Image and Video Fundamentals

- Light and Color Models
  - RGB, HSB
  - Luminace and Chrominace
    YIQ, YUV, YCrCb
- Image Data Formats
- Video Camera and Display
- Scanning Video and Interlaced Scanning
- Analogy NTSC and PAL Video
- Digital Video
- Luma Sampling and Chroma Sub-Sampling
- Video Coding Standards Organizations

History

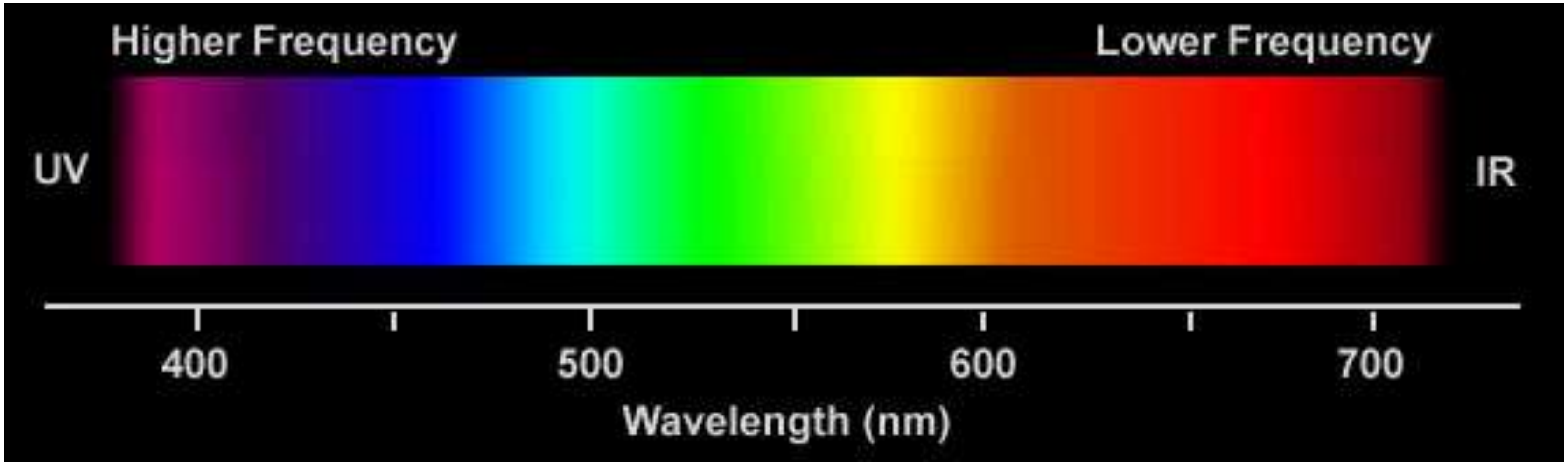
- 1839: Daguerreotype Cameras
- 1893: Telephone Audio Broadcasting (Puskas)
- 1895: Wireless Communication (Marconi, Popov)
- 1895: Film Presentation (Lumiere Brothers)
- 1919: Radio Broadcasting (Holland, Canada)
- 1934: US establishes FCC
- 1935: TV Broadcasting (Germany, Britain)
- 1941: US B&W TV

History (Cont…)

- 1951: Videotape Recorder (Bing Crosby Enterprises)
- 1953: US Color TV (NTSC)
- 1963: Geostationary Satellites
- 1985: FCC establishes ATSC - standard by 1993?
- 1989: Analog HDTV Broadcasting (Japan)
- 1993: VCD (Video on CD Based on MPEG-1)
- 1994: Digital Video Broadcast & CD Based on MPEG-2
- 1996: ATSC Standard Adopted
- 1999: Internet/Web Video Broadcasting (MPEG-4)
- 2001: Wireless Internet Video Communications
- 2003: Digital TV Broadcast (Japan)

Light

- Light exhibits some properties that make it appear to consist of particles; at other times, it behaves like a wave.
- Light is electromagnetic energy that radiates from a source of energy (or a source of light) in the form of waves
- Visible light is in the 400 nm – 700 nm range of electromagnetic spectrum



Intensity of Light

- The strength of the radiation from a light source is measured using the unit called the candela, or candle power. The total energy from the light source, including heat and all electromagnetic radiation, is called radiance and is usually expressed in watts.

- *Luminance* is a measure of the light strength that is actually perceived by the human eye. Radiance is a measure of the total output of the source; luminance measures just the portion that is perceived.

- *Brightness* is a subjective, psychological measure of perceived intensity. Brightness is practically impossible to measure objectively. It is relative. For example, a burning candle in a darkened room will appear bright to the viewer; it will not appear bright in full sunshine.

- The strength of light diminishes in inverse square proportion to its distance from its source. This effect accounts for the need for high intensity projectors for showing multimedia productions on a screen to an audience.

Basics of Color

- ***Color*** is the sensation registered when light of different wavelengths is perceived by the brain.
- Observed in objects that reflect or emit certain wavelengths of light.
- Can create the sensation of any color by mixing appropriate amounts of the three primary colors — *red*, *green*, *and blue*.
- Can create colors on computer monitors using the emission of three wavelengths of light in appropriate combinations.
- ***Hue*** distinguishes among colors such as red, green, and yellow.
- ***Saturation*** refers to how far color is from a gray of equal intensity.
- ***Lightness*** embodies the achromatic notion of perceived intensity of a reflecting object.
- ***Brightness*** is used instead of lightness for a self-luminous object such as CRT.

