Colour Vision 2
Metamers and Theories of Colour Perception
Structure

- Metamers: colour mixing (of light).
- Three theories of colour vision
  - Trichromatic Theory
  - Opponent process Theory
  - Dual process Theory
- Colour aftereffects as evidence for these theories.
Making colours

• A TV is evidence that any colour (almost) can be created by a combination of 3 primary colours.
• But which three colours?
• *Almost* any red-ish, blue-ish and green-ish lights will do …
Metamerism

This yellow can be made from a mixture of red and green lights...
Metamers

If two different luminance spectra are perceived as the same colour then these two spectra are *metamers* of each other.
Metamers

When viewed in isolation, if two differently coloured surfaces (i.e., with different luminance spectra) produce the same cone outputs then they are perceived as the same colour.

Cone triplet outputs

- S: -10mV
- M: -20mV
- L: -30mV

Perceived Colour 1
Why are there metamers?

‘Metamers’ for one cone

If you had only one cone type then the output produced by a given wavelength (eg 520nm) can be reproduced exactly by a different wavelength (600nm).

The same type of behaviour ensures that many different spectra can induce the same outputs in the three cone types.

This is the principle of univariance: a cone’s output indicates how much light it absorbed, not the wavelength of that light.
Metameric matching for two cone types

- If we had 2 cone types then we could match any single test wavelength with a combination of two coloured torches.
Metameric matching for two cone types

- A green torch yields a response from the M and L cone types which is less than their response to the test light.
Metameric matching for two cone types

- The difference in cone outputs can be made up by adjusting the brightness of a red torch …
Metameric matching for two cone types

- **M-cone** response to test light =  
  \[
  \text{M-cone response to green torch} + \text{M-cone response to red torch}.
  \]

- **L-cone** response to test light =  
  \[
  \text{L-cone response to green torch} + \text{L-cone response to red torch}.
  \]

In practice, we get to adjust Brightness of torches too.
Metamers and cone outputs

Test light

Luminance spectrum reflected from white surface

Cones

Cone triplet outputs

-10mV

-20mV

-30mV

Perceived Colour 1
Different illuminance spectrum gives different luminance spectrum, but same cone outputs, and therefore same perceived colour (when viewed in isolation).
Metamer summary

• Metamers exist because any *single* cone triplet output can be produced by *many* different luminance spectra.

• In terms of metameric matching, this means that any cone triplet can be produced by many settings for three torches used to create the luminance spectrum.

• Most importantly, because a given cone triplet produces a single perceived colour (when viewed in isolation), *each perceived colour can be produced by many different spectra.*
Colour Blindness

• 8 % males and < 1% females are colour blind.

• In general, being colour blind means being unable to distinguish between certain colours.

Engine painted by William Stroudley in a colour he called 'improved engine green'. This is an orangey-brown to trichromats
From Thompson on viperlib.
Theories of colour perception
In order to understand colour perception, we must establish what takes place here. A first stage in doing this is to consider the facts about the psychological experience of colour perception. This was what the original theories of colour perception were based on.
Theories of Colour Vision: 1
Young-Helmholtz Trichromatic Theory

- The trichromatic theory states that there are 3 types of colour receptor in the human eye, with different but overlapping responses to different wavelengths of light.
- Progressively constructed by Palmer (1777), Young (1802) and Helmholtz (1856).
- The fact that *metameric matching* required exactly THREE lights was used to support this theory.
- Posits that different patterns of activation correspond to the perception of different colours.
- Existence of three cone types was confirmed by Dartnall, Bowmaker, and Mollon in 1983(!).
Strengths of Trichromatic Theory

• Accounts for the 3 (red, green, blue) dimensions of colour space.
• Accounts for metameric matching (mixing of 3 colours (red, green, blue) is sufficient to match any other visible colour).
• Partially accounts for the three basic varieties of colour blindness:
  - Protanopes lack the long-wavelength receptors
  - Deutanopes lack the mid-wavelength receptors
  - Tritanopes lack the short-wavelength receptors.
Weaknesses of Trichromatic Theory

Doesn’t fully explain colour blindness:

In reality, colour loss in colour blindness occurs in pairs: inability to discriminate *pairs* red-green or yellow-blue.

Colours are never lost in isolation and pairings other than those above are never found.
Weaknesses of Trichromatic Theory

• Accounts for red/green aftereffects, but not blue/yellow aftereffects …
Colour Afterimages
Colour Afterimages
Take home message from these colour aftereffects:

They provide evidence for red-green and blue-yellow opponency, as the aftereffects always involve these particular colour opposites.
Theories of Colour Vision: 2

Opponent process theory

• These observations led to speculation of a pairwise polarity between the colours red/green and yellow/blue.

• Mainly in response to his subjective experience, Ewald Hering developed the **opponent process theory** of colour perception (1878-1964).

• This assumes there are 4 ‘primary’ colours (Red Green Blue Yellow).
Opponent process theory

Colour-opponent cells found in retina and LGN. Here are RFs of ganglion cells sensitive to outputs of cones

Eg, Output maximal if red light in centre and green in surround.
Opponent process theory

These **double opponent cells** are found in the blobs of primary visual cortex. Blue/yellow cells are also found there.

Output maximal if red light in centre and green in surround and is minimal if green light in centre and red in surround.

D = Alignment of color blobs along L and R ocular dominance columns.
Constructing opponent channels

• This is all very well, but how to make B/Y …
Theories of Colour Vision: 3
The Dual Process Theory
Hurvich and Jameson, 1957

• Reconciled the debate between trichromatic theory and opponent process theory by suggesting that both occur, but at different levels in the visual system:
• Trichromatic analysis occurs first followed by an opponent process.
• This theory has subsequently been supported by neurophysiological evidence, but remember…
• These theories were based mainly on introspection and intuitive experience, at the time the theories were proposed scientists did not have access to the brain imaging techniques in use today.
The Dual Process Theory

- Cones yield three channels (L, M, and S) with outputs $r_L$, $r_M$, and $r_S$ ...
The Dual Process Theory

Channel outputs $r_L, r_M, r_S$ are recombined to yield 3 new channels:

- **Red-green** = $r_L - r_M$,
- **Blue-Yellow** = $r_S - (r_L + r_M)$,
- **Luminance** = $r_L + r_M$.
So which theory is correct?

- The dual process theory has largely been supported by physiological evidence.
- The dual process theory adopts ideas from both the trichromatic theory and the opponent process theory.
- The photoreceptors in the retina are trichromatic - with peaks at long (red), medium (green) and short (blue) wavelengths – as predicted by Helmholtz.
- Ganglion cells and cells in the LGN (both of which receive input from retinal photoreceptors) show red-green and yellow-blue opponent processes.
Summary

• There are three main theories of colour vision; the trichromatic theory, the opponent process theory and the dual processes theory. These theories were postulated before we had detailed information about the anatomy of the visual system.

• Neurophysiological evidence has been found which supports all theories, the photoreceptors are trichromatic, ganglion cells and cells in the LGN have colour opponent receptive fields.

• Colour after effects provide compelling evidence of colour opponency (with specific colour pairings).
Reading

Essential
• Frisby and Stone, Seeing Colour

Background