Digital Audio/Image/Video Representation

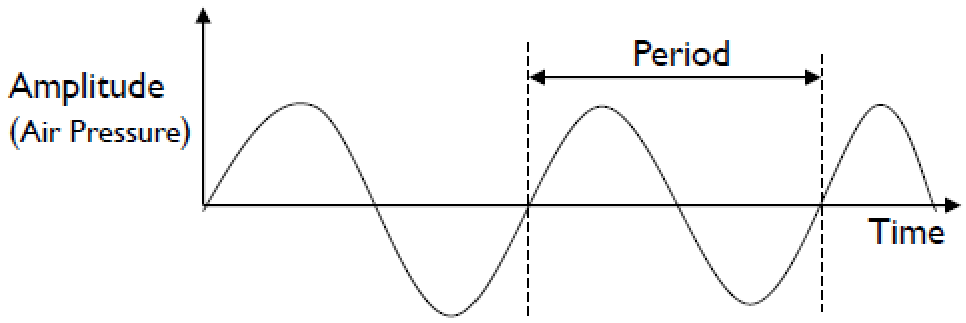
Prof. Dr. Uluğ Bayazıt

Outline

- Digital audio representation
  - Quantization
  - Sampling
- Digital Image Representation
  - Color System
  - Chrominance Subsampling
- Digital Video Representation
- Hardware Requirements

Digital Audio Representation

- Sound
  - due to vibration of matter (i.e., air molecules).
  - continuous wave that travels through air.
    - *Amplitude :* measure of the displacement of air pressure wave from its mean or quiescent state (in decibels (dB))
      - Peak amplitude, peak-to-peak amplitude
    - *Period* is the length of one full cycle
    - *Frequency* represents the number of periods in a second (in hertz, Hz, cycles/second).
      - the reciprocal value of the period



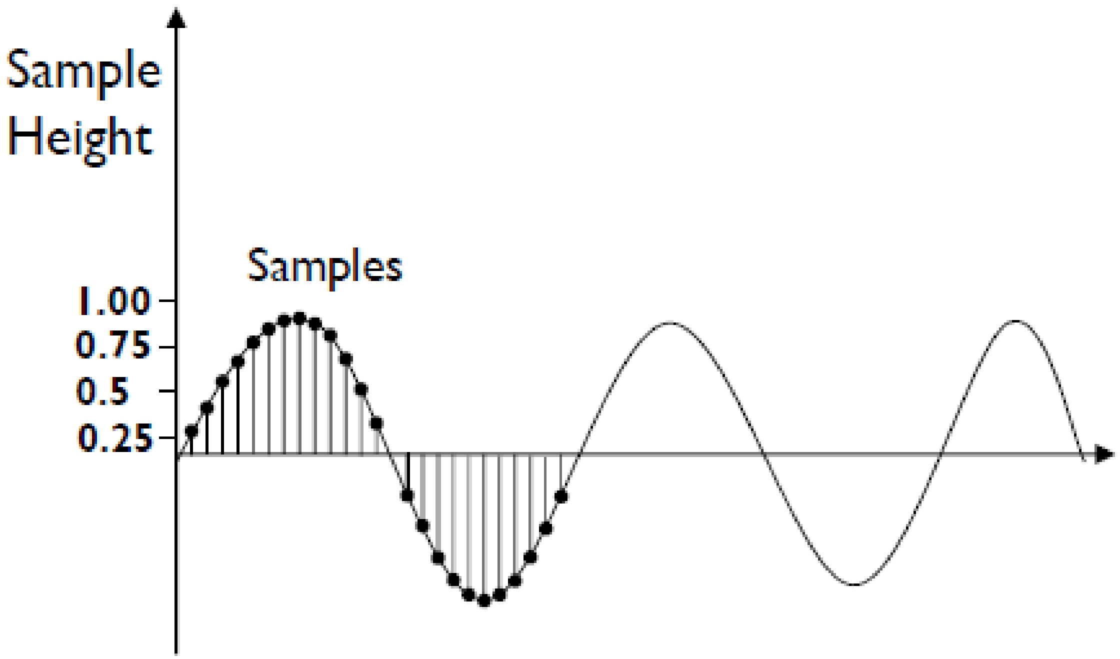
Digital audio representation

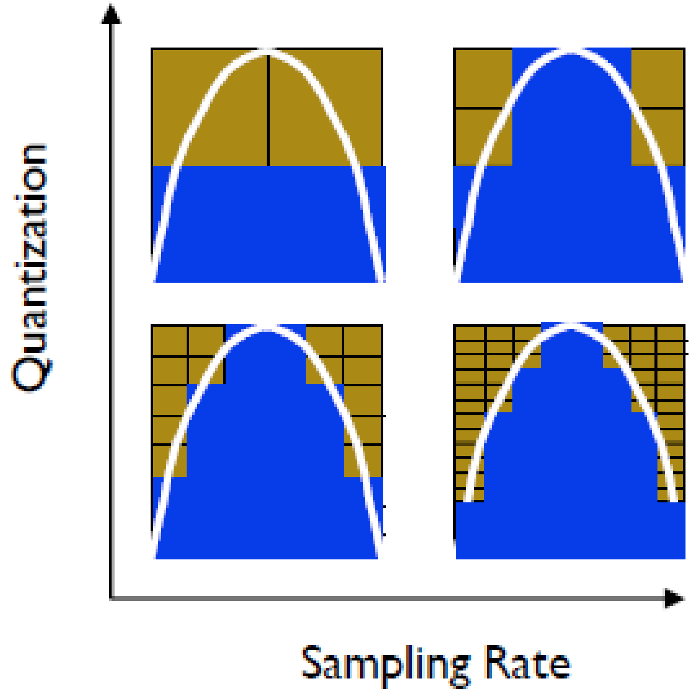
Processing steps:

- *Transducer* (inside a microphone) converts pressure to voltage levels.
- *A/D converter* converts analog (voltage, current) signal into a digital stream by discrete sampling.
  - Discretization in time
  - Discretization in amplitude (*quantization*).
- *In a computer*,
  - these values are sampled at intervals to yield a vector of values (samples).

Sampling

Quantization





Sampling Rate &Nyquist Theorem

- Direct relationship between sampling rate, sound quality (fidelity) and storage space.
- Q:How often do you need to sample a signal to avoid losing information?
  - Sampling rate is not playback rate!
- A: It depends on how fast the signal is changing. In reality, more than twice per cycle (a.k.a. *Nyquist sampling theorem*).
  - If a signal $f(t)$ is sampled at regular intervals of time and at a rate higher than twice the highest significant signal frequency, then the samples contain all the information of the original signal.

- Human hearing
  - Perceptible frequency (audio) range: 20Hz – 20kHz (voice is between 500Hz-2KHz).
  - Discard frequencies above 20KHz (22.05 kHz for CD's) by low pass filtering.
  - Sample at twice the maximum frequency (44.1kHz for CD's)

