Colour, Vision & Perception
Colour is a matter of …

- Physics (colour)
- Physiology (vision)
- Psychology (perception)
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Light

- Light from the sun is composed of an almost continuous spectrum of electromagnetic radiation.

- A majority of the light waves above 2,000 nanometers (infrared wavelengths) are absorbed by carbon dioxide, water vapor, and ozone.

- The shorter ultraviolet waves are also absorbed by the ozone layer. This filtering effect of the atmosphere limits the spectrum of light waves reaching the ground to those having wavelengths between 320 and 2,000 nanometres.
Physics - Electromagnetic Spectrum

![Electromagnetic Spectrum Diagram](Image)

The electromagnetic spectrum includes a range of frequencies and wavelengths. At the highest frequencies are gamma rays, followed by X-rays, ultraviolet (UV) light, infrared (IR) light, microwave radiation, radio waves, and finally long radio waves at the lowest frequencies. The spectrum is divided into regions based on wavelength: visible light, ultraviolet, infrared, and radio waves.

Visible spectrum:
- Violet: 4,000 Å (400 nm)
- Indigo: 4,250 Å (425 nm)
- Blue: 4,700 Å (470 nm)
- Aqua: 4,900 Å (490 nm)
- Green: 5,500 Å (550 nm)
- Yellow: 6,000 Å (600 nm)
- Orange: 6,300 Å (630 nm)
- Red: 6,650 Å (665 nm)
- Dark Red: 7,000 Å (700 nm)
Simple colour models

Receptors in the eye are sensitive to RGB (biologically)

Printers CYM model
Additive vs subtractive colour
RGB vs CMYK

**rgb colors**
(what you see on screen)

**cmyk colors**
(printing inks will do this)
Colour Dimensions: Hue

- Hue
  - a property of the wavelengths of light (i.e., “colour”)
Saturation

- purity of the hue
- for example, red is more saturated than pink
- the portion of pure hue in any given colour is the degree of saturation

Saturation is the degree of colour **intensity** associated with a colour's perceptual difference from a white, black or gray of equal lightness.
Colour Dimensions: Value

- **Lightness/Brightness** ("Value")
  - how much light *appears* to be reflected from a surface
  - some hues are inherently lighter or darker
  - for example, you can’t really imagine “dark yellow” in the same way as you can “dark blue”
Value is also affected by background

Percentage Gray Scales Ranging from 0% to 100% Black in steps of 10

A. Shown against a background of 15% Black
Value is also affected by background

Percentage Gray Scales Ranging from 0% to 100% Black in steps of 10

A. Shown against a background of 15% Black

B. Shown against a background of 75% Black
Value is also affected by background

Percentage Gray Scales Ranging from 0% to 100% Black in steps of 10

A. Shown against a background of 15% Black

B. Shown against a background of 75% Black

Note that the lighter squares look brighter against the dark background while the darker squares stand out better against the lighter background.
Saturation vs. Value
Saturation vs. Value
Don't be fooled by models

- Colour perception is not uniform
Live Demonstration
Colour is a matter of …

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- Physics (colour)
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Physiology of the eye (i)

- Cross section of the eye
- Zonulas: attach lens to ciliary muscle
- Aqueous humor
- Cornea
- Pupil: changes amount of light entering the eye
- Lens: bends light to focus it on the retina
- Iris
- Ciliary muscle: contraction alters curvature of lens
- Retina: layer that contains photoreceptors
- Vitreous chamber
- Optic nerve
- Central artery and vein
- Optic disc
- Fovea
Physiology of the eye (ii)
Physiology of the eye (iii)

Receptors: Rods & Cones
Retina (i)

• Retina covered with light-sensitive receptors

• Rods (circa 120 million)
  ▪ scotopic vision: (poor acuity)
  ▪ good for low luminance, mostly peripheral; very sensitive to light
  ▪ primarily for night vision & perceiving movement (we’re all colour-blind at night)

• Cones (circa 6 million) - color
  ▪ photopic vision: (good acuity)
  ▪ require substantial luminance; not very sensitive to light
  ▪ primarily used to sense colour
Retina (ii)
Retina (iii)

• The centre of retina has most of the cones, the fovea has only cones.
  ▪ high acuity of objects focussed at centre (reading, threading needles etc.)

