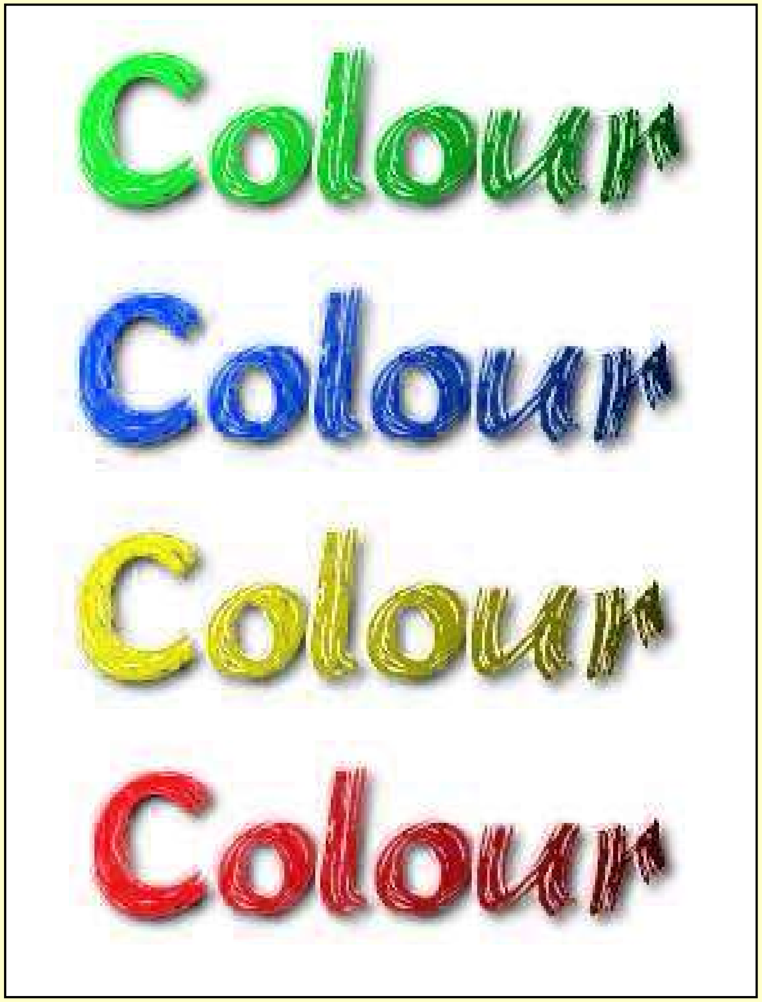
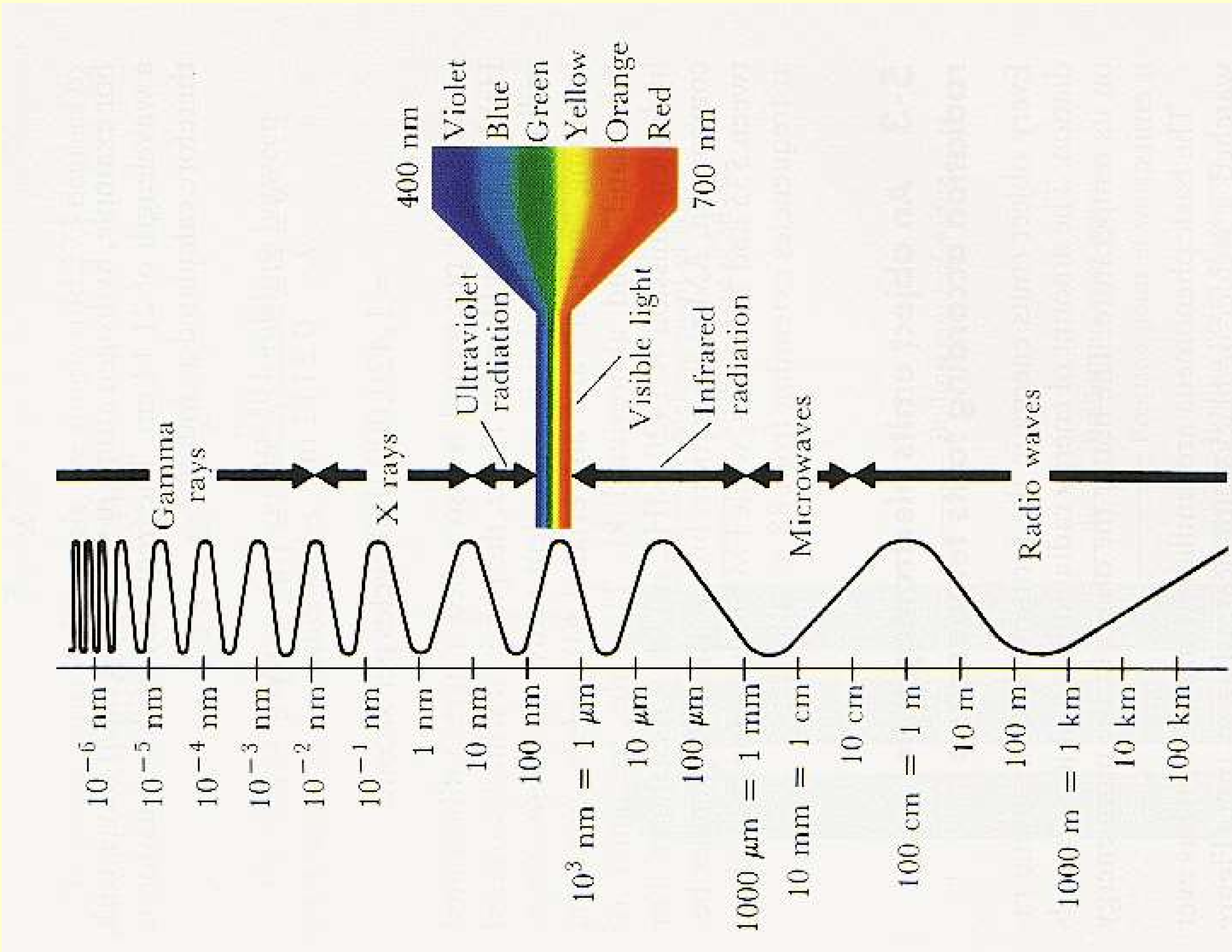

Colour
Colour
Colour
Colour

Colour

- What is colour?
- Human-centric view of colour
- Computer-centric view of colour
- Colour models
- Monitor production of colour
- Accurate colour reproduction

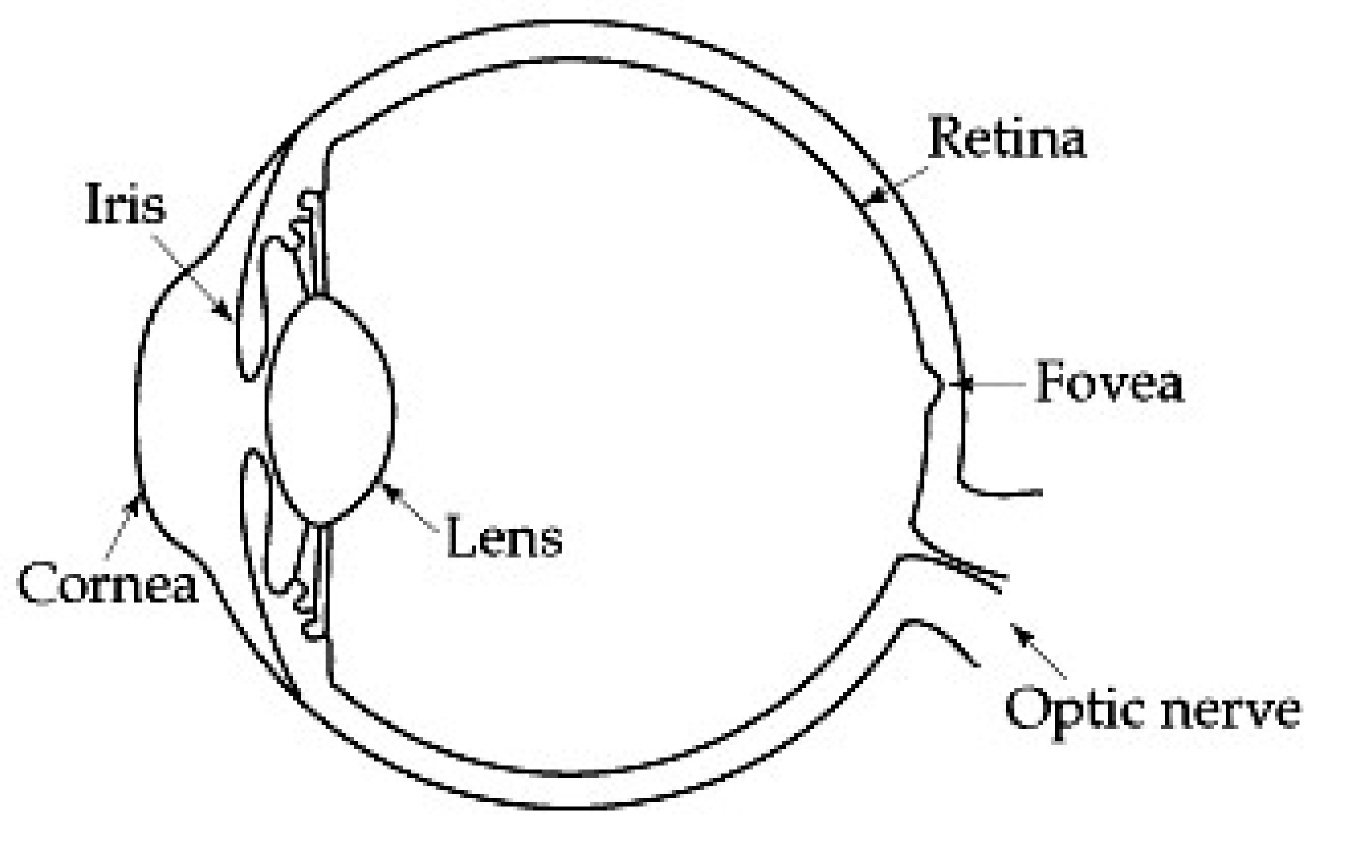
Cunliffe & Elliott, Chapter 8
Chapman & Chapman, Digital Multimedia, Chapter 5

