

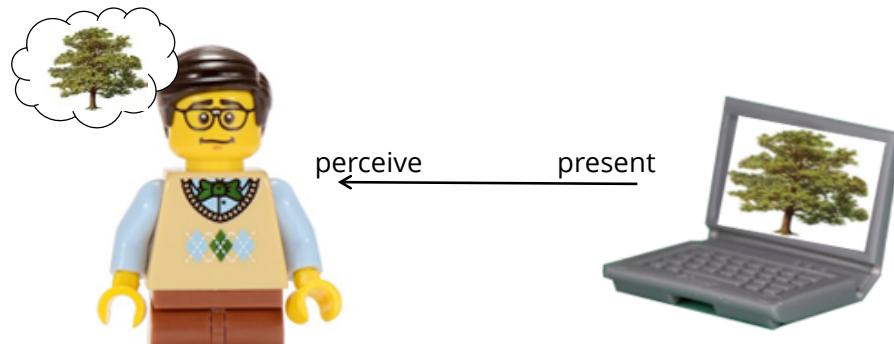
Visual Perception

temporal resolution
spatial resolution
colour perception
display devices

Psychophysics

Human Elements of Graphical Output

- Psychophysics: “out there” vs. “in here”
 - relationship between external stimuli and internal sensations
- Temporal resolution
- Spatial Resolution
- Colour Perception



Temporal Resolution: Flicker

- Critical Flicker Frequency (CFF)
 - when perception of intermittent light source changes from flickering to continuous light
 - dependent on brightness of stimulus, wavelength, others ...

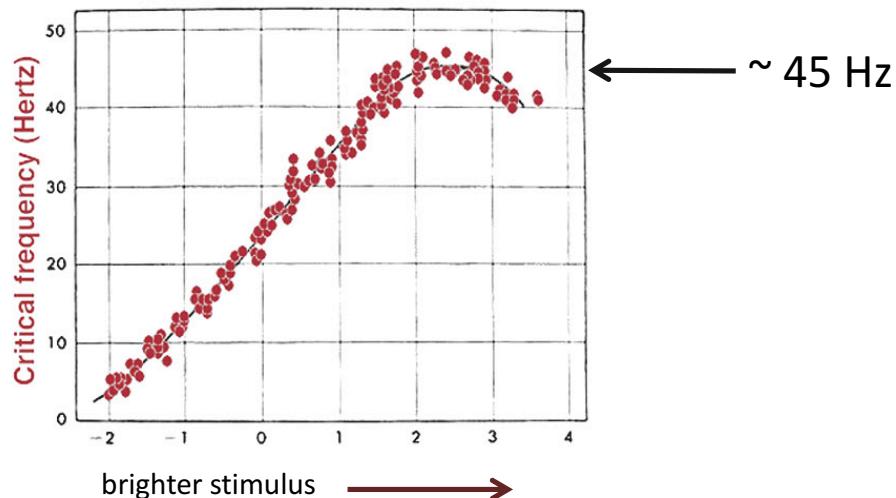


Image: <http://webvision.med.utah.edu>

Visual Perception 3

Temporal Resolution: Flicker into Motion

- CFF can also create perception of continuous motion
 - motion blur, frame interlacing helps
- 24 FPS film, 60 FPS NTSC video, HFR video 120 FPS



Image: <http://webvision.med.utah.edu>

Visual Perception 4



Zoetrope, mechanical example of CFF
- https://youtu.be/-hE_fA9M580?t=5s

Visual Perception 5

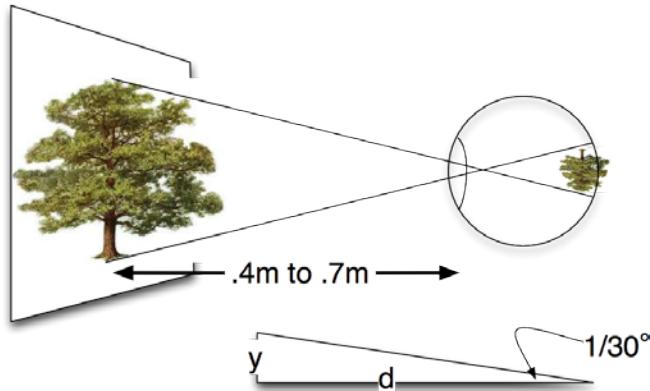
Spatial Resolution: Visual Acuity

- spatial resolution of visual processing system
 - 20/20 (6/6) vision: separate lines 1 arc minute ($1/60^\circ$) apart at 20 feet (6 m)
- High resolution only applies to about 1% of the photoreceptors in the eye
 - eye “focus” means moving area of interest to the high-resolution part of retina
 - other 99% of photoreceptors help determine where to focus



