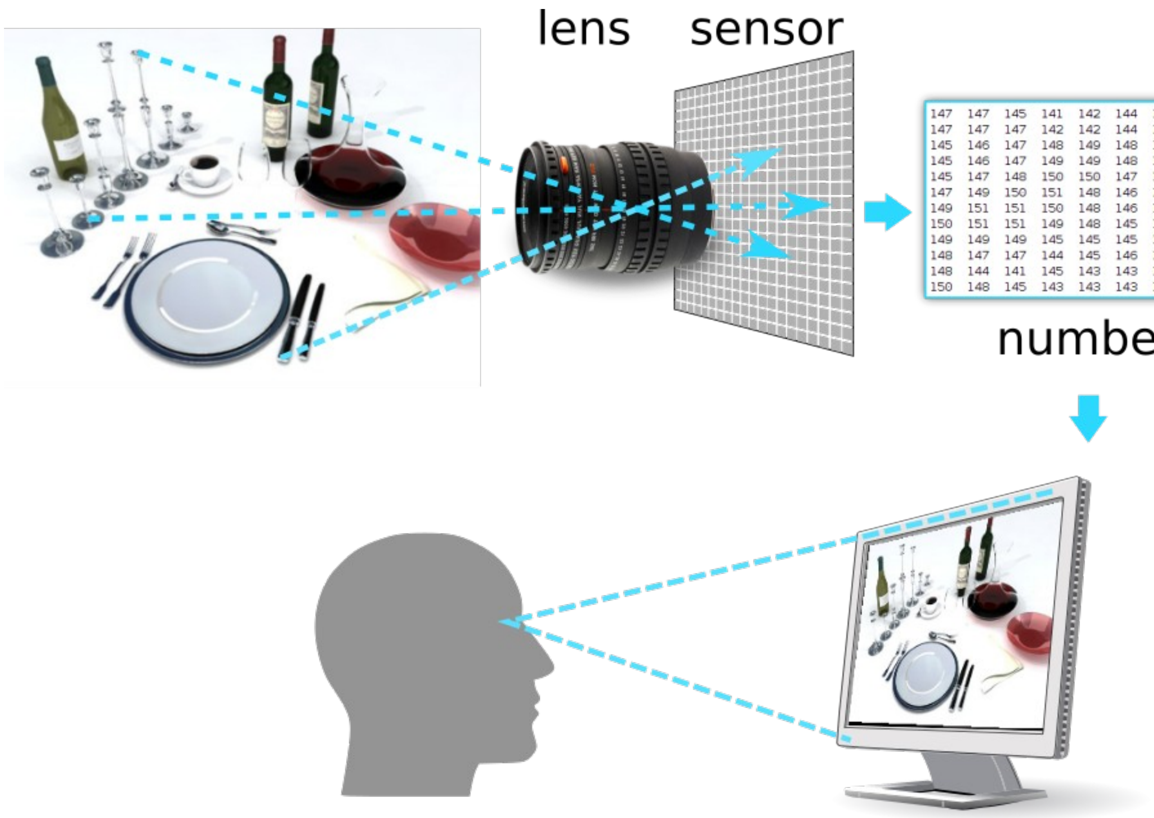
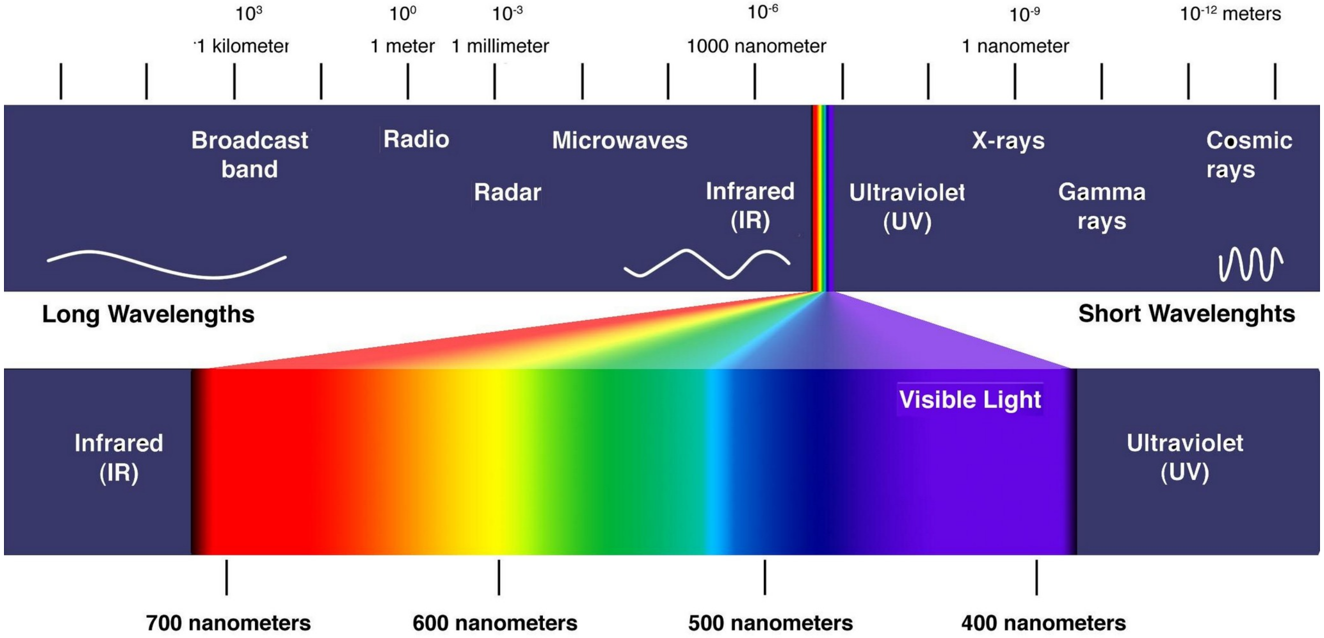
Image formation

World, image, eye



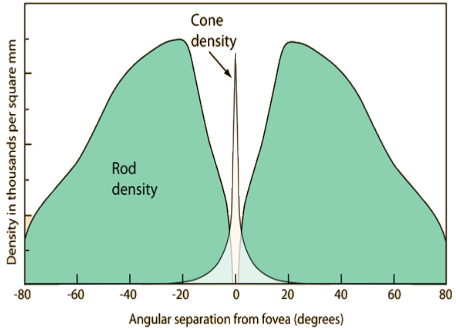
Light

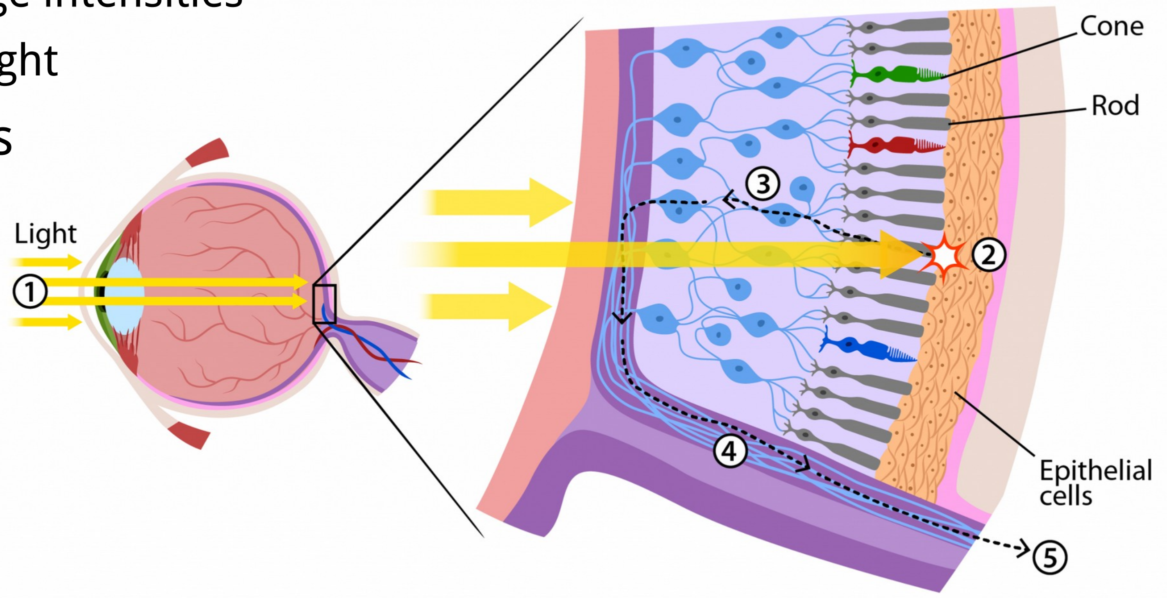


- Light is electromagnetic waves / particles (photons)
- Visible light is light with wavelength from ~400nm to ~700nm

