Multimedia Systems - Video

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Image & Video Capture

- An image is captured when a camera scans a scene
  - Colour => Red (R), Green (G) and Blue (B) array of digital samples
  - Density of samples (pixels) gives resolution
- A video is captured when a camera scans a scene at multiple time instants
- Each sample is called a frame giving rise to a frame rate (frames/sec) measured in Hz
  - TV (full motion video) is 25Hz
  - Mobile video telephony is 8-15 Hz … jerky

Image Capture

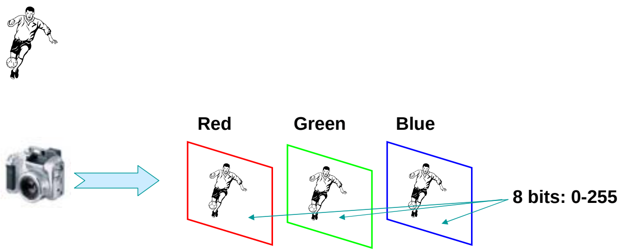
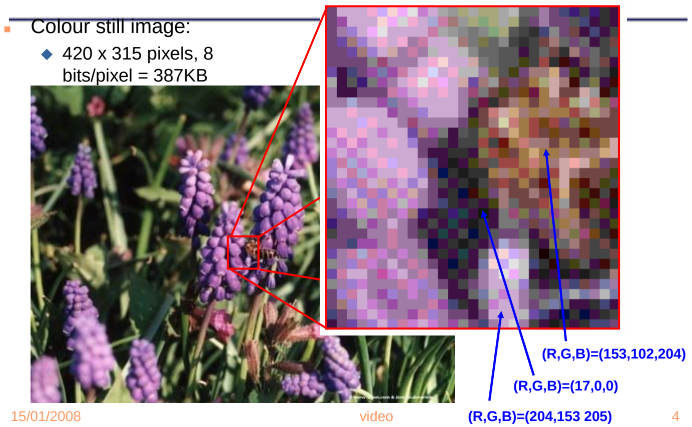
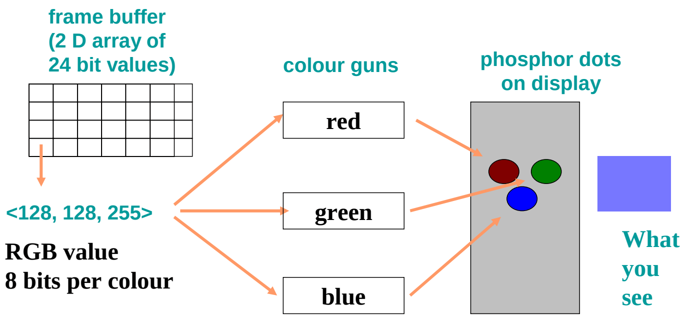


Image Data (RGB)

- Colour still image:
  - 420 x 315 pixels, 8 bits/pixel = 387KB



Video Technology: generating a colour



Human Visual Perception

- Mixing three primary colours in varying proportions, the perception of different colours can be created
- Human eye build up of
  - Cones to perceive colour
  - By exciting retina using different intensities of the three primary colours, the same colour may be perceived by the brain even if its unique wavelength is not present.

Human Information processing

- Identical colour combinations can cause different colour sensation under different conditions
- Likewise two different colour can be perceived identical …
- the human eye & brain
  - Interpolation
  - Pictures and events that can still be identified as separate
  - Colour interaction in the brain
- Adaptation
  - General-brightness adaptation
  - Lateral adaptation
  - Chromatic adaptation

Colour

- Colour is a visual feature which is immediately perceived
- Salient chromatic properties are captured
- Colour can add great value to an image
- Presence and distributions of colours induce sensations and conveys meanings in the observer according to specific rules
- Representing colour on digital images and reproducing accurately on output devices are not at all straightforward
- Distances in colour space should correspond to human perceptual distance

Colour Space

- To deal with colour we need to quantify it in some way
  - gives us the notion of colour space or domain
- Hierarchy of colour sets
  - Perceivable by human beings
  - Displayed on a monitor screen
  - Calculated and stored in a frame memory