Hue, Saturation and Brightness/Luminance

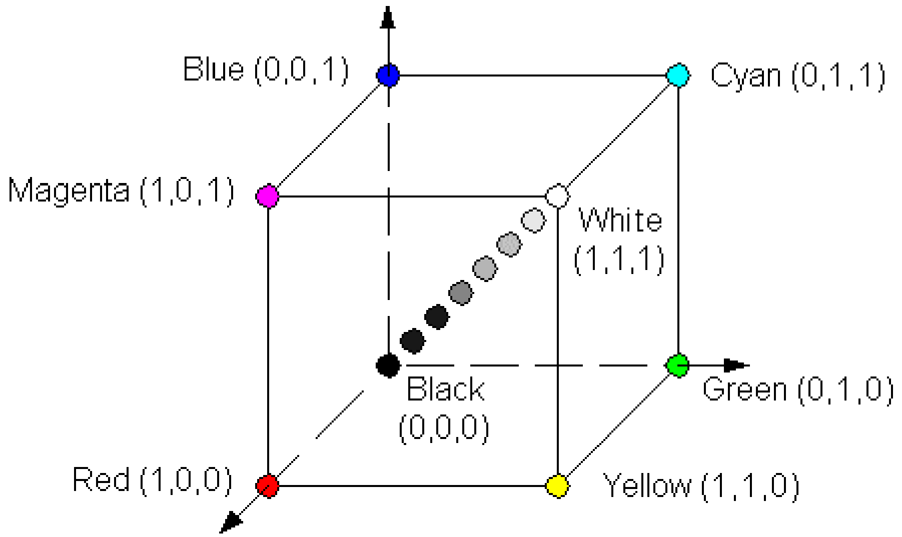
H
dominant wavelength

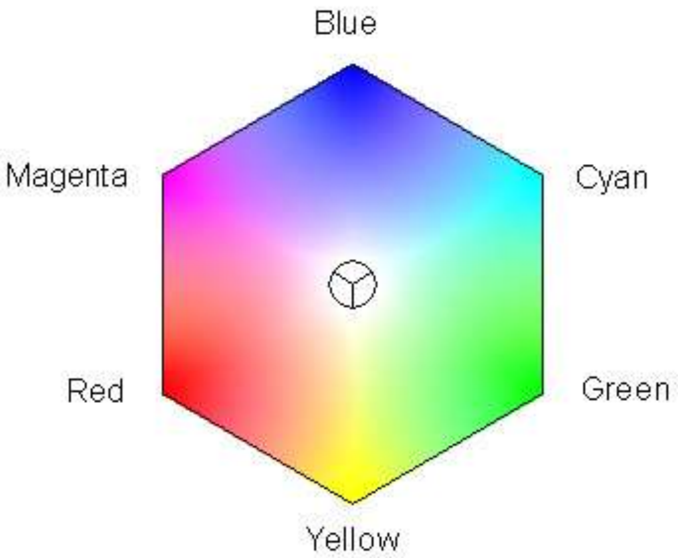
S
purity
% white

B/L
luminance

Color Models in Images

- **RGB color model**: each displayed color is described by three independent parameters- the luminance of each of the three primary colors (0 – 1) - primary used in color CRT monitors
- Employs a Cartesian coordinate system. The RGB primaries are *additive*; which means that individual contributions of each primary are added for the creation of a new color.

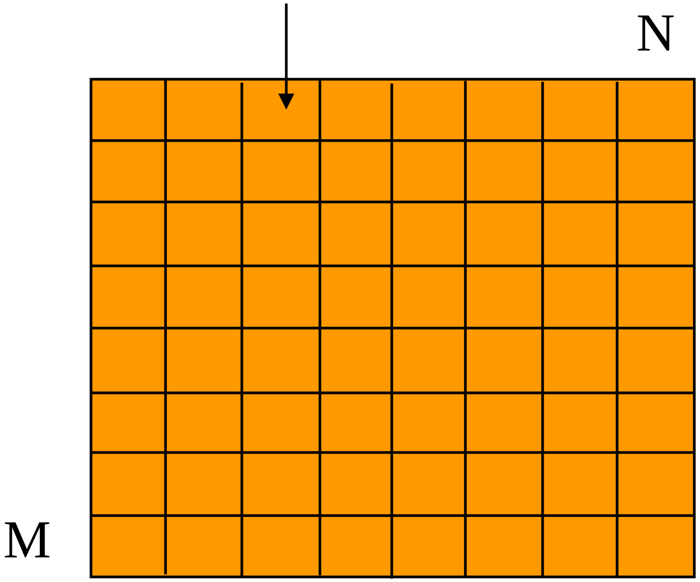




Graphic/Image Data Structure

- Pixels: picture elements in digital images
- Image resolution ($M*N$): number of pixels in a digital image

Pixel: $p(x,y)=(r_{xy}, g_{xy}, b_{xy})$



Pixel Array/Matrix

$$\begin{bmatrix} p(1,1) & p(1,2) & \ldots & p(1,N) \\ p(2,1) & p(2,2) & \ldots & p(2,N) \\ & \ldots & & \\ & \ldots & & \\ p(M,1) & p(M,2) & \ldots & p(M,N) \end{bmatrix}$$

Monochrome & Gray-scale Images

- Monochrome image
  - Each pixel is stored as a single bit ($p(x,y)=0$ or 1)
  - A 640 X 480 monochrome image requires 37.5 Kbytes

- Gray-scale image ($p(x,y)=0\sim1$)
  - Each pixel is usually stored as a byte (0 to 255 levels)
  - A 640 X 480 gray-scale image requires over 300 KBytes

Pseudo & True-Color Images

- 8-bit (pseudo) color image
  - One byte for each pixel
  - Support 256 colors
  - A 640 X 480 8-bit color image requires 307.2 KBytes
- 24-bit (true) color image
  - Three bytes for each pixel
  - Support 256X256X256 colors
  - A 640 X 480 24-bit color image requires 921.6 KBytes

Image Data Formats

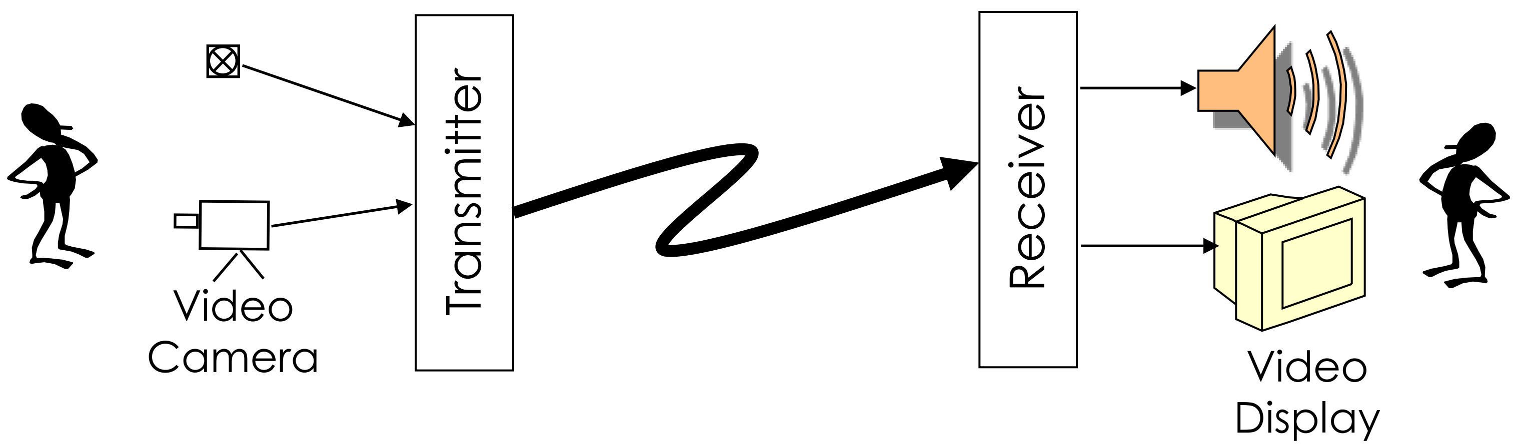
- Standard system independent formats
  - **GIF**: Graphics Interchange Format by the UNISYS and Compuserve
    - initially designed for transmitting images over phone lines
    - Limited to 8-bit color images
  - **JPEG**: a standard for photographic (still) image compression by the Joint Photographic Experts Group
    - Take advantage of limitations of human vision system to achieve high rates of compression
    - Lossy compression which allows user to set the desired level of quality
  - **TIFF**: Tagged Image File Format by the Aldus Corp.
    - Lossless format to store many different types of images
    - No major advantages over JPEG and not user-controllable

