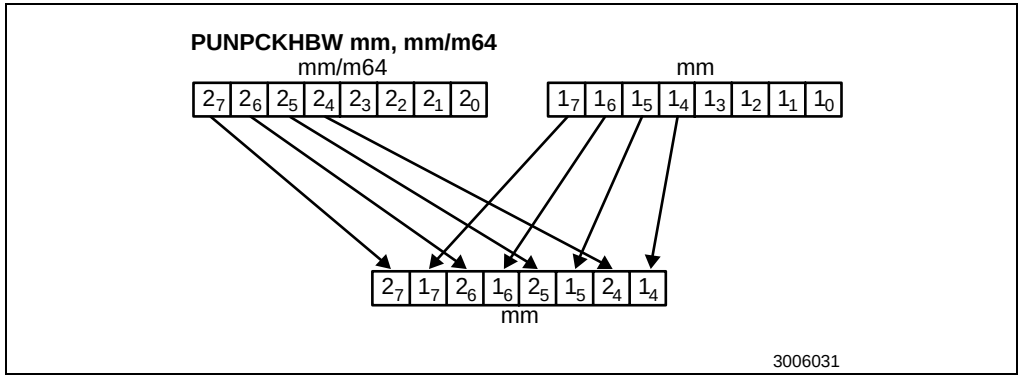


Figure 3-83. High-Order Unpacking and Interleaving of Bytes With the PUNPCKHBW Instruction

The PUNPCKHBW instruction interleaves the four high-order bytes of the source operand and the four high-order bytes of the destination operand and writes them to the destination operand.

The PUNPCKHWD instruction interleaves the two high-order words of the source operand and the two high-order words of the destination operand and writes them to the destination operand.

The PUNPCKHDQ instruction interleaves the high-order doubleword of the source operand and the high-order doubleword of the destination operand and writes them to the destination operand.

PUNPCKHBW/PUNPCKHWD/PUNPCKHDQ—Unpack High Packed Data (Continued)

If the source operand is all zeroes, the result (stored in the destination operand) contains zero extensions of the high-order data elements from the original value in the destination operand. With the PUNPCKHBW instruction the high-order bytes are zero extended (that is, unpacked into unsigned words), and with the PUNPCKHWD instruction, the high-order words are zero extended (unpacked into unsigned doublewords).

Operation

```
IF instruction is PUNPCKHBW
    THEN
        DEST(7..0) ← DEST(39..32);
        DEST(15..8) ← SRC(39..32);
        DEST(23..16) ← DEST(47..40);
        DEST(31..24) ← SRC(47..40);
        DEST(39..32) ← DEST(55..48);
        DEST(47..40) ← SRC(55..48);
        DEST(55..48) ← DEST(63..56);
        DEST(63..56) ← SRC(63..56);
ELSE IF instruction is PUNPCKHW
    THEN
        DEST(15..0) ← DEST(47..32);
        DEST(31..16) ← SRC(47..32);
        DEST(47..32) ← DEST(63..48);
        DEST(63..48) ← SRC(63..48);
    ELSE (* instruction is PUNPCKHDQ *)
        DEST(31..0) ← DEST(63..32)
        DEST(63..32) ← SRC(63..32);
FI;
```

PUNPCKHBW/PUNPCKHWD/PUNPCKHDQ—Unpack High Packed Data (Continued)

Intel C/C++ Compiler Intrinsic Equivalents

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_punpckhbw (__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_unpckhi_pi8 (__m64 m1, __m64 m2)

Interleave the four 8-bit values from the high half of m1 with the four values from the high half of m2 and take the least significant element from m1.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_punpckhwd (__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_unpckhi_pi16 (__m64 m1, __m64 m2)

Interleave the two 16-bit values from the high half of m1 with the two values from the high half of m2 and take the least significant element from m1.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_punpckhdq (__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_unpckhi_pi32 (__m64 m1, __m64 m2)

Interleave the 32-bit value from the high half of m1 with the 32-bit value from the high half of m2 and take the least significant element from m1.

Flags Affected

None.

PUNPCKHBW/PUNPCKHWD/PUNPCKHDQ—Unpack High Packed Data (Continued)

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PUNPCKLBW/PUNPCKLWD/PUNPCKLDQ—Unpack Low Packed Data

Opcode	Instruction	Description
0F 60 /r	PUNPCKLBW *mm, mm/m32*	Interleave low-order bytes from *mm* and *mm/m64* into *mm.*
0F 61 /r	PUNPCKLWD *mm, mm/m32*	Interleave low-order words from *mm* and *mm/m64* into *mm.*
0F 62 /r	PUNPCKLDQ *mm, mm/m32*	Interleave low-order doublewords from *mm* and *mm/m64* into *mm.*

Description

These instructions unpack and interleave the low-order data elements (bytes, words, or doublewords) of the destination and source operands into the destination operand (refer to Figure 3-84). The destination operand must be an MMX™ technology register; the source operand may be either an MMX™ technology register or a memory location. When source data comes from an MMX™ technology register, the upper 32 bits of the register are ignored. When the source data comes from a memory, only 32-bits are accessed from memory.

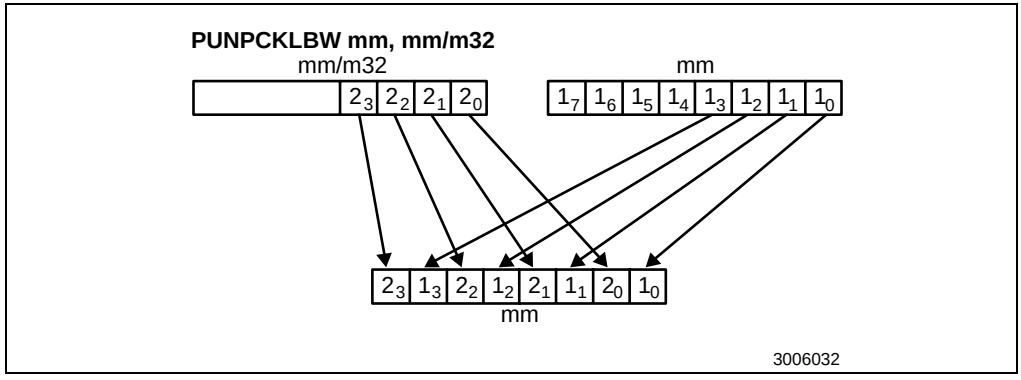


Figure 3-84. Low-Order Unpacking and Interleaving of Bytes With the PUNPCKLBW Instruction

The PUNPCKLBW instruction interleaves the four low-order bytes of the source operand and the four low-order bytes of the destination operand and writes them to the destination operand.

The PUNPCKLWD instruction interleaves the two low-order words of the source operand and the two low-order words of the destination operand and writes them to the destination operand.

The PUNPCKLDQ instruction interleaves the low-order doubleword of the source operand and the low-order doubleword of the destination operand and writes them to the destination operand.

PUNPCKLBW/PUNPCKLWD/PUNPCKLDQ—Unpack Low Packed Data (Continued)

If the source operand is all zeroes, the result (stored in the destination operand) contains zero extensions of the high-order data elements from the original value in the destination operand. With the PUNPCKLBW instruction the low-order bytes are zero extended (that is, unpacked into unsigned words), and with the PUNPCKLWD instruction, the low-order words are zero extended (unpacked into unsigned doublewords).

Operation

```
IF instruction is PUNPCKLBW
    THEN
        DEST(63..56) ← SRC(31..24);
        DEST(55..48) ← DEST(31..24);
        DEST(47..40) ← SRC(23..16);
        DEST(39..32) ← DEST(23..16);
        DEST(31..24) ← SRC(15..8);
        DEST(23..16) ← DEST(15..8);
        DEST(15..8) ← SRC(7..0);
        DEST(7..0) ← DEST(7..0);
ELSE IF instruction is PUNPCKLWD
    THEN
        DEST(63..48) ← SRC(31..16);
        DEST(47..32) ← DEST(31..16);
        DEST(31..16) ← SRC(15..0);
        DEST(15..0) ← DEST(15..0);
    ELSE (* instruction is PUNPCKLDQ *)
        DEST(63..32) ← SRC(31..0);
        DEST(31..0) ← DEST(31..0);
FI;
```

PUNPCKLBW/PUNPCKLWD/PUNPCKLDQ—Unpack Low Packed Data (Continued)

Intel C/C++ Compiler Intrinsic Equivalents

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_punpcklbw (__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_unpcklo_pi8 (__m64 m1, __m64 m2)

Interleave the four 8-bit values from the low half of m1 with the four values from the low half of m2 and take the least significant element from m1.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_punpcklwd (__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_unpcklo_pi16 (__m64 m1, __m64 m2)

Interleave the two 16-bit values from the low half of m1 with the two values from the low half of m2 and take the least significant element from m1.

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_punpckldq (__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_unpcklo_pi32 (__m64 m1, __m64 m2)

Interleave the 32-bit value from the low half of m1 with the 32-bit value from the low half of m2 and take the least significant element from m1.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

PUNPCKLBW/PUNPCKLWD/PUNPCKLDQ—Unpack Low Packed Data (Continued)

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PUSH—Push Word or Doubleword Onto the Stack

Opcode	Instruction	Description
FF /6	PUSH *r/m16*	Push *r/m16*
FF /6	PUSH *r/m32*	Push *r/m32*
50+*rw*	PUSH *r16*	Push *r16*
50+*rd*	PUSH *r32*	Push *r32*
6A	PUSH *imm8*	Push *imm8*
68	PUSH *imm16*	Push *imm16*
68	PUSH *imm32*	Push *imm32*
0E	PUSH CS	Push CS
16	PUSH SS	Push SS
1E	PUSH DS	Push DS
06	PUSH ES	Push ES
0F A0	PUSH FS	Push FS
0F A8	PUSH GS	Push GS

Description

This instruction decrements the stack pointer and then stores the source operand on the top of the stack. The address-size attribute of the stack segment determines the stack pointer size (16 bits or 32 bits), and the operand-size attribute of the current code segment determines the amount the stack pointer is decremented (two bytes or four bytes). For example, if these address- and operand-size attributes are 32, the 32-bit ESP register (stack pointer) is decremented by four and, if they are 16, the 16-bit SP register is decremented by 2.(The B flag in the stack segment's segment descriptor determines the stack's address-size attribute, and the D flag in the current code segment's segment descriptor, along with prefixes, determines the operand-size attribute and also the address-size attribute of the source operand.) Pushing a 16-bit operand when the stack address-size attribute is 32 can result in a misaligned the stack pointer (that is, the stack pointer is not aligned on a doubleword boundary).

The PUSH ESP instruction pushes the value of the ESP register as it existed before the instruction was executed. Thus, if a PUSH instruction uses a memory operand in which the ESP register is used as a base register for computing the operand address, the effective address of the operand is computed before the ESP register is decremented.

In the real-address mode, if the ESP or SP register is 1 when the PUSH instruction is executed, the processor shuts down due to a lack of stack space. No exception is generated to indicate this condition.

Intel Architecture Compatibility

For Intel Architecture processors from the Intel 286 on, the PUSH ESP instruction pushes the value of the ESP register as it existed before the instruction was executed. (This is also true in the real-address and virtual-8086 modes.) For the Intel 8086 processor, the PUSH SP instruction pushes the new value of the SP register (that is the value after it has been decremented by 2).

PUSH—Push Word or Doubleword Onto the Stack (Continued)

Operation

```
IF StackAddrSize = 32
THEN
    IF OperandSize = 32
        THEN
            ESP ← ESP – 4;
            SS:ESP ← SRC; (* push doubleword *)
        ELSE (* OperandSize = 16*)
            ESP ← ESP – 2;
            SS:ESP ← SRC; (* push word *)
    FI;
ELSE (* StackAddrSize = 16*)
    IF OperandSize = 16
        THEN
            SP ← SP – 2;
             SS:SP ← SRC; (* push word *)
        ELSE (* OperandSize = 32*)
            SP ← SP – 4;
            SS:SP ← SRC; (* push doubleword *)
    FI;
FI;
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

PUSH—Push Word or Doubleword Onto the Stack (Continued)

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.
	If the new value of the SP or ESP register is outside the stack segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

PUSHA/PUSHAD—Push All General-Purpose Registers

Opcode	Instruction	Description
60	PUSHA	Push AX, CX, DX, BX, original SP, BP, SI, and DI
60	PUSHAD	Push EAX, ECX, EDX, EBX, original ESP, EBP, ESI, and EDI

Description

These instructions push the contents of the general-purpose registers onto the stack. The registers are stored on the stack in the following order: EAX, ECX, EDX, EBX, EBP, ESP (original value), EBP, ESI, and EDI (if the current operand-size attribute is 32) and AX, CX, DX, BX, SP (original value), BP, SI, and DI (if the operand-size attribute is 16). These instructions perform the reverse operation of the POPA/POPAD instructions. The value pushed for the ESP or SP register is its value before prior to pushing the first register (refer to the “Operation” section below).

The PUSHA (push all) and PUSHAD (push all double) mnemonics reference the same opcode. The PUSHA instruction is intended for use when the operand-size attribute is 16 and the PUSHAD instruction for when the operand-size attribute is 32. Some assemblers may force the operand size to 16 when PUSHA is used and to 32 when PUSHAD is used. Others may treat these mnemonics as synonyms (PUSHA/PUSHAD) and use the current setting of the operand-size attribute to determine the size of values to be pushed from the stack, regardless of the mnemonic used.

In the real-address mode, if the ESP or SP register is 1, 3, or 5 when the PUSHA/PUSHAD instruction is executed, the processor shuts down due to a lack of stack space. No exception is generated to indicate this condition.

PUSHA/PUSHAD—Push All General-Purpose Register (Continued)

Operation

```
IF OperandSize = 32 (* PUSHAD instruction *)
    THEN
        Temp ← (ESP);
        Push(EAX);
        Push(ECX);
        Push(EDX);
        Push(EBX);
        Push(Temp);
        Push(EBP);
        Push(ESI);
        Push(EDI);
    ELSE (* OperandSize = 16, PUSHA instruction *)
        Temp ← (SP);
        Push(AX);
        Push(CX);
        Push(DX);
        Push(BX);
        Push(Temp);
        Push(BP);
        Push(SI);
        Push(DI);
FI;
```

Flags Affected

None.

Protected Mode Exceptions

#SS(0)	If the starting or ending stack address is outside the stack segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory reference is made while the current privilege level is 3 and alignment checking is enabled.

PUSHA/PUSHAD—Push All General-Purpose Register (Continued)

Real-Address Mode Exceptions

#GP	If the ESP or SP register contains 7, 9, 11, 13, or 15.

Virtual-8086 Mode Exceptions

#GP(0)	If the ESP or SP register contains 7, 9, 11, 13, or 15.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory reference is made while alignment checking is enabled.

PUSHF/PUSHFD—Push EFLAGS Register onto the Stack

Opcode	Instruction	Description
9C	PUSHF	Push lower 16 bits of EFLAGS
9C	PUSHFD	Push EFLAGS

Description

These instructions decrement the stack pointer by four (if the current operand-size attribute is 32) and pushes the entire contents of the EFLAGS register onto the stack, or decrements the stack pointer by two (if the operand-size attribute is 16) and pushes the lower 16 bits of the EFLAGS register (that is, the FLAGS register) onto the stack. (These instructions reverse the operation of the POPF/POPFD instructions.) When copying the entire EFLAGS register to the stack, the VM and RF flags (bits 16 and 17) are not copied; instead, the values for these flags are cleared in the EFLAGS image stored on the stack. Refer to Section 3.6.3. in Chapter 3, *Basic Execution Environment* of the *Intel Architecture Software Developer's Manual, Volume 1*, for information about the EFLAGS registers.

The PUSHF (push flags) and PUSHFD (push flags double) mnemonics reference the same opcode. The PUSHF instruction is intended for use when the operand-size attribute is 16 and the PUSHFD instruction for when the operand-size attribute is 32. Some assemblers may force the operand size to 16 when PUSHF is used and to 32 when PUSHFD is used. Others may treat these mnemonics as synonyms (PUSHF/PUSHFD) and use the current setting of the operand-size attribute to determine the size of values to be pushed from the stack, regardless of the mnemonic used.

When in virtual-8086 mode and the I/O privilege level (IOPL) is less than 3, the PUSHF/PUSHFD instruction causes a general protection exception (#GP).

In the real-address mode, if the ESP or SP register is 1, 3, or 5 when the PUSHA/PUSHAD instruction is executed, the processor shuts down due to a lack of stack space. No exception is generated to indicate this condition.

PUSHF/PUSHFD—Push EFLAGS Register onto the Stack (Continued)

Operation

```
IF (PE=0) OR (PE=1 AND ((VM=0) OR (VM=1 AND IOPL=3)))
(* Real-Address Mode, Protected mode, or Virtual-8086 mode with IOPL equal to 3 *)
    THEN
        IF OperandSize = 32
            THEN
                push(EFLAGS AND 00FCFFFFH);
                (* VM and RF EFLAG bits are cleared in image stored on the stack*)
            ELSE
                push(EFLAGS); (* Lower 16 bits only *)
        FI;
    ELSE (* In Virtual-8086 Mode with IOPL less than 0 *)
        #GP(0); (* Trap to virtual-8086 monitor *)
FI;
```

Flags Affected

None.

Protected Mode Exceptions

#SS(0)	If the new value of the ESP register is outside the stack segment boundary.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory reference is made while the current privilege level is 3 and alignment checking is enabled.

Real-Address Mode Exceptions

None.

Virtual-8086 Mode Exceptions

#GP(0)	If the I/O privilege level is less than 3.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory reference is made while alignment checking is enabled.

PXOR—Logical Exclusive OR

Opcode	Instruction	Description
0F EF /r	PXOR *mm, mm/m64*	XOR quadword from *mm/m64* to quadword in *mm*.

Description

This instruction performs a bitwise logical exclusive-OR (XOR) operation on the quadword source (second) and destination (first) operands and stores the result in the destination operand location (refer to Figure 3-85). The source operand can be an MMX™ technology register or a quadword memory location; the destination operand must be an MMX™ technology register. Each bit of the result is 1 if the corresponding bits of the two operands are different; each bit is 0 if the corresponding bits of the operands are the same.

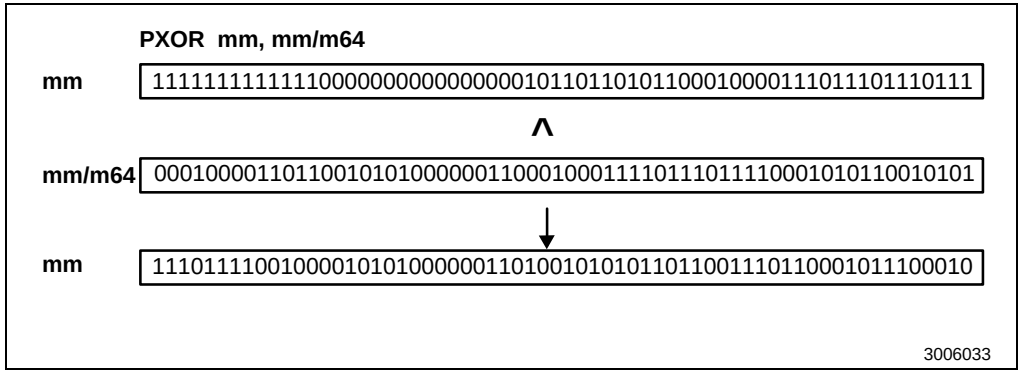


Figure 3-85. Operation of the PXOR Instruction

Operation

DEST ← DEST XOR SRC;

Intel C/C++ Compiler Intrinsic Equivalent

Pre-4.0 Intel C/C++ Compiler intrinsic:

__m64 _m_pxor(__m64 m1, __m64 m2)

Version 4.0 and later Intel C/C++ Compiler intrinsic:

__m64 _mm_xor_si64(__m64 m1, __m64 m2)

Perform a bitwise XOR of the 64-bit value in m1 with the 64-bit value in m2.

PXOR—Logical Exclusive OR (Continued)

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.

Virtual-8086 Mode Exceptions

#GP	If any part of the operand lies outside of the effective address space from 0 to FFFFH.
#UD	If EM in CR0 is set.
#NM	If TS in CR0 is set.
#MF	If there is a pending FPU exception.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

RCL/RCR/ROL/ROR-—Rotate

Opcode	Instruction	Description
D0 /2	RCL *r/m8*,1	Rotate nine bits (CF,*r/m8*) left once
D2 /2	RCL *r/m8*,CL	Rotate nine bits (CF,*r/m8*) left CL times
C0 /2 *ib*	RCL *r/m8,imm8*	Rotate nine bits (CF,*r/m8*) left *imm8* times
D1 /2	RCL *r/m16*,1	Rotate 17 bits (CF,*r/m16*) left once
D3 /2	RCL *r/m16*,CL	Rotate 17 bits (CF,*r/m16*) left CL times
C1 /2 *ib*	RCL *r/m16,imm8*	Rotate 17 bits (CF,*r/m16*) left *imm8* times
D1 /2	RCL *r/m32*,1	Rotate 33 bits (CF,*r/m32*) left once
D3 /2	RCL *r/m32*,CL	Rotate 33 bits (CF,*r/m32*) left CL times
C1 /2 *ib*	RCL *r/m32,imm8*	Rotate 33 bits (CF,*r/m32*) left *imm8* times
D0 /3	RCR *r/m8*,1	Rotate nine bits (CF,*r/m8*) right once
D2 /3	RCR *r/m8*,CL	Rotate nine bits (CF,*r/m8*) right CL times
C0 /3 *ib*	RCR *r/m8,imm8*	Rotate nine bits (CF,*r/m8*) right *imm8* times
D1 /3	RCR *r/m16*,1	Rotate 17 bits (CF,*r/m16*) right once
D3 /3	RCR *r/m16*,CL	Rotate 17 bits (CF,*r/m16*) right CL times
C1 /3 *ib*	RCR *r/m16,imm8*	Rotate 17 bits (CF,*r/m16*) right *imm8* times
D1 /3	RCR *r/m32*,1	Rotate 33 bits (CF,*r/m32*) right once
D3 /3	RCR *r/m32*,CL	Rotate 33 bits (CF,*r/m32*) right CL times
C1 /3 *ib*	RCR *r/m32,imm8*	Rotate 33 bits (CF,*r/m32*) right *imm8* times
D0 /0	ROL *r/m8*,1	Rotate eight bits *r/m8* left once
D2 /0	ROL *r/m8*,CL	Rotate eight bits *r/m8* left CL times
C0 /0 *ib*	ROL *r/m8,imm8*	Rotate eight bits *r/m8* left *imm8* times
D1 /0	ROL *r/m16*,1	Rotate 16 bits *r/m16* left once
D3 /0	ROL *r/m16*,CL	Rotate 16 bits *r/m16* left CL times
C1 /0 *ib*	ROL *r/m16,imm8*	Rotate 16 bits *r/m16* left *imm8* times
D1 /0	ROL *r/m32*,1	Rotate 32 bits *r/m32* left once
D3 /0	ROL *r/m32*,CL	Rotate 32 bits *r/m32* left CL times
C1 /0 *ib*	ROL *r/m32,imm8*	Rotate 32 bits *r/m32* left *imm8* times
D0 /1	ROR *r/m8*,1	Rotate eight bits *r/m8* right once
D2 /1	ROR *r/m8*,CL	Rotate eight bits *r/m8* right CL times
C0 /1 *ib*	ROR *r/m8,imm8*	Rotate eight bits *r/m16* right *imm8* times
D1 /1	ROR *r/m16*,1	Rotate 16 bits *r/m16* right once
D3 /1	ROR *r/m16*,CL	Rotate 16 bits *r/m16* right CL times
C1 /1 *ib*	ROR *r/m16,imm8*	Rotate 16 bits *r/m16* right *imm8* times
D1 /1	ROR *r/m32*,1	Rotate 32 bits *r/m32* right once
D3 /1	ROR *r/m32*,CL	Rotate 32 bits *r/m32* right CL times
C1 /1 *ib*	ROR *r/m32,imm8*	Rotate 32 bits *r/m32* right *imm8* times

RCL/RCR/ROL/ROR-—Rotate (Continued)

Description

These instructions shift (rotate) the bits of the first operand (destination operand) the number of bit positions specified in the second operand (count operand) and stores the result in the destination operand. The destination operand can be a register or a memory location; the count operand is an unsigned integer that can be an immediate or a value in the CL register. The processor restricts the count to a number between 0 and 31 by masking all the bits in the count operand except the five least-significant bits.

The rotate left (ROL) and rotate through carry left (RCL) instructions shift all the bits toward more-significant bit positions, except for the most-significant bit, which is rotated to the least-significant bit location. For more information, refer to Figure 6-10 in Chapter 6, *Instruction Set Summary* of the *Intel Architecture Software Developer's Manual, Volume 1*. The rotate right (ROR) and rotate through carry right (RCR) instructions shift all the bits toward less significant bit positions, except for the least-significant bit, which is rotated to the most-significant bit location.

The RCL and RCR instructions include the CF flag in the rotation. The RCL instruction shifts the CF flag into the least-significant bit and shifts the most-significant bit into the CF flag. For more information, refer to Figure 6-10 in Chapter 6, *Instruction Set Summary* of the *Intel Architecture Software Developer's Manual, Volume 1*. The RCR instruction shifts the CF flag into the most-significant bit and shifts the least-significant bit into the CF flag. For the ROL and ROR instructions, the original value of the CF flag is not a part of the result, but the CF flag receives a copy of the bit that was shifted from one end to the other.

The OF flag is defined only for the 1-bit rotates; it is undefined in all other cases (except that a zero-bit rotate does nothing, that is affects no flags). For left rotates, the OF flag is set to the exclusive OR of the CF bit (after the rotate) and the most-significant bit of the result. For right rotates, the OF flag is set to the exclusive OR of the two most-significant bits of the result.

Intel Architecture Compatibility

The 8086 does not mask the rotation count. However, all other Intel Architecture processors (starting with the Intel 286 processor) do mask the rotation count to five bits, resulting in a maximum count of 31. This masking is done in all operating modes (including the virtual-8086 mode) to reduce the maximum execution time of the instructions.

Operation

```
(* RCL and RCR instructions *)
SIZE ← OperandSize
CASE (determine count) OF
    SIZE = 8:     tempCOUNT ← (COUNT AND 1FH) MOD 9;
    SIZE = 16:    tempCOUNT ← (COUNT AND 1FH) MOD 17;
    SIZE = 32:    tempCOUNT ← COUNT AND 1FH;
ESAC;
(* RCL instruction operation *)
```

RCL/RCR/ROL/ROR-—Rotate (Continued)

```
WHILE (tempCOUNT ≠ 0)
    DO
        tempCF ← MSB(DEST);
        DEST ← (DEST ∗ 2) + CF;
        CF ← tempCF;
        tempCOUNT ← tempCOUNT – 1;
    OD;
ELIHW;
IF COUNT = 1
    THEN OF ← MSB(DEST) XOR CF;
    ELSE OF is undefined;
FI;
(* RCR instruction operation *)
IF COUNT = 1
    THEN OF ← MSB(DEST) XOR CF;
    ELSE OF is undefined;
FI;
WHILE (tempCOUNT ≠ 0)
    DO
        tempCF ← LSB(SRC);
        DEST ← (DEST / 2) + (CF * 2SIZE);
        CF ← tempCF;
        tempCOUNT ← tempCOUNT – 1;
    OD;
(* ROL and ROR instructions *)
SIZE ← OperandSize
CASE (determine count) OF
    SIZE = 8:    tempCOUNT ← COUNT MOD 8;
    SIZE = 16:   tempCOUNT ← COUNT MOD 16;
    SIZE = 32:   tempCOUNT ← COUNT MOD 32;
ESAC;
(* ROL instruction operation *)
WHILE (tempCOUNT ≠ 0)
    DO
        tempCF ← MSB(DEST);
        DEST ← (DEST ∗ 2) + tempCF;
        tempCOUNT ← tempCOUNT – 1;
    OD;
ELIHW;
CF ← LSB(DEST);
IF COUNT = 1
    THEN OF ← MSB(DEST) XOR CF;
    ELSE OF is undefined;
FI;
```

RCL/RCR/ROL/ROR-—Rotate (Continued)

```
(* ROR instruction operation *)
WHILE (tempCOUNT ≠ 0)
    DO
        tempCF ← LSB(SRC);
        DEST ← (DEST / 2) + (tempCF ∗ 2^SIZE);
        tempCOUNT ← tempCOUNT – 1;
    OD;
ELIHW;
CF ← MSB(DEST);
IF COUNT = 1
    THEN OF ← MSB(DEST) XOR MSB – 1(DEST);
    ELSE OF is undefined;
FI;
```

Flags Affected

The CF flag contains the value of the bit shifted into it. The OF flag is affected only for single-bit rotates (refer to “Description” above); it is undefined for multi-bit rotates. The SF, ZF, AF, and PF flags are not affected.

Protected Mode Exceptions

#GP(0)	If the source operand is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

RCL/RCR/ROL/ROR-—Rotate (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

RCPPS—Packed Single-FP Reciprocal

Opcode	Instruction	Description
0F,53,/r	RCPPS *xmm1, xmm2/m128*	Return a packed approximation of the reciprocal of *XMM2/Mem.*

Description

RCPPS returns an approximation of the reciprocal of the SP FP numbers from xmm2/m128. The maximum error for this approximation is:

Error <=1.5x2-12

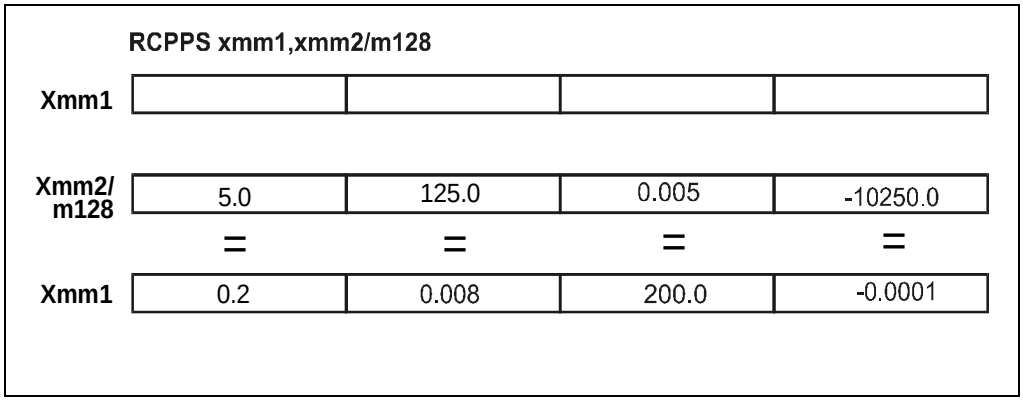


Figure 3-86. Operation of the RCPPS Instruction

Operation

```
DEST[31-0] = APPROX (1.0/(SRC/m128[31-0]));
DEST[63-32] = APPROX (1.0/(SRC/m128[63-32]));
DEST[95-64] = APPROX (1.0/(SRC/m128[95-64]));
DEST[127-96] = APPROX (1.0/(SRC/m128[127-96]));
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_rcp_ps(__m128 a)

Computes the approximations of the reciprocals of the four SP FP values of a.

RCPPS—Packed Single-FP Reciprocal (Continued)

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.

Comments

RCPPS is not affected by the rounding control in MXCSR. Denormal inputs are treated as zeroes (of the same sign) and underflow results are always flushed to zero, with the sign of the operand.

RCPSS—Scalar Single-FP Reciprocal

Opcode	Instruction	Description
F3,0F,53,/r	RCPSS xmm1, xmm2/m32	Return an approximation of the reciprocal of the lower SP FP number in XMM2/Mem.

Description

RCPSS returns an approximation of the reciprocal of the lower SP FP number from xmm2/m32; the upper three fields are passed through from xmm1. The maximum error for this approximation is:

|Error| <= $1.5x2^{-12}$

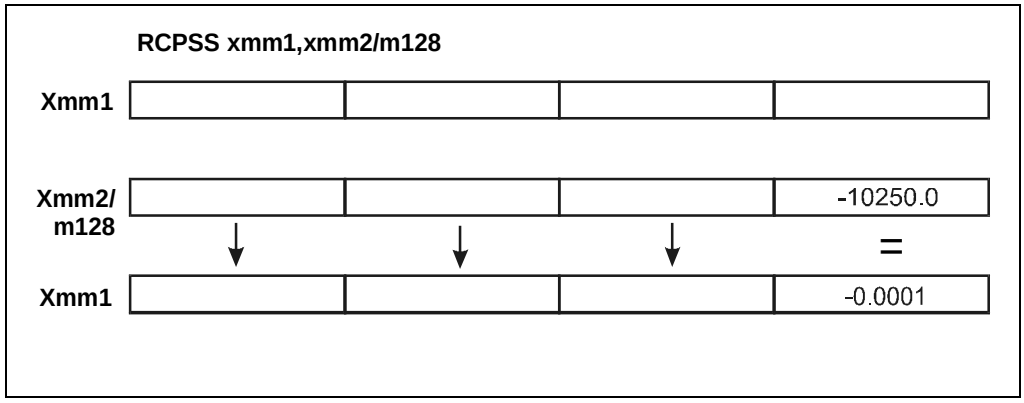


Figure 3-87. Operation of the RCPSS Instruction

Operation

```
DEST[31-0] = APPROX (1.0/(SRC/m32[31-0]));
DEST[63-32] = DEST[63-32];
DEST[95-64] = DEST[95-64];
DEST[127-96] = DEST[127-96];
```

RCPSS—Scalar Single-FP Reciprocal (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_rcp_ss(__m128 a)

Computes the approximation of the reciprocal of the lower SP FP value of a; the upper three SP FP values are passed through.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#AC	For unaligned memory reference if the current privilege level is 3.
#NM	If TS bit in CR0 is set.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

Comments

RCPSS is not affected by the rounding control in MXCSR. Denormal inputs are treated as zeroes (of the same sign) and underflow results are always flushed to zero, with the sign of the operand.

RDMSR—Read from Model Specific Register

Opcode	Instruction	Description
0F 32	RDMSR	Load MSR specified by ECX into EDX:EAX

Description

This instruction loads the contents of a 64-bit model specific register (MSR) specified in the ECX register into registers EDX:EAX. The EDX register is loaded with the high-order 32 bits of the MSR and the EAX register is loaded with the low-order 32 bits. If less than 64 bits are implemented in the MSR being read, the values returned to EDX:EAX in unimplemented bit locations are undefined.

This instruction must be executed at privilege level 0 or in real-address mode; otherwise, a general protection exception #GP(0) will be generated. Specifying a reserved or unimplemented MSR address in ECX will also cause a general protection exception.

The MSRs control functions for testability, execution tracing, performance-monitoring and machine check errors. Appendix B, *Model-Specific Registers (MSRs)*, in the *Intel Architecture Software Developer's Manual, Volume 3*, lists all the MSRs that can be read with this instruction and their addresses.

The CPUID instruction should be used to determine whether MSRs are supported (EDX[5]=1) before using this instruction.

Intel Architecture Compatibility

The MSRs and the ability to read them with the RDMSR instruction were introduced into the Intel Architecture with the Pentium® processor. Execution of this instruction by an Intel Architecture processor earlier than the Pentium® processor results in an invalid opcode exception #UD.

Operation

```
EDX:EAX ← MSR[ECX];
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the current privilege level is not 0.
	If the value in ECX specifies a reserved or unimplemented MSR address.

RDMSR—Read from Model Specific Register (Continued)

Real-Address Mode Exceptions

#GP	If the value in ECX specifies a reserved or unimplemented MSR address.

Virtual-8086 Mode Exceptions

#GP(0)	The RDMSR instruction is not recognized in virtual-8086 mode.

RDPMC—Read Performance-Monitoring Counters

Opcode	Instruction	Description
0F 33	RDPMC	Read performance-monitoring counter specified by ECX into EDX:EAX

Description

This instruction loads the contents of the 40-bit performance-monitoring counter specified in the ECX register into registers EDX:EAX. The EDX register is loaded with the high-order eight bits of the counter and the EAX register is loaded with the low-order 32 bits. The Pentium® Pro processor has two performance-monitoring counters (0 and 1), which are specified by placing 0000H or 0001H, respectively, in the ECX register.

The RDPMC instruction allows application code running at a privilege level of 1, 2, or 3 to read the performance-monitoring counters if the PCE flag in the CR4 register is set. This instruction is provided to allow performance monitoring by application code without incurring the overhead of a call to an operating-system procedure.

The performance-monitoring counters are event counters that can be programmed to count events such as the number of instructions decoded, number of interrupts received, or number of cache loads. Appendix A, *Performance-Monitoring Events*, in the *Intel Architecture Software Developer's Manual, Volume 3*, lists all the events that can be counted.

The RDPMC instruction does not serialize instruction execution. That is, it does not imply that all the events caused by the preceding instructions have been completed or that events caused by subsequent instructions have not begun. If an exact event count is desired, software must use a serializing instruction (such as the CPUID instruction) before and/or after the execution of the RDPMC instruction.

The RDPMC instruction can execute in 16-bit addressing mode or virtual-8086 mode; however, the full contents of the ECX register are used to determine the counter to access and a full 40-bit result is returned (the low-order 32 bits in the EAX register and the high-order nine bits in the EDX register).

Intel Architecture Compatibility

The RDPMC instruction was introduced into the Intel Architecture in the Pentium® Pro processor and the Pentium® processor with MMX™ technology. The other Pentium® processors have performance-monitoring counters, but they must be read with the RDMSR instruction.

Operation

```
IF (ECX = 0 OR 1) AND ((CR4.PCE = 1) OR ((CR4.PCE = 0) AND (CPL=0)))
    THEN
        EDX:EAX ← PMC[ECX];
    ELSE (* ECX is not 0 or 1 and/or CR4.PCE is 0 and CPL is 1, 2, or 3 *)
        #GP(0); FI;
```

RDPMC—Read Performance-Monitoring Counters (Continued)

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the current privilege level is not 0 and the PCE flag in the CR4 register is clear.
	If the value in the ECX register is not 0 or 1.

Real-Address Mode Exceptions

#GP	If the PCE flag in the CR4 register is clear.
	If the value in the ECX register is not 0 or 1.

Virtual-8086 Mode Exceptions

#GP(0)	If the PCE flag in the CR4 register is clear.
	If the value in the ECX register is not 0 or 1.

RDTSC—Read Time-Stamp Counter

Opcode	Instruction	Description
0F 31	RDTSC	Read time-stamp counter into EDX:EAX

Description

This instruction loads the current value of the processor's time-stamp counter into the EDX:EAX registers. The time-stamp counter is contained in a 64-bit MSR. The high-order 32 bits of the MSR are loaded into the EDX register, and the low-order 32 bits are loaded into the EAX register. The processor increments the time-stamp counter MSR every clock cycle and resets it to 0 whenever the processor is reset.

The time stamp disable (TSD) flag in register CR4 restricts the use of the RDTSC instruction. When the TSD flag is clear, the RDTSC instruction can be executed at any privilege level; when the flag is set, the instruction can only be executed at privilege level 0. The time-stamp counter can also be read with the RDMSR instruction, when executing at privilege level 0.

The RDTSC instruction is not a serializing instruction. Thus, it does not necessarily wait until all previous instructions have been executed before reading the counter. Similarly, subsequent instructions may begin execution before the read operation is performed.

This instruction was introduced into the Intel Architecture in the Pentium® processor.

Operation

```
IF (CR4.TSD = 0) OR ((CR4.TSD = 1) AND (CPL=0))
    THEN
        EDX:EAX ← TimeStampCounter;
    ELSE (* CR4 is 1 and CPL is 1, 2, or 3 *)
        #GP(0)
FI;
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the TSD flag in register CR4 is set and the CPL is greater than 0.

Real-Address Mode Exceptions

#GP	If the TSD flag in register CR4 is set.

Virtual-8086 Mode Exceptions

#GP(0)	If the TSD flag in register CR4 is set.