Perceiving light

- Eye perceives light that falls on the retina
- Retina is composed of two types of cells
  - Cones - Sensitive to color and large intensities
  - Rods - Sensitive to low intensity light
- There are more rods than cones
- Not uniform distribution





Why are we trichromatic?

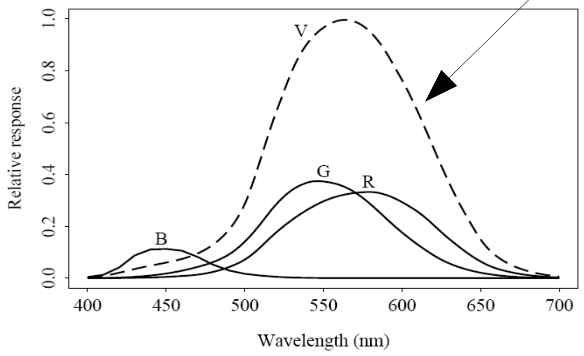
- Young-Helmholtz theory (19th century)
- Three types/lengths of cones
  - Different wavelengths (R=L, G=M, B=H)
- It is not yet entirely clear how brain combines color information
  - Ganglion trigger to differences R-G, G-B, B-R (opponent theory)
- All three channels are combined into achromatic information

Spectral sensitivity of the eye

- Eye is most sensitive to the middle of visible spectrum
- Cone distribution approximately R:G:B == 40:20:1 (varies from human to human)
- Rods are more sensitive to wavelengths closer to the red part of the spectrum.

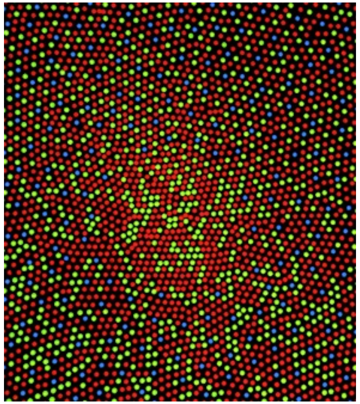
Cones sensitivity

The curve for blue is not plotted on the correct scale, it is much lower than the curve for red or green.



Rods sensitivity

Sensitivity of rods is similar to the overall sensitivity curve V for cones, it is only shifted towards the red spectrum.

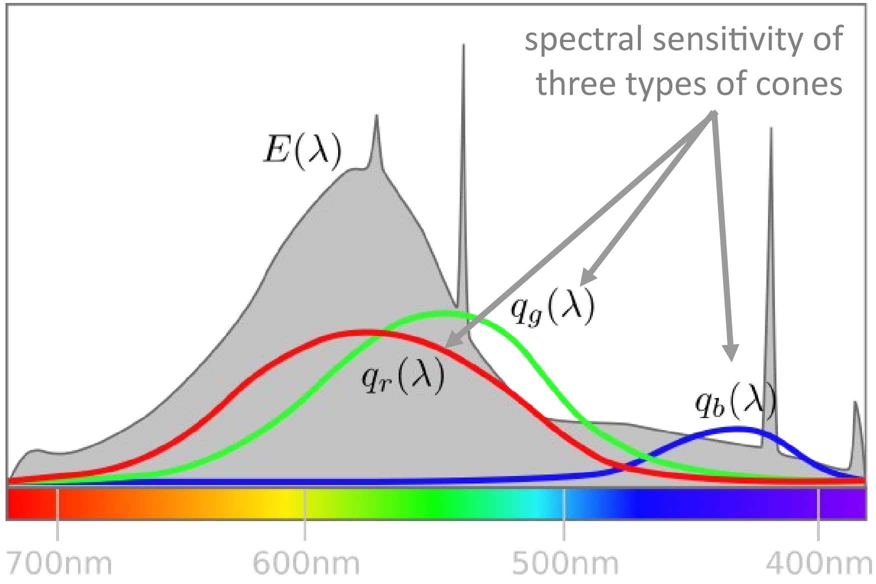


Cone distribution

Cones sensitivity

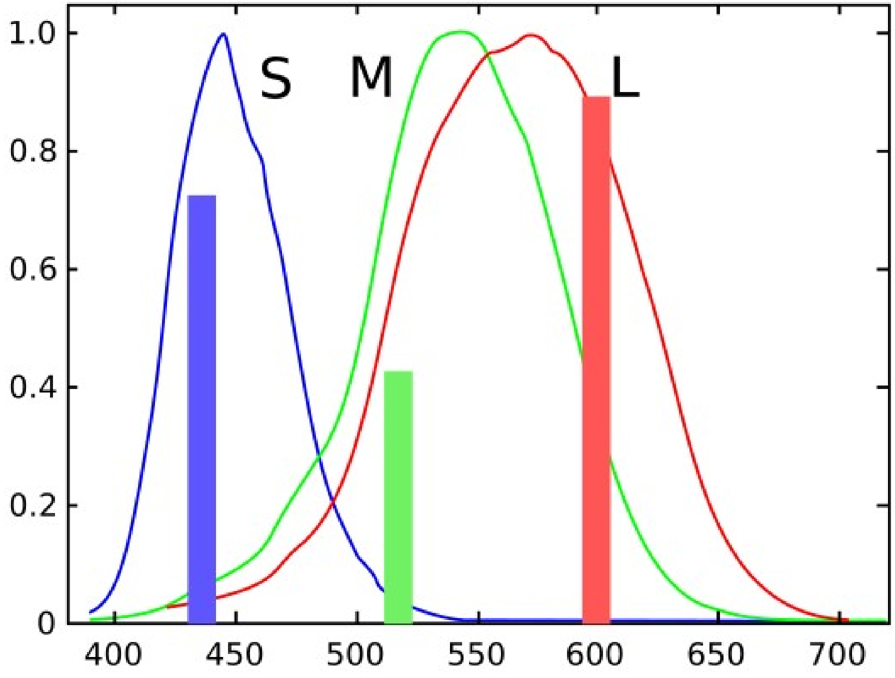
- Cones are triggered with different intensity with respect to the light's wavelength
- Filtering color spectrum $E(\lambda)$

$$R = \int E(\lambda) q_r(\lambda) d\lambda$$
$$G = \int E(\lambda) q_g(\lambda) d\lambda$$
$$B = \int E(\lambda) q_b(\lambda) d\lambda$$



