Digital image processing and analysis

3. Colour: physical origins, perception and characterisation

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Previous lecture:

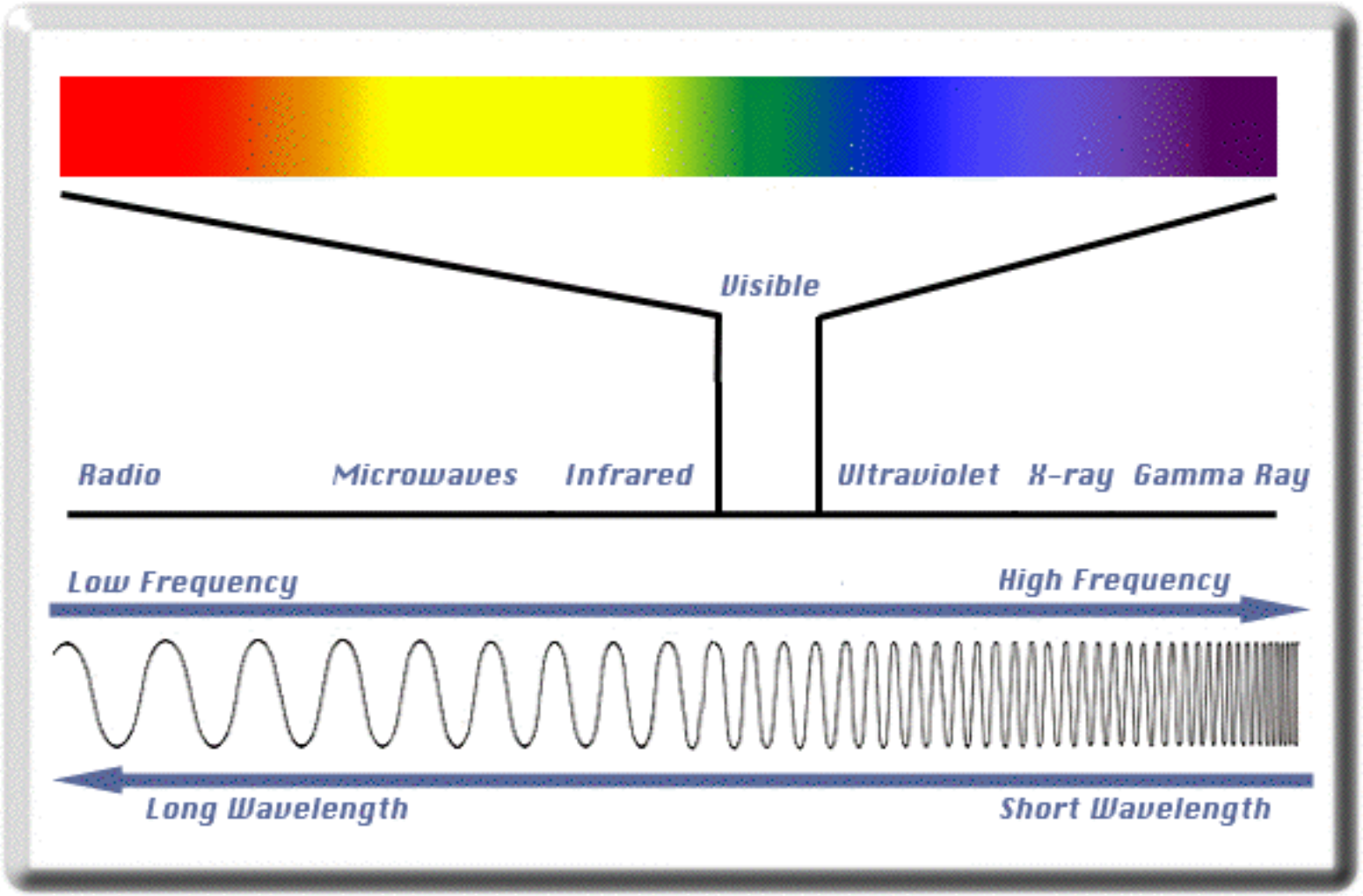
- Digital image properties
  - **Computer representation** – pixels
  - **Sampling** – related to image coordinates
  - **Quantisation** – related to image values
- … and how they relate to image acquisition

In this lecture we shall find out about:

- Colours and their origins
  - Physical underpinnings
  - Human visual perception
- Colour images
  - Image acquisition
  - Colour spaces