Electromagnetic Spectrum



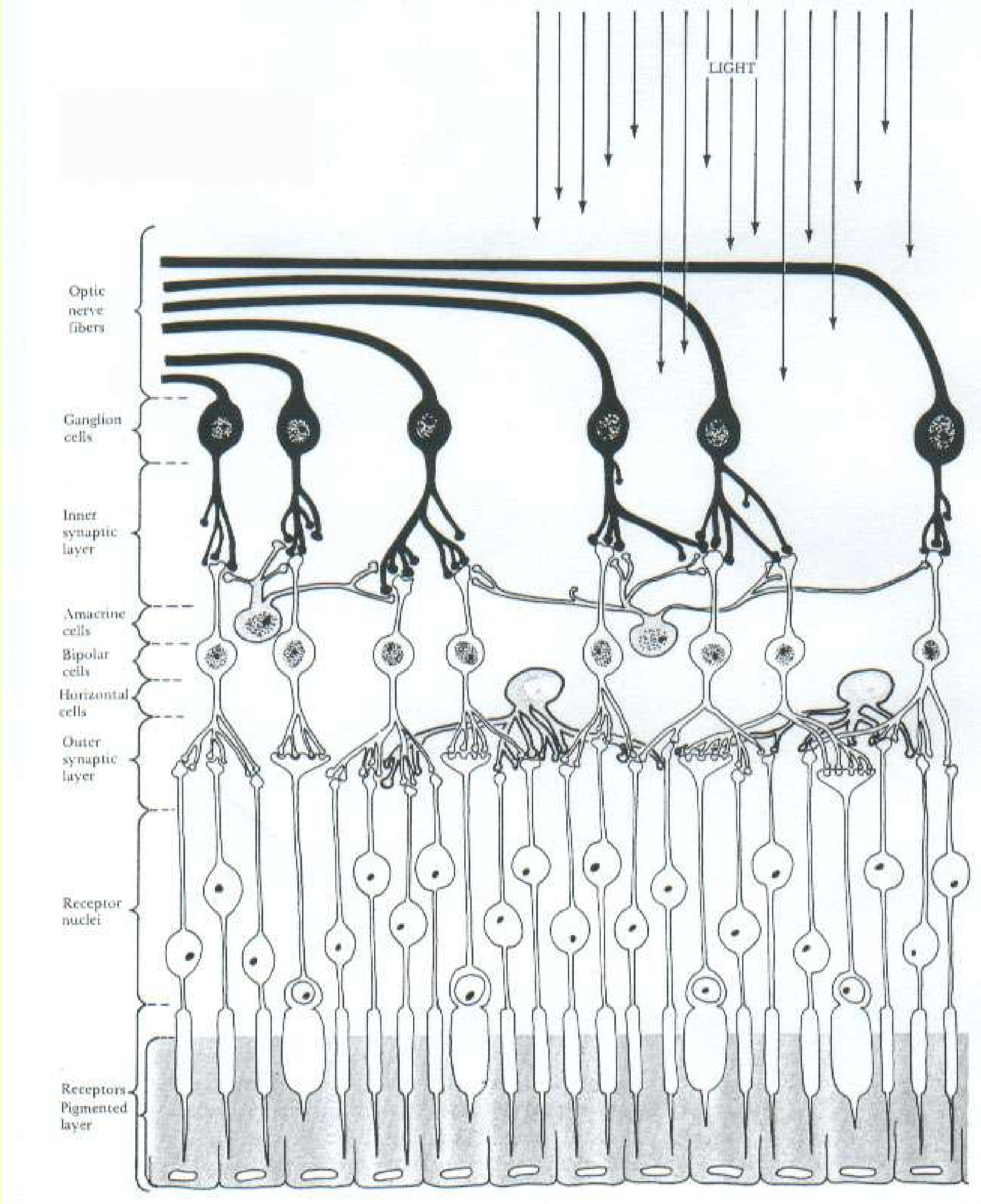
Why/How do we perceive colours?

- Before answering this, we look at what happens when light rays enter our eyes



Photoreceptors

- The retina is the area at the back of the eye on which the image we see is formed.
- Photoreceptors are sensitive to light, and send signals to the brain about what we see.
- Two different types of receptors, commonly called *rods* and *cones*
  - Rods are for the night vision in black and white
  - Cones are for daytime colour vision


LIGHT
Optic nerve fibers
Ganglion cells
Inner synaptic layer
Amacrine cells
Bipolar cells
Horizontal cells
Outer synaptic layer
Receptor nuclei
Receptors
Pigmented layer

Rods

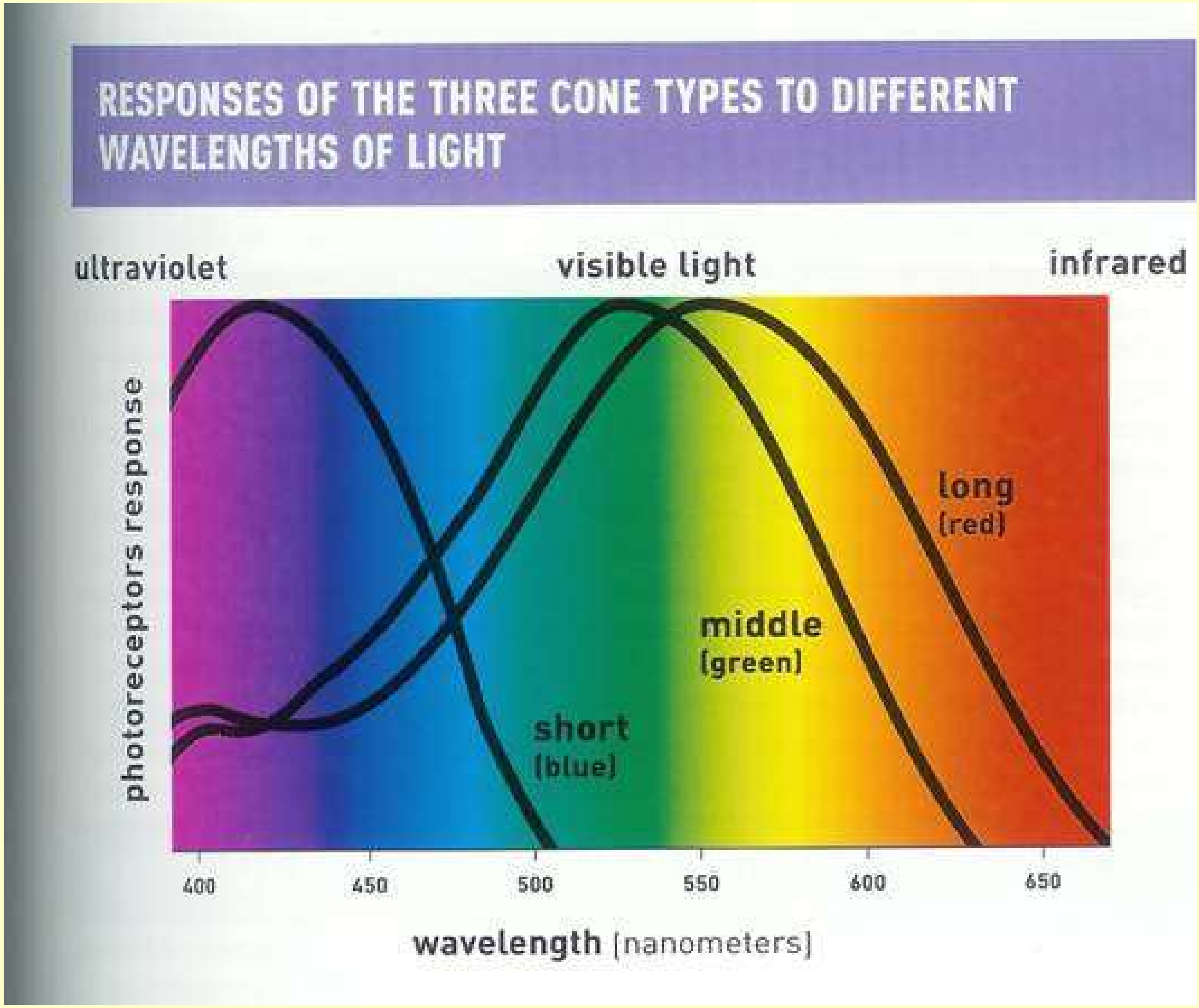
- Rods are very sensitive to light, and allow us to see under a very low level of illumination
- They give us our night vision, in shades of white, grey and black
- About 120 millions rods in one eye
- Located mainly towards the edges of the retina (so better for peripheral vision)
- Cannot resolve fine detail
- Subject to light saturation
  - Ever been looking up at the stars, and a neighbour's security light comes on and temporarily dazzles you?