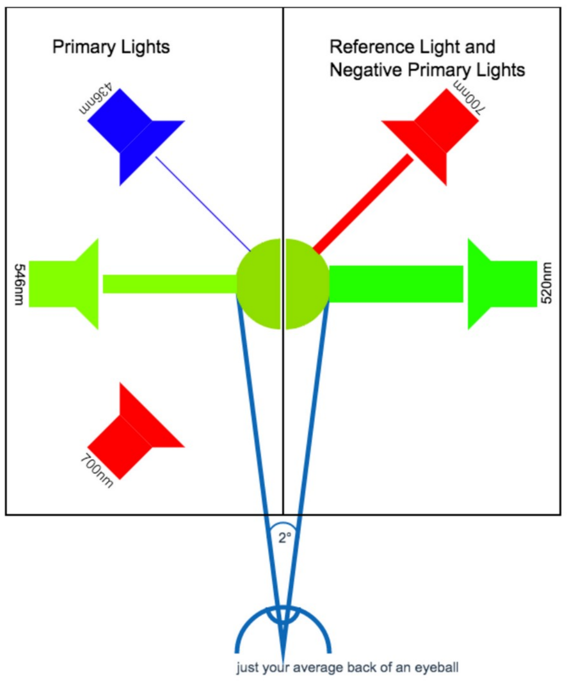
Simulating color

- Stimulating cone cells
- Metamerism
- Color primaries
  - Trichromatic (3+)
  - Different standards



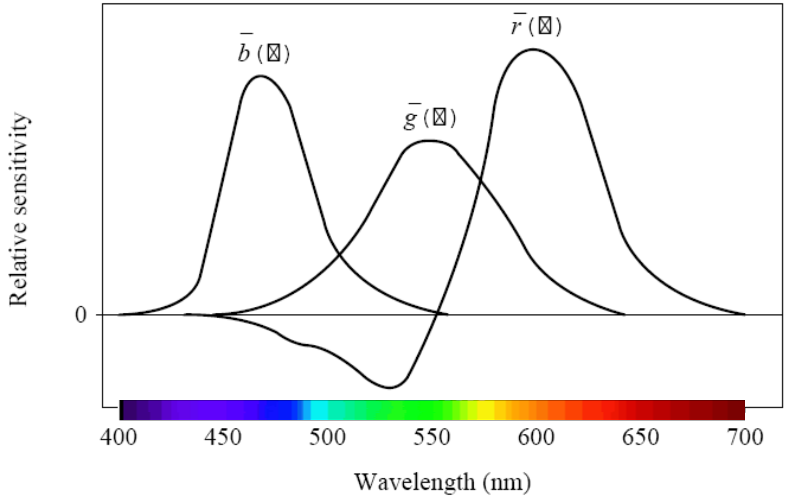
Measuring color perception

- Color reproduction evaluation
- Quantitative evaluation it in terms of human perception
- The tristimulus colorimeter experiment
  - Matching reference color
  - A person is controlling the intensity of three color channels
  - Standard observer (field-of-view)
  - Negative light

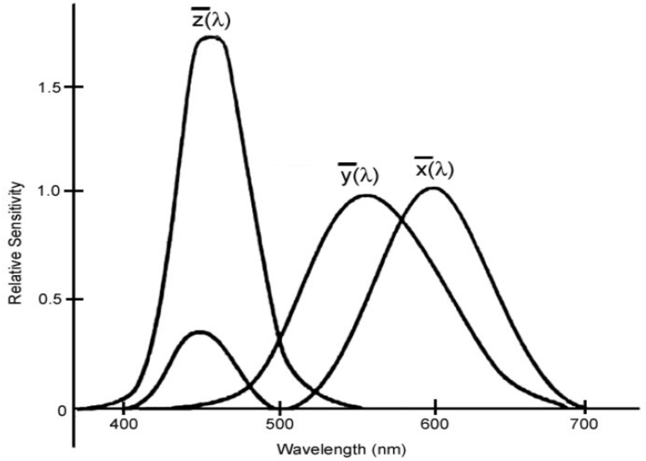


CIE 1931 curves

- Established by Commission Internationale de l'Eclairage (CIE)
- Results of the experiment are three color matching functions
- Non-negative artificial curves determined experimentally (linear transformation)



Negative values denote that the person had to adjust the light of the reference color

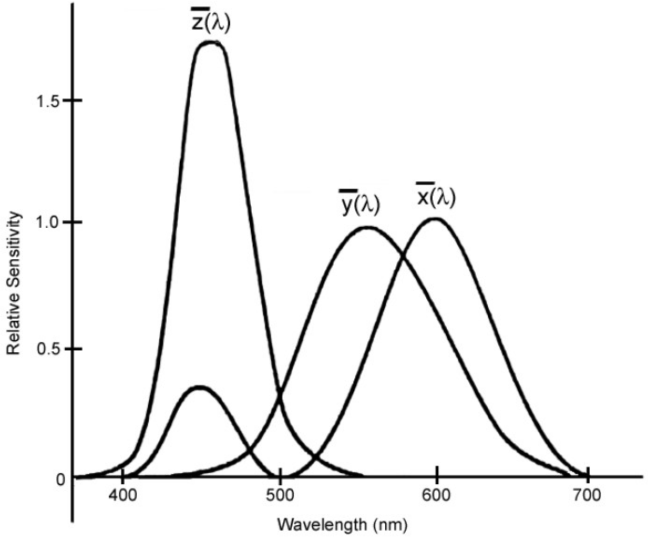


The y(λ) curve matches the overall sensitivity curve V(λ)

The CIE XYZ model

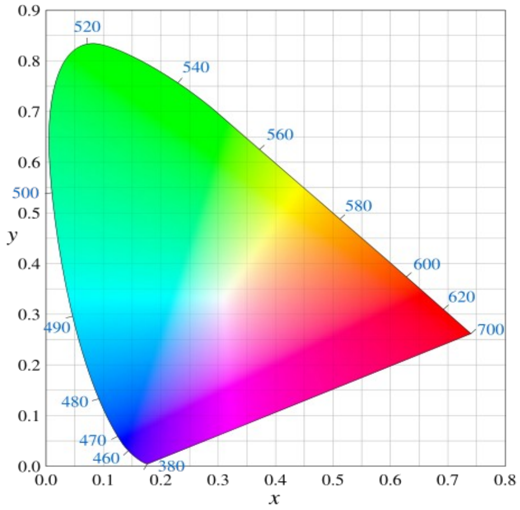
- Arbitrary color determined by spectrum E(λ), can be formulated with values of the three stimuli X, Y, Z
- The CIE XYZ standard:

$$X = \int E(\lambda)\bar{x}(\lambda)d\lambda$$
$$Y = \int E(\lambda)\bar{y}(\lambda)d\lambda$$
$$Z = \int E(\lambda)\bar{z}(\lambda)d\lambda$$



Chromatic diagram

- 3D space visualization is difficult $x = \frac{X}{X+Y+Z}, \; y = \frac{Y}{X+Y+Z}, \; z = \frac{Z}{X+Y+Z}$
- Normalized redundant system $x + y + z = 1$
  - Display (x,y) when z=0
  - Chromatic components: (x, y)
  - Luminance: Y
- Saturated colors at borders
- White color in the middle
- Mixture of two light sources corresponds to color on the line between their colors in chromatic diagram