Image Data Formats (Cont…)

- **PS/EPS**: a typesetting language
  - including vector/structured graphics and bit-mapped images
  - Used in several popular graphics programs (Adobe)
  - no compression, files are large

- System dependent formats
  - **BMP**: support 24-bit bitmap images for Microsoft Windows
  - **XBM**: support 24-bit bitmap images for X Windows systems
  - Many, many others

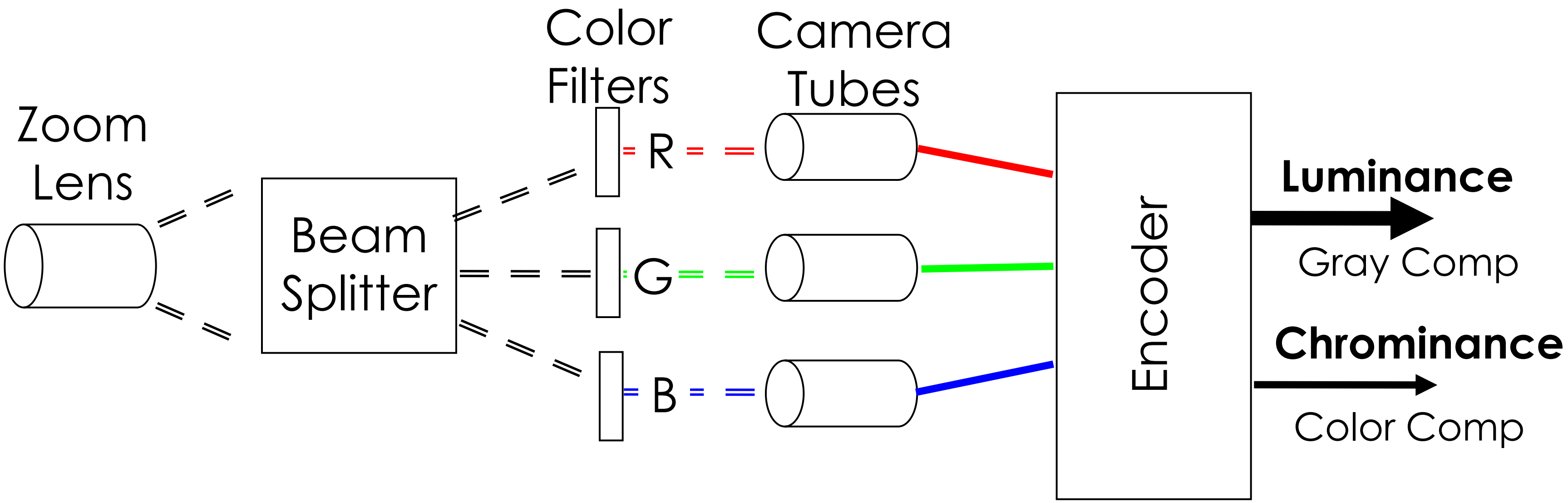
Video Communication/Broadcast System



Goals:

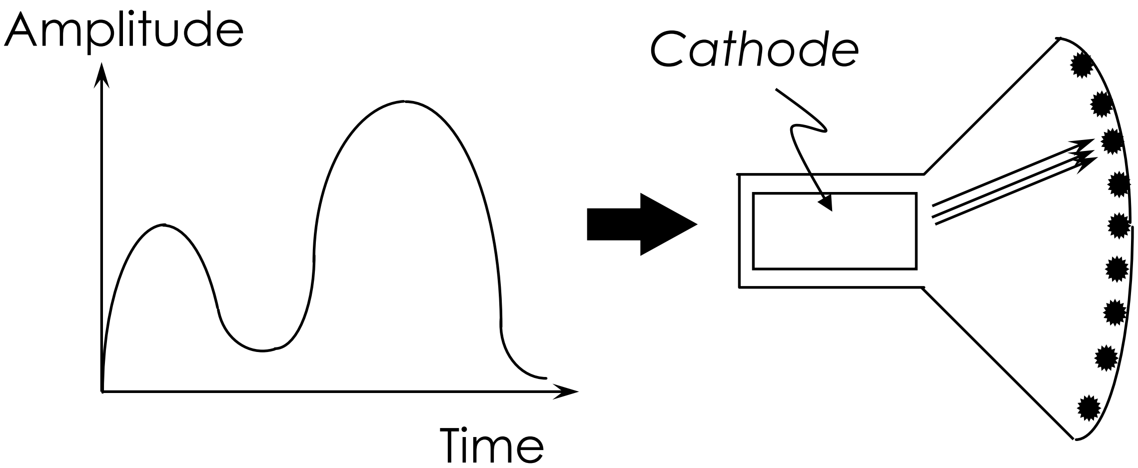
1. Efficient use of bandwidth
2. High viewer perception of quality

Camera Operation



- Camera has 1, 2, or 3 tubes for sampling
- More tubes (CCD's) and better lens produce better pictures
- Video composed of luminance and chrominance signals
- Composite video combines luminance and chrominance
- Component video sends signals separately