Spatial Resolution Implications

- Best pixel density for displays?
 - density is ppcm (pixels per cm)



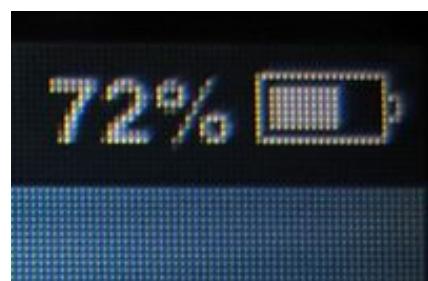
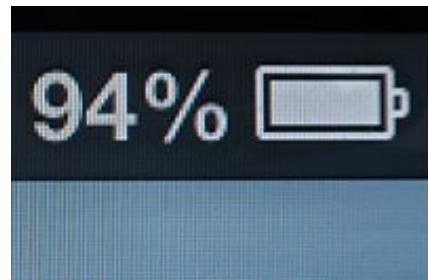
$$y = 0.233\text{mm} \text{ (at } .4\text{m}), y = 0.407\text{mm} \text{ (at } .7\text{m})$$

We can see individual pixels larger than about 0.47 to 0.82 mm

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"Retina" Displays

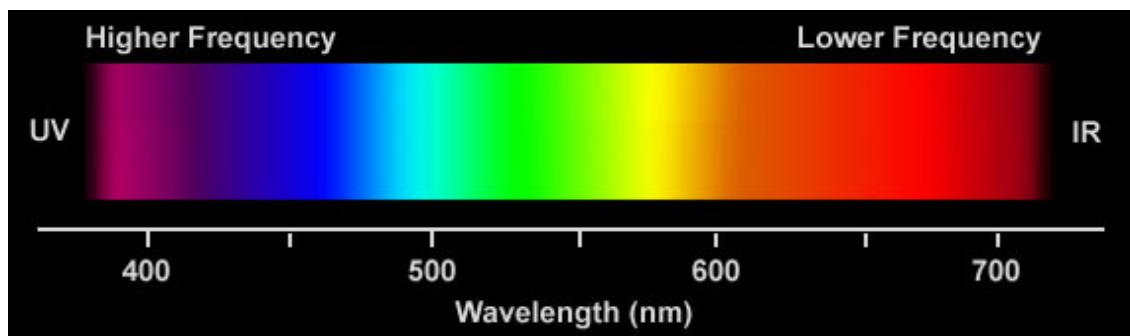
- iPhone X "Super Retina"
 - 2436 by 1125 px
 - 180 ppcm, pixel size 0.056 mm
- At what distance can we see pixels?
$$d = 0.056/(2 \tan 30^\circ) = 48 \text{ mm}$$
- 15 inch MacBook "Retina"
 - 2800 by 1800 px
 - 87 ppcm, pixel size 0.12 mm
- At what distance can we see pixels?
$$d = 0.12/(2 \tan 30^\circ) = 103 \text{ mm}$$



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Visible Colour Spectrum

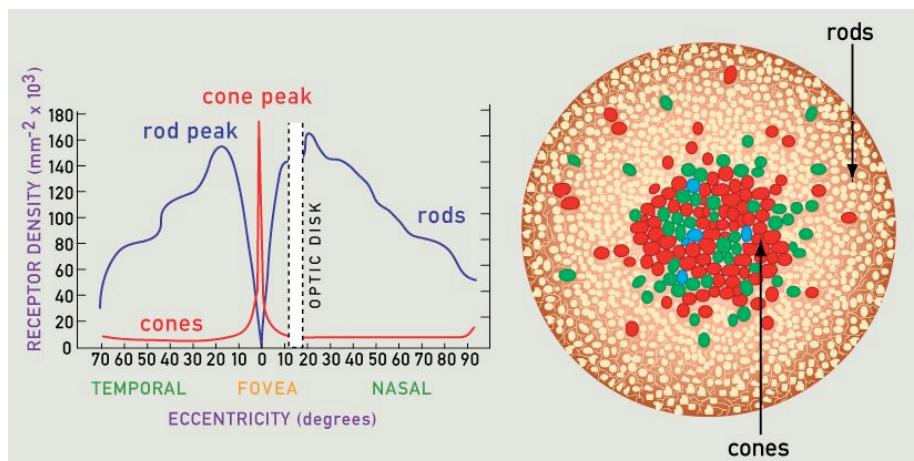
- Wavelength determines colour (in nanometres, nm)
 - Ultraviolet (UV)
 - Infrared (IR) (near IR used for input ~850nm)
- Combined wavelengths
 - example: orange is around 600 – 620 nm, but “orange light” can be brighter/darker when other wavelengths added