• Edge of retina is dominated by rods.
  ▪ detecting motion of threats in periphery (leopards, assassins etc.)

http://www.olympusmicro.com/primer/lightandcolor/humanvisionintro.html
Low light versus bright light

- In very low light levels, vision is **scotopic**: light is detected by rod cells of the retina.
- Rods are maximally sensitive to wavelengths near 500 nm, and play little, if any, role in colour vision.
- In brighter light, such as daylight, vision is **photopic**: light is detected by cone cells which are responsible for colour vision.
- Cones are sensitive to a range of wavelengths, but are most sensitive to wavelengths near 555 nm.
- Between these regions, **mesopic** vision comes into play and both rods and cones provide signals.
Three different types of cones:

- S (short wavelength): 400 nm
- M (medium wavelength): 500 nm
- L (long wavelength): 600 nm

Normalized cone response (linear energy)

Wavelength (nm)

400 450 500 550 600 650 700
Colour Perception via Cones

- Three types of cone: blue, green and “red”
- Each sensitive to different band of spectrum
- Light is perceived as white when all three cone cell types are simultaneously stimulated by equal amounts of red, green, and blue light
- Other colours are perceived by combining stimulation – a cone “fires”, which indicates its “colour” (blue, green or red). The strength of the firing is combined with that of other receptors to create the infinitely subtle spectrum we see.
Distribution of photoreceptors

- Red grabs your attention, why?
- Why not blue?
Distribution of photoreceptors

• Types of cone are not distributed evenly
  ▪ mainly reds (64%) & very few blues (4%)
  ▪ comparative insensitivity to short wavelengths: cyan to deep-blue:
    ▪ high sensitivity to long wavelengths: yellow & orange

• Centre of retina (high acuity) has no blue cones.
  ▪ This means small blue objects disappear if you fixate on them
Relative brightness sensitivity of the human visual system as a function of wavelength (in daylight)
Colour sensitivity (ii)

• Visual acuity peaks at about 22, and from there begins a steady decline

• As we age …
  ▪ we all develop a condition called presbyopia that makes it harder to shift the distance of our focus (from paper to screen, for example)
  ▪ lenses become less and less transparent (i.e. cloudy)
  ▪ macular degeneration yellows the area around the fovea
  ▪ fluid between lens and retina absorbs more light
  ▪ with yellowing, shorter wavelengths of visible light are absorbed, so blue hues appear darker

• … we perceive a lower level of brightness and require more contrast to see fine details and read text
Focus

• Different wavelengths of light focused at different distances behind eye’s lens
  ▪ need for constant refocusing causes fatigue
  ▪ be careful about colour combinations

• Pure (saturated) colours require more focusing than less pure (desaturated)
Focus, example!

CAN’T EASILY READ RED ON BLUE
Colour deficiency

• Trouble discriminating colours
  ▪ besets about 9% of population (male), about 0.4% (female)

• Different photoreceptor response
  ▪ reduces capability to discern small colour differences
  ▪ particularly those of low brightness

• Dichromacy
  ▪ a more severe form of colour blindness
  ▪ occurs when one of the receptors is seriously deviant in its absorption characteristics
  ▪ red-green deficiency is best known: can’t discriminate colours dependent on red and green
Colour deficiency explored

Normal colour vision

Green-insensitive dichromate

Available light without green

Red-insensitive dichromate

Available light without red

Red perceived as both red & green

Green perceived as both red & green

http://www.firelily.com/opinions/color.html
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Perception: Colour meanings?

• What colours are associated with:
  ▪ Health?
  ▪ Fun?
  ▪ Death?

• Depends on culture
  ▪ Blue – “authority” or “calm” in European culture, “villainy” in Japanese, “virtue” and “truth” in Arabic
  ▪ Black for mourning death in Europe, white in Asia
Internationalisation is difficult!
Colour: top five beginner's mistakes

- Too many bright colours
- Saturated complementary colours
- Giving priority to hue instead of value
- Visual inconsistency
- Deep blue text
Too many bright colours
Saturated complementary colours
Giving priority to hue instead of value
Visual inconsistency
Deep blue text
Too many bright colours
Colour Guidelines

• Avoid simultaneous display of highly saturated, spectrally extreme colours
  ▪ e.g., no blues at the same time as reds.
  ▪ few natural saturated colours – no saturated blue in nature

• Opponent colours can go well together
Too many bright colours
Saturated complementary colours
Giving priority to hue instead of value
Visual inconsistency
Deep blue text
Too many bright colours

Saturated complementary colours

Giving priority to hue instead of value

Visual inconsistency

Deep blue text
Saturated complementary colours

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• Users may be working with an application 8 hours a day – give them a break!

• Pink for MS Word?
Too many bright colours

Saturated complementary colours

Giving priority to hue instead of value

Visual inconsistency

Deep blue text
Too many bright colours
Saturated complementary colours
Giving priority to hue instead of value
Visual inconsistency
Deep blue text
Colour Guidelines (cont.)

- At age 60, when compared to the visual efficiency of a 20-year old, only 33 percent of the light incident on the cornea reaches the photoreceptors in the retina. This value drops to around 12.5 percent by the mid-70s.
- Older users need higher brightness levels to distinguish colours.
- Older users often experience difficulty discriminating between colours that differ primarily in their blue content, such as blue and gray or red and purple.
- Use *value* as well as *colour* differences: design with value first.
Choose dark colours with hues from the bottom half of the hue circle against light colours from the top half of the circle. Avoid contrasting light colours from the bottom half against dark colours from the top half.
For most people with partial sight and/or congenital colour deficiencies, the lightness values of colours in the bottom half of the hue circle tend to be reduced.
Too many bright colours
Saturated complementary colours
Giving priority to hue instead of value
Visual inconsistency
Deep blue text
Too many bright colours

Saturated complementary colours

Giving priority to hue instead of value

Visual inconsistency

Deep blue text
Colour Guidelines (cont.)

