Computer Graphics:
13-Vision,Light and Displays

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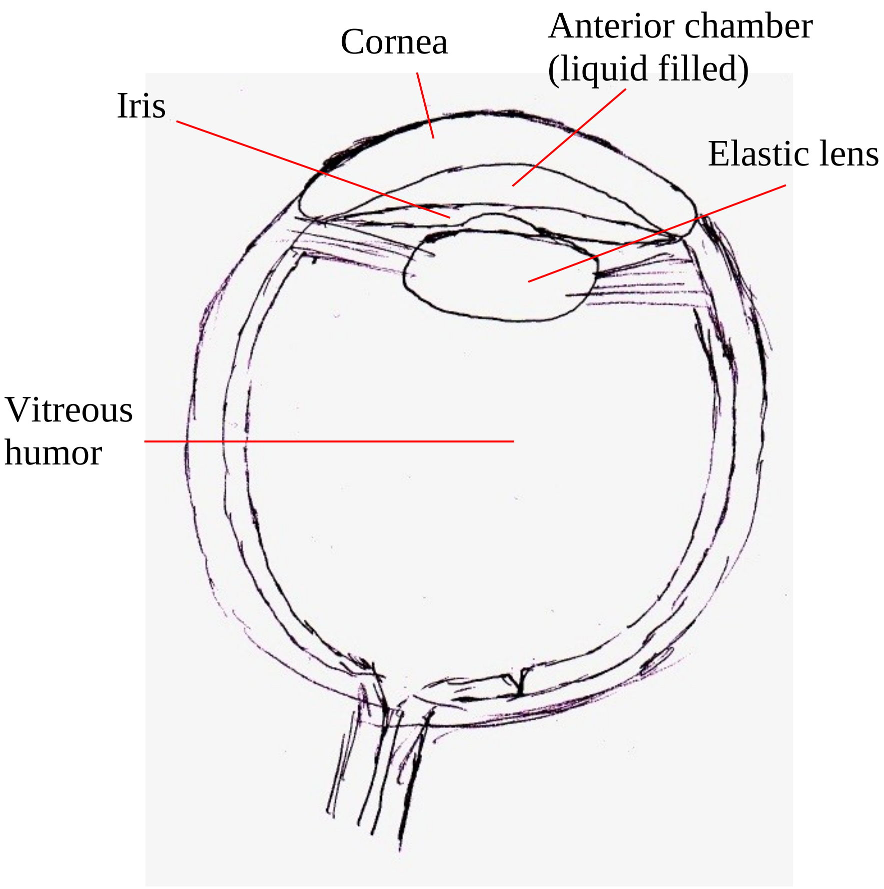
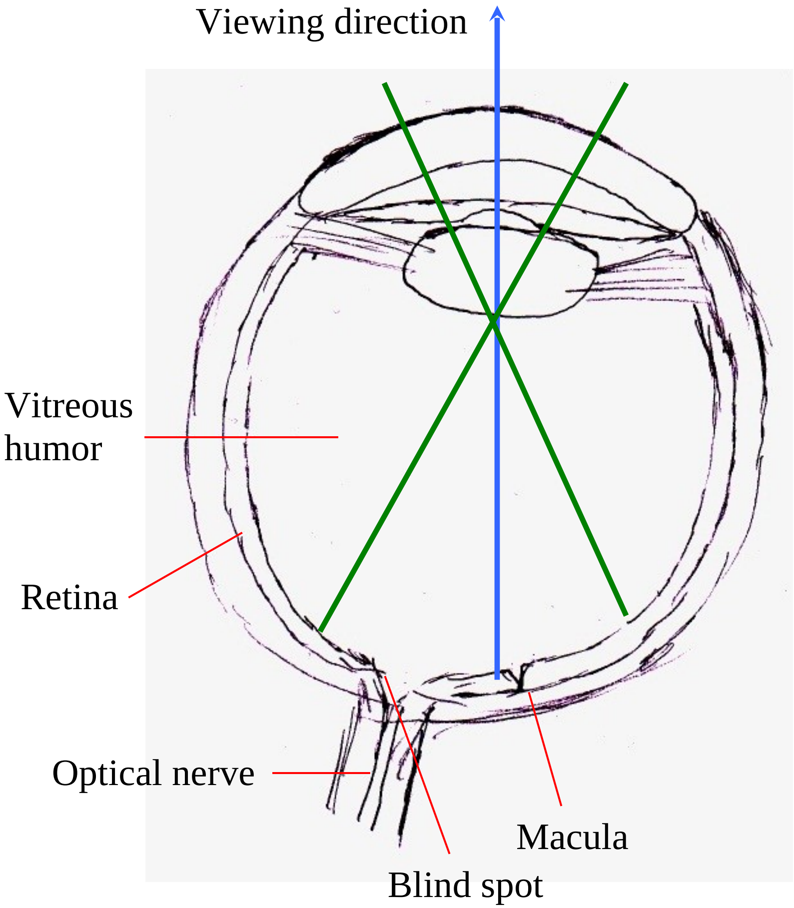
The human eye

- Evolution perfected our visual system
- It works like a pinhole camera
- Image reversed on retina
- The iris regulates light
- The cornea and the elastic lens focus light for the retina
- Light travels through the eye, which is filled with a jelly-like liquid called *vitreous humor*.



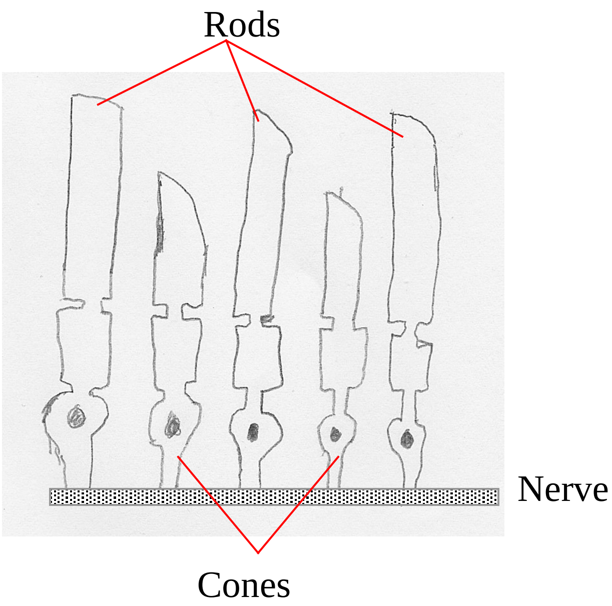
The human eye

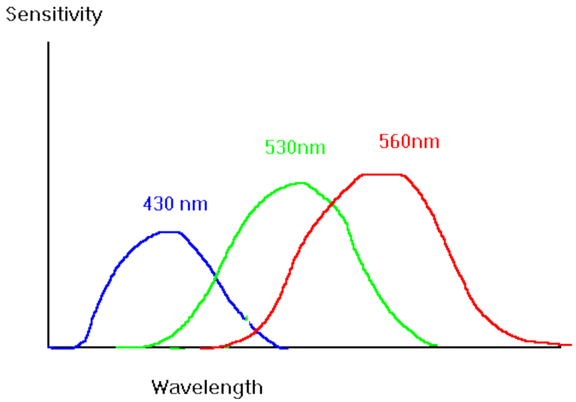
- At the back end of the eye, the photoreceptor parts are on the the retina
- In the retina, where the optical nerve is, there is a blind spot for vision
- Photoreceptors are spread on the retina, more densely around the macula, which is the point of maximum visual acuity.
- Eyes sample the environment continously



The human eye

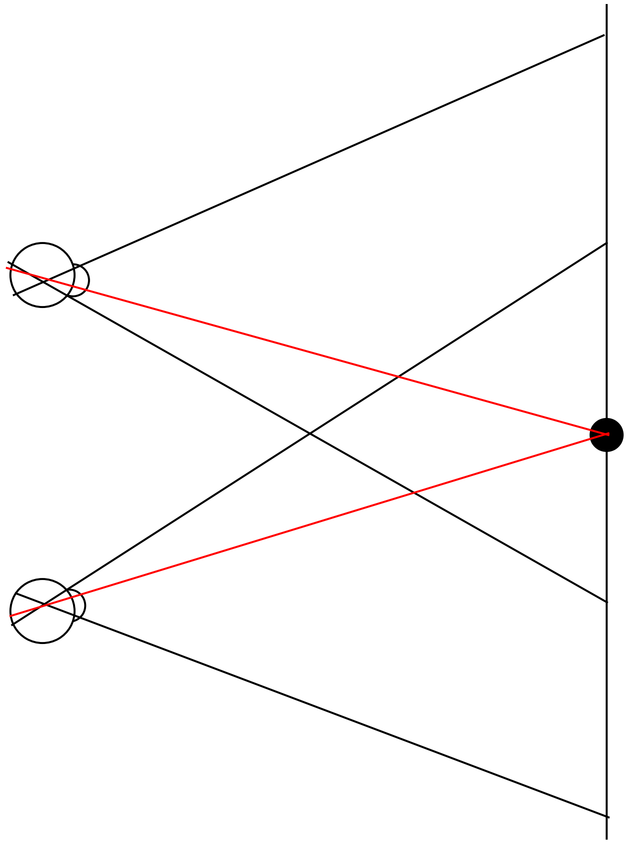
- At the back end of the eye, the retina has embedded photoreceptors
- The photoreceptors are of two types: *rods* and *cones*
- Rods are responsible for light intensity (500-550nm)
- Cones for colour, with three types of different wavelength sensitivity
- Cones are sensitive to different wavelengths but less sensitive than rods
- Vision works differently from day (cones) to night (rods)