Quantization

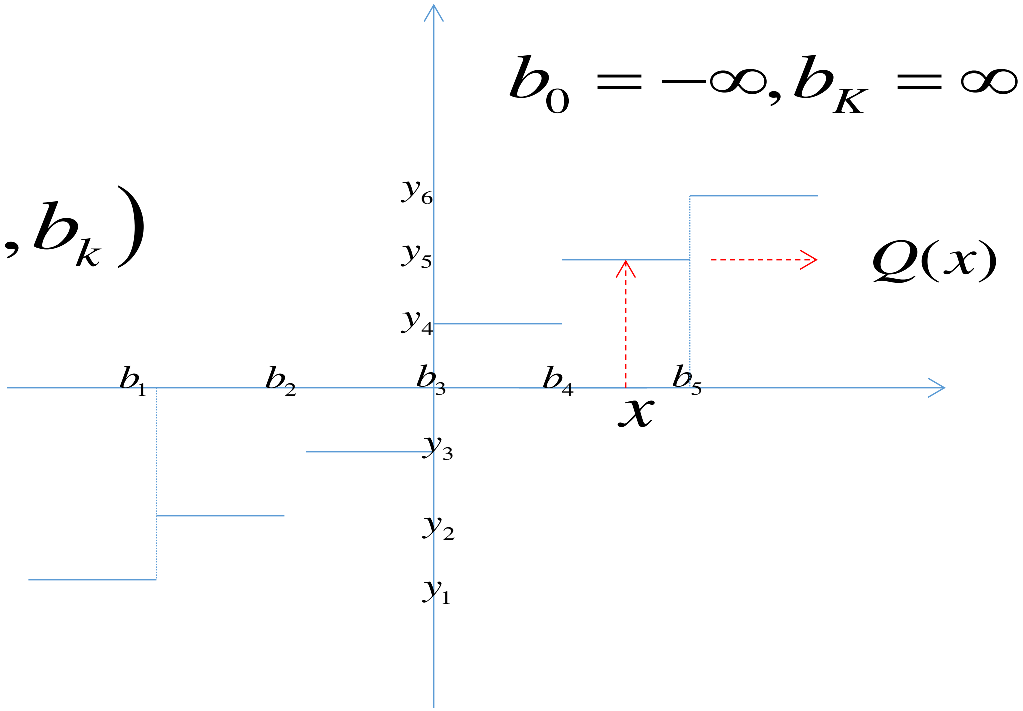
- Sample precision - the resolution of a sample value.
- Quantization is an approximation (rounding)
  - Approximation quality depends on <u>the number of bits</u> used to represent the height of the waveform.
- **Sony CD 16 bits**, Philips D/A converter 14 bits
- Audio formats are described by sample rate and quantization
  - Voice quality (Pulse code modulation)- 8 bits quantization, 8,000 Hz mono (64 Kbps)
  - CD quality - 16 bits quantization, 44,100 Hz linear stereo (705.6 Kbps for mono, 1.411 Mbps for stereo (left and right channels))

Scalar quantization

- $Y = Q(X)$ where $Q(.)$ is a staircase function
  - Decision boundaries b_k
  - Reconstruction (quant.) levels y_k

$$b_0 = -\infty, b_K = \infty$$

$$Q(x) = y_k \text{ if } x \in B_k = [b_{k-1}, b_k)$$



Uniform scalar quantization

- All granular bins are of same size

$$b_k - b_{k-1} = \Delta \quad \text{for} \;\; k = 2,\ldots,K-1$$

- If $\quad f_X(x) = 0 \;\; \text{for } x > x_{\max}, x < -x_{\max}$

$$\Delta = \frac{2x_{\max}}{K}$$

- Within each bin distribution is approx. uniform
  - Assume $\quad f_X(x \mid x \in B_k) \approx \frac{1}{\Delta}, \qquad (k\text{-}1) < x \le k\Delta$
  - Quantization levels $y_k = \frac{b_k + b_{k-1}}{2}$ are then optimal

MSE distortion approximation

- Uniform quantizer MSE distortion

$$D_{Q,MSE} = D_{G,MSE}(B_k) \cong \int_{-\Delta/2}^{\Delta/2} x^2 f_X(x \mid x \in B_k)\,dx$$

$$= \int_{-\Delta/2}^{\Delta/2} x^2 \frac{1}{\Delta}\,dx = \frac{\Delta^2}{12}$$

- Assume fixed length coding of quantization indices with n bits

$$K = 2^n, \Delta = 2\frac{x_{\max}}{2^n}$$

$$SNR(dB) = 10\log_{10}\left(\frac{\sigma_X^2}{D_{Q,MSE}}\right) = 10\log_{10}\left(\frac{\sigma_X^2.12}{\Delta^2}\right)$$

$$= 10\log_{10}\left(\frac{\sigma_X^2.12.2^{2n}}{4x_{\max}^2}\right) = 10\log_{10}\left(\frac{\sigma_X^2.12}{4x_{\max}^2}\right) + 20\log_{10}2^n$$

$= C + 6.02ndB$ with every bit SNR increases by 6dB

Signal-to-Noise Ratio

- A measure of the quality of the signal. Let P_{signal} and P_{noise} be the signal power and noise power (variances), respectively
- SNR = 10 log10 (P_{signal} / P_{noise})
- Assuming quantization error is uniform, and the variance of signal is not too large compared to the maximum signal value x_{max}, then each bit adds about 6 dB of resolution!
  - Assume fixed length coding of quantization indices with n bits $K = 2^n, \Delta = 2\frac{x_{\max}}{2^n}$

$$
\begin{aligned}
SNR(dB) &= 10\log_{10}\left(\frac{\sigma_X^2}{D_{Q,MSE}}\right) = 10\log_{10}\left(\frac{\sigma_X^2.12}{\Delta^2}\right) \\
&= 10\log_{10}\left(\frac{\sigma_X^2.12.2^{2n}}{4x_{\max}^2}\right) = 10\log_{10}\left(\frac{\sigma_X^2.12}{4x_{\max}^2}\right) + 20\log_{10} 2^n \\
&= C + 6.02ndB
\end{aligned}
$$

Pulse Code Modulation (PCM)

- The two step process of sampling and quantization is known as *Pulse Code Modulation.*
  - Based on the Nyquist sampling theorem.
  - Used in speech and CD encoding.

Representation of Audio Samples

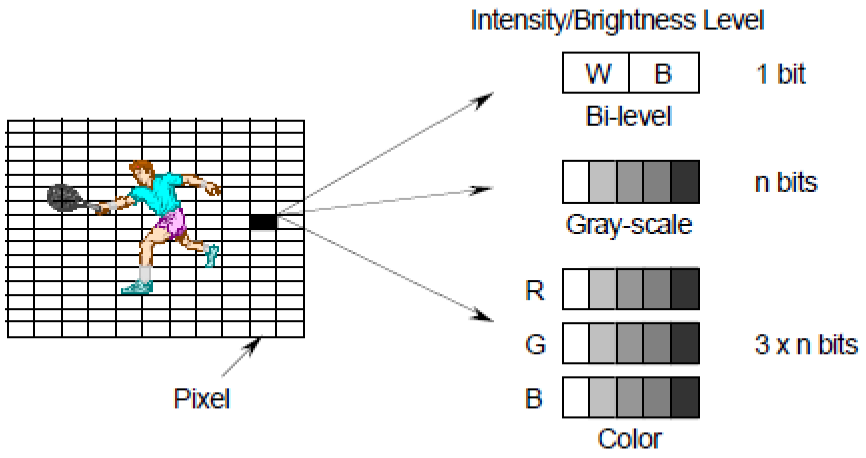
- Audio samples are represented as formats characterized by four parameters:
  - *Sample rate:* Sampling frequency
  - *Precision:* Number of bits used to store audio samples
  - *Encoding:* Audio data representation (compression)
  - *Channel:* Multiple channels of audio may be interleaved at sample boundaries.
- Raw speech data
  - PCM-encoded speech (64 Kbps)
  - Music (1.411 Mbps for stereo)
  - strains the bandwidth of cellular networks/Internet => compression is needed!

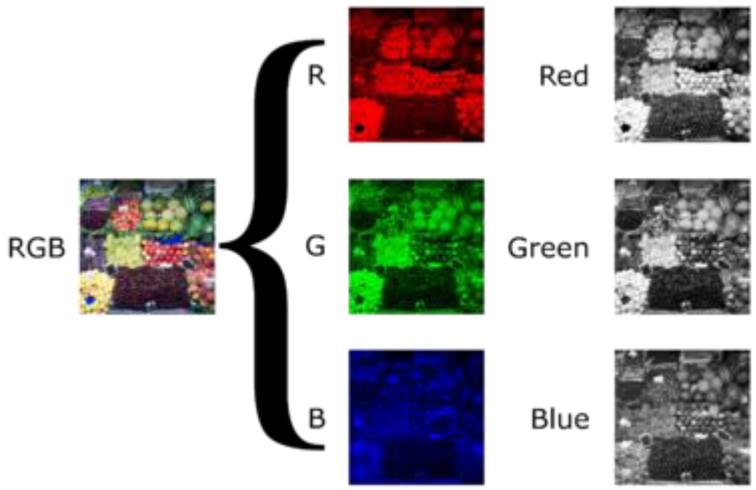
Audio compression basics

- Audio samples are encoded (compressed) based on
  - Non-uniform quantization - humans are more sensitive to changes in “quiet” sounds than “loud” sounds:
    - Companding (compress- uniform quantize – expand) | μ-law and A law companders
  - High correlation between adjacent samples
    - Difference encoding
  - Psychoacoustic Principles - humans do not hear all frequencies the same way due to *Auditory Masking:*
    - Simultaneous masking
    - Temporal masking
- These approaches are used in MPEG-1 Layer 3, *known as MP3.*
  - Reduces bit rate for CD quality music down to 128 or 112 Kbps.

