# Computer Graphics: 4-Vision,Light and Colour Spaces

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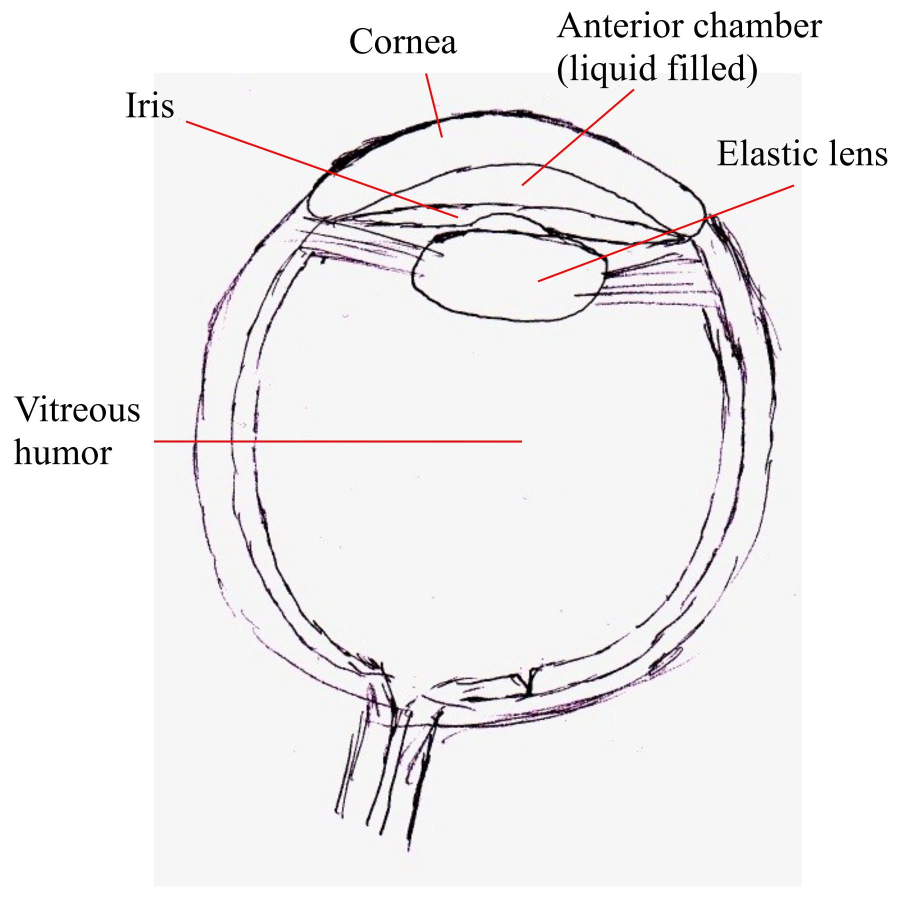
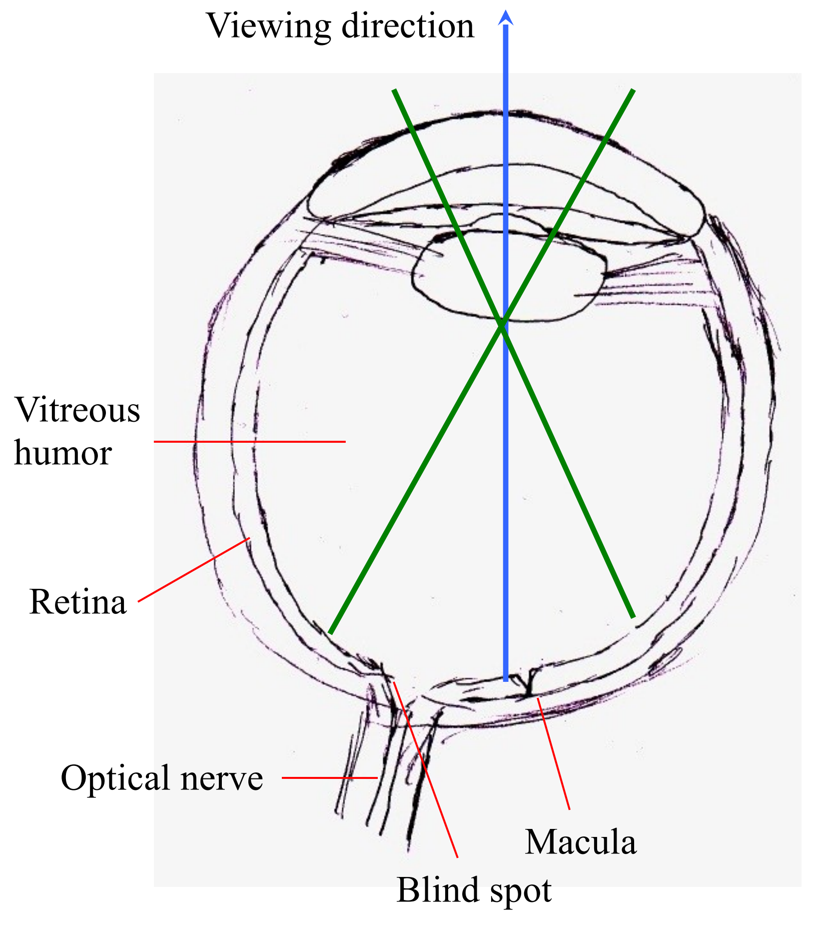
# The human eye