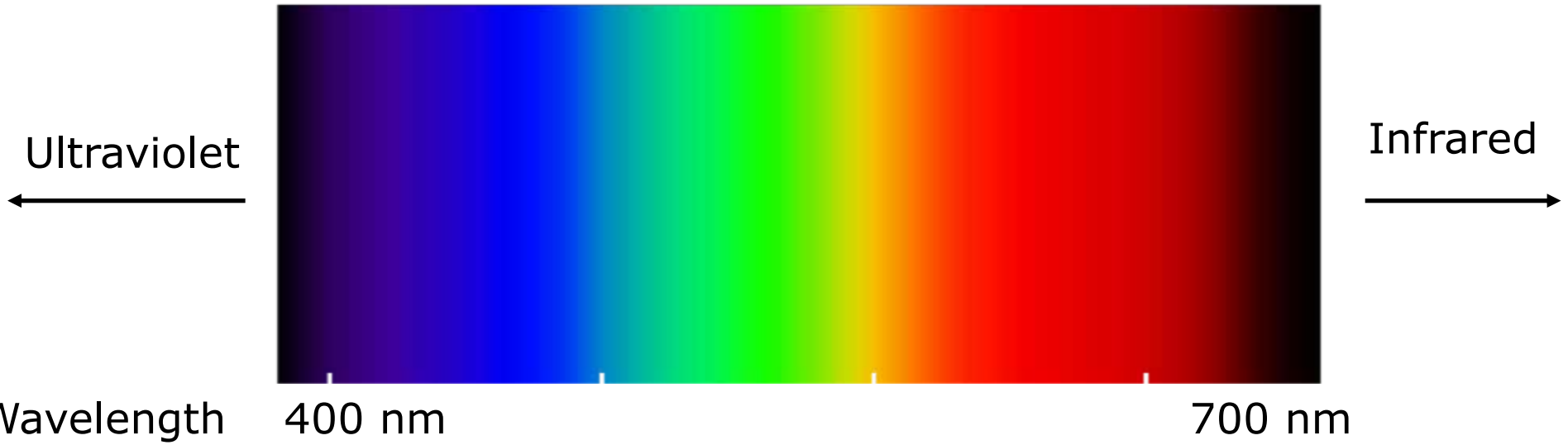
What is colour
Physical underpinnings

Light – a part of electromagnetic spectrum



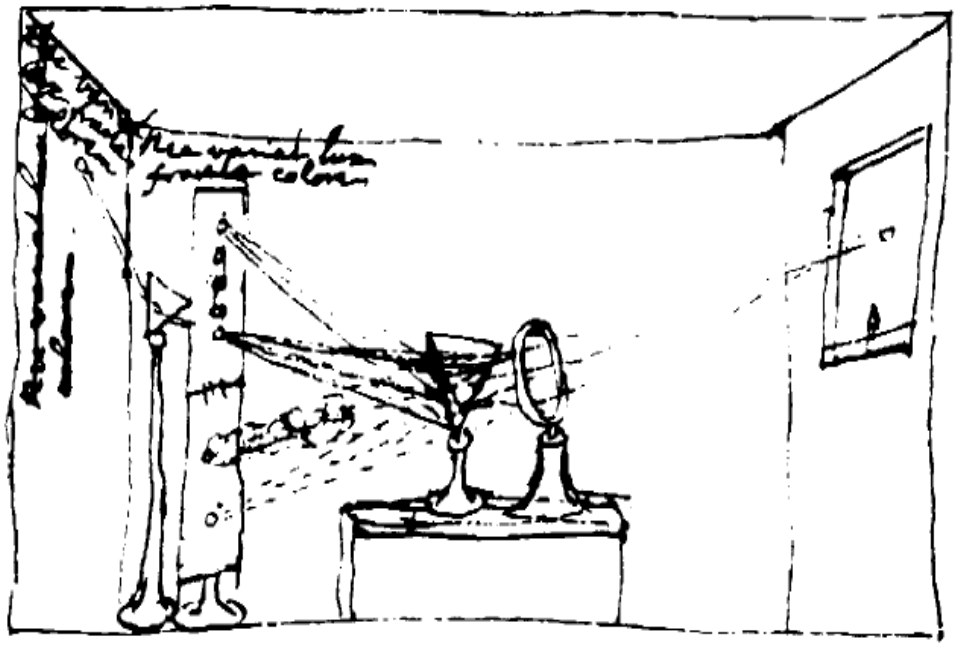
What is colour
Physical underpinnings

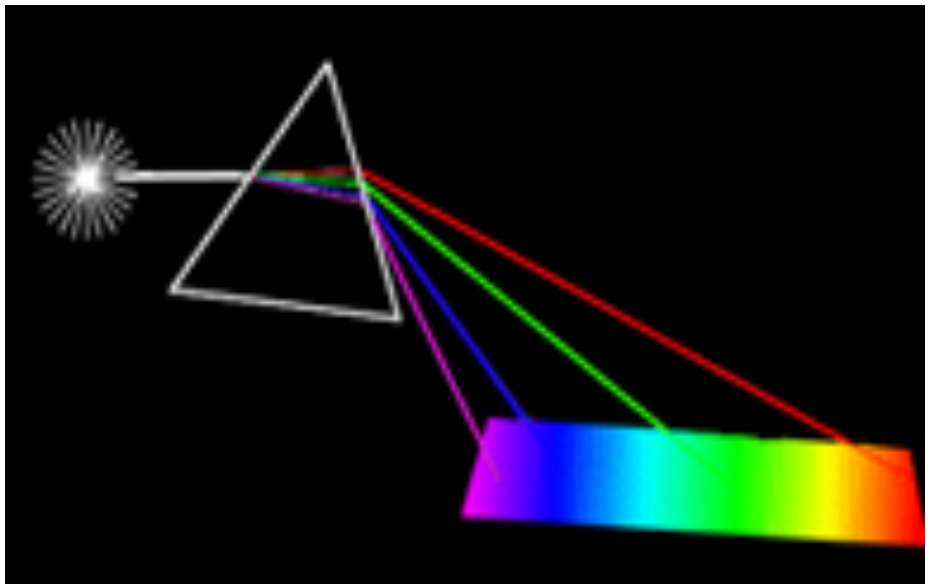
Colour spectrum – visible light



What is colour
Physical underpinnings

Newton's experiment

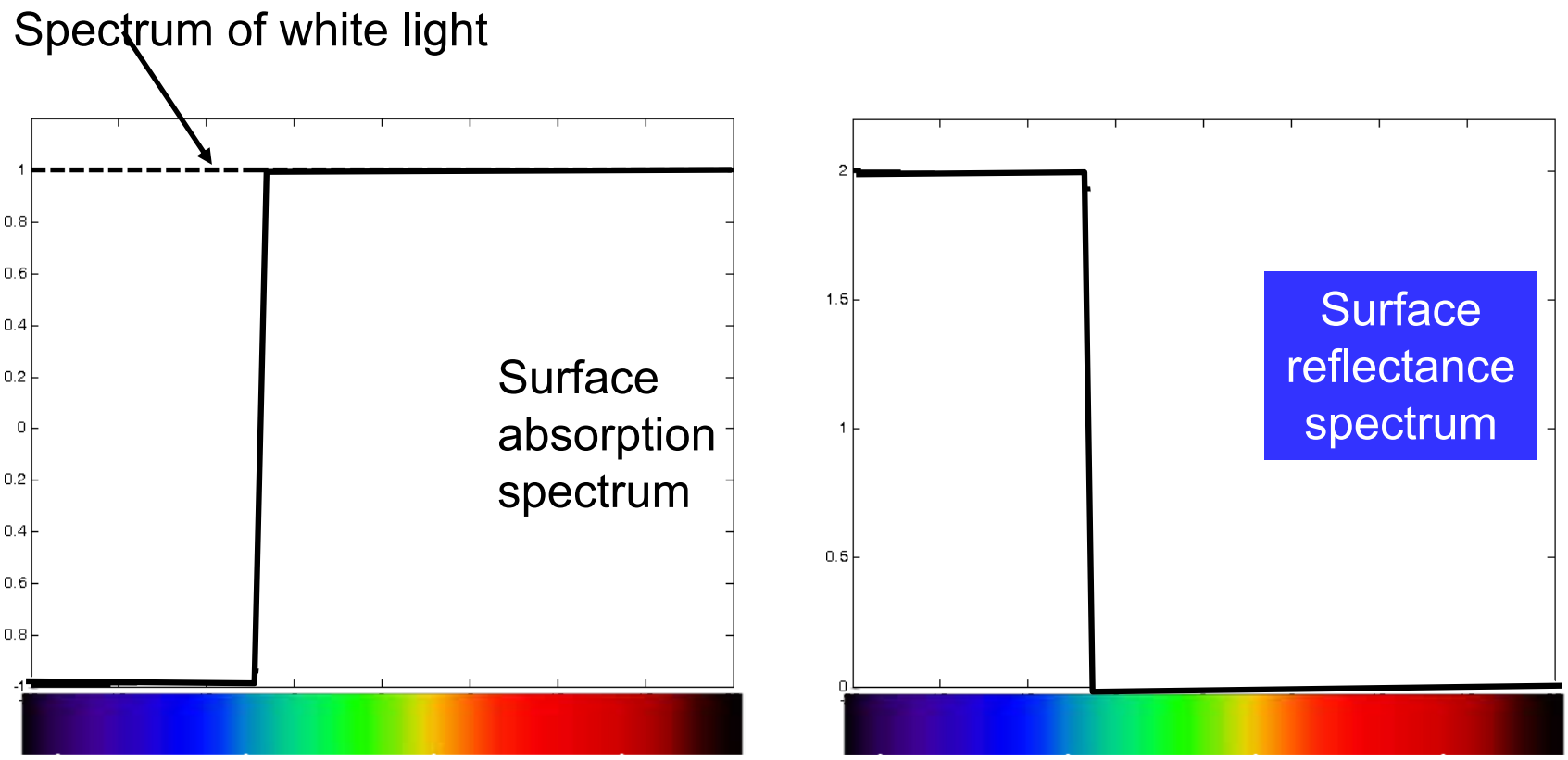




Conclusion:

"White" light is a combinations of many different light wavelengths

What is colour
Physical underpinnings

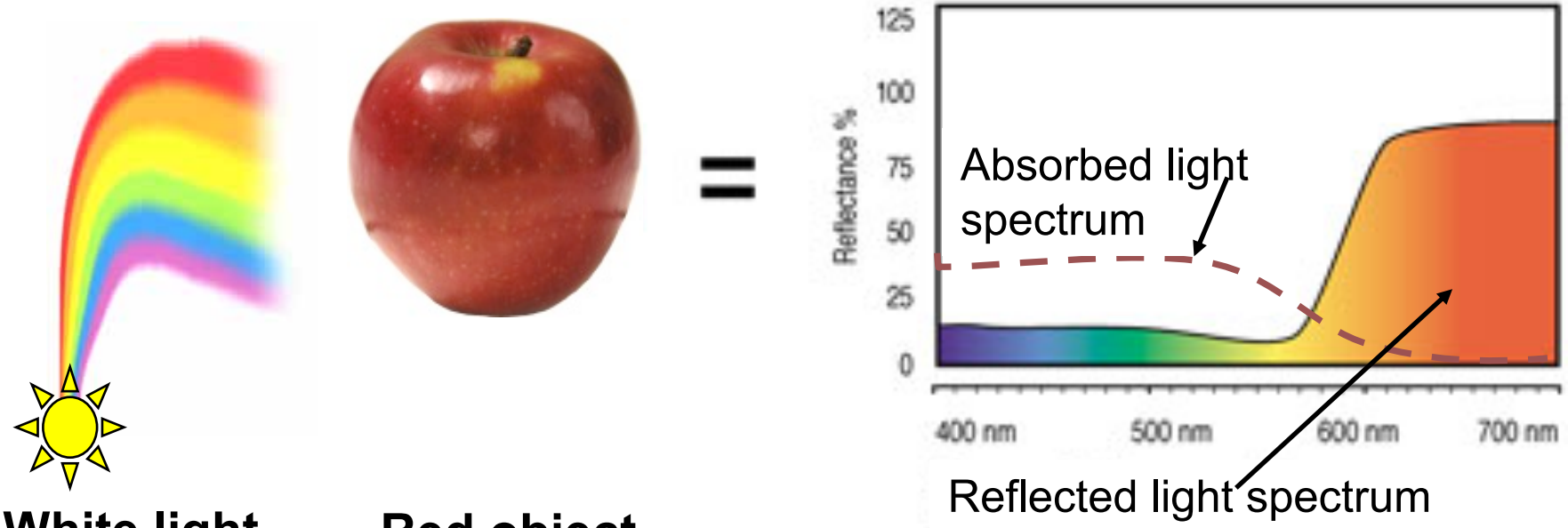


White light is a mixture of all wavelengths, at equal magnitudes

Object absorbs certain parts of the spectrum and reflects the remaining parts.