Video Display Scanning

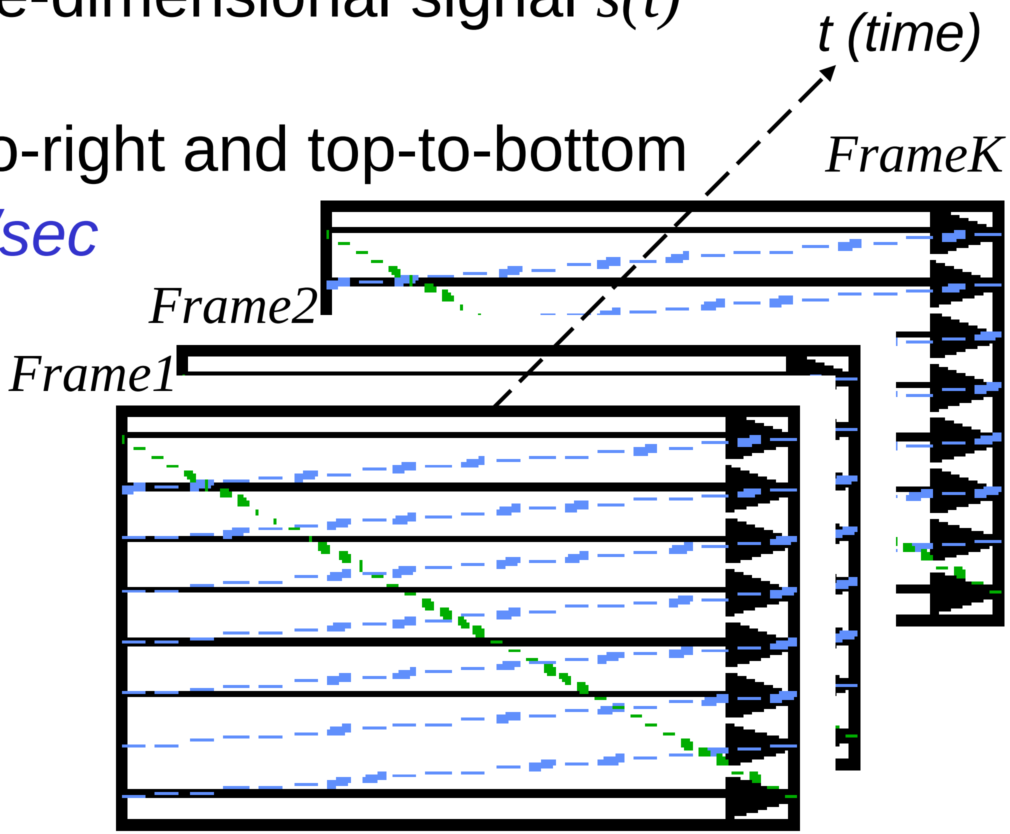


- Three guns (RGB) energize phosphors
  - Varying energy changes perceived intensity
  - Different energies to different phosphors produces different colors
  - Phosphors decay so you have to refresh
- Different technologies
  - Shadow mask (delta-gun dot mask)
  - PIL slot mask
  - Single-gun (3 beams) aperture-grille (Trinitron)

Scanning Video

- Video is obtained via *raster scanning*, which transforms a 3-D signal *p(x, y, t)* into a one-dimensional signal *s(t)* which can be transmitted.
- Progressive scanning: left-to-right and top-to-bottom
  - Samples in time: *frames/sec*
  - Samples along y: *lines*
  - Samples along x: *pixels*

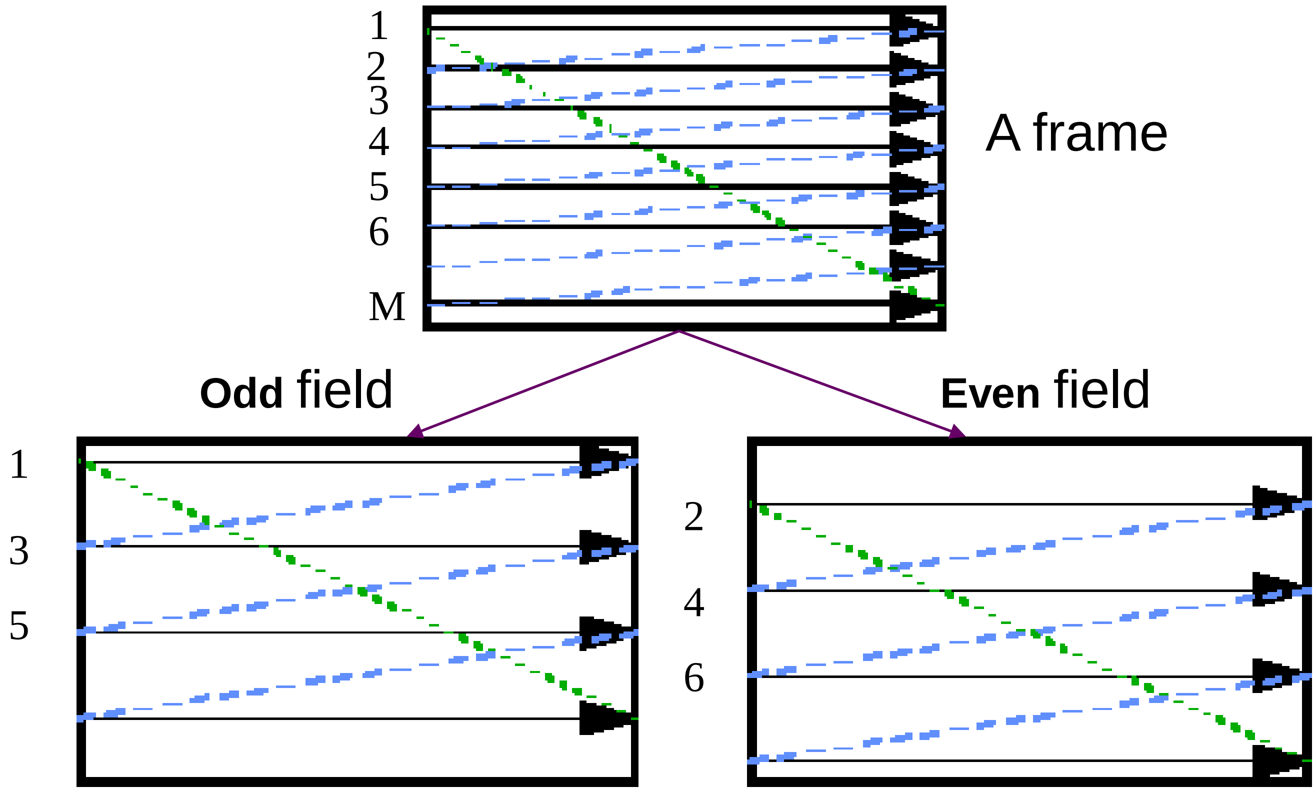
    (only for digital video)
- We perceive the images as continuous, not discrete: human visual system performs the interpolation !
- How many frames, lines, and pixels ?