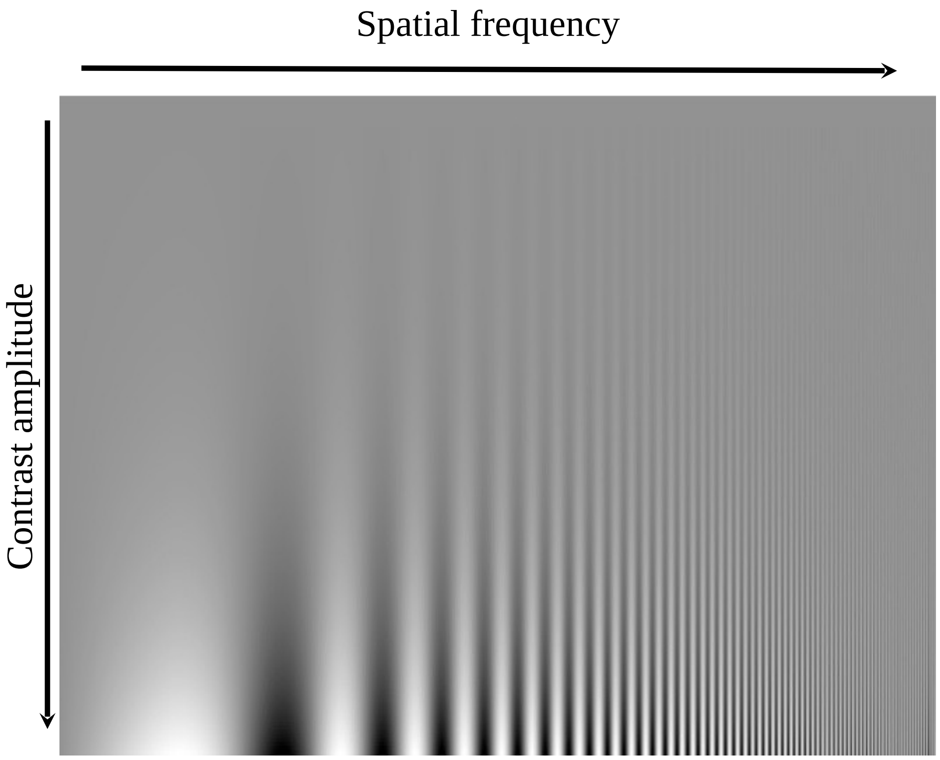
Stereoscopic vision

- The two eyes are slightly displaced (ca. 6 cm)
- This generates a difference in the view of the left and right eye
- This difference gets automatically processed by the brain to give us the 3D distance feeling
- This very process is used for stereoscopic displays to give a 3D picture



Luminance perception

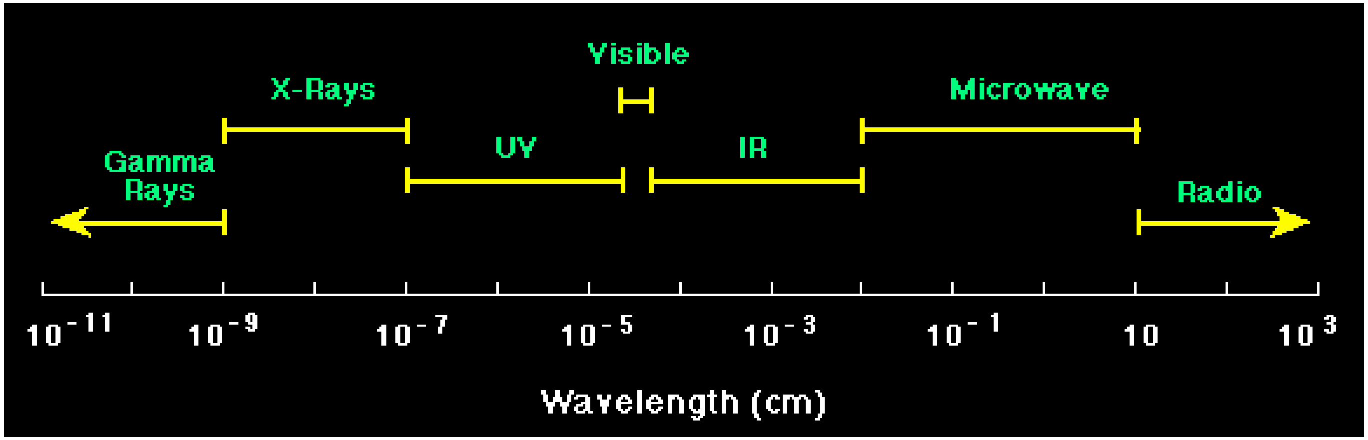
- When humans view an environment, the iris opens or closes so as to allow optimal luminance and contrast vision
- Luminance (= intensity) is perceived in a logarithmic way
- This is why we perceive a greater jump in intensity when we exchange a 50 Watts bulb with a 100 Watts bulb,
  - less so when we exchange a a 100 Watts bulb with a 150 watts bulb
- In humans at the age of 20, contrast maximizes at a frequency of 2 cycles/degree
- Look at picture to confirm this

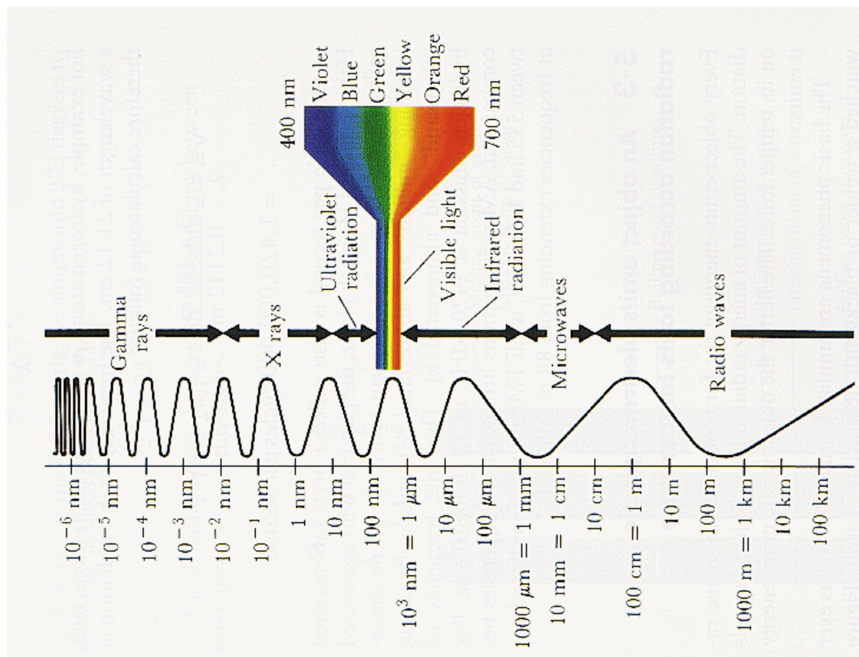


Flickering

- Our visual system gets fooled to see continuous movement if we display at least 24 frames per second
- When displays refresh is below 60 Hz then the visual system sees flickering on the display
- The perception of flickering is higher when contrast is higher
- This flickering can also be seen at higher display rates when objects move on the screen

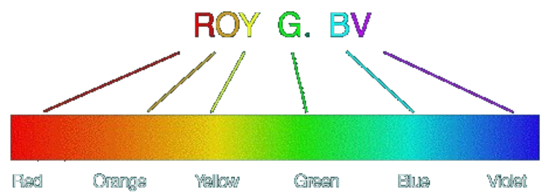
Electromagnetic waves





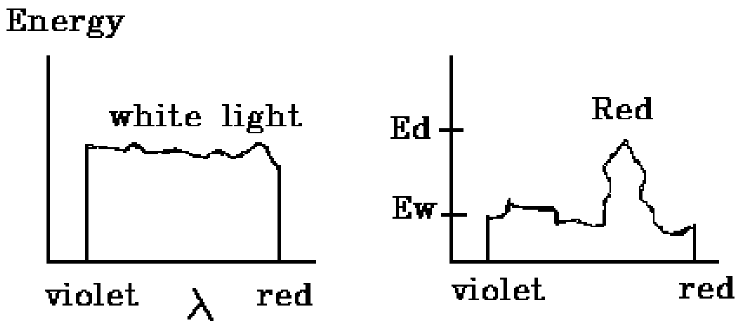
Light and colour

- White light sources emit all freq. over visible light spectrum
- Visible light is in the frequency range between 400 and 700 nm



- Light hits surfaces, which absorbe some colours and reflect others.
- Reflected colours give us the perception of color
- Dominant wavelength is called color or hue of surface

- Eyes respond to two more quantities:
  - Brightness: prop. to intensity (=energy)
  - Saturation: how „pure“ color is, i.e. how much other frequencies are present in spectrum
- Brightness= area below curve
- Purity=E_d-E_w



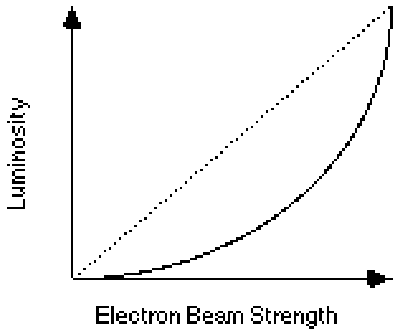
Achromatic Light

- Only attribute: quantity of light.
  Physically
  - Intensity
  - Luminance

  Perceptually
  - Brightness
- Represented through scalar in [0,1]
  (0=black, 1=white)