REP/REPE/REPZ/REPNE/REPNZ—Repeat String Operation Prefix

Opcode	Instruction	Description
F3 6C	REP INS *r/m8*, DX	Input (E)CX bytes from port DX into ES:[(E)DI]
F3 6D	REP INS *r/m16*,DX	Input (E)CX words from port DX into ES:[(E)DI]
F3 6D	REP INS *r/m32*,DX	Input (E)CX doublewords from port DX into ES:[(E)DI]
F3 A4	REP MOVS *m8,m8*	Move (E)CX bytes from DS:[(E)SI] to ES:[(E)DI]
F3 A5	REP MOVS *m16,m16*	Move (E)CX words from DS:[(E)SI] to ES:[(E)DI]
F3 A5	REP MOVS *m32,m32*	Move (E)CX doublewords from DS:[(E)SI] to ES:[(E)DI]
F3 6E	REP OUTS DX,*r/m8*	Output (E)CX bytes from DS:[(E)SI] to port DX
F3 6F	REP OUTS DX,*r/m16*	Output (E)CX words from DS:[(E)SI] to port DX
F3 6F	REP OUTS DX,*r/m32*	Output (E)CX doublewords from DS:[(E)SI] to port DX
F3 AC	REP LODS AL	Load (E)CX bytes from DS:[(E)SI] to AL
F3 AD	REP LODS AX	Load (E)CX words from DS:[(E)SI] to AX
F3 AD	REP LODS EAX	Load (E)CX doublewords from DS:[(E)SI] to EAX
F3 AA	REP STOS *m8*	Fill (E)CX bytes at ES:[(E)DI] with AL
F3 AB	REP STOS *m16*	Fill (E)CX words at ES:[(E)DI] with AX
F3 AB	REP STOS *m32*	Fill (E)CX doublewords at ES:[(E)DI] with EAX
F3 A6	REPE CMPS *m8,m8*	Find nonmatching bytes in ES:[(E)DI] and DS:[(E)SI]
F3 A7	REPE CMPS *m16,m16*	Find nonmatching words in ES:[(E)DI] and DS:[(E)SI]
F3 A7	REPE CMPS *m32,m32*	Find nonmatching doublewords in ES:[(E)DI] and DS:[(E)SI]
F3 AE	REPE SCAS *m8*	Find non-AL byte starting at ES:[(E)DI]
F3 AF	REPE SCAS *m16*	Find non-AX word starting at ES:[(E)DI]
F3 AF	REPE SCAS *m32*	Find non-EAX doubleword starting at ES:[(E)DI]
F2 A6	REPNE CMPS *m8,m8*	Find matching bytes in ES:[(E)DI] and DS:[(E)SI]
F2 A7	REPNE CMPS *m16,m16*	Find matching words in ES:[(E)DI] and DS:[(E)SI]
F2 A7	REPNE CMPS *m32,m32*	Find matching doublewords in ES:[(E)DI] and DS:[(E)SI]
F2 AE	REPNE SCAS *m8*	Find AL, starting at ES:[(E)DI]
F2 AF	REPNE SCAS *m16*	Find AX, starting at ES:[(E)DI]
F2 AF	REPNE SCAS *m32*	Find EAX, starting at ES:[(E)DI]

Description

These instructions repeat a string instruction the number of times specified in the count register ((E)CX) or until the indicated condition of the ZF flag is no longer met. The REP (repeat), REPE (repeat while equal), REPNE (repeat while not equal), REPZ (repeat while zero), and REPNZ (repeat while not zero) mnemonics are prefixes that can be added to one of the string instructions. The REP prefix can be added to the INS, OUTS, MOVS, LODS, and STOS instructions, and the REPE, REPNE, REPZ, and REPNZ prefixes can be added to the CMPS and SCAS instructions. (The REPZ and REPNZ prefixes are synonymous forms of the REPE and REPNE prefixes, respectively.) The behavior of the REP prefix is undefined when used with non-string instructions.

REP/REPE/REPZ/REPNE/REPNZ—Repeat String Operation Prefix (Continued)

The REP prefixes apply only to one string instruction at a time. To repeat a block of instructions, use the LOOP instruction or another looping construct.

All of these repeat prefixes cause the associated instruction to be repeated until the count in register (E)CX is decremented to 0 (refer to the following table). If the current address-size attribute is 32, register ECX is used as a counter, and if the address-size attribute is 16, the CX register is used. The REPE, REPNE, REPZ, and REPNZ prefixes also check the state of the ZF flag after each iteration and terminate the repeat loop if the ZF flag is not in the specified state. When both termination conditions are tested, the cause of a repeat termination can be determined either by testing the (E)CX register with a JECXZ instruction or by testing the ZF flag with a JZ, JNZ, and JNE instruction.

Repeat Conditions

Repeat Prefix	Termination Condition 1	Termination Condition 2
REP	ECX=0	None
REPE/REPZ	ECX=0	ZF=0
REPNE/REPNZ	ECX=0	ZF=1

When the REPE/REPZ and REPNE/REPNZ prefixes are used, the ZF flag does not require initialization because both the CMPS and SCAS instructions affect the ZF flag according to the results of the comparisons they make.

A repeating string operation can be suspended by an exception or interrupt. When this happens, the state of the registers is preserved to allow the string operation to be resumed upon a return from the exception or interrupt handler. The source and destination registers point to the next string elements to be operated on, the EIP register points to the string instruction, and the ECX register has the value it held following the last successful iteration of the instruction. This mechanism allows long string operations to proceed without affecting the interrupt response time of the system.

When a fault occurs during the execution of a CMPS or SCAS instruction that is prefixed with REPE or REPNE, the EFLAGS value is restored to the state prior to the execution of the instruction. Since the SCAS and CMPS instructions do not use EFLAGS as an input, the processor can resume the instruction after the page fault handler.

Use the REP INS and REP OUTS instructions with caution. Not all I/O ports can handle the rate at which these instructions execute.

A REP STOS instruction is the fastest way to initialize a large block of memory.

REP/REPE/REPZ/REPNE/REPNZ—Repeat String Operation Prefix (Continued)

Operation

```
IF AddressSize = 16
    THEN
        use CX for CountReg;
    ELSE (* AddressSize = 32 *)
        use ECX for CountReg;
FI;
WHILE CountReg ≠ 0
    DO
        service pending interrupts (if any);
        execute associated string instruction;
        CountReg ← CountReg – 1;
        IF CountReg = 0
            THEN exit WHILE loop
        FI;
        IF (repeat prefix is REPZ or REPE) AND (ZF=0)
        OR (repeat prefix is REPNZ or REPNE) AND (ZF=1)
            THEN exit WHILE loop
        FI;
    OD;
```

Flags Affected

None; however, the CMPS and SCAS instructions do set the status flags in the EFLAGS register.

Exceptions (All Operating Modes)

None; however, exceptions can be generated by the instruction a repeat prefix is associated with.

RET—Return from Procedure

Opcode	Instruction	Description
C3	RET	Near return to calling procedure
CB	RET	Far return to calling procedure
C2 *iw*	RET *imm16*	Near return to calling procedure and pop *imm16* bytes from stack
CA *iw*	RET *imm16*	Far return to calling procedure and pop *imm16* bytes from stack

Description

This instruction transfers program control to a return address located on the top of the stack. The address is usually placed on the stack by a CALL instruction, and the return is made to the instruction that follows the CALL instruction.

The optional source operand specifies the number of stack bytes to be released after the return address is popped; the default is none. This operand can be used to release parameters from the stack that were passed to the called procedure and are no longer needed. It must be used when the CALL instruction used to switch to a new procedure uses a call gate with a non-zero word count to access the new procedure. Here, the source operand for the RET instruction must specify the same number of bytes as is specified in the word count field of the call gate.

The RET instruction can be used to execute three different types of returns:

- Near return—A return to a calling procedure within the current code segment (the segment currently pointed to by the CS register), sometimes referred to as an intrasegment return.
- Far return—A return to a calling procedure located in a different segment than the current code segment, sometimes referred to as an intersegment return.
- Inter-privilege-level far return—A far return to a different privilege level than that of the currently executing program or procedure.

The inter-privilege-level return type can only be executed in protected mode. Refer to Section 4.3., *Calling Procedures Using CALL and RET* in Chapter 4, *Procedure Calls, Interrupts, and Exceptions* of the *Intel Architecture Software Developer's Manual, Volume 1*, for detailed information on near, far, and inter-privilege-level returns.

When executing a near return, the processor pops the return instruction pointer (offset) from the top of the stack into the EIP register and begins program execution at the new instruction pointer. The CS register is unchanged.

When executing a far return, the processor pops the return instruction pointer from the top of the stack into the EIP register, then pops the segment selector from the top of the stack into the CS register. The processor then begins program execution in the new code segment at the new instruction pointer.

RET—Return from Procedure (Continued)

The mechanics of an inter-privilege-level far return are similar to an intersegment return, except that the processor examines the privilege levels and access rights of the code and stack segments being returned to determine if the control transfer is allowed to be made. The DS, ES, FS, and GS segment registers are cleared by the RET instruction during an inter-privilege-level return if they refer to segments that are not allowed to be accessed at the new privilege level. Since a stack switch also occurs on an inter-privilege level return, the ESP and SS registers are loaded from the stack.

If parameters are passed to the called procedure during an inter-privilege level call, the optional source operand must be used with the RET instruction to release the parameters on the return. Here, the parameters are released both from the called procedure's stack and the calling procedure's stack (that is, the stack being returned to).

Operation

```
(* Near return *)
IF instruction = near return
    THEN;
        IF OperandSize = 32
            THEN
                IF top 12 bytes of stack not within stack limits THEN #SS(0); FI;
                EIP ← Pop();
            ELSE (* OperandSize = 16 *)
                IF top 6 bytes of stack not within stack limits
                    THEN #SS(0)
                FI;
                tempEIP ← Pop();
                tempEIP ← tempEIP AND 0000FFFFH;
                IF tempEIP not within code segment limits THEN #GP(0); FI;
                EIP ← tempEIP;
        FI;
    IF instruction has immediate operand
        THEN IF StackAddressSize=32
            THEN
                ESP ← ESP + SRC; (* release parameters from stack *)
            ELSE (* StackAddressSize=16 *)
                SP ← SP + SRC; (* release parameters from stack *)
        FI;
    FI;

(* Real-address mode or virtual-8086 mode *)
IF ((PE = 0) OR (PE = 1 AND VM = 1)) AND instruction = far return
    THEN;
```

RET—Return from Procedure (Continued)

```
        IF OperandSize = 32
            THEN
                IF top 12 bytes of stack not within stack limits THEN #SS(0); FI;
                EIP ← Pop();
                CS ← Pop(); (* 32-bit pop, high-order 16 bits discarded *)
            ELSE (* OperandSize = 16 *)
                IF top 6 bytes of stack not within stack limits THEN #SS(0); FI;
                tempEIP ← Pop();
                tempEIP ← tempEIP AND 0000FFFFH;
                IF tempEIP not within code segment limits THEN #GP(0); FI;
                EIP ← tempEIP;
                CS ← Pop(); (* 16-bit pop *)
        FI;
    IF instruction has immediate operand
        THEN
            SP ← SP + (SRC AND FFFFH); (* release parameters from stack *)
    FI;
FI;

(* Protected mode, not virtual-8086 mode *)
IF (PE = 1 AND VM = 0) AND instruction = far RET
    THEN
        IF OperandSize = 32
            THEN
                IF second doubleword on stack is not within stack limits THEN #SS(0); FI;
            ELSE (* OperandSize = 16 *)
                IF second word on stack is not within stack limits THEN #SS(0); FI;
        FI;
    IF return code segment selector is null THEN GP(0); FI;
    IF return code segment selector addrsses descriptor beyond diescriptor table limit
        THEN GP(selector; FI;
    Obtain descriptor to which return code segment selector points from descriptor table
    IF return code segment descriptor is not a code segment THEN #GP(selector); FI;
    if return code segment selector RPL < CPL THEN #GP(selector); FI;
    IF return code segment descriptor is conforming
        AND return code segment DPL > return code segment selector RPL
            THEN #GP(selector); FI;
    IF return code segment descriptor is not present THEN #NP(selector); FI:
    IF return code segment selector RPL > CPL
        THEN GOTO RETURN-OUTER-PRIVILEGE-LEVEL;
        ELSE GOTO RETURN-TO-SAME-PRIVILEGE-LEVEL
    FI;
END;FI;
```

RET—Return from Procedure (Continued)

```
RETURN-SAME-PRIVILEGE-LEVEL:
    IF the return instruction pointer is not within ther return code segment limit
        THEN #GP(0);
    FI;
    IF OperandSize=32
        THEN
            EIP ← Pop();
            CS ← Pop(); (* 32-bit pop, high-order 16 bits discarded *)
            ESP ← ESP + SRC; (* release parameters from stack *)
        ELSE (* OperandSize=16 *)
            EIP ← Pop();
            EIP ← EIP AND 0000FFFFH;
            CS ← Pop(); (* 16-bit pop *)
            ESP ← ESP + SRC; (* release parameters from stack *)
    FI;

RETURN-OUTER-PRIVILEGE-LEVEL:
    IF top (16 + SRC) bytes of stack are not within stack limits (OperandSize=32)
        OR top (8 + SRC) bytes of stack are not within stack limits (OperandSize=16)
            THEN #SS(0); FI;
    FI;
    Read return segment selector;
    IF stack segment selector is null THEN #GP(0); FI;
    IF return stack segment selector index is not within its descriptor table limits
            THEN #GP(selector); FI;
    Read segment descriptor pointed to by return segment selector;
    IF stack segment selector RPL ≠ RPL of the return code segment selector
        OR stack segment is not a writable data segment
        OR stack segment descriptor DPL ≠ RPL of the return code segment selector
            THEN #GP(selector); FI;
        IF stack segment not present THEN #SS(StackSegmentSelector); FI;
    IF the return instruction pointer is not within the return code segment limit THEN #GP(0); FI:
     CPL ← ReturnCodeSegmentSelector(RPL);
    IF OperandSize=32
        THEN
            EIP ← Pop();
            CS ← Pop(); (* 32-bit pop, high-order 16 bits discarded *)
             (* segment descriptor information also loaded *)
            CS(RPL) ← CPL;
            ESP ← ESP + SRC; (* release parameters from called procedure's stack *)
            tempESP ← Pop();
            tempSS ← Pop(); (* 32-bit pop, high-order 16 bits discarded *)
             (* segment descriptor information also loaded *)
            ESP ← tempESP;
            SS ← tempSS;
```

RET—Return from Procedure (Continued)

```
        ELSE (* OperandSize=16 *)
            EIP ← Pop();
            EIP ← EIP AND 0000FFFFH;
            CS ← Pop(); (* 16-bit pop; segment descriptor information also loaded *)
            CS(RPL) ← CPL;
            ESP ← ESP + SRC; (* release parameters from called procedure's stack *)
            tempESP ← Pop();
            tempSS ← Pop(); (* 16-bit pop; segment descriptor information also loaded *)
             (* segment descriptor information also loaded *)
            ESP ← tempESP;
            SS ← tempSS;
    FI;
    FOR each of segment register (ES, FS, GS, and DS)
        DO;
            IF segment register points to data or non-conforming code segment
            AND CPL > segment descriptor DPL; (* DPL in hidden part of segment register *)
                THEN (* segment register invalid *)
                    SegmentSelector ← 0; (* null segment selector *)
            FI;
        OD;
    For each of ES, FS, GS, and DS
    DO
        IF segment selector index is not within descriptor table limits
            OR segment descriptor indicates the segment is not a data or
                readable code segment
            OR if the segment is a data or non-conforming code segment and the segment
                descriptor's DPL < CPL or RPL of code segment's segment selector
                THEN
                    segment selector register ← null selector;
    OD;
    ESP ← ESP + SRC; (* release parameters from calling procedure's stack *)
```

Flags Affected

None.

RET—Return from Procedure (Continued)

Protected Mode Exceptions

#GP(0)	If the return code or stack segment selector null.
	If the return instruction pointer is not within the return code segment limit
#GP(selector)	If the RPL of the return code segment selector is less then the CPL.
	If the return code or stack segment selector index is not within its descriptor table limits.
	If the return code segment descriptor does not indicate a code segment.
	If the return code segment is non-conforming and the segment selector's DPL is not equal to the RPL of the code segment's segment selector
	If the return code segment is conforming and the segment selector's DPL greater than the RPL of the code segment's segment selector
	If the stack segment is not a writable data segment.
	If the stack segment selector RPL is not equal to the RPL of the return code segment selector.
	If the stack segment descriptor DPL is not equal to the RPL of the return code segment selector.
#SS(0)	If the top bytes of stack are not within stack limits.
	If the return stack segment is not present.
#NP(selector)	If the return code segment is not present.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory access occurs when the CPL is 3 and alignment checking is enabled.

Real-Address Mode Exceptions

#GP	If the return instruction pointer is not within the return code segment limit
#SS	If the top bytes of stack are not within stack limits.

RET—Return from Procedure (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If the return instruction pointer is not within the return code segment limit
#SS(0)	If the top bytes of stack are not within stack limits.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory access occurs when alignment checking is enabled.

ROL/ROR—Rotate

Refer to entry for RCL/RCR/ROL/ROR—Rotate.

RSM—Resume from System Management Mode

Opcode	Instruction	Description
0F AA	RSM	Resume operation of interrupted program

Description

This instruction returns program control from system management mode (SMM) to the application program or operating-system procedure that was interrupted when the processor received an SSM interrupt. The processor's state is restored from the dump created upon entering SMM. If the processor detects invalid state information during state restoration, it enters the shutdown state. The following invalid information can cause a shutdown:

- Any reserved bit of CR4 is set to 1.
- Any illegal combination of bits in CR0, such as (PG=1 and PE=0) or (NW=1 and CD=0).
- (Intel Pentium® and Intel486™ processors only.) The value stored in the state dump base field is not a 32-KByte aligned address.

The contents of the model-specific registers are not affected by a return from SMM.

Refer to Chapter 11, *System Management Mode (SMM)*, in the *Intel Architecture Software Developer's Manual, Volume 3*, for more information about SMM and the behavior of the RSM instruction.

Operation

```
ReturnFromSSM;
ProcessorState ← Restore(SSMDump);
```

Flags Affected

All.

Protected Mode Exceptions

#UD	If an attempt is made to execute this instruction when the processor is not in SMM.

Real-Address Mode Exceptions

#UD	If an attempt is made to execute this instruction when the processor is not in SMM.

Virtual-8086 Mode Exceptions

#UD	If an attempt is made to execute this instruction when the processor is not in SMM.

RSQRTPS—Packed Single-FP Square Root Reciprocal

Opcode	Instruction	Description
0F,52,/r	RSQRTPS *xmm1, xmm2/m128*	Return a packed approximation of the square root of the reciprocal of *XMM2/Mem.*

Description

RSQRTPS returns an approximation of the reciprocal of the square root of the SP FP numbers from xmm2/m128. The maximum error for this approximation is:

$|Error| <= 1.5x2^{-12}$

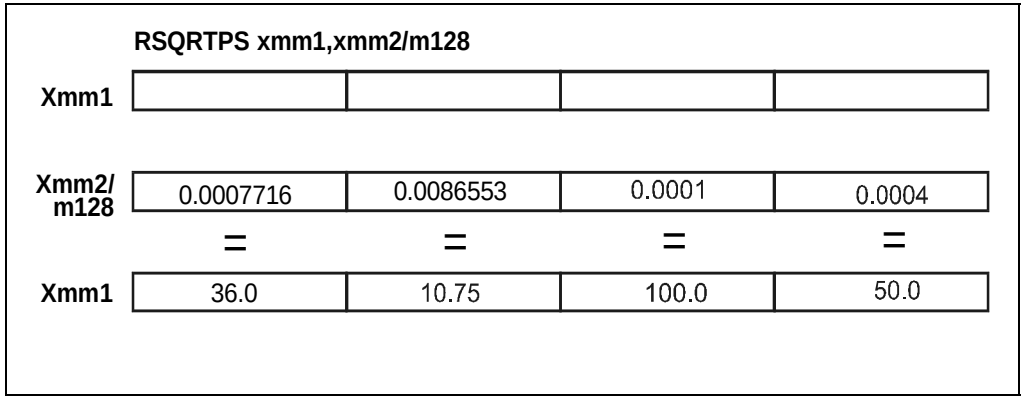


Figure 3-88. Operation of the RSQRTPS Instruction

Operation

```
DEST[31-0] = APPROX (1.0/SQRT(SRC/m128[31-0]));
DEST[63-32] = APPROX (1.0/SQRT(SRC/m128[63-32]));
DEST[95-64] = APPROX (1.0/SQRT(SRC/m128[95-64]));
DEST[127-96] = APPROX (1.0/SQRT(SRC/m128[127-96]));
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_rsqrt_ps(__m128 a)

Computes the approximations of the reciprocals of the square roots of the four SP FP values of a.

RSQRTPS—Packed Single-FP Square Root Reciprocal (Continued)

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.

Comments

RSQRTPS is not affected by the rounding control in MXCSR. Denormal inputs are treated as zeroes (of the same sign) and underflow results are always flushed to zero, with the sign of the operand.

RSQRTSS—Scalar Single-FP Square Root Reciprocal

Opcode	Instruction	Description
F3,0F,52,/r	RSQRTSS *xmm1, xmm2/m32*	Return an approximation of the square root of the reciprocal of the lowest SP FP number in *XMM2/Mem.*

Description

RSQRTSS returns an approximation of the reciprocal of the square root of the lowest SP FP number from xmm2/m32; the upper three fields are passed through from xmm1. The maximum error for this approximation is:

$|Error| <= 1.5x2^{-12}$

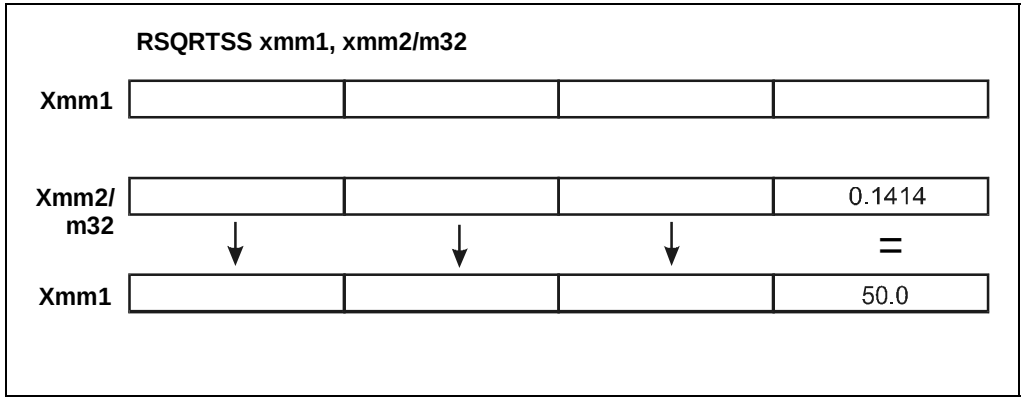


Figure 3-89. Operation of the RSQRTSS Instruction

Operation

```
DEST[31-0] = APPROX (1.0/SQRT(SRC/m32[31-0]));
DEST[63-32] = DEST[63-32];
DEST[95-64] = DEST[95-64];
DEST[127-96] = DEST[127-96];
```

RSQRTSS—Scalar Single-FP Square Root Reciprocal (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_rsqrt_ss(__m128 a)

Computes the approximation of the reciprocal of the square root of the lower SP FP value of a; the upper three SP FP values are passed through.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3)

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

Comments

RSQRTSS is not affected by the rounding control in MXCSR. Denormal inputs are treated as zeroes (of the same sign) and underflow results are always flushed to zero, with the sign of the operand.

SAHF—Store AH into Flags

Opcode	Instruction	Clocks	Description
9E	SAHF	2	Loads SF, ZF, AF, PF, and CF from AH into EFLAGS register

Description

This instruction loads the SF, ZF, AF, PF, and CF flags of the EFLAGS register with values from the corresponding bits in the AH register (bits 7, 6, 4, 2, and 0, respectively). Bits 1, 3, and 5 of register AH are ignored; the corresponding reserved bits (1, 3, and 5) in the EFLAGS register remain as shown in the "Operation" section below.

Operation

EFLAGS(SF:ZF:0:AF:0:PF:1:CF) ← AH;

Flags Affected

The SF, ZF, AF, PF, and CF flags are loaded with values from the AH register. Bits 1, 3, and 5 of the EFLAGS register are unaffected, with the values remaining 1, 0, and 0, respectively.

Exceptions (All Operating Modes)

None.

SAL/SAR/SHL/SHR—Shift

Opcode	Instruction	Description
D0 /4	SAL *r/m8*,1	Multiply *r/m8* by 2, once
D2 /4	SAL *r/m8*,CL	Multiply *r/m8* by 2, CL times
C0 /4 *ib*	SAL *r/m8,imm8*	Multiply *r/m8* by 2, *imm8* times
D1 /4	SAL *r/m16*,1	Multiply *r/m16* by 2, once
D3 /4	SAL *r/m16*,CL	Multiply *r/m16* by 2, CL times
C1 /4 *ib*	SAL *r/m16,imm8*	Multiply *r/m16* by 2, *imm8* times
D1 /4	SAL *r/m32*,1	Multiply *r/m32* by 2, once
D3 /4	SAL *r/m32*,CL	Multiply *r/m32* by 2, CL times
C1 /4 *ib*	SAL *r/m32,imm8*	Multiply *r/m32* by 2, *imm8* times
D0 /7	SAR *r/m8*,1	Signed divide* *r/m8* by 2, once
D2 /7	SAR *r/m8*,CL	Signed divide* *r/m8* by 2, CL times
C0 /7 *ib*	SAR *r/m8,imm8*	Signed divide* *r/m8* by 2, *imm8* times
D1 /7	SAR *r/m16*,1	Signed divide* *r/m16* by 2, once
D3 /7	SAR *r/m16*,CL	Signed divide* *r/m16* by 2, CL times
C1 /7 *ib*	SAR *r/m16,imm8*	Signed divide* *r/m16* by 2, *imm8* times
D1 /7	SAR *r/m32*,1	Signed divide* *r/m32* by 2, once
D3 /7	SAR *r/m32*,CL	Signed divide* *r/m32* by 2, CL times
C1 /7 *ib*	SAR *r/m32,imm8*	Signed divide* *r/m32* by 2, *imm8* times
D0 /4	SHL *r/m8*,1	Multiply *r/m8* by 2, once
D2 /4	SHL *r/m8*,CL	Multiply *r/m8* by 2, CL times
C0 /4 *ib*	SHL *r/m8,imm8*	Multiply *r/m8* by 2, *imm8* times
D1 /4	SHL *r/m16*,1	Multiply *r/m16* by 2, once
D3 /4	SHL *r/m16*,CL	Multiply *r/m16* by 2, CL times
C1 /4 *ib*	SHL *r/m16,imm8*	Multiply *r/m16* by 2, *imm8* times
D1 /4	SHL *r/m32*,1	Multiply *r/m32* by 2, once
D3 /4	SHL *r/m32*,CL	Multiply *r/m32* by 2, CL times
C1 /4 *ib*	SHL *r/m32,imm8*	Multiply *r/m32* by 2, *imm8* times
D0 /5	SHR *r/m8*,1	Unsigned divide *r/m8* by 2, once
D2 /5	SHR *r/m8*,CL	Unsigned divide *r/m8* by 2, CL times
C0 /5 *ib*	SHR *r/m8,imm8*	Unsigned divide *r/m8* by 2, *imm8* times
D1 /5	SHR *r/m16*,1	Unsigned divide *r/m16* by 2, once
D3 /5	SHR *r/m16*,CL	Unsigned divide *r/m16* by 2, CL times
C1 /5 *ib*	SHR *r/m16,imm8*	Unsigned divide *r/m16* by 2, *imm8* times
D1 /5	SHR *r/m32*,1	Unsigned divide *r/m32* by 2, once
D3 /5	SHR *r/m32*,CL	Unsigned divide *r/m32* by 2, CL times
C1 /5 *ib*	SHR *r/m32,imm8*	Unsigned divide *r/m32* by 2, *imm8* times

NOTE:

* Not the same form of division as IDIV; rounding is toward negative infinity.

SAL/SAR/SHL/SHR—Shift (Continued)

Description

These instructions shift the bits in the first operand (destination operand) to the left or right by the number of bits specified in the second operand (count operand). Bits shifted beyond the destination operand boundary are first shifted into the CF flag, then discarded. At the end of the shift operation, the CF flag contains the last bit shifted out of the destination operand.

The destination operand can be a register or a memory location. The count operand can be an immediate value or register CL. The count is masked to five bits, which limits the count range to 0 to 31. A special opcode encoding is provided for a count of 1.

The shift arithmetic left (SAL) and shift logical left (SHL) instructions perform the same operation; they shift the bits in the destination operand to the left (toward more significant bit locations). For each shift count, the most significant bit of the destination operand is shifted into the CF flag, and the least significant bit is cleared. Refer to Figure 6-6 in Chapter 6, *Instruction Set Summary* of the *Intel Architecture Software Developer's Manual, Volume 1.*

The shift arithmetic right (SAR) and shift logical right (SHR) instructions shift the bits of the destination operand to the right (toward less significant bit locations). For each shift count, the least significant bit of the destination operand is shifted into the CF flag, and the most significant bit is either set or cleared depending on the instruction type. The SHR instruction clears the most significant bit. For more information, refer to Figure 6-7 in Chapter 6, *Instruction Set Summary* of the *Intel Architecture Software Developer's Manual, Volume 1*. The SAR instruction sets or clears the most significant bit to correspond to the sign (most significant bit) of the original value in the destination operand. In effect, the SAR instruction fills the empty bit position's shifted value with the sign of the unshifted value. For more information, refer to Figure 6-8 in Chapter 6, *Instruction Set Summary* of the *Intel Architecture Software Developer's Manual, Volume 1*.

The SAR and SHR instructions can be used to perform signed or unsigned division, respectively, of the destination operand by powers of 2. For example, using the SAR instruction to shift a signed integer one bit to the right divides the value by 2.

Using the SAR instruction to perform a division operation does not produce the same result as the IDIV instruction. The quotient from the IDIV instruction is rounded toward zero, whereas the "quotient" of the SAR instruction is rounded toward negative infinity. This difference is apparent only for negative numbers. For example, when the IDIV instruction is used to divide -9 by 4, the result is -2 with a remainder of -1. If the SAR instruction is used to shift -9 right by two bits, the result is -3 and the "remainder" is +3; however, the SAR instruction stores only the most significant bit of the remainder (in the CF flag).

The OF flag is affected only on 1-bit shifts. For left shifts, the OF flag is cleared to 0 if the most-significant bit of the result is the same as the CF flag (that is, the top two bits of the original operand were the same); otherwise, it is set to 1. For the SAR instruction, the OF flag is cleared for all 1-bit shifts. For the SHR instruction, the OF flag is set to the most-significant bit of the original operand.

SAL/SAR/SHL/SHR—Shift (Continued)

Intel Architecture Compatibility

The 8086 does not mask the shift count. However, all other Intel Architecture processors (starting with the Intel 286 processor) do mask the shift count to five bits, resulting in a maximum count of 31. This masking is done in all operating modes (including the virtual-8086 mode) to reduce the maximum execution time of the instructions.

Operation

```
tempCOUNT ← (COUNT AND 1FH);
tempDEST ← DEST;
WHILE (tempCOUNT ≠ 0)
DO
    IF instruction is SAL or SHL
        THEN
            CF ← MSB(DEST);
        ELSE (* instruction is SAR or SHR *)
            CF ← LSB(DEST);
    FI;
    IF instruction is SAL or SHL
        THEN
            DEST ← DEST ∗ 2;
        ELSE
            IF instruction is SAR
                THEN
                    DEST ← DEST / 2 (*Signed divide, rounding toward negative infinity*);
                ELSE (* instruction is SHR *)
                    DEST ← DEST / 2 ; (* Unsigned divide *);
            FI;
    FI;
    tempCOUNT ← tempCOUNT – 1;
OD;
(* Determine overflow for the various instructions *)
IF COUNT = 1
    THEN
        IF instruction is SAL or SHL
            THEN
                OF ← MSB(DEST) XOR CF;
            ELSE
                IF instruction is SAR
                    THEN
                        OF ← 0;
                    ELSE (* instruction is SHR *)
                        OF ← MSB(tempDEST);
                FI;
        FI;
```

SAL/SAR/SHL/SHR—Shift (Continued)

```
    ELSE IF COUNT = 0
        THEN
            All flags remain unchanged;
        ELSE (* COUNT neither 1 or 0 *)
            OF ← undefined;
    FI;
FI;
```

Flags Affected

The CF flag contains the value of the last bit shifted out of the destination operand; it is undefined for SHL and SHR instructions where the count is greater than or equal to the size (in bits) of the destination operand. The OF flag is affected only for 1-bit shifts (refer to "Description" above); otherwise, it is undefined. The SF, ZF, and PF flags are set according to the result. If the count is 0, the flags are not affected. For a non-zero count, the AF flag is undefined.

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

SAL/SAR/SHL/SHR—Shift (Continued)

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

SBB—Integer Subtraction with Borrow

Opcode	Instruction	Description
1C *ib*	SBB AL,*imm8*	Subtract with borrow *imm8* from AL
1D *iw*	SBB AX,*imm16*	Subtract with borrow *imm16* from AX
1D *id*	SBB EAX,*imm32*	Subtract with borrow *imm32* from EAX
80 /3 *ib*	SBB *r/m8,imm8*	Subtract with borrow *imm8* from *r/m8*
81 /3 *iw*	SBB *r/m16,imm16*	Subtract with borrow *imm16* from *r/m16*
81 /3 *id*	SBB *r/m32,imm32*	Subtract with borrow *imm32* from *r/m32*
83 /3 *ib*	SBB *r/m16,imm8*	Subtract with borrow sign-extended *imm8* from *r/m16*
83 /3 *ib*	SBB *r/m32,imm8*	Subtract with borrow sign-extended *imm8* from *r/m32*
18 /*r*	SBB *r/m8,r8*	Subtract with borrow *r8* from *r/m8*
19 /*r*	SBB *r/m16,r16*	Subtract with borrow *r16* from *r/m16*
19 /*r*	SBB *r/m32,r32*	Subtract with borrow *r32* from *r/m32*
1A /*r*	SBB *r8,r/m8*	Subtract with borrow *r/m8* from *r8*
1B /*r*	SBB *r16,r/m16*	Subtract with borrow *r/m16* from *r16*
1B /*r*	SBB *r32,r/m32*	Subtract with borrow *r/m32* from *r32*

Description

This instruction adds the source operand (second operand) and the carry (CF) flag, and subtracts the result from the destination operand (first operand). The result of the subtraction is stored in the destination operand. The destination operand can be a register or a memory location; the source operand can be an immediate, a register, or a memory location. (However, two memory operands cannot be used in one instruction.) The state of the CF flag represents a borrow from a previous subtraction.

When an immediate value is used as an operand, it is sign-extended to the length of the destination operand format.

The SBB instruction does not distinguish between signed or unsigned operands. Instead, the processor evaluates the result for both data types and sets the OF and CF flags to indicate a borrow in the signed or unsigned result, respectively. The SF flag indicates the sign of the signed result.

The SBB instruction is usually executed as part of a multibyte or multiword subtraction in which a SUB instruction is followed by a SBB instruction.

Operation

```
DEST ← DEST – (SRC + CF);
```

Flags Affected

The OF, SF, ZF, AF, PF, and CF flags are set according to the result.

SBB—Integer Subtraction with Borrow (Continued)

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

SCAS/SCASB/SCASW/SCASD—Scan String

Opcode	Instruction	Description
AE	SCAS m8	Compare AL with byte at ES:(E)DI and set status flags
AF	SCAS m16	Compare AX with word at ES:(E)DI and set status flags
AF	SCAS m32	Compare EAX with doubleword at ES(E)DI and set status flags
AE	SCASB	Compare AL with byte at ES:(E)DI and set status flags
AF	SCASW	Compare AX with word at ES:(E)DI and set status flags
AF	SCASD	Compare EAX with doubleword at ES:(E)DI and set status flags

Description

These instructions compare the byte, word, or double word specified with the memory operand with the value in the AL, AX, or EAX register, and sets the status flags in the EFLAGS register according to the results. The memory operand address is read from either the ES:EDI or the ES:DI registers (depending on the address-size attribute of the instruction, 32 or 16, respectively). The ES segment cannot be overridden with a segment override prefix.

At the assembly-code level, two forms of this instruction are allowed: the “explicit-operands” form and the “no-operands” form. The explicit-operand form (specified with the SCAS mnemonic) allows the memory operand to be specified explicitly. Here, the memory operand should be a symbol that indicates the size and location of the operand value. The register operand is then automatically selected to match the size of the memory operand (the AL register for byte comparisons, AX for word comparisons, and EAX for doubleword comparisons). This explicit-operand form is provided to allow documentation; however, note that the documentation provided by this form can be misleading. That is, the memory operand symbol must specify the correct **type** (size) of the operand (byte, word, or doubleword), but it does not have to specify the correct **location**. The location is always specified by the ES:(E)DI registers, which must be loaded correctly before the compare string instruction is executed.

The no-operands form provides “short forms” of the byte, word, and doubleword versions of the SCAS instructions. Here also ES:(E)DI is assumed to be the memory operand and the AL, AX, or EAX register is assumed to be the register operand. The size of the two operands is selected with the mnemonic: SCASB (byte comparison), SCASW (word comparison), or SCASD (doubleword comparison).

After the comparison, the (E)DI register is incremented or decremented automatically according to the setting of the DF flag in the EFLAGS register. (If the DF flag is 0, the (E)DI register is incremented; if the DF flag is 1, the (E)DI register is decremented.) The (E)DI register is incremented or decremented by one for byte operations, by two for word operations, or by four for doubleword operations.

The SCAS, SCASB, SCASW, and SCASD instructions can be preceded by the REP prefix for block comparisons of ECX bytes, words, or doublewords. More often, however, these instructions will be used in a LOOP construct that takes some action based on the setting of the status flags before the next comparison is made. Refer to “REP/REPE/REPZ/REPNE /REPNZ—Repeat String Operation Prefix” in this chapter for a description of the REP prefix.

SCAS/SCASB/SCASW/SCASD—Scan String (Continued)

Operation

```
IF (byte cmparison)
    THEN
        temp ← AL – SRC;
        SetStatusFlags(temp);
            THEN IF DF = 0
                THEN (E)DI ← (E)DI + 1;
                ELSE (E)DI ← (E)DI – 1;
            FI;
    ELSE IF (word comparison)
        THEN
            temp ← AX – SRC;
            SetStatusFlags(temp)
                THEN IF DF = 0
                    THEN (E)DI ← (E)DI + 2;
                    ELSE (E)DI ← (E)DI – 2;
                FI;
        ELSE (* doubleword comparison *)
            temp ← EAX – SRC;
            SetStatusFlags(temp)
                THEN IF DF = 0
                    THEN (E)DI ← (E)DI + 4;
                    ELSE (E)DI ← (E)DI – 4;
                FI;
    FI;
FI;
```

Flags Affected

The OF, SF, ZF, AF, PF, and CF flags are set according to the temporary result of the comparison.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the limit of the ES segment.
	If the ES register contains a null segment selector.
	If an illegal memory operand effective address in the ES segment is given.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

SCAS/SCASB/SCASW/SCASD—Scan String (Continued)

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

SET*cc*—Set Byte on Condition

Opcode	Instruction	Description
0F 97	SETA *r/m8*	Set byte if above (CF=0 and ZF=0)
0F 93	SETAE *r/m8*	Set byte if above or equal (CF=0)
0F 92	SETB *r/m8*	Set byte if below (CF=1)
0F 96	SETBE *r/m8*	Set byte if below or equal (CF=1 or ZF=1)
0F 92	SETC *r/m8*	Set if carry (CF=1)
0F 94	SETE *r/m8*	Set byte if equal (ZF=1)
0F 9F	SETG *r/m8*	Set byte if greater (ZF=0 and SF=OF)
0F 9D	SETGE *r/m8*	Set byte if greater or equal (SF=OF)
0F 9C	SETL *r/m8*	Set byte if less (SF<>OF)
0F 9E	SETLE *r/m8*	Set byte if less or equal (ZF=1 or SF<>OF)
0F 96	SETNA *r/m8*	Set byte if not above (CF=1 or ZF=1)
0F 92	SETNAE *r/m8*	Set byte if not above or equal (CF=1)
0F 93	SETNB *r/m8*	Set byte if not below (CF=0)
0F 97	SETNBE *r/m8*	Set byte if not below or equal (CF=0 and ZF=0)
0F 93	SETNC *r/m8*	Set byte if not carry (CF=0)
0F 95	SETNE *r/m8*	Set byte if not equal (ZF=0)
0F 9E	SETNG *r/m8*	Set byte if not greater (ZF=1 or SF<>OF)
0F 9C	SETNGE *r/m8*	Set if not greater or equal (SF<>OF)
0F 9D	SETNL *r/m8*	Set byte if not less (SF=OF)
0F 9F	SETNLE *r/m8*	Set byte if not less or equal (ZF=0 and SF=OF)
0F 91	SETNO *r/m8*	Set byte if not overflow (OF=0)
0F 9B	SETNP *r/m8*	Set byte if not parity (PF=0)
0F 99	SETNS *r/m8*	Set byte if not sign (SF=0)
0F 95	SETNZ *r/m8*	Set byte if not zero (ZF=0)
0F 90	SETO *r/m8*	Set byte if overflow (OF=1)
0F 9A	SETP *r/m8*	Set byte if parity (PF=1)
0F 9A	SETPE *r/m8*	Set byte if parity even (PF=1)
0F 9B	SETPO *r/m8*	Set byte if parity odd (PF=0)
0F 98	SETS *r/m8*	Set byte if sign (SF=1)
0F 94	SETZ *r/m8*	Set byte if zero (ZF=1)

Description

This instruction sets the destination operand to 0 or 1 depending on the settings of the status flags (CF, SF, OF, ZF, and PF) in the EFLAGS register. The destination operand points to a byte register or a byte in memory. The condition code suffix (*cc*) indicates the condition being tested for.

The terms “above” and “below” are associated with the CF flag and refer to the relationship between two unsigned integer values. The terms “greater” and “less” are associated with the SF and OF flags and refer to the relationship between two signed integer values.

SET*cc*—Set Byte on Condition (Continued)

Many of the SET*cc* instruction opcodes have alternate mnemonics. For example, the SETG (set byte if greater) and SETNLE (set if not less or equal) both have the same opcode and test for the same condition: ZF equals 0 and SF equals OF. These alternate mnemonics are provided to make code more intelligible. Appendix B, *EFLAGS Condition Codes*, in the *Intel Architecture Software Developer's Manual, Volume 1*, shows the alternate mnemonics for various test conditions.

Some languages represent a logical one as an integer with all bits set. This representation can be obtained by choosing the logically opposite condition for the SET*cc* instruction, then decrementing the result. For example, to test for overflow, use the SETNO instruction, then decrement the result.

Operation

```
IF condition
    THEN DEST ← 1
    ELSE DEST ← 0;
FI;
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.