Progressive scanning

Interlaced Scanning

- If the frame rate is too slow - > flickering and jagged movements
- Tradeoff between spatial and temporal resolution
  - Slow moving objects with high spatial resolution
  - Fast moving objects with high frame rate
- ***Interlaced scanning***: scan all even lines, then scan all odd lines.
- A frame is divided into 2 fields (sampled at different time)



RGB Color Model

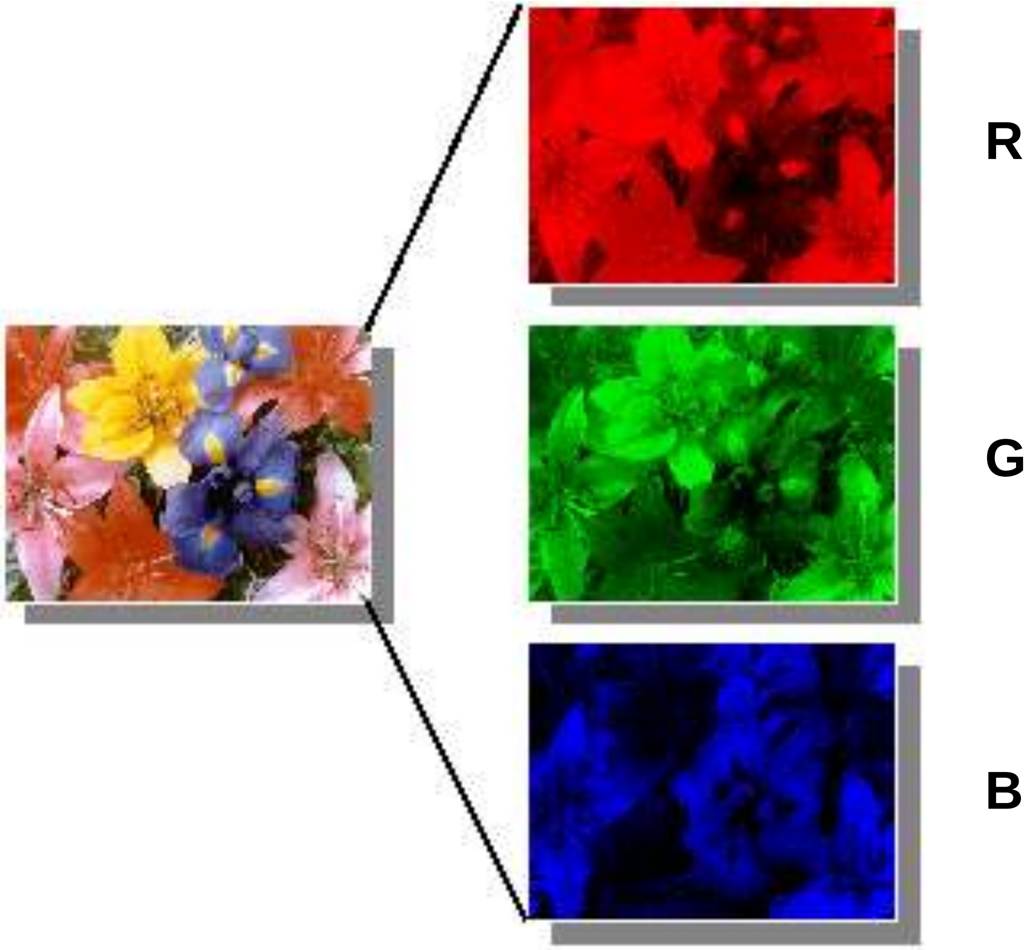
- Three basic colors

  R: Red

  G: Green

  B: Blue

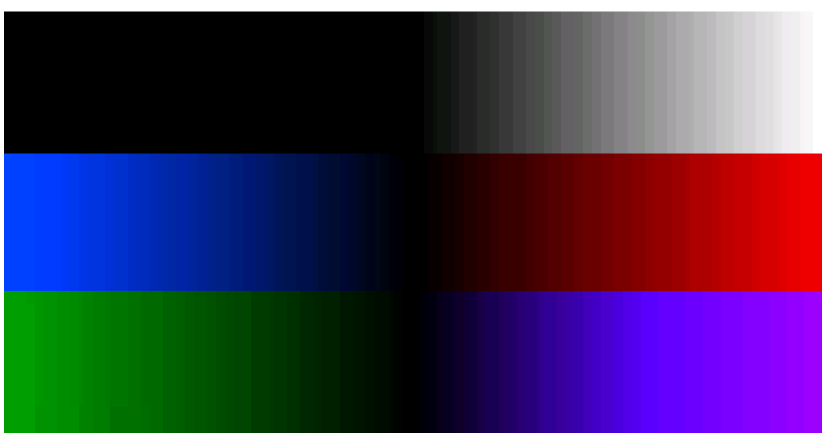
➔ A picture consists of three images

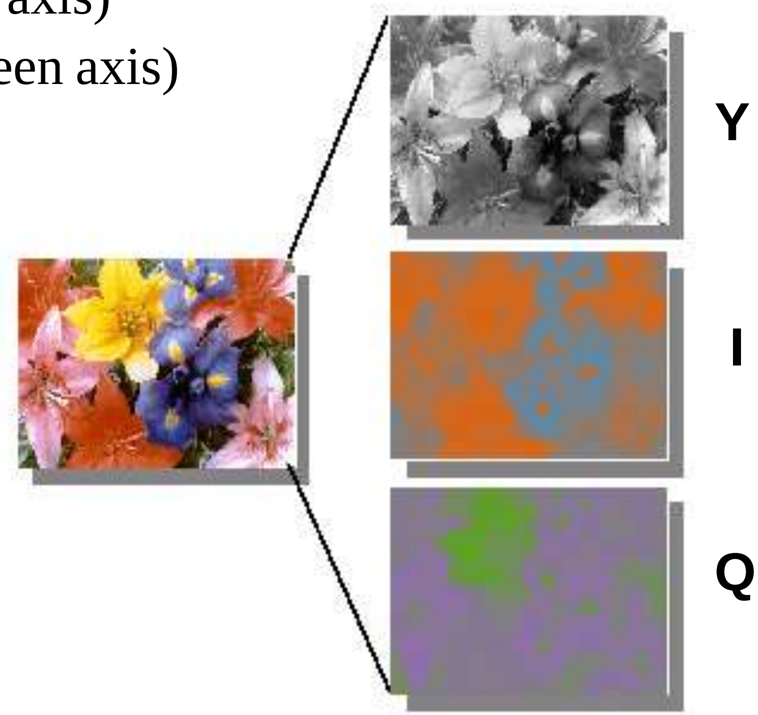


YIQ Color Model

YIQ color model: used in NTSC color TV

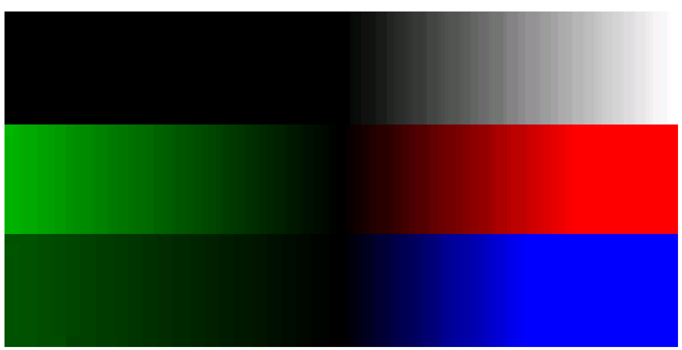
- **Y - Luminance** containing brightness and detail (monochrome TV)
- To create the Y signal, the red, green and blue inputs to the Y signal must be balanced to compensate for the color perception misbalance of the eye.
  - **Y = 0.3R + 0.59G + 0.11B**
- **Chrominance**
  - **I = 0.6R – 0.28G - 0.32B** (cyan-orange axis)