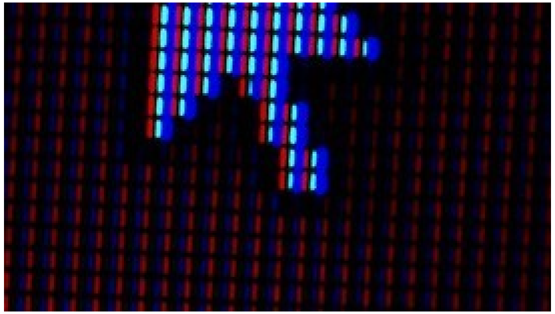


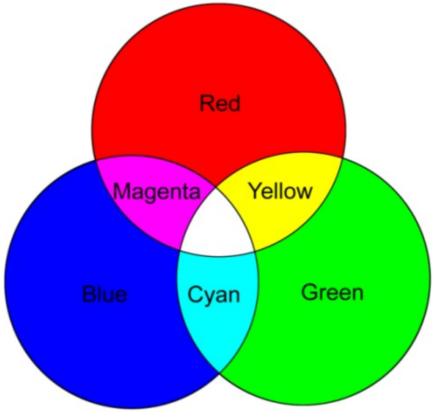
Color spaces / models

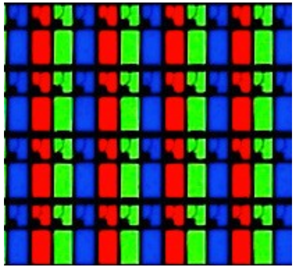
- Low level representation
  - Individual pixels
  - Different use-cases
- Reproduction
  - Additive
  - Subtractive

Additive models

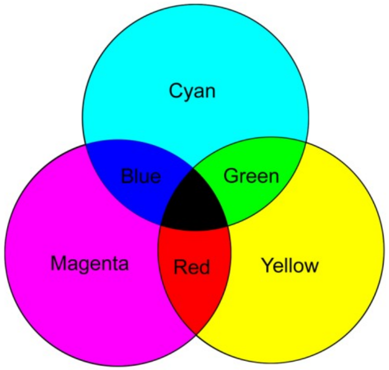
- Active reproduction
  - Starting with black
  - Add color
- Devices
  - Monitors
  - Television
  - Projectors

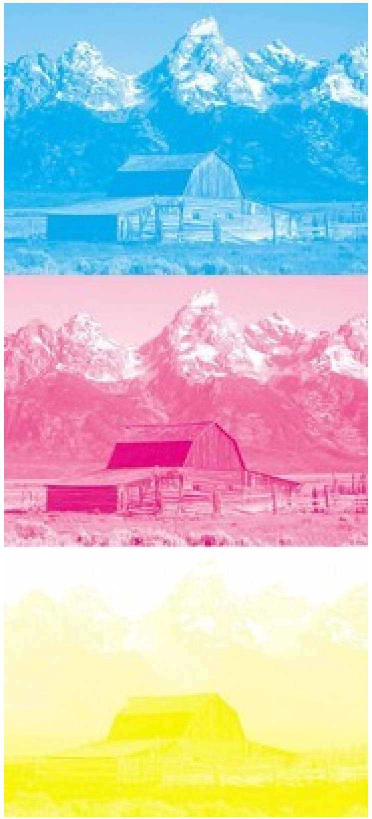






Subtractive models





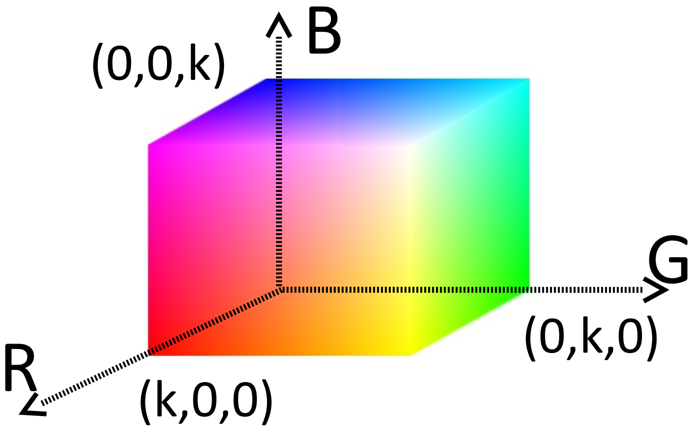
- Starting point is white
- We then add pigments that remove wavelengths by absorption
  - Yellow pigment absorbs blue and still reflects red and green
  - Green pigment only reflects green
- Usage
  - Crayons
  - Printers (CMYK)
  - Analogue photographic paper

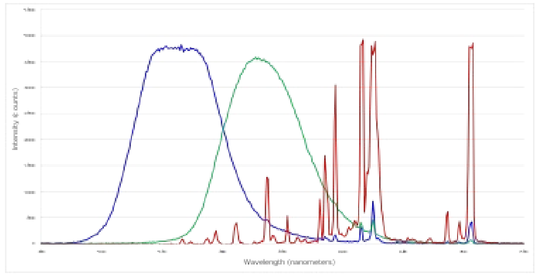
The RGB color space

- Three primaries: red, green, blue
- Foundations in color cathode television
- k ... maximum value of primary color

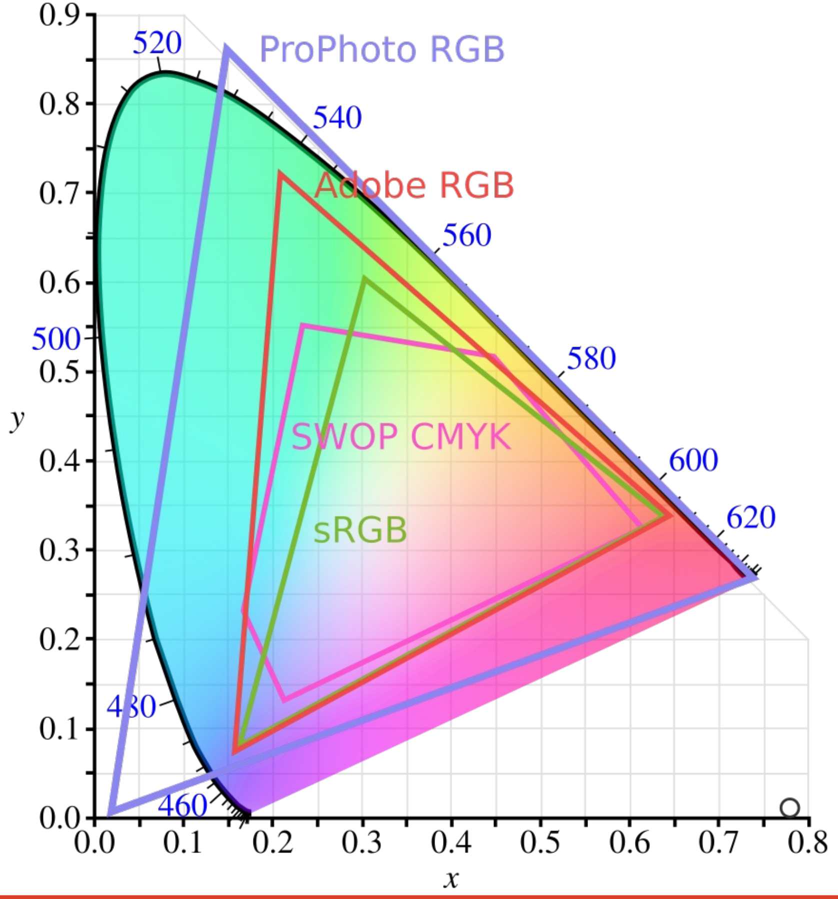
$$\begin{bmatrix} x_r & x_g & x_b \\ y_r & y_g & y_b \\ z_r & z_g & z_b \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

Different standards define the matrix differently (sRGB, Adobe RGB, Adobe wide gamut RGB)