SFENCE—Store Fence

Opcode	Instruction	Description
0F AE /7	SFENCE	Guarantees that every store instruction that precedes in program order the store fence instruction is globally visible before any store instruction which follows the fence is globally visible.

Description

Weakly ordered memory types can enable higher performance through such techniques as out-of-order issue, write-combining, and write-collapsing. Memory ordering issues can arise between a producer and a consumer of data and there are a number of common usage models which may be affected by weakly ordered stores:

1. library functions, which use weakly ordered memory to write results
2. compiler-generated code, which also benefit from writing weakly-ordered results
3. hand-written code

The degree to which a consumer of data knows that the data is weakly ordered can vary for these cases. As a result, the SFENCE instruction provides a performance-efficient way of ensuring ordering between routines that produce weakly-ordered results and routines that consume this data. The SFENCE is ordered with respect to stores and other SFENCE instructions.

SFENCE uses the following ModRM encoding:

Mod (7:6) = 11B

Reg/Opcode (5:3) = 111B

R/M (2:0) = 000B

All other ModRM encodings are defined to be reserved, and use of these encodings risks incompatibility with future processors.

Operation

```
WHILE (NOT(preceding_stores_globally_visible)) WAIT();
```

Intel C/C++ Compiler Intrinsic Equivalent

void_mm_sfence(void)

Guarantees that every preceding store is globally visible before any subsequent store.

Numeric Exceptions

None.

SFENCE—Store Fence (Continued)

Protected Mode Exceptions

None.

Real-Address Mode Exceptions

None.

Virtual-8086 Mode Exceptions

None.

Comments

SFENCE ignores the value of CR4.OSFXSR. SFENCE will not generate an invalid exception if CR4.OSFXSR = 0

SGDT/SIDT—Store Global/Interrupt Descriptor Table Register

Opcode	Instruction	Description
0F 01 /0	SGDT *m*	Store GDTR to *m*
0F 01 /1	SIDT *m*	Store IDTR to *m*

Description

These instructions store the contents of the global descriptor table register (GDTR) or the interrupt descriptor table register (IDTR) in the destination operand. The destination operand specifies a 6-byte memory location. If the operand-size attribute is 32 bits, the 16-bit limit field of the register is stored in the lower two bytes of the memory location and the 32-bit base address is stored in the upper four bytes. If the operand-size attribute is 16 bits, the limit is stored in the lower two bytes and the 24-bit base address is stored in the third, fourth, and fifth byte, with the sixth byte filled with 0s.

The SGDT and SIDT instructions are only useful in operating-system software; however, they can be used in application programs without causing an exception to be generated.

Refer to "LGDT/LIDT—Load Global/Interrupt Descriptor Table Register" in this chapter for information on loading the GDTR and IDTR.

Intel Architecture Compatibility

The 16-bit forms of the SGDT and SIDT instructions are compatible with the Intel 286 processor, if the upper eight bits are not referenced. The Intel 286 processor fills these bits with 1s; the Pentium® Pro, Pentium®, Intel486™, and Intel386™ processors fill these bits with 0s.

SGDT/SIDT—Store Global/Interrupt Descriptor Table Register (Continued)

Operation

```
IF instruction is IDTR
    THEN
        IF OperandSize = 16
            THEN
                DEST[0:15] ← IDTR(Limit);
                DEST[16:39] ← IDTR(Base); (* 24 bits of base address loaded; *)
                DEST[40:47] ← 0;
            ELSE (* 32-bit Operand Size *)
                DEST[0:15] ← IDTR(Limit);
                DEST[16:47] ← IDTR(Base); (* full 32-bit base address loaded *)
        FI;
    ELSE (* instruction is SGDT *)
        IF OperandSize = 16
            THEN
                DEST[0:15] ← GDTR(Limit);
                DEST[16:39] ← GDTR(Base); (* 24 bits of base address loaded; *)
                DEST[40:47] ← 0;
            ELSE (* 32-bit Operand Size *)
                DEST[0:15] ← GDTR(Limit);
                DEST[16:47] ← GDTR(Base); (* full 32-bit base address loaded *)
        FI; FI;
```

Flags Affected

None.

Protected Mode Exceptions

#UD	If the destination operand is a register.
#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory access occurs when the CPL is 3 and alignment checking is enabled.

SGDT/SIDT—Store Global/Interrupt Descriptor Table Register (Continued)

Real-Address Mode Exceptions

#UD	If the destination operand is a register.
#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#UD	If the destination operand is a register.
#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If an unaligned memory access occurs when alignment checking is enabled.

SHL/SHR—Shift Instructions

Refer to entry for SAL/SAR/SHL/SHR—Shift.

SHLD—Double Precision Shift Left

Opcode	Instruction	Description
0F A4	SHLD *r/m16,r16,imm8*	Shift *r/m16* to left *imm8* places while shifting bits from *r16* in from the right
0F A5	SHLD *r/m16,r16*,CL	Shift *r/m16* to left CL places while shifting bits from *r16* in from the right
0F A4	SHLD *r/m32,r32,imm8*	Shift *r/m32* to left *imm8* places while shifting bits from *r32* in from the right
0F A5	SHLD *r/m32,r32*,CL	Shift *r/m32* to left CL places while shifting bits from *r32* in from the right

Description

This instruction shifts the first operand (destination operand) to the left the number of bits specified by the third operand (count operand). The second operand (source operand) provides bits to shift in from the right (starting with bit 0 of the destination operand). The destination operand can be a register or a memory location; the source operand is a register. The count operand is an unsigned integer that can be an immediate byte or the contents of the CL register. Only bits 0 through 4 of the count are used, which masks the count to a value between 0 and 31. If the count is greater than the operand size, the result in the destination operand is undefined.

If the count is one or greater, the CF flag is filled with the last bit shifted out of the destination operand. For a 1-bit shift, the OF flag is set if a sign change occurred; otherwise, it is cleared. If the count operand is 0, the flags are not affected.

The SHLD instruction is useful for multiprecision shifts of 64 bits or more.

SHLD—Double Precision Shift Left (Continued)

Operation

```
COUNT ← COUNT MOD 32;
SIZE ← OperandSize
IF COUNT = 0
    THEN
        no operation
    ELSE
        IF COUNT ≥ SIZE
            THEN (* Bad parameters *)
                DEST is undefined;
                CF, OF, SF, ZF, AF, PF are undefined;
            ELSE (* Perform the shift *)
                CF ← BIT[DEST, SIZE – COUNT];
                (* Last bit shifted out on exit *)
                FOR i ← SIZE – 1 DOWNTO COUNT
                DO
                    Bit(DEST, i) ← Bit(DEST, i – COUNT);
                OD;
                FOR i ← COUNT – 1 DOWNTO 0
                DO
                    BIT[DEST, i] ← BIT[SRC, i – COUNT + SIZE];
                OD;
        FI;
FI;
```

Flags Affected

If the count is one or greater, the CF flag is filled with the last bit shifted out of the destination operand and the SF, ZF, and PF flags are set according to the value of the result. For a 1-bit shift, the OF flag is set if a sign change occurred; otherwise, it is cleared. For shifts greater than one bit, the OF flag is undefined. If a shift occurs, the AF flag is undefined. If the count operand is 0, the flags are not affected. If the count is greater than the operand size, the flags are undefined.

SHLD—Double Precision Shift Left (Continued)

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

SHRD—Double Precision Shift Right

Opcode	Instruction	Description
0F AC	SHRD *r/m16,r16,imm8*	Shift *r/m16* to right *imm8* places while shifting bits from *r16* in from the left
0F AD	SHRD *r/m16,r16*,CL	Shift *r/m16* to right CL places while shifting bits from *r16* in from the left
0F AC	SHRD *r/m32,r32,imm8*	Shift *r/m32* to right *imm8* places while shifting bits from *r32* in from the left
0F AD	SHRD *r/m32,r32*,CL	Shift *r/m32* to right CL places while shifting bits from *r32* in from the left

Description

This instruction shifts the first operand (destination operand) to the right the number of bits specified by the third operand (count operand). The second operand (source operand) provides bits to shift in from the left (starting with the most significant bit of the destination operand). The destination operand can be a register or a memory location; the source operand is a register. The count operand is an unsigned integer that can be an immediate byte or the contents of the CL register. Only bits 0 through 4 of the count are used, which masks the count to a value between 0 and 31. If the count is greater than the operand size, the result in the destination operand is undefined.

If the count is one or greater, the CF flag is filled with the last bit shifted out of the destination operand. For a 1-bit shift, the OF flag is set if a sign change occurred; otherwise, it is cleared. If the count operand is 0, the flags are not affected.

The SHRD instruction is useful for multiprecision shifts of 64 bits or more.

SHRD—Double Precision Shift Right (Continued)

Operation

```
COUNT ← COUNT MOD 32;
SIZE ← OperandSize
IF COUNT = 0
    THEN
        no operation
    ELSE
        IF COUNT ≥ SIZE
            THEN (* Bad parameters *)
                DEST is undefined;
                CF, OF, SF, ZF, AF, PF are undefined;
            ELSE (* Perform the shift *)
                CF ← BIT[DEST, COUNT – 1]; (* last bit shifted out on exit *)
                FOR i ← 0 TO SIZE – 1 – COUNT
                    DO
                        BIT[DEST, i] ← BIT[DEST, i – COUNT];
                    OD;
                FOR i ← SIZE – COUNT TO SIZE – 1
                    DO
                        BIT[DEST,i] ← BIT[inBits,i+COUNT – SIZE];
                    OD;
        FI;
FI;
```

Flags Affected

If the count is one or greater, the CF flag is filled with the last bit shifted out of the destination operand and the SF, ZF, and PF flags are set according to the value of the result. For a 1-bit shift, the OF flag is set if a sign change occurred; otherwise, it is cleared. For shifts greater than one bit, the OF flag is undefined. If a shift occurs, the AF flag is undefined. If the count operand is 0, the flags are not affected. If the count is greater than the operand size, the flags are undefined.

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

SHRD—Double Precision Shift Right (Continued)

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

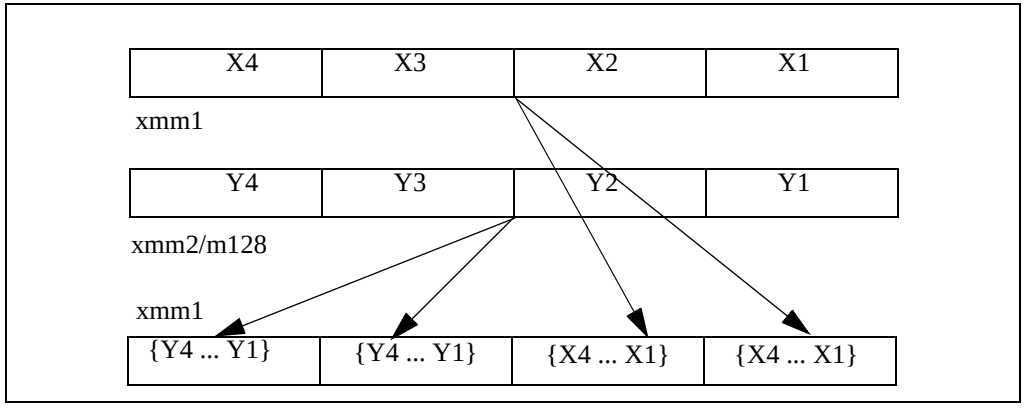
SHUFPS—Shuffle Single-FP

Opcode	Instruction	Description
0F,C6,/r, ib	SHUFPS *xmm1, xmm2/m128, imm8*	Shuffle Single.

Description

The SHUFPS instruction is able to shuffle any of the four SP FP numbers from xmm1 to the lower two destination fields; the upper two destination fields are generated from a shuffle of any of the four SP FP numbers from xmm2/m128.

Example 3-1. SHUFPS Instruction



By using the same register for both sources, SHUFPS can return any combination of the four SP FP numbers from this register. Bits 0 and 1 of the immediate field are used to select which of the four input SP FP numbers will be put in the first SP FP number of the result; bits 3 and 2 of the immediate field are used to select which of the four input SP FP will be put in the second SP FP number of the result; etc.

SHUFPS—Shuffle Single-FP (Continued)

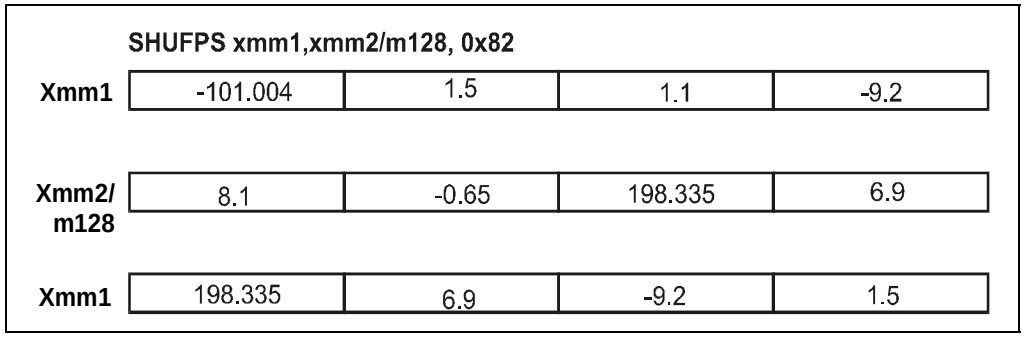


Figure 3-90. Operation of the SHUFPS Instruction

Operation

```
FP_SELECT = (imm8 >> 0) AND 0X3;
IF (FP_SELECT = 0) THEN
    DEST[31-0] = DEST[31-0];
ELSE
    IF (FP_SELECT = 1) THEN
        DEST[31-0] = DEST[63-32];
    ELSE
        IF (FP_SELECT = 2) THEN
            DEST[31-0] = DEST[95-64];
        ELSE
            DEST[31-0] = DEST[127-96];
        FI
    FI
FI
```

SHUFPS—Shuffle Single-FP (Continued)

```
FP_SELECT = (imm8 >> 2) AND 0X3;
IF (FP_SELECT = 0) THEN
    DEST[63-32] = DEST[31-0];
ELSE
    IF (FP_SELECT = 1) THEN
        DEST[63-32] = DEST[63-32];
    ELSE
        IF (FP_SELECT = 2) THEN
            DEST[63-32] = DEST[95-64];
        ELSE
            DEST[63-32] = DEST[127-96];
        FI
    FI
FI

FP_SELECT = (imm8 >> 4) AND 0X3;
IF (FP_SELECT = 0) THEN
    DEST[95-64] = SRC/m128[31-0];
ELSE
    IF (FP_SELECT = 1) THEN
        DEST[95-64] = SRC/m128 [63-32];
    ELSE
        IF (FP_SELECT = 2) THEN
            DEST[95-64] = SRC/m128 [95-64];
        ELSE
            DEST[95-64] = SRC/m128 [127-96];
        FI
    FI
FI

FP_SELECT = (imm8 >> 6) AND 0X3;
IF (FP_SELECT = 0) THEN
    DEST[127-96] = SRC/m128 [31-0];
ELSE
    IF (FP_SELECT = 1) THEN
        DEST[127-96] = SRC/m128 [63-32];
    ELSE
        IF (FP_SELECT = 2) THEN
            DEST[127-96] = SRC/m128 [95-64];
        ELSE
            DEST[127-96] = SRC/m128 [127-96];
        FI
    FI
FI
```

SHUFPS—Shuffle Single-FP (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_shuffle_ps(__m128 a, __m128 b, unsigned int imm8)

Selects four specific SP FP values from a and b, based on the mask i. The mask must be an immediate.

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

SHUFPS—Shuffle Single-FP (Continued)

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code) For a page fault.

Comments

The usage of Repeat Prefix (F3H) with SHUFPS is reserved. Different processor implementations may handle this prefix differently. Usage of this prefix with SHUFPS risks incompatibility with future processors.

SIDT—Store Interrupt Descriptor Table Register

Refer to entry for SGDT/SIDT—Store Global/Interrupt Descriptor Table Register.

SLDT—Store Local Descriptor Table Register

Opcode	Instruction	Description
0F 00 /0	SLDT *r/m16*	Stores segment selector from LDTR in *r/m16*
0F 00 /0	SLDT *r/m32*	Store segment selector from LDTR in low-order 16 bits of *r/m32*

Description

This instruction stores the segment selector from the local descriptor table register (LDTR) in the destination operand. The destination operand can be a general-purpose register or a memory location. The segment selector stored with this instruction points to the segment descriptor (located in the GDT) for the current LDT. This instruction can only be executed in protected mode.

When the destination operand is a 32-bit register, the 16-bit segment selector is copied into the lower-order 16 bits of the register. The high-order 16 bits of the register are cleared to 0s for the Pentium® Pro processor and are undefined for Pentium®, Intel486™, and Intel386™ processors. When the destination operand is a memory location, the segment selector is written to memory as a 16-bit quantity, regardless of the operand size.

The SLDT instruction is only useful in operating-system software; however, it can be used in application programs.

Operation

```
DEST ← LDTR(SegmentSelector);
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

SLDT—Store Local Descriptor Table Register (Continued)

Real-Address Mode Exceptions

#UD The SLDT instruction is not recognized in real-address mode.

Virtual-8086 Mode Exceptions

#UD The SLDT instruction is not recognized in virtual-8086 mode.

SMSW—Store Machine Status Word

Opcode	Instruction	Description
0F 01 /4	SMSW *r/m16*	Store machine status word to *r/m16*
0F 01 /4	SMSW *r32/m16*	Store machine status word in low-order 16 bits of *r32/m16*; high-order 16 bits of *r32* are undefined

Description

This instruction stores the machine status word (bits 0 through 15 of control register CR0) into the destination operand. The destination operand can be a 16-bit general-purpose register or a memory location.

When the destination operand is a 32-bit register, the low-order 16 bits of register CR0 are copied into the low-order 16 bits of the register and the upper 16 bits of the register are undefined. When the destination operand is a memory location, the low-order 16 bits of register CR0 are written to memory as a 16-bit quantity, regardless of the operand size.

The SMSW instruction is only useful in operating-system software; however, it is not a privileged instruction and can be used in application programs.

This instruction is provided for compatibility with the Intel 286 processor. Programs and procedures intended to run on the Pentium® Pro, Pentium®, Intel486™, and Intel386™ processors should use the MOV (control registers) instruction to load the machine status word.

Operation

```
DEST ← CR0[15:0]; (* Machine status word *);
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

SMSW—Store Machine Status Word (Continued)

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

SQRTPS—Packed Single-FP Square Root

Opcode	Instruction	Description
0F,51,/r	SQRTPS xmm1, xmm2/m128	Square Root of the packed SP FP numbers in XMM2/Mem.

Description

The SQRTPS instruction returns the square root of the packed SP FP numbers from xmm2/m128.

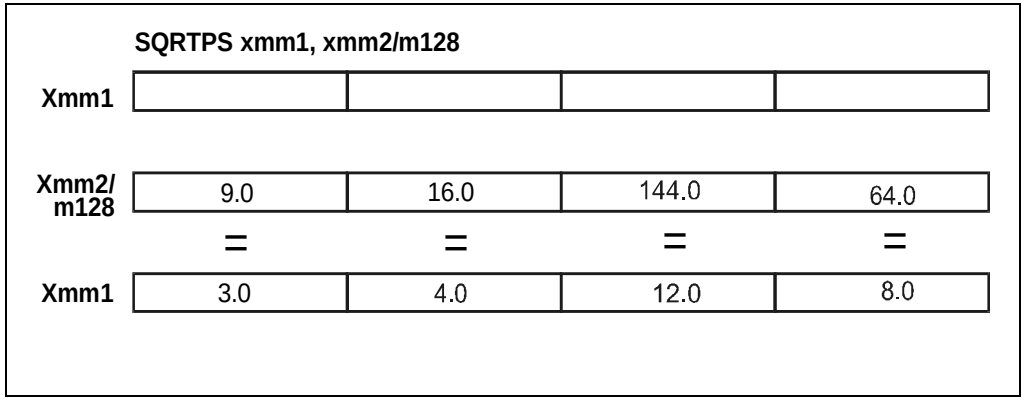


Figure 3-91. Operation of the SQRTPS Instruction

Operation

```
DEST[31-0] = SQRT (SRC/m128[31-0]);
DEST[63-32] = SQRT (SRC/m128[63-32]);
DEST[95-64] = SQRT (SRC/m128[95-64]);
DEST[127-96] = SQRT (SRC/m128[127-96]);
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_sqrt_ps(__m128 a)

Computes the square roots of the four SP FP values of a.

SQRTPS—Packed Single-FP Square Root (Continued)

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

Numeric Exceptions

Invalid, Precision, Denormal.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

SQRTPS—Packed Single-FP Square Root (Continued)

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code) For a page fault.

SQRTSS—Scalar Single-FP Square Root

Opcode	Instruction	Description
F3,0F,51,/r	SQRTSS *xmm1*, *xmm2/m32*	Square Root of the lower SP FP number in *XMM2/Mem.*

Description

The SQRTSS instructions return the square root of the lowest SP FP numbers of their operand.

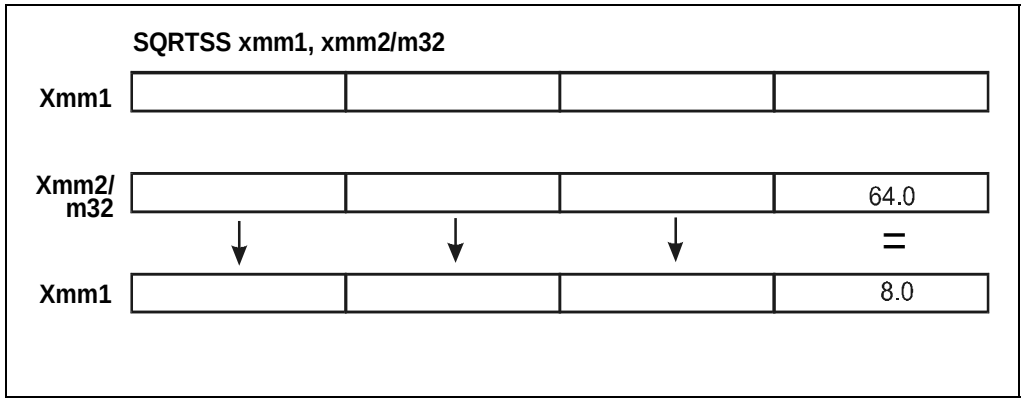


Figure 3-92. Operation of the SQRTSS Instruction

Operation

```
DEST[31-0] = SQRT (SRC/m32[31-0]);
DEST[63-32] = DEST[63-32];
DEST[95-64] = DEST[95-64];
DEST[127-96] = DEST[127-96];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_sqrt_ss(__m128 a)

Computes the square root of the lower SP FP value of a; the upper three SP FP values are passed through.

SQRTSS—Scalar Single-FP Square Root (Continued)

Exceptions

None.

Numeric Exceptions

Invalid, Precision, Denormal.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

SQRTSS—Scalar Single-FP Square Root (Continued)

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

STC—Set Carry Flag

Opcode	Instruction	Description
F9	STC	Set CF flag

Description

This instruction sets the CF flag in the EFLAGS register.

Operation

CF ← 1;

Flags Affected

The CF flag is set. The OF, ZF, SF, AF, and PF flags are unaffected.

Exceptions (All Operating Modes)

None.

STD—Set Direction Flag

Opcode	Instruction	Description
FD	STD	Set DF flag

Description

This instruction sets the DF flag in the EFLAGS register. When the DF flag is set to 1, string operations decrement the index registers (ESI and/or EDI).

Operation

DF ← 1;

Flags Affected

The DF flag is set. The CF, OF, ZF, SF, AF, and PF flags are unaffected.

Operation

DF ← 1;

Exceptions (All Operating Modes)

None.

STI—Set Interrupt Flag

Opcode	Instruction	Description
FB	STI	Set interrupt flag; external, maskable interrupts enabled at the end of the next instruction

Description

This instruction sets the interrupt flag (IF) in the EFLAGS register. After the IF flag is set, the processor begins responding to external, maskable interrupts after the next instruction is executed. The delayed effect of this instruction is provided to allow interrupts to be enabled just before returning from a procedure (or subroutine). For instance, if an STI instruction is followed by an RET instruction, the RET instruction is allowed to execute before external interrupts are recognized[1]. This behavior allows external interrupts to be disabled at the beginning of a procedure and enabled again at the end of the procedure. If the STI instruction is followed by a CLI instruction (which clears the IF flag), the effect of the STI instruction is negated.

The IF flag and the STI and CLI instructions have no affect on the generation of exceptions and NMI interrupts.

The following decision table indicates the action of the STI instruction (bottom of the table) depending on the processor's mode of operation and the CPL and IOPL of the currently running program or procedure (top of the table).

PE =	0	1	1	1
VM =	X	0	0	1
CPL	X	≤ IOPL	> IOPL	=3
IOPL	X	X	X	=3
IF ← 1	Y	Y	N	Y
#GP(0)	N	N	Y	N

NOTES:

X Don't care.

N Action in Column 1 not taken.

Y Action in Column 1 taken.

1. Note that in a sequence of instructions that individually delay interrupts past the following instruction, only the first instruction in the sequence is guaranteed to delay the interrupt, but subsequent interrupt-delaying instructions may not delay the interrupt. Thus, in the following instruction sequence:

   ```
   STI
   MOV SS, AX
   MOV ESP, EBP
   ```

   interrupts may be recognized before MOV ESP, EBP executes, even though MOV SS, AX normally delays interrupts for one instruction.

STI—Set Interrupt Flag (Continued)

Operation

```
IF PE=0  (* Executing in real-address mode *)
    THEN
        IF ← 1;  (* Set Interrupt Flag *)
    ELSE  (* Executing in protected mode or virtual-8086 mode *)
        IF VM=0  (* Executing in protected mode*)
            THEN
                IF IOPL = 3
                    THEN
                        IF ← 1;
                    ELSE
                        IF  CPL ≤ IOPL
                            THEN
                                IF ← 1;
                            ELSE
                                #GP(0);
                        FI;
                FI;
            ELSE  (* Executing in Virtual-8086 mode *)
                #GP(0); (* Trap to virtual-8086 monitor *)
        FI;
FI;
```

Flags Affected

The IF flag is set to 1.

Protected Mode Exceptions

#GP(0)	If the CPL is greater (has less privilege) than the IOPL of the current program or procedure.

Real-Address Mode Exceptions

None.

Virtual-8086 Mode Exceptions

#GP(0)	If the CPL is greater (has less privilege) than the IOPL of the current program or procedure.

STMXCSR—Store Streaming SIMD Extension Control/Status

Opcode	Instruction	Description
0F,AE,/3	STMXCSR m32	Store Streaming SIMD Extension control/status word to m32.

Description

The MXCSR control/status register is used to enable masked/unmasked exception handling, to set rounding modes, to set flush-to-zero mode, and to view exception status flags. Refer to LDMXCSR for a description of the format of MXCSR. The linear address corresponds to the address of the least-significant byte of the referenced memory data. The reserved bits in the MXCSR are stored as zeroes.

Operation

```
m32 = MXCSR;
```

Intel C/C++ Compiler Intrinsic Equivalent

_mm_getcsr(void)

Returns the contents of the control register.

Exceptions

None.

Numeric Exceptions

None.

STMXCSR—Store Streaming SIMD Extension Control/Status (Continued)

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.
#AC	For unaligned memory reference.

Comments

The usage of Repeat Prefix (F3H) with STMXCSR is reserved. Different processor implementations may handle this prefix differently. Usage of this prefix with STMXCSR risks incompatibility with future processors.

STOS/STOSB/STOSW/STOSD—Store String

Opcode	Instruction	Description
AA	STOS m8	Store AL at address ES:(E)DI
AB	STOS m16	Store AX at address ES:(E)DI
AB	STOS m32	Store EAX at address ES:(E)DI
AA	STOSB	Store AL at address ES:(E)DI
AB	STOSW	Store AX at address ES:(E)DI
AB	STOSD	Store EAX at address ES:(E)DI

Description

These instructions store a byte, word, or doubleword from the AL, AX, or EAX register, respectively, into the destination operand. The destination operand is a memory location, the address of which is read from either the ES:EDI or the ES:DI registers (depending on the address-size attribute of the instruction, 32 or 16, respectively). The ES segment cannot be overridden with a segment override prefix.

At the assembly-code level, two forms of this instruction are allowed: the “explicit-operands” form and the “no-operands” form. The explicit-operands form (specified with the STOS mnemonic) allows the destination operand to be specified explicitly. Here, the destination operand should be a symbol that indicates the size and location of the destination value. The source operand is then automatically selected to match the size of the destination operand (the AL register for byte operands, AX for word operands, and EAX for doubleword operands). This explicit-operands form is provided to allow documentation; however, note that the documentation provided by this form can be misleading. That is, the destination operand symbol must specify the correct **type** (size) of the operand (byte, word, or doubleword), but it does not have to specify the correct **location**. The location is always specified by the ES:(E)DI registers, which must be loaded correctly before the store string instruction is executed.

The no-operands form provides “short forms” of the byte, word, and doubleword versions of the STOS instructions. Here also ES:(E)DI is assumed to be the destination operand and the AL, AX, or EAX register is assumed to be the source operand. The size of the destination and source operands is selected with the mnemonic: STOSB (byte read from register AL), STOSW (word from AX), or STOSD (doubleword from EAX).

After the byte, word, or doubleword is transferred from the AL, AX, or EAX register to the memory location, the (E)DI register is incremented or decremented automatically according to the setting of the DF flag in the EFLAGS register. (If the DF flag is 0, the (E)DI register is incremented; if the DF flag is 1, the (E)DI register is decremented.) The (E)DI register is incremented or decremented by one for byte operations, by two for word operations, or by four for doubleword operations.

STOS/STOSB/STOSW/STOSD—Store String (Continued)

The STOS, STOSB, STOSW, and STOSD instructions can be preceded by the REP prefix for block loads of ECX bytes, words, or doublewords. More often, however, these instructions are used within a LOOP construct because data needs to be moved into the AL, AX, or EAX register before it can be stored. Refer to "REP/REPE/REPZ/REPNE /REPNZ—Repeat String Operation Prefix" in this chapter for a description of the REP prefix.

Operation

```
IF (byte store)
    THEN
        DEST ← AL;
            THEN IF DF = 0
                THEN (E)DI ← (E)DI + 1;
                ELSE (E)DI ← (E)DI – 1;
            FI;
    ELSE IF (word store)
        THEN
            DEST ← AX;
                THEN IF DF = 0
                    THEN (E)DI ← (E)DI + 2;
                    ELSE (E)DI ← (E)DI – 2;
                FI;
        ELSE (* doubleword store *)
            DEST ← EAX;
                THEN IF DF = 0
                    THEN (E)DI ← (E)DI + 4;
                    ELSE (E)DI ← (E)DI – 4;
                FI;
    FI;
FI;
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the limit of the ES segment.
	If the ES register contains a null segment selector.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

STOS/STOSB/STOSW/STOSD—Store String (Continued)

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the ES segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the ES segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

STR—Store Task Register

Opcode	Instruction	Description
0F 00 /1	STR *r/m16*	Stores segment selector from TR in *r/m16*

Description

This instruction stores the segment selector from the task register (TR) in the destination operand. The destination operand can be a general-purpose register or a memory location. The segment selector stored with this instruction points to the task state segment (TSS) for the currently running task.

When the destination operand is a 32-bit register, the 16-bit segment selector is copied into the lower 16 bits of the register and the upper 16 bits of the register are cleared to 0s. When the destination operand is a memory location, the segment selector is written to memory as a 16-bit quantity, regardless of operand size.

The STR instruction is useful only in operating-system software. It can only be executed in protected mode.

Operation

```
DEST ← TR(SegmentSelector);
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the destination is a memory operand that is located in a nonwritable segment or if the effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

STR—Store Task Register (Continued)

Real-Address Mode Exceptions

#UD The STR instruction is not recognized in real-address mode.

Virtual-8086 Mode Exceptions

#UD The STR instruction is not recognized in virtual-8086 mode.

SUB—Subtract

Opcode	Instruction	Description
2C *ib*	SUB AL,*imm8*	Subtract *imm8* from AL
2D *iw*	SUB AX,*imm16*	Subtract *imm16* from AX
2D *id*	SUB EAX,*imm32*	Subtract *imm32* from EAX
80 /5 *ib*	SUB *r/m8,imm8*	Subtract *imm8* from *r/m8*
81 /5 *iw*	SUB *r/m16,imm16*	Subtract *imm16* from *r/m16*
81 /5 *id*	SUB *r/m32,imm32*	Subtract *imm32* from *r/m32*
83 /5 *ib*	SUB *r/m16,imm8*	Subtract sign-extended *imm8* from *r/m16*
83 /5 *ib*	SUB *r/m32,imm8*	Subtract sign-extended *imm8* from *r/m32*
28 /*r*	SUB *r/m8,r8*	Subtract *r8* from *r/m8*
29 /*r*	SUB *r/m16,r16*	Subtract *r16* from *r/m16*
29 /*r*	SUB *r/m32,r32*	Subtract *r32* from *r/m32*
2A /*r*	SUB *r8,r/m8*	Subtract *r/m8* from *r8*
2B /*r*	SUB *r16,r/m16*	Subtract *r/m16* from *r16*
2B /*r*	SUB *r32,r/m32*	Subtract *r/m32* from *r32*

Description

This instruction subtracts the second operand (source operand) from the first operand (destination operand) and stores the result in the destination operand. The destination operand can be a register or a memory location; the source operand can be an immediate, register, or memory location. (However, two memory operands cannot be used in one instruction.) When an immediate value is used as an operand, it is sign-extended to the length of the destination operand format.

The SUB instruction does not distinguish between signed or unsigned operands. Instead, the processor evaluates the result for both data types and sets the OF and CF flags to indicate a borrow in the signed or unsigned result, respectively. The SF flag indicates the sign of the signed result.

Operation

DEST ← DEST – SRC;

Flags Affected

The OF, SF, ZF, AF, PF, and CF flags are set according to the result.

SUB—Subtract (Continued)

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

SUBPS—Packed Single-FP Subtract

Opcode	Instruction	Description
0F,5C,/r	SUBPS *xmm1 xmm2/m128*	Subtract packed SP FP numbers in *XMM2/Mem* from *XMM1*.

Description

The SUBPS instruction subtracts the packed SP FP numbers of both their operands.

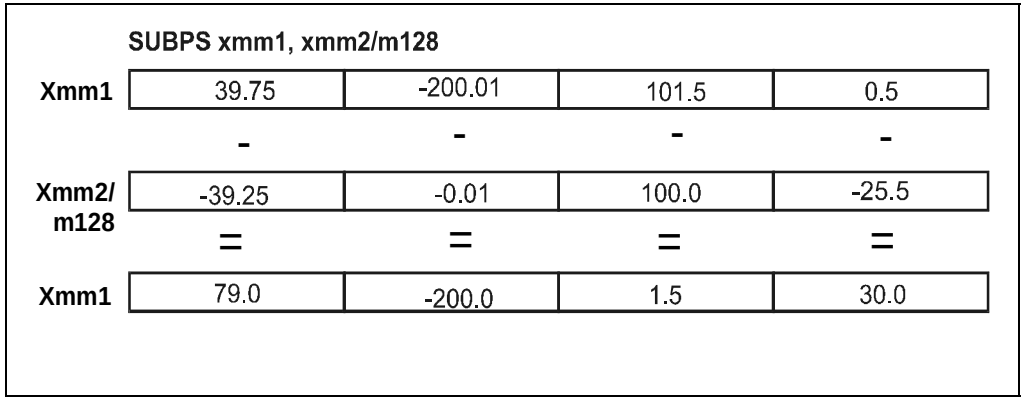


Figure 3-93. Operation of the SUBPS Instruction

Operation

```
DEST[31-0] = DEST[31-0] - SRC/m128[31-0];
DEST[63-32] = DEST[63-32] - SRC/m128[63-32];
DEST[95-64] = DEST[95-64] - SRC/m128[95-64];
DEST[127-96] = DEST[127-96] - SRC/m128[127-96];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_sub_ps(__m128 a, __m128 b)

Subtracts the four SP FP values of a and b.

SUBPS—Packed Single-FP Subtract (Continued)

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

Numeric Exceptions

Overflow, Underflow, Invalid, Precision, Denormal.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

SUBPS—Packed Single-FP Subtract (Continued)

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code) For a page fault.

SUBSS—Scalar Single-FP Subtract

Opcode	Instruction	Description
F3,0F,5C, /r	SUBSS *xmm1, xmm2/m32*	Subtract the lower SP FP numbers in *XMM2/Mem* from *XMM1*.

Description

The SUBSS instruction subtracts the lower SP FP numbers of both their operands.

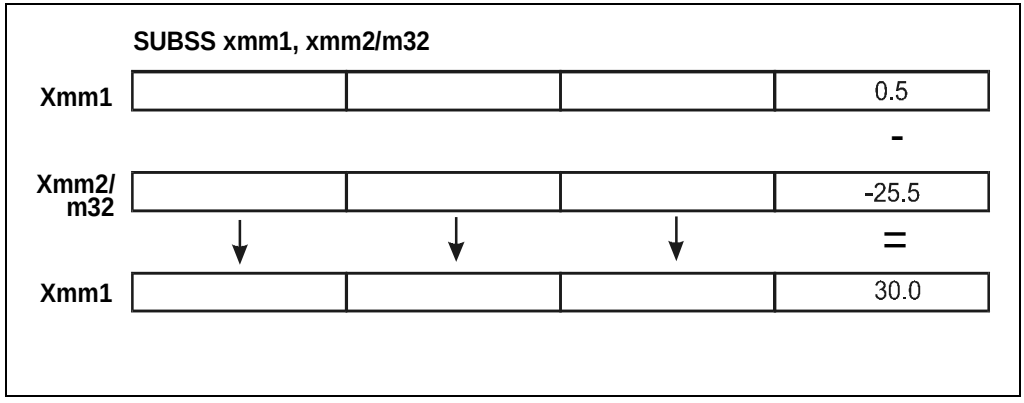


Figure 3-94. Operation of the SUBSS Instruction

Operation

```
DEST[31-0] = DEST[31-0] - SRC/m32[31-0];
DEST[63-32] = DEST[63-32];
DEST[95-64] = DEST[95-64];
DEST[127-96] = DEST[127-96];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_sub_ss(__m128 a, __m128 b)

Subtracts the lower SP FP values of a and b. The upper three SP FP values are passed through from a.