Digital Image Representation

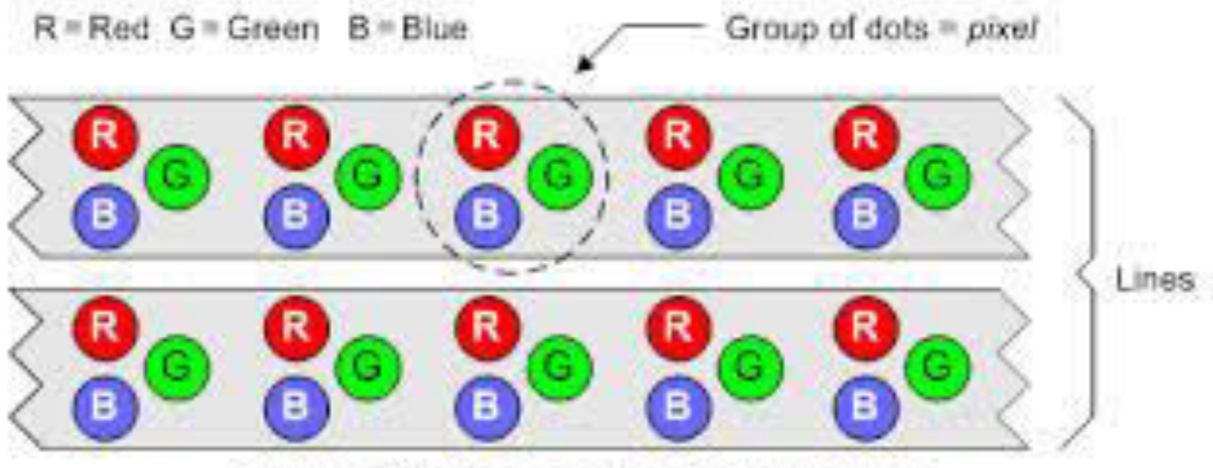
- An image is a collection of *picture elements or pixels* on a nxm grid.
  - Pixel representation can be bi-level, gray-scale, or color.
  - *Resolution specifies the distance between points – akin to sample rate.*





Pixels

- Images are made up of dots called **pixels for picture elements**
  - The number of pixels affects the resolution of the monitor
  - The higher the resolution, the better the image quality
    - at a given viewing distance



Groups of dots on a color television screen

Color

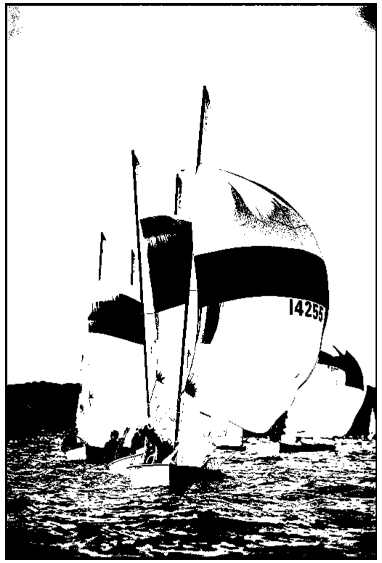
- The amount of information per pixel is known as the *color depth*
  - Monochrome (1 bit per pixel)
  - Gray-scale (8 bits per pixel)
  - Color (8 /16 /18 bits per pixel)
    - 8-bit indexes to a color palette
    - 16 bits
      - 5 bits for each RGB + 1 bit Alpha (16 bits)
      - 4 bits for each RGB ,Alpha
      - 5 bits for each RB+ 6 bits for G
    - 18 bits
      - 6 bits for each RGB (cheap LCD displays)
  - True color (24 or 32 bits per pixel)
    - RGB (sRGB 24 bits) : 2^{24} color variation of which 2/3rd can be discriminated
    - RGB + Alpha (RGBA 32 bits)
  - Deep color (30/36/48 bits per pixel)
    - More recent (HEVC(H.265-High Efficiency Video Coding), HDMI 1.3)
    - More info than can be displayed all at once

Example of color depth

24 bits

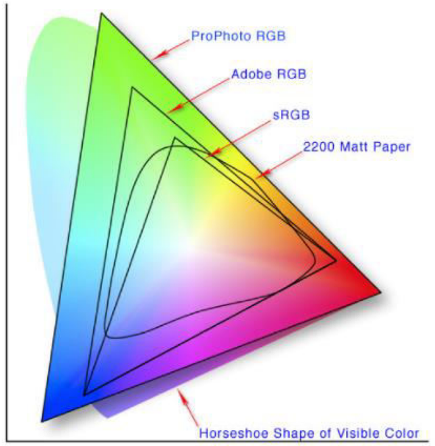
8 bits

4 bits

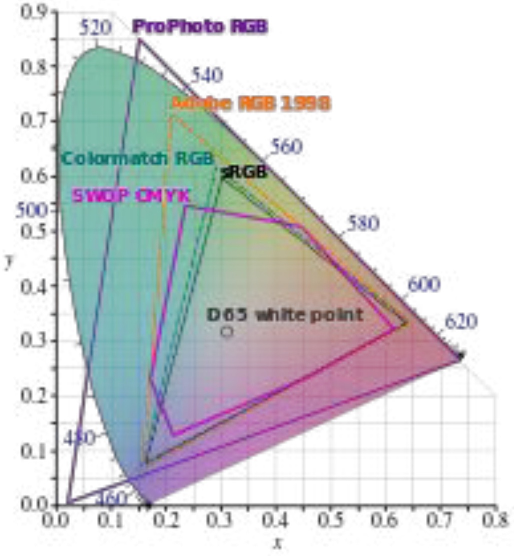


1 bit

Color spaces

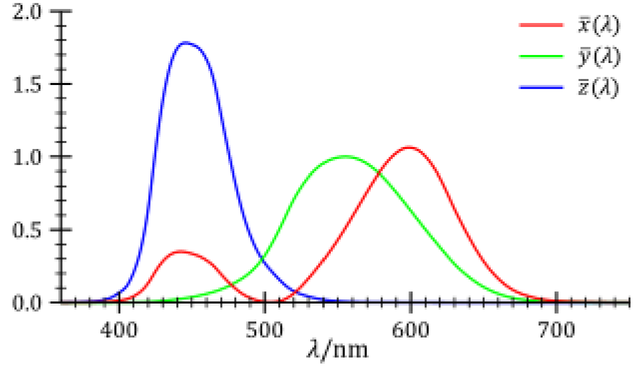


- A method by which we can specify, create, and visualize color.
  - Color model: specifies the abstract model describing the way colors can be represented as tuples of numbers (color components) – specifies coordinate system
  - Mapping function associates to a color space for color interpretation => a gamut
  - Gamut/Color space: abstract three dimensional region within which we can plot points that represent a (visible) color – recently carries the notion of color model as well
- Why more than one color space? Different color spaces are better for different applications.
  - Humans => Hue, Saturation, Lightness or Brightness (HSL or HSB)
  - CRT monitors => Red Green Blue (RGB)
  - Printers => Cyan Magenta Yellow Black (CMYK)
  - Compression => Luminance and Chrominance (YIQ, YUV, YCbCr)