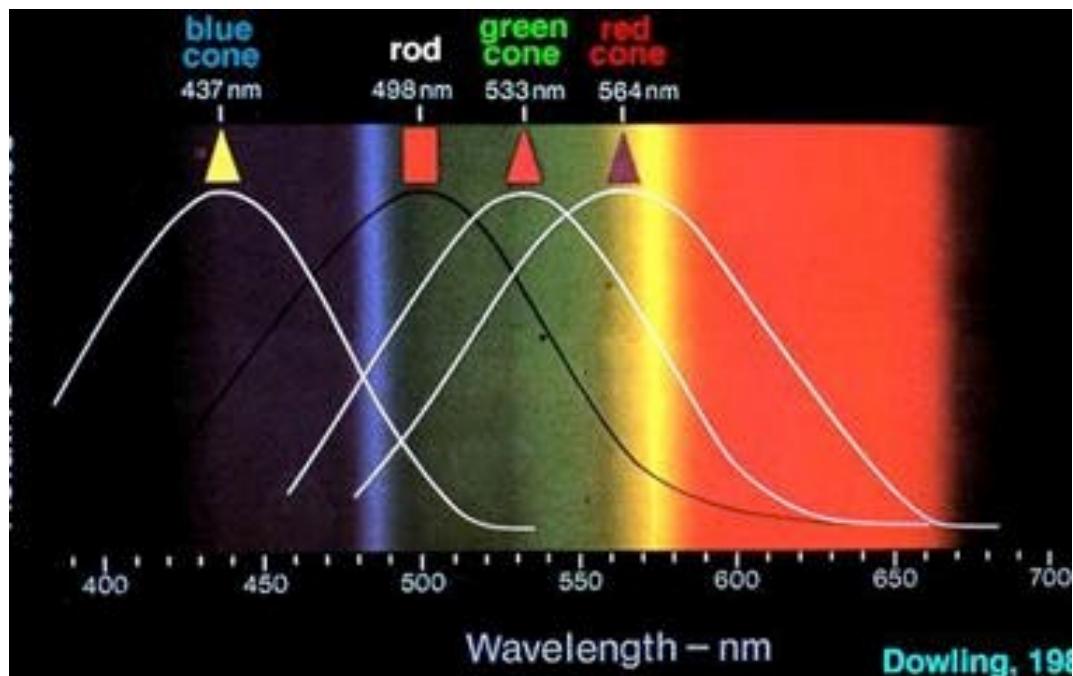
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Colour Perception

- Two different light sensors in human eye
 - **Cones** perceive colour (focus)
 - **Rods** distinguish light from dark (peripheral vision)
- cones and rods not evenly distributed
 - spatial resolution of visual field drops significantly at edges



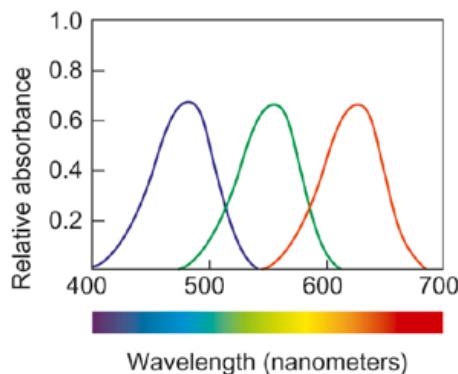
Rod and Cone Color Sensitivity



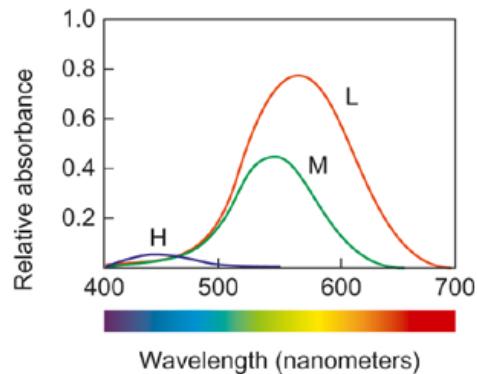
Visual Perception Credit: Fleet

3 Types of Cones means Trichromatic Vision

- Blue, green, and “red” cones (almost yellow)
- Variations in stimulation lead to sensing of different colors
- Few blue cones (but rods sense blue too)
- Harder to notice blues than reds and no blues in center