Color space comparision



- Different coverage
- Conversion loss
  - Rounding
  - Truncation

The CIE L*a*b* color space

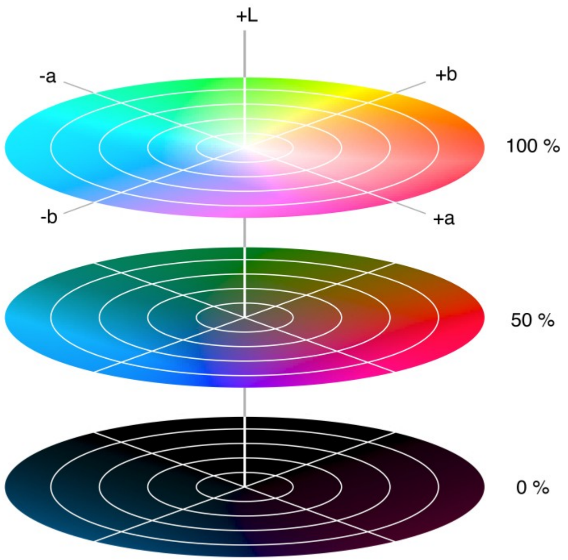
- Different projection of the same colors
- Mimics human color perception - similar colors are near in color space

$$L^\star = 116\, f\left(\frac{Y}{Y_{\mathrm{n}}}\right) - 16$$

$$a^\star = 500\left(f\left(\frac{X}{X_{\mathrm{n}}}\right) - f\left(\frac{Y}{Y_{\mathrm{n}}}\right)\right)$$

$$b^\star = 200\left(f\left(\frac{Y}{Y_{\mathrm{n}}}\right) - f\left(\frac{Z}{Z_{\mathrm{n}}}\right)\right)$$

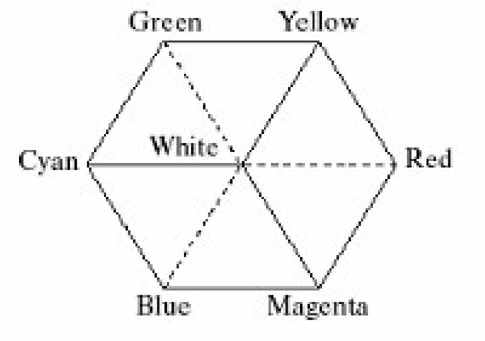
$$\Delta E = \sqrt{(L\ast)^2 + (a\ast)^2 + (b\ast)^2}$$

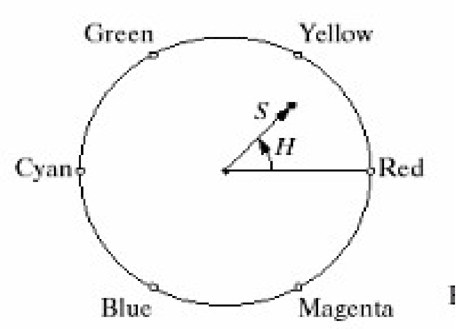


(X_n, Y_n, Z_n) value of white color according to CIE XYZ

The HSV color space

- Hue, Saturation, Value
- Psychological motivation
- Non-linear: hue is an angle





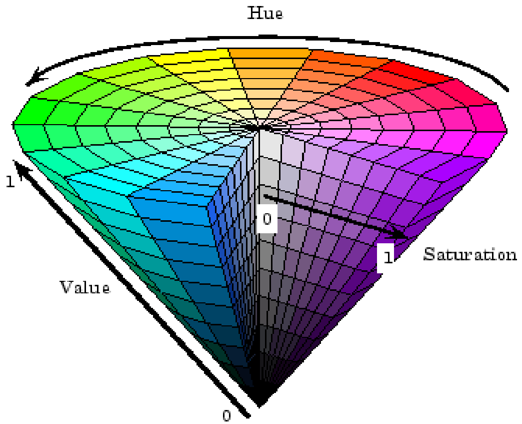
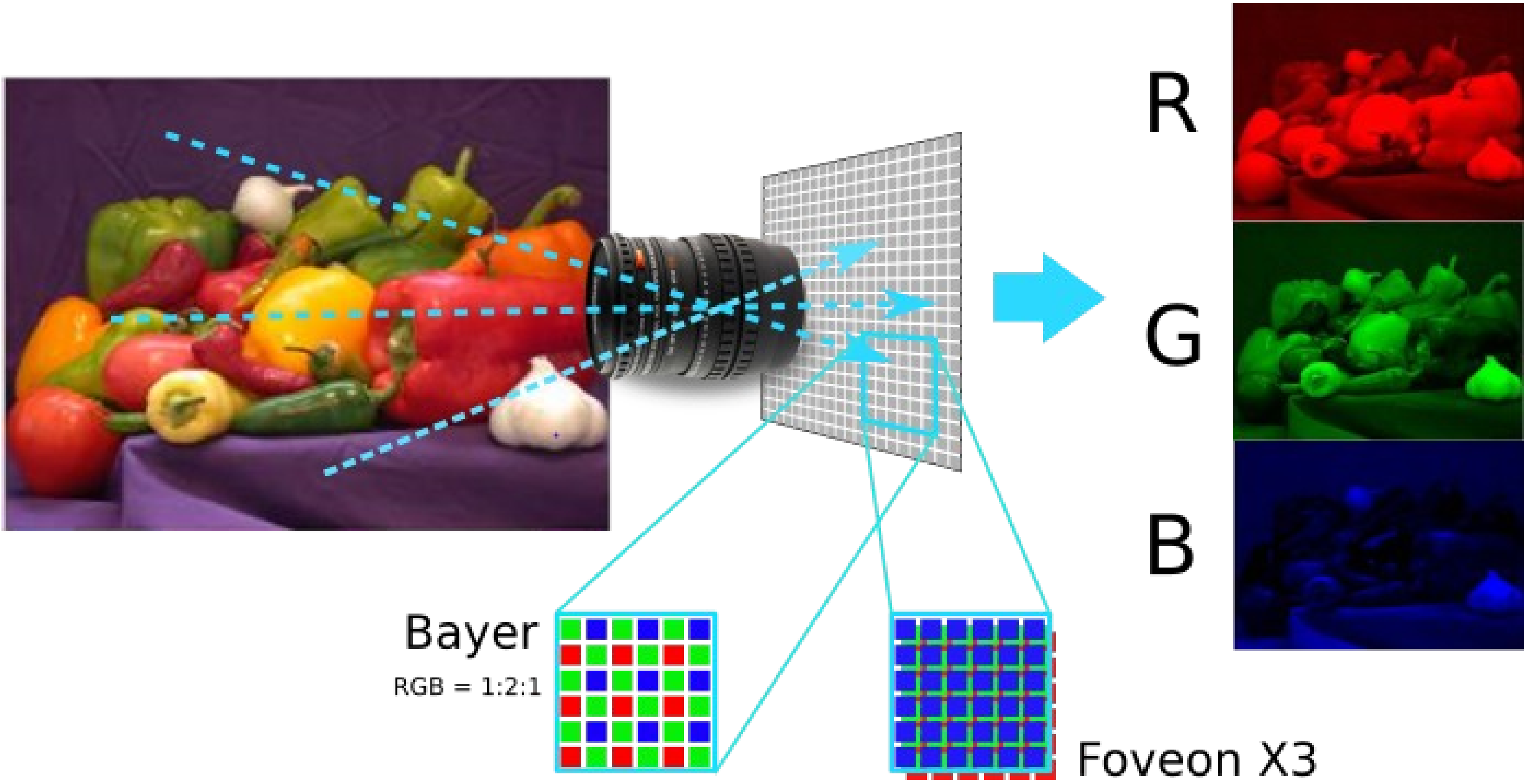