CIE (International Commission on Illumination) XYZ and RGB spaces

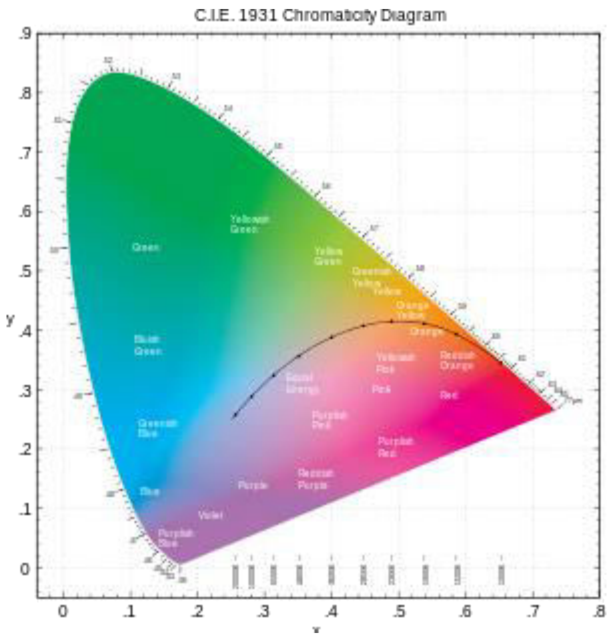
- Color matching functions ($M(\lambda)$ spectral power distribution)
  - XYZ



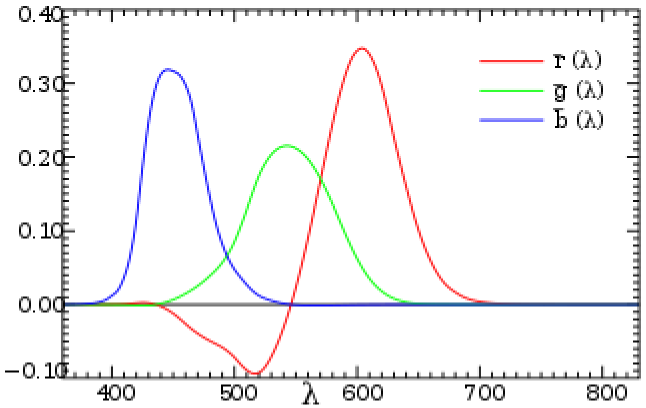
$$X = \int_{380}^{780} M(\lambda)\,\bar{x}(\lambda)\,d\lambda \qquad x = \frac{X}{X+Y+Z}$$

$$Y = \int_{380}^{780} M(\lambda)\,\bar{y}(\lambda)\,d\lambda \qquad y = \frac{Y}{X+Y+Z}$$

$$Z = \int_{380}^{780} M(\lambda)\,\bar{z}(\lambda)\,d\lambda \qquad z = \frac{Z}{X+Y+Z} = 1 - x - y$$



  - RGB

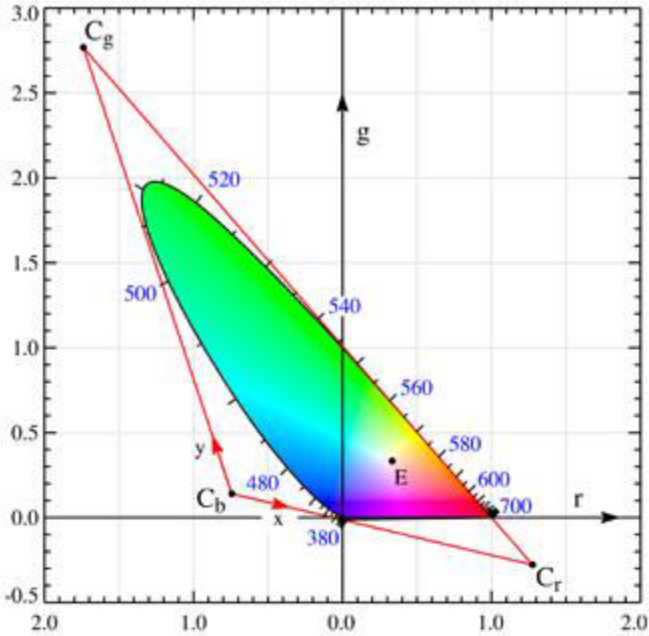


$$R = \int_0^\infty M(\lambda)\,\bar{r}(\lambda)\,d\lambda \qquad r = \frac{R}{R+G+B},$$

$$G = \int_0^\infty M(\lambda)\,\bar{g}(\lambda)\,d\lambda \qquad g = \frac{G}{R+G+B}.$$

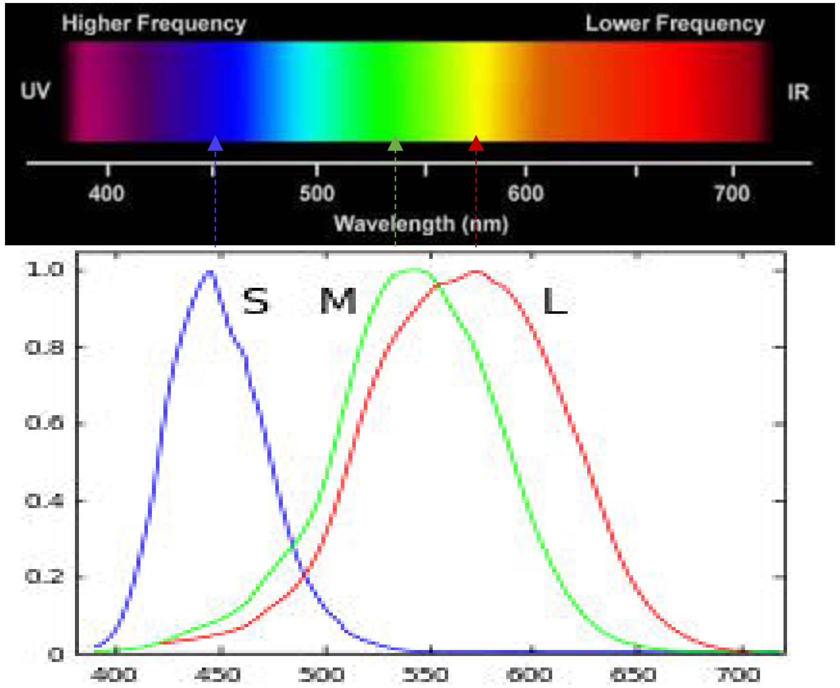
$$B = \int_0^\infty M(\lambda)\,\bar{b}(\lambda)\,d\lambda$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 0.41847 & -0.15866 & -0.082835 \\ -0.091169 & 0.25243 & 0.015708 \\ 0.00092090 & -0.0025498 & 0.17860 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$



Visible spectrum/Sensitivity

- three kinds of cone cells, which sense light, with spectral sensitivity peaks in
  - short (*S*, 420–440 nm),
  - middle (*M*, 530–540 nm),
  - long (*L*, 560–580 nm) wavelengths
- *three* parameters, corresponding to levels of *stimulus* of the three types of cone cells, can in principle describe any color sensation
  - LMS color space