What is colour
Physical underpinnings

We see/image light reflected from surfaces

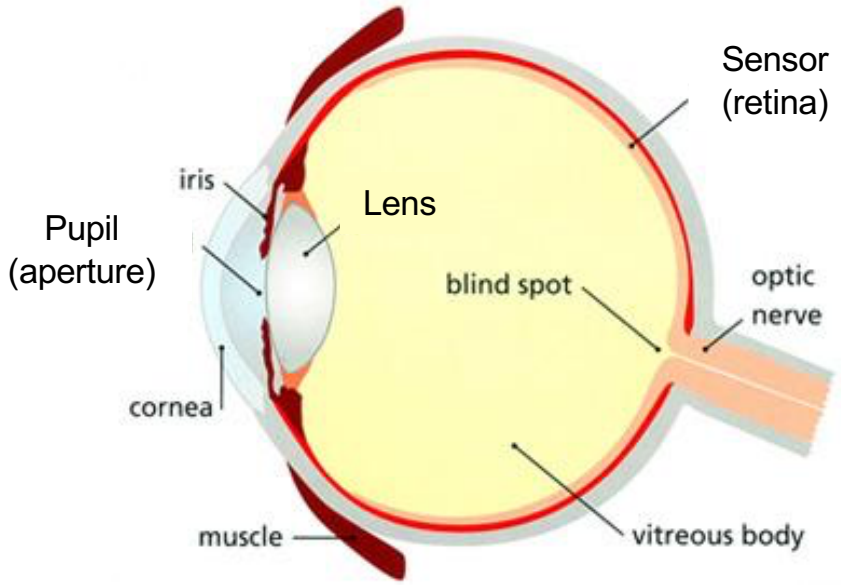


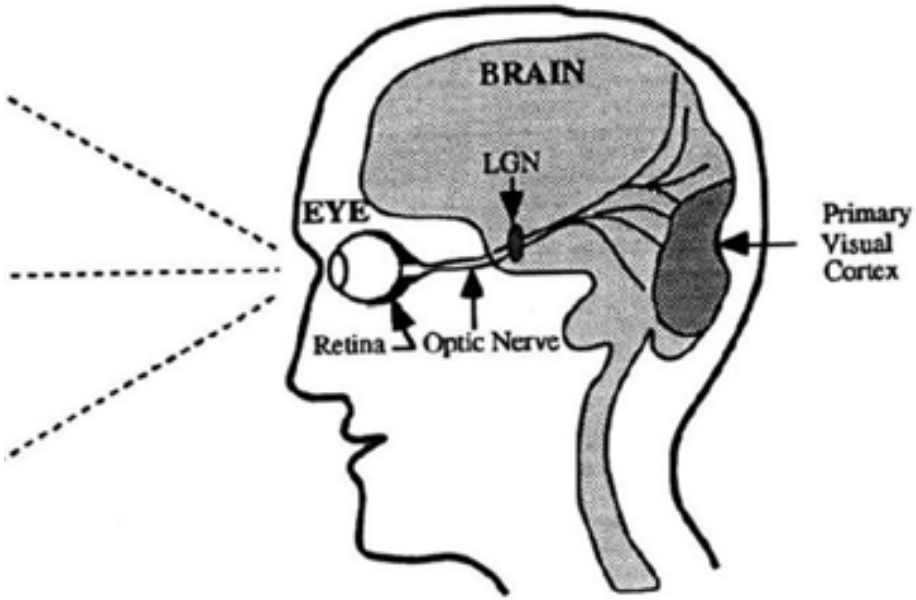
White light **Red object**

White light is a mixture of all wavelengths, at equal magnitudes

What is colour
Sensing

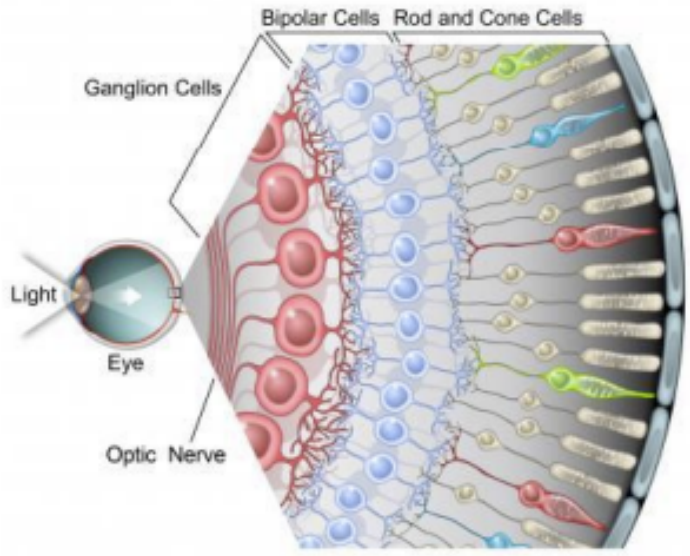
The eye and the brain





What is colour
Sensing

Retina



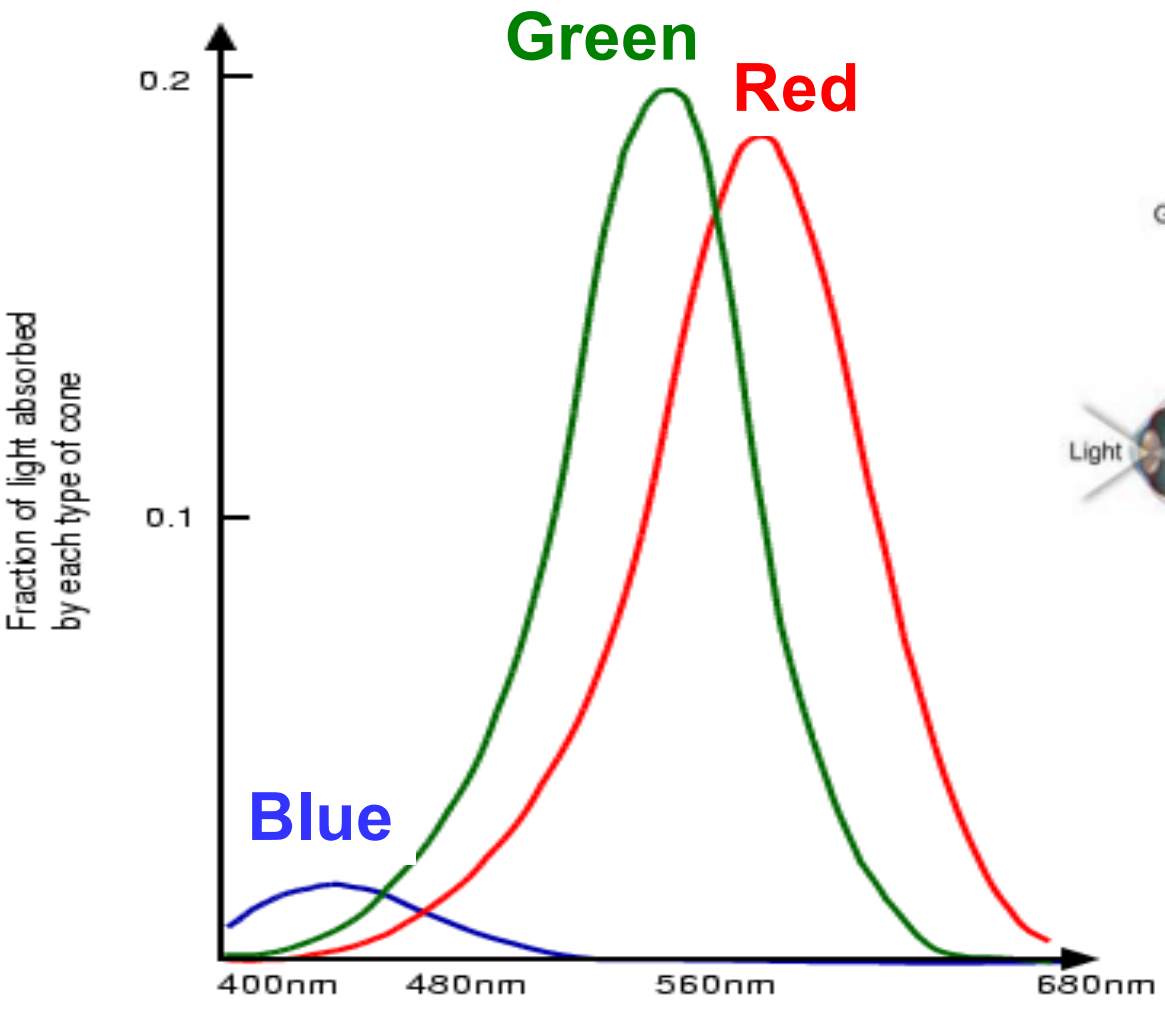
Cones
detect detail and colour, central, 6 million

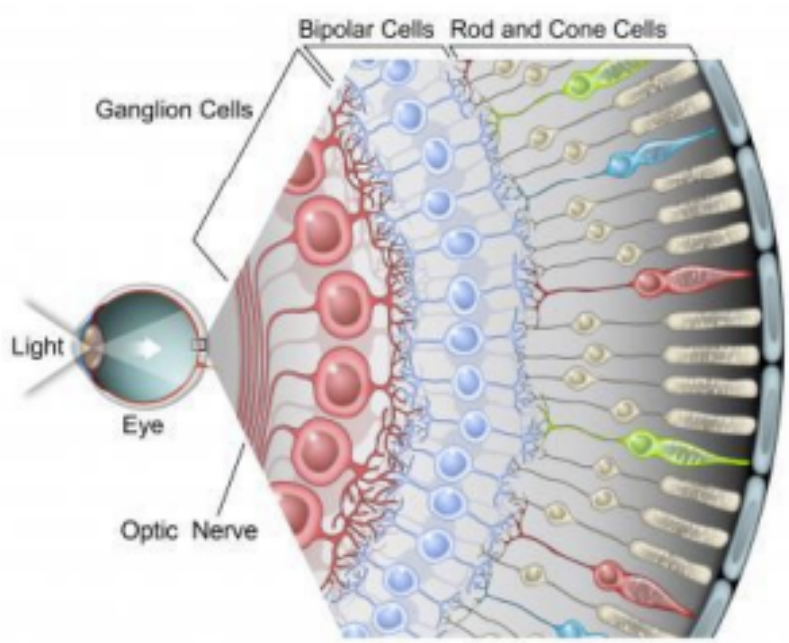
Rods
sensitive to light & motion, off-centre, 120 million

Fovea
densely packed with cones, fine detail, uniform resolution

What is colour
Sensing

Colour (spectral) sensitivity of the cones





What is colour
Sensing

Colour is a percept

- White is a colour, the perception which is evoked by light that stimulates all three types of colour sensitive cone cells in the human eye in nearly equal amounts and with high brightness. [Wikipedia]

- Red is a colour, the perception of which is evoked by light that stimulates "red" sensitive cones in the human eye, and no other cones ("green" or "blue")

Colour is not a physical phenomenon

What is colour
Sensing

Colour vision deficiency (colour blindness)

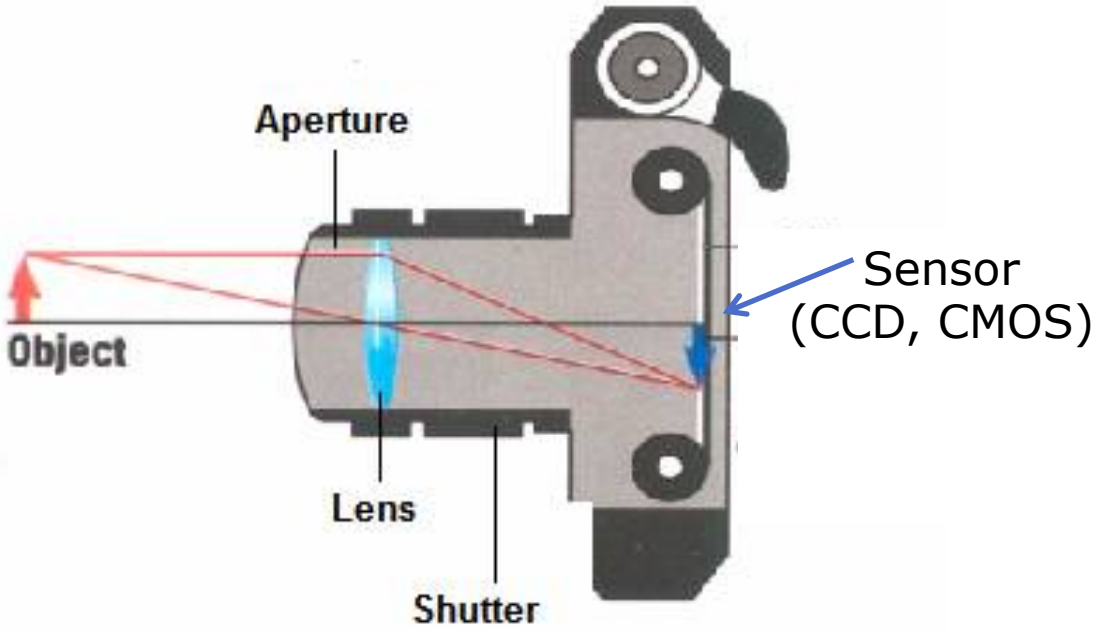
- The decreased ability to see colour or differences in colour.
- Caused by a deficiency one or more of the three sets of color sensing cones in the eye.

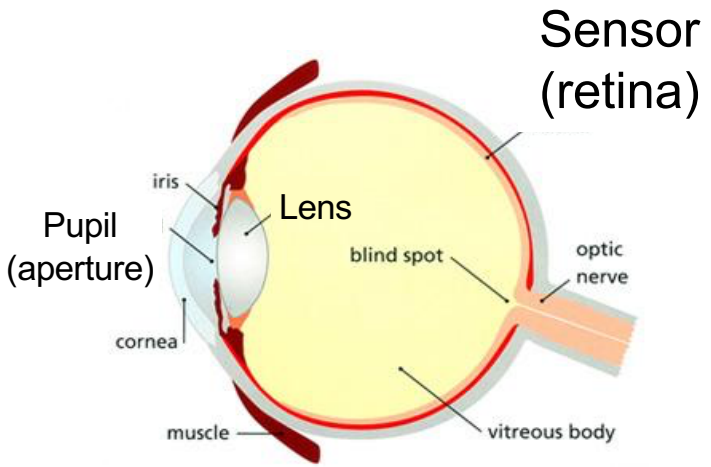
Typical perception

Deficient perception

[Source: Wikipedia]