Representation of Colour Stimuli

- Points in three dimensional space
- Calorimetric models
  - CIE Chromaticity diagram
- Physiologically inspired models
  - CIE XYZ, RGB
- Psychological models
  - HSV,
- Hardware-oriented models
  - RGB, CMY, YIQ
- User-oriented models
  - HLS, HSV, HSB

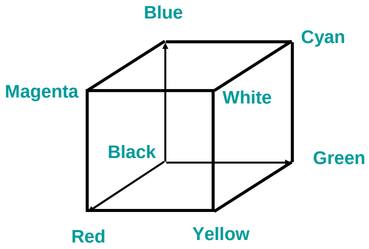
Video Technology: representing colour

- monochrome
  - bilevel
    - one bit/pixel: 0 = black, 1 = white
  - grey-scale
    - e.g., 8 bits/pixel = 256 intensities
- colour
  - value for each colour gun
  - no of bits gives colour range
    - e.g., 24 bits = 8 bits for red, 8 bits for green, 8 bits for blue
    - colour depth

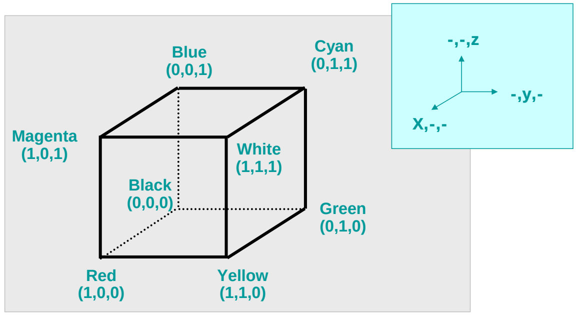
Video Technology: Colour Models: RGB

- RGB = Red Green Blue
- directly modelled in device (i.e., corresponds to colour guns in display)
- easy to implement
- not based on visual (perceived) colours
- not perceptually uniform

Video Technology: Colour Models: RGB Colour Space



Video Technology: Colour Models: RGB Colour Space



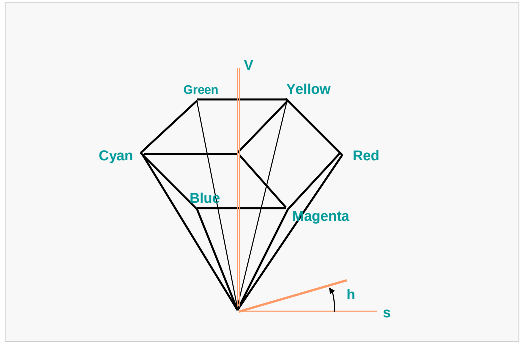
Video Technology: Colour Models: RGB

- Colour is labeled as a relative weights of three primary colours, in an additive system using the primaries Red, Green, Blue
- It is perceptually non-linear space
  - Equal distances in the space do not necessarily correspond to perceptually equal sensation
- Non-linear relationship between RGB values & the intensity produced in each phosphor dot, low intensity values produce small changes in response to screen
- It is not a good colour description system

Video Technology: Colour Models: HSV

- HSV = hue, saturation, value (intensity)
- "painter's model"
- better model for representing colours as we see them ("I want a bright highly saturated apple green.")
- can be converted to/from RGB
- like RGB, axes not perceptually uniform
- variant: HLS (hue, lightness, saturation)

Video Technology: Colour Models: HSV Colour Space



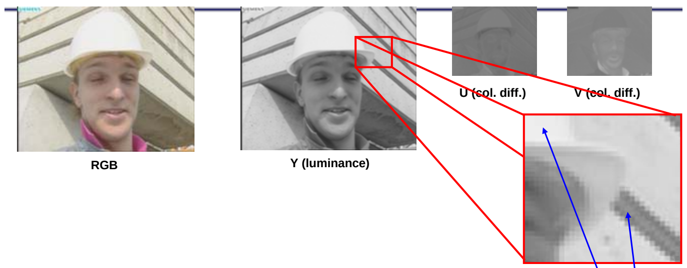
Video Technology: Colour Models: HSV

- Non-linear transformation of RGB cube
- Hue : quality by which we distinguish one family from others
- Chroma: quality by which we distinguish a strong colour from weak ones
- Value: It is that quality by which we distinguish a light colour from a dark one
- H corresponds to selecting a colour; S corresponds to selecting the amount of white; selecting V corresponds to adding black
- Perceptually non-linear
  - Perceptual in the sense that we are using attributes that we normally think of
  - Attributes are not independent
- variant: HLS (hue, lightness, saturation)