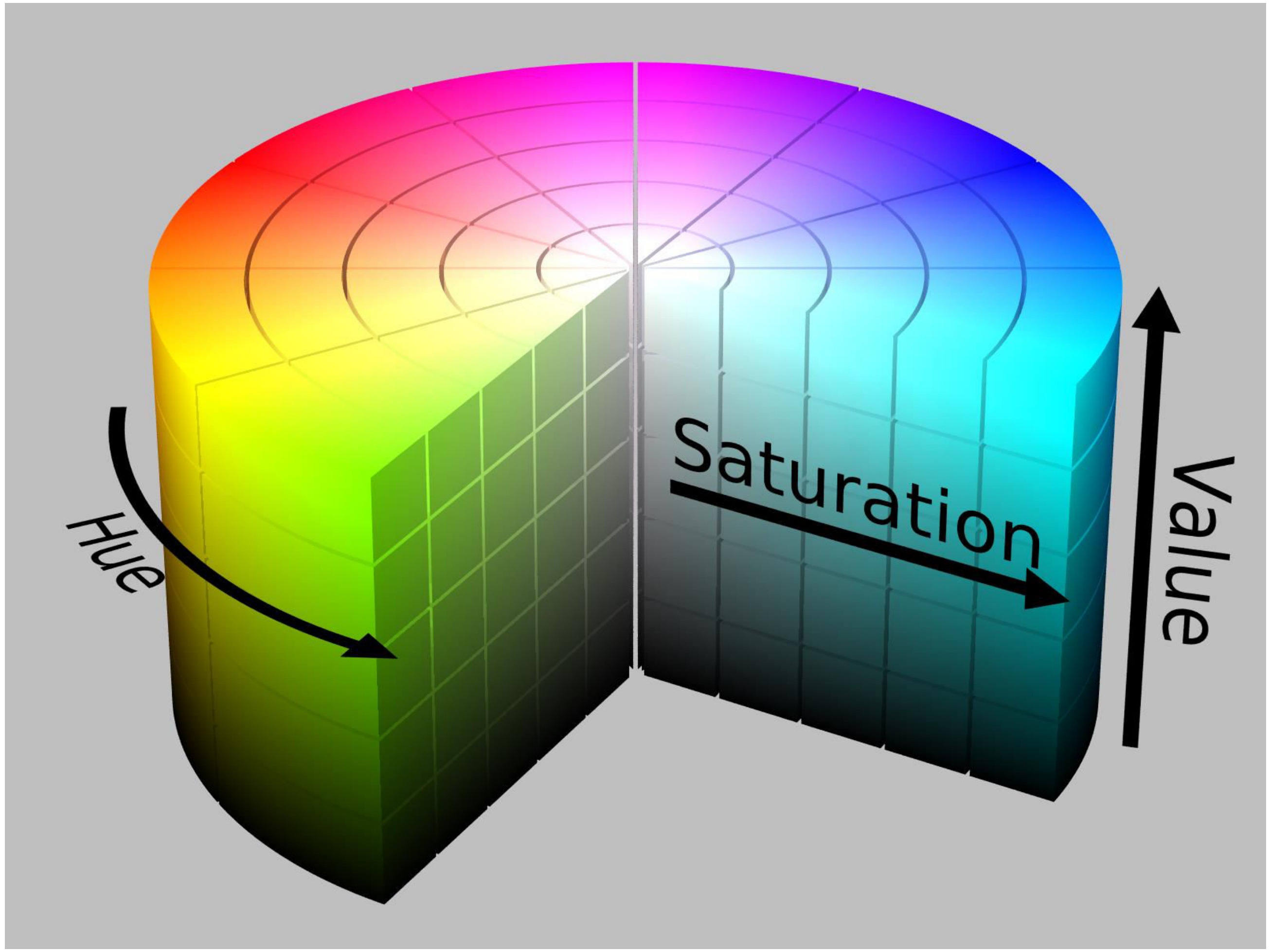


HSB

Hue: Color in pure form

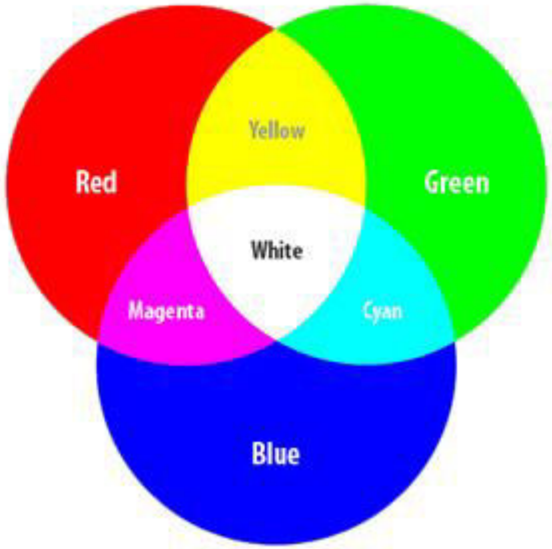
Saturation: Purity – degree to which hue differs from neutral gray with same brightness

Brightness: Level of illumination (intensity of light)



RGB

- RGB (Red-Green-Blue) is the most widely used color system.
- Represents each pixel as a color triplet in the form (R, G, B), e.g., for 24-bit color, each numerical values are 8 bits (varies from 0 to 255).
  - (0, 0, 0) = black
  - (255, 255, 255) = white
  - (255, 0, 0) = red
  - (0, 255, 255) = cyan
  - (65, 65, 65) = a shade of gray
- RGB is an additive model.
  - No beam => no light
  - 3 beams => white



CMYK (Cyan, Magenta, Yellow, Key(black)) color system

- For printing, there is no light source. We see light reflected from the surface of the paper.
- CMYK is a subtractive color model

YUV color system

- PAL (Phase Alternating Line) standard.
  - Humans are more sensitive to luminance (brightness) fidelity than color fidelity.
  - *Luminance* (Y) - Encodes the brightness or intensity.
  - *Chrominance* (U and V) -Encodes the color information.
- Compatible with black/white
- Reduced bandwidth for chrominance components
  - YUV420 uses 1 byte for luminance component, and 4 bits for each chrominance components.
    - Requires only 2/3 of the space (RGB = 24 bits), so better compression! This coding ratio is called 4:2:2 subsampling.
- RGB => YUV

  $Y = 0.299R + 0.587G + 0.114B$

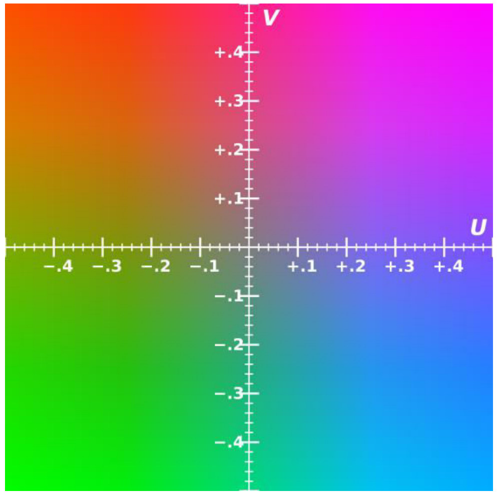
  $U = (B-Y) * 0.492=-0.14713R-0.28886G+0.436B$

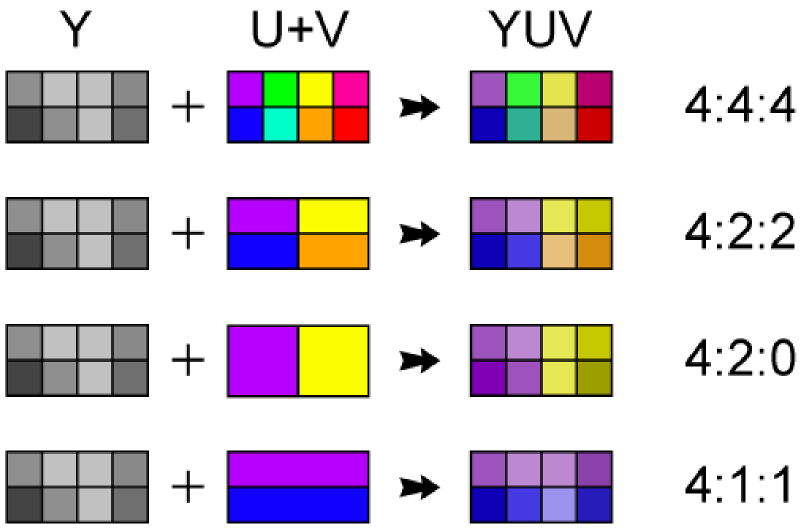
  $V = (R-Y) * 0.877=0.615R-0.51499G-0.10001B$
- YUV => RBG

  $R=Y + 1.14V$

  $G=Y - 0.395U - 0.581V$

  $B=Y + 2.033U$





YCrCb color system

- Closely related to YUV. It is a scaled and shifted YUV.
  - Cb (blue) and Cr (red) chrominance.
  - Used in JPEG and MPEG.
- YCbCr => RGB