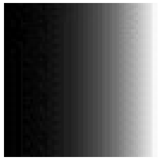
Gamma correction

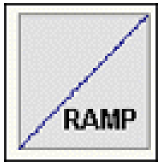
- Light intensity is not linear
- Test for example 3 light bulbs at 50, 100 and 150W
  - Perceived distance between 50 and 100 bigger
- The eye is sensitive to ratio intensity levels, less so to absolute intensities.
  - Thus, we percieve the 50/100 ratio differently from 100/150 (to achieve the same visual effect, we‘d have to have a 200 W bulb)
- To correct the linearity of displays, this perceptual behaviour has to be compensated for
- Multiply by a function which makes the display perceptually linear



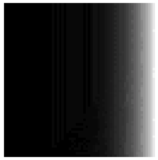
Monitor intensity response

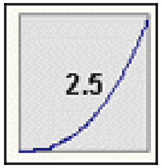
Monitor input





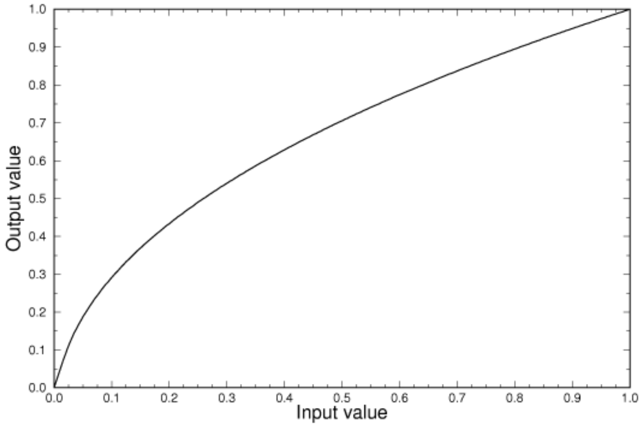
Monitor output



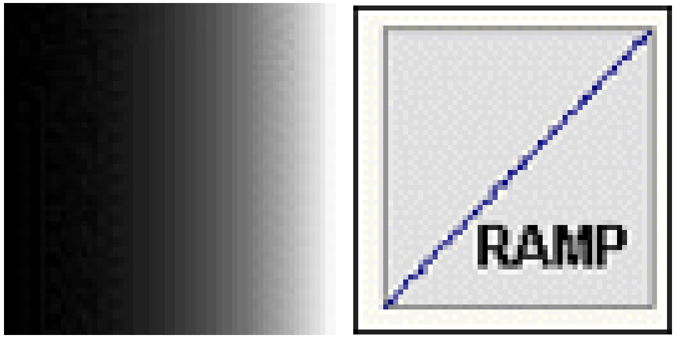


Gamma correction

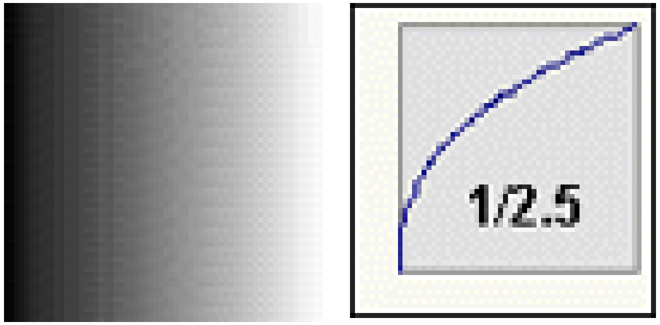
- Gamma correction uses a function so that intensity values are spaced as log
- How do I space the intensities?
  - The rule of thumb is multiplying by a function compensating the device weaknesses
  - Resulting luminosity: $L' = L^{1/2.5}$ (for monitors)



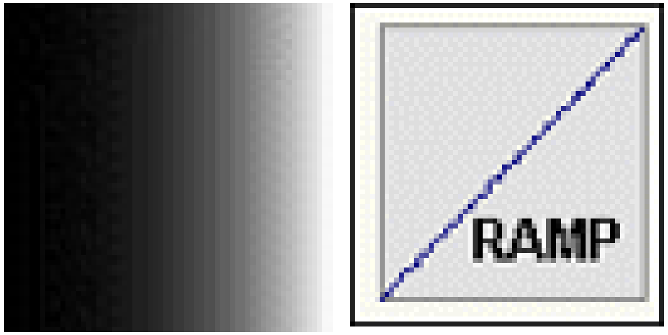
Typical gamma correction function



Monitor input



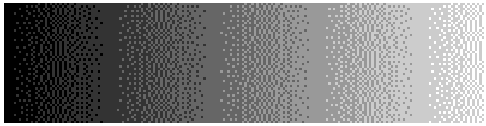
Gamma corr. input



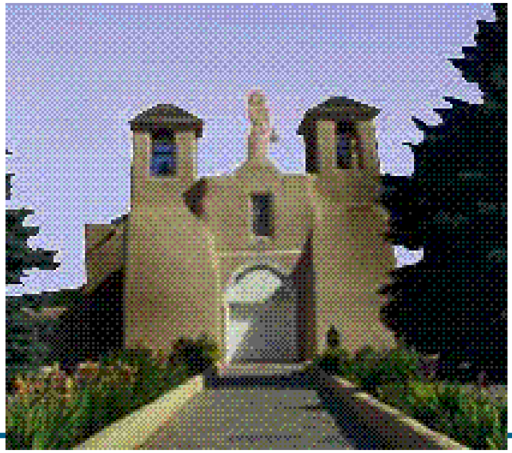
Gamma corr. output

Dithering

- Some devices, such as printers, are not able to print greyscales
- By definition, dithering is the process of simulating more colors when fewe colors are available
- Example grayscale with a b/w device:

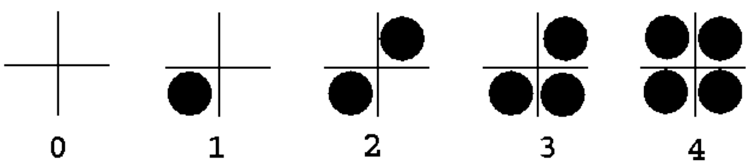


- Example full color with only 256 colors available

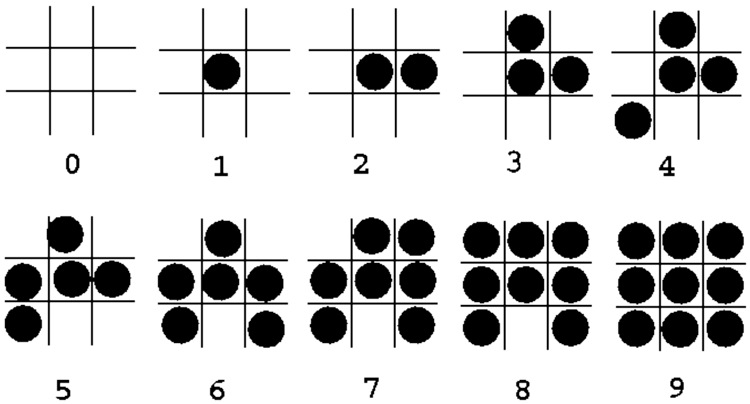


Halftoning

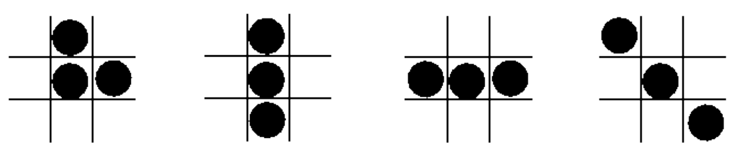
- When the device is only b&w, often clusters of dots are used to do the dithering (halftoning)
- 2x2 grid simulating 5 intensities



- 3x3 grid simulating 10 intensities

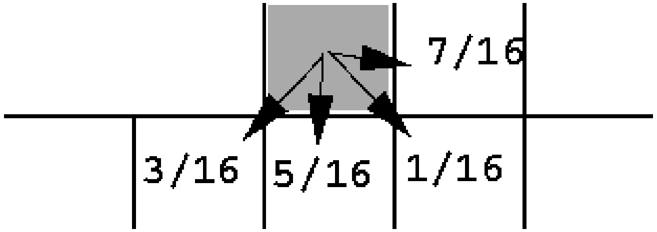


- Careful! Avoid patterns!



Error diffusion

- Often it is convenient to distribute (diffuse) the error made by one pixel color approximation to the pixel neighbours
- Usually error is diffused to pixels right and below current pixel



- Mathematically, error diffusion adds to the pixel values around the difference from the real intensity to the plotted one multiplied by some factors a,b,c,d such that their sum is 1
- [a,b,c,d]=[7/16,3/16,5/16/1/16]
- Resulting code chunk would look like follows

```
M[i][j+1]   += a*err;
M[i+1][j-1] += b*err;
M[i+1][j]   += c*err;
M[i+1][j+1] += d*err;
```