Ideal Cone Response



Actual Cone Response

Humans, Birds, and Bees

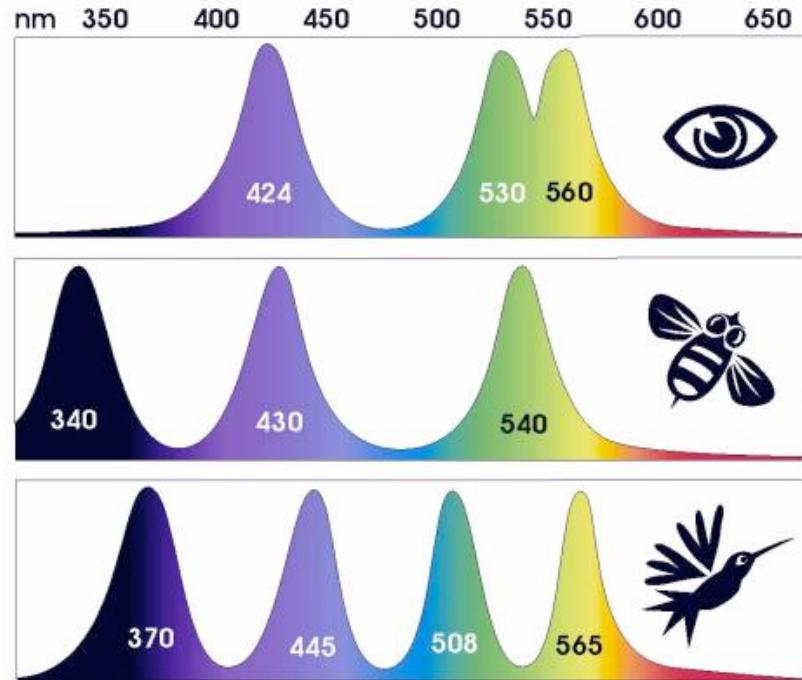


Image: <http://fieldguidetohummingbirds.wordpress.com>

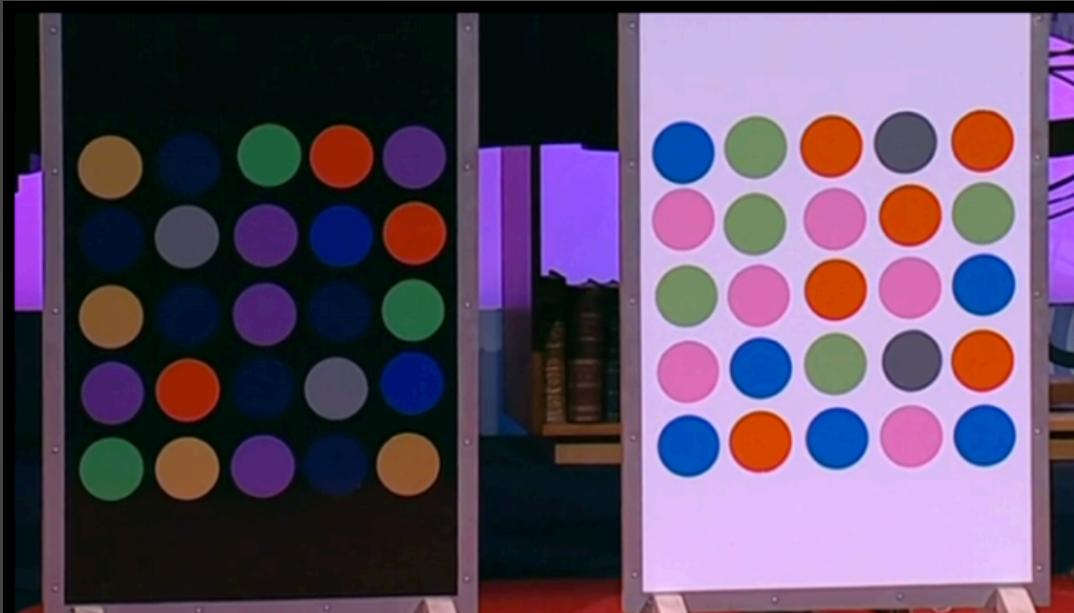
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What color is the dress?