Cones

- Cones are less sensitive to light than the rods, so can tolerate more light
- There are about 6 million cones, mainly concentrated on the fovea area of the retina
- Three types of cone, each sensitive to a different wavelength - this allows colour vision
- The actual wavelengths that the cones are most sensitive to are 560nm, 530nm, 430nm, commonly labelled “red”, “green”, “blue” respectively
  - better labelling would be “short”, “medium”, and “long” wavelengths

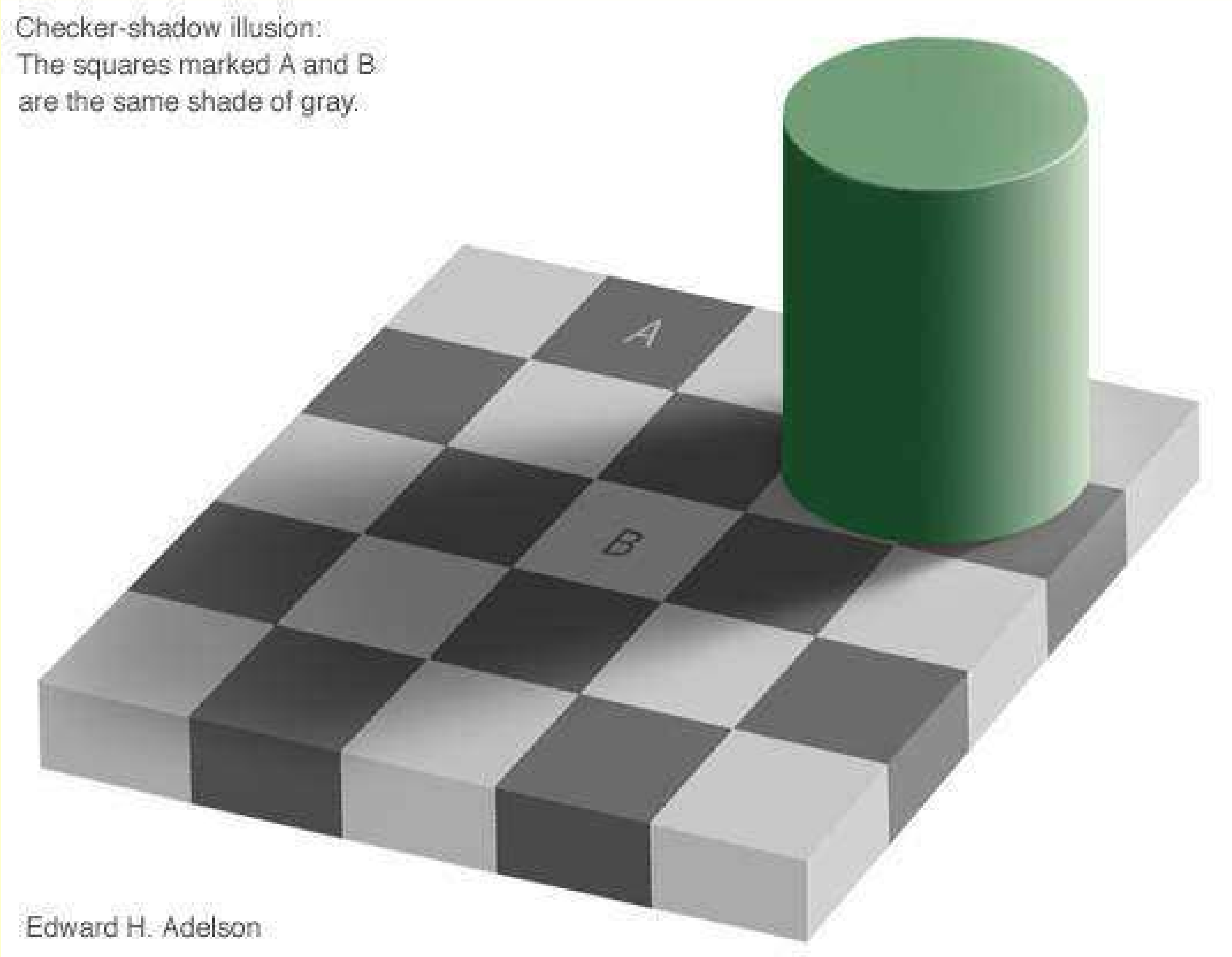
Cone sensitivity

- 60% cones red
- 30% green
- 10% blue



What is colour perception for?

- To support the animal in its ecology
- To enable it to identify food (etc.) in different lighting conditions
  - colour constancy
  - The ability to recognise colours in different illuminations
  - A difficult problem for computer systems
    - And one that can result in unexpected visual illusions


Checker-shadow illusion:
The squares marked A and B
are the same shade of gray.
A
B
Edward H. Adelson

Colour constancy example

Above are parts of the two sections, without the surrounding parts of the image.

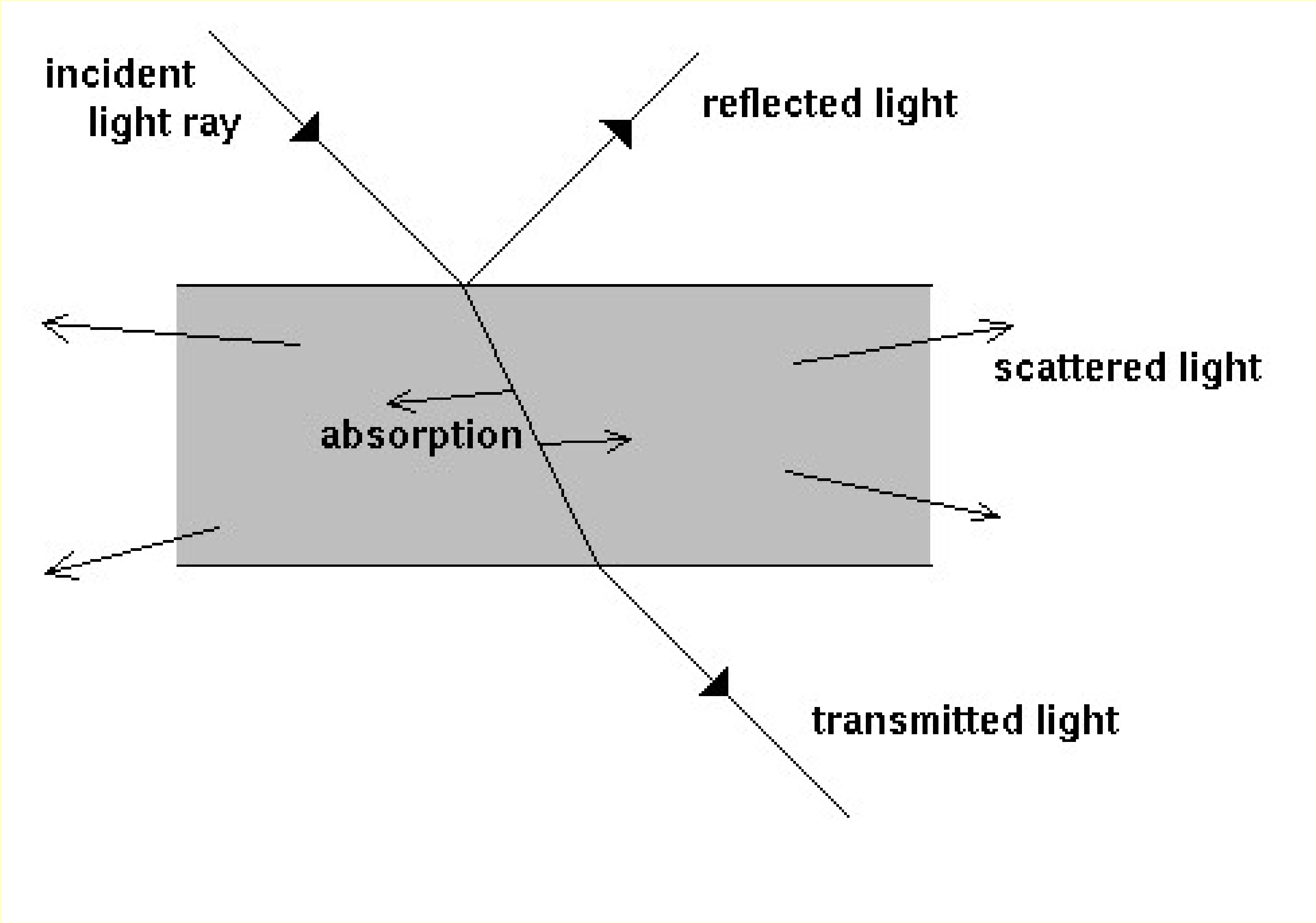
The eye/brain corrects for the expected effect of the shadow.