- Most known: Floyd-Steinberg
  a=c=3/8, b=0, c=1/4

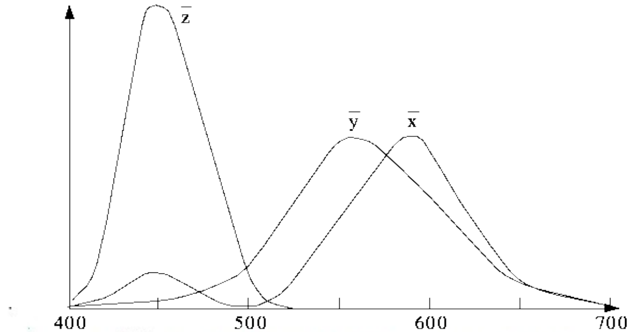
Example: Floyd and Steinberg

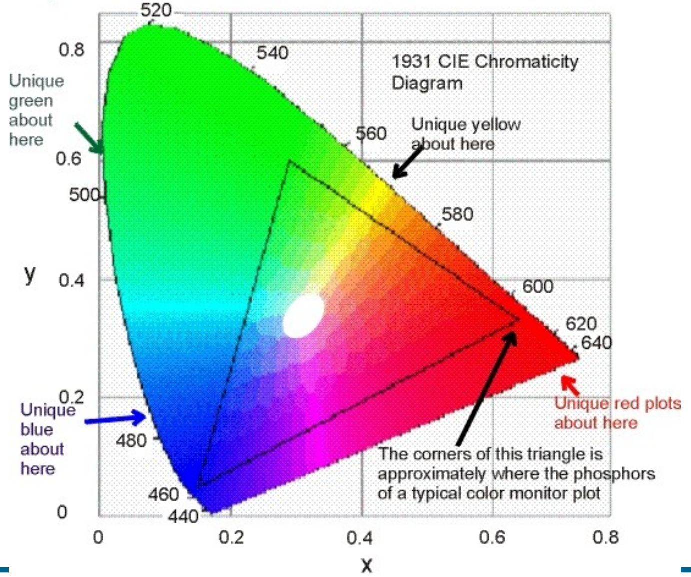
Coloured light

- Lights can be added to form new colors.
- Sources ST by adding them one obtains white are called complementary
  - Red-cyan, green-magenta, blue-yellow
- Usually 3 basic colours are taken to form range of colours (colour gamut)
- No triplet of colours can generate all possible colours, but a good choice of them can reproduce many

CIE chromaticity diagram

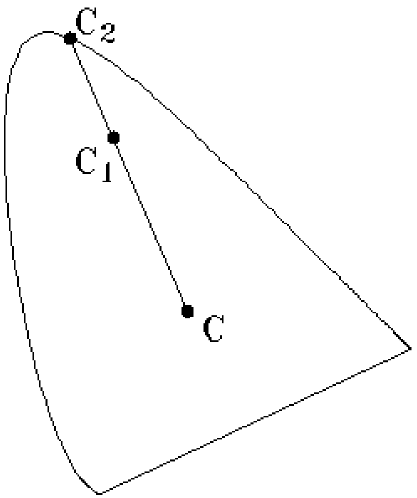
- CIE international standard (1931)
  - Allows all colors to be expressed as sum of 3 primary „colors“
  - Remember, no color triplet can express real colors, so CIE primary colors are virtual colors: A, B, C
  - All other colors are explressable through 3 components:
    x=A/(A+B+C)
    y=B/(A+B+C)
    z=C/(A+B+C)
  - Note that x+y+z=1
- CIE chromaticity diagram: plots X vs. Y for all visible colors

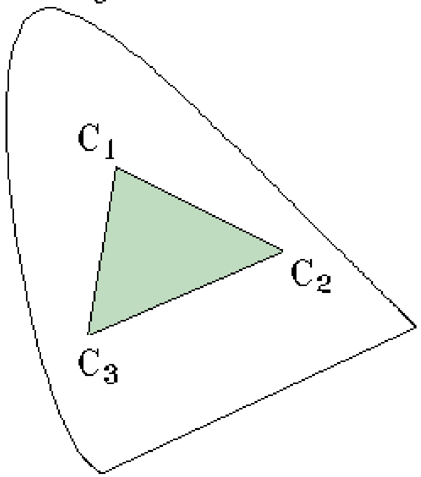




CIE chromaticity diagram

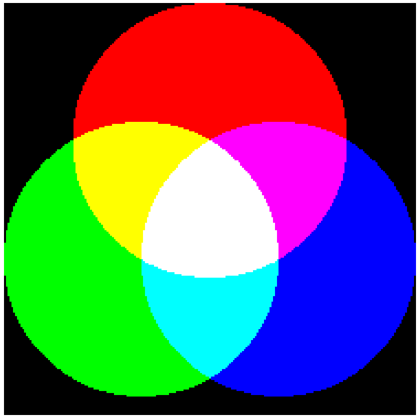
- Centre C represents white light
- For color C_1, Dominant wavelength is C_2,
- Purity is the lengths fraction $(C_1-C)/(C-C_2)$
- Gamut is colors between C_1 and C_2
- For three colors, gamut is triangle between them
- Note why 3 colors cannot genarate all colors

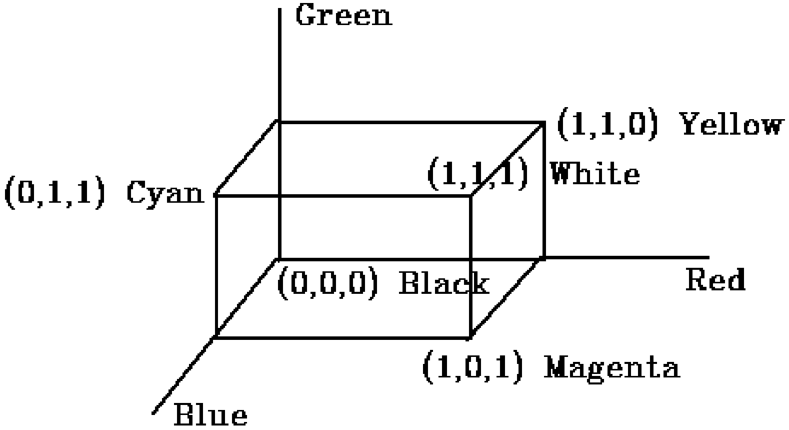




RGB color model

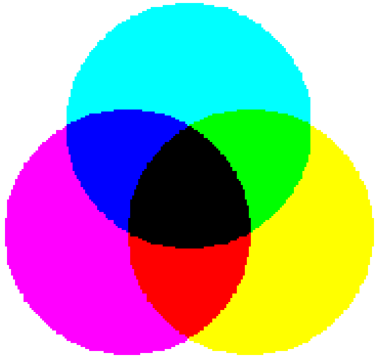
- Uses red-green-blue as base colors (wavelength is not specified)
- Used for additive colors (light emitting)
- Can be represented on unit cube
- RGB axes, colors are points in space
- Complementary colors are colors adding up to white (1,1,1)



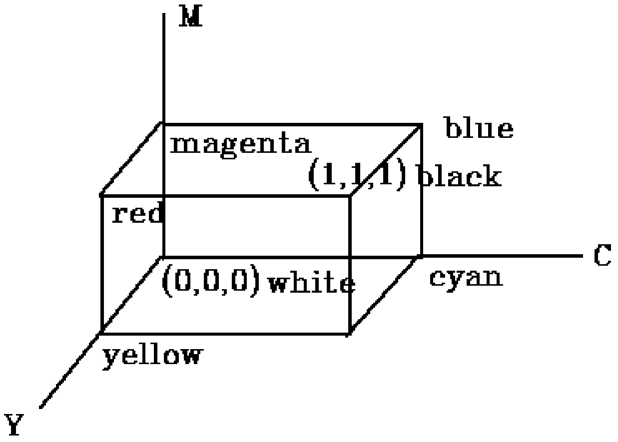


CMY color model

- Uses cyan-magenta-yellow as base colors
- Used for subtractive colors (light absorbing)
- Can be represented on unit cube, with CMY axes
- Note that subtractive implies that cyan=blue+green, thus cyan absorbs red light
- Complementary colors are colors adding up to white (1,1,1)



- So the conversion formulas between RGB and CMY are
  C = 1 - R
  M = 1 - G
  Y = 1 - B

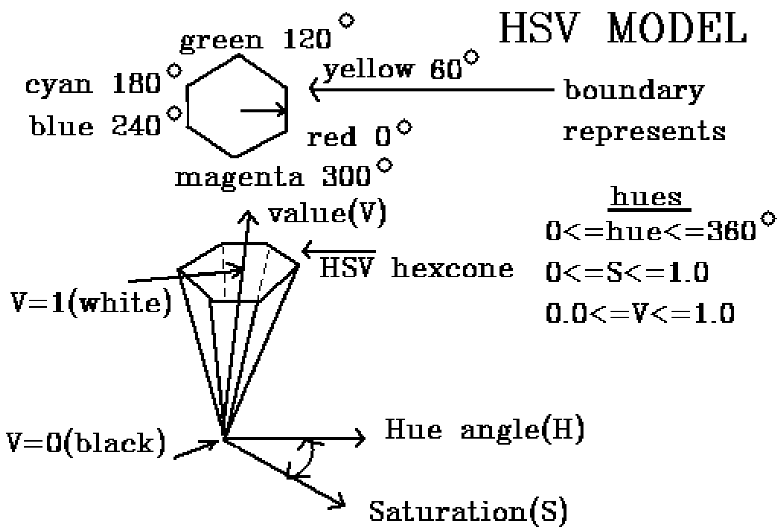


CMYK color model

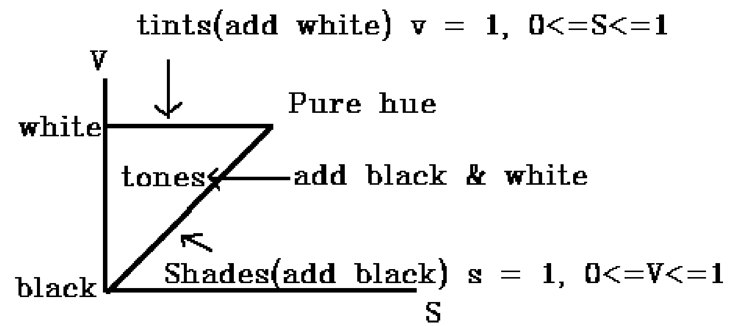
- Sometimes, in printers pure black (K) is added to the basic CMY since C+M+Y is never pure black with real colours (this explains 4 colour cartridges)
- Here, K=Min(C,M,Y)
- And consequently
  C=C-K
  M=M-K
  Y=Y-K