A screenshot of a Wired.com article. The header includes the WIRED logo, a 'SUBSCRIBE' button, and a search icon. The author is ADAM ROGERS and the date is 02.26.15 10:28 PM. The main title is 'THE SCIENCE OF WHY NO ONE AGREES ON THE COLOR OF THIS DRESS'. Below the title are three side-by-side photographs of the same dress, showing it appearing different colors (white/gold, blue/black, and blue) depending on the lighting.

<http://www.wired.com/2015/02/science-one-agrees-color-dress/>

Visual Perception 14

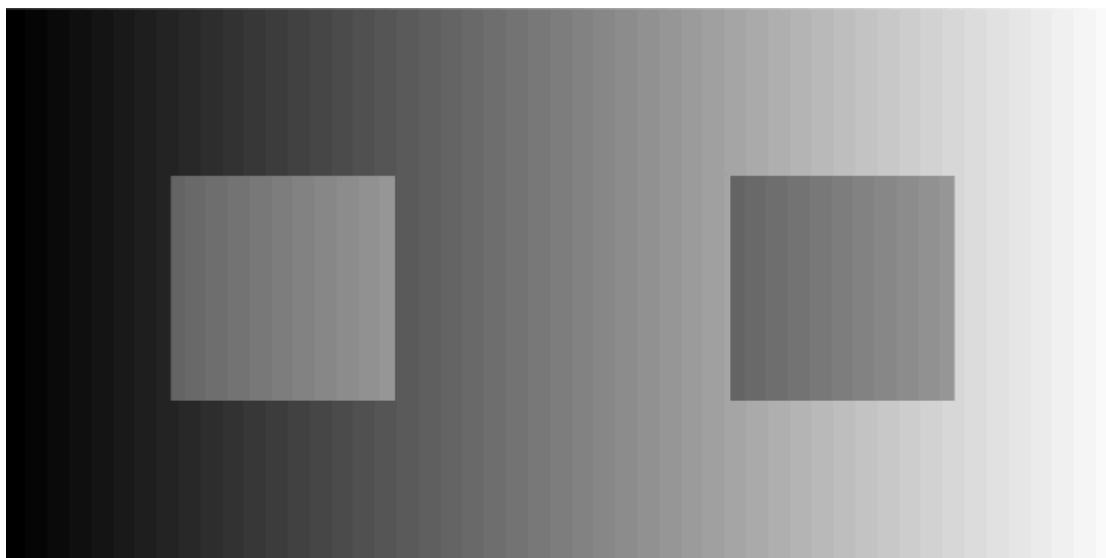


Beau Lotto, **Optical illusions show how we see** (Ted 2009)

- https://www.ted.com/talks/beau_lotto_optical_illusions_show_how_we_see#t-461256

Contrast, not Brightness

- We are more sensitive to differences in colour and brightness, than absolute brightness levels.



<http://www.psy.ritsumei.ac.jp/~akitaoka/ECVP2005b.html>

Colour Presentation Matters

- Our ability to discriminate colours depends on presentation
- Example: it's harder to tell two colours apart when
 - the colours are pale
 - the object is small or thin
 - the colour patches are far apart