- 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*.



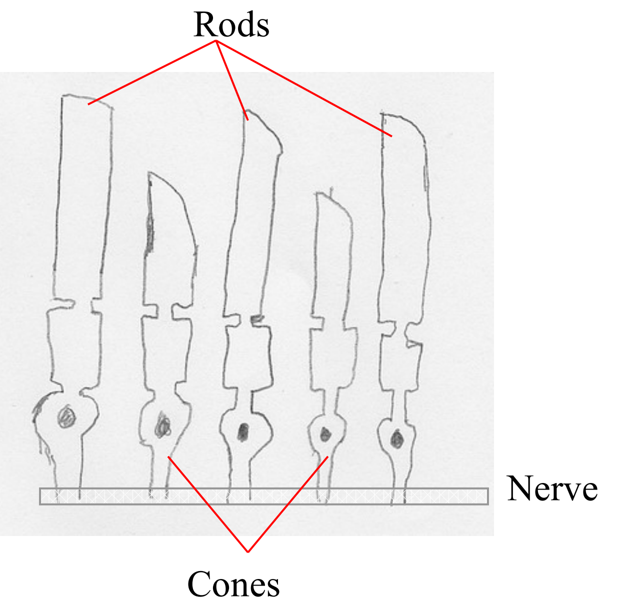
# The human eye

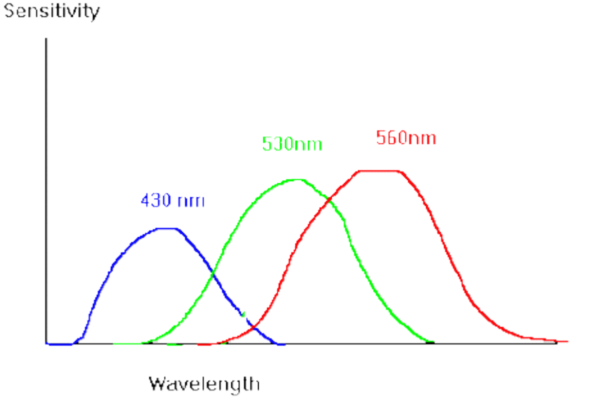
- At the back end of the eye, the photoreceptor parts are on the the retina
- In the retina, where the optical nerve is, there is a blind spot for vision
- Photoreceptors are spread on the retina, more densely around the  macula, which is the point of maximum visual acuity.
- Eyes sample the environment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