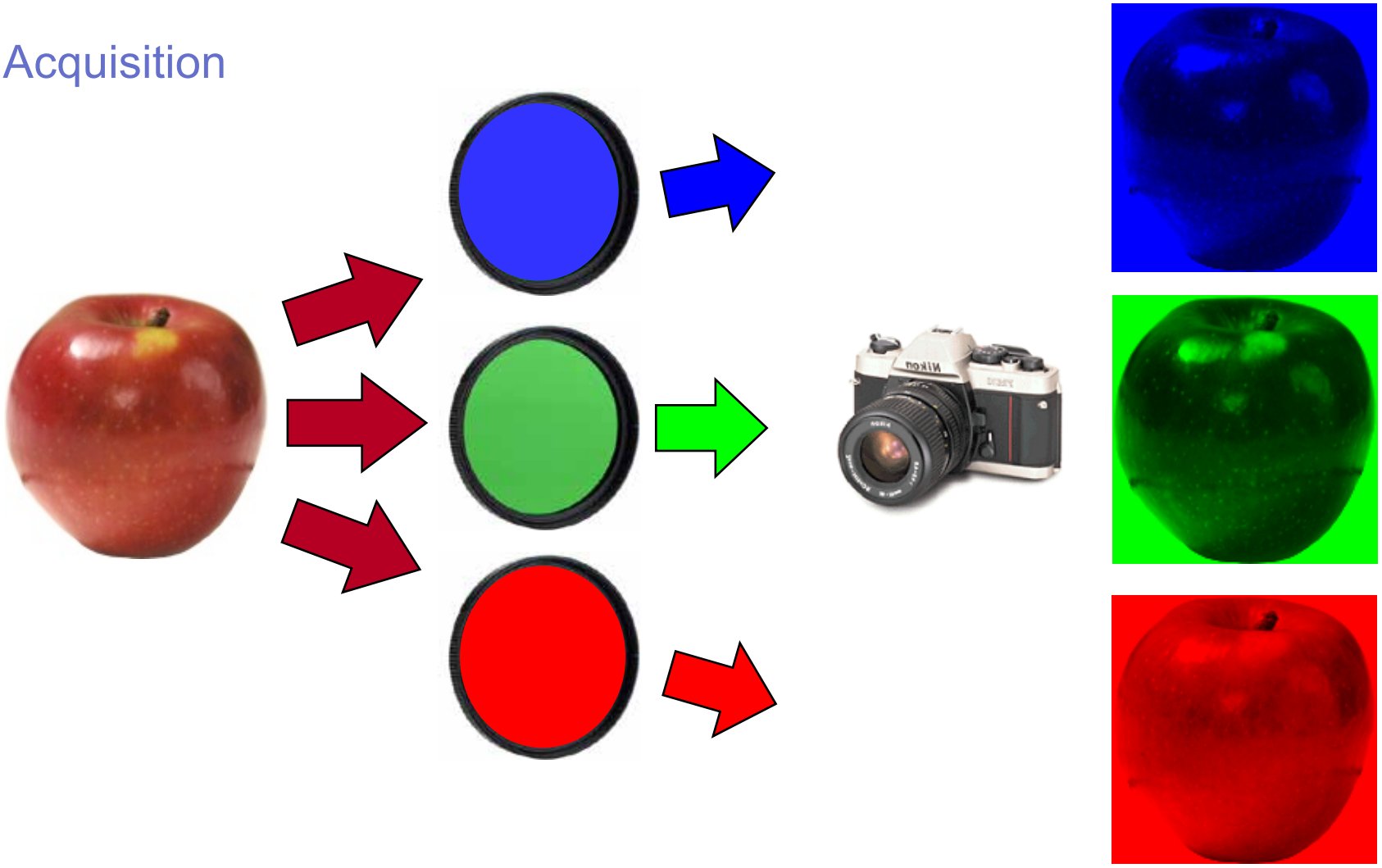
Colour images
Acquisition





Colour images
Acquisition

Acquisition



Primary colours tutorial http://micro.magnet.fsu.edu/primer/lightandcolor/primaryhome.html

