12 Data abstraction

- Packages and encapsulation
- Classes, subclasses, and inheritance

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Packages

- A **package** (or **module**) is a named group of components declared for a common purpose.
- These components may be types, constants, variables, procedures, inner packages, etc. (depending on the PL).
- The meaning of a package is the set of bindings exported by the package
  - often called the package's **application program interface** (**API**).

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Example: simple Python module

- Outline of a module (dictionary.py)

```
words = […]

def contains (word):
    global words
    return (word in words)

def add (word):
    global words
    if word not in words:
        words += [word]
```

- This module's API:

{ `words` → a list of words,
`contains` → a function that tests whether a word is in the list,
`add` → a procedure that adds a word to the list }

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Encapsulation *(1)*

- Some of the components of a program-unit (package/class) may be private. This is called **encapsulation**.
- Levels of privacy:
  - A component is **private** if it is visible only inside the program-unit.
  - A component is **protected** if it is visible only inside the program-unit and certain “friendly” program-units.
  - A component is **public** if it is visible to application code outside the program-unit.
- A program-unit’s API consists of its public bindings only.

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Encapsulation *(2)*

- Most PLs (such as Ada, Java, Haskell) allow individual components of a program-unit to be specified as private/protected/public.
- Python has a *convention* that components whose names start with "_" are private, whilst those whose names start with letters are public.
  - This convention is not enforced by the Python compiler.

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Example: Python module with encapsulation

- Outline of a module (dictionary.py)

```
_words = […]

def contains (word):
    global _words
    return (word in _words)

def add (word):
    global _words
    if word not in _words:
        _words += [word]
```

- This module's API:

{ `contains` → a function that tests whether a word is in the list,
`add` → a procedure that adds a word to the list }

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Example: Java packages

- In Java, the components of a package are classes and inner packages.
- Package components are added incrementally.
- Outline of a class declaration within a package:

```
package sprockets;

import widgets.*;

public class C {
    …
}
```

declares that class `C` is a component of package `sprockets`

declares that class `C` uses public components of package `widgets`

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Classes *(1)*

- An **object** is a tagged tuple of variable components (**instance variables**), equipped with operations that access these instance variables.
- A **constructor** is an operation that initializes a newly created object.
- An **instance method** is an operation that inspects and/or updates an existing object of class *C*. That object (known as the **receiver object**) is determined by the method call.
- A **class** is a set of similar objects. All objects of a given class *C* have similar instance variables, and are equipped with the same operations.

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Classes *(2)*

- A Java class declaration:
  - declares its instance variables
  - defines its constructors and instance methods
  - specifies whether each of these is private, protected, or public.
- A Java instance method call has the form "*O*`.`*M*`(...)`":
  - The expression *O* yields the receiver object.
  - *M* is the name of the instance method to be called.
  - The call executes the method body, with **`this`** bound to the receiver object.

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Example: Java class *(1)*

- Class declaration:

```
class Dict {

    private int size;
    private String[] words;

    public Dict (int capacity)
    { … }

    public void add (String w)
    {   if (! this.contains(w))
            this.words[this.size++] = w; }

    public boolean contains (String w)
    { … }

}
```

Example: Java class *(2)*

- Possible application code:

```
Dict mainDict = new Dict (10000);
Dict userDict = new Dict (1000);
…
if (! mainDict.contains (currentWord)
  && ! userDict.contains (currentWord))
    userDict.add (currentWord);
```

- Illegal application code:

```
userDict.size = 0;
out.print (userDict.words[0]);
```

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Subclasses

- If C' is a **subclass** of C (or C is a **superclass** of C'), then C' is a set of objects that are similar to one another but richer than the objects of class C:
  - An object of class C' has all the instance variables of an object of class C, but may have extra instance variables.
  - An object of class C' is equipped with all the instance methods of class C, but may override some of them, and may be equipped with extra instance methods.

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Inheritance

- By default, a subclass **inherits** (shares) its superclass’s instance methods.
- Alternatively, a subclass may **override** some of its superclass’s instance methods, by providing more specialized versions of these methods.