Video Technology: Colour Models: YUV

- colour model used for TV signal transmission
- Y represents luminance (intensity of monochrome signal)
- U,V carry separate colour information (colour difference values)
- Y = 0.2125R + 0.7154G + 0.0721B
- U = B-Y, V = R-Y
- typically, Y contributes most to signal bandwidth

Image Data (YUV)



- See:
  - [A.K. Jain, *Fundamentals of Digital Image Processing*, Prentice Hall, 1988]

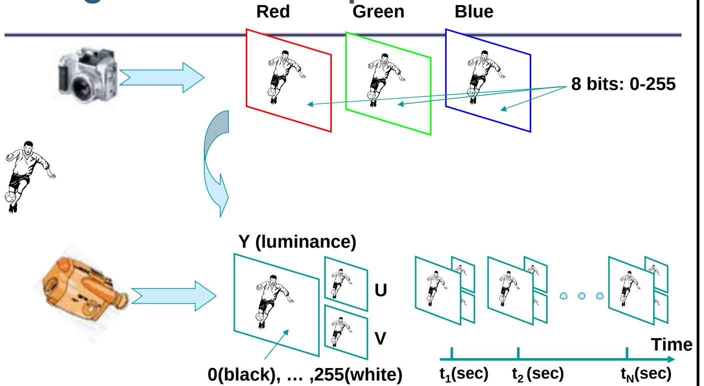
Video Technology: CIE Colour Specification System

- Commission Internationale d'Éclairage
- colour labelling system
- "XYZ" space
- international standard (1931)
- based on colour matching functions determined by experiments with human subjects
- gives uniform colour spaces
- needs transformation into one of the other models

Video Technology: Colour Models: CMYK

- CMYK = cyan, magenta, yellow, black
- "printer's model"
- a subtractive model
- set of practically available CMYK colours ("process colours") are not equivalent to RGB set

Image & Video Capture



Video Sequence

- Consists of number of frames
  - Images produced by digitising time-varying signal generated by the sensors in a camera
  - Bit-mapped images
- Camera
  - Circuitry Inside a Camera
  - Purely digital signal (data stream) is fed into a computer via a high speed interface
    - IEEE 1394 (FireWire)
- Computer
  - Broadcast video is fed into a video capture card attached to the computer
  - Video capture card- analogue signal is converted into a digital form

Video Data

- Desktop PC
  - CIF (352 x 288), 8 bpp, 30hz = 8.7 MB/sec
  - 30 sec clip = 261 MB
- Video to mobile device
  - QCIF (176 x 144), 8 bpp, 30 hz = 2.2 MB/sec
  - 30 sec clip = 65 MB
- High Definition TV (HDTV)
  - 1280 x 720, 24 bpp, 50 hz = 0.4 GB/sec
  - 2.5 hour movie = 3.4 TB

Pushing the hardware

- Consumers expectations are based on broadcast television
- Consumer equipment plays back at reduced frame rate resulting in jittery- dropped frames
- In order to accommodate low-end PCs considerable compromises over quality must be made

Persistence of vision

- If a sequence of still images is presented to our eyes at sufficiently high rate (frame rate~40 fps), we experience a continuous visual sensation rather than perceiving individual images
  - A lag in the eye's response to visual stimuli which results in after images
- If the consecutive images only differ by a small amount, any changes from one to next will be perceived as movement of elements within images
- Film projector displays an image twice (24 fps becomes 48 fps)

Human Perception

- What frame rate perceived as smooth?
  - No identification of single frames if refresh frequency is high enough
  - Perception of 16 frames/s as continuous sequence
  - Depends on material
- More sensitive to low frequencies
- More sensitive to changes in luminance and blue-orange axis
- Vision emphasizes edge detection