SUBSS—Scalar Single-FP Subtract (Continued)

Exceptions

None.

Numeric Exceptions

Overflow, Underflow, Invalid, Precision, Denormal.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

SUBSS—Scalar Single-FP Subtract (Continued)

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF(fault-code)	For a page fault.

SYSENTER—Fast Transition to System Call Entry Point

Opcode	Instruction	Description
0F, 34	SYSENTER	Transition to System Call Entry Point

Description

The SYSENTER instruction is part of the "Fast System Call" facility introduced on the Pentium® II processor. The SYSENTER instruction is optimized to provide the maximum performance for transitions to protection ring 0 (CPL = 0).

The SYSENTER instruction sets the following registers according to values specified by the operating system in certain model-specific registers.

CS register set to the value of (SYSENTER_CS_MSR)

EIP register set to the value of (SYSENTER_EIP_MSR)

SS register set to the sum of (8 plus the value in SYSENTER_CS_MSR)

ESP register set to the value of (SYSENTER_ESP_MSR)

The processor does not save user stack or return address information, and does not save any registers.

The SYSENTER and SYSEXIT instructions do not constitute a call/return pair; therefore, the system call "stub" routines executed by user code (typically in shared libraries or DLLs) must perform the required register state save to create a system call/return pair.

The SYSENTER instruction always transfers to a flat protected mode kernel at CPL = 0. SYSENTER can be invoked from all modes except real mode. The instruction requires that the following conditions are met by the operating system:

- The CS selector for the target ring 0 code segment is 32 bits, mapped as a flat 0-4 GB address space with execute and read permissions
- The SS selector for the target ring 0 stack segment is 32 bits, mapped as a flat 0-4 GB address space with read, write, and accessed permissions. This selector (Target Ring 0 SS Selector) is assigned the value of the new (CS selector + 8).

An operating system provides values for CS, EIP, SS, and ESP for the ring 0 entry point through use of model-specific registers within the processor. These registers can be read from and written to by using the RDMSR and WRMSR instructions. The register addresses are defined to remain fixed at the following addresses on future processors that provide support for this feature.

Name	Description	Address
SYSENTER_CS_MSR	Target Ring 0 CS Selector	174h
SYSENTER_ESP_MSR	Target Ring 0 ESP	175h
SYSENTER_EIP_MSR	Target Ring 0 Entry Point EIP	176h

SYSENTER—Fast Transition to System Call Entry Point (Continued)

The presence of this facility is indicated by the SYSENTER Present (SEP) bit 11 of CPUID. An operating system that detects the presence of the SEP bit must also qualify the processor family and model to ensure that the SYSENTER/SYSEXIT instructions are actually present. For example:

```
IF (CPUID SEP bit is set)
    IF (Family == 6) AND (Model < 3) AND (Stepping < 3)
        THEN
        Fast System Call NOT supported
        FI;
    ELSE Fast System Call is supported
FI
```

The Pentium® Pro processor (Model = 1) returns a set SEP CPUID feature bit, but does not support the SYSENTER/SYSEXIT instructions.

SYSENTER—Fast Transition to System Call Entry Point (Continued)

Operation

```
SYSENTER
    IF CR0.PE == 0 THEN #GP(0)
    IF SYSENTER_CS_MSR == 0 THEN #GP(0)

    EFLAGS.VM := 0                      // Prevent VM86 mode
    EFLAGS.IF := 0                      // Mask interrupts

    CS.SEL := SYSENTER_CS_MSR           // Operating system provides CS

    // Set rest of CS to a fixed value
    CS.SEL.CPL := 0                     // CPL = 0
    CS.SEL.BASE := 0                    // Flat segment
    CS.SEL.LIMIT := 0xFFFF              // 4G limit
    CS.SEL.G := 1                       // 4 KB granularity
    CS.SEL.S := 1
    CS.SEL.TYPE_xCRA := 1011            // Execute + Read, Accessed
    CS.SEL.D := 1                       // 32 bit code
    CS.SEL.DPL := 0
    CS.SEL.RPL := 0
    CS.SEL.P := 1
    SS.SEL := CS.SEL+8

    // Set rest of SS to a fixed value
    SS.SEL.BASE := 0                    // Flat segment
    SS.SEL.LIMIT := 0xFFFF              // 4G limit
    SS.SEL.G := 1                       // 4 KB granularity
    SS.SEL.S := 1
    SS.SEL.TYPE_xCRA := 0011            // Read/Write, Accessed
    SS.SEL.D := 1                       // 32 bit stack
    SS.SEL.DPL := 0
    SS.SEL.RPL := 0
    SS.SEL.P := 1

    ESP := SYSENTER_ESP_MSR
    EIP := SYSENTER_EIP_MSR
```

SYSENTER—Fast Transition to System Call Entry Point (Continued)

Exceptions

#GP(0)	If SYSENTER_CS_MSR contains zero.

Numeric Exceptions

None.

Real Address Mode Exceptions

#GP(0)	If protected mode is not enabled.

SYSEXIT—Fast Transition from System Call Entry Point

Opcode	Instruction	Description
0F, 35	SYSEXIT	Transition from System Call Entry Point

Description

The SYSEXIT instruction is part of the "Fast System Call" facility introduced on the Pentium® II processor. The SYSEXIT instruction is optimized to provide the maximum performance for transitions to protection ring 3 (CPL = 3) from protection ring 0 (CPL = 0).

The SYSEXIT instruction sets the following registers according to values specified by the operating system in certain model-specific or general purpose registers.

CS register — set to the sum of (16 plus the value in SYSENTER_CS_MSR)

EIP register — set to the value contained in the EDX register

SS register — set to the sum of (24 plus the value in SYSENTER_CS_MSR)

ESP register — set to the value contained in the ECX register

The processor does not save kernel stack or return address information, and does not save any registers.

The SYSENTER and SYSEXIT instructions do not constitute a call/return pair; therefore, the system call "stub" routines executed by user code (typically in shared libraries or DLLs) must perform the required register state restore to create a system call/return pair.

The SYSEXIT instruction always transfers to a flat protected mode user at CPL = 3. SYSEXIT can be invoked only from protected mode and CPL = 0. The instruction requires that the following conditions are met by the operating system:

- The CS selector for the target ring 3 code segment is 32 bits, mapped as a flat 0-4 GB address space with execute, read, and non-conforming permissions.
- The SS selector for the target ring 3 stack segment is 32 bits, mapped as a flat 0-4 GB address space with expand-up, read, and write permissions.

An operating system must set the following:

Name	Description
CS Selector	The Target Ring 3 CS Selector. This is assigned the sum of (16 + the value of SYSENTER_CS_MSR).
SS Selector	The Target Ring 3 SS Selector. This is assigned the sum of (24 + the value of SYSENTER_CS_MSR).
EIP	Target Ring 3 Return EIP. This is the target entry point, and is assigned the value contained in the EDX register.
ESP	Target Ring 3 Return ESP. This is the target entry point, and is assigned the value contained in the ECX register.

SYSEXIT—Fast Transition from System Call Entry Point (Continued)

The presence of this facility is indicated by the SYSENTER Present (SEP) bit 11 of CPUID. An operating system that detects the presence of the SEP bit must also qualify the processor family and model to ensure that the SYSENTER/SYSEXIT instructions are actually present, as described for the SYSENTER instruction. The Pentium® Pro processor (Model = 1) returns a set SEP CPUID feature bit, but does not support the SYSENTER/SYSEXIT instructions.

Operation

```
SYSEXIT
        IF SYSENTER_CS_MSR == 0 THEN #GP(0)
        IF CR0.PE == 0 THEN #GP(0)
        IF CPL <> 0 THEN #GP(0)

        // Changing CS:EIP and SS:ESP is required

        CS.SEL := (SYSENTER_CS_MSR + 16)      // Selector for return CS
        CS.SEL.RPL := 3

        // Set rest of CS to a fixed value
        CS.SEL.BASE := 0                      // Flat segment
        CS.SEL.LIMIT := 0xFFFF                // 4G limit
        CS.SEL.G := 1                         // 4 KB granularity
        CS.SEL.S := 1
        CS.SEL.TYPE_xCRA := 1011              // Execute, Read, Non-Conforming Code
        CS.SEL.D := 1                         // 32 bit code
        CS.SEL.DPL := 3
        CS.SEL.P := 1

        SS.SEL := (SYSENTER_CS_MSR + 24)
        SS.SEL.RPL := 3

        // Set rest of SS to a fixed value
        SS.SEL.BASE := 0                      // Flat segment
        SS.SEL.LIMIT := 0xFFFF                // 4G limit
        SS.SEL.G := 1                         // 4 KB granularity
        SS.SEL.S := 1
        SS.SEL.TYPE_xCRA := 0011              // Expand Up, Read/Write, Data
        SS.SEL.D := 1                         // 32 bit stack
        SS.SEL.DPL := 3
        SS.SEL.CPL := 3
        SS.SEL.P := 1

        ESP := ECX
        EIP := EDX
```

SYSEXIT—Fast Transition from System Call Entry Point (Continued)

Exceptions

#GP(0)	If SYSENTER_CS_MSR contains zero.

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	If CPL is non-zero.

Real Address Mode Exceptions

#GP(0)	If protected mode is not enabled.

TEST—Logical Compare

Opcode	Instruction	Description
A8 *ib*	TEST AL,*imm8*	AND *imm8* with AL; set SF, ZF, PF according to result
A9 *iw*	TEST AX,*imm16*	AND *imm16* with AX; set SF, ZF, PF according to result
A9 *id*	TEST EAX,*imm32*	AND *imm32* with EAX; set SF, ZF, PF according to result
F6 /0 *ib*	TEST *r/m8,imm8*	AND *imm8* with *r/m8*; set SF, ZF, PF according to result
F7 /0 *iw*	TEST *r/m16,imm16*	AND *imm16* with *r/m16*; set SF, ZF, PF according to result
F7 /0 *id*	TEST *r/m32,imm32*	AND *imm32* with *r/m32*; set SF, ZF, PF according to result
84 /*r*	TEST *r/m8,r8*	AND *r8* with *r/m8*; set SF, ZF, PF according to result
85 /*r*	TEST *r/m16,r16*	AND *r16* with *r/m16*; set SF, ZF, PF according to result
85 /*r*	TEST *r/m32,r32*	AND *r32* with *r/m32*; set SF, ZF, PF according to result

Description

This instruction computes the bit-wise logical AND of first operand (source 1 operand) and the second operand (source 2 operand) and sets the SF, ZF, and PF status flags according to the result. The result is then discarded.

Operation

```
TEMP ← SRC1 AND SRC2;
SF ← MSB(TEMP);
IF TEMP = 0
    THEN ZF ← 1;
    ELSE ZF ← 0;
FI:
PF ← BitwiseXNOR(TEMP[0:7]);
CF ← 0;
OF ← 0;
(*AF is Undefined*)
```

Flags Affected

The OF and CF flags are cleared to 0. The SF, ZF, and PF flags are set according to the result (refer to the “Operation” section above). The state of the AF flag is undefined.

TEST—Logical Compare (Continued)

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

UCOMISS—Unordered Scalar Single-FP compare and set EFLAGS

Opcode	Instruction	Description
0F,2E,/r	UCOMISS *xmm1, xmm2/m32*	Compare lower SP FP number in *XMM1* register with lower SP FP number in *XMM2/Mem* and set the status flags accordingly.

Description

The UCOMISS instructions compare the two lowest scalar SP FP numbers, and set the ZF,PF,CF bits in the EFLAGS register as described above. In addition, the OF, SF, and AF bits in the EFLAGS register are zeroed out. The unordered predicate is returned if either source operand is a NaN (qNaN or sNaN).

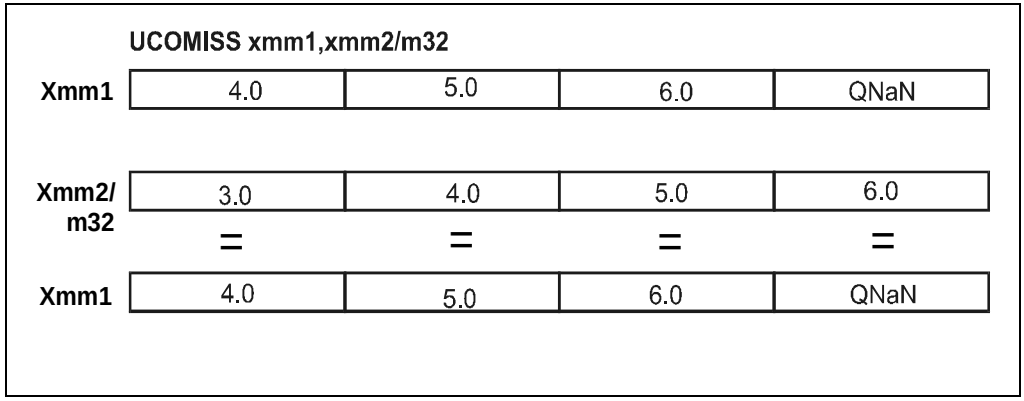


Figure 3-95. Operation of the UCOMISS Instruction, Condition One

EFLAGS: OF,SF,AF=000
EFLAGS: ZF,PF,CF=111
MXCSR flags: Invalid flag is set

UCOMISS—Unordered Scalar Single-FP compare and set EFLAGS (Continued)

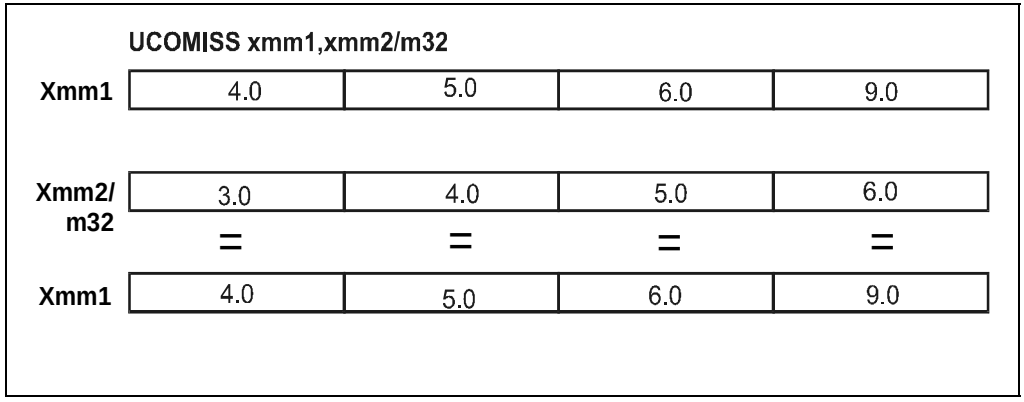


Figure 3-96. Operation of the UCOMISS Instruction, Condition Two

EFLAGS: OF,SF,AF=000
EFLAGS: ZF,PF,CF=000
MXCSR flags: Invalid flag is set

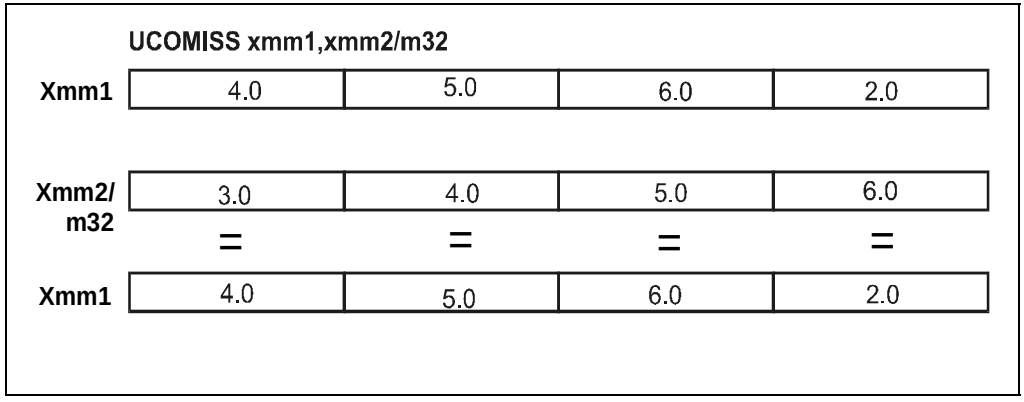


Figure 3-97. Operation of the UCOMISS Instruction, Condition Three

EFLAGS: OF,SF,AF=000
EFLAGS: ZF,PF,CF=001
MXCSR flags: Invalid flag is set

UCOMISS—Unordered Scalar Single-FP compare and set EFLAGS (Continued)

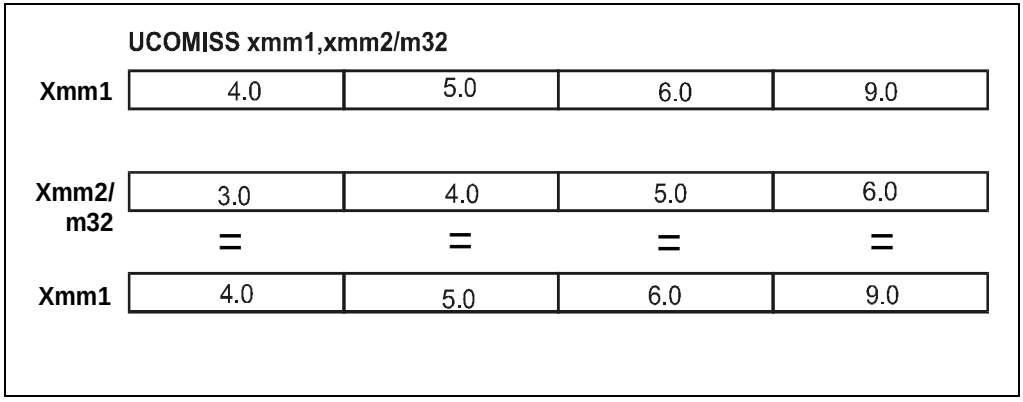


Figure 3-98. Operation of the UCOMISS Instruction, Condition Four

EFLAGS: OF,SF,AF=000
EFLAGS: ZF,PF,CF=100
MXCSR flags: Invalid flag is set

UCOMISS—Unordered Scalar Single-FP compare and set EFLAGS (Continued)

Operation

```
OF = 0;
SF = 0;
AF = 0;

IF ((DEST[31-0]  UNORD SRC/m32[31-0]) = TRUE) THEN
    ZF = 1;
    PF = 1;
    CF = 1;
ELSE
    IF ((DEST[31-0] GTRTHAN SRC/m32[31-0]) = TRUE)THEN
        ZF = 0;
        PF = 0;
        CF = 0;
    ELSE
        IF ((DEST[31-0] LESSTHAN SRC/m32[31-0]) = TRUE THEN
            ZF = 0;
            PF = 0;
            CF = 1;
        ELSE
            ZF = 1;
            PF = 0;
            CF = 0;
        FI
    FI
FI
```

UCOMISS—Unordered Scalar Single-FP compare and set EFLAGS (Continued)

Intel C/C++ Compiler Intrinsic Equivalent

_mm_ucomieq_ss(__m128 a, __m128 b)

Compares the lower SP FP value of a and b for a equal to b. If a and b are equal, 1 is returned. Otherwise 0 is returned.

_mm_ucomilt_ss(__m128 a, __m128 b)

Compares the lower SP FP value of a and b for a less than b. If a is less than b, 1 is returned. Otherwise 0 is returned.

_mm_ucomile_ss(__m128 a, __m128 b)

Compares the lower SP FP value of a and b for a less than or equal to b. If a is less than or equal to b, 1 is returned. Otherwise 0 is returned.

_mm_ucomigt_ss(__m128 a, __m128 b)

Compares the lower SP FP value of a and b for a greater than b. If a is greater than b are equal, 1 is returned. Otherwise 0 is returned.

_mm_ucomige_ss(__m128 a, __m128 b)

Compares the lower SP FP value of a and b for a greater than or equal to b. If a is greater than or equal to b, 1 is returned. Otherwise 0 is returned.

_mm_ucomineq_ss(__m128 a, __m128 b)

Compares the lower SP FP value of a and b for a not equal to b. If a and b are not equal, 1 is returned. Otherwise 0 is returned.

Exceptions

None.

Numeric Exceptions

Invalid (if sNaN operands), Denormal. Integer EFLAGS values will not be updated in the presence of unmasked numeric exceptions.

UCOMISS—Unordered Scalar Single-FP compare and set EFLAGS (Continued)

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF (fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#AC	For unaligned memory reference. To enable #AC exceptions, three conditions must be true(CR0.AM is set; EFLAGS.AC is set; current CPL is 3).
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#XM	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =1).
#UD	For an unmasked Streaming SIMD Extension numeric exception (CR4.OSXMMEXCPT =0).
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

UCOMISS—Unordered Scalar Single-FP compare and set EFLAGS (Continued)

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#AC	For unaligned memory reference if the current privilege level is 3.
#PF (fault-code)	For a page fault.

Comments

UCOMISS differs from COMISS in that it signals an invalid numeric exception when a source operand is an sNaN; COMISS signals invalid if a source operand is either a qNaN or an sNaN.

The usage of Repeat (F2H, F3H) and Operand-size (66H) prefixes with UCOMISS is reserved. Different processor implementations may handle these prefixes differently. Usage of these prefixes with UCOMISS risks incompatibility with future processors.

UD2—Undefined Instruction

Opcode	Instruction	Description
0F 0B	UD2	Raise invalid opcode exception

Description

This instruction generates an invalid opcode. This instruction is provided for software testing to explicitly generate an invalid opcode. The opcode for this instruction is reserved for this purpose.

Other than raising the invalid opcode exception, this instruction is the same as the NOP instruction.

Operation

```
#UD (* Generates invalid opcode exception *);
```

Flags Affected

None.

Exceptions (All Operating Modes)

#UD	Instruction is guaranteed to raise an invalid opcode exception in all operating modes).

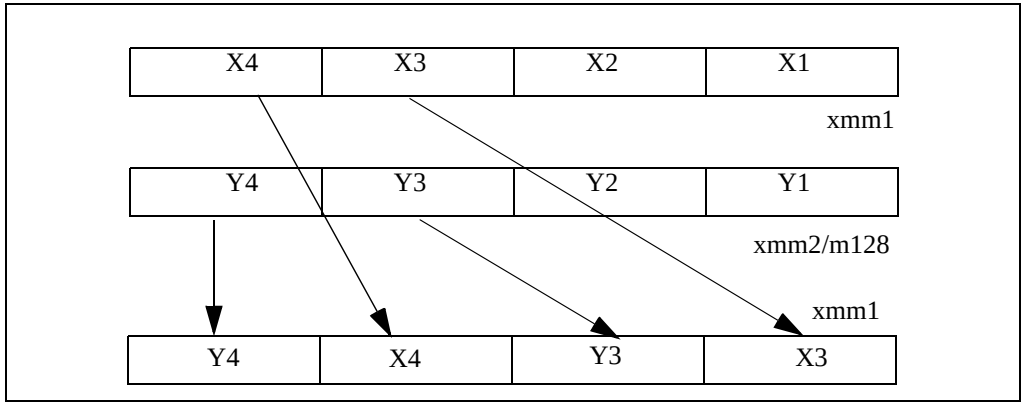
UNPCKHPS—Unpack High Packed Single-FP Data

Opcode	Instruction	Description
0F,15,/r	UNPCKHPS *xmm1, xmm2/m128*	Interleaves SP FP numbers from the high halves of *XMM1* and *XMM2/Mem* into *XMM1* register.

Description

The UNPCKHPS instruction performs an interleaved unpack of the high-order data elements of XMM1 and XMM2/Mem. It ignores the lower half of the sources.

Example 3-2. UNPCKHPS Instruction



UNPCKHPS—Unpack High Packed Single-FP Data (Continued)

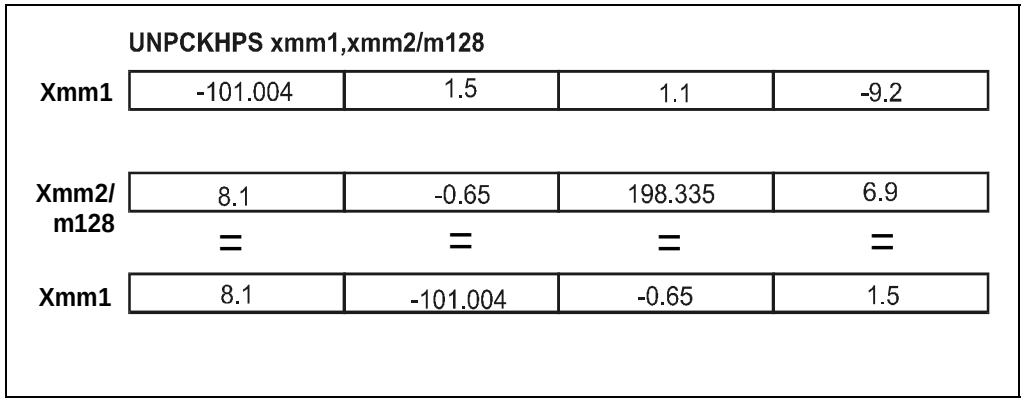


Figure 3-99. Operation of the UNPCKHPS Instruction

Operation

```
DEST[31-0] = DEST[95-64];
DEST[63-32] = SRC/m128[95-64];
DEST[95-64] = DEST[127-96];
DEST[127-96] = SRC/m128[127-96];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_unpackhi_ps(__m128 a, __m128 b)

Selects and interleaves the upper two SP FP values from a and b.

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

Numeric Exceptions

None.

UNPCKHPS—Unpack High Packed Single-FP Data (Continued)

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.

Comments

When unpacking from a memory operand, an implementation may decide to fetch only the appropriate 64 bits. Alignment to 16-byte boundary and normal segment checking will still be enforced.

The usage of Repeat Prefix (F3H) with UNPCKHPS is reserved. Different processor implementations may handle this prefix differently. Usage of this prefix with UNPCKHPS risks incompatibility with future processors.

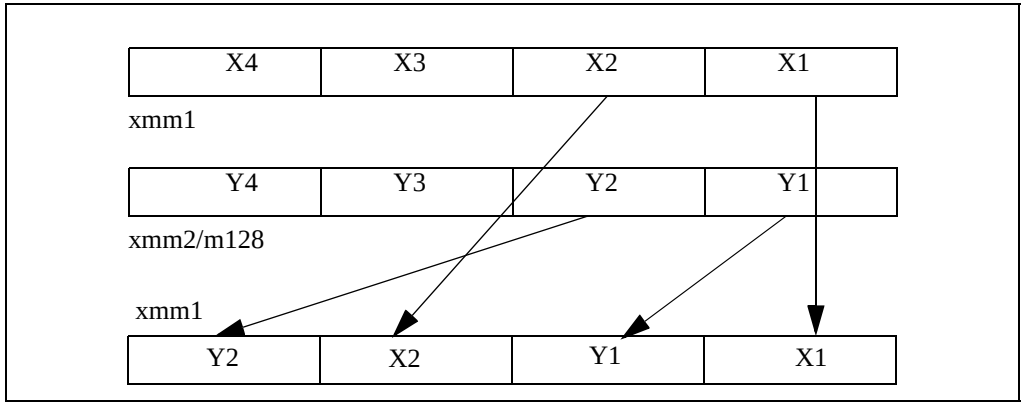
UNPCKLPS—Unpack Low Packed Single-FP Data

Opcode	Instruction	Description
0F,14,/r	UNPCKLPS *xmm1, xmm2/m128*	Interleaves SP FP numbers from the low halves of *XMM1* and *XMM2/Mem* into *XMM1* register.

Description

The UNPCKLPS instruction performs an interleaved unpack of the low-order data elements of XMM1 and XMM2/Mem. It ignores the upper half part of the sources.

Example 3-3. UNPCKLPS Instruction



UNPCKLPS—Unpack Low Packed Single-FP Data (Continued)

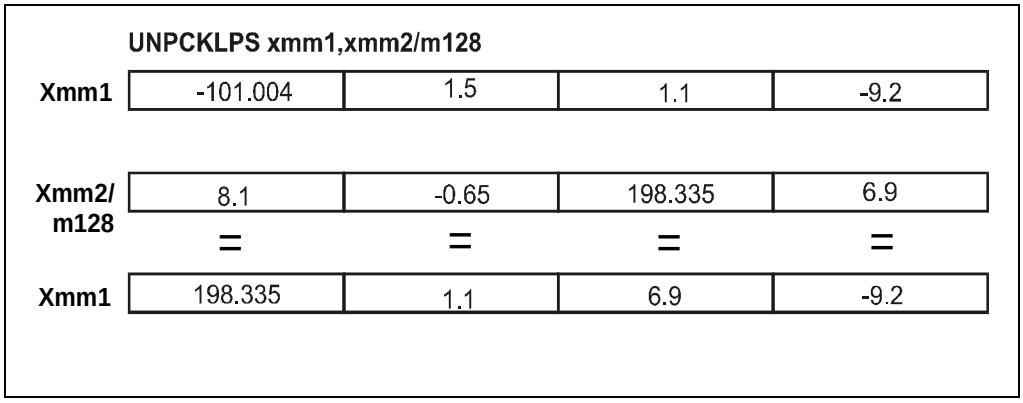


Figure 3-100. Operation of the UNPCKLPS Instruction

Operation

```
DEST[31-0] = DEST[31-0];
DEST[63-32] = SRC/m128[31-0];
DEST[95-64] = DEST[63-32];
DEST[127-96] = SRC/m128[63-32];
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_unpacklo_ps(__m128 a, __m128 b)

Selects and interleaves the lower two SP FP values from a and b.

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

Numeric Exceptions

None.

UNPCKLPS—Unpack Low Packed Single-FP Data (Continued)

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.

Comments

When unpacking from a memory operand, an implementation may decide to fetch only the appropriate 64 bits. Alignment to 16-byte boundary and normal segment checking will still be enforced.

The usage of Repeat Prefixes (F2H, F3H) with UNPCKLPS is reserved. Different processor implementations may handle this prefix differently. Usage of these prefixes with UNPCKLPS risks incompatibility with future processors.

VERR/VERW—Verify a Segment for Reading or Writing

Opcode	Instruction	Description
0F 00 /4	VERR *r/m16*	Set ZF=1 if segment specified with *r/m16* can be read
0F 00 /5	VERW *r/m16*	Set ZF=1 if segment specified with *r/m16* can be written

Description

These instructions verify whether the code or data segment specified with the source operand is readable (VERR) or writable (VERW) from the current privilege level (CPL). The source operand is a 16-bit register or a memory location that contains the segment selector for the segment to be verified. If the segment is accessible and readable (VERR) or writable (VERW), the ZF flag is set; otherwise, the ZF flag is cleared. Code segments are never verified as writable. This check cannot be performed on system segments.

To set the ZF flag, the following conditions must be met:

- The segment selector is not null.
- The selector must denote a descriptor within the bounds of the descriptor table (GDT or LDT).
- The selector must denote the descriptor of a code or data segment (not that of a system segment or gate).
- For the VERR instruction, the segment must be readable.
- For the VERW instruction, the segment must be a writable data segment.
- If the segment is not a conforming code segment, the segment’s DPL must be greater than or equal to (have less or the same privilege as) both the CPL and the segment selector's RPL.

The validation performed is the same as is performed when a segment selector is loaded into the DS, ES, FS, or GS register, and the indicated access (read or write) is performed. The segment selector's value cannot result in a protection exception, enabling the software to anticipate possible segment access problems.

VERR/VERW—Verify a Segment for Reading or Writing (Continued)

Operation

```
IF SRC(Offset) > (GDTR(Limit) OR (LDTR(Limit))
        THEN
            ZF ← 0
Read segment descriptor;
IF SegmentDescriptor(DescriptorType) = 0 (* system segment *)
    OR (SegmentDescriptor(Type) ≠ conforming code segment)
    AND (CPL > DPL) OR (RPL > DPL)
        THEN
            ZF ← 0
        ELSE
            IF ((Instruction = VERR) AND (segment = readable))
                OR ((Instruction = VERW) AND (segment = writable))
                THEN
                    ZF ← 1;
            FI;
FI;
```

Flags Affected

The ZF flag is set to 1 if the segment is accessible and readable (VERR) or writable (VERW); otherwise, it is cleared to 0.

Protected Mode Exceptions

The only exceptions generated for these instructions are those related to illegal addressing of the source operand.

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register is used to access memory and it contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

VERR/VERW—Verify a Segment for Reading or Writing (Continued)

Real-Address Mode Exceptions

#UD	The VERR and VERW instructions are not recognized in real-address mode.

Virtual-8086 Mode Exceptions

#UD	The VERR and VERW instructions are not recognized in virtual-8086 mode.

WAIT/FWAIT—Wait

Opcode	Instruction	Description
9B	WAIT	Check pending unmasked floating-point exceptions.
9B	FWAIT	Check pending unmasked floating-point exceptions.

Description

These instructions cause the processor to check for and handle pending, unmasked, floating-point exceptions before proceeding. (FWAIT is an alternate mnemonic for the WAIT).

This instruction is useful for synchronizing exceptions in critical sections of code. Coding a WAIT instruction after a floating-point instruction insures that any unmasked floating-point exceptions the instruction may raise are handled before the processor can modify the instruction's results. Refer to Section 7.9., *Floating-Point Exception Synchronization* in Chapter 7, *Floating-Point Unit* of the *Intel Architecture Software Developer's Manual, Volume 1*, for more information on using the WAIT/FWAIT instruction.

Operation

```
CheckForPendingUnmaskedFloatingPointExceptions;
```

FPU Flags Affected

The C0, C1, C2, and C3 flags are undefined.

Floating-Point Exceptions

None.

Protected Mode Exceptions

#NM MP and TS in CR0 is set.

Real-Address Mode Exceptions

#NM MP and TS in CR0 is set.

Virtual-8086 Mode Exceptions

#NM MP and TS in CR0 is set.

WBINVD—Write Back and Invalidate Cache

Opcode	Instruction	Description
0F 09	WBINVD	Write back and flush Internal caches; initiate writing-back and flushing of external caches.

Description

This instruction writes back all modified cache lines in the processor's internal cache to main memory and invalidates (flushes) the internal caches. The instruction then issues a special-function bus cycle that directs external caches to also write back modified data and another bus cycle to indicate that the external caches should be invalidated.

After executing this instruction, the processor does not wait for the external caches to complete their write-back and flushing operations before proceeding with instruction execution. It is the responsibility of hardware to respond to the cache write-back and flush signals.

The WDINVD instruction is a privileged instruction. When the processor is running in protected mode, the CPL of a program or procedure must be 0 to execute this instruction. This instruction is also a serializing instruction. For more information, refer to Section 7.4., *Serializing Instructions* in Chapter 7, *Multiple-Processor Management* of the *Intel Architecture Software Developer's Manual, Volume 3*.

In situations where cache coherency with main memory is not a concern, software can use the INVD instruction.

Intel Architecture Compatibility

The WBINVD instruction is implementation dependent, and its function may be implemented differently on future Intel Architecture processors. The instruction is not supported on Intel Architecture processors earlier than the Intel486™ processor.