Example: Java class and subclasses *(1)*

- Class declaration:

```
class Shape {
    protected float x, y;

    public Shape ()
    { x = 0.0; y = 0.0; }

    public final void move (
           float dx, float dy)
    { x += dx;  y += dy; }

    public void draw ()
    { … }   // draws a point at (x, y)
}
```

abbreviations for **this.**x and **this.**y

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Example: Java class and subclasses *(2)*

- Subclass declaration:

```
class Circle extends Shape {
    private float r;
    public Circle (float radius)
    { x = 0.0;  y = 0.0;  r = radius; }
    public void draw ()
    { … }  // draws a circle centred at (x, y)
    public float diameter ()
    { return 2.0*r; }
}
```

Example: Java class and subclasses *(3)*

- Subclass declaration:

```
class Box extends Shape {

    private float w, h;

    public Box (…)
    { … }

    public void draw ()
    { … }   // draws a box centred at (x, y)

    public float width ()
    { return w; }

    public float height ()
    { return h; }

}
```

Example: Java class and subclasses *(4)*

- Possible application code:

```
Shape s = new Shape();
Circle c = new Circle(10.0);
s.move(12.0, 5.0);
c.move(3.0, 4.0);
… c.diameter() …

s.draw();       ---------- draws a point at (12, 5)
c.draw();       ---------- draws a circle centred at (3, 4)

s = c;
s.draw();       ---------- ditto! (dynamic dispatch)
```

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Overriding

- Each instance method of a class *C* is inherited by the subclass *C′*, unless it is overridden by *C′*.
- The overriding method in class *C′* has the same name and type as the original method in class *C*.
- Most OO PLs allow the programmer to specify whether an instance method is **virtual** (may be overridden) or not:
  - In C++, an instance method specified as `virtual` may be overridden.
  - In Java, an instance method specified as `final` may *not* be overridden.

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Dynamic dispatch

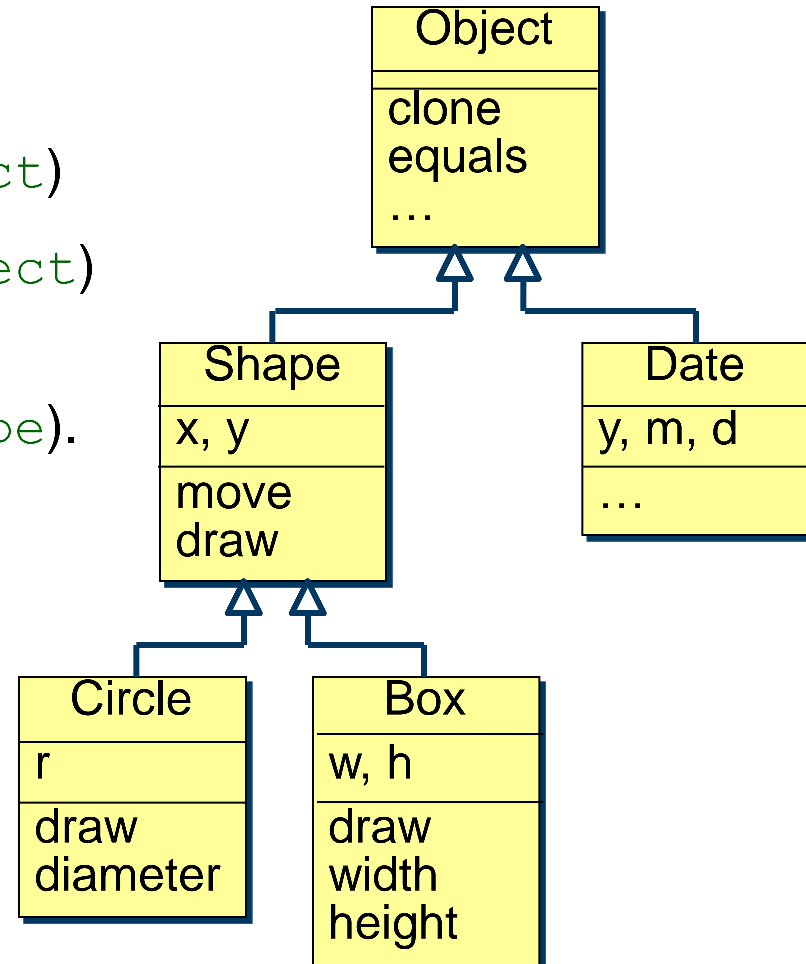
- In every OO PL, a variable of type *C* may refer to an object of any subclass of *C*.
- If method *M* is virtual, then the method call "`O.M(…)`" entails **dynamic dispatch**:
  - The *compiler* infers the type of *O*, say class *C*. It then checks that class *C* is equipped with an instance method named *M*, of the appropriate type.
  - At *run-time*, however, it might turn out that the receiver object is of class *C'*, a subclass of *C*. The receiver object's tag is used to determine its actual class, and hence determine which of the methods named *M* is to be called.