  Y = 0.257R + 0.504G + 0.098B + 16

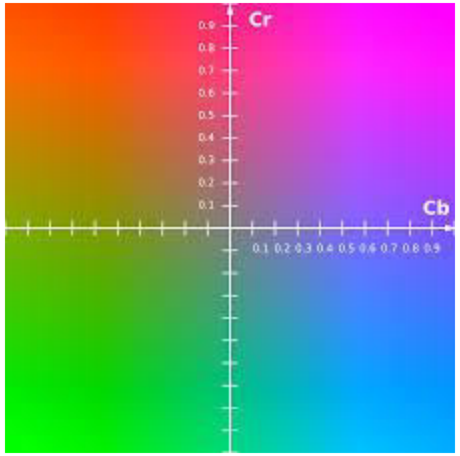
  Cb = - 0.148R - 0.291G + 0.439B + 128

  Cr = 0.439R - 0.368G - 0.071B + 128
- RGB => YCbCr

  R=1.164Y+1.596Cr-222.921

  G=1.164Y-0.392Cb-0.823Cr+135.576

  B=1.164Y+2.017Cb-276.836



$$Y \in [16,235]$$
$$Cb \in [16,240]$$
$$Cr \in [16,240]$$

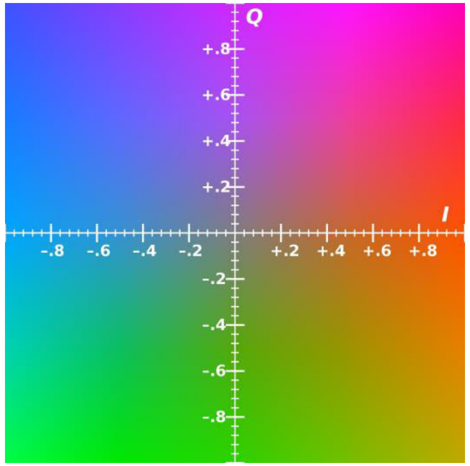
YIQ color system

- Used in NTSC color TV broadcasting. B/W TV if only Y is used.
- YIQ signal
  - similar to YUV

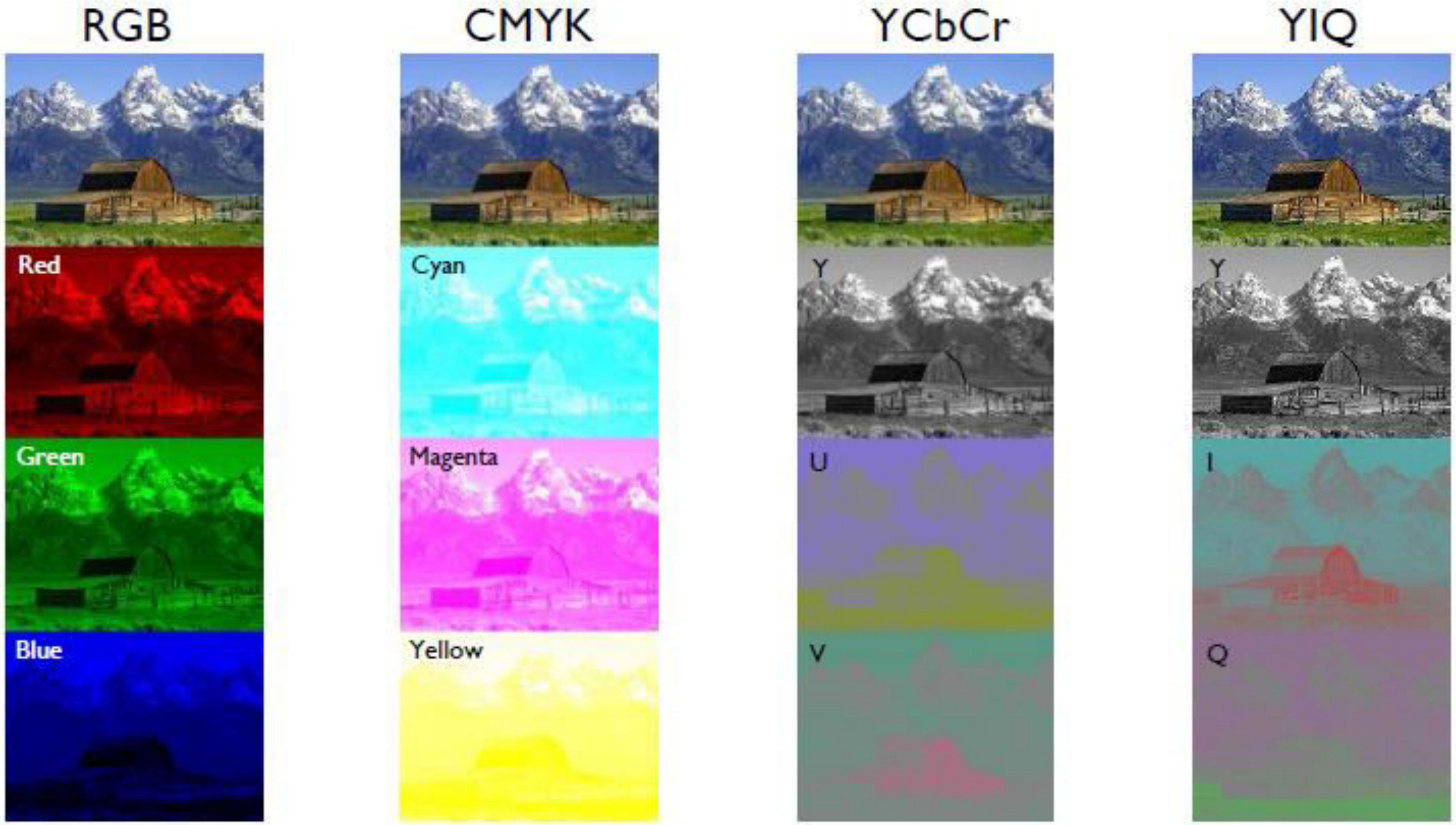
    $Y = 0.299R + 0.587G + 0.114B$

    $I = 0.596R - 0.275G - 0.321B$

    $Q = 0.212R -0.528G + 0.311B$
- Composite signal
  - All information is composed into one signal.
  - To decode, need modulation methods for eliminating interference b/w luminance and chrominance components.

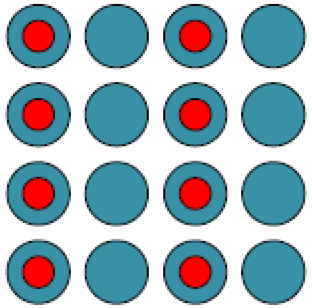


Color decomposition



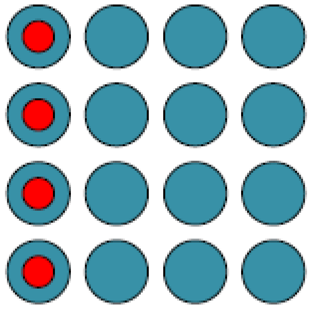
Chrominance Subsampling

- Cut chrominance bandwidth in half/quarter?
  - Use 4-bits/2bits per pixel.
- Human eye less sensitive to variations in color than in brightness.
- Compression achieved with little loss in perceptual quality.
- **4:2:2 Subsampling**
  - For every 4 luminance samples, take 2 chrominance samples (subsampling by 2:1 horizontally only).
  - Chrominance planes just as tall, half as wide.
  - Reduces bandwidth by 1/3
  - Used in professional editing (high-end digital video formats)

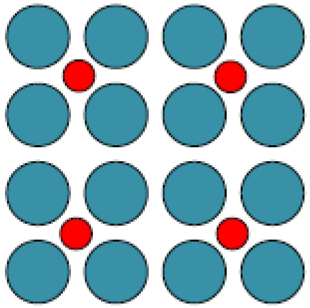


Chrominance subsampling

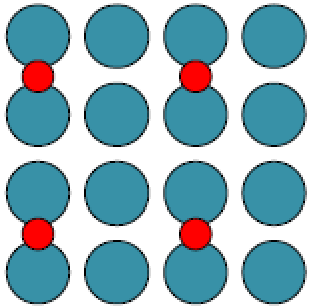
- **4:1:1 Subsampling**
  - For every 4 luminance samples, take 1 chrominance sample (subsampling by 4:1 horizontally only).
  - Used in digital video.