HSV color model

- More intuitive than RGB to use
- Colors are represented on a hexagonal cone



- Centre of top hexagon white
- Why is this more intuitive?
- Because artists work like that, by adding black to add shades or white to add tints
- A section of the cone does exactly this
- Humans distunguish: 128 hues, 130 tints (saturation), and 16-23 shades: =ca 380000 colors

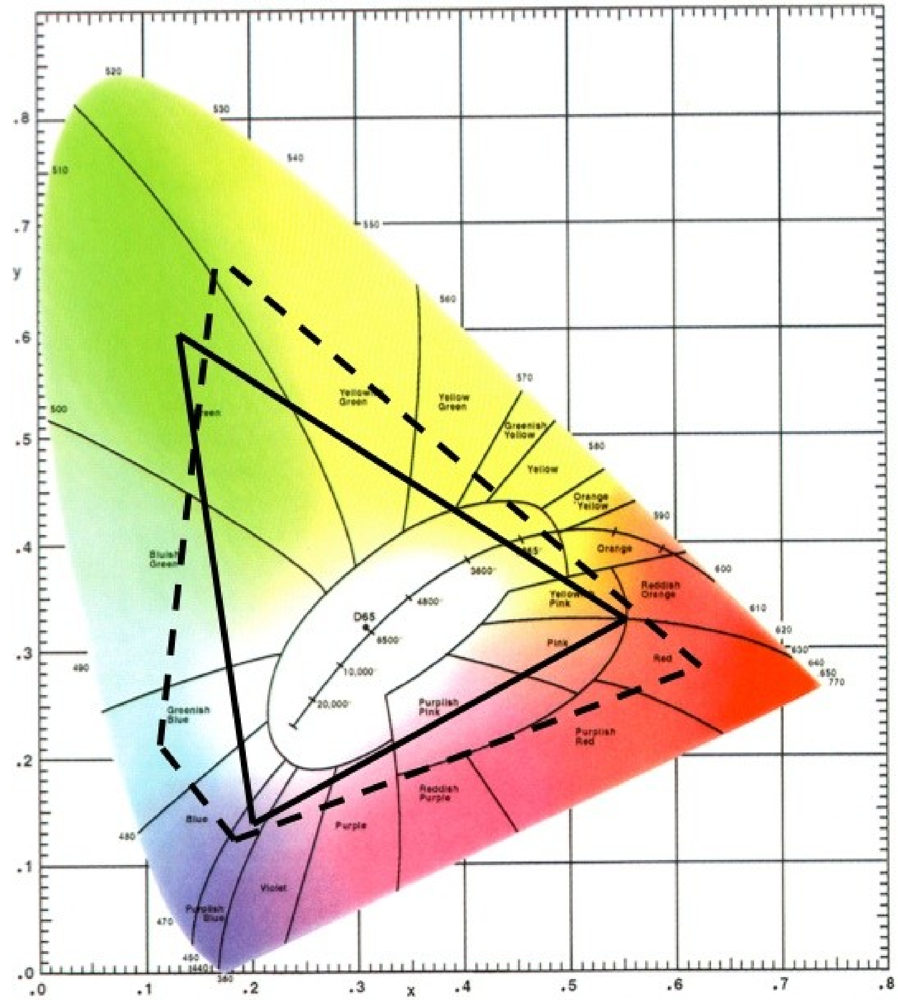


Calibration

- Modern display hardware allow to set the parameters so as to calibrate displays
- This is done either at the monitor level, or on the graphics card
- Sometimes additional measuring devices are used, such as Pantone's Spyder2Pro
- This is very important for arts and the printing industry, where colour requirements are very important
- For prints, the characteristics of the printer have also to be calibrated
- Ever seen this type of tests by camera/printer tests?

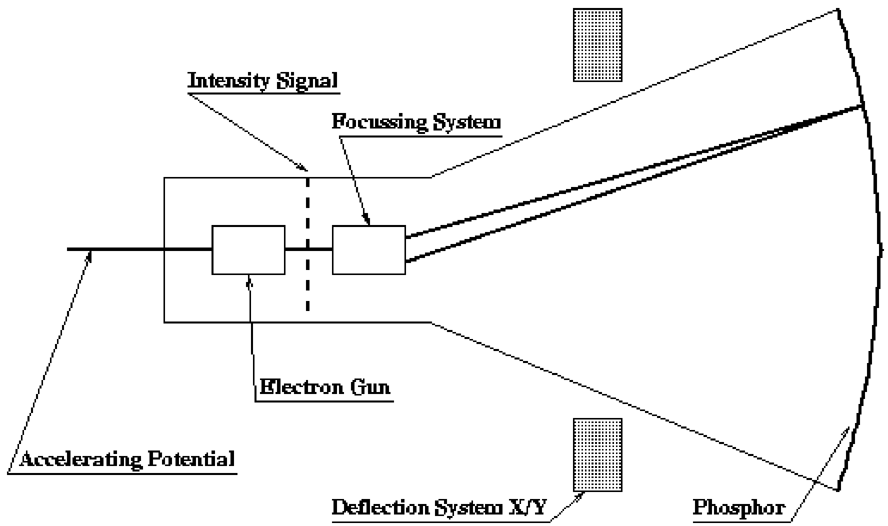
Displays

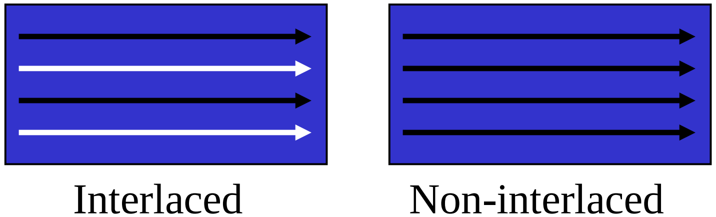
- Most important characteristics of a display device:
  - Resolution (number of pixels in both direction)
  - Aspect ratio
  - Contrast of the display
  - View angle sensitivity
  - Refresh rate (at least 60Hz)
  - Coverage of the colour gamut spectrum and tonal resolution
    - Note that adding basic colours to a printer enlarges the gamut of the device
    - This is however not practiced in monitors/projectors

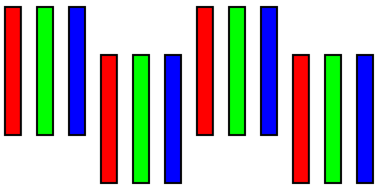


CRTs

- Cathode Ray Tube devices stem from TV technology
- Idea is simple: an electron beam traces lines on the screen lighting dots
- The electron beam is emitted at back of device
- Then accelerated through mask
- Deflected at will, so as to trace pixels linewise
- The screen is coated with phosphors
- The screen is retraced many times per second, typically between 25fps and 100fps
- There are two ways for tracing the screen with the electron beam: interlaced or non interlaced

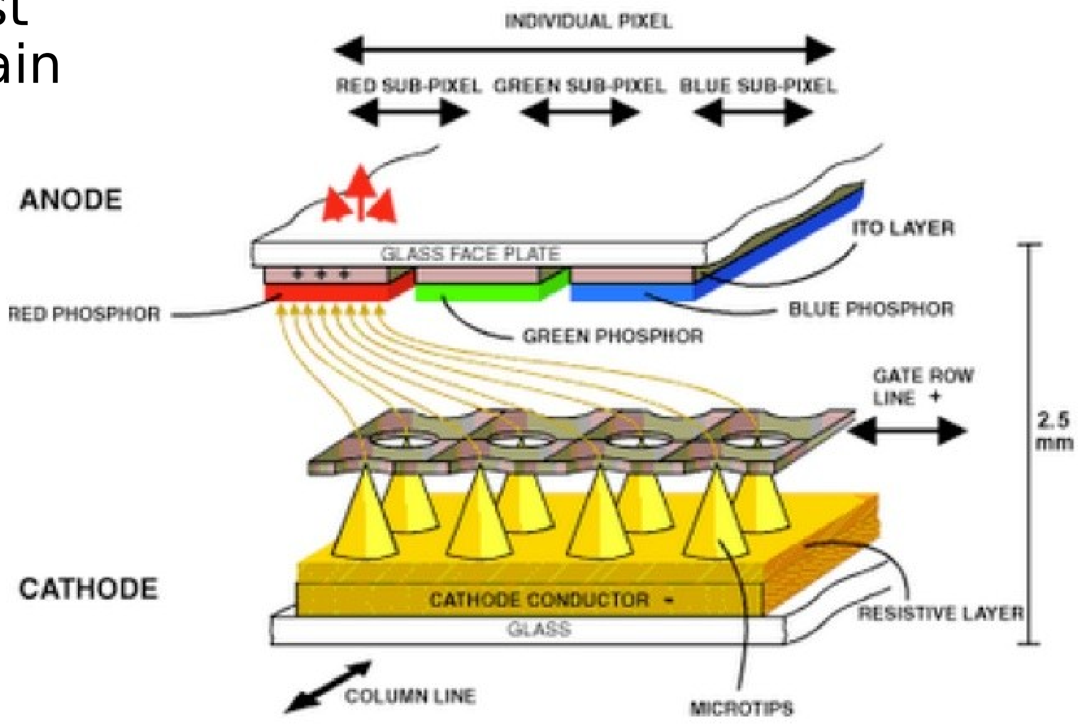






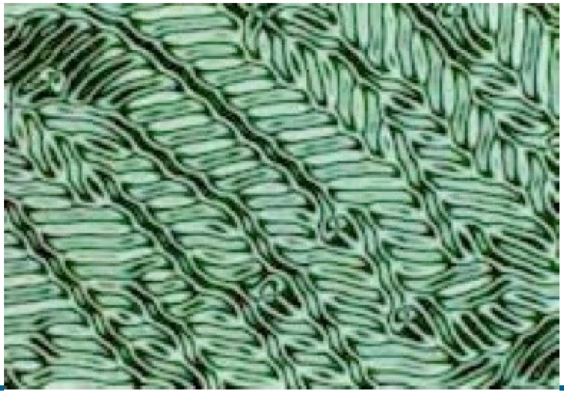
Field Emission Displays (FED)