What colour is this dress?

What is colour?

- There are two possible reasons why an object may be coloured:
  - It may reflect light unevenly over the visible spectrum
  - It may emit light unevenly over the visible spectrum.
- If an object reflects light evenly, it will be white or grey or black
- If it emits light whose energy is spread evenly over the spectrum, the light will be white.

Reflected light: Light incident on a surface



Why are things coloured?

- Most things reflect, rather than emit, light
- Materials have different absorption and scattering characteristics for different wavelengths of light

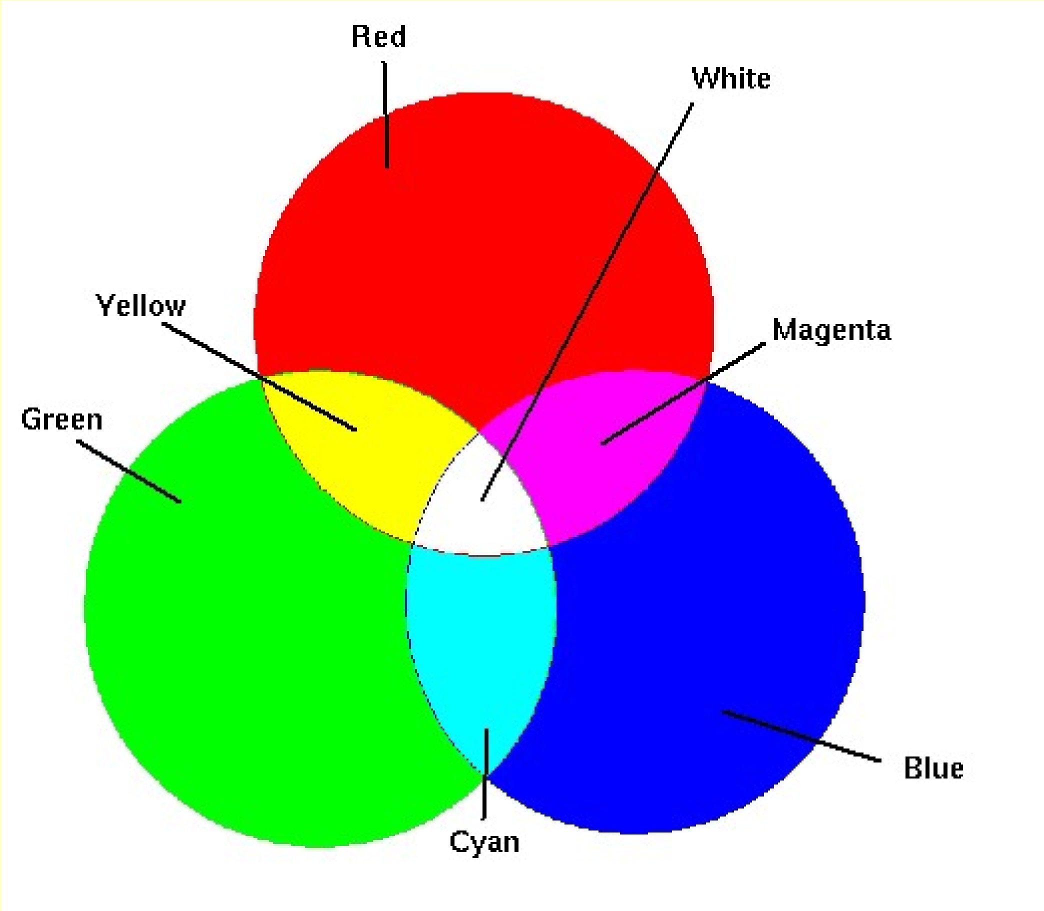
Examples:

- A yellow object absorbs a lot of blue light, but scatters in the longer (red and green) wavelengths

- Black clothing gets very hot in sunlight, because it doesn’t scatter much light (obviously not, as it’s black!) so it absorbs a lot (as heat)

Emitting light: Additive Colour Matching

- Mixing different amounts and wavelengths of light together produces colours
- Maxwell's trichromatic colour theory



Colour Models

Different ways of constructing colours

- some ways are from primaries
- some are more numerical ways

Some of the more common systems:

- RGB (red green blue)
- CMY (cyan magenta yellow)
- CMYK (cyan magenta yellow black)
- HSV (hue saturation value)
- CIE (Commission Internationale d'Eclairange) primaries

RGB

- Additive colour scheme
- Adds red, green and blue amounts starting from black.
- Typical colour scheme used in graphics programming, image files, HTML etc.
- R, G, B values typically all from 0-255 (so stored in 1 byte)

Examples:

- Orange R=255 G=135 B=75
- Turquoise R=23 G=173 B=178

CMY and CMYK

- CMY = Cyan Magenta Yellow
- CMYK has added black and is used for printing
- Amount of Cyan in a colour is the same as how much red is "missing" in the colour compared to white (with the red fully on)
- Similarly,
  - Amount of Magenta = amount of green missing
  - Amount of Yellow = amount of blue missing
- Subtractive system

RGB and CMY

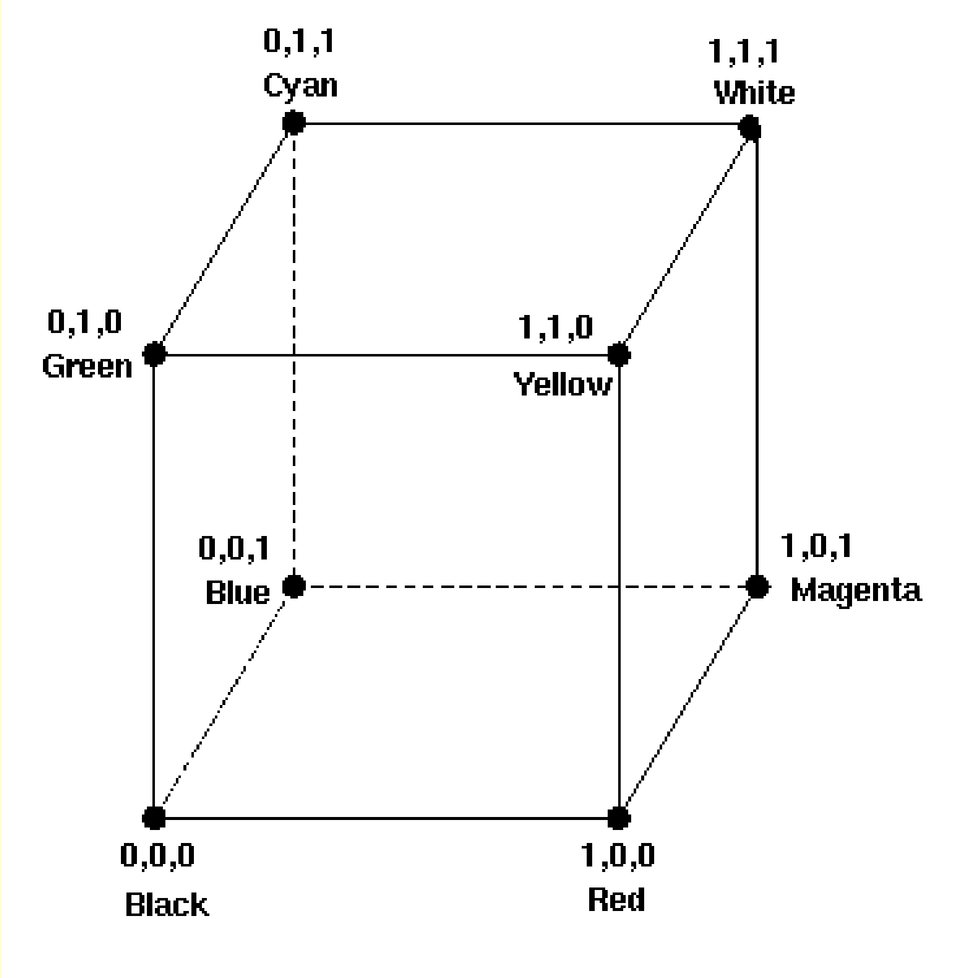
- RGB and CMY are complementary colour models