- **4:2:0 Subsampling**
  - For every 4 luminance samples, take 1 chrominance sample (subsampling by 2:1 both horizontally and vertically).
  - Chrominance halved in both directions.
  - Most commonly used.
  - Three varieties:



JPEG, MPEG-1, MJPEG



MPEG-2

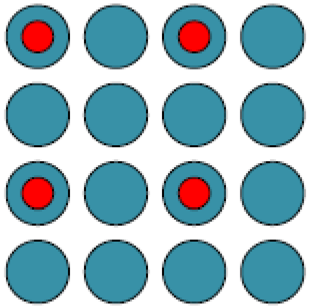


Image compression motivation

- A single digitized image of 1024 pixels x 1024 pixels, 24 bits per pixels requires
  - ~25 Mbits of storage
  - ~7 minutes to send over a 64 Kbps modem!
  - ~3-25 seconds to send over a 1-8 Mbps ADSL!
    - Think of downloading a document with several such images.
  - Some form of compression is needed!

Image compression basics

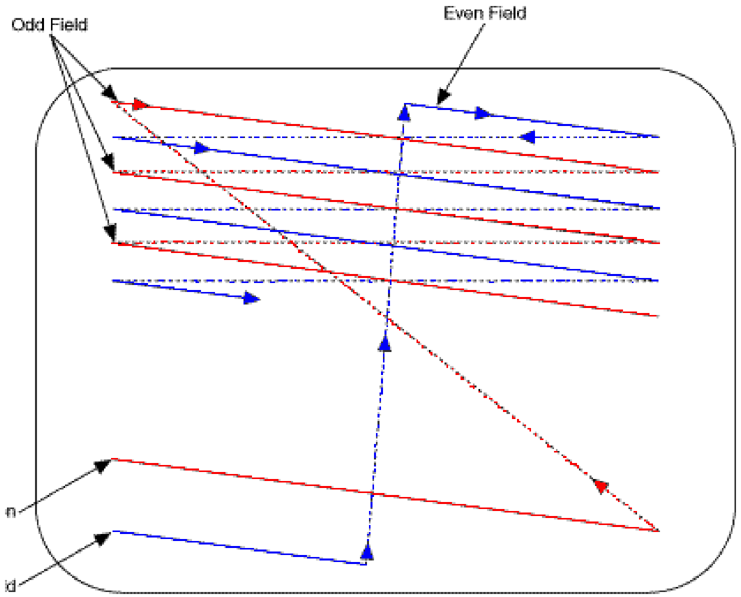
- Lossless - no information is lost:
  - Exploits redundancy / probability distribution
  - Most probable data encoded with fewer bits
- Lossy - approximation of original image
  - Looks for how pixel values change
  - Human eye more sensitive to luminance than chrominance.
  - Human eye less sensitive to subtle feature of the image.
    - Give priority to low-pass image signal wrt high pass image signal
- JPEG uses both techniques

Digital Video Representation

- Can be thought of as a sequence of moving images (or frames).
- Important parameters in video:
  - Frame (image) resolution (e.g., *n*x*m* pixels)
  - Quantization (e.g., *k*-bits per pixel)
  - Frame rate (*p* frames per second, i.e., fps)
- Continuity of motion is achieved at
  - a minimal 15 fps
  - is good at 30 fps
  - HDTV recommends 60 fps!

Standard Video Data Formats

- National Television System Committee (NTSC)
  - Set the standard for transmission of analog color pictures back in 1953!
  - Used in the US and Japan.
  - 525 lines (480 visible) per frame.
  - Resolution? Not digital, but equivalent to the quality produced by a digital image of 720x486 pixels.
  - 30 fps (i.e., delay between frames = 33.3 ms).
  - Video aspect ratio of 4:3 (e.g., 12 in. wide, 9 in. high)
  - Two interlaced fields per frame at 262.5 lines at 60 fields per second
    - Matches 60 Hz power line frequency
    - Increases vertical resolution (to which eye is sensitive)



Standard Video formats

- PAL (Phase Alternating Line):
  - Used in parts of Western Europe.
  - 625 lines (576 visible) per frame.
  - 25 fps (i.e., delay between frames = 40 ms).
  - Two interlaced fields per frame at 312.5 lines at 50 fields per second
    - Matches 50 Hz power line frequency
    - Increases vertical resolution (to which eye is sensitive)
- SECAM: French Standard

SDTV/HDTV/UHDTV

- Technical Societies
  - Advanced Television Systems Committee (ATSC)
  - **MPEG (Motion Pictures Experts Group)**
  - SMPTE (Society of Motion Pictures & Television Engineers)
- 60fps+
- SDTV
  - Resolutions of 720x480, 720x576 pixels
- HDTV
  - Resolutions of 1280x720, 1920x1080 pixels
- Ultra HDTV
  - Resolutions of 3840x2160 (4K), 7680x4320 (8K) pixels
- Video aspect ratio of 16:9 (wide screen)
- MPEG-2/MPEG-4 H.264/H.265 for video compression
- Both interlaced and progressive (except for H.265 which does not support interlaced)
- AC-3 (Dolby Audio Coding-3)/AAC (MPEG-2, MPEG-4) for audio compression

Course Overview
Multimedia Computing

Prof. Dr. Uluğ Bayazıt

Outline

- Definition of multimedia
- Purpose of multimedia
- Applications of multimedia
- Technical challenges of multimedia
- Course outline
- Course administration information

Definition of multimedia

- Development, integration, and delivery of any combination of text, graphics, animations, sound, or video through a computer.
  - refers to content that uses a combination of different content forms
    - text, audio, still images, animation, video, or interactive content forms
  - as opposed to media that use only rudimentary computer displays such as text-only or traditional forms of printed or hand-produced material
- Convergence of multiple disciplines
  - graphics, visualization, HCI, computer vision, data compression, graph theory, networking, database systems
  - keynote interactivity

Purpose of multimedia

- Better representation of information by using audio/video/animation rather than by only using text, images and graphics.
- Collaboration and virtual environments.
  - Geographically based, real-time augmented-reality, massively multiplayer online video games
- Potential for improving our lives (e.g., learning, entertainment, and work).
  - Cooperative education environments that allow schoolchildren to share a single educational game using two mice at once that pass control back and forth
- High Market Demand!
  - Major driver of Computer Technology

Research areas

- **Multimedia processing and coding. (compression, content based analysis, content based retrival, security)**
- **Multimedia system support and networking. (protocols, operating systems, servers, clients, databases, storage media)**
- **Multimedia tools, end systems, and applications. (hypermedia systems, user interfaces, multimodal interaction and integration, education, collaborative learning and design, virtual environments)**

Evolution of basic forms of multimedia

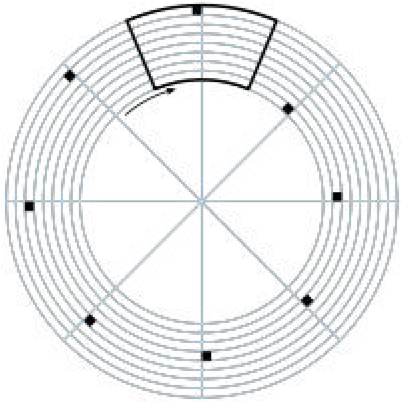
- Audio

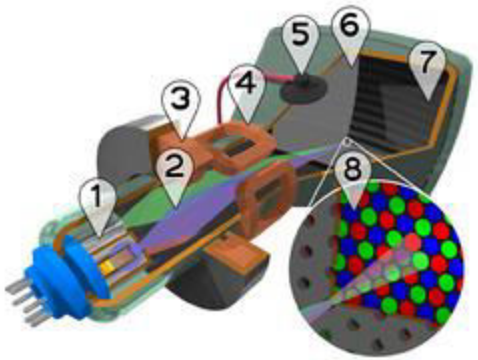




-phonautograph (1850’s)
-phonograph cylinder (1870’s)
-gramaphone disc (1880’s-1980’s)
-magnetic tape (invented 1930’s)
-cassette, 8-track cartridge (1960’s)
-CD (1982)