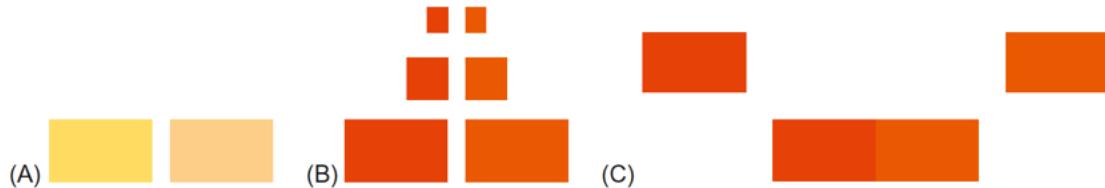


FIGURE 5.4

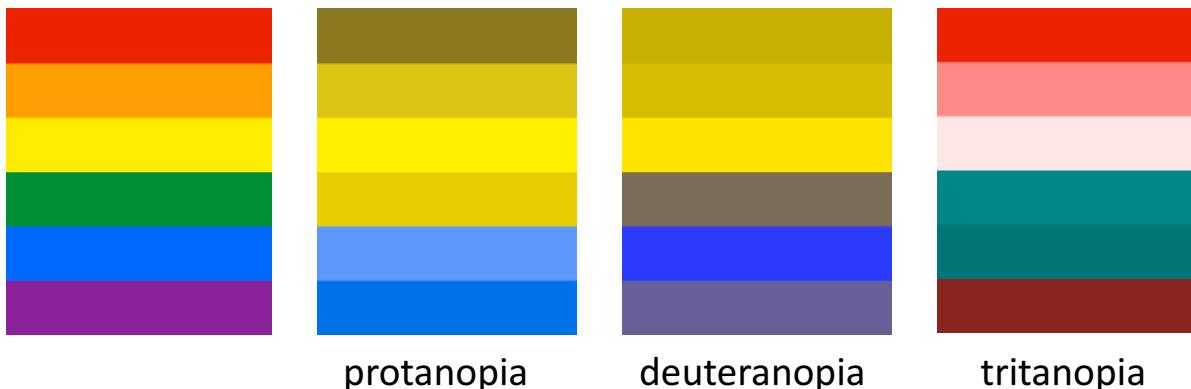
Factors affecting the ability to distinguish colors: (A) paleness, (B) size, (C) separation.

(Johnson, page 41)

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Colour Blindness

- monochromacy: 2 or 3 types of cones missing
- dichromacy: 1 type of cone missing
 - Protanopia: missing red cones (~1% of males)
 - Deutanopia: missing green cones (~1% of males)
 - Tritanopia: missing blue cones, (and blue sensitive rods) (rare)