Image formation in camera



Video

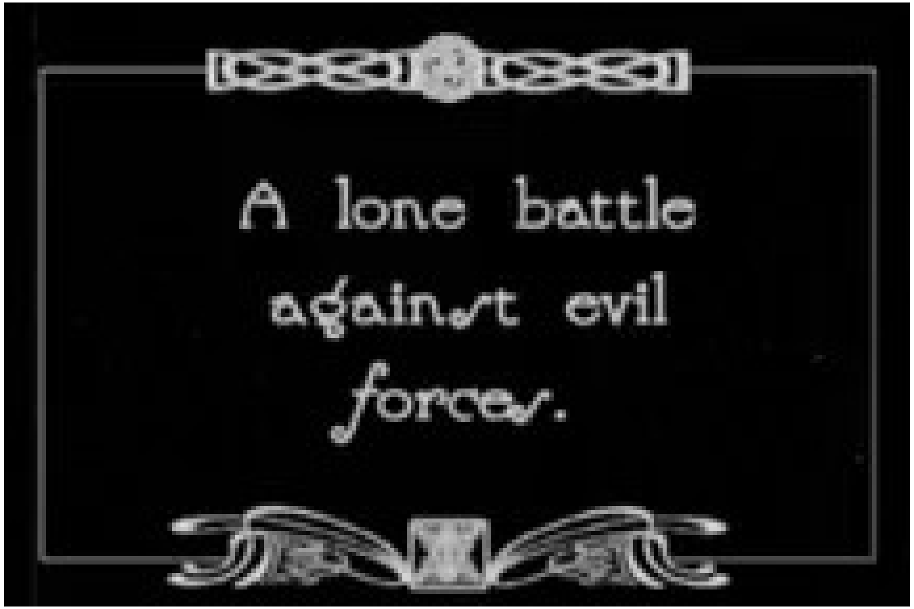
- Videre (lat.) - to see
- Electronic medium for the recording, copying, playback, broadcasting, and display of moving visual (and audio) media
- Digital video – digital representation of video
  - Sequence of digital images
  - Compression algorithms
  - (+ digital sound)

Temporal resolution

- Human perception system (eye+brain) can perceive about 10 - 12 images per second as separate images.
- Persistence of vision
  - Image „remains“ in cortex for 1/25s
  - Neuron saturation

Film projector

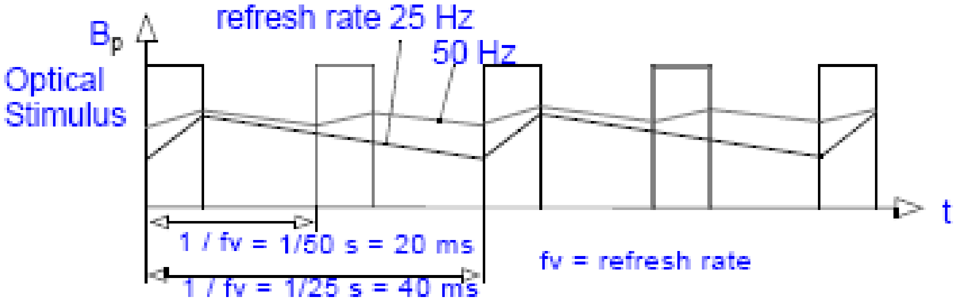
- For video illusion we need 16 images per second (FPS)
- ~1920: silent films use 20-26fps, 1930: 24fps

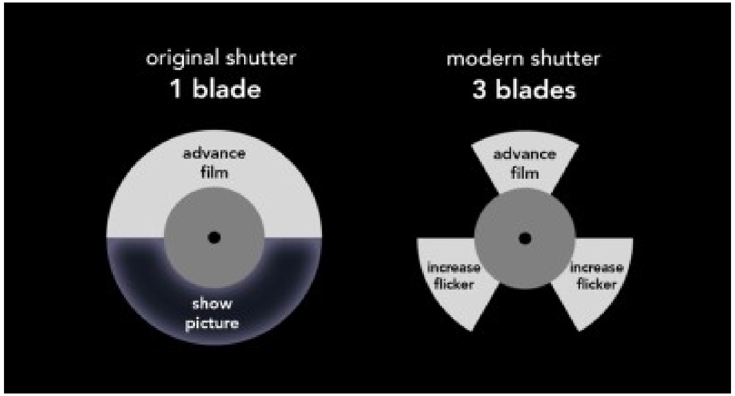


Why is the projection flickering?

Flickering

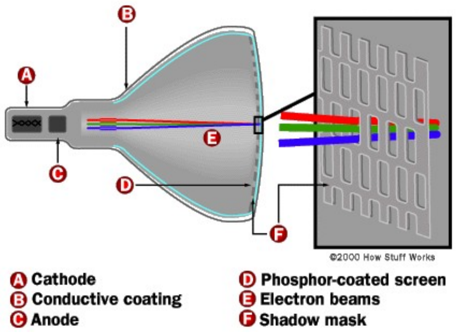
- Shutter closed during film movement
- High illumination change - flickering
- Darker display - higher shutter frame rate

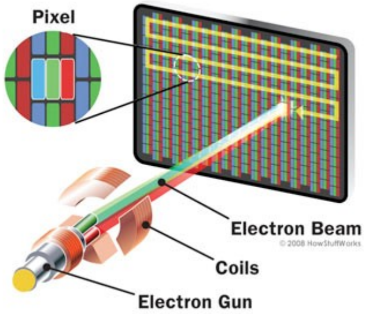


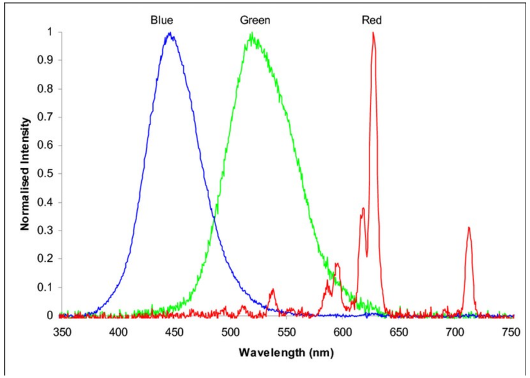


Cathode displays

- Electron beam traversing matrix of fluorescent particles
- When a particle (pixel) is hit, it briefly glows
- To maintain realism, the beam has to refresh the screen fast enough (refresh frequency)
- CRT monitors (<50Hz flickering) (~100Hz no flickering)



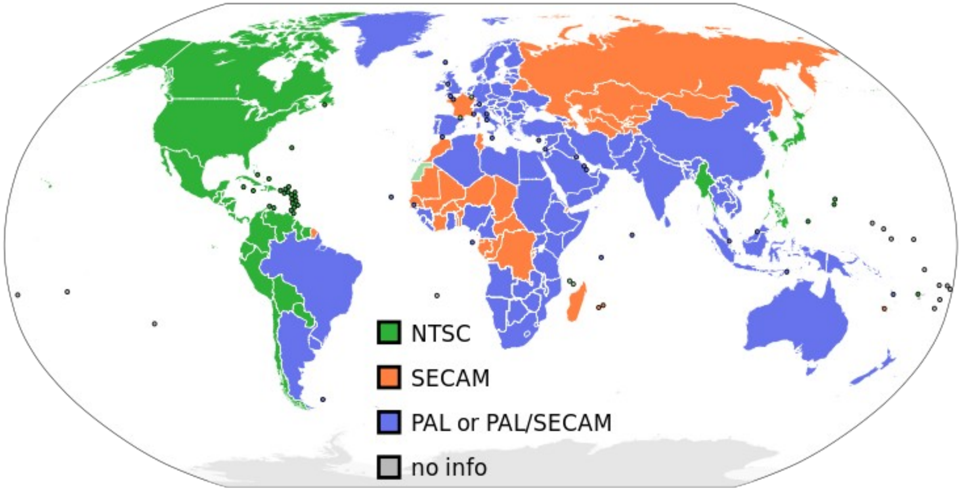




Encoding color

- Composite video
  - Suitable for lower bandwidth
  - Luminosity and color mixed in common signal
  - Channel cross-talk
  - Analog TV: NTSC, PAL, SECAM
- Component video
  - Separate signals for color channels
  - Better image reproduction, no cross-talk
  - BNC, RCA, VGA