C = G+B = W-R

M = R+B = W-G

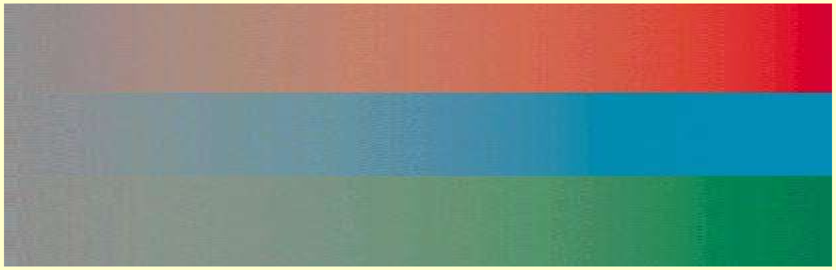
Y = R+G = W-B

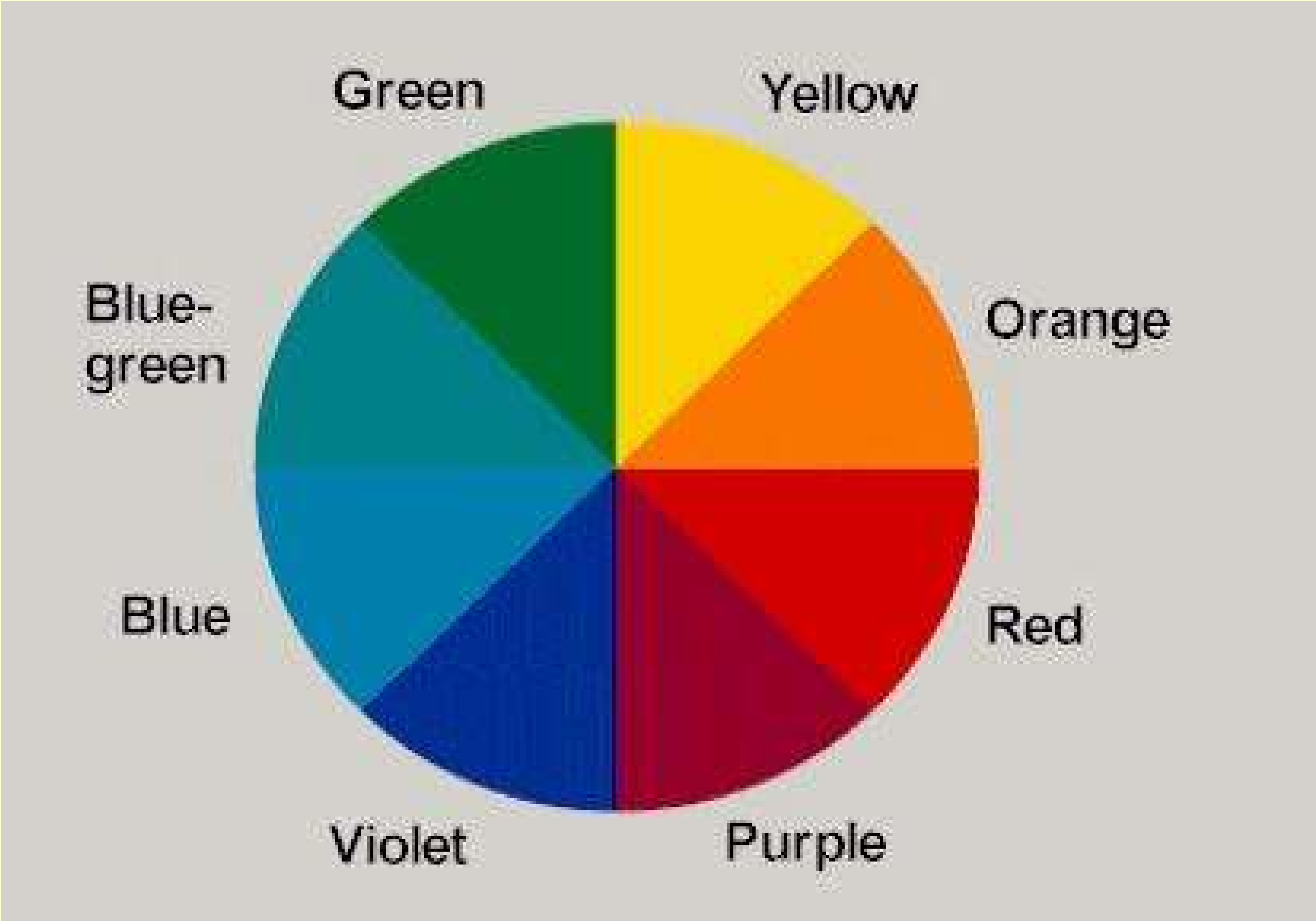
(W = white)