  - **Q = 0.21R – 0.52G + 0.31B** (purple-green axis)
- Human eyes are most sensitive to Y, next to I, next to Q.

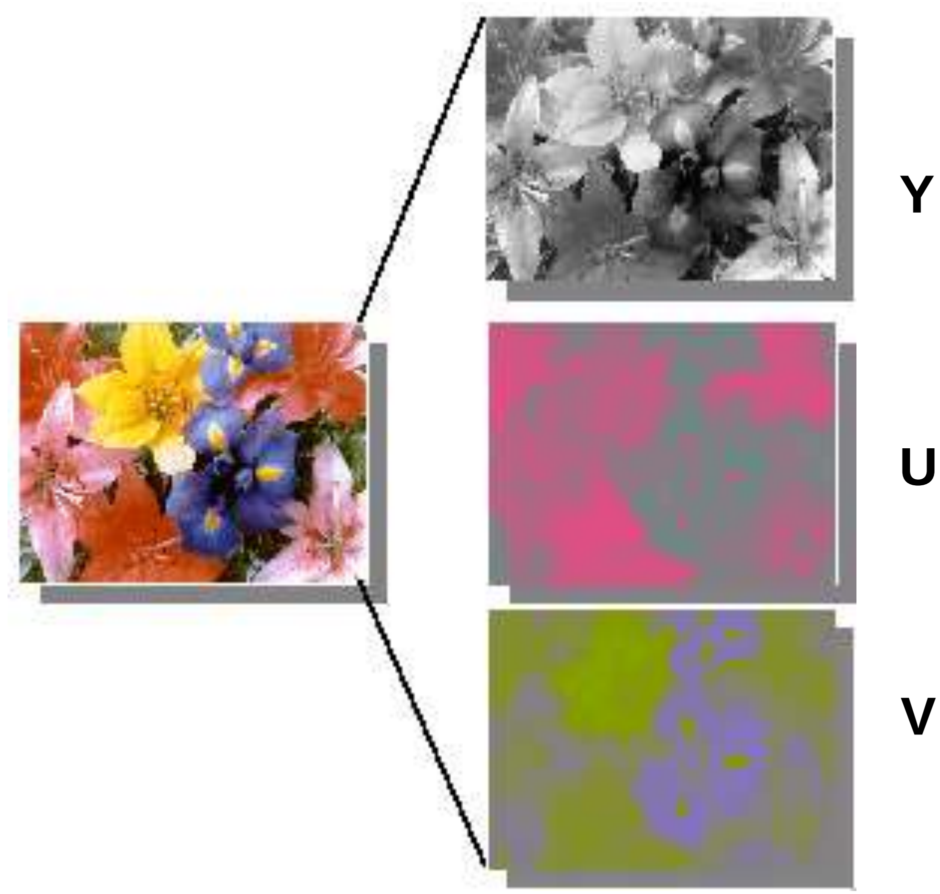




YUV Color Model

- **YUV color model**: used for PAL TV and CCIR 601 standard
- Same definition for Y as in YIQ model
- Chrominance is defined by U and V – the color differences
  - **U = B – Y**
  - **V = R – Y**





YCrCb Color Model

- **YCbCr color model**: used in JPEG and MPEG
- Closely related to YUV: scaled and shifted YUV
  - **Cb = ((B – Y)/2) + 0.5**
  - **Cr = ((R – Y)/1.6) + 0.5**

- Chrominance value in YCbCr are always in the range of **0 to 1** (normalization)

  → *Make digital processing easy*

Color Models in Video (Cont…)

- Color models based on linear transformation from RGB color space

$$C = M_{3x3} \, x \, C_{RGB}$$

YIQ (used in NTSC TV standard). Change of basis matrix: $\begin{pmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{pmatrix}$

YUV (used in PAL and SECAM). Change of basis matrix: $\begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.100 \end{pmatrix}$