Colour images
Acquisition

Bayer filter

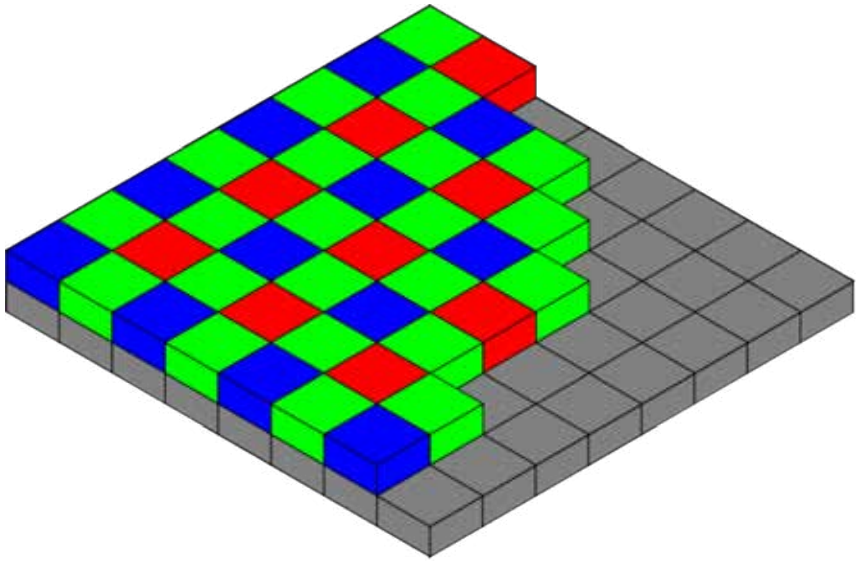


Image mosaic

Interpolated final image

Colour images
Acquisition

Bayer filter

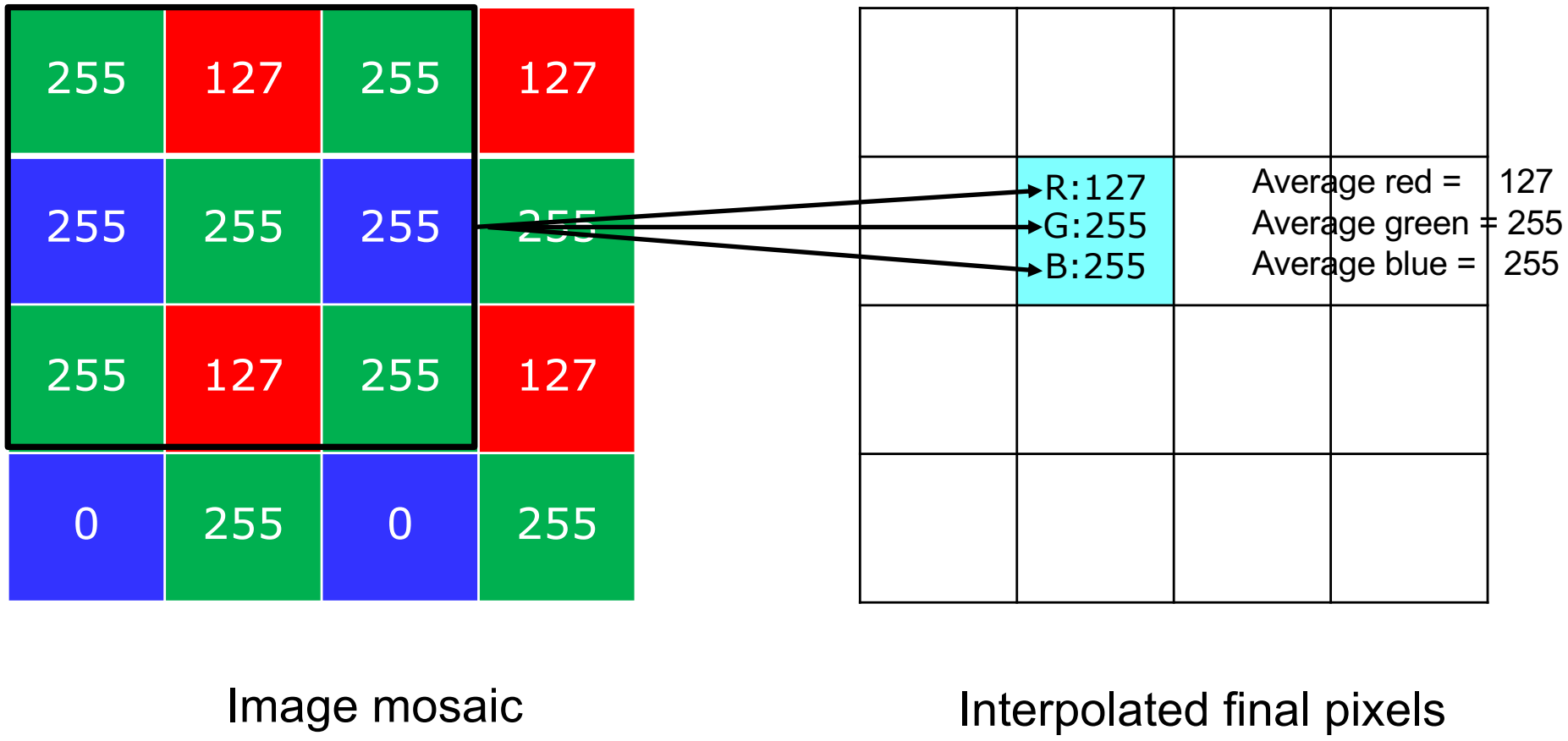


Image mosaic

Interpolated final pixels

Colour images
Acquisition

Bayer filter

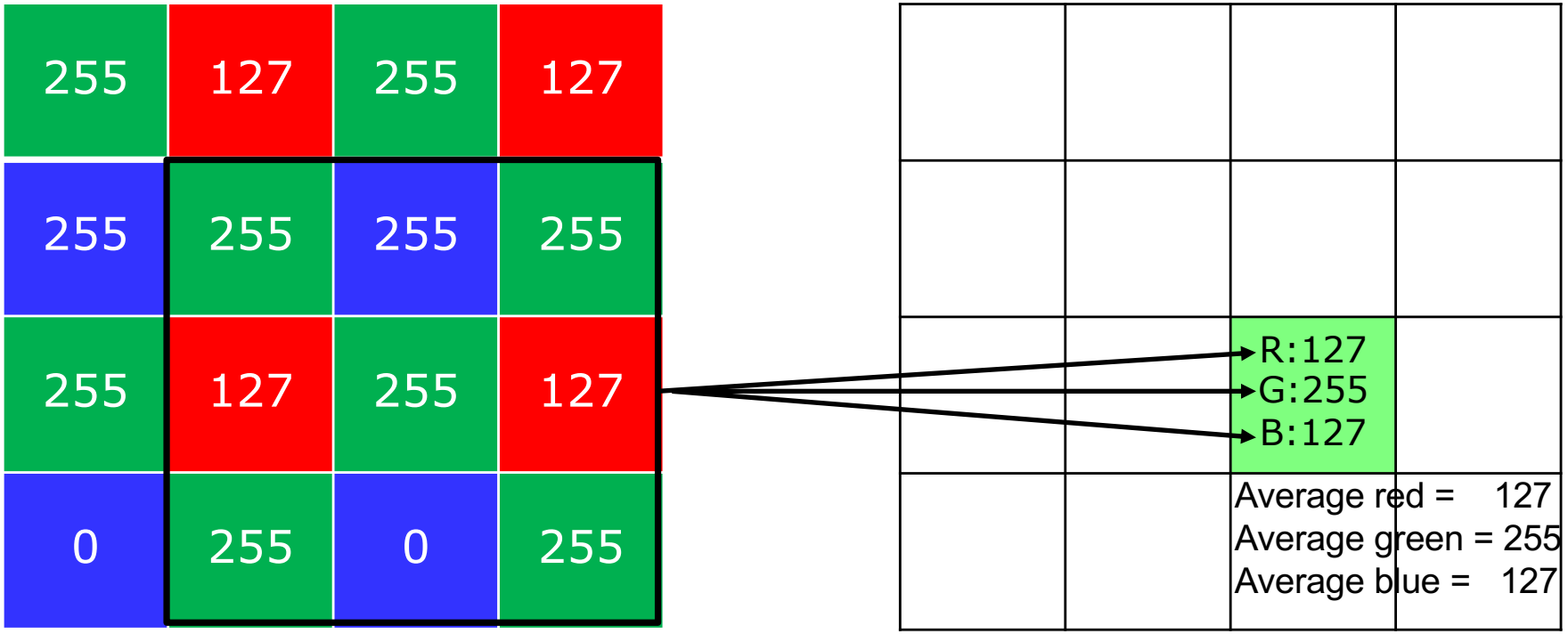


Image mosaic

Interpolated final pixels

Colour images
Acquisition

Bayer filter

255	127	255	127
255	255	255	255
255	127	255	127
0	255	0	255

Image mosaic

	R:127 G:255 B:255	R:127 G:255 B:255	
	R:127 G:255 B:127	R:127 G:255 B:127	

Interpolated final pixels

Colour images
Acquisition

Bayer filter

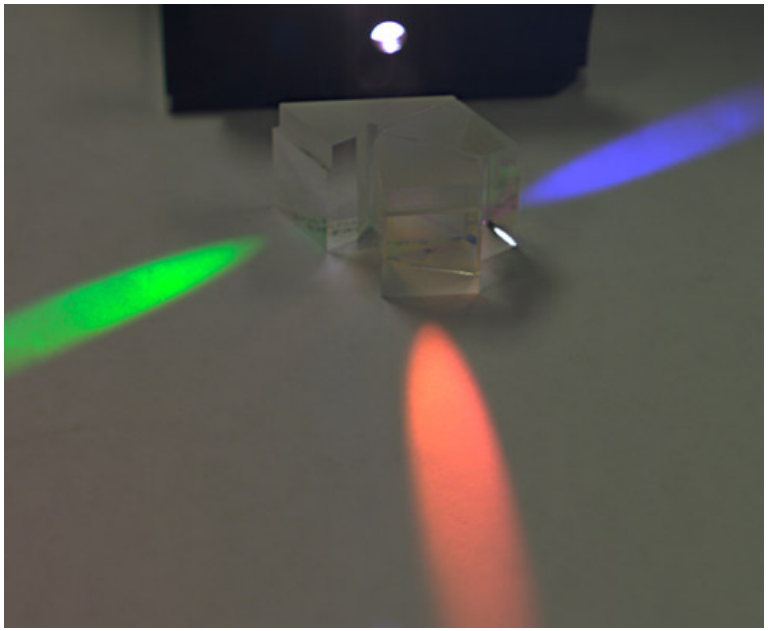
Image mosaic

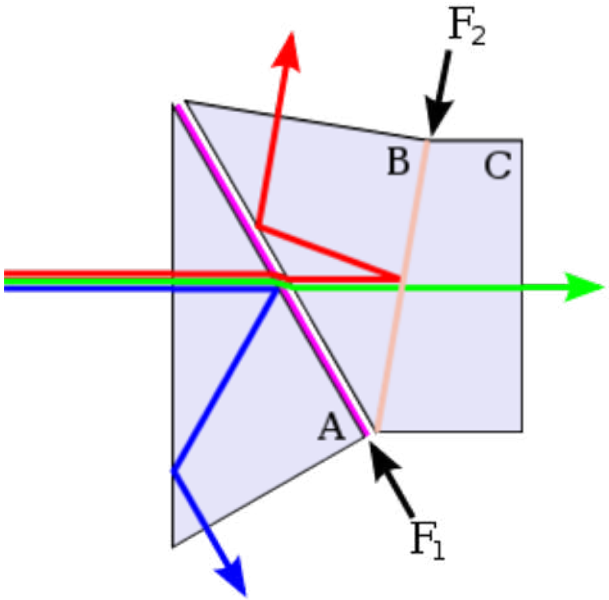
	R:255 G:255 B:255	R:255 G:255 B:255	
	R:255 G:255 B:255	R:255 G:255 B:255	

Interpolated final pixels

Colour images
Acquisition

Three-CCD (3CCD)

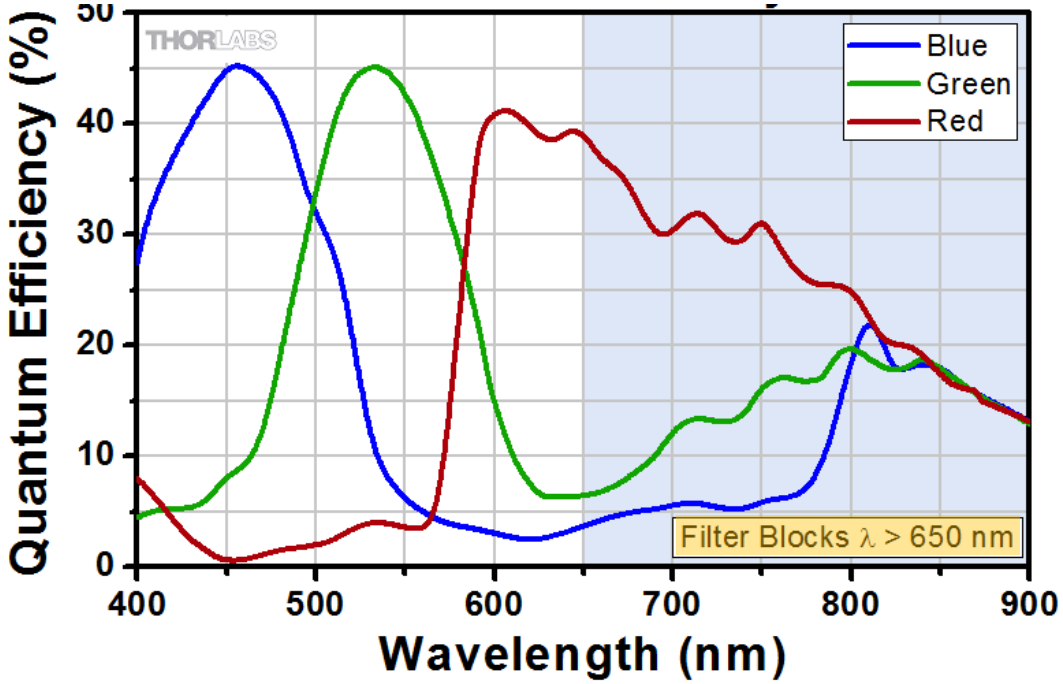




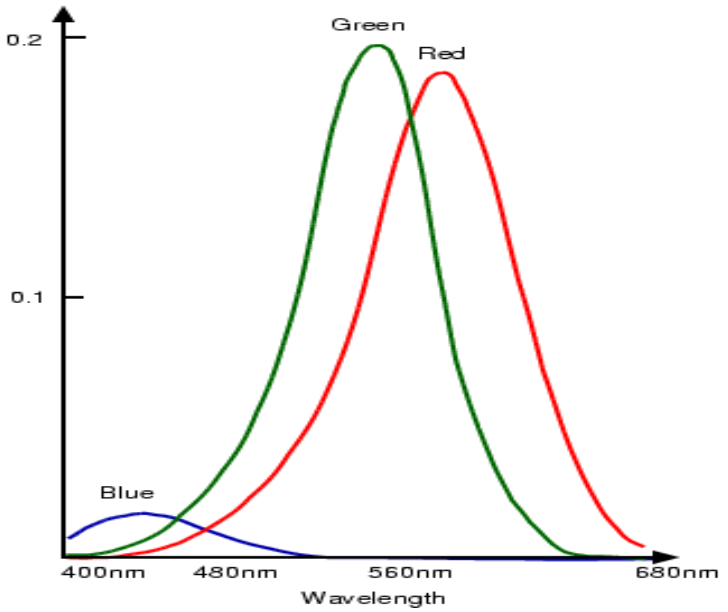
Prisms

Colour images
Acquisition

Spectral sensitivity of a typical CMOS sensor



Spectral sensitivity of the cones



Colour spaces

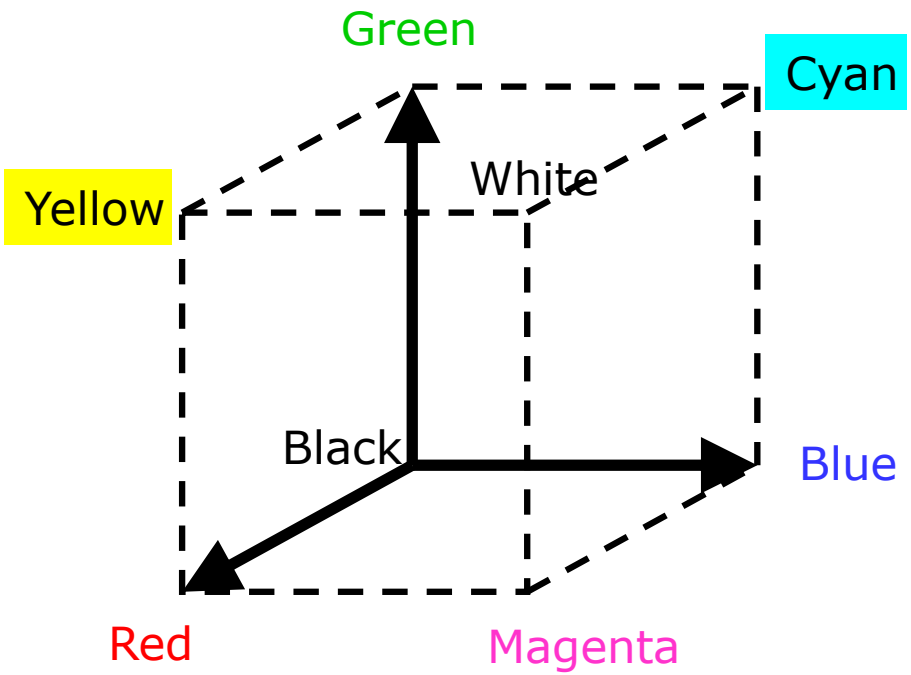
- A colour space represents a system for measuring colours
- Most colours can be represented using three colour components
- They are called the **primary colours** (or the primaries)

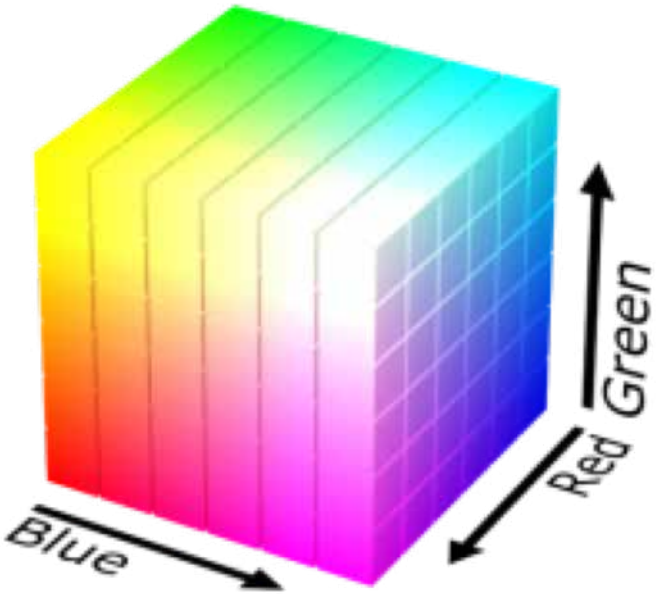
Colour spaces

- There are many colour spaces.
- The choice of a particular space depends on the context in which we want to describe colours. The four most common colour spaces are:
  - RGB
  - HSV
  - CMY (K)
  - XYZ