Operation

```
WriteBack(InternalCaches);
Flush(InternalCaches);
SignalWriteBack(ExternalCaches);
SignalFlush(ExternalCaches);
Continue (* Continue execution);
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If the current privilege level is not 0.

WBINVD—Write Back and Invalidate Cache (Continued)

Real-Address Mode Exceptions

None.

Virtual-8086 Mode Exceptions

#GP(0)	The WBINVD instruction cannot be executed at the virtual-8086 mode.

WRMSR—Write to Model Specific Register

Opcode	Instruction	Description
0F 30	WRMSR	Write the value in EDX:EAX to MSR specified by ECX

Description

This instruction writes the contents of registers EDX:EAX into the 64-bit model specific register (MSR) specified in the ECX register. The high-order 32 bits are copied from EDX and the low-order 32 bits are copied from EAX. Always set the undefined or reserved bits in an MSR to the values previously read.

This instruction must be executed at privilege level 0 or in real-address mode; otherwise, a general protection exception #GP(0) will be generated. Specifying a reserved or unimplemented MSR address in ECX will also cause a general protection exception.

When the WRMSR instruction is used to write to an MTRR, the TLBs are invalidated, including the global entries. For more information, refer to Section 3.7., *Translation Lookaside Buffers (TLBs)* in Chapter 3, *Protected-Mode Memory Management* of the *Intel Architecture Software Developer's Manual, Volume 3*. MTRRs are an implementation-specific feature of the Pentium® Pro processor.

The MSRs control functions for testability, execution tracing, performance monitoring and machine check errors. Appendix B, *Model-Specific Registers (MSRs)*, in the *Intel Architecture Software Developer's Manual, Volume 3*, lists all the MSRs that can be written to with this instruction and their addresses.

The WRMSR instruction is a serializing instruction. For more information, refer to Section 7.4., *Serializing Instructions* in Chapter 7, *Multiple-Processor Management* of the *Intel Architecture Software Developer's Manual, Volume 3*.

The CPUID instruction should be used to determine whether MSRs are supported (EDX[5]=1) before using this instruction.

Intel Architecture Compatibility

The MSRs and the ability to read them with the WRMSR instruction were introduced into the Intel Architecture with the Pentium® processor. Execution of this instruction by an Intel Architecture processor earlier than the Pentium® processor results in an invalid opcode exception #UD.

Operation

MSR[ECX] ← EDX:EAX;

Flags Affected

None.

WRMSR—Write to Model Specific Register (Continued)

Protected Mode Exceptions

#GP(0)	If the current privilege level is not 0.
	If the value in ECX specifies a reserved or unimplemented MSR address.

Real-Address Mode Exceptions

#GP	If the value in ECX specifies a reserved or unimplemented MSR address.

Virtual-8086 Mode Exceptions

#GP(0)	The WRMSR instruction is not recognized in virtual-8086 mode.

XADD—Exchange and Add

Opcode	Instruction	Description
0F C0/r	XADD *r/m8,r8*	Exchange *r8* and *r/m8*; load sum into *r/m8*.
0F C1/r	XADD *r/m16,r16*	Exchange *r16* and *r/m16*; load sum into *r/m16*.
0F C1/r	XADD *r/m32,r32*	Exchange *r32* and *r/m32*; load sum into *r/m32*.

Description

This instruction exchanges the first operand (destination operand) with the second operand (source operand), then loads the sum of the two values into the destination operand. The destination operand can be a register or a memory location; the source operand is a register.

This instruction can be used with a LOCK prefix.

Intel Architecture Compatibility

Intel Architecture processors earlier than the Intel486™ processor do not recognize this instruction. If this instruction is used, you should provide an equivalent code sequence that runs on earlier processors.

Operation

```
TEMP ← SRC + DEST
SRC ← DEST
DEST ← TEMP
```

Flags Affected

The CF, PF, AF, SF, ZF, and OF flags are set according to the result of the addition, which is stored in the destination operand.

Protected Mode Exceptions

#GP(0)	If the destination is located in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

XADD—Exchange and Add (Continued)

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

XCHG—Exchange Register/Memory with Register

Opcode	Instruction	Description
90+*rw*	XCHG AX,*r16*	Exchange *r16* with AX
90+*rw*	XCHG *r16*,AX	Exchange AX with *r16*
90+*rd*	XCHG EAX,*r32*	Exchange *r32* with EAX
90+*rd*	XCHG *r32*,EAX	Exchange EAX with *r32*
86 /*r*	XCHG *r/m8,r8*	Exchange *r8* (byte register) with byte from *r/m8*
86 /*r*	XCHG *r8,r/m8*	Exchange byte from *r/m8* with *r8* (byte register)
87 /*r*	XCHG *r/m16,r16*	Exchange *r16* with word from *r/m16*
87 /*r*	XCHG *r16,r/m16*	Exchange word from *r/m16* with *r16*
87 /*r*	XCHG *r/m32,r32*	Exchange *r32* with doubleword from *r/m32*
87 /*r*	XCHG *r32,r/m32*	Exchange doubleword from *r/m32* with *r32*

Description

This instruction exchanges the contents of the destination (first) and source (second) operands. The operands can be two general-purpose registers or a register and a memory location. If a memory operand is referenced, the processor's locking protocol is automatically implemented for the duration of the exchange operation, regardless of the presence or absence of the LOCK prefix or of the value of the IOPL. Refer to the LOCK prefix description in this chapter for more information on the locking protocol.

This instruction is useful for implementing semaphores or similar data structures for process synchronization. Refer to Section 7.1.2., *Bus Locking* in Chapter 7, *Multiple-Processor Management* of the *Intel Architecture Software Developer's Manual, Volume 3*, for more information on bus locking.

The XCHG instruction can also be used instead of the BSWAP instruction for 16-bit operands.

Operation

TEMP ← DEST
DEST ← SRC
SRC ← TEMP

Flags Affected

None.

XCHG—Exchange Register/Memory with Register (Continued)

Protected Mode Exceptions

#GP(0)	If either operand is in a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

XLAT/XLATB—Table Look-up Translation

Opcode	Instruction	Description
D7	XLAT *m8*	Set AL to memory byte DS:[(E)BX + unsigned AL]
D7	XLATB	Set AL to memory byte DS:[(E)BX + unsigned AL]

Description

This instruction locates a byte entry in a table in memory, using the contents of the AL register as a table index, then copies the contents of the table entry back into the AL register. The index in the AL register is treated as an unsigned integer. The XLAT and XLATB instructions get the base address of the table in memory from either the DS:EBX or the DS:BX registers (depending on the address-size attribute of the instruction, 32 or 16, respectively). The DS segment may be overridden with a segment override prefix.

At the assembly-code level, two forms of this instruction are allowed: the “explicit-operand” form and the “no-operand” form. The explicit-operand form (specified with the XLAT mnemonic) allows the base address of the table to be specified explicitly with a symbol. This explicit-operands form is provided to allow documentation; however, note that the documentation provided by this form can be misleading. That is, the symbol does not have to specify the correct base address. The base address is always specified by the DS:(E)BX registers, which must be loaded correctly before the XLAT instruction is executed.

The no-operands form (XLATB) provides a “short form” of the XLAT instructions. Here also the processor assumes that the DS:(E)BX registers contain the base address of the table.

Operation

```
IF AddressSize = 16
    THEN
        AL ← (DS:BX + ZeroExtend(AL))
    ELSE (* AddressSize = 32 *)
        AL ← (DS:EBX + ZeroExtend(AL));
FI;
```

Flags Affected

None.

Protected Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.

XLAT/XLATB—Table Look-up Translation (Continued)

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.

XOR—Logical Exclusive OR

Opcode	Instruction	Description
34 *ib*	XOR AL,*imm8*	AL XOR *imm8*
35 *iw*	XOR AX,*imm16*	AX XOR *imm16*
35 *id*	XOR EAX,*imm32*	EAX XOR *imm32*
80 /6 *ib*	XOR *r/m8,imm8*	*r/m8* XOR *imm8*
81 /6 *iw*	XOR *r/m16,imm16*	*r/m16* XOR *imm16*
81 /6 *id*	XOR *r/m32,imm32*	*r/m32* XOR *imm32*
83 /6 *ib*	XOR *r/m16,imm8*	*r/m16* XOR *imm8 (sign-extended)*
83 /6 *ib*	XOR *r/m32,imm8*	*r/m32* XOR *imm8 (sign-extended)*
30 /*r*	XOR *r/m8,r8*	*r/m8* XOR *r8*
31 /*r*	XOR *r/m16,r16*	*r/m16* XOR *r16*
31 /*r*	XOR *r/m32,r32*	*r/m32* XOR *r32*
32 /*r*	XOR *r8,r/m8*	*r8* XOR *r/m8*
33 /*r*	XOR *r16,r/m16*	*r8* XOR *r/m8*
33 /*r*	XOR *r32,r/m32*	*r8* XOR *r/m8*

Description

This instruction performs a bitwise exclusive OR (XOR) operation on the destination (first) and source (second) operands and stores the result in the destination operand location. The source operand can be an immediate, a register, or a memory location; the destination operand can be a register or a memory location. (However, two memory operands cannot be used in one instruction.) Each bit of the result is 1 if the corresponding bits of the operands are different; each bit is 0 if the corresponding bits are the same.

Operation

DEST ← DEST XOR SRC;

Flags Affected

The OF and CF flags are cleared; the SF, ZF, and PF flags are set according to the result. The state of the AF flag is undefined.

XOR—Logical Exclusive OR (Continued)

Protected Mode Exceptions

#GP(0)	If the destination operand points to a nonwritable segment.
	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
	If the DS, ES, FS, or GS register contains a null segment selector.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made while the current privilege level is 3.

Real-Address Mode Exceptions

#GP	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS	If a memory operand effective address is outside the SS segment limit.

Virtual-8086 Mode Exceptions

#GP(0)	If a memory operand effective address is outside the CS, DS, ES, FS, or GS segment limit.
#SS(0)	If a memory operand effective address is outside the SS segment limit.
#PF(fault-code)	If a page fault occurs.
#AC(0)	If alignment checking is enabled and an unaligned memory reference is made.

XORPS—Bit-wise Logical Xor for Single-FP Data

Opcode	Instruction	Description
0F,57,/r	XORPS *xmm1, xmm2/m128*	XOR 128 bits from *XMM2/Mem* to *XMM1* register.

Description

The XORPS instruction returns a bit-wise logical XOR between XMM1 and XMM2/Mem.

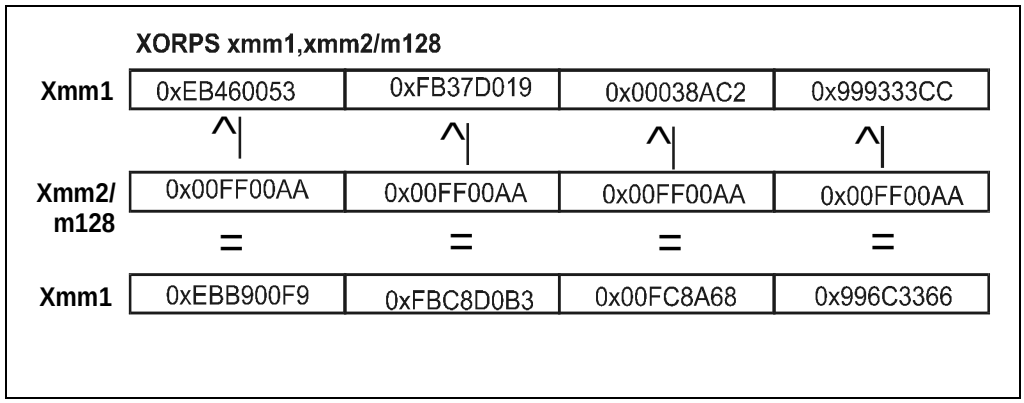


Figure 3-101. Operation of the XORPS Instruction

Operation

```
DEST[127-0] = DEST/m128[127-0] XOR SRC/m128[127-0]
```

Intel C/C++ Compiler Intrinsic Equivalent

__m128 _mm_xor_ps(__m128 a, __m128 b)

Computes bitwise EXOR (exclusive-or) of the four SP FP values of a and b.

Exceptions

General protection exception if not aligned on 16-byte boundary, regardless of segment.

XORPS—Bit-wise Logical Xor for Single-FP Data (Continued)

Numeric Exceptions

None.

Protected Mode Exceptions

#GP(0)	For an illegal memory operand effective address in the CS, DS, ES, FS, or GS segments.
#SS(0)	For an illegal address in the SS segment.
#PF(fault-code)	For a page fault.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Real Address Mode Exceptions

Interrupt 13	If any part of the operand would lie outside of the effective address space from 0 to 0FFFFH.
#UD	If CR0.EM = 1.
#NM	If TS bit in CR0 is set.
#UD	If CR4.OSFXSR(bit 9) = 0.
#UD	If CPUID.XMM(EDX bit 25) = 0.

Virtual 8086 Mode Exceptions

Same exceptions as in Real Address Mode.

#PF(fault-code)	For a page fault.

Comments

The usage of Repeat Prefix (F3H) with XORPS is reserved. Different processor implementations may handle this prefix differently. Usage of this prefix with XORPS risks incompatibility.

A

Opcode Map

APPENDIX A
OPCODE MAP

The opcode tables in this chapter are provided to aid in interpreting Intel Architecture object code. The instructions are divided into three encoding groups: 1-byte opcode encodings, 2-byte opcode encodings, and escape (floating-point) encodings. The 1- and 2-byte opcode encodings are used to encode integer, system, MMX™ technology, and Streaming SIMD Extensions. The opcode maps for these instructions are given in Tables A-1 through A-5. Sections A.3.1. through A.3.4. give instructions for interpreting 1- and 2-byte opcode maps. The escape encodings are used to encode floating-point instructions. The opcode maps for these instructions are given in Tables A-6 through A-21. Section A.3.4. gives instructions for interpreting the escape opcode maps.

The opcode tables in this section aid in interpreting Pentium® processor object code. Use the four high-order bits of the opcode as an index to a row of the opcode table; use the four low-order bits as an index to a column of the table. If the opcode is 0FH, refer to the 2-byte opcode table and use the second byte of the opcode to index the rows and columns of that table.

The escape (ESC) opcode tables for floating-point instructions identify the eight high-order bits of the opcode at the top of each page. If the accompanying ModR/M byte is in the range 00H through BFH, bits 3 through 5 identified along the top row of the third table on each page, along with the REG bits of the ModR/M, determine the opcode. ModR/M bytes outside the range 00H through BFH are mapped by the bottom two tables on each page.

Refer to Chapter 2 for detailed information on the ModR/M byte, register values, and the various addressing forms.

A.1. KEY TO ABBREVIATIONS

Operands are identified by a two-character code of the form Zz. The first character, an uppercase letter, specifies the addressing method; the second character, a lowercase letter, specifies the type of operand.

A.2. CODES FOR ADDRESSING METHOD

The following abbreviations are used for addressing methods:

A Direct address. The instruction has no ModR/M byte; the address of the operand is encoded in the instruction; and no base register, index register, or scaling factor can be applied (for example, far JMP (EA)).

C The reg field of the ModR/M byte selects a control register (for example, MOV (0F20, 0F22)).

D The reg field of the ModR/M byte selects a debug register (for example, MOV (0F21,0F23)).

E A ModR/M byte follows the opcode and specifies the operand. The operand is either a general-purpose register or a memory address. If it is a memory address, the address is computed from a segment register and any of the following values: a base register, an index register, a scaling factor, a displacement.

F EFLAGS Register.

G The reg field of the ModR/M byte selects a general register (for example, AX (000)).

I Immediate data. The operand value is encoded in subsequent bytes of the instruction.

J The instruction contains a relative offset to be added to the instruction pointer register (for example, JMP (0E9), LOOP).

M The ModR/M byte may refer only to memory (for example, BOUND, LES, LDS, LSS, LFS, LGS, CMPXCHG8B).

O The instruction has no ModR/M byte; the offset of the operand is coded as a word or double word (depending on address size attribute) in the instruction. No base register, index register, or scaling factor can be applied (for example, MOV (A0–A3)).

P The reg field of the ModR/M byte selects a packed quadword MMX™ technology register.

Q A ModR/M byte follows the opcode and specifies the operand. The operand is either an MMX™ technology register or a memory address. If it is a memory address, the address is computed from a segment register and any of the following values: a base register, an index register, a scaling factor, and a displacement.

R The mod field of the ModR/M byte may refer only to a general register (for example, MOV (0F20-0F24, 0F26)).

S The reg field of the ModR/M byte selects a segment register (for example, MOV (8C,8E)).

T The reg field of the ModR/M byte selects a test register (for example, MOV (0F24,0F26)).

V The reg field of the ModR/M byte selects a packed SIMD floating-point register.

W An ModR/M byte follows the opcode and specifies the operand. The operand is either a SIMD floating-point register or a memory address. If it is a memory address, the address is computed from a segment register and any of the following values: a base register, an index register, a scaling factor, and a displacement

X Memory addressed by the DS:SI register pair (for example, MOVS, CMPS, OUTS, or LODS).

Y Memory addressed by the ES:DI register pair (for example, MOVS, CMPS, INS, STOS, or SCAS).

A.2.1. Codes for Operand Type

The following abbreviations are used for operand types:

a	Two one-word operands in memory or two double-word operands in memory, depending on operand-size attribute (used only by the BOUND instruction).
b	Byte, regardless of operand-size attribute.
c	Byte or word, depending on operand-size attribute.
d	Doubleword, regardless of operand-size attribute.
dq	Double-quadword, regardless of operand-size attribute.
p	32-bit or 48-bit pointer, depending on operand-size attribute.
pi	Quadword MMX™ technology register (e.g. mm0)
ps	128-bit packed FP single-precision data.
q	Quadword, regardless of operand-size attribute.
s	6-byte pseudo-descriptor.
ss	Scalar element of a 128-bit packed FP single-precision data.
si	Doubleword integer register (e.g., eax)
v	Word or doubleword, depending on operand-size attribute.
w	Word, regardless of operand-size attribute.

A.2.2. Register Codes

When an operand is a specific register encoded in the opcode, the register is identified by its name (for example, AX, CL, or ESI). The name of the register indicates whether the register is 32, 16, or 8 bits wide. A register identifier of the form eXX is used when the width of the register depends on the operand-size attribute. For example, eAX indicates that the AX register is used when the operand-size attribute is 16, and the EAX register is used when the operand-size attribute is 32.

A.3. OPCODE LOOK-UP EXAMPLES

This section provides several examples to demonstrate how the following opcode maps are used. Refer to the introduction to Chapter 3, *Instruction Set Reference*, in the *Intel Architecture Software Developer's Manual, Volume 2* for detailed information on the ModR/M byte, register values, and the various addressing forms.

A.3.1. One-Byte Opcode Instructions

The opcode maps for 1-byte opcodes are shown in Tables A-1 and A-2. Looking at the 1-byte opcode maps, the instruction and its operands can be determined from the hexadecimal opcode. For example:

Opcode: 030500000000H

LSB address					MSB address
03	05	00	00	00	00

Opcode 030500000000H for an ADD instruction can be interpreted from the 1-byte opcode map as follows. The first digit (0) of the opcode indicates the row, and the second digit (3) indicates the column in the opcode map tables. The first operand (type Gv) indicates a general register that is a word or doubleword depending on the operand-size attribute. The second operand (type Ev) indicates that a ModR/M byte follows that specifies whether the operand is a word or doubleword general-purpose register or a memory address. The ModR/M byte for this instruction is 05H, which indicates that a 32-bit displacement follows (00000000H). The reg/opcode portion of the ModR/M byte (bits 3 through 5) is 000, indicating the EAX register. Thus, it can be determined that the instruction for this opcode is ADD EAX, mem_op, and the offset of mem_op is 00000000H.

Some 1- and 2-byte opcodes point to “group” numbers. These group numbers indicate that the instruction uses the reg/opcode bits in the ModR/M byte as an opcode extension (refer to Section A.3.3.).

A.3.2. Two-Byte Opcode Instructions

Instructions that begin with 0FH can be found in the two-byte opcode maps given in Tables A-3 and A-4. The second opcode byte is used to reference a particular row and column in the tables. For example, the opcode 0FA4050000000003H is located on the two-byte opcode map in row A, column 4. This opcode indicates a SHLD instruction with the operands Ev, Gv, and Ib. These operands are defined as follows:

Ev The ModR/M byte follows the opcode to specify a word or doubleword operand

Gv The reg field of the ModR/M byte selects a general-purpose register

Ib Immediate data is encoded in the subsequent byte of the instruction.

The third byte is the ModR/M byte (05H). The mod and opcode/reg fields indicate that a 32-bit displacement follows, located in the EAX register, and is the source.

The next part of the opcode is the 32-bit displacement for the destination memory operand (00000000H), and finally the immediate byte representing the count of the shift (03H).

By this breakdown, it has been shown that this opcode represents the instruction:

```
SHLD DS:00000000H, EAX, 3
```

The next part of the SHLD opcode is the 32-bit displacement for the destination memory operand (00000000H), which is followed by the immediate byte representing the count of the shift (03H). By this breakdown, it has been shown that the opcode 0FA4050000000003H represents the instruction:

```
SHLD DS:00000000H, EAX, 3.
```

Lower case is used in the following tables to highlight the mnemonics added by MMX™ technology and Streaming SIMD Extensions.

Table A-1. One-Byte Opcode Map[1] (Left)

	0	1	2	3	4	5	6	7
0	ADD Eb, Gb	ADD Ev, Gv	ADD Gb, Eb	ADD Gv, Ev	ADD AL, Ib	ADD eAX, Iv	PUSH ES	POP ES
1	ADC Eb, Gb	ADC Ev, Gv	ADC Gb, Eb	ADC Gv, Ev	ADC AL, Ib	ADC eAX, Iv	PUSH SS	POP SS
2	AND Eb, Gb	AND Ev, Gv	AND Gb, Eb	AND Gv, Ev	AND AL, Ib	AND eAX, Iv	SEG = ES	DAA
3	XOR Eb, Gb	XOR Ev, Gv	XOR Gb, Eb	XOR Gb, Ev	XOR AL, Ib	XOR eAX, Iv	SEG = SS	AAA
4	INC general register eAX	INC general register eCX	INC general register eDX	INC general register eBX	INC general register eSP	INC general register eBP	INC general register eSI	INC general register eDI
5	PUSH general register eAX	PUSH general register eCX	PUSH general register eDX	PUSH general register eBX	PUSH general register eSP	PUSH general register eBP	PUSH general register eSI	PUSH general register eDI
6	PUSHA PUSHAD	POPA POPAD	BOUND Gv, Ma	ARPL Ew, Gw	SEG = FS	SEG = GS	Opd Size	Addr Size
7	Jcc - Short-displacement jump on condition O	Jcc - Short-displacement jump on condition NO	Jcc - Short-displacement jump on condition B/NAE/C	Jcc - Short-displacement jump on condition NB/AE/NC	Jcc - Short-displacement jump on condition Z/E	Jcc - Short-displacement jump on condition NZ/NE	Jcc - Short-displacement jump on condition BE/NA	Jcc - Short-displacement jump on condition NBE/A
8	Immediate Grp 1[2] Eb, Ib	Immediate Grp 1[2] Ev, Iv	Immediate Grp 1[2] Ev, Ib	Immediate Grp 1[2] Ev, Ib	TEST Eb, Gb	TEST Ev, Gv	XCHG Eb, Gb	XCHG Ev, Gv
9	NOP	XCHG word or double-word register with eAX eCX	XCHG word or double-word register with eAX eDX	XCHG word or double-word register with eAX eBX	XCHG word or double-word register with eAX eSP	XCHG word or double-word register with eAX eBP	XCHG word or double-word register with eAX eSI	XCHG word or double-word register with eAX eDI
A	MOV AL, Ob	MOV eAX, Ov	MOV Ob, AL	MOV Ov, eAX	MOVSB Xb, Yb	MOVSW Xv, Yv	CMPSB Xb, Yb	CMPSW Xv, Yv
B	MOV immediate byte into byte register AL	MOV immediate byte into byte register CL	MOV immediate byte into byte register DL	MOV immediate byte into byte register BL	MOV immediate byte into byte register AH	MOV immediate byte into byte register CH	MOV immediate byte into byte register DH	MOV immediate byte into byte register BH
C	Shift Grp 2[2] Eb,Ib	Shift Grp 2[2] Ev,Ib	RET Iw	RET	LES Gv, Mp	LDS Gv, Mp	Grp 12[2] - MOV Eb, Ib	Grp 12[2] - MOV Ev, Iv
D	Shift Grp 2[2] Eb, 1	Shift Grp 2[2] Ev, 1	Shift Grp 2[2] Eb, CL	Shift Grp 2[2] Ev, CL	AAM Ib	AAD Ib		XLAT/XLATB
E	LOOPNE LOOPNZ Jb	LOOPE/ LOOPZ Jb	LOOP Jb	JCXZ/ JECXZ Jb	IN AL, Ib	IN eAX, Ib	OUT Ib, AL	OUT Ib, eAX
F	LOCK		REPNE	REP/ REPE	HLT	CMC	Unary Grp 3[2] Eb	Unary Grp 3[2] Ev

Table A-2. One-Byte Opcode Map[1] (Right)

8	9	A	B	C	D	E	F	
OR						PUSH CS	2-byte escape	0
Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	eAX, Iv		POP CS	
SBB						PUSH DS	POP DS	1
Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	eAX, Iv			
SUB						SEG =CS	DAS	2
Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	eAX, Iv			
CMP						SEG =DS	AAS	3
Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev	AL, Ib	eAX, Iv			
DEC general register								4
eAX	eCX	eDX	eBX	eSP	eBP	eSI	eDI	
POP into general register								5
eAX	eCX	eDX	eBX	eSP	eBP	eSI	eDI	
PUSH Iv	IMUL Gv, Ev, Iv	PUSH Ib	IMUL Gv, Ev, Ib	INSB Yb, DX	INSW/D Yv, DX	OUTSB DX, Xb	OUTSW/D DX, Xv	6
Jcc - Short displacement jump on condition								7
S	NS	P/PE	NP/PO	L/NGE	NL/GE	LE/NG	NLE/G	
MOV				MOV Ew, Sw	LEA Gv, M	MOV Sw, Ew	POP Ev	8
Eb, Gb	Ev, Gv	Gb, Eb	Gv, Ev					
CBW/ CWDE	CWD/ CDQ	CALL Ap	FWAIT/ WAIT	PUSHF/ PUSHFD Fv	POPF/ POPFD Fv	SAHF	LAHF	9
TEST		STOS/ STOSB Yb, AL	STOS/ STOSW/ STOTSD Yv, eAX	LODSB AL, Xb	LODSW/ LODSD eAX, Xv	SCAS/ SCASB AL, Yb	SCASW/ SCASD/ SCAS eAX, Xv	A
AL, Ib	eAX, Iv							
MOV immediate word or double into word or double register								B
eAX	eCX	eDX	eBX	eSP	eBP	eSI	eDI	
ENTER Iw, Ib	LEAVE	RET Iw	RET	INT 3	INT Ib	INTO	IRET	C
ESC (Escape to coprocessor instruction set)								D
CALL Jv	JMP			IN		OUT		E
	near JV	far AP	short Jb	AL, DX	eAX, DX	DX, AL	DX, eAX	
CLC	STC	CLI	STI	CLD	STD	INC/DEC Grp 4[2]	INC/DEC Grp 5[2]	F

NOTES:

1. All blanks in the opcode maps A-1 and A-2 are reserved and should not be used. Do not depend on the operation of these undefined opcodes.
2. Bits 5, 4, and 3 of ModR/M byte used as an opcode extension (refer to Section A.3.3.).

Table A-3. Two-Byte Opcode Map[1] (Left) (First Byte is OFH)

	0	1	2	3	4	5	6	7
0	Grp 6[2]	Grp 7[2]	LAR Gv, Ew	LSL Gv, Ew			CLTS	
1	movups Vps, Wps movss (F3) Vss, Wss	movups Wps, Vps movss (F3) Wss, Vss	movlps Vq, Wq movhlps Vq, Vq	movlps Vq, Wq	unpcklps Vps, Wq	unpckhps Vps, Wq	movhps Vq, Wq movlhps Vq, Vq	movhps Wq, Vq
2	MOV Rd, Cd	MOV Rd, Dd	MOV Cd, Rd	MOV Dd, Rd				
3	WRMSR	RDTSC	RDMSR	RDPMC	SYSENTER	SYSEXIT		
4	CMOVcc - Conditional Move							
	O	NO	B/C/NAE	AE/NB/NC	E/Z	NE/NZ	BE/NA	A/NBE
	Gv, Ev							
5	movmskps Ed, Vps	sqrtps Vps, Wps sqrtss (F3) Vss, Wss	rsqrtps Vps, Wps rsqrtss Vss, Wss	rcpps Vps, Wps rcpss Vss, Wss	andps Vps, Wps	andnps Vps, Wps	orps Vps, Wps	xorps Vps, Wps
6	punpcklbw Pq, Qd	punpcklwd Pq, Qd	punpckldq Pq, Qd	packsswb Pq, Qq	pcmpgtb Pq, Qq	pcmpgtw Pq, Qq	pcmpgtd Pq, Qq	packuswb Pq, Qq
7		pshimw[3] Pq, Qq (Grp 13[2])	pshimd[3] Pq, Qq (Grp 14[2])	pshimq[3] Pq, Qq (Grp 15[2])	pcmpeqb Pq, Qq	pcmpeqw Pq, Qq	pcmpeqd Pq, Qq	emms
8	Jcc - Long-displacement jump on condition							
	O	NO	B/C/NAE	AE/NB/NC	E/Z	NE/NZ	BE/NA	A/NBE
9	SETcc - Byte Set on condition (Eb)							
	O	NO	B/C/NAE	AE/NB/NC	E/Z	NE/NZ	BE/NA	A/NBE
	Eb							
A	PUSH FS	POP FS	CPUID	BT Ev, Gv	SHLD Ev, Gv, Ib	SHLD Ev, Gv, CL		
B	CMPXCHG		LSS Mp	BTR Ev, Gv	LFS Mp	LGS Mp	MOVZx	
	Eb, Gb	Ev, Gv					Gv, Eb	Gv, Ew
C	XADD Eb, Gb	XADD Ev, Gv	cmpps Vps, Wps, Ib cmpss (F3) Vss, Wss, Ib		pinsrw Pq, Ed, Ib	pextrw Gd, Pq, Ib	shufps Vps, Wps, Ib	Grp 9[2]
D		psrlw Pq, Qq	psrld Pq, Qq	psrlq Pq, Qq		pmullw Pq, Qq		pmovmskb Gd, Pq
E	pavgb Pq, Qq	psraw Pq, Qq	psrad Pq, Qq	pavgw Pq, Qq	pmulhuw Pq, Qq	pmulhw Pq, Qq		movntq Wq, Vq
F		psllw Pq, Qq	pslld Pq, Qq	psllq Pq, Qq		pmaddwd Pq, Qq	psadbw Pq, Qq	

Table A-4. Two-Byte Opcode Map[1] (Right) (First Byte is OFH)

8	9	A	B	C	D	E	F	
INVD	WBINVD		2 byte Illegal Opcodes UD2[4]					0
Prefetch (Grp 17[2])								1
movaps Vps, Wps	movaps Wps, Vps	cvtpi2ps Vps, Qq cvtsi2ss (F3) Vss, Qq	movntps Wps, Vps	cvttps2pi Qq, Wps cvttss2si (F3) Gd, Wss	cvtps2pi Qq, Wps cvtss2si (F3) Gd, Wss	ucomiss Vss, Wss	comiss Vps, Wps	2
								3
CMOVcc - Conditional Move								4
S	NS	P/PE	NP/PO	L/NGE	GE/NL	LE/NG	G/NLE	
Gv, Ev								
addps Vps, Wps addss (F3) Vss, Wss	mulps Vps, Wps mulss (F3) Vss, Wss			subps Vps, Wps subss (F3) Vss, Wss	minps Vps, Wps minss (F3) Vss, Wss	divps Vps, Wps divss (F3) Vss, Wss	maxps Vps, Wps maxss (F3) Vss, Wss	5
punpckhbw Pq, Qd	punpckhwd Pq, Qd	punpckhdq Pq, Qd	packssdw Pq, Qd			movd Pd, Ed	movq Pq, Qq	6
MMX UD						movd Ed, Pd	movq Qq, Pq	7
Jcc - Long-displacement jump on condition								8
S	NS	P/PE	NP/PO	L/NGE	GE/NL	LE/NG	G/NLE	
SETcc - Byte Set on condition								9
S	NS	P/PE	NP/PO	L/NGE	GE/NL	LE/NG	G/NLE	
Eb								
PUSH GS	POP GS	RSM	BTS Ev, Gv	SHRD Ev, Gv, Ib	SHRD Ev, Gv, CL	Grp 16[2]	IMUL Gv, Ev	A
	Grp 11[2] Invalid Opcode[4]	Grp 8[2] Ev, Ib	BTC Ev, Gv	BSF Gv, Ev	BSR Gv, Ev	MOVSx Gv, Eb	MOVSx Gv, Ew	B
BSWAP								C
EAX	ECX	EDX	EBX	ESP	EBP	ESI	EDI	
psubusb Pq, Qq	psubusw Pq, Qq	pminub Pq, Qq	pand Pq, Qq	paddusb Pq, Qq	paddusw Pq, Qq	pmaxub Pq, Qq	pandn Pq, Qq	D
psubsb Pq, Qq	psubsw Pq, Qq	pminsw Pq, Qq	por Pq, Qq	paddsb Pq, Qq	paddsw Pq, Qq	pmaxsw Pq, Qq	pxor Pq, Qq	E
psubb Pq, Qq	psubw Pq, Qq	psubd Pq, Qq		paddb Pq, Qq	paddw Pq, Qq	padd Pq, Qq		F

NOTES:

1. All blanks in the opcode maps A-3 and A-4 are reserved and should not be used. Do not depend on the operation of these undefined opcodes.
2. Bits 5, 4, and 3 of ModR/M byte used as an opcode extension (refer to Section A.3.3.).
3. These abbreviations are not actual mnemonics. When shifting by immediate shift counts, the PSHIMD mnemonic represents the PSLLD, PSRAD, and PSRLD instructions, PSHIMW represents the PSLLW, PSRAW, and PSRLW instructions, and PSHIMQ represents the PSLLQ and PSRLQ instructions. The instructions that shift by immediate counts are differentiated by ModR/M bytes (refer to Section A.3.3.).
4. Use the 0F0B opcode (UD2 instruction) or the 0FB9H opcode when deliberately trying to generate an invalid opcode exception (#UD).

A.3.3. Opcode Extensions For One- And Two-byte Opcodes

Some of the 1-byte and 2-byte opcodes use bits 5, 4, and 3 of the ModR/M byte (the nnn field in Figure A-1) as an extension of the opcode. Those opcodes that have opcode extensions are indicated in Table A-5 with group numbers (Group 1, Group 2, etc.). The group numbers (ranging from 1 to A) provide an entry point into Table A-5 where the encoding of the opcode extension field can be found. For example, the ADD instruction with a 1-byte opcode of 80H is a Group 1 instruction. Table A-5 indicates that the opcode extension that must be encoded in the ModR/M byte for this instruction is 000B.

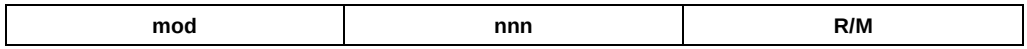


Figure A-1. ModR/M Byte nnn Field (Bits 5, 4, and 3)

Table A-5. Opcode Extensions for One- and Two-Byte Opcodes by Group Number[1]

			Encoding of Bits 5,4,3 of the ModR/M Byte							
Opcode	**Group**	**Mod 7,6**	**000**	**001**	**010**	**011**	**100**	**101**	**110**	**111**
80-83	1	mem	ADD	OR	ADC	SBB	AND	SUB	XOR	CMP
		11								
C0, C1 reg, imm D0, D1 reg, 1 D2, D3 reg, CL	2	mem	ROL	ROR	RCL	RCR	SHL/SAL	SHR		SAR
		11								
F6, F7	3	mem	TEST Ib/Iv		NOT	NEG	MUL AL/eAX	IMUL AL/eAX	DIV AL/eAX	IDIV AL/eAX
		11								
FE	4	mem	INC Eb	DEC Eb						
		11								
FF	5	mem	INC Ev	DEC Ev	CALL Ev	CALL Ep	JMP Ev	JMP Ep	PUSH Ev	
		11								
OF OO	6	mem	SLDT Ew	STR Ew	LLDT Ew	LTR Ew	VERR Ew	VERW Ew		
		11								
OF O1	7	mem	SGDT Ms	SIDT Ms	LGDT Ms	LIDT Ms	SMSW Ew		LMSW Ew	INVLPG
		11								
OF BA	8	mem					BT	BTS	BTR	BTC
		11								
OF C7	9	mem		CMPXCH8B Mq						
		11								
OF B9	11	mem								
		11								
C6	12	mem	MOV Ev, Iv							
		11								
C7	12	mem								
		11	MOV Ev, Iv							
OF 71	13	mem								
		11			psrlw Pq, Ib		psraw Pq, Ib		psllw Pq, Ib	
OF 72	14	mem								
		11			psrld Pq, Ib		psrad Pq, Ib		pslld Pq, Ib	
OF 73	15	mem								
		11			psrlq Pq, Ib				psllq Pq, Ib	
OF AE	16	mem	fxsave	fxrstor	ldmxcsr	stmxcsr				
		11								sfence
OF 18	17	mem	prefetch NTA	prefetch T0	prefetch T1	prefetch T2				
		11								

NOTE:

1. All blanks in the opcode map are reserved and should not be used. Do not depend on the operation of these undefined opcodes.

A.3.4. Escape Opcode Instructions

The opcode maps for the escape instruction opcodes (floating-point instruction opcodes) are given in Tables A-6 through A-21. These opcode maps are grouped by the first byte of the opcode from D8 through DF. Each of these opcodes has a ModR/M byte. If the ModR/M byte is within the range of 00H through BFH, bits 5, 4, and 3 of the ModR/M byte are used as an opcode extension, similar to the technique used for 1-and 2-byte opcodes (refer to Section A.3.3.). If the ModR/M byte is outside the range of 00H through BFH, the entire ModR/M byte is used as an opcode extension.

A.3.4.1. OPCODES WITH MODR/M BYTES IN THE 00H THROUGH BFH RANGE

The opcode DD0504000000H can be interpreted as follows. The instruction encoded with this opcode can be located in Section A.3.4.8.. Since the ModR/M byte (05H) is within the 00H through BFH range, bits 3 through 5 (000) of this byte indicate the opcode to be for an FLD double-real instruction (refer to Table A-8). The double-real value to be loaded is at 00000004H, which is the 32-bit displacement that follows and belongs to this opcode.

A.3.4.2. OPCODES WITH MODR/M BYTES OUTSIDE THE 00H THROUGH BFH RANGE

The opcode D8C1H illustrates an opcode with a ModR/M byte outside the range of 00H through BFH. The instruction encoded here, can be located in Section A.3.4.. In Table A-7, the ModR/M byte C1H indicates row C, column 1, which is an FADD instruction using ST(0), ST(1) as the operands.

A.3.4.3. ESCAPE OPCODES WITH D8 AS FIRST BYTE

Tables A-6 and A-7 contain the opcodes maps for the escape instruction opcodes that begin with D8H. Table A-6 shows the opcode map if the accompanying ModR/M byte within the range of 00H through BFH. Here, the value of bits 5, 4, and 3 (the nnn field in Figure A-1) selects the instruction.

Table A-6. D8 Opcode Map When ModR/M Byte is Within 00H to BFH[1]

nnn Field of ModR/M Byte (refer to Figure A-1)							
000	001	010	011	100	101	110	111
FADD single-real	FMUL single-real	FCOM single-real	FCOMP single-real	FSUB single-real	FSUBR single-real	FDIV single-real	FDIVR single-real

Table A-7 shows the opcode map if the accompanying ModR/M byte is outside the range of 00H to BFH. In this case the first digit of the ModR/M byte selects the row in the table and the second digit selects the column.

Table A-7. D8 Opcode Map When ModR/M Byte is Outside 00H to BFH[1]

	0	1	2	3	4	5	6	7
C	FADD							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
D	FCOM							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),T(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
E	FSUB							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
F	FDIV							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
	8	9	A	B	C	D	E	F
C	FMUL							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
D	FCOMP							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),T(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
E	FSUBR							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
F	FDIVR							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)

A.3.4.4. ESCAPE OPCODES WITH D9 AS FIRST BYTE

Tables A-8 and A-9 contain opcodes maps for escape instruction opcodes that begin with D9H. Table A-8 shows the opcode map if the accompanying ModR/M byte is within the range of 00H through BFH. Here, the value of bits 5, 4, and 3 (the Figure A-1 nnn field) selects the instruction.

Table A-8. D9 Opcode Map When ModR/M Byte is Within 00H to BFH[1].

nnn Field of ModR/M Byte (refer to Figure A-1)							
000	001	010	011	100	101	110	111
FLD single-real		FST single-real	FSTP single-real	FLDENV 14/28 bytes	FLDCW 2 bytes	FSTENV 14/28 bytes	FSTCW 2 bytes

NOTE:

1. All blanks in the opcode map are reserved and should not be used. Do not depend on the operation of these undefined opcodes.

Table A-9 shows the opcode map if the accompanying ModR/M byte is outside the range of 00H to BFH. In this case the first digit of the ModR/M byte selects the row in the table and the second digit selects the column.

Table A-9. D9 Opcode Map When ModR/M Byte is Outside 00H to BFH[1]

	0	1	2	3	4	5	6	7
C	FLD							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
D	FNOP							
E	FCHS	FABS			FTST	FXAM		
F	F2XM1	FYL2X	FPTAN	FPATAN	FXTRACT	FPREM1	FDECSTP	FINCSTP
	8	9	A	B	C	D	E	F
C	FXCH							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
D								
E	FLD1	FLDL2T	FLDL2E	FLDPI	FLDLG2	FLDLN2	FLDZ	
F	FPREM	FYL2XP1	FSQRT	FSINCOS	FRNDINT	FSCALE	FSIN	FCOS

NOTE:

1. All blanks in the opcode map are reserved and should not be used. Do not depend on the operation of these undefined opcodes.

A.3.4.5. ESCAPE OPCODES WITH DA AS FIRST BYTE

Tables A-10 and A-11 contain the opcodes maps for the escape instruction opcodes that begin with DAH. Table A-10 shows the opcode map if the accompanying ModR/M byte within the range of 00H through BFH. Here, the value of bits 5, 4, and 3 (the nnn field in Figure A-1) selects the instruction.

Table A-10. DA Opcode Map When ModR/M Byte is Within 00H to BFH[1]

nnn Field of ModR/M Byte (refer to Figure A-1)							
000	001	010	011	100	101	110	111
FIADD dword-integer	FIMUL dword-integer	FICOM dword-integer	FICOMP dword-integer	FISUB dword-integer	FISUBR dword-integer	FIDIV dword-integer	FIDIVR dword-integer

NOTE:

1. All blanks in the opcode map are reserved and should not be used. Do not depend on the operation of these undefined opcodes.

Table A-11 shows the opcode map if the accompanying ModR/M byte is outside the range of 00H to BFH. In this case the first digit of the ModR/M byte selects the row in the table and the second digit selects the column.

Table A-11. DA Opcode Map When ModR/M Byte is Outside 00H to BFH[1]

	0	1	2	3	4	5		7
C	FCMOVB							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
D	FCMOVBE							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
E								
F								
	8	9	A	B	C	D	E	F
C	FCMOVE							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
D	FCMOVU							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
E		FUCOMPP						
F								

NOTE:

1. All blanks in the opcode map are reserved and should not be used. Do not depend on the operation of these undefined opcodes.

A.3.4.6. ESCAPE OPCODES WITH DB AS FIRST BYTE

Tables A-12 and A-13 contain the opcodes maps for the escape instruction opcodes that begin with DBH. Table A-12 shows the opcode map if the accompanying ModR/M byte within the range of 00H through BFH. Here, the value of bits 5, 4, and 3 (the nnn field in Figure A-1) selects the instruction.

Table A-12. DB Opcode Map When ModR/M Byte is Within 00H to BFH[1]

nnn Field of ModR/M Byte (refer to Figure A-1)							
000	001	010	011	100	101	110	111
FILD dword-integer		FIST dword-integer	FISTP dword-integer		FLD extended-real		FSTP extended-real

NOTE:

1. All blanks in the opcode map are reserved and should not be used. Do not depend on the operation of these undefined opcodes.

Table A-13 shows the opcode map if the accompanying ModR/M byte is outside the range of 00H to BFH. In this case the first digit of the ModR/M byte selects the row in the table and the second digit selects the column.

Table A-13. DB Opcode Map When ModR/M Byte is Outside 00H to BFH[1]

	0	1	2	3	4	5		7
C	FCMOVNB							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
D	FCMOVNBE							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
E			FCLEX	FINIT				
F	FCOMI							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
	8	9	A	B	C	D	E	F
C	FCMOVNE							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
D	FCMOVNU							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
E	FUCOMI							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
F								

NOTE:

1. All blanks in the opcode map are reserved and should not be used. Do not depend on the operation of these undefined opcodes.

A.3.4.7. ESCAPE OPCODES WITH DC AS FIRST BYTE

Tables A-14 and A-15 contain the opcodes maps for the escape instruction opcodes that begin with DCH. Table A-14 shows the opcode map if the accompanying ModR/M byte within the range of 00H through BFH. Here, the value of bits 5, 4, and 3 (the nnn field in Figure A-1) selects the instruction.

Table A-14. DC Opcode Map When ModR/M Byte is Within 00H to BFH[1]

nnn Field of ModR/M Byte (refer to Figure A-1)							
000	001	010	011	100	101	110	111
FADD double-real	FMUL double-real	FCOM double-real	FCOMP double-real	FSUB double-real	FSUBR double-real	FDIV double-real	FDIVR double-real

NOTE:

1. All blanks in the opcode map are reserved and should not be used. Do not depend on the operation of these undefined opcodes.

Table A-15 shows the opcode map if the accompanying ModR/M byte is outside the range of 00H to BFH. In this case the first digit of the ModR/M byte selects the row in the table and the second digit selects the column.

Table A-15. DC Opcode Map When ModR/M Byte is Outside 00H to BFH[4]

	0	1	2	3	4	5		7
C	FADD							
	ST(0),ST(0)	ST(1),ST(0)	ST(2),ST(0)	ST(3),ST(0)	ST(4),ST(0)	ST(5),ST(0)	ST(6),ST(0)	ST(7),ST(0)
D								
E	FSUBR							
	ST(0),ST(0)	ST(1),ST(0)	ST(2),ST(0)	ST(3),ST(0)	ST(4),ST(0)	ST(5),ST(0)	ST(6),ST(0)	ST(7),ST(0)
F	FDIVR							
	ST(0),ST(0)	ST(1),ST(0)	ST(2),ST(0)	ST(3),ST(0)	ST(4),ST(0)	ST(5),ST(0)	ST(6),ST(0)	ST(7),ST(0)
	8	9	A	B	C	D	E	F
C	FMUL							
	ST(0),ST(0)	ST(1),ST(0)	ST(2),ST(0)	ST(3),ST(0)	ST(4),ST(0)	ST(5),ST(0)	ST(6),ST(0)	ST(7),ST(0)
D								
E	FSUB							
	ST(0),ST(0)	ST(1),ST(0)	ST(2),ST(0)	ST(3),ST(0)	ST(4),ST(0)	ST(5),ST(0)	ST(6),ST(0)	ST(7),ST(0)
F	FDIV							
	ST(0),ST(0)	ST(1),ST(0)	ST(2),ST(0)	ST(3),ST(0)	ST(4),ST(0)	ST(5),ST(0)	ST(6),ST(0)	ST(7),ST(0)

NOTE:

1. All blanks in the opcode map are reserved and should not be used. Do not depend on the operation of these undefined opcodes.

A.3.4.8. ESCAPE OPCODES WITH DD AS FIRST BYTE

Tables A-16 and A-17 contain the opcodes maps for the escape instruction opcodes that begin with DDH. Table A-16 shows the opcode map if the accompanying ModR/M byte within the range of 00H through BFH. Here, the value of bits 5, 4, and 3 (the nnn field in Figure A-1) selects the instruction.

Table A-16. DD Opcode Map When ModR/M Byte is Within 00H to BFH[1]

nnn Field of ModR/M Byte (refer to Figure A-1)							
000	001	010	011	100	101	110	111
FLD double-real		FST double-real	FSTP double-real	FRSTOR 98/108bytes		FSAVE 98/108bytes	FSTSW 2 bytes

NOTE:

1. All blanks in the opcode map are reserved and should not be used. Do not depend on the operation of these undefined opcodes.

Table A-17 shows the opcode map if the accompanying ModR/M byte is outside the range of 00H to BFH. In this case the first digit of the ModR/M byte selects the row in the table and the second digit selects the column.

Table A-17. DD Opcode Map When ModR/M Byte is Outside 00H to BFH[1]

	0	1	2	3	4	5		7
C	FFREE							
	ST(0)	ST(1)	ST(2)	ST(3)	ST(4)	ST(5)	ST(6)	ST(7)
D	FST							
	ST(0)	ST(1)	ST(2)	ST(3)	ST(4)	ST(5)	ST(6)	ST(7)
E	FUCOM							
	ST(0),ST(0)	ST(1),ST(0)	ST(2),ST(0)	ST(3),ST(0)	ST(4),ST(0)	ST(5),ST(0)	ST(6),ST(0)	ST(7),ST(0)
F								
	8	9	A	B	C	D	E	F
C								
D	FSTP							
	ST(0)	ST(1)	ST(2)	ST(3)	ST(4)	ST(5)	ST(6)	ST(7)
E	FUCOMP							
	ST(0)	ST(1)	ST(2)	ST(3)	ST(4)	ST(5)	ST(6)	ST(7)
F								

NOTE:

1. All blanks in the opcode map are reserved and should not be used. Do not depend on the operation of these undefined opcodes.

A.3.4.9. ESCAPE OPCODES WITH DE AS FIRST BYTE

Tables A-18 and A-19 contain the opcodes maps for the escape instruction opcodes that begin with DEH. Table A-18 shows the opcode map if the accompanying ModR/M byte within the range of 00H through BFH. Here, the value of bits 5, 4, and 3 (the nnn field in Figure A-1) selects the instruction.

Table A-18. DE Opcode Map When ModR/M Byte is Within 00H to BFH[1]

nnn Field of ModR/M Byte (refer to Figure A-1)							
000	001	010	011	100	101	110	111
FIADD word-integer	FIMUL word-integer	FICOM word-integer	FICOMP word-integer	FISUB word-integer	FISUBR word-integer	FIDIV word-integer	FIDIVR word-integer

NOTE:

1. All blanks in the opcode map are reserved and should not be used. Do not depend on the operation of these undefined opcodes.

Table A-19 shows the opcode map if the accompanying ModR/M byte is outside the range of 00H to BFH. In this case the first digit of the ModR/M byte selects the row in the table and the second digit selects the column.

Table A-19. DE Opcode Map When ModR/M Byte is Outside 00H to BFH[1]

	0	1	2	3	4	5		7
C	FADDP							
	ST(0),ST(0)	ST(1),ST(0)	ST(2),ST(0)	ST(3),ST(0)	ST(4),ST(0)	ST(5),ST(0)	ST(6),ST(0)	ST(7),ST(0)
D								
E	FSUBRP							
	ST(0),ST(0)	ST(1),ST(0)	ST(2),ST(0)	ST(3),ST(0)	ST(4),ST(0)	ST(5),ST(0)	ST(6),ST(0)	ST(7),ST(0)
F	FDIVRP							
	ST(0),ST(0)	ST(1),ST(0)	ST(2),ST(0)	ST(3),ST(0)	ST(4),ST(0)	ST(5),ST(0)	ST(6),ST(0)	ST(7),ST(0)
	8	9	A	B	C	D	E	F
C	FMULP							
	ST(0),ST(0)	ST(1),ST(0)	ST(2),ST(0)	ST(3),ST(0)	ST(4),ST(0)	ST(5),ST(0)	ST(6),ST(0)	ST(7),ST(0)
D		FCOMPP						
E	FSUBP							
	ST(0),ST(0)	ST(1),ST(0)	ST(2),ST(0)	ST(3),ST(0)	ST(4),ST(0)	ST(5),ST(0)	ST(6),ST(0)	ST(7),ST(0)
F	FDIVP							
	ST(0),ST(0)	ST(1),ST(0)	ST(2),ST(0).	ST(3),ST(0)	ST(4),ST(0)	ST(5),ST(0)	ST(6),ST(0)	ST(7),ST(0)

NOTE:

1. All blanks in the opcode map are reserved and should not be used. Do not depend on the operation of these undefined opcodes.

A.3.4.10. ESCAPE OPCODES WITH DF AS FIRST BYTE

Tables A-20 and A-21 contain the opcodes maps for the escape instruction opcodes that begin with DFH. Table A-20 shows the opcode map if the accompanying ModR/M byte within the range of 00H through BFH. Here, the value of bits 5, 4, and 3 (the nnn field in Figure A-1) selects the instruction.

Table A-20. DF Opcode Map When ModR/M Byte is Within 00H to BFH[1]

nnn Field of ModR/M Byte (refer to Figure A-1)							
000	001	010	011	100	101	110	111
FILD word-integer		FIST word-integer	FISTP word-integer	FBLD packed-BCD	FILD qword-integer	FBSTP packed-BCD	FISTP qword-integer

NOTE:

1. All blanks in the opcode map are reserved and should not be used. Do not depend on the operation of these undefined opcodes.

Table A-21 shows the opcode map if the accompanying ModR/M byte is outside the range of 00H to BFH. In this case the first digit of the ModR/M byte selects the row in the table and the second digit selects the column.

Table A-21. DF Opcode Map When ModR/M Byte is Outside 00H to BFH[1]

	0	1	2	3	4	5		7
C								
D								
E	FSTSW AX							
F	FCOMIP							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
	8	9	A	B	C	D	E	F
C								
D								
E	FUCOMIP							
	ST(0),ST(0)	ST(0),ST(1)	ST(0),ST(2)	ST(0),ST(3)	ST(0),ST(4)	ST(0),ST(5)	ST(0),ST(6)	ST(0),ST(7)
F								

NOTE:

1. All blanks in the opcode map are reserved and should not be used. Do not depend on the operation of these undefined opcodes.

B

Instruction Formats and Encodings

APPENDIX B
INSTRUCTION FORMATS AND ENCODINGS

This appendix shows the formats and encodings of the Intel Architecture instructions. The main format and encoding tables are Tables B-10, B-14, B-20, and B-23.

B.1. MACHINE INSTRUCTION FORMAT

All Intel Architecture instructions are encoded using subsets of the general machine instruction format shown in Figure B-1. Each instruction consists of an opcode, a register and/or address mode specifier (if required) consisting of the ModR/M byte and sometimes the scale-index-base (SIB) byte, a displacement (if required), and an immediate data field (if required).

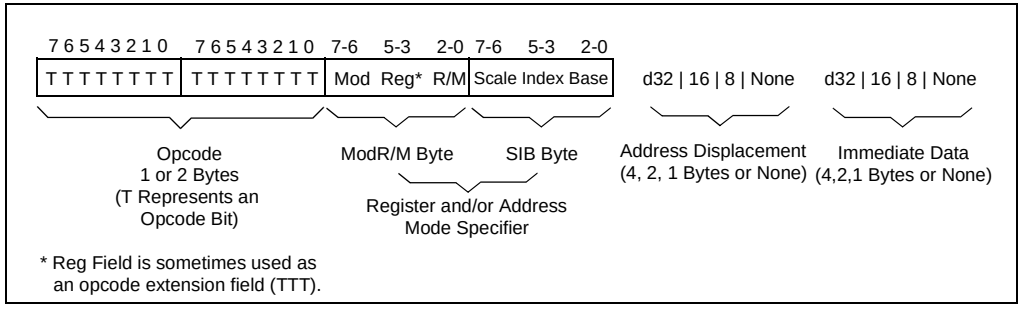


Figure B-1. General Machine Instruction Format

The primary opcode for an instruction is encoded in one or two bytes of the instruction. Some instructions also use an opcode extension field encoded in bits 5, 4, and 3 of the ModR/M byte. Within the primary opcode, smaller encoding fields may be defined. These fields vary according to the class of operation being performed. The fields define such information as register encoding, conditional test performed, or sign extension of immediate byte.

Almost all instructions that refer to a register and/or memory operand have a register and/or address mode byte following the opcode. This byte, the ModR/M byte, consists of the mod field, the reg field, and the R/M field. Certain encodings of the ModR/M byte indicate that a second address mode byte, the SIB byte, must be used.

If the selected addressing mode specifies a displacement, the displacement value is placed immediately following the ModR/M byte or SIB byte. If a displacement is present, the possible sizes are 8, 16, or 32 bits.

If the instruction specifies an immediate operand, the immediate value follows any displacement bytes. An immediate operand, if specified, is always the last field of the instruction.

Table B-1 lists several smaller fields or bits that appear in certain instructions, sometimes within the opcode bytes themselves. The following tables describe these fields and bits and list the allowable values. All of these fields (except the d bit) are shown in the integer instruction formats given in Table B-10.

Table B-1. Special Fields Within Instruction Encodings

Field Name	Description	Number of Bits
reg	General-register specifier (refer to Table B-2 or B-3)	3
w	Specifies if data is byte or full-sized, where full-sized is either 16 or 32 bits (refer to Table B-4)	1
s	Specifies sign extension of an immediate data field (refer to Table B-5)	1
sreg2	Segment register specifier for CS, SS, DS, ES (refer to Table B-6)	2
sreg3	Segment register specifier for CS, SS, DS, ES, FS, GS (refer to Table B-6)	3
eee	Specifies a special-purpose (control or debug) register (refer to Table B-7)	3
tttn	For conditional instructions, specifies a condition asserted or a condition negated (refer to Table B-8)	4
d	Specifies direction of data operation (refer to Table B-9)	1

B.1.1. Reg Field (reg)

The reg field in the ModR/M byte specifies a general-purpose register operand. The group of registers specified is modified by the presence of and state of the w bit in an encoding (refer to Table B-4). Table B-2 shows the encoding of the reg field when the w bit is not present in an encoding, and Table B-3 shows the encoding of the reg field when the w bit is present.

Table B-2. Encoding of reg Field When w Field is Not Present in Instruction

reg Field	Register Selected during 16-Bit Data Operations	Register Selected during 32-Bit Data Operations
000	AX	EAX
001	CX	ECX
010	DX	EDX
011	BX	EBX
100	SP	ESP
101	BP	EBP
110	SI	ESI
111	DI	EDI

Table B-3. Encoding of reg Field When w Field is Present in Instruction

Register Specified by reg Field during 16-Bit Data Operations		
	Function of w Field	
reg	When w = 0	When w = 1
000	AL	AX
001	CL	CX
010	DL	DX
011	BL	BX
100	AH	SP
101	CH	BP
110	DH	SI
111	BH	DI

Register Specified by reg Field during 32-Bit Data Operations		
	Function of w Field	
reg	When w = 0	When w = 1
000	AL	EAX
001	CL	ECX
010	DL	EDX
011	BL	EBX
100	AH	ESP
101	CH	EBP
110	DH	ESI
111	BH	EDI

B.1.2. Encoding of Operand Size Bit (w)

The current operand-size attribute determines whether the processor is performing 16-or 32-bit operations. Within the constraints of the current operand-size attribute, the operand-size bit (w) can be used to indicate operations on 8-bit operands or the full operand size specified with the operand-size attribute (16 bits or 32 bits). Table B-4 shows the encoding of the w bit depending on the current operand-size attribute.

Table B-4. Encoding of Operand Size (w) Bit

w Bit	Operand Size When Operand-Size Attribute is 16 bits	Operand Size When Operand-Size Attribute is 32 bits
0	8 Bits	8 Bits
1	16 Bits	32 Bits

B.1.3. Sign Extend (s) Bit

The sign-extend (s) bit occurs primarily in instructions with immediate data fields that are being extended from 8 bits to 16 or 32 bits. Table B-5 shows the encoding of the s bit.

Table B-5. Encoding of Sign-Extend (s) Bit

s	Effect on 8-Bit Immediate Data	Effect on 16- or 32-Bit Immediate Data
0	None	None
1	Sign-extend to fill 16-bit or 32-bit destination	None

B.1.4. Segment Register Field (sreg)

When an instruction operates on a segment register, the reg field in the ModR/M byte is called the sreg field and is used to specify the segment register. Table B-6 shows the encoding of the sreg field. This field is sometimes a 2-bit field (sreg2) and other times a 3-bit field (sreg3).

Table B-6. Encoding of the Segment Register (sreg) Field

2-Bit sreg2 Field	Segment Register Selected
00	ES
01	CS
10	SS
11	DS

3-Bit sreg3 Field	Segment Register Selected
000	ES
001	CS
010	SS
011	DS
100	FS
101	GS
110	Reserved*
111	Reserved*

***** Do not use reserved encodings.

B.1.5. Special-Purpose Register (eee) Field

When the control or debug registers are referenced in an instruction they are encoded in the eee field, which is located in bits 5, 4, and 3 of the ModR/M byte. Table B-7 shows the encoding of the eee field.

Table B-7. Encoding of Special-Purpose Register (eee) Field

eee	Control Register	Debug Register
000	CR0	DR0
001	Reserved*	DR1
010	CR2	DR2
011	CR3	DR3
100	CR4	Reserved*
101	Reserved*	Reserved*
110	Reserved*	DR6
111	Reserved*	DR7

***** Do not use reserved encodings.

B.1.6. Condition Test Field (tttn)

For conditional instructions (such as conditional jumps and set on condition), the condition test field (tttn) is encoded for the condition being tested for. The tt part of the field gives the condition to test and the n part indicates whether to use the condition (n = 0) or its negation (n = 1). For 1-byte primary opcodes, the tttn field is located in bits 3,2,1, and 0 of the opcode byte; for 2-byte primary opcodes, the tttn field is located in bits 3,2,1, and 0 of the second opcode byte. Table B-8 shows the encoding of the tttn field.

Table B-8. Encoding of Conditional Test (tttn) Field

t t t n	Mnemonic	Condition
0000	O	Overflow
0001	NO	No overflow
0010	B, NAE	Below, Not above or equal
0011	NB, AE	Not below, Above or equal
0100	E, Z	Equal, Zero
0101	NE, NZ	Not equal, Not zero
0110	BE, NA	Below or equal, Not above
0111	NBE, A	Not below or equal, Above
1000	S	Sign
1001	NS	Not sign
1010	P, PE	Parity, Parity Even
1011	NP, PO	Not parity, Parity Odd
1100	L, NGE	Less than, Not greater than or equal to
1101	NL, GE	Not less than, Greater than or equal to
1110	LE, NG	Less than or equal to, Not greater than
1111	NLE, G	Not less than or equal to, Greater than

B.1.7. Direction (d) Bit

In many two-operand instructions, a direction bit (d) indicates which operand is considered the source and which is the destination. Table B-9 shows the encoding of the d bit. When used for integer instructions, the d bit is located at bit 1 of a 1-byte primary opcode. This bit does not appear as the symbol “d” in Table B-10; instead, the actual encoding of the bit as 1 or 0 is given. When used for floating-point instructions (in Table B-23), the d bit is shown as bit 2 of the first byte of the primary opcode.

Table B-9. Encoding of Operation Direction (d) Bit

d	Source	Destination
0	reg Field	ModR/M or SIB Byte
1	ModR/M or SIB Byte	reg Field

B.2. INTEGER INSTRUCTION FORMATS AND ENCODINGS

Table B-10 shows the formats and encodings of the integer instructions.

Table B-10. Integer Instruction Formats and Encodings

Instruction and Format	Encoding
AAA – ASCII Adjust after Addition	0011 0111
AAD – ASCII Adjust AX before Division	1101 0101 : 0000 1010
AAM – ASCII Adjust AX after Multiply	1101 0100 : 0000 1010
AAS – ASCII Adjust AL after Subtraction	0011 1111
ADC – ADD with Carry	
register1 to register2	0001 000w : 11 reg1 reg2
register2 to register1	0001 001w : 11 reg1 reg2
memory to register	0001 001w : mod reg r/m
register to memory	0001 000w : mod reg r/m
immediate to register	1000 00sw : 11 010 reg : immediate data
immediate to AL, AX, or EAX	0001 010w : immediate data
immediate to memory	1000 00sw : mod 010 r/m : immediate data
ADD – Add	
register1 to register2	0000 000w : 11 reg1 reg2
register2 to register1	0000 001w : 11 reg1 reg2
memory to register	0000 001w : mod reg r/m
register to memory	0000 000w : mod reg r/m
immediate to register	1000 00sw : 11 000 reg : immediate data
immediate to AL, AX, or EAX	0000 010w : immediate data
immediate to memory	1000 00sw : mod 000 r/m : immediate data

Table B-10. Integer Instruction Formats and Encodings (Contd.)

Instruction and Format	Encoding
AND – Logical AND	
register1 to register2	0010 000w : 11 reg1 reg2
register2 to register1	0010 001w : 11 reg1 reg2
memory to register	0010 001w : mod reg r/m
register to memory	0010 000w : mod reg r/m
immediate to register	
immediate to AL, AX, or EAX	0010 010w : immediate data
immediate to memory	1000 00sw : mod 100 r/m : immediate data
ARPL – Adjust RPL Field of Selector	
from register	0110 0011 : 11 reg1 reg2
from memory	0110 0011 : mod reg r/m
BOUND – Check Array Against Bounds	0110 0010 : mod reg r/m
BSF – Bit Scan Forward	
register1, register2	0000 1111 : 1011 1100 : 11 reg2 reg1
memory, register	0000 1111 : 1011 1100 : mod reg r/m
BSR – Bit Scan Reverse	
register1, register2	0000 1111 : 1011 1101 : 11 reg2 reg1
memory, register	0000 1111 : 1011 1101 : mod reg r/m
BSWAP – Byte Swap	0000 1111 : 1100 1 reg
BT – Bit Test	
register, immediate	0000 1111 : 1011 1010 : 11 100 reg: imm8 data
memory, immediate	0000 1111 : 1011 1010 : mod 100 r/m : imm8 data
register1, register2	0000 1111 : 1010 0011 : 11 reg2 reg1
memory, reg	0000 1111 : 1010 0011 : mod reg r/m
BTC – Bit Test and Complement	
register, immediate	0000 1111 : 1011 1010 : 11 111 reg: imm8 data
memory, immediate	0000 1111 : 1011 1010 : mod 111 r/m : imm8 data
register1, register2	0000 1111 : 1011 1011 : 11 reg2 reg1
memory, reg	0000 1111 : 1011 1011 : mod reg r/m
BTR – Bit Test and Reset	
register, immediate	0000 1111 : 1011 1010 : 11 110 reg: imm8 data
memory, immediate	0000 1111 : 1011 1010 : mod 110 r/m : imm8 data
register1, register2	0000 1111 : 1011 0011 : 11 reg2 reg1
memory, reg	0000 1111 : 1011 0011 : mod reg r/m

Table B-10. Integer Instruction Formats and Encodings (Contd.)

Instruction and Format	Encoding
BTS – Bit Test and Set	
register, immediate	0000 1111 : 1011 1010 : 11 101 reg: imm8 data
memory, immediate	0000 1111 : 1011 1010 : mod 101 r/m : imm8 data
register1, register2	0000 1111 : 1010 1011 : 11 reg2 reg1
memory, reg	0000 1111 : 1010 1011 : mod reg r/m
CALL – Call Procedure (in same segment)	
direct	1110 1000 : full displacement
register indirect	1111 1111 : 11 010 reg
memory indirect	1111 1111 : mod 010 r/m
CALL – Call Procedure (in other segment)	
direct	1001 1010 : unsigned full offset, selector
indirect	1111 1111 : mod 011 r/m
CBW – Convert Byte to Word	1001 1000
CDQ – Convert Doubleword to Qword	1001 1001
CLC – Clear Carry Flag	1111 1000
CLD – Clear Direction Flag	1111 1100
CLI – Clear Interrupt Flag	1111 1010
CLTS – Clear Task-Switched Flag in CR0	0000 1111 : 0000 0110
CMC – Complement Carry Flag	1111 0101
CMOVcc – Conditional Move	
register2 to register1	0000 1111: 0100 tttn : 11 reg1 reg2
memory to register	0000 1111: 0100 tttn : mod mem r/m
CMP – Compare Two Operands	
register1 with register2	0011 100w : 11 reg1 reg2
register2 with register1	0011 101w : 11 reg1 reg2
memory with register	0011 100w : mod reg r/m
register with memory	0011 101w : mod reg r/m
immediate with register	1000 00sw : 11 111 reg : immediate data
immediate with AL, AX, or EAX	0011 110w : immediate data
immediate with memory	1000 00sw : mod 111 r/m
CMPS/CMPSB/CMPSW/CMPSD – Compare String Operands	1010 011w
CMPXCHG – Compare and Exchange	
register1, register2	0000 1111 : 1011 000w : 11 reg2 reg1
memory, register	0000 1111 : 1011 000w : mod reg r/m

Table B-10. Integer Instruction Formats and Encodings (Contd.)

Instruction and Format	Encoding
CMPXCHG8B – Compare and Exchange 8 Bytes	