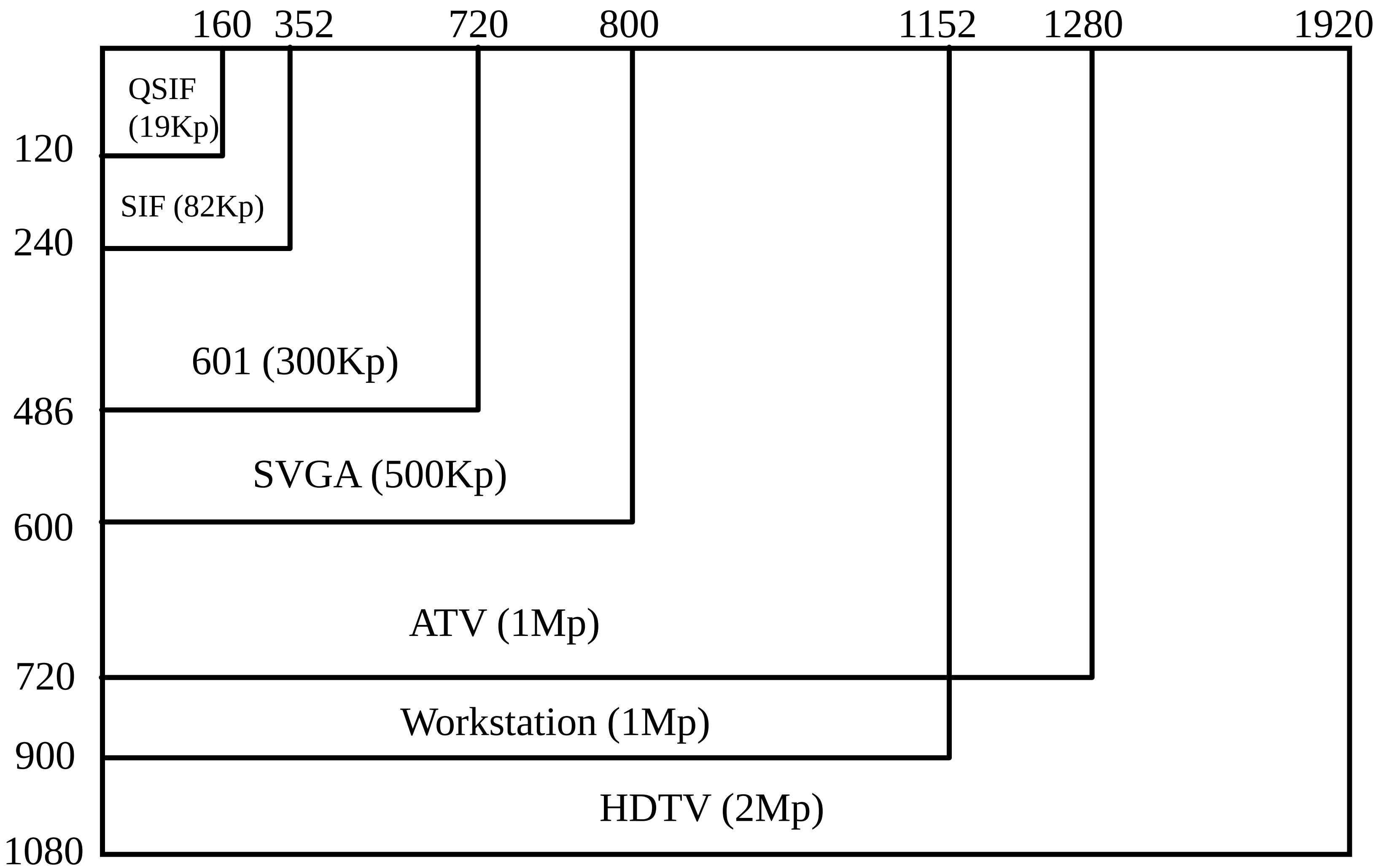
YCrCb (used in JPEG and MPEG). Change of basis matrix: $\begin{pmatrix} 0.2990 & 0.5870 & 0.1140 \\ 0.5000 & -0.4187 & -0.0813 \\ -0.1687 & -0.3313 & 0.5000 \end{pmatrix}$

Analog NTSC and PAL Video

- NTSC Video: Japan, US, …
  - 525 scan lines per frame, 30 frames per second
  - Interlaced, each frame is divided into 2 fields, 262.5 lines/field
  - 20 lines reserved for control information at the beginning of each field
  - So a maximum of 485 lines of visible data
  - Color representation: YIQ color model
- PAL Video: China, UK, …
  - 625 scan lines per frame, 25 frames per second (40 msec/frame) Interlaced, each frame is divided into 2 fields, 312.5 lines/field
  - Uses YUV color model
  - Approximately 20% more lines than NTSC
  - NTSC vs. PAL ➔ roughly same bandwidth

Digital Video

- Analog TV is a continuous signal
- Digital TV uses discrete numeric values
  - Signal is sampled, and samples are quantized
  - *Sub-sampling to reduce image resolution or size*
- Image represented by pixel array



Sample Quantization – Pixel Resolution

- Pixel resolution depends quantization levels/bits
- Usually, 8 bits for each luma/chroma sample when no compression

→ 8bits/1byte per pixel for gray image, 24bits/3byetes for true color image

(a) (b) (c) (d)

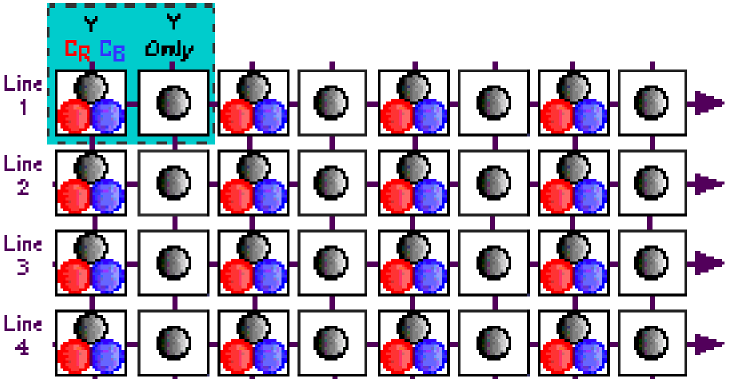
Luminace (gray) picture

Num.	Level	Bit	
(a)	2	1	(Monochrome)
(b)	4	2	
(c)	8	3	
(d)	16	4	
(e)	32	5	
(f)	64	6	

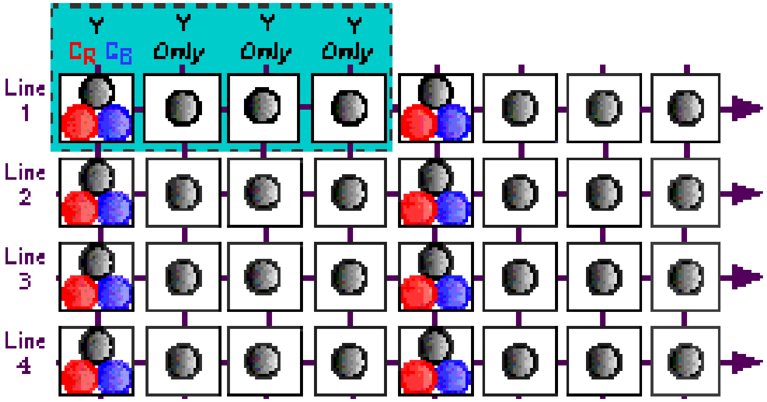
(e) (f)