• Don't forget perception interworks with memory – associate objects with hue across screens (recognition over recall)
Using colour consistently: Canon Exilim EX-250

Battery life indicator

Zero bars to three bars

Also “traffic light” indication:
• one bar: red
• two bars: yellow
• three bars: green

Picture quality indicator

Word labels “low, normal and fine”

Also “traffic light” indication:
• low:
• normal: yellow
• fine:

Question: What colour is “fine”?
Using colour consistently: Canon Exilim EX-250

What colour is “fine”?

- If “fine” is green, then we can imagine a sort of quantity metaphor in operation: “more is better” – more power, more pixels.
- However, in this interface, “fine” was red.
- Why?
- Our best guess is that the designer intended a resources metaphor: beware, you’re using resources, you won’t be able to carry on doing this for much longer.

Thanks to Tom Castle for this example
Too many bright colours
Saturated complementary colours
Giving priority to hue instead of value
Visual inconsistency
Deep blue text
Too many bright colours

Saturated complementary colours

Giving priority to hue instead of value

Visual inconsistency

Deep blue text
Colour Guidelines (cont.)

- Avoid pure blue for text, lines, and small shapes
- Never distinguish between two states purely on basis of colour.
  - colour should supplement the major information channel
- Avoid single-colour distinctions
  - mixtures of colours should differ in more than one dimension
e.g., two colours shouldn’t differ only by amount of red
  - helps colour-deficient observers
If you remember nothing else …

• Colour can be helpful, but easily misused
• Design in black & white first
• Add colour for emphasis, when your design is complete
• Colour should never be the only visual cue for anything
Interface Hall of Fame or Shame?
Interface Hall of Fame or Shame?

- A dialogue box which asks if you want to delete records:
  - two choices
  - yes (green), no (red)
Hall of Shame!

- A dialogue box which asks if you want to delete records:
  - two choices
  - yes (green), no (red)

- What are the problems here?
  - Yes = “good”: Green = “good”
  - Red/Green colour deficiency
  - Potential cultural mismatch
Interface Hall of Fame or Shame?
### Interface Hall of Fame or Shame?

**Check iPhone availability at your local Apple Store**

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<thead>
<tr>
<th>California Stores</th>
<th>Wednesday, July 4</th>
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<tbody>
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Hall of Shame!

- Colour-only indication!
- Gotta hope your users aren’t colour-blind.
- Blue text!
  - goes against all we know,
  - it’s hard to focus on, and
  - combined with red leads to eye strain

Check iPhone availability at your local Apple Store

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Interface Hall of Fame or Shame?

• Woolf College was officially opened on the 13<sup>th</sup> of March 2009

• I started lecturing in it that September

• Here’s what I found …
This is the “visualiser control screen” in the Woolf Lecture Theatre. The Woolf Lecture Theatre has three display screens, and this panel allows the lecturer to determine what is displayed on each screen.

You can allocate a resource to each screen:

- DVD
- Video
- PC
- Laptop
- Visualiser (a high-tech version of an ohp)

At this time, I have the visualiser displaying on each screen.
For each screen, you can also:

Make the screen blank (this doesn’t work)

Turn off the projector (“do not turn off the projector”)

Lock the current image to the screen. Useful if you are producing a series of hand-written slides on the visualiser, for instance, and want to keep the first page visible (on screen one, say) whilst you continue to write and display (on screen two, say)
When the resource is active – that is, when I have “locked” a device to a screen – the outer border changes from green to red. That’s all. Bit of a problem if I’m red/green colour blind, really. Here a red border means “locked”.

And that’s not all ...
You’ll notice that every other aspect of the interface also has the same, colour-only, indication of activity ...

The “freezing” of an image to a screen
You’ll notice that every other aspect of the interface also has the same, colour-only, indication of activity …

So, tell me. What is the status of the middle screen?

Bizarrely – truly bizarrely – the status of the middle screen is that the projector is on and it is not blank. The screen is “locked” to the visualiser, but the picture is not “frozen” to the screen. The picture IS “frozen” to the left- and right- hand screens.

Every control indicator is red-green, but whether red or green indicates “active” varies from control to control.

Please, *please* promise me you’ll never design anything as terrible as this
• Most slides written by Sally Fincher, University of Kent
• The first two “Hall of Fame/Shame” examples today were first used by James Landay.
• The hue/saturation/value images were taken from: http://www.ncsu.edu/scivis/lessons/colormodels/color_models2.html
• There are very good guidelines at: http://www.olympusmicro.com/primer/lightandcolor/humanvisionintro.html, much of the material on aging was taken from this
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