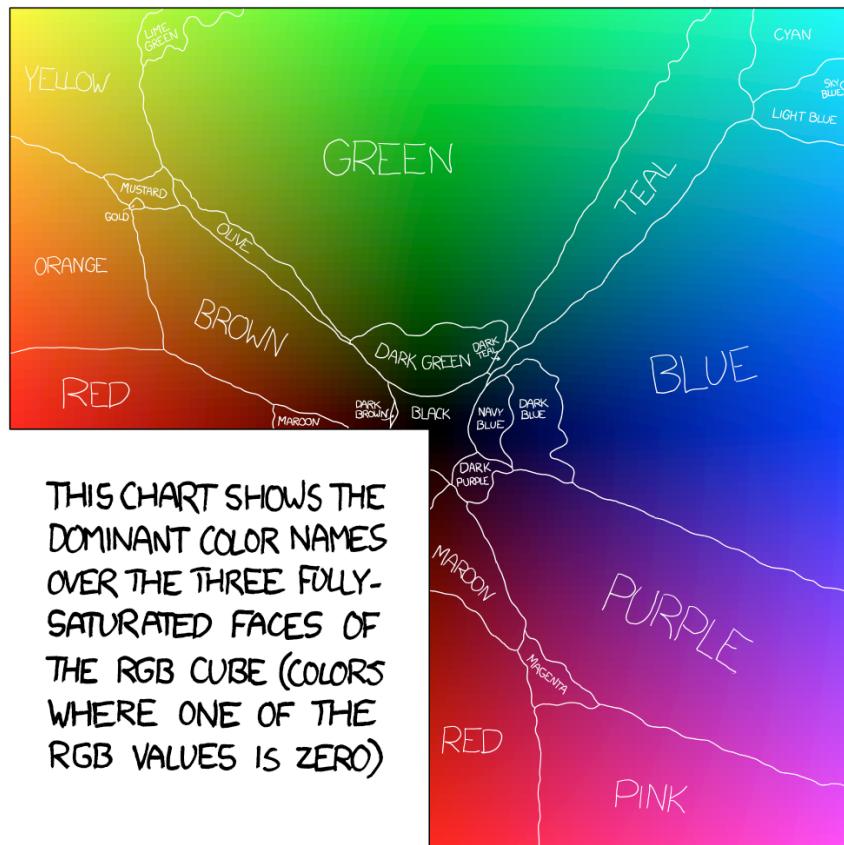


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Using Colour



Visual Perception 19

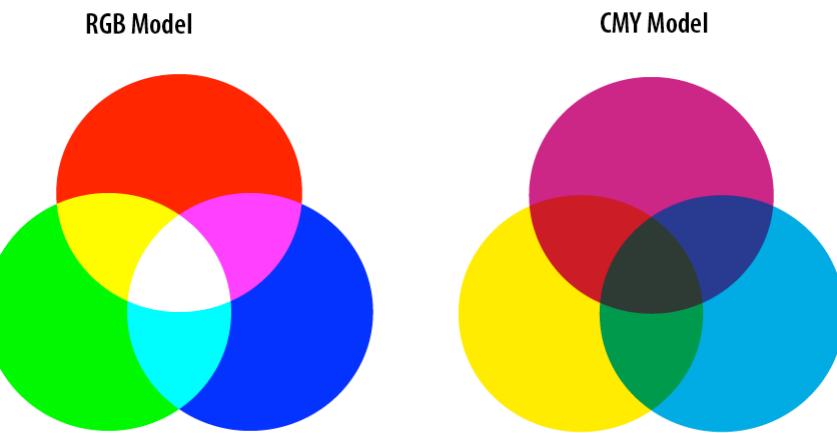


XKCD Colour Survey Results

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Colour Models

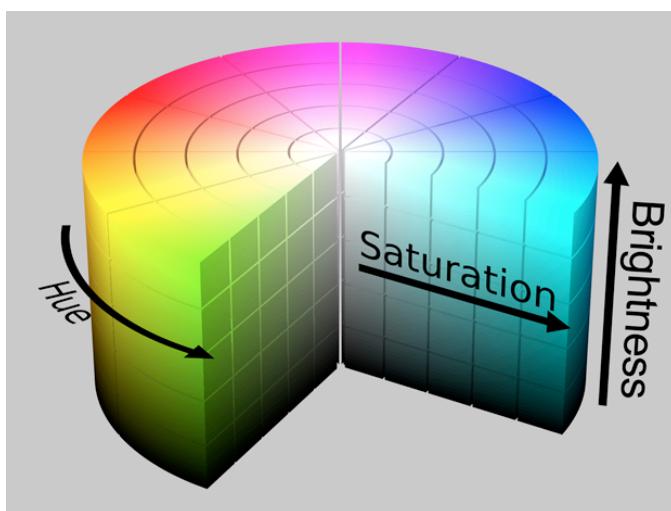
- **Additive**
 - coloured light is added to produce white
 - RGB for displays
 - HSV/HSB to describe colour
- **Subtractive**
 - coloured light is absorbed to produce black
 - CMY/CMYK – printing



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HSV/HSB Color model

- **Hue:** determines color (approximation of wavelength)
- **Saturation:** how much hue: e.g. red vs. pink vs. white
- **Value/Brightness:** how much light is reflected

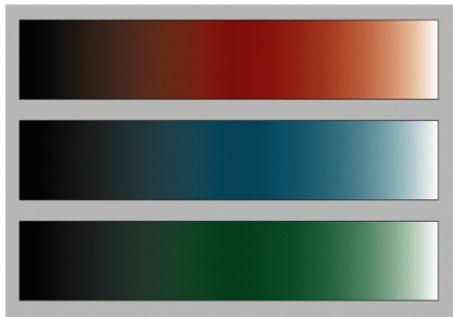


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Value/Brightness vs. Saturation

▪ Value/Brightness

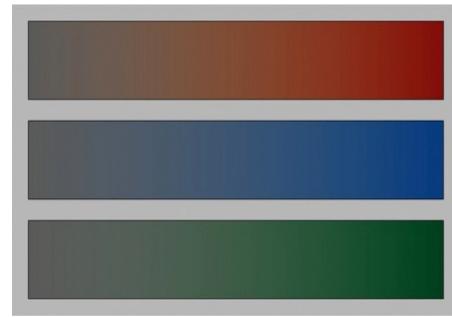
- Reflecting less to more light



(black to white)
Fixed saturation,
changing value/brightness

▪ Saturation

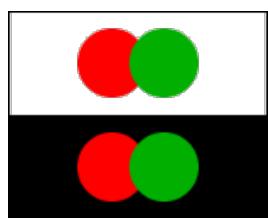
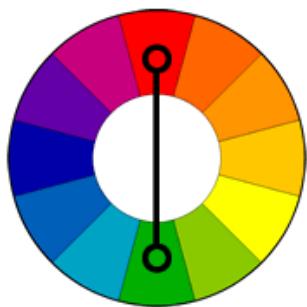
- Containing less to more hue



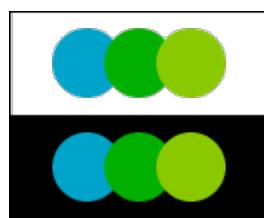
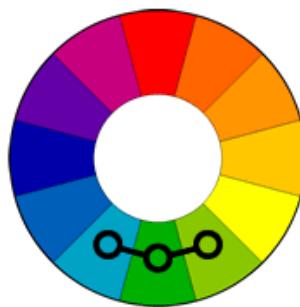
(gray to red, green, or blue)
Fixed value/brightness,
changing saturation