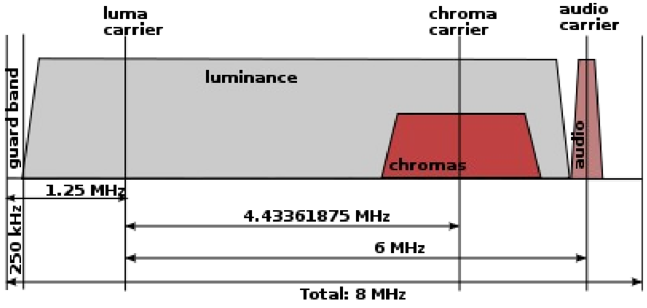
Analog television formats

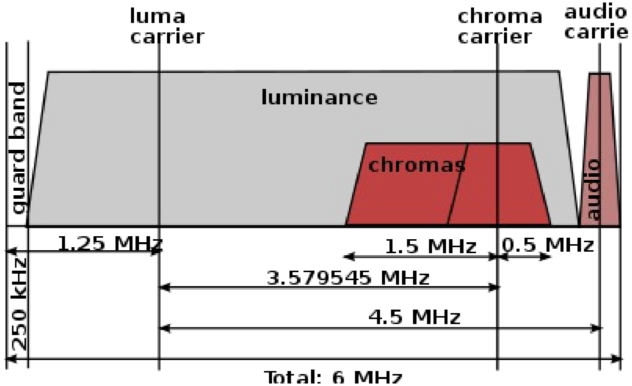


TV standard	FPS	# lines	Frequency band (MHz)	Channel allocation (MHz)		
				Y	I or U	Q or V
NTSC	29.97	525	6.0	4.2	1.6	0.6
PAL	25	625	8.0	5.5	1.8	1.8
SECAM	25	625	8.0	6.0	2.0	2.0

Analog television

- PAL
  - Phase Alternating Line
  - 625 lines per image
  - 25fps, aspect ratio 4:3, interlaced
  - YUV color space
- NTSC
  - Used in North America
  - YIQ color space
  - 525 lines (29.97fps), interlaced
  - Color tone shift due to geography and weather
  - To reduce channel cross-talk the chroma phase is alternating



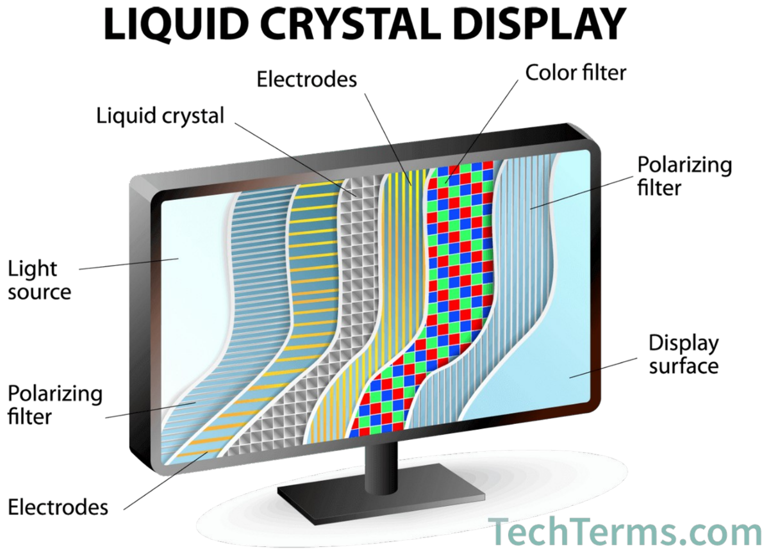


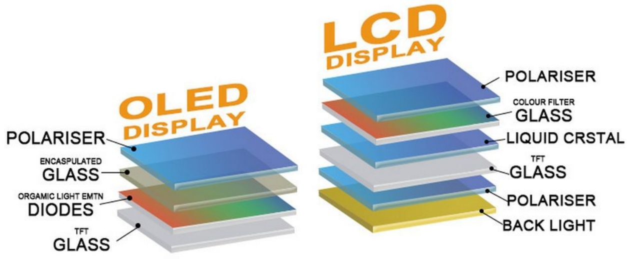
Digital video

- Storing on digital devices
- Direct manipulation (de-noising, cutting, etc.)
- Inclusion in multimedia applications
- Direct access to different parts of videos
- Copying does not degrade quality
- Easier decoding, better noise tolerance

Flat panel displays

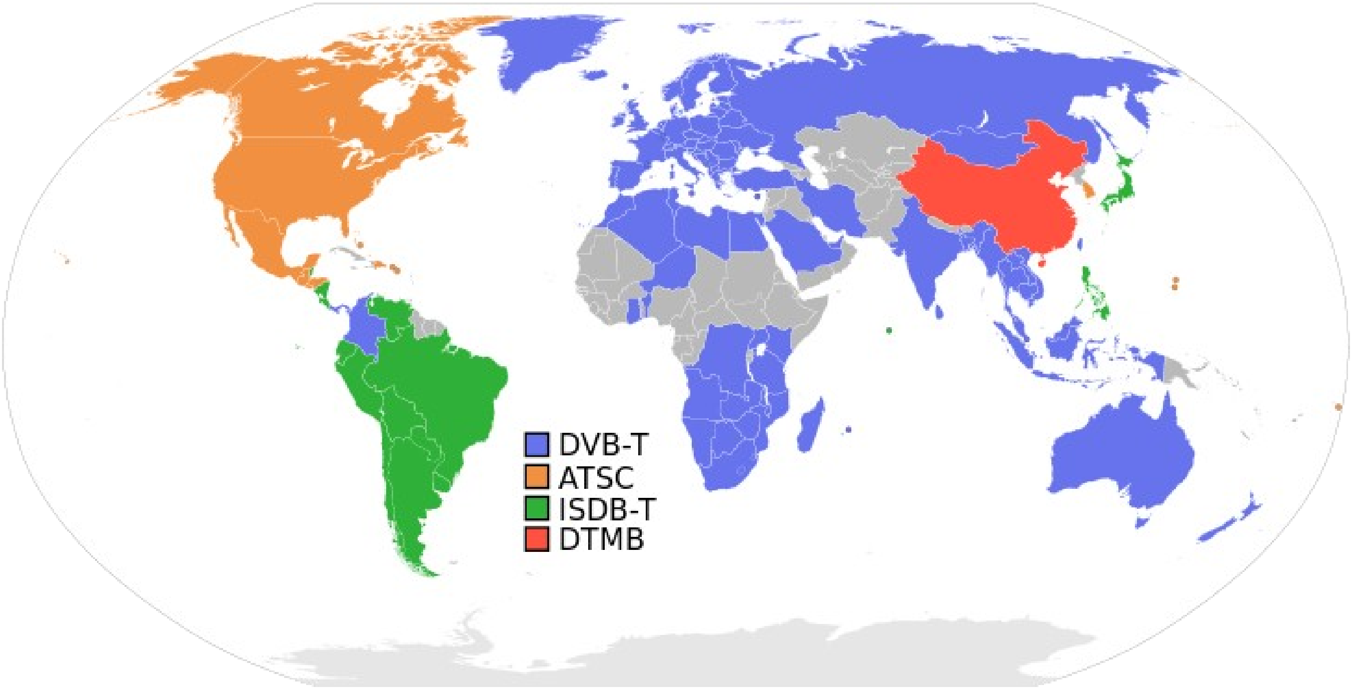
- Liquid crystal (LCD)
  - Fluorescent backlight
- Light-emitting diode (LED)
  - LED backlights
  - Still LCD
- Organic LED (OLED)
  - OLEDs for individual pixels
- *(Plasma)*