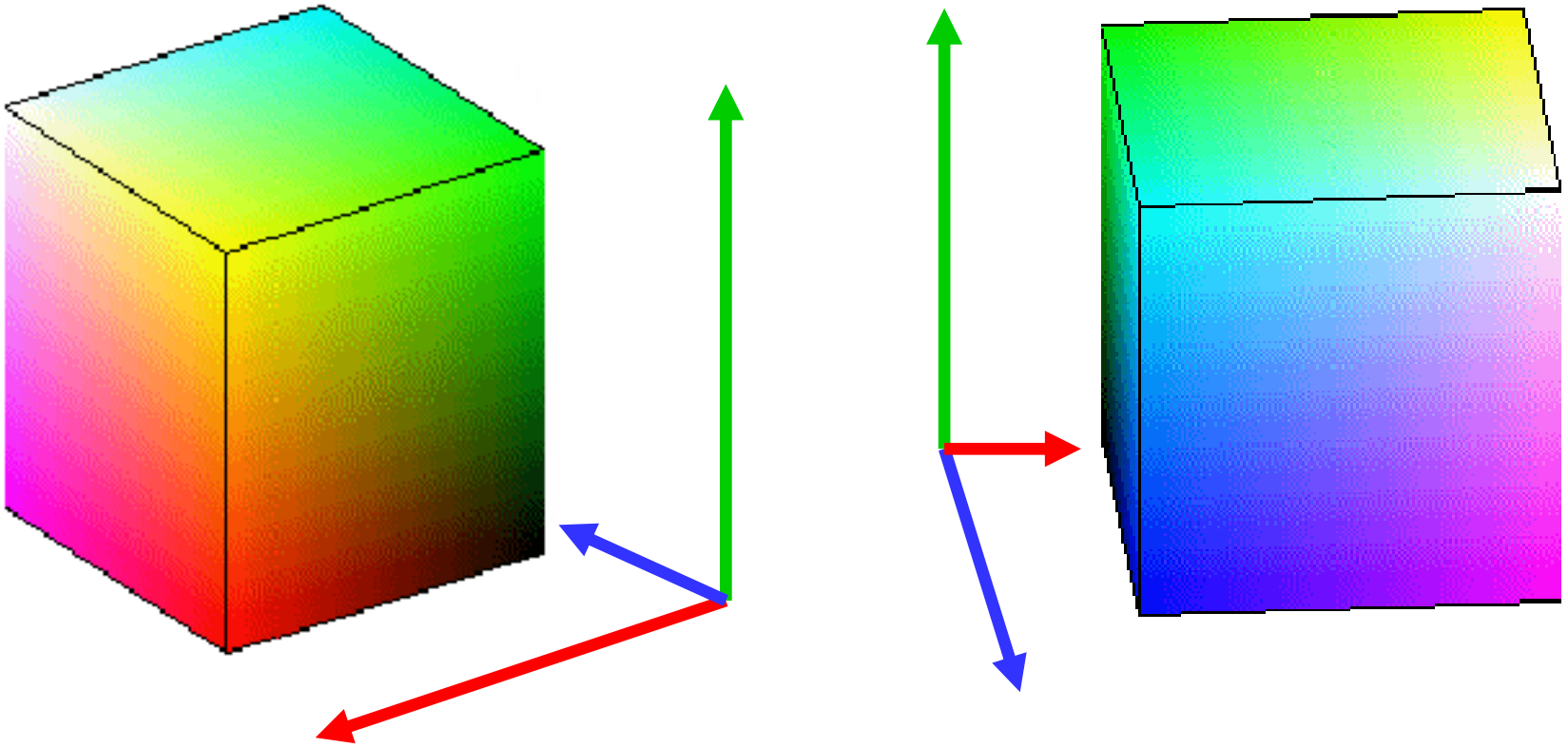
Colour spaces
RGB

- Primaries: Red - Green - Blue
- Similar to colours detected by colour receptors in the eye
- Used in display technology





Colour spaces
RGB



Colour spaces
RGB

Mixing is **additive**

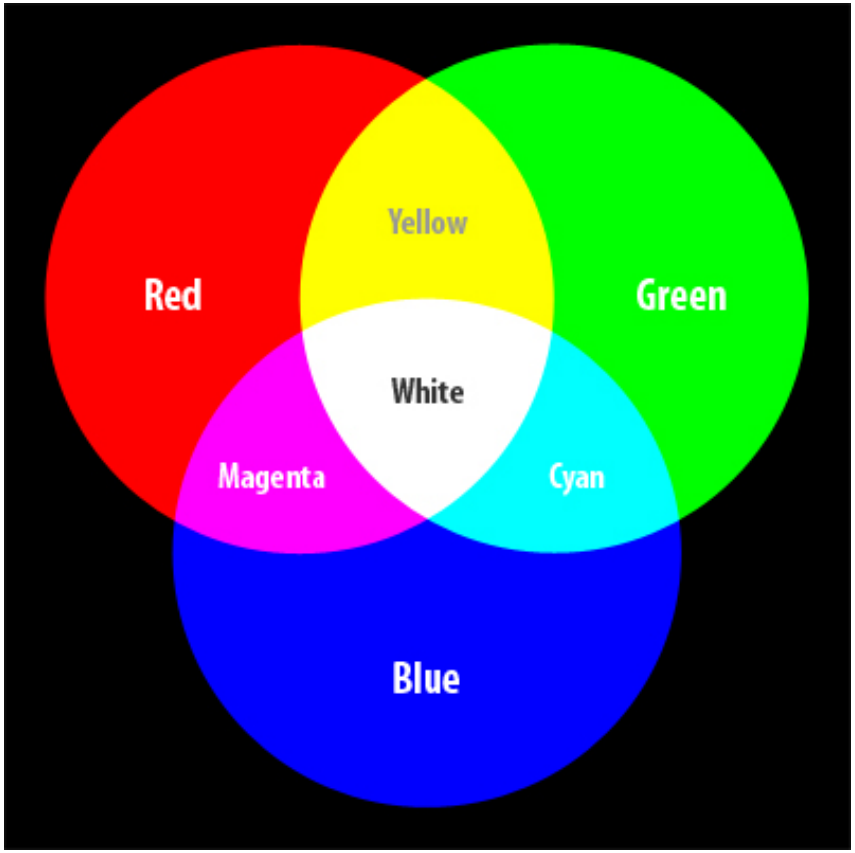


Image source: http://www.netsourceinc.com/blog/quick-color-guide

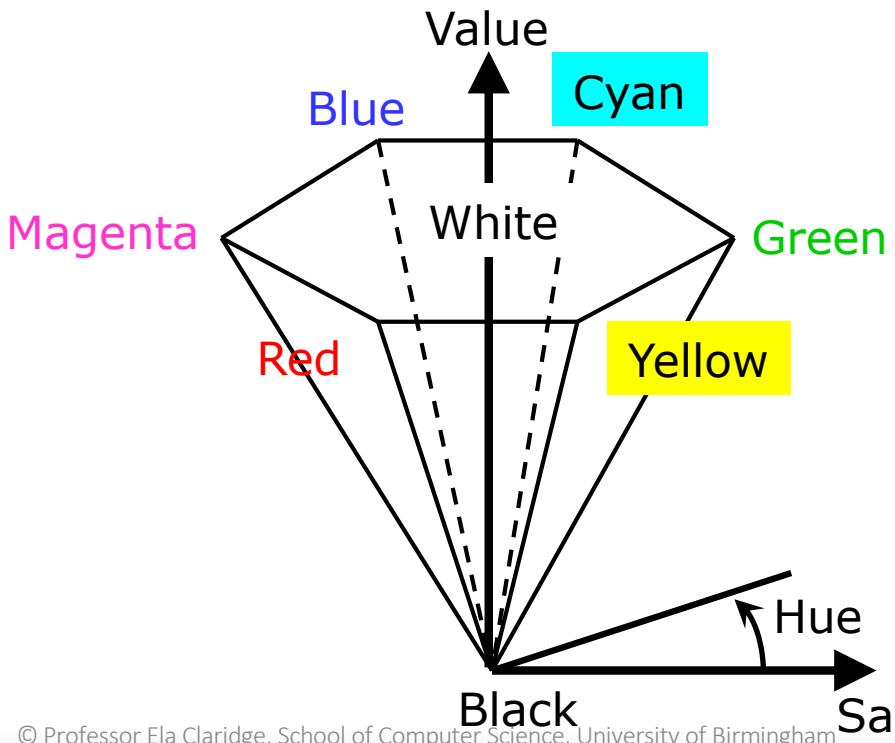
Colour spaces
RGB

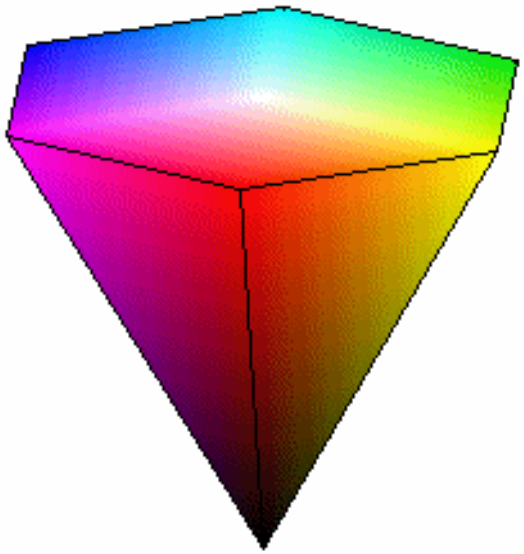
RGB

Colour spaces
HSV / HSL

- Primaries: Hue - Saturation – Value
- Or: Hue – Saturation – Lightness

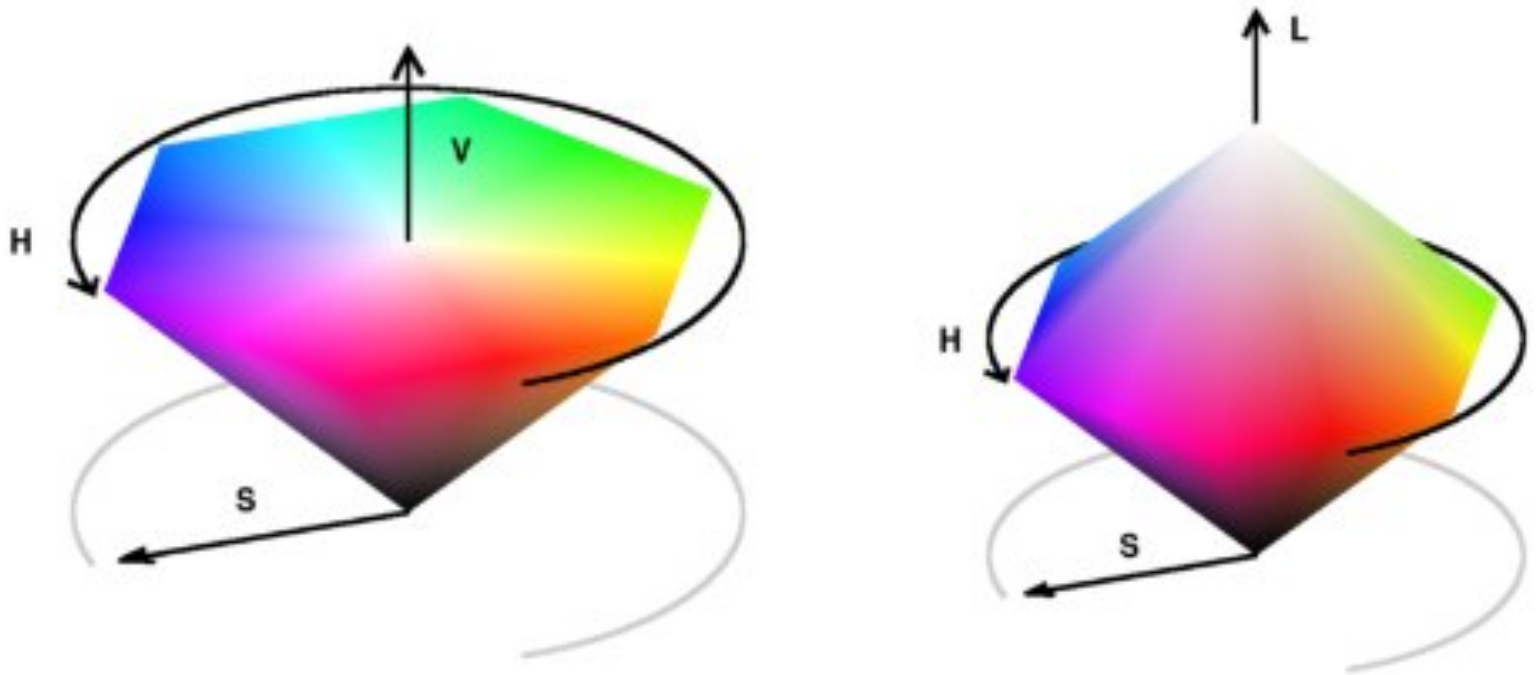
- Colour space related to subjective description of colours