memory, register	0000 1111 : 1100 0111 : mod reg r/m
CPUID – CPU Identification	0000 1111 : 1010 0010
CWD – Convert Word to Doubleword	1001 1001
CWDE – Convert Word to Doubleword	1001 1000
DAA – Decimal Adjust AL after Addition	0010 0111
DAS – Decimal Adjust AL after Subtraction	0010 1111
DEC – Decrement by 1	
register	1111 111w : 11 001 reg
register (alternate encoding)	0100 1 reg
memory	1111 111w : mod 001 r/m
DIV – Unsigned Divide	
AL, AX, or EAX by register	1111 011w : 11 110 reg
AL, AX, or EAX by memory	1111 011w : mod 110 r/m
ENTER – Make Stack Frame for High Level Procedure	1100 1000 : 16-bit displacement : 8-bit level (L)
HLT – Halt	1111 0100
IDIV – Signed Divide	
AL, AX, or EAX by register	1111 011w : 11 111 reg
AL, AX, or EAX by memory	1111 011w : mod 111 r/m
IMUL – Signed Multiply	
AL, AX, or EAX with register	1111 011w : 11 101 reg
AL, AX, or EAX with memory	1111 011w : mod 101 reg
register1 with register2	0000 1111 : 1010 1111 : 11 : reg1 reg2
register with memory	0000 1111 : 1010 1111 : mod reg r/m
register1 with immediate to register2	0110 10s1 : 11 reg1 reg2 : immediate data
memory with immediate to register	0110 10s1 : mod reg r/m : immediate data
IN – Input From Port	
fixed port	1110 010w : port number
variable port	1110 110w
INC – Increment by 1	
reg	1111 111w : 11 000 reg
reg (alternate encoding)	0100 0 reg
memory	1111 111w : mod 000 r/m
INS – Input from DX Port	0110 110w

Table B-10. Integer Instruction Formats and Encodings (Contd.)

Instruction and Format	Encoding
INT n – Interrupt Type n	1100 1101 : type
INT – Single-Step Interrupt 3	1100 1100
INTO – Interrupt 4 on Overflow	1100 1110
INVD – Invalidate Cache	0000 1111 : 0000 1000
INVLPG – Invalidate TLB Entry	0000 1111 : 0000 0001 : mod 111 r/m
IRET/IRETD – Interrupt Return	1100 1111
J*cc* – Jump if Condition is Met	
8-bit displacement	0111 tttn : 8-bit displacement
full displacement	0000 1111 : 1000 tttn : full displacement
JCXZ/JECXZ – Jump on CX/ECX Zero Address-size prefix differentiates JCXZ and JECXZ	1110 0011 : 8-bit displacement
JMP – Unconditional Jump (to same segment)	
short	1110 1011 : 8-bit displacement
direct	1110 1001 : full displacement
register indirect	1111 1111 : 11 100 reg
memory indirect	1111 1111 : mod 100 r/m
JMP – Unconditional Jump (to other segment)	
direct intersegment	1110 1010 : unsigned full offset, selector
indirect intersegment	1111 1111 : mod 101 r/m
LAHF – Load Flags into AHRegister	1001 1111
LAR – Load Access Rights Byte	
from register	0000 1111 : 0000 0010 : 11 reg1 reg2
from memory	0000 1111 : 0000 0010 : mod reg r/m
LDS – Load Pointer to DS	1100 0101 : mod reg r/m
LEA – Load Effective Address	1000 1101 : mod reg r/m
LEAVE – High Level Procedure Exit	1100 1001
LES – Load Pointer to ES	1100 0100 : mod reg r/m
LFS – Load Pointer to FS	0000 1111 : 1011 0100 : mod reg r/m
LGDT – Load Global Descriptor Table Register	0000 1111 : 0000 0001 : mod 010 r/m
LGS – Load Pointer to GS	0000 1111 : 1011 0101 : mod reg r/m
LIDT – Load Interrupt Descriptor Table Register	
LLDT – Load Local Descriptor Table Register	
LDTR from register	0000 1111 : 0000 0000 : 11 010 reg
LDTR from memory	0000 1111 : 0000 0000 : mod 010 r/m

Table B-10. Integer Instruction Formats and Encodings (Contd.)

Instruction and Format	Encoding
LMSW – Load Machine Status Word	
from register	0000 1111 : 0000 0001 : 11 110 reg
from memory	0000 1111 : 0000 0001 : mod 110 r/m
LOCK – Assert LOCK# Signal Prefix	1111 0000
LODS/LODSB/LODSW/LODSD – Load String Operand	1010 110w
LOOP – Loop Count	1110 0010 : 8-bit displacement
LOOPZ/LOOPE – Loop Count while Zero/Equal	1110 0001 : 8-bit displacement
LOOPNZ/LOOPNE – Loop Count while not Zero/Equal	1110 0000 : 8-bit displacement
LSL – Load Segment Limit	
from register	0000 1111 : 0000 0011 : 11 reg1 reg2
from memory	0000 1111 : 0000 0011 : mod reg r/m
LSS – Load Pointer to SS	0000 1111 : 1011 0010 : mod reg r/m
LTR – Load Task Register	
from register	0000 1111 : 0000 0000 : 11 011 reg
from memory	0000 1111 : 0000 0000 : mod 011 r/m
MOV – Move Data	
register1 to register2	1000 100w : 11 reg1 reg2
register2 to register1	1000 101w : 11 reg1 reg2
memory to reg	1000 101w : mod reg r/m
reg to memory	1000 100w : mod reg r/m
immediate to register	1100 011w : 11 000 reg : immediate data
immediate to register (alternate encoding)	1011 w reg : immediate data
immediate to memory	1100 011w : mod 000 r/m : immediate data
memory to AL, AX, or EAX	1010 000w : full displacement
AL, AX, or EAX to memory	1010 001w : full displacement
MOV – Move to/from Control Registers	
CR0 from register	0000 1111 : 0010 0010 : 11 000 reg
CR2 from register	0000 1111 : 0010 0010 : 11 010reg
CR3 from register	0000 1111 : 0010 0010 : 11 011 reg
CR4 from register	0000 1111 : 0010 0010 : 11 100 reg
register from CR0-CR4	0000 1111 : 0010 0000 : 11 eee reg

Table B-10. Integer Instruction Formats and Encodings (Contd.)

Instruction and Format	Encoding
MOV – Move to/from Debug Registers	
DR0-DR3 from register	0000 1111 : 0010 0011 : 11 eee reg
DR4-DR5 from register	0000 1111 : 0010 0011 : 11 eee reg
DR6-DR7 from register	0000 1111 : 0010 0011 : 11 eee reg
register from DR6-DR7	0000 1111 : 0010 0001 : 11 eee reg
register from DR4-DR5	0000 1111 : 0010 0001 : 11 eee reg
register from DR0-DR3	0000 1111 : 0010 0001 : 11 eee reg
MOV – Move to/from Segment Registers	
register to segment register	1000 1110 : 11 sreg3 reg
register to SS	1000 1110 : 11 sreg3 reg
memory to segment reg	1000 1110 : mod sreg3 r/m
memory to SS	1000 1110 : mod sreg3 r/m
segment register to register	1000 1100 : 11 sreg3 reg
segment register to memory	1000 1100 : mod sreg3 r/m
MOVS/MOVSB/MOVSW/MOVSD – Move Data from String to String	1010 010w
MOVSX – Move with Sign-Extend	
register2 to register1	0000 1111 : 1011 111w : 11 reg1 reg2
memory to reg	0000 1111 : 1011 111w : mod reg r/m
MOVZX – Move with Zero-Extend	
register2 to register1	0000 1111 : 1011 011w : 11 reg1 reg2
memory to register	0000 1111 : 1011 011w : mod reg r/m
MUL – Unsigned Multiply	
AL, AX, or EAX with register	1111 011w : 11 100 reg
AL, AX, or EAX with memory	1111 011w : mod 100 reg
NEG – Two's Complement Negation	
register	1111 011w : 11 011 reg
memory	1111 011w : mod 011 r/m
NOP – No Operation	1001 0000
NOT – One's Complement Negation	
register	1111 011w : 11 010 reg
memory	1111 011w : mod 010 r/m

Table B-10. Integer Instruction Formats and Encodings (Contd.)

Instruction and Format	Encoding
OR – Logical Inclusive OR	
register1 to register2	0000 100w : 11 reg1 reg2
register2 to register1	0000 101w : 11 reg1 reg2
memory to register	0000 101w : mod reg r/m
register to memory	0000 100w : mod reg r/m
immediate to register	1000 00sw : 11 001 reg : immediate data
immediate to AL, AX, or EAX	0000 110w : immediate data
immediate to memory	1000 00sw : mod 001 r/m : immediate data
OUT – Output to Port	
fixed port	1110 011w : port number
variable port	1110 111w
OUTS – Output to DX Port	0110 111w
POP – Pop a Word from the Stack	
register	1000 1111 : 11 000 reg
register (alternate encoding)	0101 1 reg
memory	1000 1111 : mod 000 r/m
POP – Pop a Segment Register from the Stack	
segment register CS, DS, ES	000 sreg2 111
segment register SS	000 sreg2 111
segment register FS, GS	0000 1111: 10 sreg3 001
POPA/POPAD – Pop All General Registers	0110 0001
POPF/POPFD – Pop Stack into FLAGS or EFLAGS Register	1001 1101
PUSH – Push Operand onto the Stack	
register	1111 1111 : 11 110 reg
register (alternate encoding)	0101 0 reg
memory	1111 1111 : mod 110 r/m
immediate	0110 10s0 : immediate data
PUSH – Push Segment Register onto the Stack	
segment register CS,DS,ES,SS	000 sreg2 110
segment register FS,GS	0000 1111: 10 sreg3 000
PUSHA/PUSHAD – Push All General Registers	0110 0000
PUSHF/PUSHFD – Push Flags Register onto the Stack	1001 1100

Table B-10. Integer Instruction Formats and Encodings (Contd.)

Instruction and Format	Encoding
RCL – Rotate thru Carry Left	
register by 1	1101 000w : 11 010 reg
memory by 1	1101 000w : mod 010 r/m
register by CL	1101 001w : 11 010 reg
memory by CL	1101 001w : mod 010 r/m
register by immediate count	1100 000w : 11 010 reg : imm8 data
memory by immediate count	1100 000w : mod 010 r/m : imm8 data
RCR – Rotate thru Carry Right	
register by 1	1101 000w : 11 011 reg
memory by 1	1101 000w : mod 011 r/m
register by CL	1101 001w : 11 011 reg
memory by CL	1101 001w : mod 011 r/m
register by immediate count	1100 000w : 11 011 reg : imm8 data
memory by immediate count	1100 000w : mod 011 r/m : imm8 data
RDMSR – Read from Model-Specific Register	0000 1111 : 0011 0010
RDPMC – Read Performance Monitoring Counters	0000 1111 : 0011 0011
RDTSC – Read Time-Stamp Counter	0000 1111 : 0011 0001
REP INS – Input String	1111 0011 : 0110 110w
REP LODS – Load String	1111 0011 : 1010 110w
REP MOVS – Move String	1111 0011 : 1010 010w
REP OUTS – Output String	1111 0011 : 0110 111w
REP STOS – Store String	1111 0011 : 1010 101w
REPE CMPS – Compare String	1111 0011 : 1010 011w
REPE SCAS – Scan String	1111 0011 : 1010 111w
REPNE CMPS – Compare String	1111 0010 : 1010 011w
REPNE SCAS – Scan String	1111 0010 : 1010 111w
RET – Return from Procedure (to same segment)	
no argument	1100 0011
adding immediate to SP	1100 0010 : 16-bit displacement
RET – Return from Procedure (to other segment)	
intersegment	1100 1011
adding immediate to SP	1100 1010 : 16-bit displacement

Table B-10. Integer Instruction Formats and Encodings (Contd.)

Instruction and Format	Encoding
ROL – Rotate Left	
register by 1	1101 000w : 11 000 reg
memory by 1	1101 000w : mod 000 r/m
register by CL	1101 001w : 11 000 reg
memory by CL	1101 001w : mod 000 r/m
register by immediate count	1100 000w : 11 000 reg : imm8 data
memory by immediate count	1100 000w : mod 000 r/m : imm8 data
ROR – Rotate Right	
register by 1	1101 000w : 11 001 reg
memory by 1	1101 000w : mod 001 r/m
register by CL	1101 001w : 11 001 reg
memory by CL	1101 001w : mod 001 r/m
register by immediate count	1100 000w : 11 001 reg : imm8 data
memory by immediate count	1100 000w : mod 001 r/m : imm8 data
RSM – Resume from System Management Mode	0000 1111 : 1010 1010
SAHF – Store AH into Flags	1001 1110
SAL – Shift Arithmetic Left	same instruction as SHL
SAR – Shift Arithmetic Right	
register by 1	1101 000w : 11 111 reg
memory by 1	1101 000w : mod 111 r/m
register by CL	1101 001w : 11 111 reg
memory by CL	1101 001w : mod 111 r/m
register by immediate count	1100 000w : 11 111 reg : imm8 data
memory by immediate count	1100 000w : mod 111 r/m : imm8 data
SBB – Integer Subtraction with Borrow	
register1 to register2	0001 100w : 11 reg1 reg2
register2 to register1	0001 101w : 11 reg1 reg2
memory to register	0001 101w : mod reg r/m
register to memory	0001 100w : mod reg r/m
immediate to register	1000 00sw : 11 011 reg : immediate data
immediate to AL, AX, or EAX	0001 110w : immediate data
immediate to memory	1000 00sw : mod 011 r/m : immediate data
SCAS/SCASB/SCASW/SCASD – Scan String	1101 111w

Table B-10. Integer Instruction Formats and Encodings (Contd.)

Instruction and Format	Encoding
SETcc – Byte Set on Condition	
register	0000 1111 : 1001 tttn : 11 000 reg
memory	0000 1111 : 1001 tttn : mod 000 r/m
SGDT – Store Global Descriptor Table Register	0000 1111 : 0000 0001 : mod 000 r/m
SHL – Shift Left	
register by 1	1101 000w : 11 100 reg
memory by 1	1101 000w : mod 100 r/m
register by CL	1101 001w : 11 100 reg
memory by CL	1101 001w : mod 100 r/m
register by immediate count	1100 000w : 11 100 reg : imm8 data
memory by immediate count	1100 000w : mod 100 r/m : imm8 data
SHLD – Double Precision Shift Left	
register by immediate count	0000 1111 : 1010 0100 : 11 reg2 reg1 : imm8
memory by immediate count	0000 1111 : 1010 0100 : mod reg r/m : imm8
register by CL	0000 1111 : 1010 0101 : 11 reg2 reg1
memory by CL	0000 1111 : 1010 0101 : mod reg r/m
SHR – Shift Right	
register by 1	1101 000w : 11 101 reg
memory by 1	1101 000w : mod 101 r/m
register by CL	1101 001w : 11 101 reg
memory by CL	1101 001w : mod 101 r/m
register by immediate count	1100 000w : 11 101 reg : imm8 data
memory by immediate count	1100 000w : mod 101 r/m : imm8 data
SHRD – Double Precision Shift Right	
register by immediate count	0000 1111 : 1010 1100 : 11 reg2 reg1 : imm8
memory by immediate count	0000 1111 : 1010 1100 : mod reg r/m : imm8
register by CL	0000 1111 : 1010 1101 : 11 reg2 reg1
memory by CL	0000 1111 : 1010 1101 : mod reg r/m
SIDT – Store Interrupt Descriptor Table Register	0000 1111 : 0000 0001 : mod 001 r/m
SLDT – Store Local Descriptor Table Register	
to register	0000 1111 : 0000 0000 : 11 000 reg
to memory	0000 1111 : 0000 0000 : mod 000 r/m

Table B-10. Integer Instruction Formats and Encodings (Contd.)

Instruction and Format	Encoding
SMSW – Store Machine Status Word	
to register	0000 1111 : 0000 0001 : 11 100 reg
to memory	0000 1111 : 0000 0001 : mod 100 r/m
STC – Set Carry Flag	1111 1001
STD – Set Direction Flag	1111 1101
STI – Set Interrupt Flag	1111 1011
STOS/STOSB/STOSW/STOSD – Store String Data	1010 101w
STR – Store Task Register	
to register	0000 1111 : 0000 0000 : 11 001 reg
to memory	0000 1111 : 0000 0000 : mod 001 r/m
SUB – Integer Subtraction	
register1 to register2	0010 100w : 11 reg1 reg2
register2 to register1	0010 101w : 11 reg1 reg2
memory to register	0010 101w : mod reg r/m
register to memory	0010 100w : mod reg r/m
immediate to register	1000 00sw : 11 101 reg : immediate data
immediate to AL, AX, or EAX	0010 110w : immediate data
immediate to memory	1000 00sw : mod 101 r/m : immediate data
TEST – Logical Compare	
register1 and register2	1000 010w : 11 reg1 reg2
memory and register	1000 010w : mod reg r/m
immediate and register	1111 011w : 11 000 reg : immediate data
immediate and AL, AX, or EAX	1010 100w : immediate data
immediate and memory	1111 011w : mod 000 r/m : immediate data
UD2 – Undefined instruction	0000 FFFF : 0000 1011
VERR – Verify a Segment for Reading	
register	0000 1111 : 0000 0000 : 11 100 reg
memory	0000 1111 : 0000 0000 : mod 100 r/m
VERW – Verify a Segment for Writing	
register	0000 1111 : 0000 0000 : 11 101 reg
memory	0000 1111 : 0000 0000 : mod 101 r/m
WAIT – Wait	1001 1011
WBINVD – Writeback and Invalidate Data Cache	0000 1111 : 0000 1001
WRMSR – Write to Model-Specific Register	0000 1111 : 0011 0000

Table B-10. Integer Instruction Formats and Encodings (Contd.)

Instruction and Format	Encoding
XADD – Exchange and Add	
register1, register2	0000 1111 : 1100 000w : 11 reg2 reg1
memory, reg	0000 1111 : 1100 000w : mod reg r/m
XCHG – Exchange Register/Memory with Register	
register1 with register2	1000 011w : 11 reg1 reg2
AL, AX, or EAX with reg	1001 0 reg
memory with reg	1000 011w : mod reg r/m
XLAT/XLATB – Table Look-up Translation	1101 0111
XOR – Logical Exclusive OR	
register1 to register2	0011 000w : 11 reg1 reg2
register2 to register1	0011 001w : 11 reg1 reg2
memory to register	0011 001w : mod reg r/m
register to memory	0011 000w : mod reg r/m
immediate to register	1000 00sw : 11 110 reg : immediate data
immediate to AL, AX, or EAX	0011 010w : immediate data
immediate to memory	1000 00sw : mod 110 r/m : immediate data
Prefix Bytes	
address size	0110 0111
LOCK	1111 0000
operand size	0110 0110
CS segment override	0010 1110
DS segment override	0011 1110
ES segment override	0010 0110
FS segment override	0110 0100
GS segment override	0110 0101
SS segment override	0011 0110

B.3. MMX™ INSTRUCTION FORMATS AND ENCODINGS

All MMX™ instructions, except the EMMS instruction, use the a format similar to the 2-byte Intel Architecture integer format. Details of subfield encodings within these formats are presented below. For information relating to the use of prefixes with MMX™ instructions, and the effects of these prefixes, see Section B.4.1. and Section 2.2., “Instruction Prefixes” in Chapter 2, *Instruction Format*.

B.3.1. Granularity Field (gg)

The granularity field (gg) indicates the size of the packed operands that the instruction is operating on. When this field is used, it is located in bits 1 and 0 of the second opcode byte. Table B-11 shows the encoding of this gg field.

Table B-11. Encoding of Granularity of Data Field (gg)

gg	Granularity of Data
00	Packed Bytes
01	Packed Words
10	Packed Doublewords
11	Quadword

B.3.2. MMX™ and General-Purpose Register Fields (mmxreg and reg)

When MMX™ technology registers (mmxreg) are used as operands, they are encoded in the ModR/M byte in the reg field (bits 5, 4, and 3) and/or the R/M field (bits 2, 1, and 0). Table B-12 shows the 3-bit encodings used for mmxreg fields.

Table B-12. Encoding of the MMX™ Register Field (mmxreg)

mmxreg Field Encoding	MMX™ Register
000	MM0
001	MM1
010	MM2
011	MM3
100	MM4
101	MM5
110	MM6
111	MM7

If an MMX™ instruction operates on a general-purpose register (reg), the register is encoded in the R/M field of the ModR/M byte. Table B-13 shows the encoding of general-purpose registers when used in MMX™ instructions.

Table B-13. Encoding of the General-Purpose Register Field (reg) When Used in MMX™ Instructions.

reg Field Encoding	Register Selected
000	EAX
001	ECX
010	EDX
011	EBX
100	ESP
101	EBP
110	ESI
111	EDI

B.3.3. MMX™ Instruction Formats and Encodings Table

Table B-14 shows the formats and encodings for MMX™ instructions for the data types supported—packed byte (B), packed word (W), packed doubleword (D), and quadword (Q). Figure B-2 describes the nomenclature used in columns (3 through 6) of the table.

Code	Meaning
Y	Supported
N	Not supported
O	Output
I	Input
n/a	Not Applicable

Figure B-2. Key to Codes for MMX™ Data Type Cross-Reference

Table B-14. MMX™ Instruction Formats and Encodings

Instruction and Format	Encoding	B	W	D	Q
EMMS - Empty MMX™ state	0000 1111:01110111	n/a	n/a	n/a	n/a
MOVD - Move doubleword		N	N	Y	N
reg to mmreg	0000 1111:01101110: 11 mmxreg reg				
reg from mmxreg	0000 1111:01111110: 11 mmxreg reg				
mem to mmxreg	0000 1111:01101110: mod mmxreg r/m				
mem from mmxreg	0000 1111:01111110: mod mmxreg r/m				
MOVQ - Move quadword		N	N	N	Y
mmxreg2 to mmxreg1	0000 1111:01101111: 11 mmxreg1 mmxreg2				
mmxreg2 from mmxreg1	0000 1111:01111111: 11 mmxreg1 mmxreg2				
mem to mmxreg	0000 1111:01101111: mod mmxreg r/m				
mem from mmxreg	0000 1111:01111111: mod mmxreg r/m				
PACKSSDW[1] - Pack dword to word data (signed with saturation)		n/a	O	I	n/a
mmxreg2 to mmxreg1	0000 1111:01101011: 11 mmxreg1 mmxreg2				
memory to mmxreg	0000 1111:01101011: mod mmxreg r/m				
PACKSSWB[1] - Pack word to byte data (signed with saturation)		O	I	n/a	n/a
mmxreg2 to mmxreg1	0000 1111:01100011: 11 mmxreg1 mmxreg2				
memory to mmxreg	0000 1111:01100011: mod mmxreg r/m				
PACKUSWB[1] - Pack word to byte data (unsigned with saturation)		O	I	n/a	n/a
mmxreg2 to mmxreg1	0000 1111:01100111: 11 mmxreg1 mmxreg2				
memory to mmxreg	0000 1111:01100111: mod mmxreg r/m				
PADD - Add with wrap-around		Y	Y	Y	N
mmxreg2 to mmxreg1	0000 1111: 111111gg: 11 mmxreg1 mmxreg2				
memory to mmxreg	0000 1111: 111111gg: mod mmxreg r/m				
PADDS - Add signed with saturation		Y	Y	N	N
mmxreg2 to mmxreg1	0000 1111: 111011gg: 11 mmxreg1 mmxreg2				
memory to mmxreg	0000 1111: 111011gg: mod mmxreg r/m				

Table B-14. MMX™ Instruction Formats and Encodings (Contd.)

Instruction and Format	Encoding	B	W	D	Q
PADDUS - Add unsigned with saturation		Y	Y	N	N
mmxreg2 to mmxreg1	0000 1111: 110111gg: 11 mmxreg1 mmxreg2				
memory to mmxreg	0000 1111: 110111gg: mod mmxreg r/m				
PAND - Bitwise And		N	N	N	Y
mmxreg2 to mmxreg1	0000 1111:11011011: 11 mmxreg1 mmxreg2				
memory to mmxreg	0000 1111:11011011: mod mmxreg r/m				
PANDN - Bitwise AndNot		N	N	N	Y
mmxreg2 to mmxreg1	0000 1111:11011111: 11 mmxreg1 mmxreg2				
memory to mmxreg	0000 1111:11011111: mod mmxreg r/m				
PCMPEQ - Packed compare for equality		Y	Y	Y	N
mmxreg1 with mmxreg2	0000 1111:011101gg: 11 mmxreg1 mmxreg2				
mmxreg with memory	0000 1111:011101gg: mod mmxreg r/m				
PCMPGT - Packed compare greater (signed)		Y	Y	Y	N
mmxreg1 with mmxreg2	0000 1111:011001gg: 11 mmxreg1 mmxreg2				
mmxreg with memory	0000 1111:011001gg: mod mmxreg r/m				
PMADD - Packed multiply add		n/a	I	O	n/a
mmxreg2 to mmxreg1	0000 1111:11110101: 11 mmxreg1 mmxreg2				
memory to mmxreg	0000 1111:11110101: mod mmxreg r/m				
PMULH - Packed multiplication		N	Y	N	N
mmxreg2 to mmxreg1	0000 1111:11100101: 11 mmxreg1 mmxreg2				
memory to mmxreg	0000 1111:11100101: mod mmxreg r/m				
PMULL - Packed multiplication		N	Y	N	N
mmxreg2 to mmxreg1	0000 1111:11010101: 11 mmxreg1 mmxreg2				
memory to mmxreg	0000 1111:11010101: mod mmxreg r/m				
POR - Bitwise Or		N	N	N	Y
mmxreg2 to mmxreg1	0000 1111:11101011: 11 mmxreg1 mmxreg2				
memory to mmxreg	0000 1111:11101011: mod mmxreg r/m				

Table B-14. MMX™ Instruction Formats and Encodings (Contd.)

Instruction and Format	Encoding	B	W	D	Q
PSLL[2] - Packed shift left logical		N	Y	Y	Y
mmxreg1 by mmxreg2	0000 1111:111100gg: 11 mmxreg1 mmxreg2				
mmxreg by memory	0000 1111:111100gg: mod mmxreg r/m				
mmxreg by immediate	0000 1111:011100gg: 11 110 mmxreg: imm8 data				
PSRA[2] - Packed shift right arithmetic		N	Y	Y	N
mmxreg1 by mmxreg2	0000 1111:111000gg: 11 mmxreg1 mmxreg2				
mmxreg by memory	0000 1111:111000gg: mod mmxreg r/m				
mmxreg by immediate	0000 1111:011100gg: 11 100 mmxreg: imm8 data				
PSRL[2] - Packed shift right logical		N	Y	Y	Y
mmxreg1 by mmxreg2	0000 1111:110100gg: 11 mmxreg1 mmxreg2				
mmxreg by memory	0000 1111:110100gg: mod mmxreg r/m				
mmxreg by immediate	0000 1111:011100gg: 11 010 mmxreg: imm8 data				
PSUB - Subtract with wrap-around		Y	Y	Y	N
mmxreg2 from mmxreg1	0000 1111:111110gg: 11 mmxreg1 mmxreg2				
memory from mmxreg	0000 1111:111110gg: mod mmxreg r/m				
PSUBS - Subtract signed with saturation		Y	Y	N	N
mmxreg2 from mmxreg1	0000 1111:111010gg: 11 mmxreg1 mmxreg2				
memory from mmxreg	0000 1111:111010gg: mod mmxreg r/m				
PSUBUS - Subtract unsigned with saturation		Y	Y	N	N
mmxreg2 from mmxreg1	0000 1111:110110gg: 11 mmxreg1 mmxreg2				
memory from mmxreg	0000 1111:110110gg: mod mmxreg r/m				
PUNPCKH - Unpack high data to next larger type		Y	Y	Y	N
mmxreg2 to mmxreg1	0000 1111:011010gg: 11 mmxreg1 mmxreg2				
memory to mmxreg	0000 1111:011010gg: mod mmxreg r/m				

Table B-14. MMX™ Instruction Formats and Encodings (Contd.)

Instruction and Format	Encoding	B	W	D	Q
PUNPCKL - Unpack low data to next larger type		Y	Y	Y	N
mmxreg2 to mmxreg1	0000 1111:011000gg: 11 mmxreg1 mmxreg2				
memory to mmxreg	0000 1111:011000gg: mod mmxreg r/m				
PXOR - Bitwise Xor		N	N	N	Y
mmxreg2 to mmxreg1	0000 1111:11101111: 11 mmxreg1 mmxreg2				
memory to mmxreg	0000 1111:11101111: mod mmxreg r/m				

NOTES:

1. The pack instructions perform saturation from signed packed data of one type to signed or unsigned data of the next smaller type.
2. The format of the shift instructions has one additional format to support shifting by immediate shift-counts. The shift operations are not supported equally for all data types.

B.4. STREAMING SIMD EXTENSION FORMATS AND ENCODINGS TABLE

The nature of the Streaming SIMD Extensions allows the use of existing instruction formats. Instructions use the ModR/M format and are preceded by the 0F prefix byte. In general, operations are not duplicated to provide two directions (i.e., separate load and store variants).

B.4.1. Instruction Prefixes

The Streaming SIMD Extensions use prefixes as specified in Table B-15, Table B-16, and Table B-17. The effect of redundant prefixes (more than one prefix from a group) is undefined and may vary from processor to processor.

Applying a prefix, in a manner not defined in this document, is considered reserved behavior. For example, Table B-15 shows general behavior for most Streaming SIMD Extensions; however, the application of a prefix (Repeat, Repeat NE, Operand Size) is reserved for the following instructions: ANDPS, ANDNPS, COMISS, FXRSTOR, FXSAVE, ORPS, LDMXCSR, MOVAPS, MOVHPS, MOVLPS, MOVMSKPS, MOVNTPS, MOVUPS, SHUFPS, STMXCSR, UCOMISS, UNPCKHPS, UNPCKLPS, XORPS.

Table B-15. Streaming SIMD Extensions Instruction Behavior with Prefixes

Prefix Type	**Effect on** Streaming SIMD Extensions
Address Size Prefix (67H)	Affects Streaming SIMD Extensions with memory operand Ignored by Streaming SIMD Extensions without memory operand.
Operand Size (66H)	Not supported and may result in undefined behavior.
Segment Override (2EH,36H,3EH,26H,64H,65H)	Affects Streaming SIMD Extensions with mem.operand Ignored by Streaming SIMD Extensions without mem operand
Repeat Prefix (F3H)	Affects Streaming SIMD Extensions
Repeat NE Prefix(F2H)	Not supported and may result in undefined behavior.
Lock Prefix (0F0H)	Generates invalid opcode exception.

Table B-16. SIMD Integer Instructions - Behavior with Prefixes

Prefix Type	**Effect on MMX™ Instructions**
Address Size Prefix (67H)	Affects **MMX™** instructions with mem. operand Ignored by **MMX™** instructions without mem. operand.
Operand Size (66H)	Reserved and may result in unpredictable behavior.
Segment Override (2EH,36H,3EH,26H,64H,65H)	Affects **MMX™** instructions with mem. operand Ignored by **MMX™** instructions without mem operand
Repeat Prefix (F3H)	Reserved and may result in unpredictable behavior.
Repeat NE Prefix(F2H)	Reserved and may result in unpredictable behavior.
Lock Prefix (0F0H)	Generates invalid opcode exception.

Table B-17. Cacheability Control Instruction Behavior with Prefixes

Prefix Type	**Effect on** Streaming SIMD Extensions
Address Size Prefix (67H)	Affects cacheability control instruction with a mem. operand Ignored by cacheability control instruction w/o a mem. operand.
Operand Size (66H)	Ignored by PREFETCH and SFENCE. Not supported and may result in undefined behavior with MOVNTPS. Ignored by MOVNTQ and MASKMOVQ.
Segment Override (2EH,36H,3EH,26H,64H,65H)	Affects cacheability control instructions with mem. operand Ignored by cacheability control instruction without mem operand
Repeat Prefix(F3H)	Ignored by PREFETCH and SFENCE instructions. Not supported and may result in undefined behavior with MOVNTPS. Ignored by MOVNTQ and MASKMOVQ.
Repeat NE Prefix(F2H)	Ignored by PREFETCH and SFENCE instructions. Not supported and may result in undefined behavior with MOVNTPS. Ignored by MOVNTQ and MASKMOVQ.
Lock Prefix (0F0H)	Generates an invalid opcode exception for all cacheability instructions.

B.4.2. Notations

Besides opcodes, two kinds of notations are found which both describe information found in the ModR/M byte:

/digit: (digit between 0 and 7)
Indicates that the instruction uses only the r/m (register and memory) operand. The reg field contains the digit that provides an extension to the instruction's opcode.

/r Indicates that the ModR/M byte of an instruction contains both a register operand and an r/m operand.

In addition, the following abbreviations are used:

r32 Intel Architecture 32-bit integer register

xmm/m128 Indicates a 128-bit multimedia register or a 128-bit memory location.

xmm/m64 Indicates a 128-bit multimedia register or a 64-bit memory location.

xmm/m32 Indicates a 128-bit multimedia register or a 32-bit memory location.

mm/m64 Indicates a 64-bit multimedia register or a 64-bit memory location.

imm8 Indicates an immediate 8-bit operand.

ib Indicates that an immediate byte operand follows the opcode, ModR/M byte or scaled-indexing byte.

When there is ambiguity, xmm1 indicates the first source operand and xmm2 the second source operand.

Table B-18 describes the naming conventions used in the Streaming SIMD Extensions mnemonics.

Table B-18. Key to Streaming SIMD Extensions Naming Convention

Mnemonic	Description
PI	Packed integer qword (e.g., mm0)
PS	Packed single FP (e.g., xmm0)
SI	Scalar integer (e.g., eax)
SS	Scalar single-FP (e.g., low 32 bits of xmm0)

B.4.3. Formats and Encodings

The following three tables show the formats and encodings for Streaming SIMD Extensions for the data types supported—packed byte (B), packed word (W), packed doubleword (D), quadword (Q), and double quadword (DQ). Table B-19, Table B-20, and Table B-21 correspond respectively to SIMD floating-point, SIMD-Integer, and Cacheability Register Fields. Figure B-3 describes the nomenclature used in columns (3 through 7) of the table.

Code	Meaning
Y	Supported
N	Not supported
O	Output
I	Input
n/a	Not Applicable

Figure B-3. Key to Codes for Streaming SIMD Extensions Data Type Cross-Reference

Table B-19. Encoding of the SIMD Floating-Point Register Field

Instruction and Format	Encoding	B	W	D	Q	DQ
ADDPS - Packed Single-FP Add		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg	00001111:01011000:11 xmmreg1 xmmreg2					
mem to xmmreg	00001111:01011000: mod xmmreg r/m					
ADDSS - Scalar Single-FP Add		n/a	n/a	Y	n/a	n/a
xmmreg to xmmreg	11110011:00001111:01011000:11 xmmreg1 xmmreg2					
mem to xmmreg	11110011:00001111:01011000: mod xmmreg r/m					
ANDNPS - Bit-wise Logical And Not for Single-FP		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg	00001111:01010101:11 xmmreg1 xmmreg2					
mem to xmmreg	00001111:01010101: mod xmmreg r/m					
ANDPS - Bit-wise Logical And for Single-FP		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg	00001111:01010100:11 xmmreg1 xmmreg2					
mem to xmmreg	00001111:01010100: mod xmmreg r/m					
CMPPS - Packed Single-FP Compare		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg, imm8	00001111:11000010:11 xmmreg1 xmmreg2: imm8					
mem to xmmreg, imm8	00001111:11000010: mod xmmreg r/m: imm8					

Table B-19. Encoding of the SIMD Floating-Point Register Field

Instruction and Format	Encoding	B	W	D	Q	DQ
CMPSS - Scalar Single-FP Compare		n/a	n/a	Y	n/a	n/a
xmmreg to xmmreg, imm8	11110011:00001111:11000010:11 xmmreg1 xmmreg2: imm8					
mem to xmmreg, imm8	11110011:00001111:11000010: mod xmmreg r/m: imm8					
COMISS - Scalar Ordered Single-FP compare and set EFLAGS		n/a	n/a	Y	n/a	n/a
xmmreg to xmmreg	00001111:00101111:11 xmmreg1 xmmreg2					
mem to xmmreg	00001111:00101111: mod xmmreg r/m					
CVTPI2PS - Packed signed INT32 to Packed Single-FP conversion		n/a	n/a	n/a	n/a	Y
mmreg to xmmreg	00001111:00101010:11 xmmreg1 mmreg1					
mem to xmmreg	00001111:00101010: mod xmmreg r/m					
CVTPS2PI - Packed Single-FP to Packed INT32 conversion		n/a	n/a	n/a	n/a	Y
xmmreg to mmreg	00001111:00101101:11 mmreg1 xmmreg1					
mem to mmreg	00001111:00101101: mod mmreg r/m					
CVTSI2SS - Scalar signed INT32 to Single-FP conversion		n/a	n/a	Y	n/a	n/a
r32 to xmmreg1	11110011:00001111:00101010:11 xmmreg r32					
mem to xmmreg	11110011:00001111:00101010: mod xmmreg r/m					
CVTSS2SI - Scalar Single-FP to signed INT32 conversion		n/a	n/a	Y	n/a	n/a
xmmreg to r32	11110011:00001111:00101101:11 r32 xmmreg					
mem to r32	11110011:00001111:00101101: mod r32 r/m					
CVTTPS2PI - Packed Single-FP to Packed INT32 Conversion (truncate)		n/a	n/a	n/a	n/a	Y
xmmreg to mmreg	00001111:00101100:11 mmreg1 xmmreg1					
mem to mmreg	00001111:00101100: mod mmreg r/m					

Table B-19. Encoding of the SIMD Floating-Point Register Field

Instruction and Format	Encoding	B	W	D	Q	DQ
CVTTSS2SI - Scalar Single-FP to signed INT32 conversion (truncate)		n/a	n/a	Y	n/a	n/a
xmmreg to r32	11110011:00001111:00101100:11 r32 xmmreg1					
mem to r32	11110011:00001111:00101100: mod r32 r/m					
DIVPS - Packed Single-FP Divide		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg	00001111:01011110:11 xmmreg1 xmmreg2					
mem to xmmreg	00001111:01011110: mod xmmreg r/m					
DIVSS - Scalar Single-FP Divide	11110011:00001111:01011110:11 xmmreg1 xmmreg2					
xmmreg to xmmreg		n/a	n/a	Y	n/a	n/a
mem to xmmreg	11110011:00001111:01011110: mod xmmreg r/m					
FXRSTOR - Restore FP/MMX™ and Streaming SIMD Extensions state	00001111:10101110:01 m512	n/a	n/a	n/a	n/a	n/a
FXSAVE - Store FP/MMX™ and Streaming SIMD Extensions state	00001111:10101110:00 m512	n/a	n/a	n/a	n/a	n/a
LDMXCSR - Load Streaming SIMD Extensions Technology Control/Status Register		n/a	n/a	n/a	n/a	n/a
m32 to MXCSR	00001111:10101110:10 m32					
MAXPS - Packed Single-FP Maximum		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg	00001111:01011111:11 xmmreg1 xmmreg2					
mem to xmmreg	00001111:01011111: mod xmmreg r/m					
MAXSS - Scalar Single-FP Maximum		n/a	n/a	Y	n/a	n/a
xmmreg to xmmreg	11110011:00001111:01011111:11 xmmreg1 xmmreg2					
mem to xmmreg	11110011:00001111:01011111: mod xmmreg r/m					
MINPS - Packed Single-FP Minimum		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg	00001111:01011101:11 xmmreg1 xmmreg2					
mem to xmmreg	00001111:01011101: mod xmmreg r/m					

Table B-19. Encoding of the SIMD Floating-Point Register Field

Instruction and Format	Encoding	B	W	D	Q	DQ
MINSS - Scalar Single-FP Minimum		n/a	n/a	Y	n/a	n/a
xmmreg to xmmreg	11110011:00001111:01011101:11 xmmreg1 xmmreg2					
mem to xmmreg	11110011:00001111:01011101: mod xmmreg r/m					
MOVAPS - Move Aligned Four Packed Single-FP		n/a	n/a	n/a	n/a	Y
xmmreg2 to xmmreg1	00001111:00101000:11 xmmreg2 xmmreg1					
mem to xmmreg1	00001111:00101000: mod xmmreg r/m					
xmmreg1 to xmmreg2	00001111:00101001:11 xmmreg1 xmmreg2					
xmmreg1 to mem	00001111:00101001: mod xmmreg r/m					
MOVHLPS - Move High to Low Packed Single-FP		n/a	n/a	n/a	Y	n/a
xmmreg to xmmreg	00001111:00010010:11 xmmreg1 xmmreg2					
MOVHPS - Move High Packed Single-FP		n/a	n/a	n/a	Y	n/a
mem to xmmreg	00001111:00010110: mod xmmreg r/m					
xmmreg to mem	00001111:00010111: mod xmmreg r/m					
MOVLHPS - Move Low to High Packed Single-FP		n/a	n/a	n/a	Y	n/a
xmmreg to xmmreg	00001111:00010110:11 xmmreg1 xmmreg2					
MOVLPS - Move Low Packed Single-FP						
mem to xmmreg	00001111:00010010: mod xmmreg r/m	n/a	n/a	n/a	Y	n/a
xmmreg to mem	00001111:00010011: mod xmmreg r/m					
MOVMSKPS - Move Mask To Integer		n/a	n/a	n/a	n/a	Y
xmmreg to r32	00001111:01010000:11 r32 xmmreg					
MOVSS - Move Scalar Single-FP		n/a	n/a	Y	n/a	n/a
xmmreg2 to xmmreg1	11110011:00001111:00010000:11 xmmreg2 xmmreg1					
mem to xmmreg1	11110011:00001111:00010000: mod xmmreg r/m					
xmmreg1 to xmmreg2	11110011:00001111:00010000:11 xmmreg1 xmmreg2					
xmmreg1 to mem	11110011:00001111:00010000: mod xmmreg r/m					

Table B-19. Encoding of the SIMD Floating-Point Register Field

Instruction and Format	Encoding	B	W	D	Q	DQ
MOVUPS - Move Unaligned Four Packed Single-FP		n/a	n/a	n/a	n/a	Y
xmmreg2 to xmmreg1	00001111:00010000:11 xmmreg2 xmmreg1					
mem to xmmreg1	00001111:00010000: mod xmmreg r/m					
xmmreg1 to xmmreg2	00001111:00010001:11 xmmreg1 xmmreg2					
xmmreg1 to mem	00001111:00010001: mod xmmreg r/m					
MULPS - Packed Single-FP Multiply		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg	00001111:01011001:11 xmmreg1 xmmreg2					
mem to xmmreg	00001111:01011001: mod xmmreg rm					
MULSS - Scalar Single-FP Multiply		n/a	n/a	Y	n/a	n/a
xmmreg to xmmreg	11110011:00001111:010111001:11 xmmreg1 xmmreg2					
mem to xmmreg	11110011:00001111:010111001: mod xmmreg r/m					
ORPS: Bit-wise Logical OR for Single-FP Data		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg	00001111:01010110:11 xmmreg1 xmmreg2					
mem to xmmreg	00001111:01010110 mod xmmreg r/m					
RCPPS - Packed Single-FP Reciprocal		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg	00001111:01010011:11 xmmreg1 xmmreg2					
mem to xmmreg	00001111:01010011: mod xmmreg r/m					
RCPSS - Scalar Single-FP Reciprocal		n/a	n/a	Y	n/a	n/a
xmmreg to xmmreg	11110011:00001111:01010011:11 xmmreg1 xmmreg2					
mem to xmmreg	11110011:00001111:01010011: mod xmmreg r/m					
RSQRTPS - Packed Single-FP Square Root Reciprocal		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg	00001111:01010010:11 xmmreg1 xmmreg2					
mem to xmmreg	00001111:01010010 mode xmmreg r/m					

Table B-19. Encoding of the SIMD Floating-Point Register Field

Instruction and Format	Encoding	B	W	D	Q	DQ
RSQRTSS - Scalar Single-FP Square Root Reciprocal		n/a	n/a	Y	n/a	n/a
xmmreg to xmmreg	11110011:00001111:01010010:11 xmmreg1 xmmreg2					
mem to xmmreg	11110011:00001111:01010010 mod xmmreg r/m					
SHUFPS - Shuffle Single-FP		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg, imm8	00001111:11000110:11 xmmreg1 xmmreg2: imm8					
mem to xmmreg, imm8	00001111:11000110: mod xmmreg r/m: imm8					
SQRTPS - Packed Single-FP Square Root		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg	00001111:01010001:11 xmmreg1 xmmreg 2					
mem to xmmreg	00001111:01010001 mod xmmreg r/m					
SQRTSS - Scalar Single-FP Square Root		n/a	n/a	Y	n/a	n/a
xmmreg to xmmreg	01010011:00001111:01010001:11 xmmreg1 xmmreg 2					
mem to xmmreg	01010011:00001111:01010001 mod xmmreg r/m					
STMXCSR - Store Streaming SIMD Extensions Technology Control/Status Register		n/a	n/a	Y	n/a	n/a
MXCSR to mem	00001111:10101110:11 m32					
SUBPS: Packed Single-FP Subtract		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg	00001111:01011100:11 xmmreg1 xmmreg2					
mem to xmmreg	00001111:01011100 mod xmmreg r/m					
SUBSS: Scalar Single-FP Subtract		n/a	n/a	Y	n/a	n/a
xmmreg to xmmreg	11110011:00001111:01011100:11 xmmreg1 xmmreg2					
mem to xmmreg	11110011:00001111:01011100 mod xmmreg r/m					
UCOMISS: Unordered Scalar Single-FP compare and set EFLAGS		n/a	n/a	Y	n/a	n/a
xmmreg to xmmreg	00001111:00101110:11 xmmreg1 xmmreg2					
mem to xmmreg	00001111:00101110 mod xmmreg r/m					

Table B-19. Encoding of the SIMD Floating-Point Register Field

Instruction and Format	Encoding	B	W	D	Q	DQ
UNPCKHPS: Unpack High Packed Single-FP Data		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg	00001111:00010101:11 xmmreg1 xmmreg2					
mem to xmmreg	00001111:00010101 mod xmmreg r/m					
UNPCKLPS: Unpack Low Packed Single-FP Data		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg	00001111:00010100:11 xmmreg1 xmmreg2					
mem to xmmreg	00001111:00010100 mod xmmreg r/m					
XORPS: Bit-wise Logical Xor for Single-FP Data		n/a	n/a	n/a	n/a	Y
xmmreg to xmmreg	00001111:01010111:11 xmmreg1 xmmreg2					
mem to xmmreg	00001111:01010111 mod xmmreg r/m					

Table B-20. Encoding of the SIMD-Integer Register Field

Instruction and Format	Encoding	B	W	D	Q	DQ
PAVGB/PAVGW - Packed Average		Y	Y	n/a	n/a	n/a
mmreg to mmreg	00001111:11100000:11 mmreg1 mmreg2					
	00001111:11100011:11 mmreg1 mmreg2					
mem to mmreg	00001111:11100000 mod mmreg r/m					
	00001111:11100011 mod mmreg r/m					
PEXTRW - Extract Word		n/a	Y	n/a	n/a	n/a
mmreg to reg32, imm8	00001111:11000101:11 mmreg r32: imm8					
PINSRW - Insert Word		n/a	Y	n/a	n/a	n/a
reg32 to mmreg, imm8	00001111:11000100:11 r32 mmreg1: imm8					