# The human eye

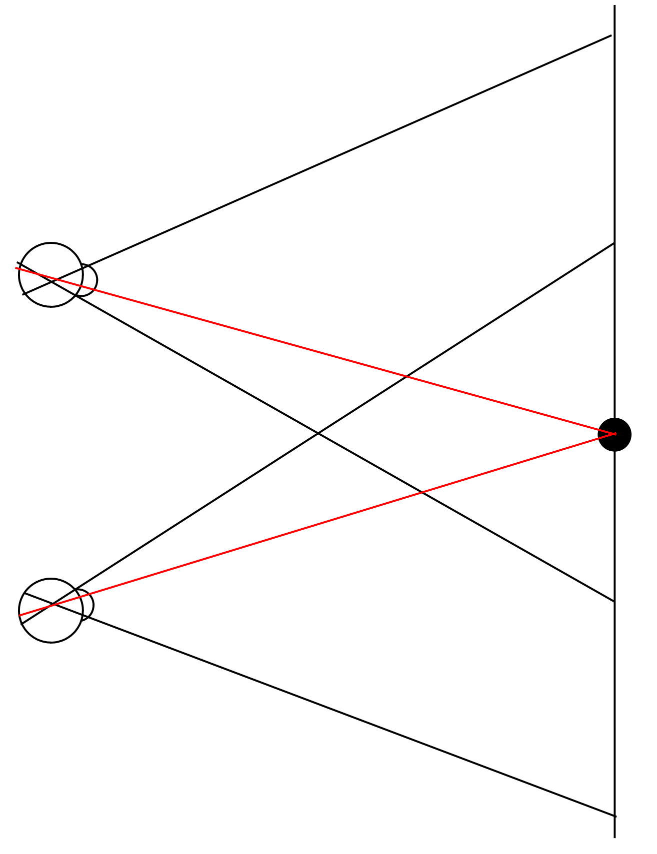
- At the back end of the eye, the retina has embedded photoreceptors
- The photoreceptors are of two types: *rods* and *cones*
- Rods are responsible for light intensity (500-550nm)
- Cones for colour, with three types of different wavelength sensitivity
- Cones are sensitive to different wavelengths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