Luma Sampling and Chroma Sub-Sampling

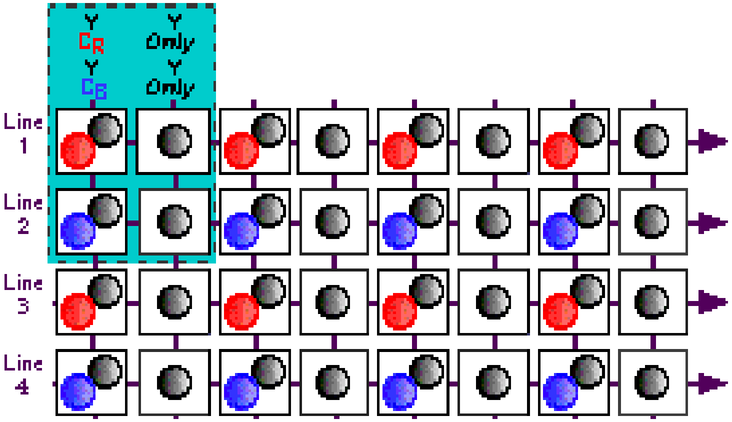
- *Chroma subsampling*: human visual system is **more sensitive to luminance than chrominance**
  → We can subsample chrominance
- 4:4:4 – No subsampling
- 4:2:2, 4:1:1 – horizontally subsample
- 4:2:0 – horizontally and vertically



4:2:2



4:1:1



4:2:0

Standards for Video

	HDTV	CCIR 601 NTSC	CCIR 601 PAL	CIF	QCIF
Luminance Resolution	1920 x 1080	720 x 486	720 x 576	352 x 288	176 x 144
Chrominance Resolution	960 x 540	360 x 486	360 x 576	176 x 144	88 x 72
Color Subsampling	4:2:2	4:2:2	4:2:2	4:2:0	4:2:0
Frames/sec	60	30	25	15	15
Aspect Ratio	16:9	4:3	4:3	4:3	4:3
Interlacing	Yes	Yes	Yes	No	No

CCIR – Consultative Committee for International Radio
CIF – Common Intermediate Format (approximately VHS quality)
QCIF – Quarter CIF

Video Bit Rate Calculation

width ~ pixels (160, 320, 640, 720, 1280, 1920, …)

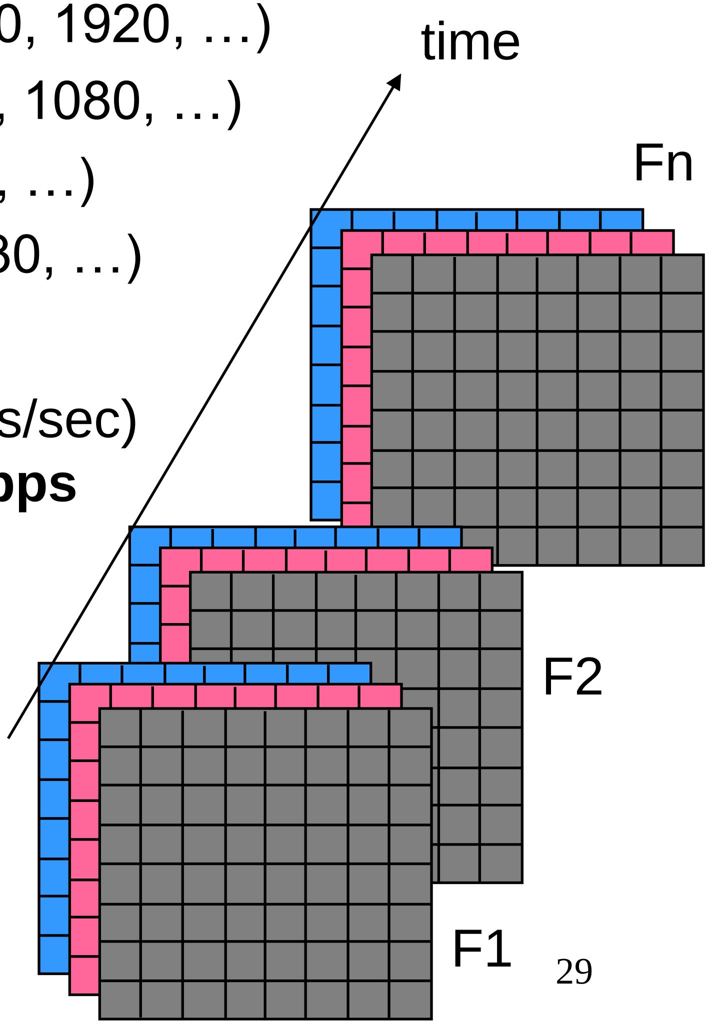
height ~ pixels (120, 240, 480, 485, 720, 1080, …)

depth ~ bits per pixel (1, 4, 8, 15, 16, 24, …)

fps ~ frames per second (5, 15, 20, 24, 30, …)

Bit Rate = width * height * depth * fps (bits/sec)

bps



One Frame =
3 pictures
(YCrCb)

Data Rate of No-Compressed Video

- Example 1: Resolution 720x385, frame rate 30 frames per sec (fps)
  - 720x485 = 349,200 pixels/frame
  - **4:4:4** sampling gives 720x485X**3**=1,047,600 bytes/frame
  - 30fps → 1.05Mx30=31.5MBytes/sec → 31.5Mx8bits=*250Mbps*
  - **4:2:2** subsampling gives 720x485x**2**=698,400 bytes/frame
  - 30fps → 0.698x30=21 MB/sec → 21Mx8=*168Mbps*

-- **bps** (bit rate) bits per second

- Example 2: Resolution 1280x720, frame rate 30fps
  - 1280x720 = 921,600 pixels/frame
  - **4:2:0** subsampling gives 921,600x**1.5**=1,382,400 bytes/frame
  - 30fps → 1.38Mx30=41MB/sec → 41x8=*328Mbps (656Mbps 4:4:4)*
- Example 3 Resolution 1080x1920, frame rate 60fps
  - 1080x1920 = 2,073,600 pixels per frame
  - **4:4:4** sampling = 2,073,600x**3** = 6,220,800 bytes/frame
  - 60fps → 2,073,600x60 = 373,248,000 bytes per second → 374MB/s = 374Mx8=*3Gbps*

➔ **Conclusion: Compressing Digital Video !!!**

Video Coding Standards Organizations

- **ITU-T**: International Telecommunication Union
  - Formerly CCITT
  - A United Nations Organization
  - Group: Video Coding Experts Group (VCEG)
  - Standards: **H.261**, **H.263**, **H.264**, etc
- **ISO**: International Standards Organization
  - Joint Photographic Experts Group (JPEG)
    - → Standards: **JPEG/JPEG2000** (still image), MJPEG (motion picture)
  - Moving Picture Experts Group (MPEG)
    - → Standards: **MPEG-1**, **MPEG-2**, **MPEG-4**, (**MPEG-7**, **MPEG-21**)
- … and more!

Demos of Image Color Models