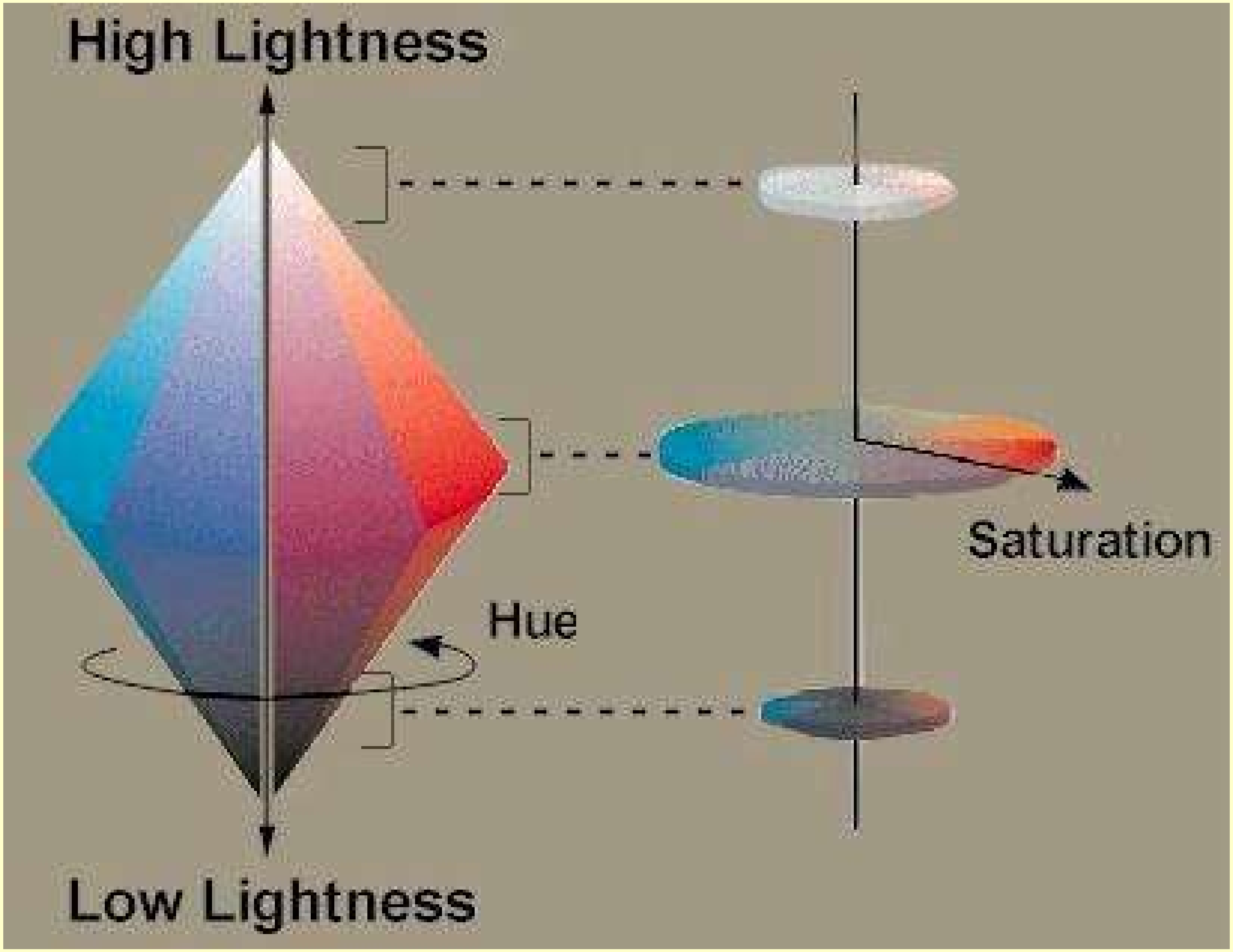


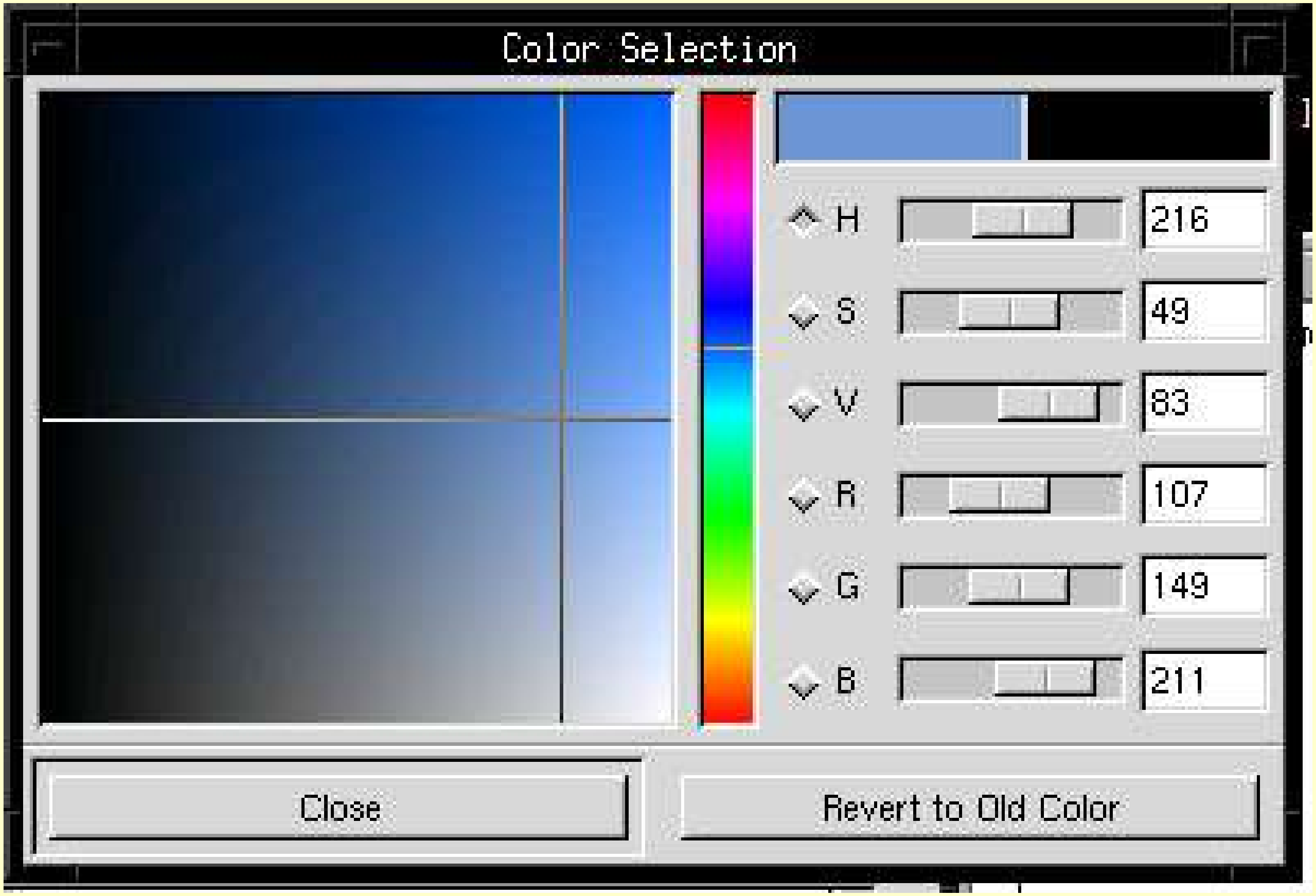
HLS/HBS/HSV

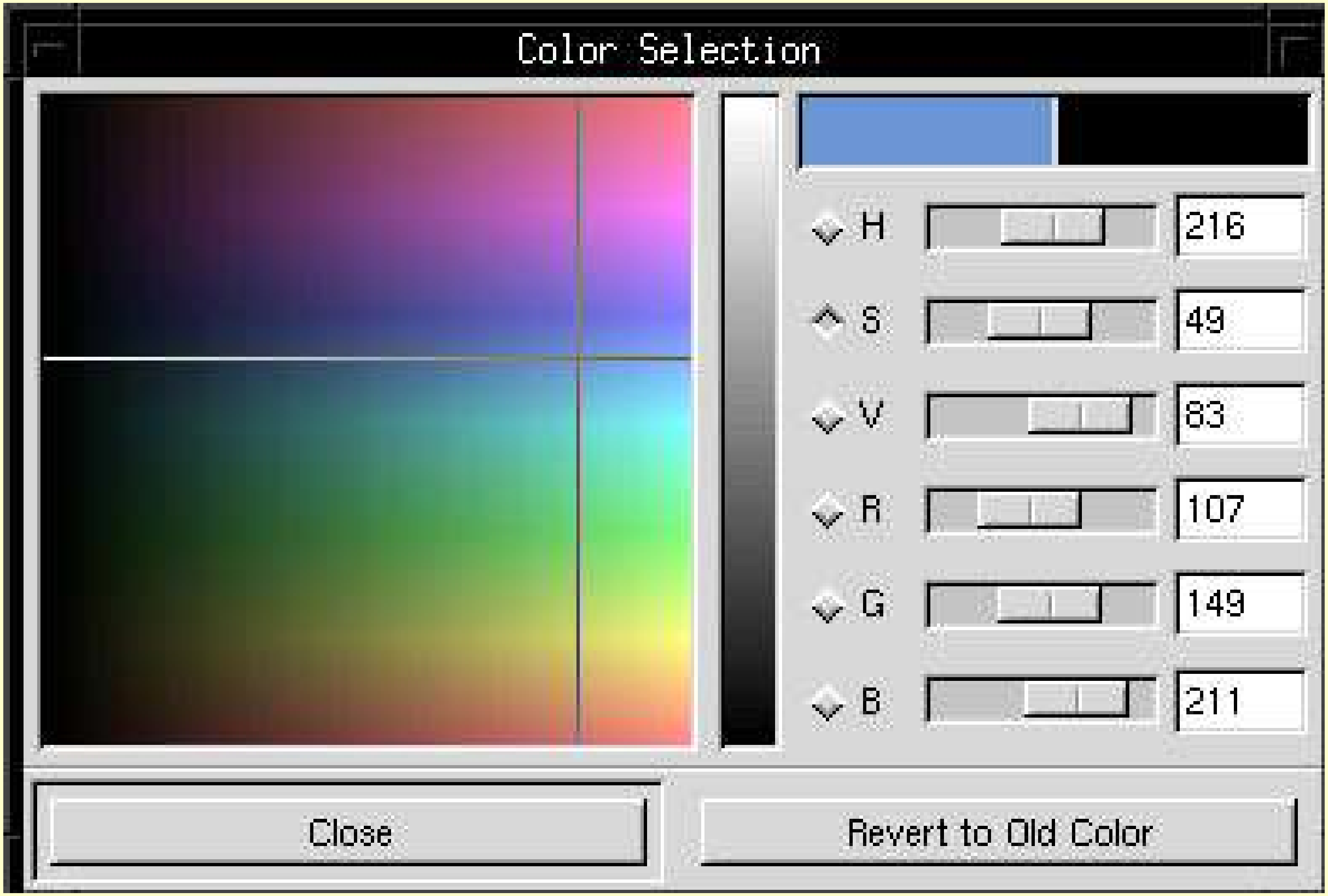
- Closer to how we think about colour
- Hue
  - which colour along spectrum of red-yellow-green-blue-violet
- Lightness or Brightness or Value
  - how much or little light is produced from an area
- Saturation or Colourfulness
  - how much colour it exhibits (greys are very unsaturated)