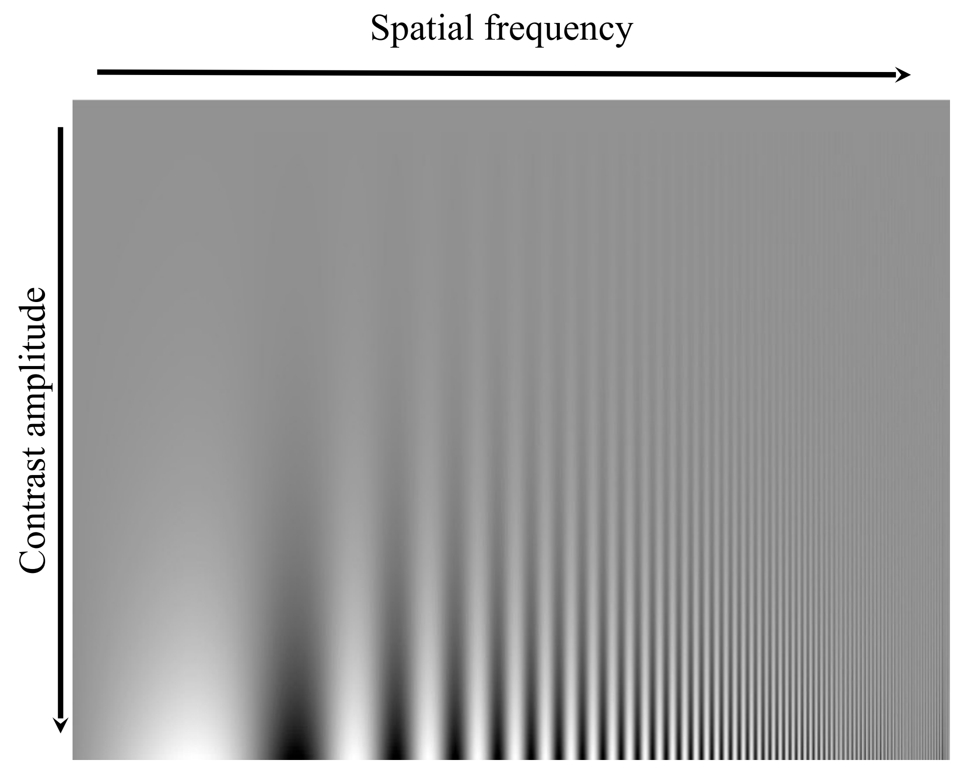
# Stereoscopic vision

- 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

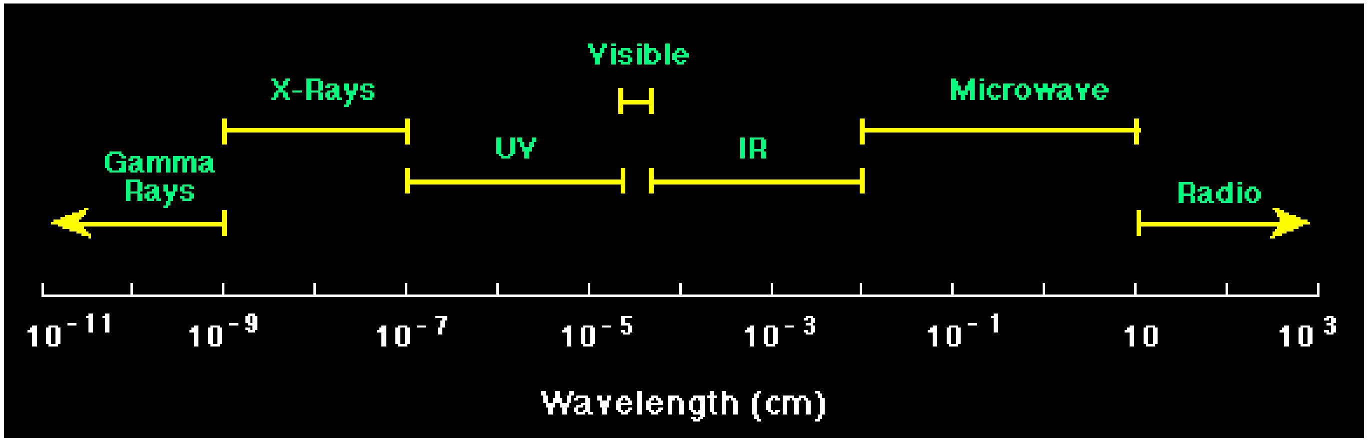
- When humans view an environment, the iris opens or closes so as to allow optimal luminance and contrast vision
- Luminance (= intensity) is perceived in a logarithmic way
- This is why we perceive a greater jump in intensity when we exchange a 50 Watts bulb with a 100 Watts bulb,
  - less so when we 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