Single inheritance

- An OO PL supports **single inheritance** if each class has at most one superclass.
- Single inheritance gives rise to a hierarchy of classes.
- Single inheritance is supported by most OO PLs, including Java.

Example: Java single inheritance

- Declared classes:
  - `Date` (subclass of `Object`)
  - `Shape` (subclass of `Object`)
  - `Circle`, `Box` (both subclasses of `Shape`).
- Hierarchy of classes:

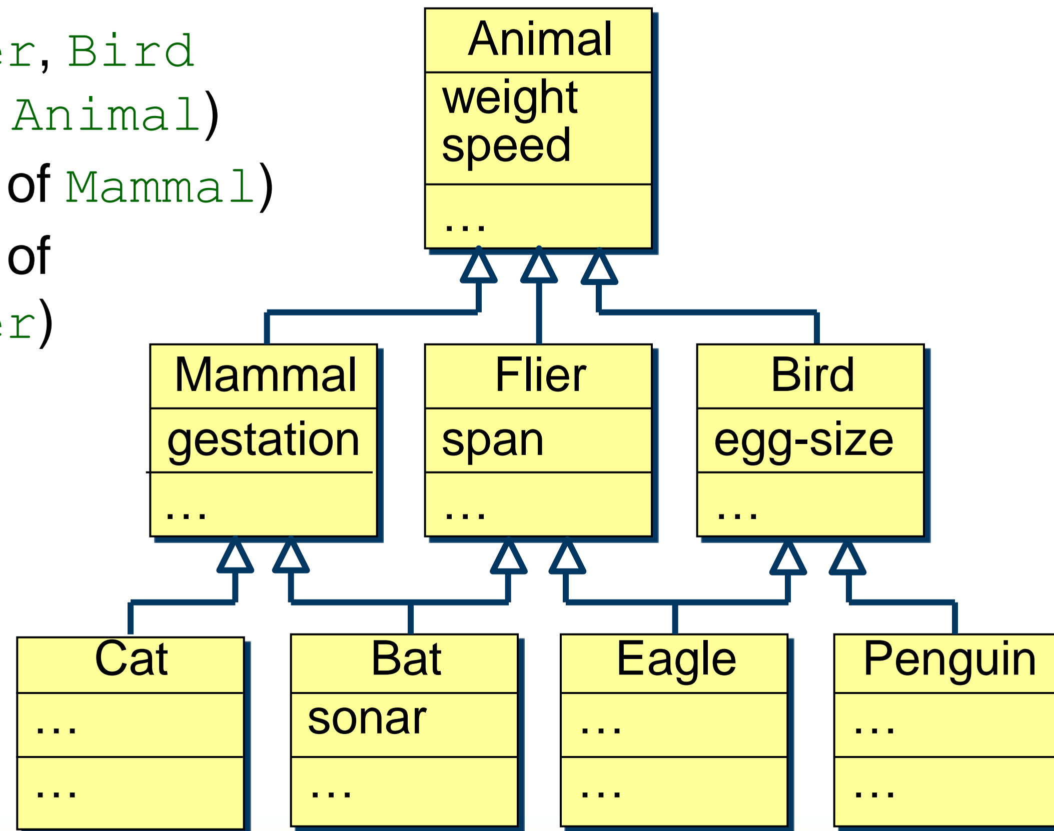


Multiple inheritance

- **Multiple inheritance** allows each class to have any number of superclasses.
- Multiple inheritance is supported by C++.
- Nevertheless, multiple inheritance gives rise to both conceptual and implementation problems.

Example: C++ multiple inheritance *(1)*

- Declared classes:
  - `Animal`
  - `Mammal`, `Flier`, `Bird` (subclasses of `Animal`)
  - `Cat` (subclass of `Mammal`)
  - `Bat` (subclass of `Mammal`, `Flier`)
  - etc.
- Class relationships:



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Example: C++ multiple inheritance *(2)*

- Suppose:
  - the `Animal` class defines a method named `move`
  - the `Mammal` and `Flier` classes both override that method.
- Which method does the `Bat` class inherit?

```
Bat b = …; b.move(…);
```

- Possible answers:
  - Make it call the `Mammal` method.
  - Force the programmer to choose.
  - Make this method call illegal.