Green
Yellow
Blue-
green
Orange
Blue
Red
Violet
Purple


High Lightness
Saturation
Hue
Low Lightness


Color Selection
H
216
S
49
V
83
R
107
G
149
B
211
Close
Revert to Old Color


Color Selection
H
216
S
49
V
83
R
107
G
149
B
211
Close
Revert to Old Color


Color Selection
H
216
S
49
V
83
R
107
G
149
B
211
Close
Revert to Old Color

Device-Dependent Colour Models

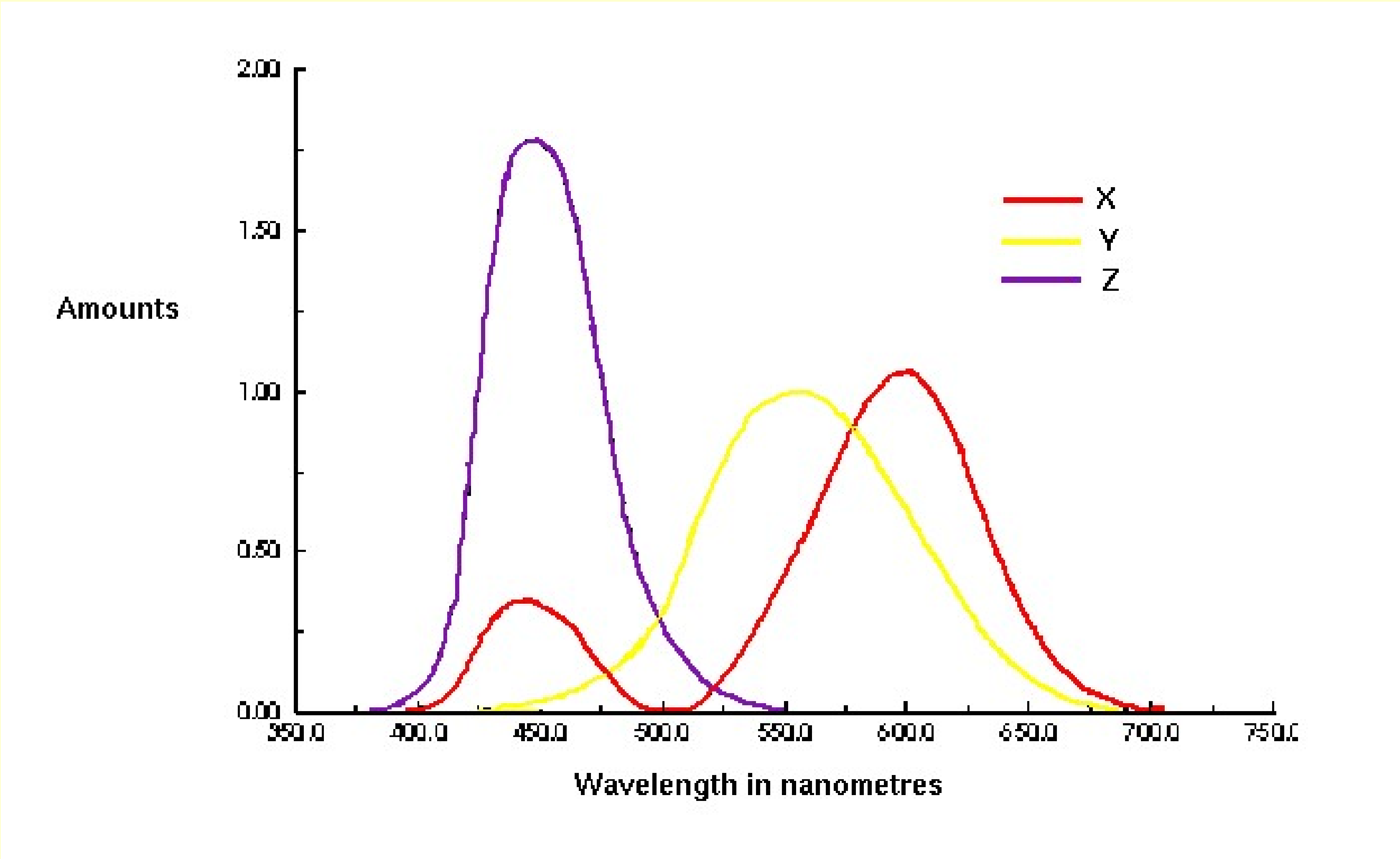
- Colour models so far: RGB, HSV,CMY,CMYK
- They are all *device-dependent*
  - specific to particular hardware
  - eg a colour with RGB values (140,60,203) will show up as slightly different colours on different monitors
- There is a need to achieve colour fidelity
  - imagine an image being created, displayed on the screen, then printed. It can be important to keep the colours the same at each stage of the process.
- What we need: a *device-independent* colour model.

CIE and the Standard Observer

- Based on experiments, the CIE (Committee Internationale de l'Éclairage) in 1931 defined a
  - Standard Observer
  - A standard set of three primaries (X,Y,Z)

- These primaries are "imaginary" primaries in that they do not actually correspond to real visible colours
- They are "not real" in the sense that they are more *saturated* (intensely colourful) than real colours
- Y is chosen to match a standard measure of brightness - also known as Gamma (γ)

XYZ



Amounts
2.00
1.50
1.00
0.50
0.00
350.0
400.0
450.0
500.0
550.0
600.0
650.0
700.0
750.0
Wavelength in nanometres
X
Y
Z

XYZ and Device Independence

- XYZ is one industry standard for a *device-independent* colour space
- Some printers and monitors are capable of using this standard to produce colour output that is faithful to the input colours
- What happens (in brief) is that the device is calibrated, so that it knows how to convert to and from XYZ and its own (*device-dependent*) colour model (RGB or CMYK)

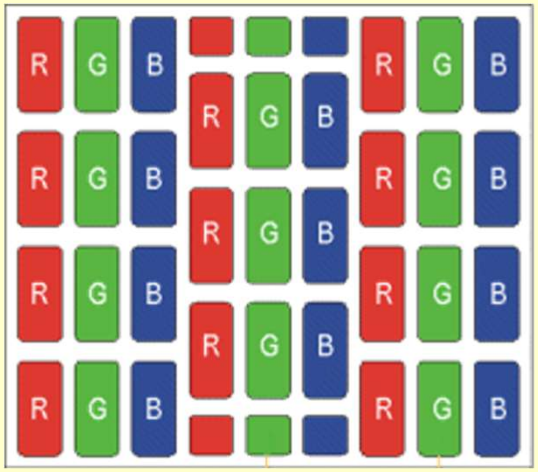
Generating Colour

Issues to consider in colour production:

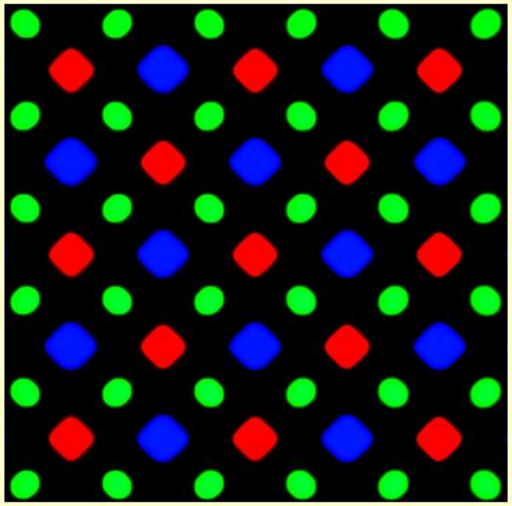
- Physical limits of hardware
- Range of colours available
- Ways to circumvent limits
  - eg by trying to increase number of colours
- Non-linearity (a.k.a. gamma correction)
- Portability
  - i.e. how to keep the colours of an image true to life

Flat Screen Monitors

- LCD: Liquid crystal display
  - Liquid crystal light gates control transmission of ambient/backlit light through polarised light filters
  - Reflective or transmissive
  - Lower power
  - Small to large: pixel pitch 0.2 to 0.5mm



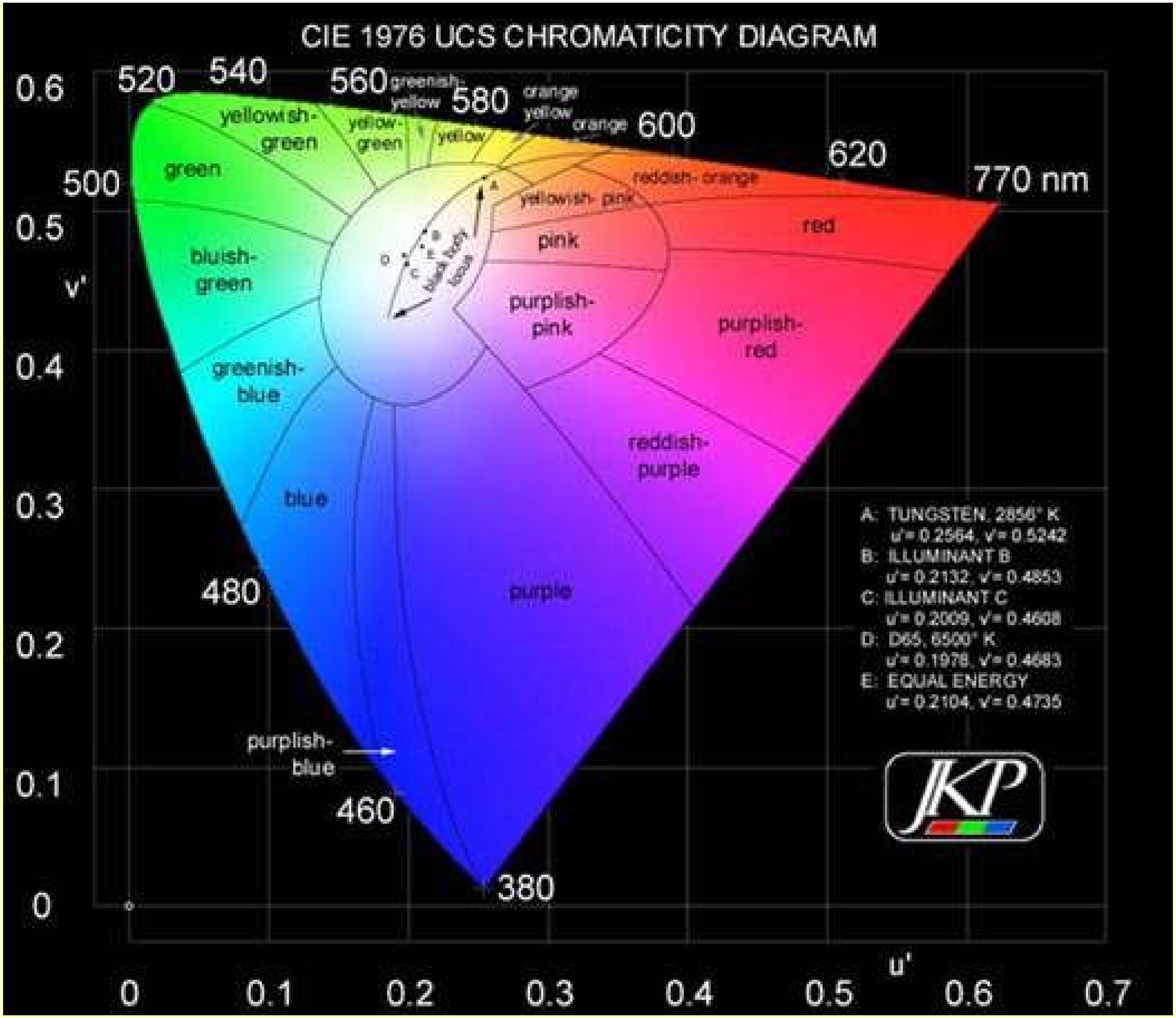
- OLED
  - Organic light-emitting diodes
  - No backlighting required
  - Thinner and lighter than LCDs
  - Higher contrast ratio and truer “black” than LCDs