Digitization: camera vs computer

- Advantage
  - Analogue signal transmitted on a cable get corrupted by noise
  - Noise will creep in if analogue data is stored on a magnetic tape
  - Camera is resistant to corruption by noise and interference
- disadvantage
  - **User has no control over digitization**
  - **Most conform to an appropriate standard**

Image & Video Processing

- When processing image/video data we have two choices:
  - Raw data … termed *uncompressed domain*
    - Direct processing of the pixel values on either a global or local basis
    - Slow - more data, may require decode process
    - Possible to extract a wide range of expressive information from raw data
  - Encoded data … termed *compressed domain*
    - Parse bitstream and process data contained therein
    - Fast - partial image reconstruction, real-time possible
    - Restricted to image/video data in bitstream
    - Compression is about throwing away information for efficient representation and transmission

Video Bit Rate Calculation

$$\left[\frac{\text{width * height * depth * fps}}{\text{compression factor}} \right] = \text{bits/sec}$$

- width ~ pixels (160, 320, 640, 720, 1280, 1920, …)
- height ~ pixels (120, 240, 480, 485, 720, 1080, …)
- depth ~ bits (1, 4, 8, 15, 16, 24, …)
- fps ~ frames per second (5, 15, 20, 24, 30, …)
- compression factor (1, 6, 24, …)

Examples

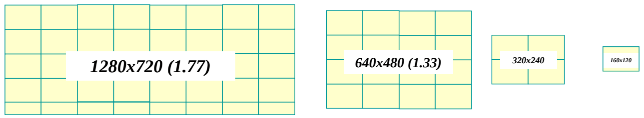
Width	Height	Depth	fps	Comp	Kb/sec	Notes
160	120	8	15	25	92	Basic Rate ISDN
160	120	16	20	20	307	
320	240	8	15	25	369	
320	240	16	24	24	1,229	MPEG1 (Primary Rate ISDN)
640	480	16	30	24	6,144	MPEG2
640	480	24	30	6	36,864	MJPEG
640	480	24	30	1	221,184	Uncompressed

Video Data Size

size of uncompressed video in gigabytes

	1920x1080	1280x720	640x480	320x240	160x120
1 sec	0.19	0.08	0.03	0.01	0.00
1 min	11.20	4.98	1.66	0.41	0.10
1 hour	671.85	298.60	99.53	24.88	6.22
1000 hours	671,846.40	298,598.40	99,532.80	24,883.20	6,220.80

image size of video



Compression

- When captured, audio/video data is referred to as as "raw" or "uncompressed"
- In practice, undergo software/hardware process to compact data:
  - Termed "compression" or "encoding"
  - Results in an efficient bitstream that can be stored or transmitted
- Requires a (less) complex process to uncompress (decode) before it can be displayed
- A system for encoding & decoding is termed a "codec"

Image Compression

- Use frequency domain analysis
  - The discrete cosine transform (DCT)

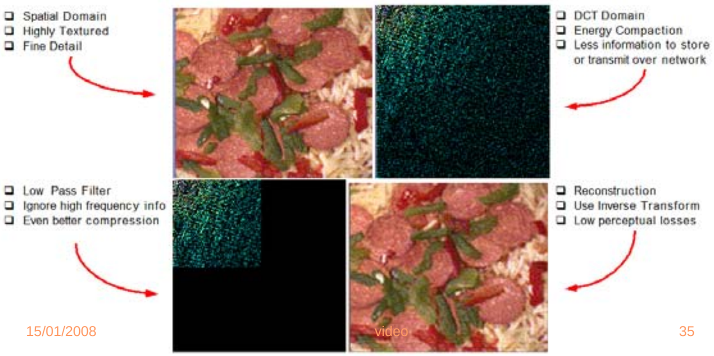


Image Compression

Effects of Compression

storage for 1 hour of compressed video in megabytes

	1920x1080	1280x720	640x480	320x240	160x120
1:1	671,846	298,598	99,533	24,883	6,221
3:1	223,949	99,533	33,178	8,294	2,074
6:1	111,974	49,766	16,589	4,147	1,037
25:1	26,874	11,944	3,981	995	249
100:1	6,718	2,986	995	249	62