Colour spaces
HSV / HSL

Conic representation of the HSV and HSL colour spaces



Source: https://uk.mathworks.com/matlabcentral/fileexchange/28790-colorspace-transformations/content/colorspace/colorspace.html

Colour spaces
CMY(K)

- Primaries: Cyan Magenta Yellow BlacK
- Used in printing technology
- Complement of RGB

Colour spaces
CMY(K)

Mixing is **subtractive**

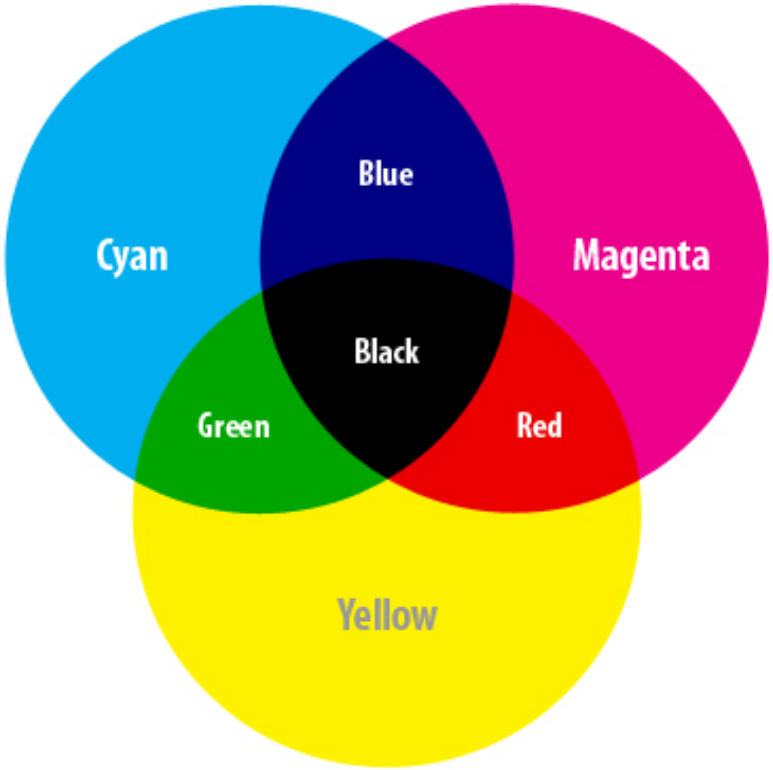


Image source: http://www.netsourceinc.com/blog/quick-color-guide

Colour spaces
CMY(K)

Colour spaces
CIE XYZ

- *CIE: Commission Internationale de l'Eclairage*
- Primaries: X, Y, Z
- Based on colour perception by humans
- Device independent

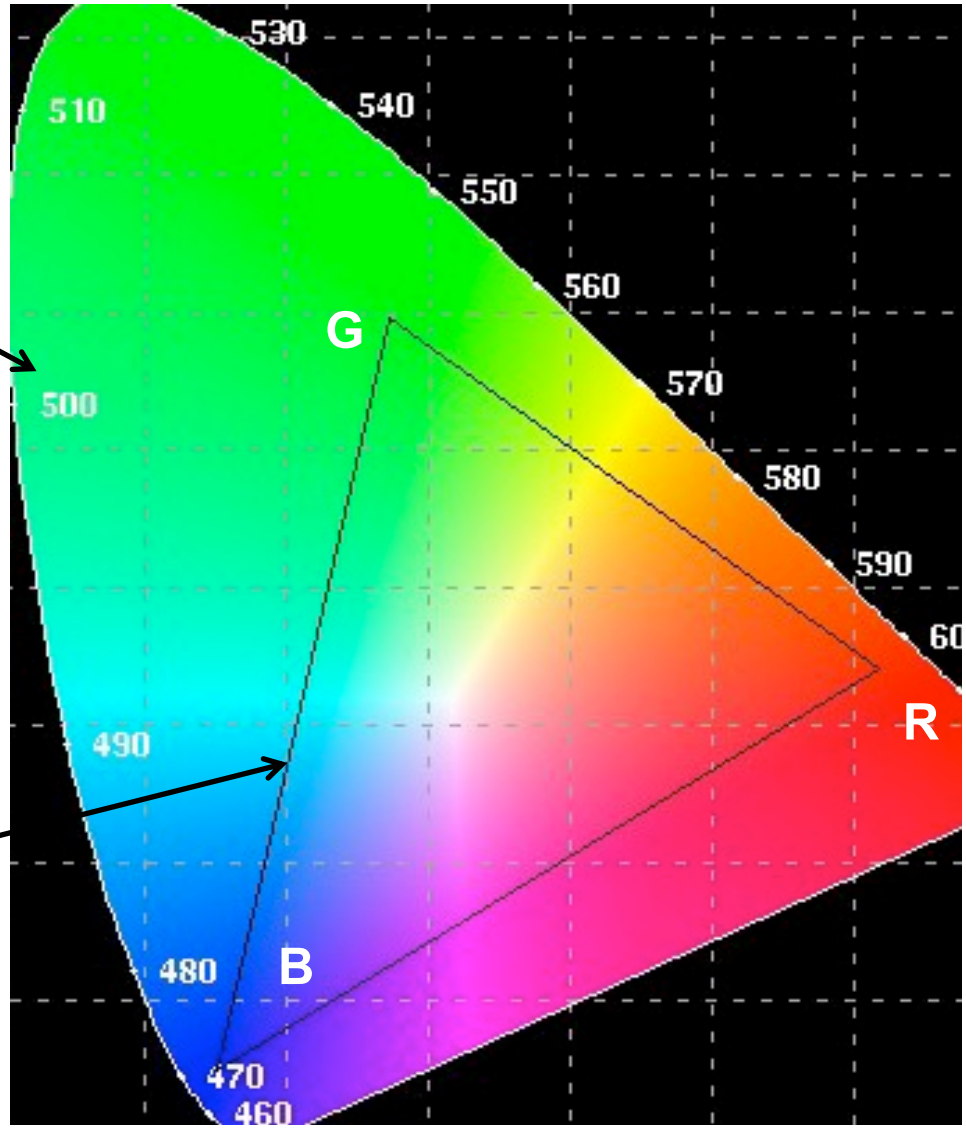
- The most common representation of the CIE XYZ space is the CIE chromacity diagram