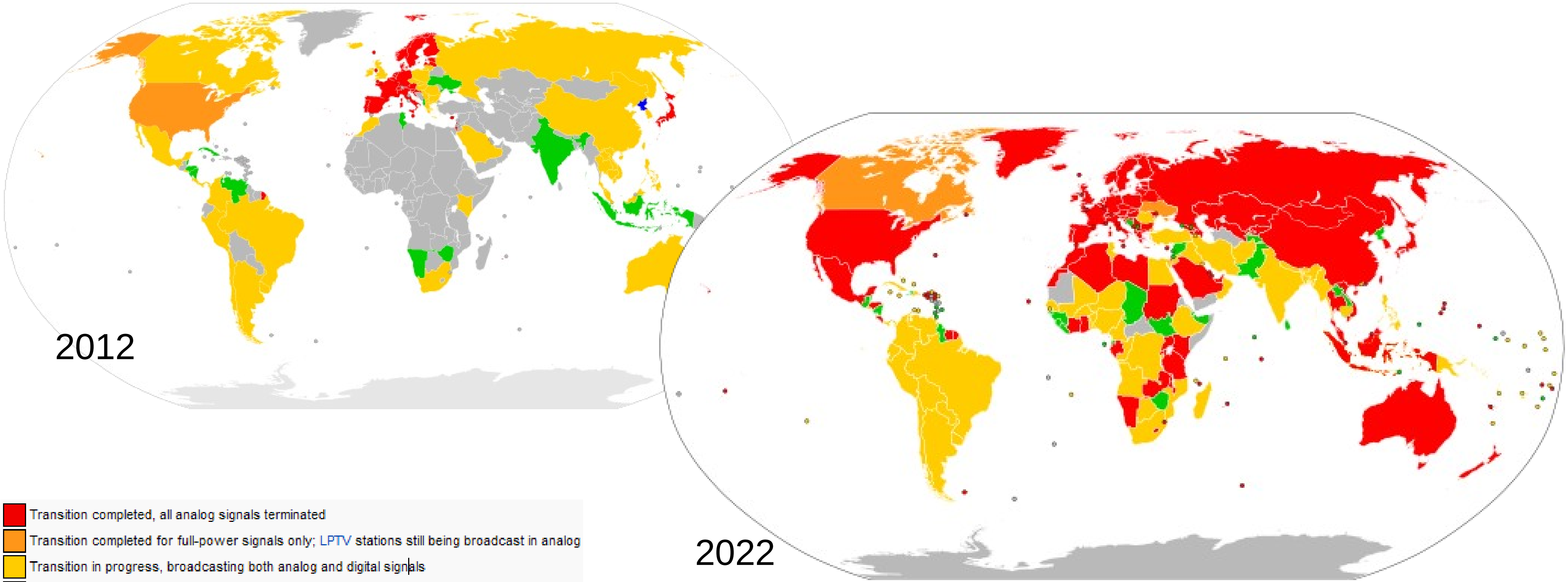


Digital terrestrial television (DTT)

Standards: DVB-T, ATSC, ISDB-T, DTMB



Transition to digital television



2012

2022

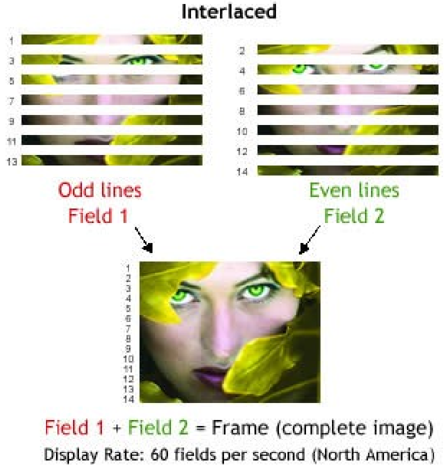
- Transition completed, all analog signals terminated
- Transition completed for full-power signals only; LPTV stations still being broadcast in analog
- Transition in progress, broadcasting both analog and digital signals
- Transition not yet started, broadcasting analog signals only
- Does not intend to transition, broadcasting analog signals only
- No information available

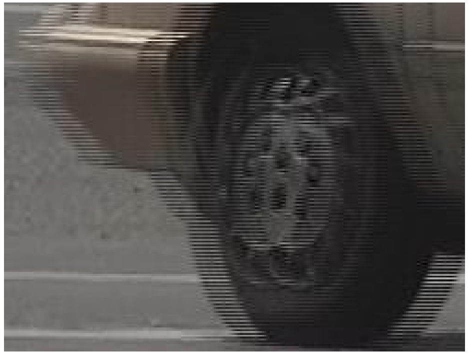
HDTV

- High resolution digital television
- Increase width of viewing angle
- First generation Sony (1970) - analog
- Standard for digital television
  - DVB, ATSC
  - Codec MPEG-2 for video compression
  - Resolution up to 1920×1080 (progressive)
  - Enables progressive and interleaved encoding (progressive default)
  - Aspect ration 16:9 (anamorphic)

Encoding rows

- Interlaced
  - Split image into two - odd and even lines
  - Reduce flickering on analog displays
  - Less space
  - Quick changes cause »combing« effect
- Progressive
  - Store each image separately
  - More space





Interlaced video example


(a)


(b)

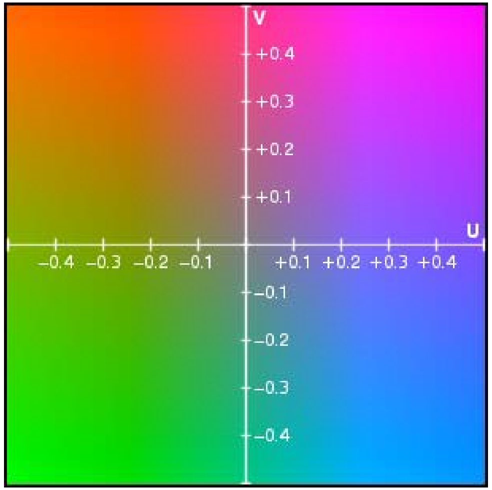

(c)


(d)

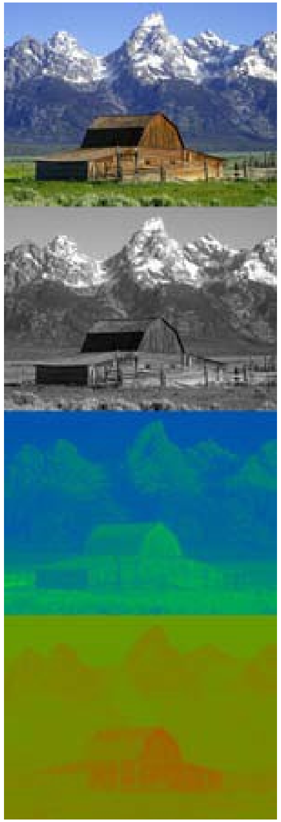
(a) Image from video, (b) field 1, (c) field 2, (d) difference between 1 and 2

Color coding

- De-correlated luminosity and color
- YUV, YIQ, YCrCb
  - Y is illumination
  - UV/IQ/CrCb are chroma components
- Conversion from RGB to YUV :
  - Y=0.229R+0.587G+0.114B
  - U=0.492(B-Y)
  - V=0.877(R-Y)



UV plane Y=0.5



Color sub-sampling

- Humans are more sensitive to changes in illumination than in color
- Color can be sub-sampled - reduce size
- How many chroma values are actually retained
  - J: horizontal sampling frequency (region width, e.g. 4)
  - a: number of chroma samples (Cr, Cb) in the first line of J pixels
  - b: number of additional chroma samples in the second line of J pixels