SEEING

'Seeing' lecture 2

The retina and colour vision

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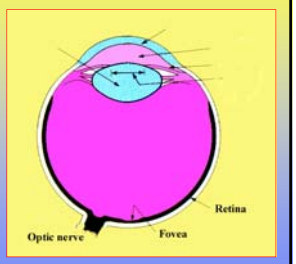
The retina

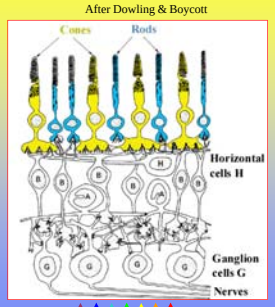
- Forming an image on the back of the eye is the easy part. 'Seeing' the image is hard
- The human eye has two separate seeing systems, interleaved: the **rod** retina and the **cone** retina



Rods & cones

- The rod retina is the low illumination seeing system, for twilight and night-time use
- The cone retina is for daytime use

After Dowling & Boycott



- Rods and cones point inwards!

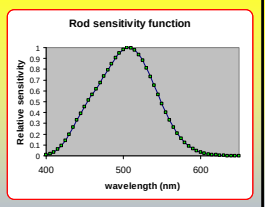
Light

Rod facts - 1

- ~120 million rods distributed over most of the retina except near the fovea
- There are no rods at the very centre of your visual field; we can't see detail in poor illumination
- Rods are connected in groups; there are far fewer optic nerves going to the brain than rods
- Rod vision detects edges and motion very well

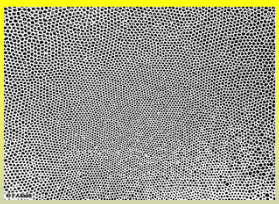
Rod facts - 2

- Rods return only a black-and-white signal to the brain; i.e. rods don't see in colour



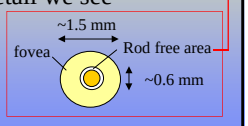
- Rods are most sensitive to turquoise light (500 nm) and pretty insensitive to red light
- Rod pigment is bleached by light and is less effective in bright light; rods take about 20 - 30 minutes of 'dark adaptation' before they are most efficient

Ahnelt, Glosmann and Schubert →

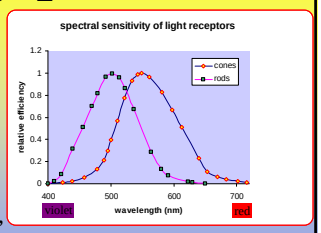


Cone facts - 1

- ~5 million cones
- There is a concentration in fovea, region about 1.5 mm in diameter (<5° view) where ~100,000 cones show us most of the detail we see
- The central part of fovea contains only cones
- Most acute vision limited to *foveola*, covering ~0.4 mm (~1.5° view)



Cone facts - 2

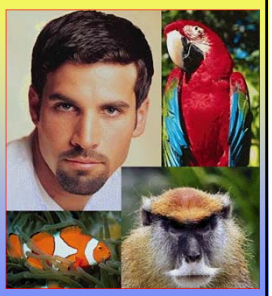


- Overall sensitivity peaks in the green
- Colour vision is provided by 3 types of cone with different coloured light absorptions, loosely called red, green and blue cones
- Sensation of whole spectrum of colours provided by exciting differently the 3 cone types

Colours show functionality

Colour vision

haves



have - nots

Trees seen in monochrome

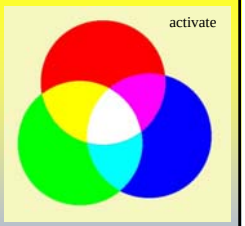
Trees seen with blue-green vision

Picture by Stoerig (1998)

Trees seen with red-green-blue vision

Picture by Stoerig (1998)

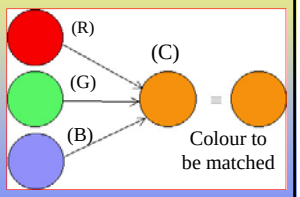
Colour mixing



- Most colours can be made by mixing 3 primary colours
- The diagram shows the effect of overlapping red, green and blue primary coloured lights on a wall
  - where all 3 colours fall, white is created when the relative amounts of each colour are right
  - where 2 colours fall, yellow, cyan and magenta are created

3-colour matching

- Superimposing variable amounts of 3 coloured primaries allows most colours to be produced



- Colour TV sets and monitors reproduce pictures using exactly this effect. It is called **additive colour mixing**

$$(C) \equiv x\,(R) + y\,(G) + z\,(B)$$

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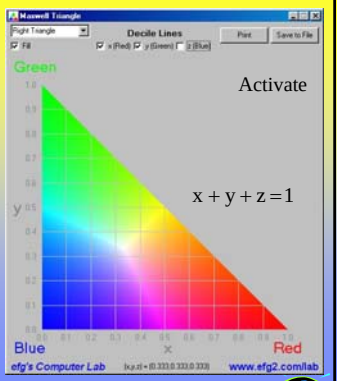
Maxwell's colour triangle