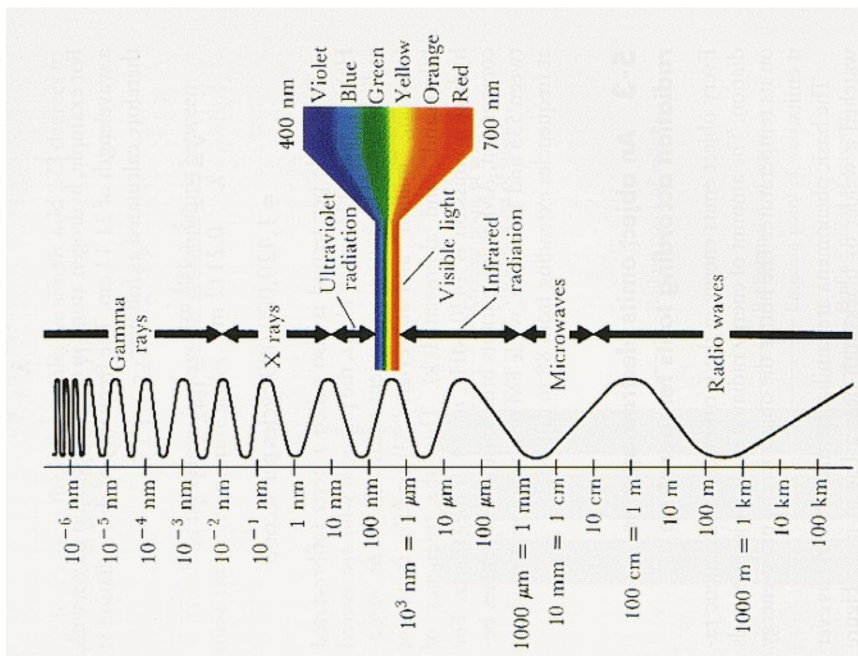


# Flickering

- 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

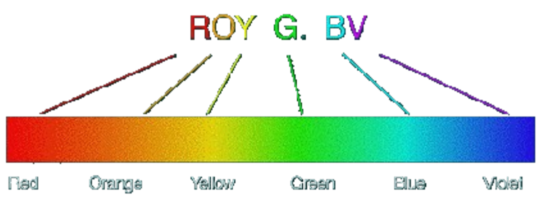
# Electromagnetic waves



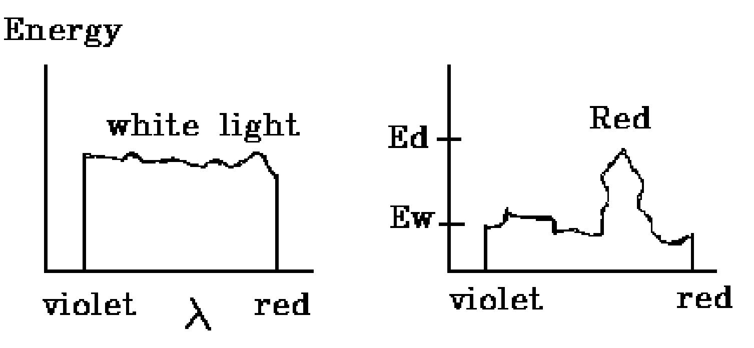
# Light and colour

- 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=$E_d$-$E_w$



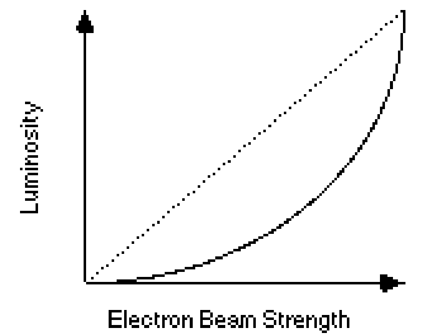
# Achromatic Light

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

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

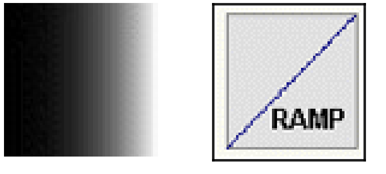