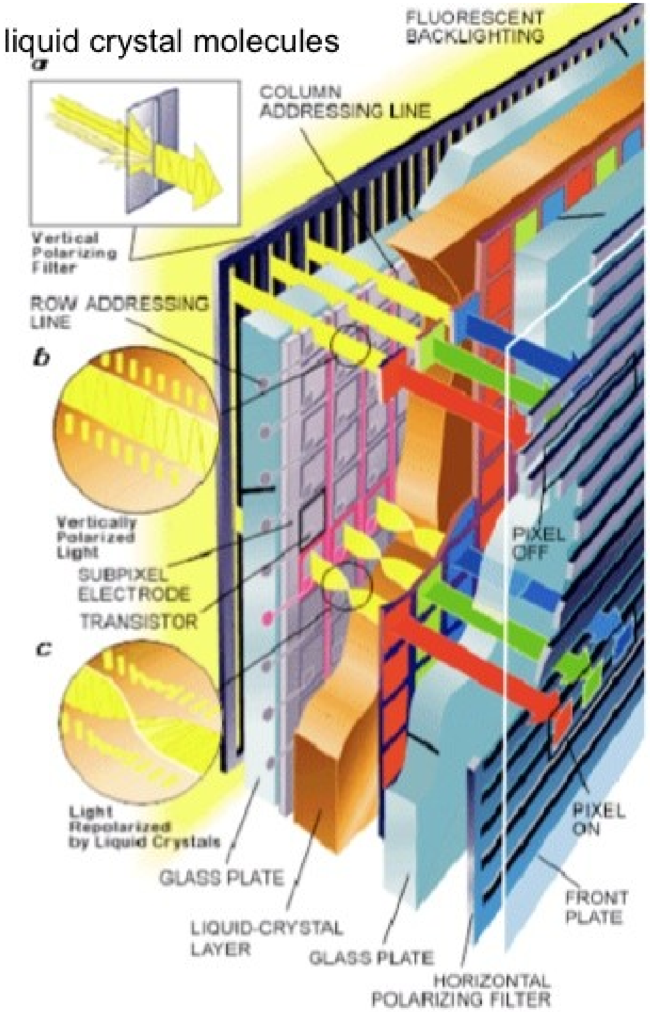
- Like CRTs, yet every pixel has its own cathode tube
- As fast and bright as CRTs
- Have higher contrast than CRTs, thus obtain better blacks
- Very expensive to produce



Lyquid Crystal Displays (LED)

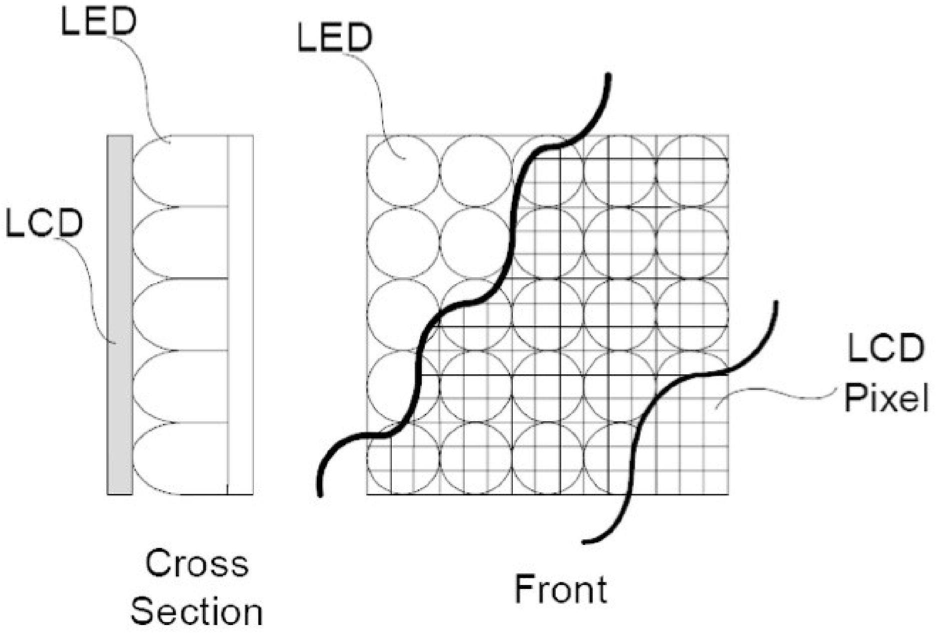
- Use current sensitive molecules
- The molecules are twisted, but when current is applied they untwist
- Transmit and polarize light, the more polarized the less intense
- Require backlight
- Colour is obtained through coloured lenses
- Pixel size <0.3 mm (0.1 per colour)
- Refresh





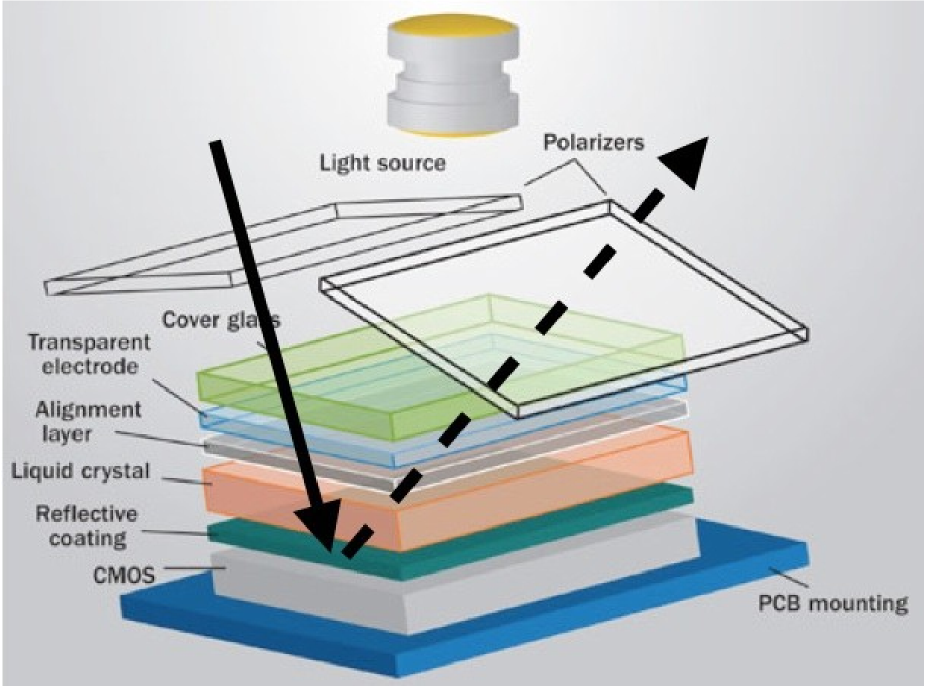
High Dynamic Range Displays (HDR)

- Instead of using at the back light, they use LED
- A low resolution image is rendered on the LEDs
- The high resolution image is rendered to the LCDs
- So two modulations are combined, obtaining a much higher resolution
- If both can display 8 bits, the combination can do 2^{16} colours



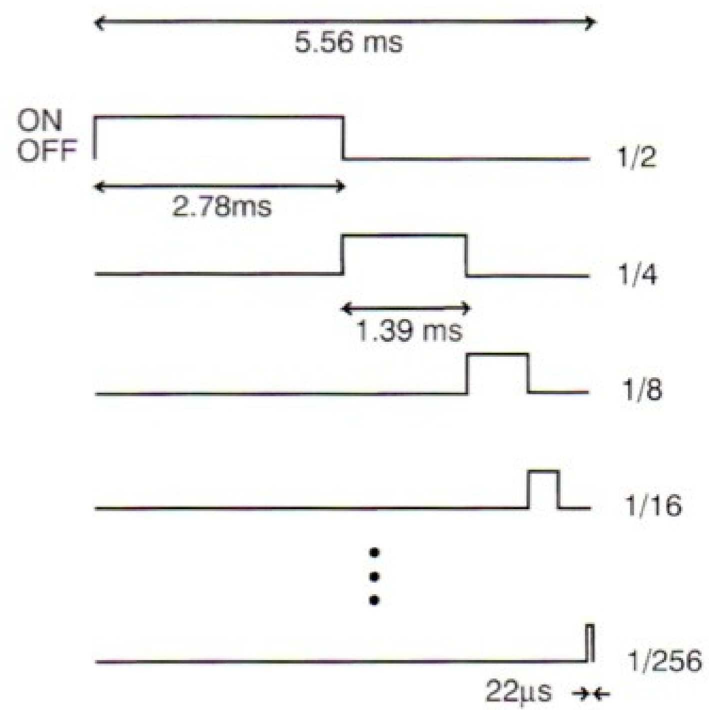
Liquid Crystals on Silicon (LCoS)