3 bytes/pixel, 30 frames/sec

Compression

- Two types:
  - Lossless: doesn't change data "simply" reorganizes
    - Used in medical applications (e.g. X-Rays) and document scanning (e.g. FAX)
  - Lossy: throws some data away during encoding
    - Used in most multimedia applications
- Popular image/video compression standards for multimedia applications:
  - JPEG (still images)
  - JPEG 2000 (enhanced functionality/quality)
  - MPEG-1 (video from CD-ROM)
  - MPEG-2 (Digital TV, DVD)
  - MPEG-4 (mobile and content-based functionality)
  - Also: ITU-T real-time telecommunications standards e.g. H.261, H.263, H.264/MPEG-4 AVC

Video codecs

- Video capture boards
  - Digitization and compression
  - Decompression and digital to analogue transformation
  - Devices compressor/decompressor (codecs)
- Hardware codecs
  - Store them on a computer
  - Then play them back to an external video monitor (TV set) attached to the VCC
  - Most hardware codecs can not provide full motion video to monitor
  - We can not know our audience will have any hardware codec available
- Software codec
  - Program that performs the same operation

What is MPEG

- MPEG: Moving Picture Experts Group (Created in1988)
- ISO (Int. Standards Organization) / IEC (Int. Electro-technical Commission)
  - ISO/IEC JTC 1 / SC 29 / WG 11
- Develop standards for the coded representation of moving pictures and associated audio

Video Technology: MJPEG

- motion JPEG
- just applies JPEG to each frame
  - YC_BC_R
  - apply to each channel
- used for compression during video capture
- compression ratios of 7:1
- no temporal compression
- Allows users to set quality parameters
- not a standard
  - MJPEG-A

Vector Quantization

- Iterative algorithm
  - Pick set of reference blocks (code book)
  - Code picture blocks by code book entries
  - Entropy/RLE code the code symbols
- How to select code book
  - Step 1: pick reference blocks
  - Step 2: compare reconstructed image to original
  - Step 3: add additional reference blocks
  - REPEAT UNTIL ERROR IS SMALL
- Slow encode, fast decode

MPEG Standards

- **MPEG-1**: Storage of moving picture and audio on storage media (CD-ROM) *11 / 1992*
  - aimed a low bit-rates of 1.5 Mb/s
  - typical of CD-ROM
- **MPEG-2**: Digital television *11 / 1994*
  - aimed at bit rates of 8-15 Mb/s
  - DVD
- **MPEG-4**: Coding of natural and synthetic media objects for multimedia applications *v1: 09 / 1998* *v2: 11 / 1999*
  - introduction of objects into the specification
  - wide range of data rates
  - important for multimedia
- **MPEG-7**: Multimedia content description for AV material

Video Technology: MPEG-1 compression approach

- Spatial compression for individual frames
- based on JPEG-like technique
- temporal compression of sequences of frames
  - looks for areas of change
  - creates difference frames
  - based on 16X16 macroblocks

Temporal Compression

- Make use of similarities of frames
  - Only difference between frames is encoded
  - Process often termed motion compensation

Second one (s2) can be approximated by pieces of the first one (s1)

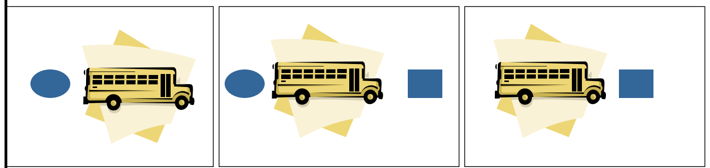
S1 acts as a reference frame

Motion Vectors

- Algorithm searches for Best matching Block
- Needs to calculate error term (Matching block)
- Needs to capture/convey spatial translation
  - Motion vector

Predicted Frames

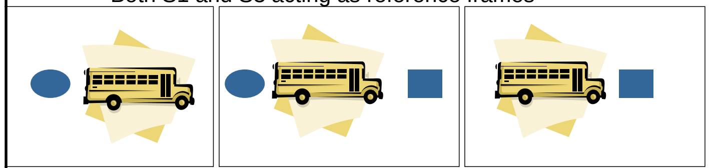
- Consider S3
  - Has macroblocks in common with S1
  - Could be reconstructed from S1
  - S3 would be then a Predicted (P) frame



Bidirectional frames

- Consider S2
  - Has macroblocks in common with S1 and S3
  - Could be constructed using pieces of S1 and S3
  - S2 would be then a Bidirectional (B) frame

    Both S1 and S3 acting as reference frames

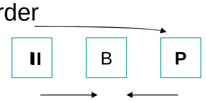


Question?