# Gamma correction

- 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

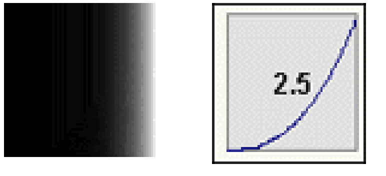


Monitor intensity response

Monitor input

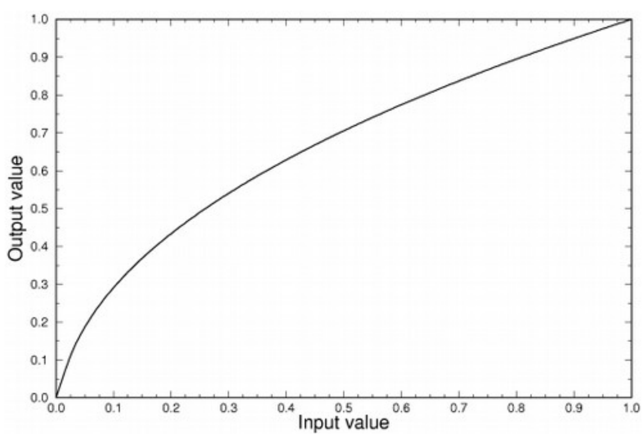



Monitor output

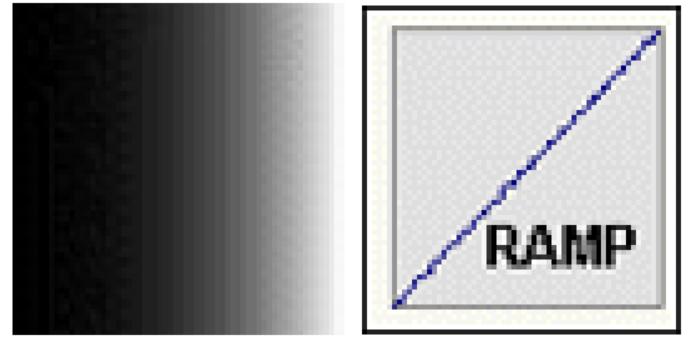


# Gamma correction

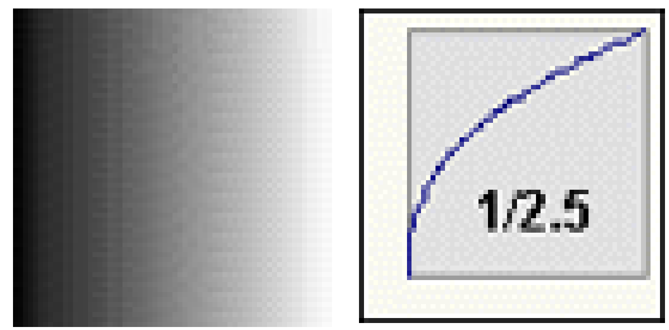
- Gamma correction uses a function so that intensity values are spaced as log
- How do I space the intensities?
  - The rule of thumb is multiplying by a function compensating the device weaknesses
  - Resulting luminosity:
    $L' = L^{1/2.5}$
    (for monitors)