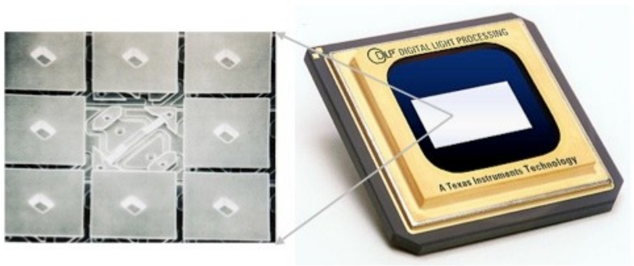
- As LCDs, they are based on polarizing light to obtain intensities and filters for color
- But LCoS are reflective, not transmissive
- The crystal material can be coated on a CMOS chip
- Thus it is way less expensive to produce, and can have a higher resolution
- Polarizers are located on the light path before and after the light is reflected
- Can be used for reflective displays, or on projectors (beamers)



Digital Micromirror Displays (DMD)

- Micromirrors which are mechanically switchable are used
- Can be done at a speed of 15μs
- Grayscales and Colour are done by modulating in time (Pulse Width Modulation) so that it is below the flicker perception of the visual system
- Can be single-chip (a colour wheel is used for achieving colour) or a three-chip system
- This is three time fa
- Used in projectors a projection flat panel
- Cheap and efficient





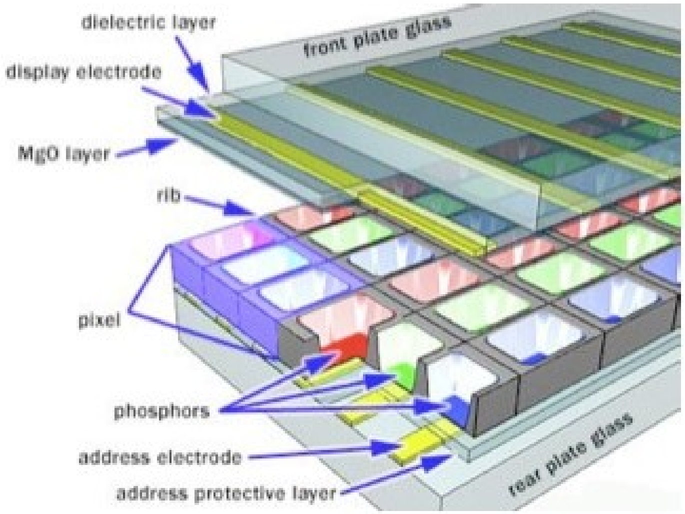
Gray scale coding example (70% luminance, 60Hz):

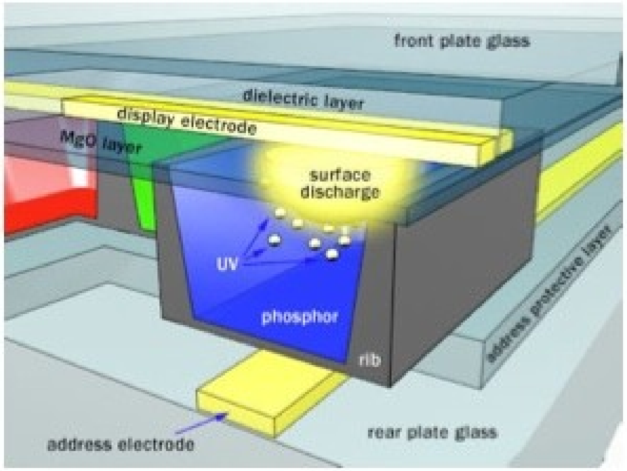
1/2,1/8,1/16,1/128,1/256

50%+12.5%+6.25%+0.78125% +0.390625%=69,921875%

Plasma Displays

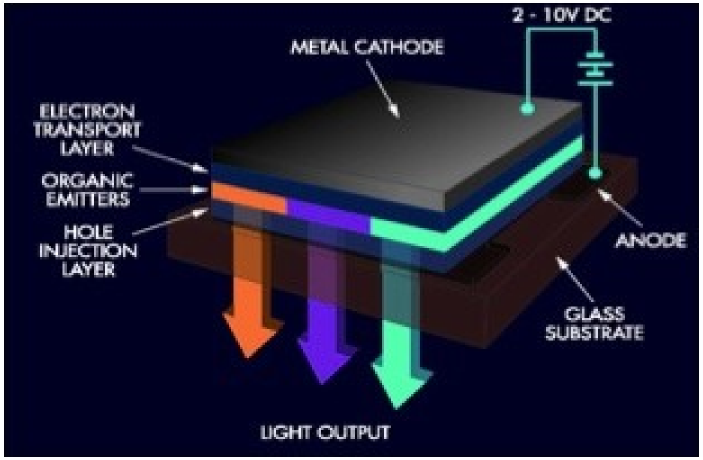
- For each colour cell, a fluorescent tube (neon or xenon)
- Stimulated by high voltage, just as neon lights
- Pixels minimum size 0.3 mm
- Good for large displays
- Very high refresh rate, because switching is very fast





Organic Light Emitting Displays (OLED)

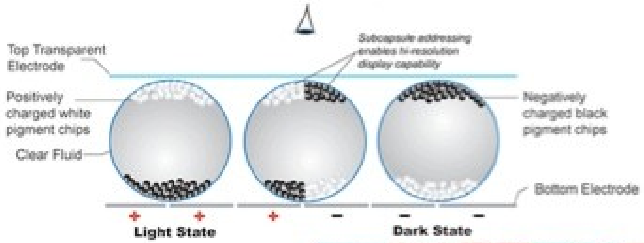
- Use organic film
- Emit light when under voltage
- Allow large displays and high resolution (300 dpi and more)
- The OLED can be printed through inkjet technology
- Can be phosphorescent (PHOLED), transparent (TOLED) AND flexible (FOLED)!
- Require low power
- Allow very thin layers
- Since no polarization is required, viewable at wider angle



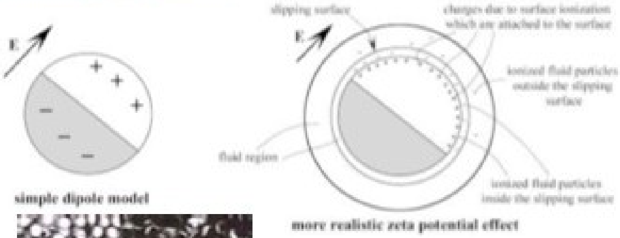
flexible polymer-based OLED

Electronic Paper

- + (black) and - (white) charged elements between two electrodes
- Elements can be rotated or moved
- Depending on polarization of electricity, black or white elements move or rotate to visible surface
- Bi-stable: no electricity is needed to keep state (only to change state)
- Active or passive matrix
- Very low power required (interesting for mobile devices)
- Might allow to build flexible displays (active / passive matrix must be flexible too)
- Grayscales: degree of rotation or ratio between black and white elements
- Color possible too
- Commercial devices currently 4 bit gray scales with >250 ms switching times