- Video



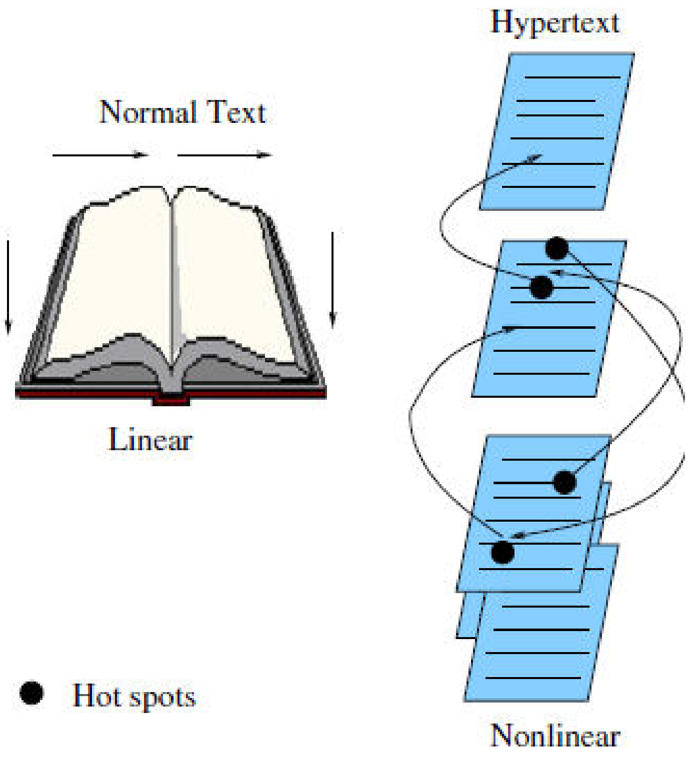


1. Three electron guns (for red, green, and blue phosphor dots)
2. Electron beams
3. Focusing coils
4. Deflection coils
5. Anode connection
6. Mask for separating beams for red, green, and blue part of displayed image
7. Phosphor layer with red, green, and blue zones
8. Close-up of the phosphor-coated inner side of the screen


-Nipkow’s disk (1884)
-Baird’s video scanning/transmission system (1925)
-Electronic TV (deflecting cathode rays) J.J. Thompson 1897, Rosing 1907
-Color TV (Le Blanc 1880, Adamian 1907)
-Digital TV (1990’s)
-Smart TV (connected TV, patented 1994)

Linear medium versus hyper medium

- Book vs. hypertext
  - Links allow nonlinear traversal over hypertext
- Hypermedia
  - includes a wide array of media such as graphics, images and especially continuous media like sound and video and links them together
  - WWW : founded by approval from CERN
    - HTML : human readable format/language for pages that identify structure and elements, based on ASCII
      - Uses tags to describe document elements
    - HTTP



XML

- Tags (structure) and their relationship to each other defined in one place, data defined in another place, rendering of tags defined in yet another document
- Global DTD (document type definition) rules for type of data
- Server side script abides by DTD rules to generate XML
- XML looks best on different devices on client side.
- XML protocol is used to exchange information between processes, like HTTP
- XML Schema – more structured, uses XML tags for type definitions

Applications

- Enabling Technologies : Embedded system, RTOS, 802.11, 802.16, UWB, UMTS/CDMA, Bluetooth, MPEG
- Mobile

Applications

- Games

Applications

- Wearable computers (CybergLog, GoogleGlass, iWatch)

Applications

Residential Services

- Education

- Commerce

- Video on demand

- Multimedia conference

Applications

Business services

- Training

- Multimedia conferencing

- Remote monitoring

Applications

Remote presence

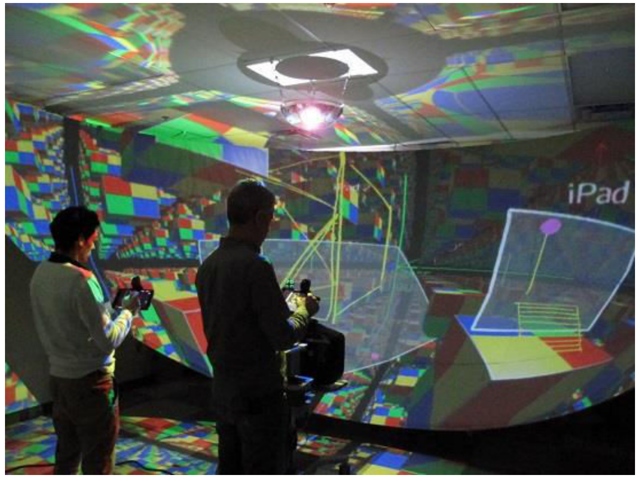
- Medical supervision

Applications

Virtual immersive environments

- As if there (entertainment)

- As if there (design-collaboration)



Other multimedia applications

- Science and Technology
  - Computational visualization and prototyping.
  - Astronomy, environmental science: efficient access to large number of satellite images.
- Medicine
  - Diagnosis and treatment - e.g., multimedia databases that provide support for queries on scanned images, X-rays, assessments, response, etc.

Challenges

- Process high volumes of data
  - Speedy, realtime
- Combine traditional media (text, images) as well as continuous media (audio/video) in the same context
- Interact with content
- Communicate data across networks that makes no QOS guarantees about
  - End-to-end delay,
  - Jitter (Variation of packet delay within a packet stream)
  - Bandwidth.
  - Packet loss
- Key technologies to develop for computation, communication, and storage.

Volume of data for different media

	Characteristics	BW Required
Speech	8000 samples/s, 1 byte/sample	8 Kbytes/s or 64 Kbps
CD Audio	44,100 samples/s, 2 bytes/sample, stereo	176.4 Kbytes/s or 1.41 Mbps
Satellite Imagery	180×180 km^2 30 m^2 resolution	600 Mbytes/image (60 MB, compressed)
NTSC Video	30 fps, 640×480 pixels, 3 bytes/pixel	27.6 Mbytes/s or 221.2 Mbps (2-8 Mbps, compressed)
HD video	60 fps, 1920×1080 pixels, 3 bytes/pixel	373.2 Mbytes/s or 2.99 Gbps (15-30 Mbps, compressed)

Course Outline
(Mostly coding/compression oriented)

- Introduction
- Audio/Image/Video Representation
- Basic Coding & Compression Techniques
- Image compression
- Video compression
- Audio compression
- Multimedia Networking
- Content based retrieval

Course information

- Administration web site
  - http://ninova.itu.edu.tr
- Textbook:
  - *Fundamentals of Multimedia*, by Li and Drew, 2014, 2nd edition, Springer International Publishing.
- Reference book:
  - *Computer Networking: A Top-Down Approach Featuring the Internet, 4th Edition*, by Kurose and Ross, 2008, Addison Wesley.
  - *Internetworking Multimedia*, by Crowcroft, Handley, and Wakeman, 1999, Morgan Kaufmann Publishers

Course information

- Office Hours: MW 9:00-10:00 and by appointment.
- Grading Policy:
- Short exams (10%)
- 1 midterm, 1 final (25%+40%)
- Final project and presentation (25%)

Final Project and Presentation

- Work in groups of 2.
  - Start early! Doing background work is more than half the work.
- 25% of the grade!
- Types of projects:
  - Implementation/Demo
- Project Proposal to be submitted by latest 5th week (no proposals accepted afterwards)
- Presentation will be done in the last 2 week(s) of class. (20 minutes each group)
- All group members must be involved in the presentation.
- Final report due during finals week.