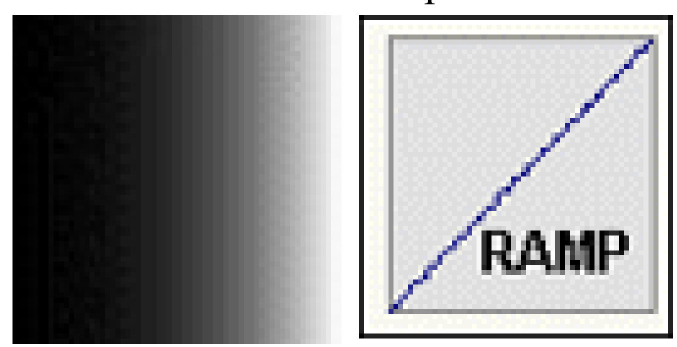

Typical gamma correction function




Monitor input




Gamma corr. input




Gamma corr. output

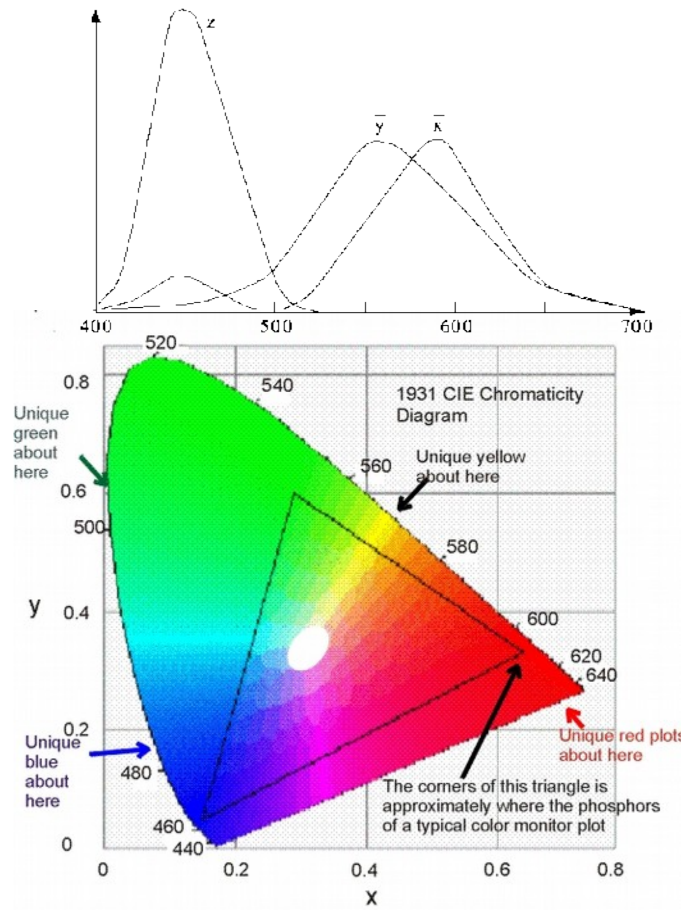
# Coloured light

- 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

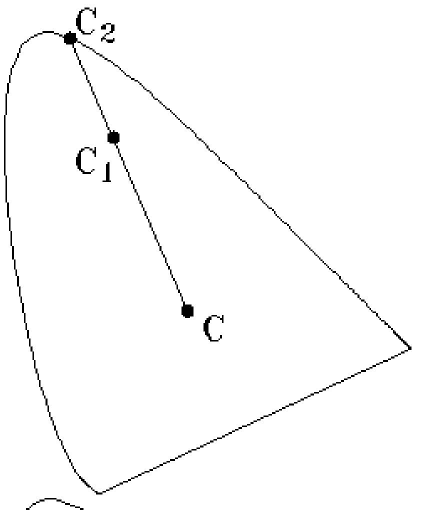
- CIE international standard (1931)
  - Allows all colors to be expressed as sum of 3 primary „colors“
  - Remember, no color triplet can express real colors, so CIE primary colors are virtual colors: A, B, C
  - All other colors are expressible through 3 components:
    x=A/(A+B+C)
    y=B/(A+B+C)
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

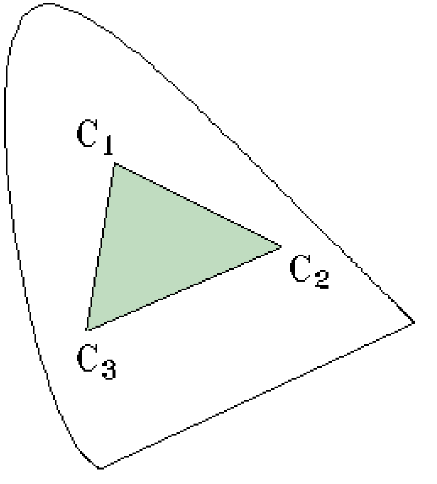
- CIE chromaticity diagram: plots X vs. Y for all visible colors



# CIE chromaticity diagram

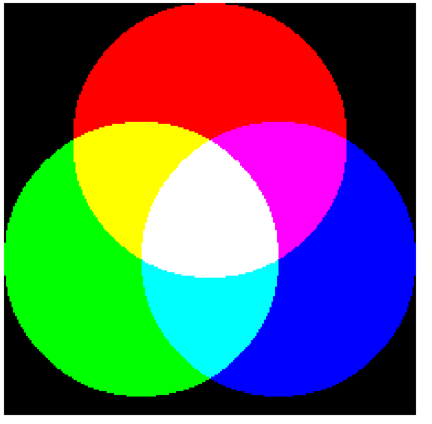
- Centre C represents white light
- For color $C_1$, Dominant wavelength is $C_2$,
- Purity is the lengths fraction $(C_1\text{-}C)/(C\text{-} C_2)$
- Gamut is colors between $C_1$ and $C_2$
- For three colors, gamut is triangle between them
- Note why 3 colors cannot genarate all colors