- Maxwell realized that the 3-colour mixing relationship (which he investigated in detail in Aberdeen) allowed colours to be represented within a triangle
- Maxwell took the world's first colour photograph, in 1861



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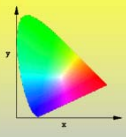
CIE chromaticity diagram

- Maxwell's triangle
  - changes when you make a new choice of primary colours (R) (G) (B)
  - cannot show all possible colours because some colours need -ve coefficients



- The Commission Internationale d'Eclairage (CIE) defined a new set of primaries (X) (Y) (Z) in terms of which all colour matches have +ve coefficients

$$(C) \equiv x\,(X) + y\,(Y) + z\,(Z)$$

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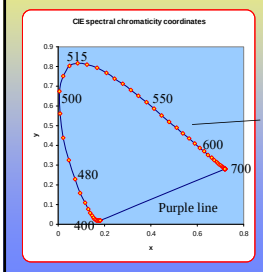
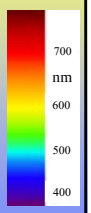
Spectral wavelengths are the purest colours



- Spectral wavelengths occur around the outside of the CIE diagram



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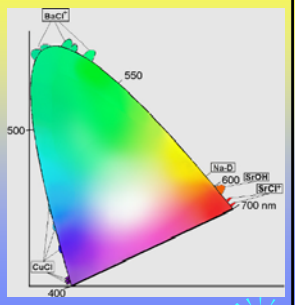
An example of plotted colours

- Colours in fireworks are produced by the rapid burning of just a few compounds
- The chromaticity chart opposite shows the spectral colours produced by these compounds
- Other colours are synthesized by additive colour mixing



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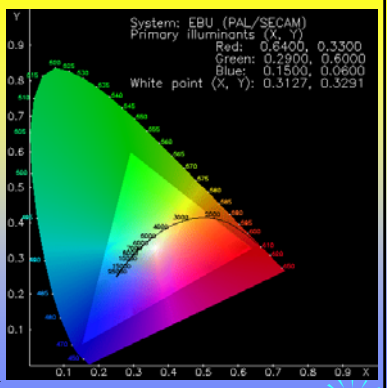
Colour TV

- Colours reproduced by a colour TV are limited to the triangle shown within the CIE diagram
  - note Planck spectrum colours
- Run program from www.efg2.com/lab



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Total 8.1% males, 0.4% females

Colour defectives

- Truly colour blind: monochromats
  - no functioning cones ~0.003% population
- Dichromats can match any colour with only 2 primaries
  - **protanopes** (1.2% males, 0.02% females) lack red sensitive cones
  - **deuteranopes** (1.5% males, 0.01% females) lack green sensitive cones
  - **tritanopes** (0.002% males, 0.001% females) lack the blue sensitive cones

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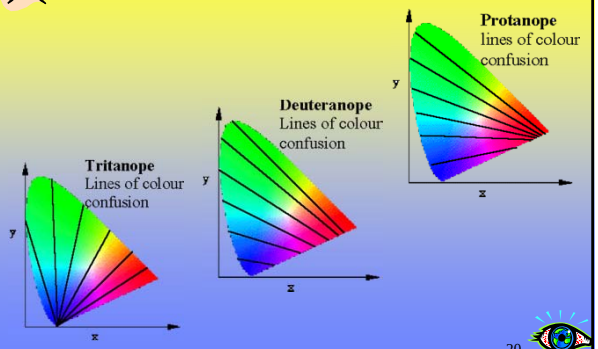
Colour confusion loci



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Anomalous trichromats

- Need 3 primaries to match a colour but do not use same amounts as 'normal' people
- Total 5.4% males, 0.4% females
- Largest group are **deuteranomolous** who exhibit a range of defects between normal vision and that of deuteranopes.
  - Most common symptom is the ability to see red light but not to see it as a different colour from green light

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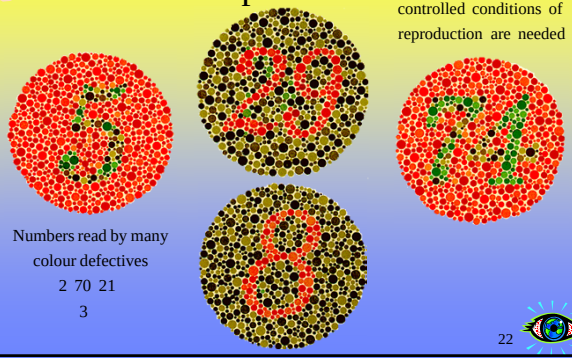
Ishihara pseudoisochromatic plates

For accuracy of testing, controlled conditions of reproduction are needed



Numbers read by many colour defectives

2 70 21

3

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Final lecture

The third lecture on 'seeing' will be on

- measuring illumination
- using lenses to improve vision (spectacles, microscopes)

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