Colour spaces
CIE XYZ

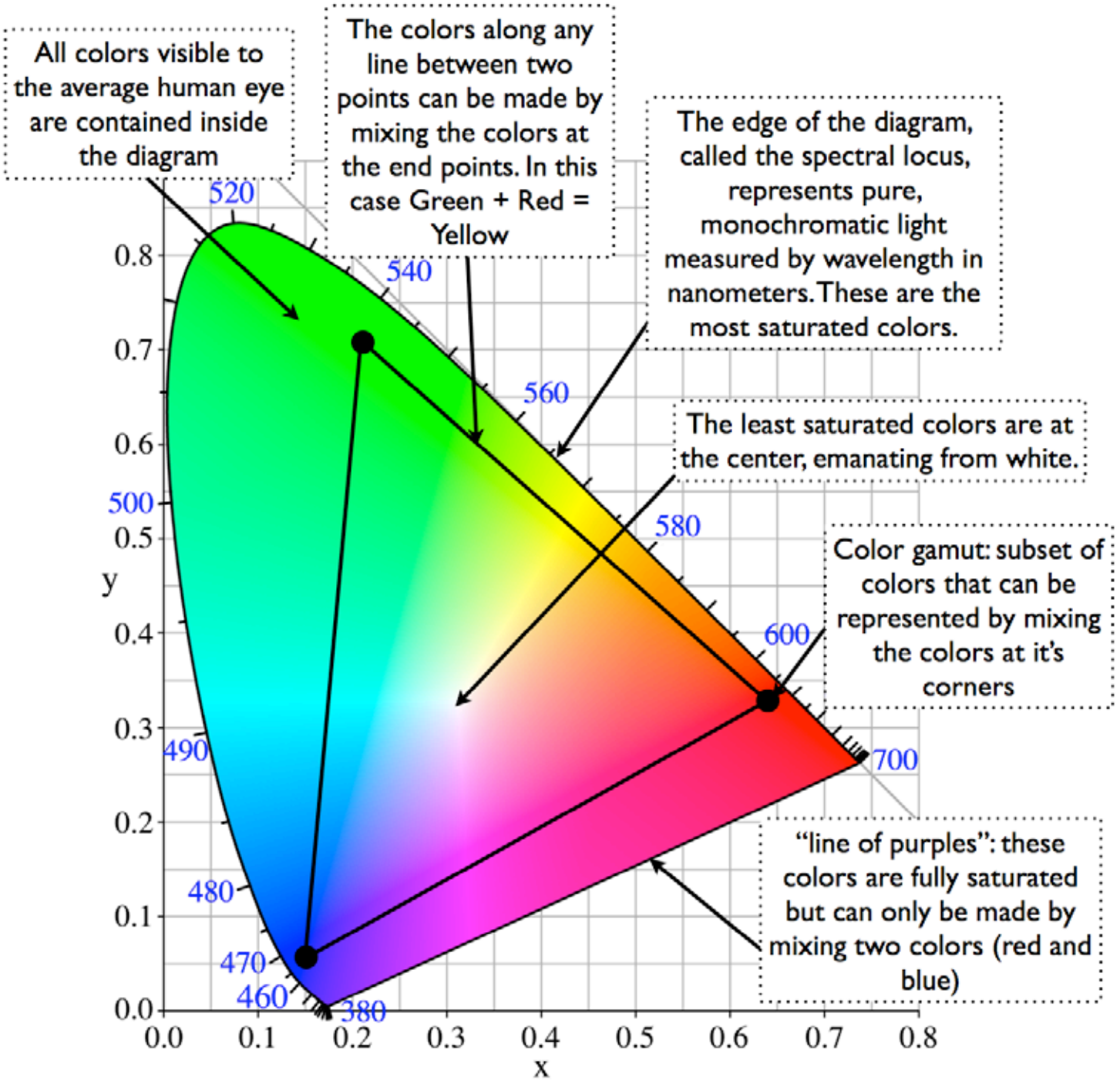
Wavelengths on the periphery

Chromacity diagram

Gamut



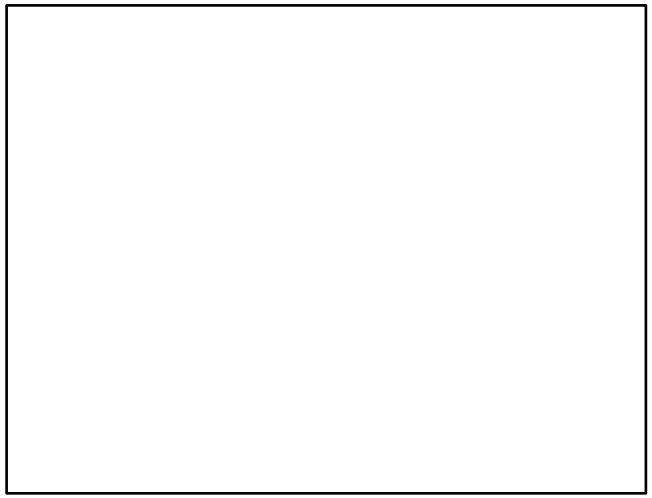
Chromacity diagram

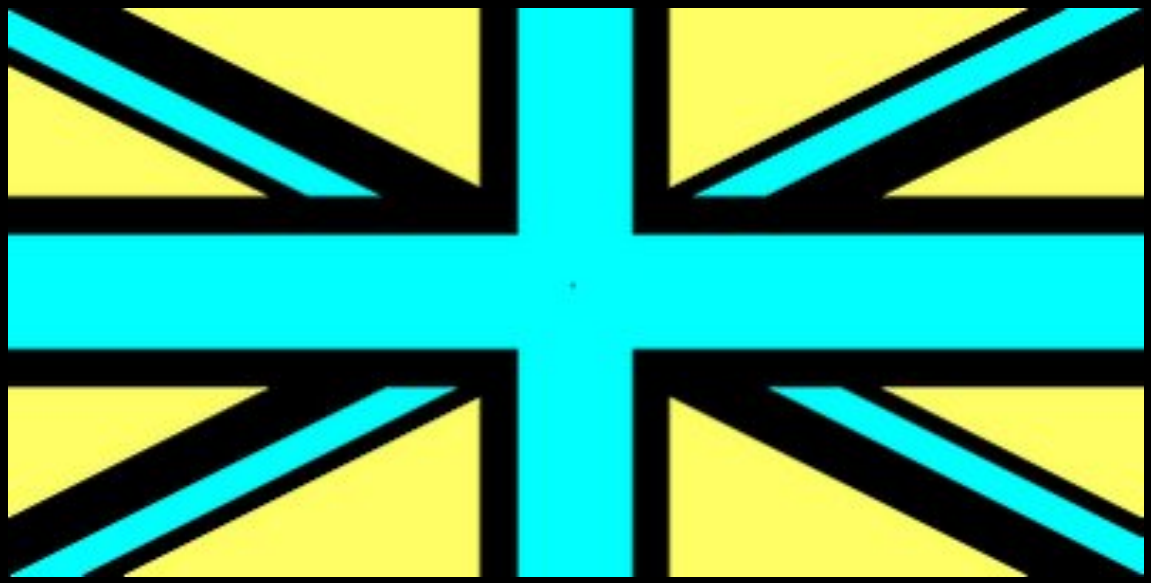


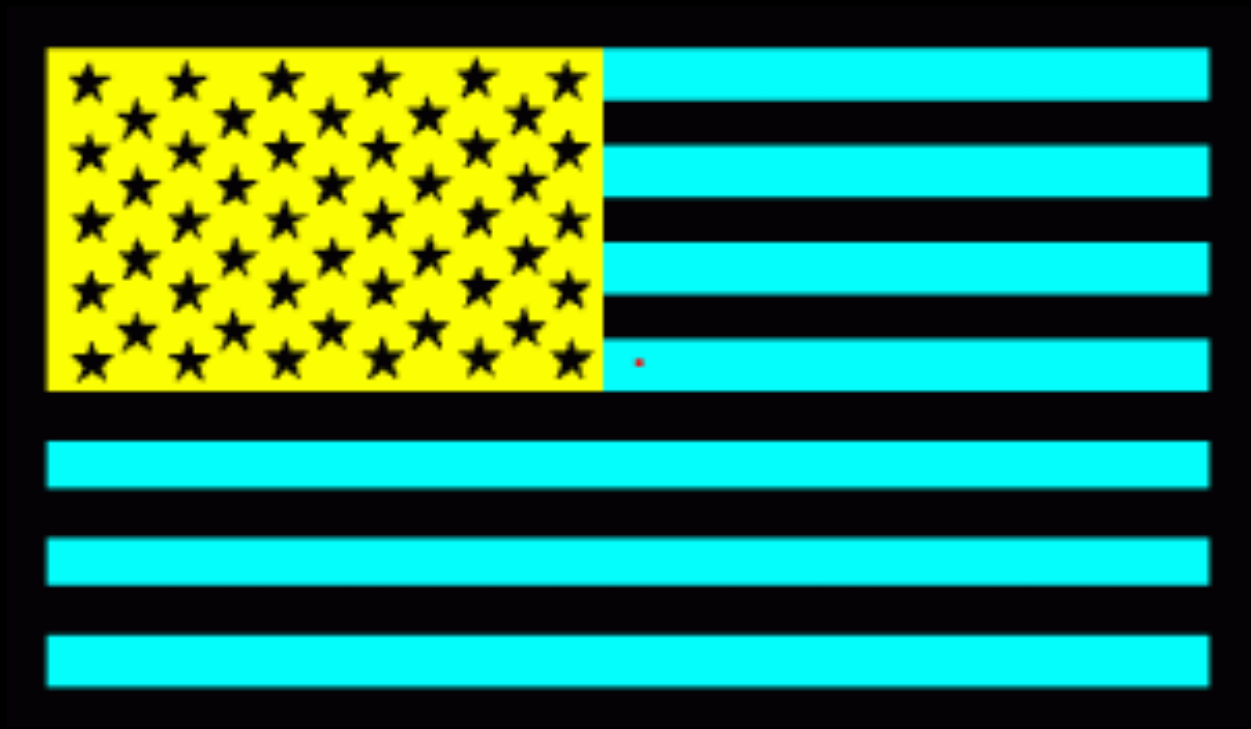
Source: https://dot-color.com/tag/chromaticity-diagram/

Colour spaces

Colour picker experiment





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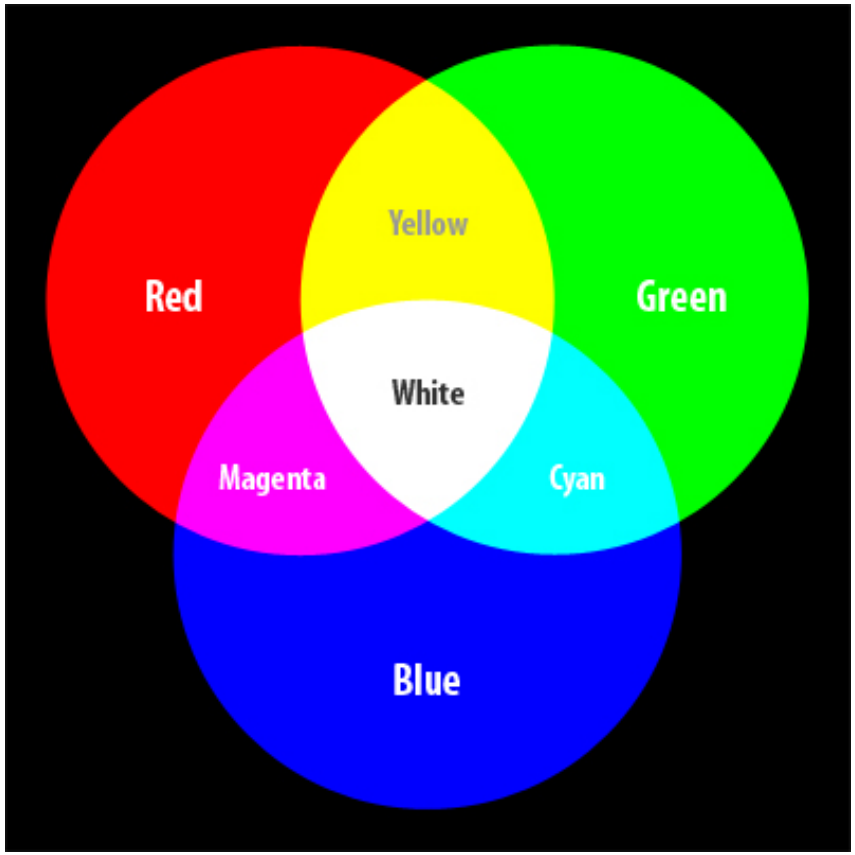
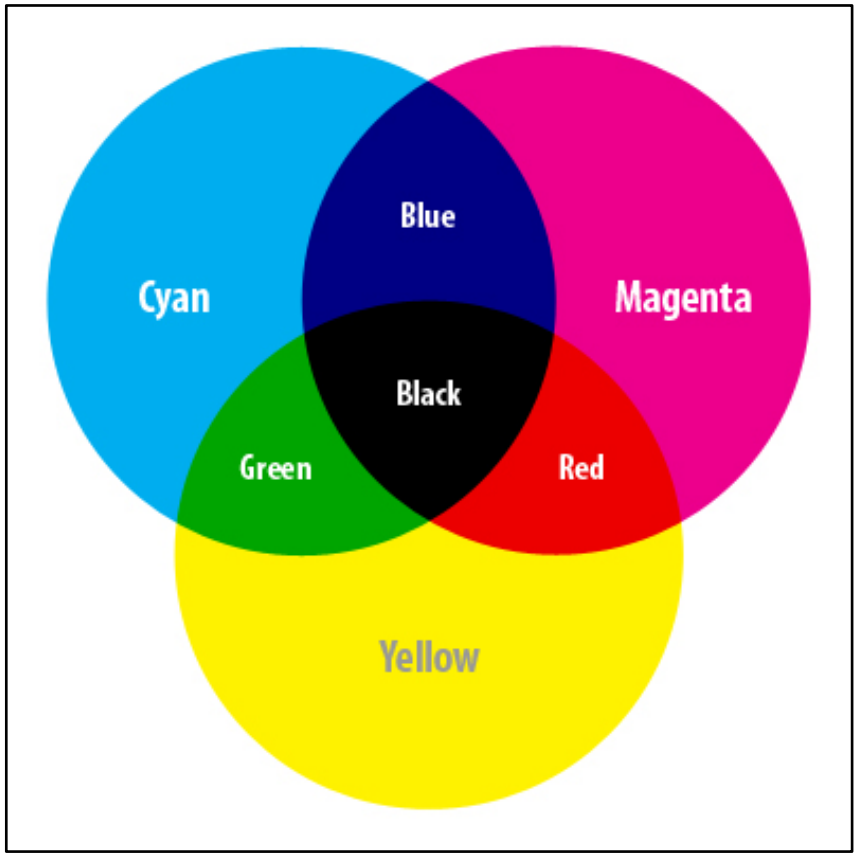
Afterimage illusion
Complementary colours





In this lecture we have covered:

- Colours and their origins
  - Physical underpinnings
  - Human visual perception
- Colour images
  - Image acquisition
  - Colour spaces

Next lecture

- Digital representation of colour images
  - Colour mixing (vector arithmetics)
  - Pixel arrays
  - Colour models

Further reading and experimentation

- **Bayer filter**: http://www.cambridgeincolour.com/tutorials/camera-sensors.htm
- https://en.wikipedia.org/wiki/Demosaicing
- **Light and colour tutorial:**
- http://micro.magnet.fsu.edu/primer/lightandcolor/index.html
- **Additive colours**: http://micro.magnet.fsu.edu/primer/java/primarycolors/additiveprimaries/index.html
- **Subtractive colours**: http://micro.magnet.fsu.edu/primer/java/primarycolors/subtractiveprimaries/index.html
- **Colour separation**: http://micro.magnet.fsu.edu/primer/java/primarycolors/colorseparation/index.html
- **Afterimage illusion**: https://en.wikipedia.org/wiki/Afterimage