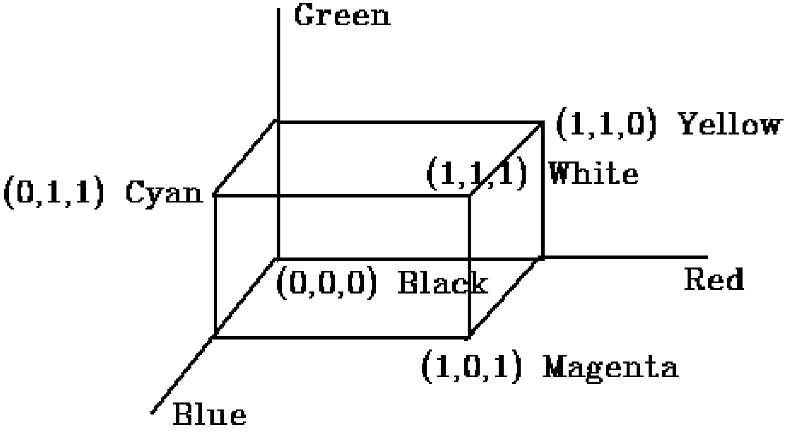


# RGB color model

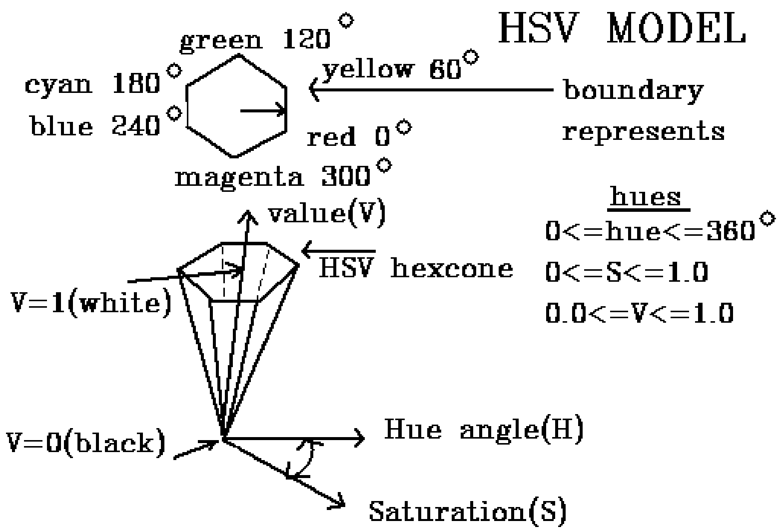
- Uses red-green-blue as base colors (wavelength is not specified)
- Used for additive colors (light emitting)
- Can be represented on unit cube
- RGB axes, colors are points in space
- Complementary colors are colors adding up to white (1,1,1)



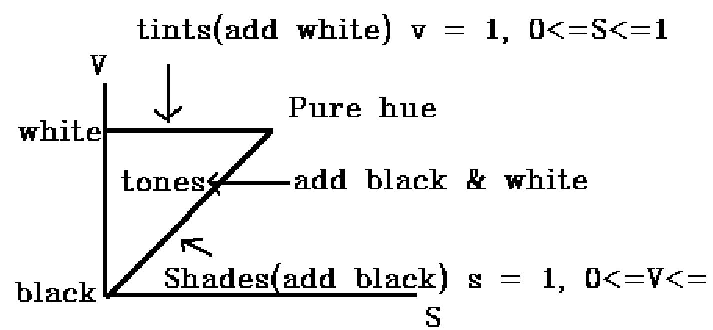


# HSV color model

- 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



# End

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