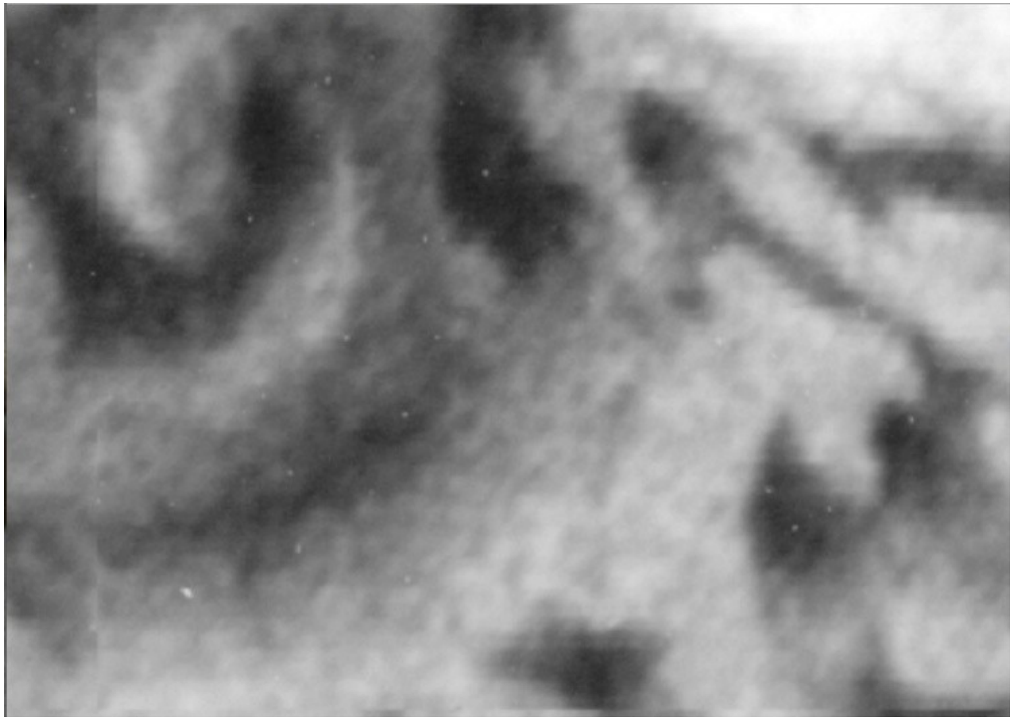
microscopic view of E-Ink



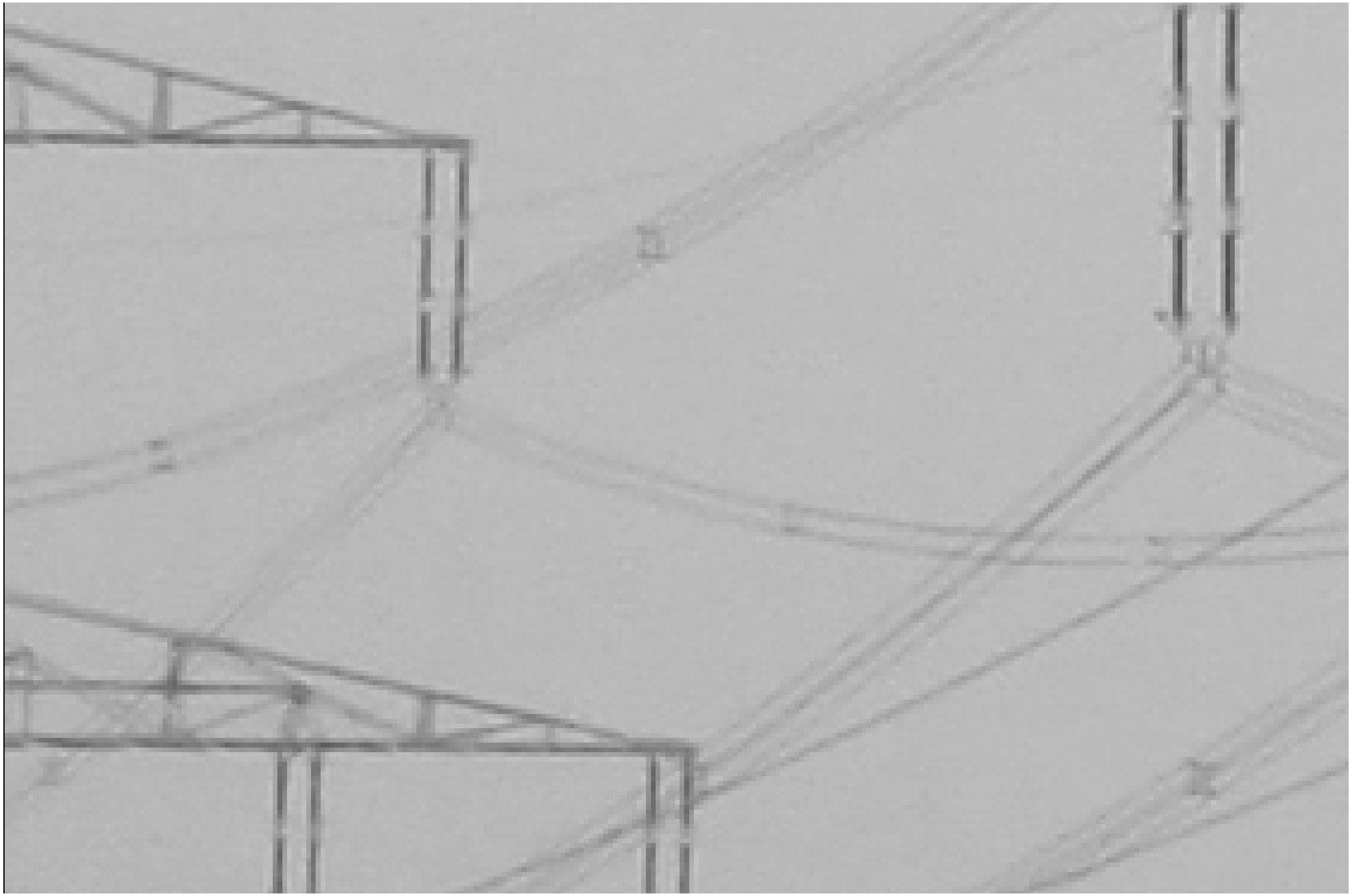
microscopic view of Electronic Paper

Analogue film

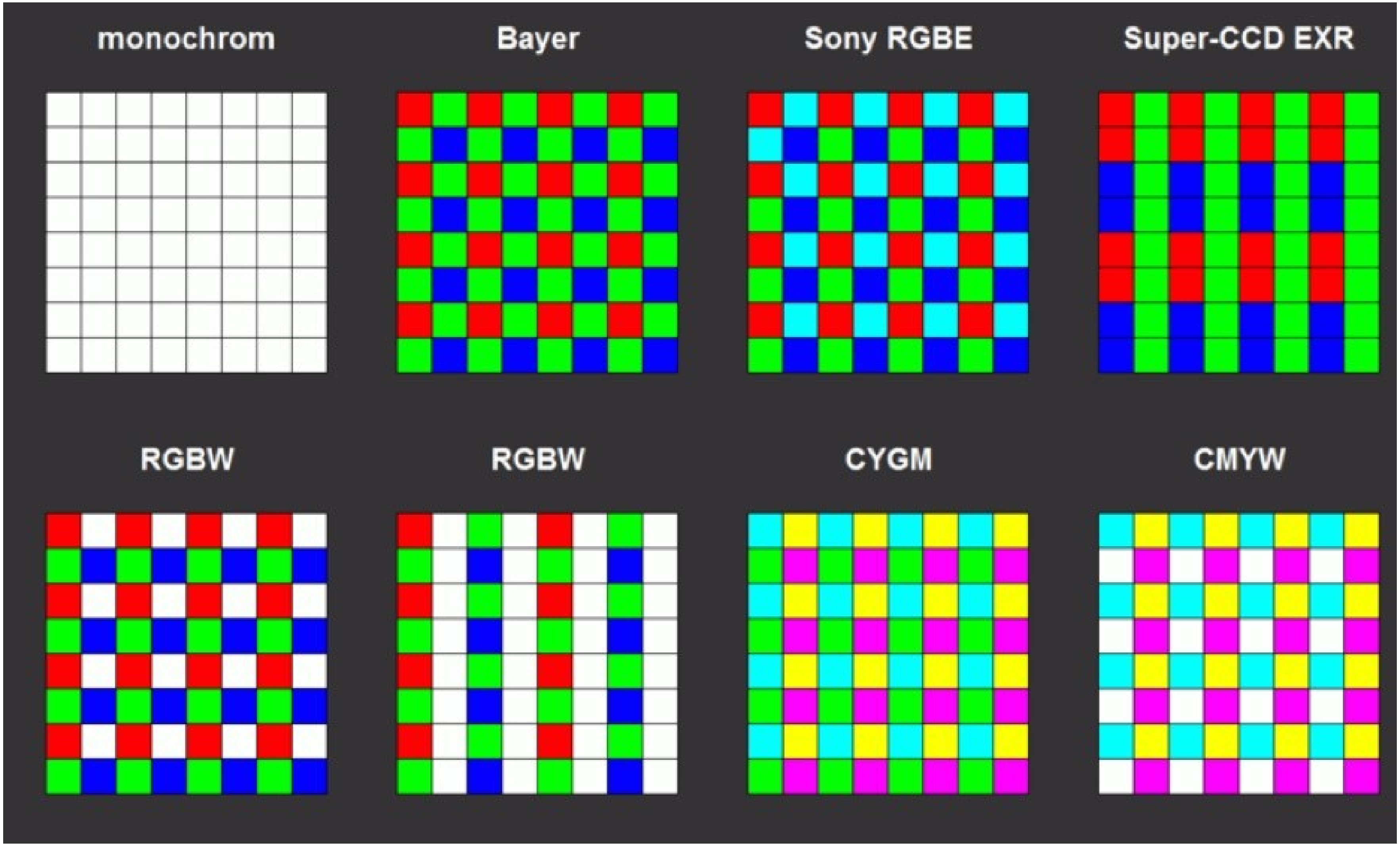
- Quality much superior than rasterized images
- Pigments dispose not on a grid
- Color on three overlapping transparent layers: each color continuous!



Analogue film

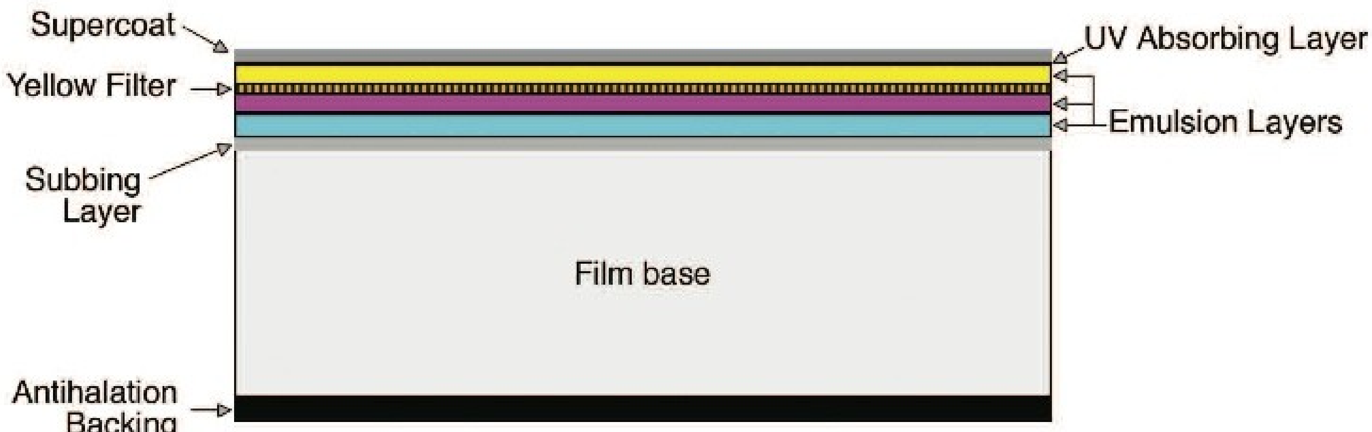


Digital sensors



Colour film

- Colour film is basically three superimposed transparent layers
- Each one of the layers is sensitive to a different basic colour
- Each layer behaves essentially like black-white film
- On top of the layer, an UV filter is present to prevent UV from penetrating the layers



Courtesy Kodak Imaging

End

+++ Ende - The end - Finis - Fin - Fine +++ Ende - The end - Finis - Fin - Fine +++