- How can we know at the time S2 is coded that there will be a matching block in S3?
- Answer:
  - S3 needs to be available for reference at the time of F2 is coded
  - i.e., S1, S2, S3 would need to be buffered
  - S2 only sent (transmission order) once it has been interpolated from S1 and S3

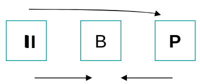
Summary (from example)

- S1 is an I frame – it is encoded without reference to any other frame
- S3 is a Pframe – it is predicted froma reference frame: in this case S1
- S2 is a B frame – it is interpolated from S1 and s3
- Display Order



Bitstream order

- What about decoder …
- How to handle B frames
  - Needs info from later I or P frames in order to construct B frame
- Display Order



  - Solution: reorder the sequence
  - Display order -> bitstream order IBP to IPB

GOPS…

- Encoders typically use a repeating sequence of I, P and B frames
- This is known as a GOP (Group of pictures)
  - Always begin with a I frame
  - Common sequence (display Order)
    - IBBBPBBBI or IBBPBBPBBI
    - N=9
  - Bitstream order
    - IPBBBIBBB or IPBBPBBIBB

Video Sequence

- Commence with a sequence header
- Followed by n GOPS where n> 0
- End with a sequence_end_code
- GOP
  - Each GOP must contain at least I frame
  - Assist random access into the sequence
    - Therefore greater apps need for RA the shorter should be the size of GOP

Role of I frames

IPBBPBBIBB

You want to resume from a given frame …

What if frame is I frame

P frame

B frame

I frames act as synchronisation points

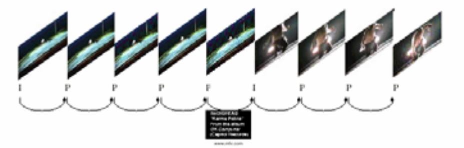
Delay between occurrence of successive I frames should not exceed 400ms

Video Technology: MPEG Frame Types: I Frames

- Intra-coded images
  - similar to a JPEG still of the frame
- Expensive but required
  - I-frames expensive as they have to compress the entire scene
  - needed as start frame for differences
  - needed for scene changes

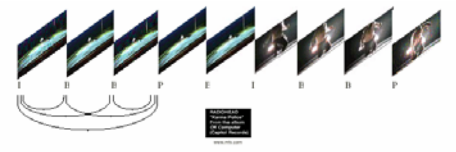
Video Technology: MPEG Frame Types: P Frames

- Predictive coded frames
- based on predicting the movement of blocks from their position in the previous frame (I or P)



Video Technology: MPEG Frame Types: B Frames

- Bi-directional frames
  - based on pair of I/P frames, before and after



MPEG 2

- Motivation …
  - Provide different qualities if image for different domains (with differing target bit rates)
    - E.g., studio quality motion video
  - MPEG-2 took on the mantle of MPEG-3
    - Encoding and compression for HDTV
  - Standard for digital broadband TV
  - Interlaced video
  - DVD quality

Profiles and levels

- MPEG-2 supports greater choice of bit rate
  - Up to HDTV picture size and resolution
  - Allows greater chrominance resolution
    - 4:2:2; 4:4:4
  - Support for wider range of apps
    - Family of compression schemes
    - Schemes defined by a profile and level
      - No single encoder/decoder has to implement all functionality
      - Comparability between newer and older equipment
  - 5 Profiles
    - High, Main, Simple, Spatially scalable, SNR scalable,4:2:2, multiview etc.

MPEG-4

- Motivation …
  - Original objective: develop a low bit rate video compression method
  - Now a set of tools for interactive multimedia scene composition, multiplexing and synchronisation
    - Digital television
    - Interactive graphics application
    - Interactive multimedia
- MPEG-4 provides
  - The standardised technological elements enabling the integration of production, distribution and content access paradigm of the fields of interactive multimedia, mobile multimedia,…