m16 to mmreg, imm8	00001111:11000100 mod mmreg r/m: imm8					
PMAXSW - Packed Signed Integer Word Maximum		n/a	Y	n/a	n/a	n/a
mmreg to mmreg	00001111:11101110:11 mmreg1 mmreg2					
mem to mmreg	00001111:11101110 mod mmreg r/m					
PMAXUB - Packed Unsigned Integer Byte Maximum		Y	n/a	n/a	n/a	n/a
mmreg to mmreg	00001111:11011110:11 mmreg1 mmreg2					
mem to mmreg	00001111:11011110 mod mmreg r/m					
PMINSW - Packed Signed Integer Word Minimum		n/a	Y	n/a	n/a	n/a
mmreg to mmreg	00001111:11101010:11 mmreg1 mmreg2					
mem to mmreg	00001111:11101010 mod mmreg r/m					
PMINUB - Packed Unsigned Integer Byte Minimum		Y'	n/a	n/a	n/a	n/a
mmreg to mmreg	00001111:11011010:11 mmreg1 mmreg2					
mem to mmreg	00001111:11011010 mod mmreg r/m					
PMOVMSKB - Move Byte Mask To Integer		O	n/a	n/a	I	n/a
mmreg to reg32	00001111:11010111:11 mmreg1 r32					

Table B-20. Encoding of the SIMD-Integer Register Field

Instruction and Format	Encoding	B	W	D	Q	DQ
PMULHUW - Packed Multiply High Unsigned		n/a	O	n/a	I	n/a
mmreg to mmreg	00001111:11100100:11 mmreg1 mmreg2					
mem to mmreg	00001111:11100100 mod mmreg r/m					
PSADBW - Packed Sum of Absolute Differences		I	O	n/a	Y	n/a
mmreg to mmreg	00001111:11110110:11 mmreg1 mmreg2					
mem to mmreg	00001111:11110110 mod mmreg r/m					
PSHUFW - Packed Shuffle Word		n/a	Y	n/a	I	n/a
mmreg to mmreg, imm8	00001111:01110000:11 mmreg1 mmreg2: imm8					
mem to mmreg, imm8	00001111:01110000:11 mod mmreg r/m: imm8					

Table B-21. Encoding of the Streaming SIMD Extensions Cacheability Control Register Field

Instruction and Format	Encoding	B	W	D	Q	DQ
MASKMOVQ - Byte Mask Write		n/a	n/a	n/a	Y	n/a
mmreg to mmreg	00001111:11110111:11 mmreg1 mmreg2					
MOVNTPS - Move Aligned Four Packed Single-FP Non Temporal		n/a	n/a	n/a	n/a	Y
xmmreg to mem	00001111:00101011 mod xmmreg r/m					
MOVNTQ - Move 64 Bits Non Temporal		n/a	n/a	n/a	Y	n/a
mmreg to mem	00001111:11100111 mod mmreg r/m					
PREFETCHT0 - Prefetch to all cache levels	00001111:00011000:01 mem	Y	Y	Y	Y	Y
PREFETCHT1 - Prefetch to all cache levels	00001111:00011000:10 mem	Y	Y	Y	Y	Y
PREFETCHT2 - Prefetch to L2 cache	00001111:00011000:11 mem	Y	Y	Y	Y	Y
PREFETCHNTA - Prefetch to L1 cache	00001111:00011000:00 mem	Y	Y	Y	Y	Y
SFENCE - Store Fence	00001111:10101110:11111000	Y	Y	Y	Y	Y

B.5. FLOATING-POINT INSTRUCTION FORMATS AND ENCODINGS

Table B-22 shows the five different formats used for floating-point instructions In all cases, instructions are at least two bytes long and begin with the bit pattern 11011.

Table B-22. General Floating-Point Instruction Formats

	Instruction										Optional Fields	
	First Byte			Second Byte								
1	11011	OPA		1	mod		1	OPB		r/m	s-i-b	disp
2	11011	MF		OPA	mod		OPB			r/m	s-i-b	disp
3	11011	d	P	OPA	1	1	OPB	R		ST(i)		
4	11011	0	0	1	1	1	1	OP				
5	11011	0	1	1	1	1	1	OP				
	15–11	10	9	8	7	6	5	4	3	2 1 0		

MF = Memory Format
- 00 — 32-bit real
- 01 — 32-bit integer
- 10 — 64-bit real
- 11 — 16-bit integer

P = Pop
- 0 — Do not pop stack
- 1 — Pop stack after operation

d = Destination
- 0 — Destination is ST(0)
- 1 — Destination is ST(i)

R XOR d = 0 — Destination OP Source
R XOR d = 1 — Source OP Destination

ST(i) = Register stack element *i*
- 000 = Stack Top
- 001 = Second stack element
- .
- .
- .
- 111 = Eighth stack element

The Mod and R/M fields of the ModR/M byte have the same interpretation as the corresponding fields of the integer instructions. The SIB byte and disp (displacement) are optionally present in instructions that have Mod and R/M fields. Their presence depends on the values of Mod and R/M, as for integer instructions.

Table B-23 shows the formats and encodings of the floating-point instructions.

Table B-23. Floating-Point Instruction Formats and Encodings

Instruction and Format	Encoding
F2XM1 – Compute $2^{ST(0)} - 1$	11011 001 : 1111 0000
FABS – Absolute Value	11011 001 : 1110 0001
FADD – Add	
ST(0) ← ST(0) + 32-bit memory	11011 000 : mod 000 r/m
ST(0) ← ST(0) + 64-bit memory	11011 100 : mod 000 r/m
ST(d) ← ST(0) + ST(i)	11011 d00 : 11 000 ST(i)
FADDP – Add and Pop	
ST(0) ← ST(0) + ST(i)	11011 110 : 11 000 ST(i)
FBLD – Load Binary Coded Decimal	11011 111 : mod 100 r/m
FBSTP – Store Binary Coded Decimal and Pop	11011 111 : mod 110 r/m
FCHS – Change Sign	11011 001 : 1110 0000
FCLEX – Clear Exceptions	11011 011 : 1110 0010
FCMOVcc – Conditional Move on EFLAG Register Condition Codes	
move if below (B)	11011 010 : 11 000 ST(i)
move if equal (E)	11011 010 : 11 001 ST(i)
move if below or equal (BE)	11011 010 : 11 010 ST(i)
move if unordered (U)	11011 010 : 11 011 ST(i)
move if not below (NB)	11011 011 : 11 000 ST(i)
move if not equal (NE)	11011 011 : 11 001 ST(i)
move if not below or equal (NBE)	11011 011 : 11 010 ST(i)
move if not unordered (NU)	11011 011 : 11 011 ST(i)
FCOM – Compare Real	
32-bit memory	11011 000 : mod 010 r/m
64-bit memory	11011 100 : mod 010 r/m
ST(i)	11011 000 : 11 010 ST(i)
FCOMP – Compare Real and Pop	
32-bit memory	11011 000 : mod 011 r/m
64-bit memory	11011 100 : mod 011 r/m
ST(i)	11011 000 : 11 011 ST(i)
FCOMPP – Compare Real and Pop Twice	11011 110 : 11 011 001
FCOMI – Compare Real and Set EFLAGS	11011 011 : 11 110 ST(i)
FCOMIP – Compare Real, Set EFLAGS, and Pop	11011 111 : 11 110 ST(i)
FCOS – Cosine of ST(0)	11011 001 : 1111 1111
FDECSTP – Decrement Stack-Top Pointer	11011 001 : 1111 0110
FDIV – Divide	
ST(0) ← ST(0) ÷ 32-bit memory	11011 000 : mod 110 r/m
ST(0) ← ST(0) ÷ 64-bit memory	11011 100 : mod 110 r/m
ST(d) ← ST(0) ÷ ST(i)	11011 d00 : 1111 R ST(i)
FDIVP – Divide and Pop	
ST(0) ← ST(0) ÷ ST(i)	11011 110 : 1111 1 ST(i)

Table B-23. Floating-Point Instruction Formats and Encodings

Instruction and Format	Encoding
FDIVR – Reverse Divide	
ST(0) ← 32-bit memory ÷ ST(0)	11011 000 : mod 111 r/m
ST(0) ← 64-bit memory ÷ ST(0)	11011 100 : mod 111 r/m
ST(d) ← ST(i) ÷ ST(0)	11011 d00 : 1111 R ST(i)
FDIVRP – Reverse Divide and Pop	
ST(0) ¨ ST(i) ÷ ST(0)	11011 110 : 1111 0 ST(i)
FFREE – Free ST(i) Register	11011 101 : 1100 0 ST(i)
FIADD – Add Integer	
ST(0) ← ST(0) + 16-bit memory	11011 110 : mod 000 r/m
ST(0) ← ST(0) + 32-bit memory	11011 010 : mod 000 r/m
FICOM – Compare Integer	
16-bit memory	11011 110 : mod 010 r/m
32-bit memory	11011 010 : mod 010 r/m
FICOMP – Compare Integer and Pop	
16-bit memory	11011 110 : mod 011 r/m
32-bit memory	11011 010 : mod 011 r/m
FIDIV	
ST(0) ← ST(0) + 16-bit memory	11011 110 : mod 110 r/m
ST(0) ← ST(0) + 32-bit memory	11011 010 : mod 110 r/m
FIDIVR	
ST(0) ← ST(0) + 16-bit memory	11011 110 : mod 111 r/m
ST(0) ← ST(0) + 32-bit memory	11011 010 : mod 111 r/m
FILD – Load Integer	
16-bit memory	11011 111 : mod 000 r/m
32-bit memory	11011 011 : mod 000 r/m
64-bit memory	11011 111 : mod 101 r/m
FIMUL	
ST(0) ← ST(0) + 16-bit memory	11011 110 : mod 001 r/m
ST(0) ← ST(0) + 32-bit memory	11011 010 : mod 001 r/m
FINCSTP – Increment Stack Pointer	11011 001 : 1111 0111
FINIT – Initialize Floating-Point Unit	
FIST – Store Integer	
16-bit memory	11011 111 : mod 010 r/m
32-bit memory	11011 011 : mod 010 r/m
FISTP – Store Integer and Pop	
16-bit memory	11011 111 : mod 011 r/m
32-bit memory	11011 011 : mod 011 r/m
64-bit memory	11011 111 : mod 111 r/m
FISUB	
ST(0) ← ST(0) + 16-bit memory	11011 110 : mod 100 r/m
ST(0) ← ST(0) + 32-bit memory	11011 010 : mod 100 r/m

Table B-23. Floating-Point Instruction Formats and Encodings

Instruction and Format	Encoding
FISUBR	
ST(0) ← ST(0) + 16-bit memory	11011 110 : mod 101 r/m
ST(0) ← ST(0) + 32-bit memory	11011 010 : mod 101 r/m
FLD – Load Real	
32-bit memory	11011 001 : mod 000 r/m
64-bit memory	11011 101 : mod 000 r/m
80-bit memory	11011 011 : mod 101 r/m
ST(i)	11011 001 : 11 000 ST(i)
FLD1 – Load +1.0 into ST(0)	11011 001 : 1110 1000
FLDCW – Load Control Word	11011 001 : mod 101 r/m
FLDENV – Load FPU Environment	11011 001 : mod 100 r/m
FLDL2E – Load $\log_2(\varepsilon)$ into ST(0)	11011 001 : 1110 1010
FLDL2T – Load $\log_2(10)$ into ST(0)	11011 001 : 1110 1001
FLDLG2 – Load $\log_{10}(2)$ into ST(0)	11011 001 : 1110 1100
FLDLN2 – Load $\log_{\varepsilon}(2)$ into ST(0)	11011 001 : 1110 1101
FLDPI – Load π into ST(0)	11011 001 : 1110 1011
FLDZ – Load +0.0 into ST(0)	11011 001 : 1110 1110
FMUL – Multiply	
ST(0) ← ST(0) × 32-bit memory	11011 000 : mod 001 r/m
ST(0) ← ST(0) × 64-bit memory	11011 100 : mod 001 r/m
ST(d) ← ST(0) × ST(i)	11011 d00 : 1100 1 ST(i)
FMULP – Multiply	
ST(0) ← ST(0) × ST(i)	11011 110 : 1100 1 ST(i)
FNOP – No Operation	11011 001 : 1101 0000
FPATAN – Partial Arctangent	11011 001 : 1111 0011
FPREM – Partial Remainder	11011 001 : 1111 1000
FPREM1 – Partial Remainder (IEEE)	11011 001 : 1111 0101
FPTAN – Partial Tangent	11011 001 : 1111 0010
FRNDINT – Round to Integer	11011 001 : 1111 1100
FRSTOR – Restore FPU State	11011 101 : mod 100 r/m
FSAVE – Store FPU State	11011 101 : mod 110 r/m
FSCALE – Scale	11011 001 : 1111 1101
FSIN – Sine	11011 001 : 1111 1110
FSINCOS – Sine and Cosine	11011 001 : 1111 1011
FSQRT – Square Root	11011 001 : 1111 1010
FST – Store Real	
32-bit memory	11011 001 : mod 010 r/m
64-bit memory	11011 101 : mod 010 r/m
ST(i)	11011 101 : 11 010 ST(i)
FSTCW – Store Control Word	11011 001 : mod 111 r/m
FSTENV – Store FPU Environment	11011 001 : mod 110 r/m

Table B-23. Floating-Point Instruction Formats and Encodings

Instruction and Format	Encoding
FSTP – Store Real and Pop	
32-bit memory	11011 001 : mod 011 r/m
64-bit memory	11011 101 : mod 011 r/m
80-bit memory	11011 011 : mod 111 r/m
ST(i)	11011 101 : 11 011 ST(i)
FSTSW – Store Status Word into AX	11011 111 : 1110 0000
FSTSW – Store Status Word into Memory	11011 101 : mod 111 r/m
FSUB – Subtract	
ST(0) ← ST(0) – 32-bit memory	11011 000 : mod 100 r/m
ST(0) ← ST(0) – 64-bit memory	11011 100 : mod 100 r/m
ST(d) ← ST(0) – ST(i)	11011 d00 : 1110 R ST(i)
FSUBP – Subtract and Pop	
ST(0) ← ST(0) – ST(i)	11011 110 : 1110 1 ST(i)
FSUBR – Reverse Subtract	
ST(0) ← 32-bit memory – ST(0)	11011 000 : mod 101 r/m
ST(0) ← 64-bit memory – ST(0)	11011 100 : mod 101 r/m
ST(d) ← ST(i) – ST(0)	11011 d00 : 1110 R ST(i)
FSUBRP – Reverse Subtract and Pop	
ST(i) ← ST(i) – ST(0)	11011 110 : 1110 0 ST(i)
FTST – Test	11011 001 : 1110 0100
FUCOM – Unordered Compare Real	11011 101 : 1110 0 ST(i)
FUCOMP – Unordered Compare Real and Pop	11011 101 : 1110 1 ST(i)
FUCOMPP – Unordered Compare Real and Pop Twice	11011 010 : 1110 1001
FUCOMI – Unordered Compare Real and Set EFLAGS	11011 011 : 11 101 ST(i)
FUCOMIP – Unordered Compare Real, Set EFLAGS, and Pop	11011 111 : 11 101 ST(i)
FXAM – Examine	11011 001 : 1110 0101
FXCH – Exchange ST(0) and ST(i)	11011 001 : 1100 1 ST(i)
FXTRACT – Extract Exponent and Significand	11011 001 : 1111 0100
FYL2X – ST(1) × $\log_2$(ST(0))	11011 001 : 1111 0001
FYL2XP1 – ST(1) × $\log_2$(ST(0) + 1.0)	11011 001 : 1111 1001
FWAIT – Wait until FPU Ready	1001 1011

C

Compiler Intrinsics and Functional Equivalents

APPENDIX C
COMPILER INTRINSICS AND FUNCTIONAL EQUIVALENTS

The two tables in this chapter itemize the Intel C/C++ compiler intrinsics and functional equivalents for the MMX™ technology instructions and Streaming SIMD Extensions.

There may be additional intrinsics that do not have an instruction equivalent. It is strongly recommended that the reader reference the compiler documentation for the complete list of supported intrinsics. Please refer to the *Intel C/C++ Compiler User's Guide for Win32* Systems With Streaming SIMD Extension Support* (Order Number 718195-00B). Appendix C catalogs use of these intrinsics.

The Section 3.1.3., "Intel C/C++ Compiler Intrinsics Equivalent" of Chapter 3, *Instruction Set Reference* has more general supporting information for the following tables.

Table C-1 presents simple intrinsics, and Table C-2 presents composite intrinsics. Some intrinsics are "composites" because they require more than one instruction to implement them.

Most of the intrinsics that use __m64 operands have two different names. If two intrinsic names are shown for the same equivalent, the first name is the intrinsic for Intel C/C++ Compiler versions prior to 4.0 and the second name should be used with the Intel C/C++ Compiler version 4.0 and future versions. The Intel C/C++ Compiler version 4.0 will support the old intrinsic names. Programs written using pre-4.0 intrinsic names will compile with version 4.0. Version 4.0 intrinsic names will not compile on pre-4.0 compilers.

Intel C/C++ Compiler version 4.0 names reflect the following naming conventions:

- a "_mm" prefix, followed by a plain spelling of the operation or the actual instruction's mnemonic, followed by a suffix indicating the operand type.
- Since there are many different types of integer data that can be contained within a __m64 data item, the following convention is used:
    - s - indicates scalar
    - p - indicates packed
    - i - indicates signed integer, or in some instructions where the sign does not matter, this is the default
    - u - indicates an unsigned integer
    - 8, 16, 32, or 64 - the bit size of the data elements.

For example, _mm_add_pi8 indicates addition of packed, 8-bit integers; _mm_slli_pi32() is a logical left shift with an immediate shift count (the "i" after the name) of a packed, 32-bit integer.

C.1. SIMPLE INTRINSICS

Table C-1. Simple Intrinsics

Mnemonic	Intrinsic	Description
ADDPS	__m128 _mm_add_ps(__m128 a, __m128 b)	Adds the four SP FP values of a and b.
ADDSS	__m128 _mm_add_ss(__m128 a, __m128 b)	Adds the lower SP FP (single-precision, floating-point) values of a and b; the upper three SP FP values are passed through from a.
ANDPS	__m128 _mm_andnot_ps(__m128 a, __m128 b)	Computes the bitwise AND-NOT of the four SP FP values of a and b.
CMPPS	__m128 _mm_cmpeq_ps(__m128 a, __m128 b)	Compare for equality.
	__m128 _mm_cmplt_ps(__m128 a, __m128 b)	Compare for less-than.
	__m128 _mm_cmple_ps(__m128 a, __m128 b)	Compare for less-than-or-equal.
	__m128 _mm_cmpgt_ps(__m128 a, __m128 b)	Compare for greater-than.
	__m128 _mm_cmpge_ps(__m128 a, __m128 b)	Compare for greater-than-or-equal.
	__m128 _mm_cmpneq_ps(__m128 a, __m128 b)	Compare for inequality.
	__m128 _mm_cmpnlt_ps(__m128 a, __m128 b)	Compare for not-less-than.
	__m128 _mm_cmpngt_ps(__m128 a, __m128 b)	Compare for not-greater-than.
	__m128 _mm_cmpnge_ps(__m128 a, __m128 b)	Compare for not-greater-than-or-equal.
	__m128 _mm_cmpord_ps(__m128 a, __m128 b)	Compare for ordered.
	__m128 _mm_cmpunord_ps(__m128 a, __m128 b)	Compare for unordered.
	__m128 _mm_cmpnle_ps(__m128 a, __m128 b)	Compare for not-less-than-or-equal.
CMPSS	__m128 _mm_cmpeq_ss(__m128 a, __m128 b)	Compare for equality.
	__m128 _mm_cmplt_ss(__m128 a, __m128 b)	Compare for less-than.
	__m128 _mm_cmple_ss(__m128 a, __m128 b)	Compare for less-than-or-equal.
	__m128 _mm_cmpgt_ss(__m128 a, __m128 b)	Compare for greater-than.
	__m128 _mm_cmpge_ss(__m128 a, __m128 b)	Compare for greater-than-or-equal.
	__m128 _mm_cmpneq_ss(__m128 a, __m128 b)	Compare for inequality.
	__m128 _mm_cmpnlt_ss(__m128 a, __m128 b)	Compare for not-less-than.
	__m128 _mm_cmpnle_ss(__m128 a, __m128 b)	Compare for not-greater-than.
	__m128 _mm_cmpngt_ss(__m128 a, __m128 b)	Compare for not-greater-than-or-equal.
	__m128 _mm_cmpnge_ss(__m128 a, __m128 b)	Compare for ordered.
	__m128 _mm_cmpord_ss(__m128 a, __m128 b)	Compare for unordered.
	__m128 _mm_cmpunord_ss(__m128 a, __m128 b)	Compare for not-less-than-or-equal.

Table C-1. Simple Intrinsics

Mnemonic	Intrinsic	Description
COMISS	int _mm_comieq_ss(__m128 a, __m128 b)	Compares the lower SP FP value of a and b for a equal to b. If a and b are equal, 1 is returned. Otherwise 0 is returned.
	int _mm_comilt_ss(__m128 a, __m128 b)	Compares the lower SP FP value of a and b for a less than b. If a is less than b, 1 is returned. Otherwise 0 is returned.
	int _mm_comile_ss(__m128 a, __m128 b)	Compares the lower SP FP value of a and b for a less than or equal to b. If a is less than or equal to b, 1 is returned. Otherwise 0 is returned.
	int _mm_comigt_ss(__m128 a, __m128 b)	Compares the lower SP FP value of a and b for a greater than b. If a is greater than b are equal, 1 is returned. Otherwise 0 is returned.
	int _mm_comige_ss(__m128 a, __m128 b)	Compares the lower SP FP value of a and b for a greater than or equal to b. If a is greater than or equal to b, 1 is returned. Otherwise 0 is returned.
	int _mm_comineq_ss(__m128 a, __m128 b)	Compares the lower SP FP value of a and b for a not equal to b. If a and b are not equal, 1 is returned. Otherwise 0 is returned.
CVTPI2PS	__m128 _mm_cvt_pi2ps(__m128 a, __m64 b) __m128 _mm_cvtpi32_ps(__m128 a, __m64b)	Convert the two 32-bit integer values in packed form in b to two SP FP values; the upper two SP FP values are passed through from a.
CVTPS2PI	__m64 _mm_cvt_ps2pi(__m128 a) __m64 _mm_cvtps_pi32(__m128 a)	Convert the two lower SP FP values of a to two 32-bit integers according to the current rounding mode, returning the integers in packed form.
CVTSI2SS	__m128 _mm_cvt_si2ss(__m128 a, int b) __m128 _mm_cvtsi32_ss(__m128a, int b)	Convert the 32-bit integer value b to an SP FP value; the upper three SP FP values are passed through from a.
CVTSS2SI	int _mm_cvt_ss2si(__m128 a) int _mm_cvtss_si32(__m128 a)	Convert the lower SP FP value of a to a 32-bit integer with truncation.
CVTTPS2PI	__m64 _mm_cvtt_ps2pi(__m128 a) __m64 _mm_cvttps_pi32(__m128 a)	Convert the two lower SP FP values of a to two 32-bit integer with truncation, returning the integers in packed form.
CVTTSS2SI	int _mm_cvtt_ss2si(__m128 a) int _mm_cvttss_si32(__m128 a)	Convert the lower SP FP value of a to a 32-bit integer according to the current rounding mode.
	__m64 _m_from_int(int i) __m64 _mm_cvtsi32_si64(int i)	Convert the integer object i to a 64-bit __m64 object. The integer value is zero extended to 64 bits.
	int _m_to_int(__m64 m) int _mm_cvtsi64_si32(__m64 m)	Convert the lower 32 bits of the __m64 object m to an integer.
DIVPS	__m128 _mm_div_ps(__m128 a, __m128 b)	Divides the four SP FP values of a and b.
DIVSS	__m128 _mm_div_ss(__m128 a, __m128 b)	Divides the lower SP FP values of a and b; the upper three SP FP values are passed through from a.
EMMS	void _m_empty() void _mm_empty()	Clears the MMX™ technology state.

Table C-1. Simple Intrinsics

Mnemonic	Intrinsic	Description
LDMXCSR	_mm_setcsr(unsigned int i)	Sets the control register to the value specified.
MASKMOVQ	void _m_maskmovq(__m64 d, __m64 n, char * p) void _mm_maskmove_si64(__m64 d, __m64 n, char *p)	Conditionally store byte elements of d to address p. The high bit of each byte in the selector n determines whether the corresponding byte in d will be stored.
MAXPS	__m128 _mm_max_ps(__m128 a, __m128 b)	Computes the maximums of the four SP FP values of a and b.
MAXSS	__m128 _mm_max_ss(__m128 a, __m128 b)	Computes the maximum of the lower SP FP values of a and b; the upper three SP FP values are passed through from a.
MINPS	__m128 _mm_min_ps(__m128 a, __m128 b)	Computes the minimums of the four SP FP values of a and b.
MINSS	__m128 _mm_min_ss(__m128 a, __m128 b)	Computes the minimum of the lower SP FP values of a and b; the upper three SP FP values are passed through from a.
MOVAPS	__m128 _mm_load_ps(float * p) void_mm_store_ps(float *p, __m128 a)	Loads four SP FP values. The address must be 16-byte-aligned. Stores four SP FP values. The address must be 16-byte-aligned.
MOVHLPS	__m128 _mm_movehl_ps(__m128 a, __m128 b)	Moves the upper 2 SP FP values of b to the lower 2 SP FP values of the result. The upper 2 SP FP values of a are passed through to the result.
MOVHPS	__m128 _mm_loadh_pi(__m128 a, __m64 * p) void_mm_storeh_pi(__m64 * p, __m128 a)	Sets the upper two SP FP values with 64 bits of data loaded from the address p; the lower two values are passed through from a. Stores the upper two SP FP values of a to the address p.
MOVLPS	__m128 _mm_loadl_pi(__m128 a, __m64 *p) void_mm_storel_pi(__m64 * p, __m128 a)	Sets the lower two SP FP values with 64 bits of data loaded from the address p; the upper two values are passed through from a. Stores the lower two SP FP values of a to the address p.
MOVLHPS	__m128 _mm_movelh_ps(__m128 a, __m128 b)	Moves the lower 2 SP FP values of b to the upper 2 SP FP values of the result. The lower 2 SP FP values of a are passed through to the result.
MOVMSKPS	int_mm_movemask_ps(__m128 a)	Creates a 4-bit mask from the most significant bits of the four SP FP values.
MOVNTPS	void_mm_stream_ps(float * p, __m128 a)	Stores the data in a to the address p without polluting the caches. The address must be 16-byte-aligned.
MOVNTQ	void_mm_stream_pi(__m64 * p, __m64 a)	Stores the data in a to the address p without polluting the caches.

Table C-1. Simple Intrinsics

Mnemonic	Intrinsic	Description
MOVSS	__m128 _mm_load_ss(float * p)	Loads an SP FP value into the low word and clears the upper three words.
	void_mm_store_ss(float * p, __m128 a)	Stores the lower SP FP value.
	__m128 _mm_move_ss(__m128 a, __m128 b)	Sets the low word to the SP FP value of b. The upper 3 SP FP values are passed through from a.
MOVUPS	__m128 _mm_loadu_ps(float * p)	Loads four SP FP values. The address need not be 16-byte-aligned.
	void_mm_storeu_ps(float *p, __m128 a)	Stores four SP FP values. The address need not be 16-byte-aligned.
MULSS	__m128 _mm_mul_ss(__m128 a, __m128 b)	Multiplies the lower SP FP values of a and b; the upper three SP FP values are passed through from a.
ORPS	__m128 _mm_or_ps(__m128 a, __m128 b)	Computes the bitwise OR of the four SP FP values of a and b.
PACKSSWB	__m64 _m_packsswb (__m64 m1, __m64 m2) __m64 _mm_packs_pi16(__m64 m1, __m64 m2)	Pack the four 16-bit values from m1 into the lower four 8-bit values of the result with signed saturation, and pack the four 16-bit values from m2 into the upper four 8-bit values of the result with signed saturation.
PACKSSDW	__m64 _m_packssdw (__m64 m1, __m64 m2) __m64 _mm_packs_pi32 (__m64 m1, __m64 m2)	Pack the two 32-bit values from m1 into the lower two 16-bit values of the result with signed saturation, and pack the two 32-bit values from m2 into the upper two 16-bit values of the result with signed saturation.
PACKUSWB	__m64 _m_packuswb(__m64 m1, __m64 m2) __m64 _mm_packs_pu16(__m64 m1, __m64 m2)	Pack the four 16-bit values from m1 into the lower four 8-bit values of the result with unsigned saturation, and pack the four 16-bit values from m2 into the upper four 8-bit values of the result with unsigned saturation.
PADDB	__m64 _m_paddb(__m64 m1, __m64 m2) __m64 _mm_add_pi8(__m64 m1, __m64 m2)	Add the eight 8-bit values in m1 to the eight 8-bit values in m2.
PADDW	__m64 _m_paddw(__m64 m1, __m64 m2) __m64 _mm_addw_pi16__m64 m1, __m64 m2)	Add the four 16-bit values in m1 to the four 16-bit values in m2.
PADDD	__m64 _m_paddd(__m64 m1, __m64 m2) __m64 _mm_add_pi32(__m64 m1, __m64 m2)	Add the two 32-bit values in m1 to the two 32-bit values in m2.
PADDSB	__m64 _m_paddsb(__m64 m1, __m64 m2) __m64 _mm_adds_pi8(__m64 m1, __m64 m2)	Add the eight signed 8-bit values in m1 to the eight signed 8-bit values in m2 and saturate.
PADDSW	__m64 _m_paddsw(__m64 m1, __m64 m2) __m64 _mm_adds_pi16(__m64 m1, __m64 m2)	Add the four signed 16-bit values in m1 to the four signed 16-bit values in m2 and saturate.
PADDUSB	__m64 _m_paddusb(__m64 m1, __m64 m2) __m64 _mm_adds_pu8(__m64 m1, __m64 m2)	Add the eight unsigned 8-bit values in m1 to the eight unsigned 8-bit values in m2 and saturate.
PADDUSW	__m64 _m_paddusw(__m64 m1, __m64 m2) __m64 _mm_adds_pu16(__m64 m1, __m64 m2)	Add the four unsigned 16-bit values in m1 to the four unsigned 16-bit values in m2 and saturate.
PAND	__m64 _m_pand(__m64 m1, __m64 m2) __m64 _mm_and_si64(__m64 m1, __m64 m2)	Perform a bitwise AND of the 64-bit value in m1 with the 64-bit value in m2.

Table C-1. Simple Intrinsics

Mnemonic	Intrinsic	Description
PANDN	__m64 _m_pandn(__m64 m1, __m64 m2) __m64 _mm_andnot_si64(__m64 m1, __m64 m2)	Perform a logical NOT on the 64-bit value in m1 and use the result in a bitwise AND with the 64-bit value in m2.
PAVGB	__m64 _mm_pavgb(__m64 a, __m64 b) __m64 _mm_avg_pu8(__m64 a, __m64 b)	Perform the packed average on the eight 8-bit values of the two operands.
PAVGW	__m64 _mm_pavgw(__m64 a, __m64 b) __m64 _mm_avg_pu16(__m64 a, __m64 b)	Perform the packed average on the four 16-bit values of the two operands.
PCMPEQB	__m64 _m_pcmpeqb (__m64 m1, __m64 m2) __m64 _mm_cmpeq_pi8(__m64 m1, __m64 m2)	If the respective 8-bit values in m1 are equal to the respective 8-bit values in m2 set the respective 8-bit resulting values to all ones, otherwise set them to all zeroes.
PCMPEQW	__m64 _m_pcmpeqw (__m64 m1, __m64 m2) __m64 _mm_cmpeq_pi16 (__m64 m1, __m64 m2)	If the respective 16-bit values in m1 are equal to the respective 16-bit values in m2 set the respective 16-bit resulting values to all ones, otherwise set them to all zeroes.
PCMPEQD	__m64 _m_pcmpeqd (__m64 m1, __m64 m2) __m64 _mm_cmpeq_pi32(__m64 m1, __m64 m2)	If the respective 32-bit values in m1 are equal to the respective 32-bit values in m2 set the respective 32-bit resulting values to all ones, otherwise set them to all zeroes.
PCMPGTB	__m64 _m_pcmpgtb (__m64 m1, __m64 m2) __m64 _mm_cmpgt_pi8 (__m64 m1, __m64 m2)	If the respective 8-bit values in m1 are greater than the respective 8-bit values in m2 set the respective 8-bit resulting values to all ones, otherwise set them to all zeroes.
PCMPGTW	__m64 _m_pcmpgtw (__m64 m1, __m64 m2) __m64 _m_cmpgt_pi16 (__m64 m1, __m64 m2)	If the respective 16-bit values in m1 are greater than the respective 16-bit values in m2 set the respective 16-bit resulting values to all ones, otherwise set them to all zeroes.
PCMPGTD	__m64 _m_pcmpgtd (__m64 m1, __m64 m2) __m64 _mm_cmpgt_pi32(__m64 m1, __m64 m2)	If the respective 32-bit values in m1 are greater than the respective 32-bit values in m2 set the respective 32-bit resulting values to all ones, otherwise set them all to zeroes.
PEXTRW	int _m_pextrw(__m64 a, int n) int _mm_extract_pi16(__m64 a, int n)	Extracts one of the four words of a. The selector n must be an immediate.
PINSRW	__m64 _m_pinsrw(__m64 a, int d, int n) __m64 _mm_insert_pi16(__m64 a, int d, int n)	Inserts word d into one of four words of a. The selector n must be an immediate.
PMADDWD	__m64 _m_pmaddwd(__m64 m1, __m64 m2) __m64 _mm_madd_pi16(__m64 m1, __m64 m2)	Multiply four 16-bit values in m1 by four 16-bit values in m2 producing four 32-bit intermediate results, which are then summed by pairs to produce two 32-bit results.
PMAXSW	__m64 _m_pmaxsw(__m64 a, __m64 b) __m64 _mm_max_pi16(__m64 a, __m64 b)	Computes the element-wise maximum of the words in a and b.
PMAXUB	__m64 _m_pmaxub(__m64 a, __m64 b) __m64 _mm_max_pu8(__m64 a, __m64 b)	Computes the element-wise maximum of the unsigned bytes in a and b.
PMINSW	__m64 _m_pminsw(__m64 a, __m64 b) __m64 _mm_min_pi16(__m64 a, __m64 b)	Computes the element-wise minimum of the words in a and b.
PMINUB	__m64 _m_pminub(__m64 a, __m64 b) __m64 _m_min_pu8(__m64 a, __m64 b)	Computes the element-wise minimum of the unsigned bytes in a and b.
PMOVMSKB	int _m_pmovmskb(__m64 a) int _mm_movemask_pi8(__m64 a)	Creates an 8-bit mask from the most significant bits of the bytes in a.

Table C-1. Simple Intrinsics

Mnemonic	Intrinsic	Description
PMULHUW	__m64 _m_pmulhuw(__m64 a, __m64 b) __m64 _mm_mulhi_pu16(__m64 a, __m64 b)	Multiplies the unsigned words in a and b, returning the upper 16 bits of the 32-bit intermediate results.
PMULHW	__m64 _m_pmulhw(__m64 m1, __m64 m2) __m64 _mm_mulhi_pi16(__m64 m1, __m64 m2)	Multiply four signed 16-bit values in m1 by four signed 16-bit values in m2 and produce the high 16 bits of the four results.
PMULLW	__m64 _m_pmullw(__m64 m1, __m64 m2) __m64 _mm_mullo_pi16(__m64 m1, __m64 m2)	Multiply four 16-bit values in m1 by four 16-bit values in m2 and produce the low 16 bits of the four results.
POR	__m64 _m_por(__m64 m1, __m64 m2) __m64 _mm_or_si64(__m64 m1, __m64 m2)	Perform a bitwise OR of the 64-bit value in m1 with the 64-bit value in m2.
PREFETCH	void _mm_prefetch(char *a, int sel)	Loads one cache line of data from address p to a location "closer" to the processor. The value i specifies the type of prefetch operation.
PSHUFW	__m64 _m_psadbw(__m64 a, __m64 b) __m64 _mm_sad_pu8(__m64 a, __m64 b)	Returns a combination of the four words of a. The selector n must be an immediate.
PSLLW	__m64 _m_pshufw(__m64 a, int n) __m64 _mm_shuffle_pi16(__m64 a, int n)	Shift four 16-bit values in m left the amount specified by count while shifting in zeroes.
	__m64 _m_psllw(__m64 m, __m64 count) __m64 _mm_sll_pi16(__m64 m, __m64 count)	Shift four 16-bit values in m left the amount specified by count while shifting in zeroes. For the best performance, count should be a constant.
PSLLD	__m64 _m_psllwi (__m64 m, int count) __m64 _m_slli_pi16(__m64 m, int count)	Shift two 32-bit values in m left the amount specified by count while shifting in zeroes.
	__m64 _m_pslld (__m64 m, __m64 count) __m64 _m_sll_pi32(__m64 m, __m64 count)	Shift two 32-bit values in m left the amount specified by count while shifting in zeroes. For the best performance, count should be a constant.
PSLLQ	__m64 _m_psllq (__m64 m, __m64 count) __m64 _mm_sll_si64(__m64 m, __m64 count) __m64 _m_psllqi (__m64 m, int count) __m64 _mm_slli_si64(__m64 m, int count)	Shift the 64-bit value in m left the amount specified by count while shifting in zeroes. Shift the 64-bit value in m left the amount specified by count while shifting in zeroes. For the best performance, count should be a constant.
PSRAW	__m64 _m_psraw (__m64 m, __m64 count) __m64 _mm_sra_pi16(__m64 m, __m64 count) __m64 _m_psrawi (__m64 m, int count) __m64 _mm_srai_pi16(__m64 m, int count)	Shift four 16-bit values in m right the amount specified by count while shifting in the sign bit. Shift four 16-bit values in m right the amount specified by count while shifting in the sign bit. For the best performance, count should be a constant.
PSRAD	__m64 _m_psrad (__m64 m, __m64 count) __m64 _mm_sra_pi32 (__m64 m, __m64 count) __m64 _m_psradi (__m64 m, int count) __m64 _mm_srai_pi32 (__m64 m, int count)	Shift two 32-bit values in m right the amount specified by count while shifting in the sign bit. Shift two 32-bit values in m right the amount specified by count while shifting in the sign bit. For the best performance, count should be a constant.

Table C-1. Simple Intrinsics

Mnemonic	Intrinsic	Description
PSRLW	__m64 _m_psrlw (__m64 m, __m64 count) __m64 _mm_srl_pi16 (__m64 m, __m64 count) __m64 _m_psrlwi (__m64 m, int count) __m64 _mm_srli_pi16(__m64 m, int count)	Shift four 16-bit values in m right the amount specified by count while shifting in zeroes. Shift four 16-bit values in m right the amount specified by count while shifting in zeroes. For the best performance, count should be a constant.
PSRLD	__m64 _m_psrld (__m64 m, __m64 count) __m64 _mm_srl_pi32 (__m64 m, __m64 count) __m64 _m_psrldi (__m64 m, int count) __m64 _mm_srli_pi32 (__m64 m, int count)	Shift two 32-bit values in m right the amount specified by count while shifting in zeroes. Shift two 32-bit values in m right the amount specified by count while shifting in zeroes. For the best performance, count should be a constant.
PSRLQ	__m64 _m_psrlq (__m64 m, __m64 count) __m64 _mm_srl_si64 (__m64 m, __m64 count) __m64 _m_psrlqi (__m64 m, int count) __m64 _mm_srli_si64 (__m64 m, int count)	Shift the 64-bit value in m right the amount specified by count while shifting in zeroes. Shift the 64-bit value in m right the amount specified by count while shifting in zeroes. For the best performance, count should be a constant.
PSUBB	__m64 _m_psubb(__m64 m1, __m64 m2) __m64 _mm_sub_pi8(__m64 m1, __m64 m2)	Subtract the eight 8-bit values in m2 from the eight 8-bit values in m1.
PSUBW	__m64 _m_psubw(__m64 m1, __m64 m2) __m64 _mm_sub_pi16(__m64 m1, __m64 m2)	Subtract the four 16-bit values in m2 from the four 16-bit values in m1.
PSUBD	__m64 _m_psubd(__m64 m1, __m64 m2) __m64 _mm_sub_pi32(__m64 m1, __m64 m2)	Subtract the two 32-bit values in m2 from the two 32-bit values in m1.
PSUBSB	__m64 _m_psubsb(__m64 m1, __m64 m2) __m64 _mm_subs_pi8(__m64 m1, __m64 m2)	Subtract the eight signed 8-bit values in m2 from the eight signed 8-bit values in m1 and saturate.
PSUBSW	__m64 _m_psubsw(__m64 m1, __m64 m2) __m64 _mm_subs_pi16(__m64 m1, __m64 m2)	Subtract the four signed 16-bit values in m2 from the four signed 16-bit values in m1 and saturate.
PSUBUSB	__m64 _m_psubusb(__m64 m1, __m64 m2) __m64 _mm_sub_pu8(__m64 m1, __m64 m2)	Subtract the eight unsigned 8-bit values in m2 from the eight unsigned 8-bit values in m1 and saturate.
PSUBUSW	__m64 _m_psubusw(__m64 m1, __m64 m2) __m64 _mm_sub_pu16(__m64 m1, __m64 m2)	Subtract the four unsigned 16-bit values in m2 from the four unsigned 16-bit values in m1 and saturate.
PUNPCKHBW	__m64 _m_punpckhbw (__m64 m1, __m64 m2) __m64 _mm_unpackhi_pi8(__m64 m1, __m64 m2)	Interleave the four 8-bit values from the high half of m1 with the four values from the high half of m2 and take the least significant element from m1.
PUNPCKHWD	__m64 _m_punpckhwd (__m64 m1, __m64 m2) __m64 _mm_unpackhi_pi16(__m64 m1,__m64 m2)	Interleave the two 16-bit values from the high half of m1 with the two values from the high half of m2 and take the least significant element from m1.
PUNPCKHDQ	__m64 _m_punpckhdq (__m64 m1, __m64 m2) __m64 _mm_unpackhi_pi32(__m64 m1, __m64 m2)	Interleave the 32-bit value from the high half of m1 with the 32-bit value from the high half of m2 and take the least significant element from m1.
PUNPCKLBW	__m64 _m_punpcklbw (__m64 m1, __m64 m2) __m64 _mm_unpacklo_pi8 (__m64 m1, __m64 m2)	Interleave the four 8-bit values from the low half of m1 with the four values from the low half of m2 and take the least significant element from m1.

Table C-1. Simple Intrinsics

Mnemonic	Intrinsic	Description
PUNPCKLWD	__m64 _m_punpcklwd (__m64 m1, __m64 m2) __m64 _mm_unpacklo_pi16(__m64 m1, __m64 m2)	Interleave the two 16-bit values from the low half of m1 with the two values from the low half of m2 and take the least significant element from m1.
PUNPCKLDQ	__m64 _m_punpckldq (__m64 m1, __m64 m2) __m64 _mm_unpacklo_pi32(__m64 m1, __m64 m2)	Interleave the 32-bit value from the low half of m1 with the 32-bit value from the low half of m2 and take the least significant element from m1.
PXOR	__m64 _m_pxor(__m64 m1, __m64 m2) __m64 _mm_xor_si64(__m64 m1, __m64 m2)	Perform a bitwise XOR of the 64-bit value in m1 with the 64-bit value in m2.
RCPPS	__m128 _mm_rcp_ps(__m128 a)	Computes the approximations of the reciprocals of the four SP FP values of a.
RCPSS	__m128 _mm_rcp_ss(__m128 a)	Computes the approximation of the reciprocal of the lower SP FP value of a; the upper three SP FP values are passed through.
RSQRTPS	__m128 _mm_rsqrt_ps(__m128 a)	Computes the approximations of the reciprocals of the square roots of the four SP FP values of a.
RSQRTSS	__m128 _mm_rsqrt_ss(__m128 a)	Computes the approximation of the reciprocal of the square root of the lower SP FP value of a; the upper three SP FP values are passed through.
SFENCE	void_mm_sfence(void)	Guarantees that every preceding store is globally visible before any subsequent store.
SHUFPS	__m128 _mm_shuffle_ps(__m128 a, __m128 b, unsigned int imm8)	Selects four specific SP FP values from a and b, based on the mask i. The mask must be an immediate.
SQRTPS	__m128 _mm_sqrt_ps(__m128 a)	Computes the square roots of the four SP FP values of a.
SQRTSS	__m128 _mm_sqrt_ss(__m128 a)	Computes the square root of the lower SP FP value of a; the upper three SP FP values are passed through.
STMXCSR	_mm_getcsr(void)	Returns the contents of the control register.
SUBPS	__m128 _mm_sub_ps(__m128 a, __m128 b)	Subtracts the four SP FP values of a and b.
SUBSS	__m128 _mm_sub_ss(__m128 a, __m128 b)	Subtracts the lower SP FP values of a and b. The upper three SP FP values are passed through from a.

Table C-1. Simple Intrinsics

Mnemonic	Intrinsic	Description
UCOMISS	_mm_ucomieq_ss(__m128 a, __m128 b)	Compares the lower SP FP value of a and b for a equal to b. If a and b are equal, 1 is returned. Otherwise 0 is returned.
	_mm_ucomilt_ss(__m128 a, __m128 b)	Compares the lower SP FP value of a and b for a less than b. If a is less than b, 1 is returned. Otherwise 0 is returned.
	_mm_ucomile_ss(__m128 a, __m128 b)	Compares the lower SP FP value of a and b for a less than or equal to b. If a is less than or equal to b, 1 is returned. Otherwise 0 is returned.
	_mm_ucomigt_ss(__m128 a, __m128 b)	Compares the lower SP FP value of a and b for a greater than b. If a is greater than b are equal, 1 is returned. Otherwise 0 is returned.
	_mm_ucomige_ss(__m128 a, __m128 b)	Compares the lower SP FP value of a and b for a greater than or equal to b. If a is greater than or equal to b, 1 is returned. Otherwise 0 is returned.
	_mm_ucomineq_ss(__m128 a, __m128 b)	Compares the lower SP FP value of a and b for a not equal to b. If a and b are not equal, 1 is returned. Otherwise 0 is returned.
UNPCKHPS	__m128 _mm_unpackhi_ps(__m128 a, __m128 b)	Selects and interleaves the upper two SP FP values from a and b.
UNPCKLPS	__m128 _mm_unpacklo_ps(__m128 a, __m128 b)	Selects and interleaves the lower two SP FP values from a and b.
XORPS	__m128 _mm_xor_ps(__m128 a, __m128 b)	Computes bitwise EXOR (exclusive-or) of the four SP FP values of a and b.

C.2. COMPOSITE INTRINSICS

Table C-2. Composite Intrinsics

Mnemonic	Intrinsic	Description
(composite)	__m128 _mm_set_ps1(float w) __m128_set1_ps(float w)	Sets the four SP FP values to w.
(composite)	__m128 _mm_set_ps(float z, float y, float x, float w)	Sets the four SP FP values to the four inputs.
(composite)	__m128 _mm_setr_ps(float z, float y, float x, float w)	Sets the four SP FP values to the four inputs in reverse order.
(composite)	__m128 _mm_setzero_ps(void)	Clears the four SP FP values.
MOVSS + shuffle	__m128 _mm_load_ps1(float * p) __m128 _mm_load1_ps(float *p)	Loads a single SP FP value, copying it into all four words.
MOVAPS + shuffle	__m128 _mm_loadr_ps(float * p)	Loads four SP FP values in reverse order. The address must be 16-byte-aligned.
MOVSS + shuffle	void _mm_store_ps1(float * p, __m128 a) void _mm_store1_ps(float *p, __m128 a)	Stores the lower SP FP value across four words.
MOVAPS + shuffle	_mm_storer_ps(float * p, __m128 a)	Stores four SP FP values in reverse order. The address must be 16-byte-aligned.

Index

INDEX

D

E

F

G

H

I

J

L

M

N

O

P

Q

R

S

T

U

V

W

X

Z