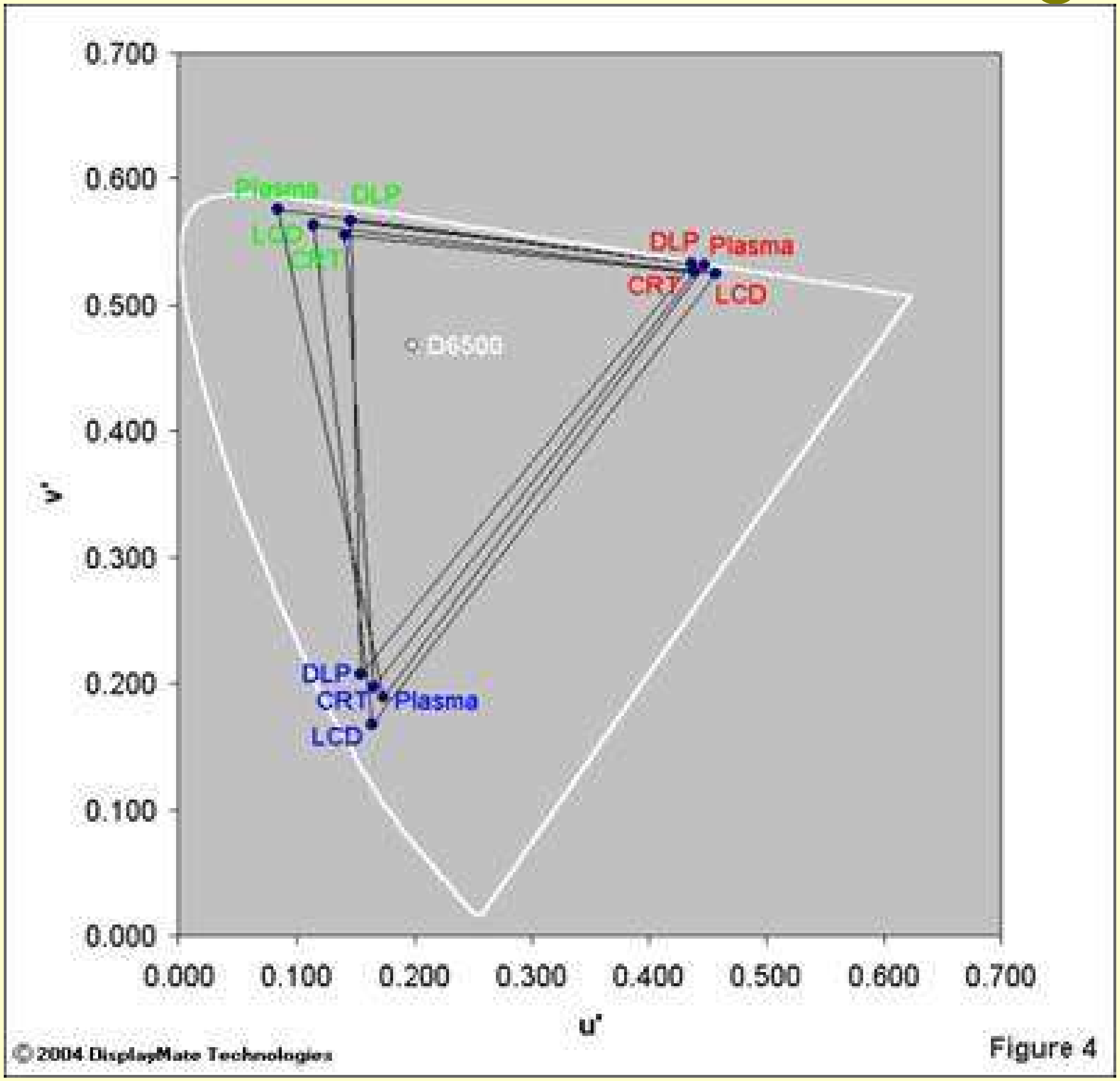
(Samsung Galaxy S5)

Monitor Gamut

- The *gamut* is the range of displayable colour
- Choice of exactly which primaries (phosphor colours) is a trade-off between
  - obtaining a large gamut
  - making the display sufficiently bright to see easily
- Note that the gamut shrinks as ambient (surrounding) light increases
  - as you will know from trying to use a monitor when the sun is shining
- The darkest colours are lost first


CIE 1976 UCS CHROMATICITY DIAGRAM
520
540
560
580
600
620
770 nm
500
480
460
380
greenish-yellow
orange yellow
orange
yellowish-green
yellow-green
yellow
reddish- orange
green
yellowish- pink
pink
red
bluish-green
purplish-pink
purplish-red
greenish-blue
reddish-purple
blue
purple
purplish-blue
v'
u'
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
A: TUNGSTEN, 2856° K
u' = 0.2564, v' = 0.5242
B: ILLUMINANT B
u' = 0.2132, v' = 0.4853
C: ILLUMINANT C
u' = 0.2009, v' = 0.4608
D: D65, 6500° K
u' = 0.1978, v' = 0.4683
E: EQUAL ENERGY
u' = 0.2104, v' = 0.4735
JKP

Gamut for different technologies

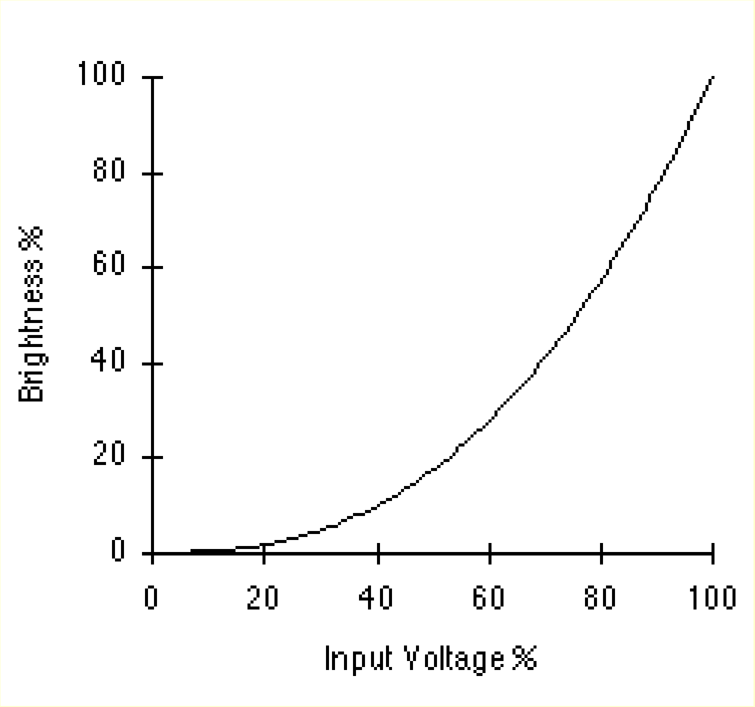


Gamma Correction

- Important issue to be aware of, concerning monitors
- Brightness is an easily-understandable concept but a subjective one
  - the same level of light is perceived to be dim in a bright environment, and very bright in a dark environment
- Luminance (*Y*, gamma) is an objective measure designed to correspond to our idea of brightness
  - measure of power, weighted by a particular spectral sensitivity function characteristic of human vision

Gamma Correction

- Roughly speaking...
  - Luminance (Y) proportional to Voltage^{gamma}
  - Gamma approximately 2.2 for LCD screens
- In other words, a linear increase in the voltage does not mean a linear increase in brightness!
- Gamma correction *may* be needed to produce linearity.



Accurate Colour Matching

- Monitor calibration alone does not ensure colour matching
- Colour matching technology requires software to perform calculations matching colours between screen and printer (or other devices)
- The calculations are between the colour models used by the devices (e.g. the RGB of a monitor or the CMYK of a printer) and an objective device-independent colour model, such as a CIE colour model
  - XYZ, or Lab (as used in Photoshop)

Colour Matching Systems

Examples:

- PANTONE has about 1000 unique colours identified by swatches
- COLORCURVE identifies colours by a lightness value, a red/green value, and a blue/yellow value
- TRUMATCH and FOCOLTONE use "swatch books" that allow the user to select CMYK colours according to what is printed on the printer

How to use:

- Install software on computer, print out samples, then choose your colour according to the printout

End of Lecture