Colour Harmony

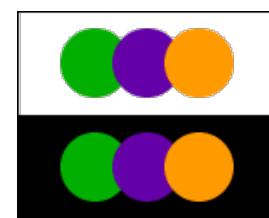
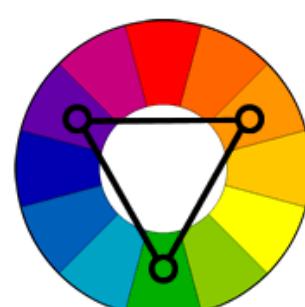
Complementary

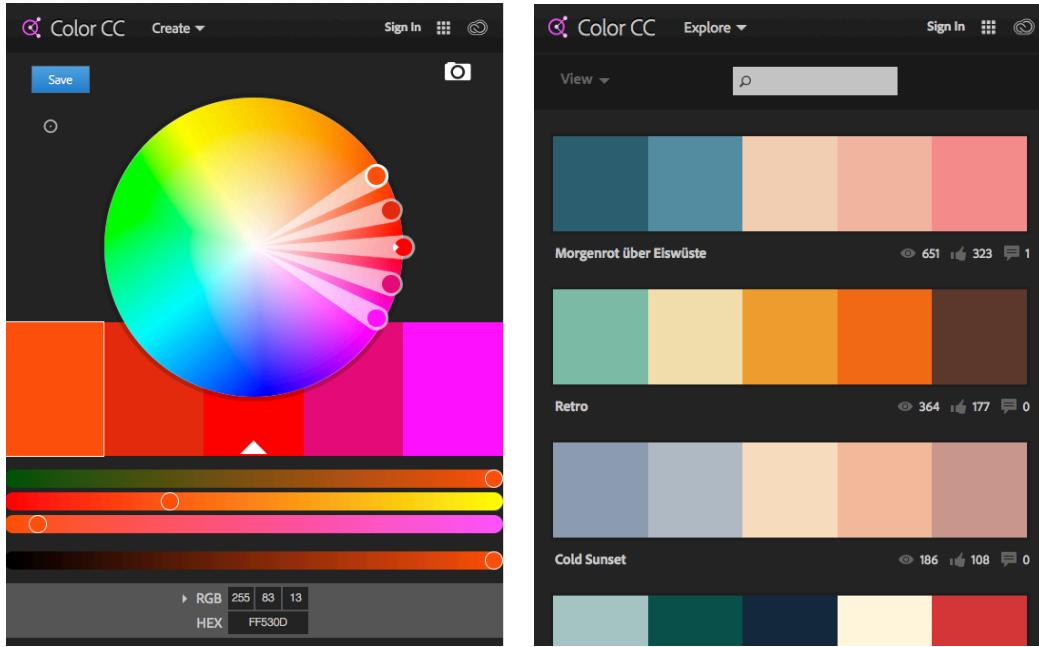


Analogous



Triad





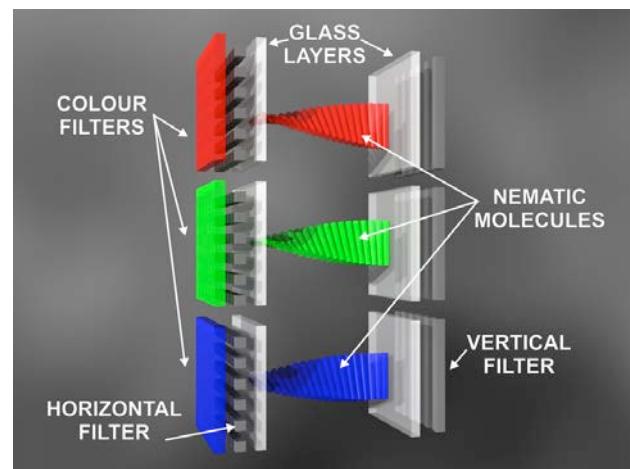
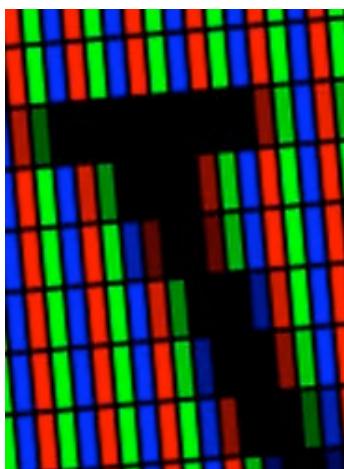
Adobe Colour Tool

- <https://color.adobe.com>

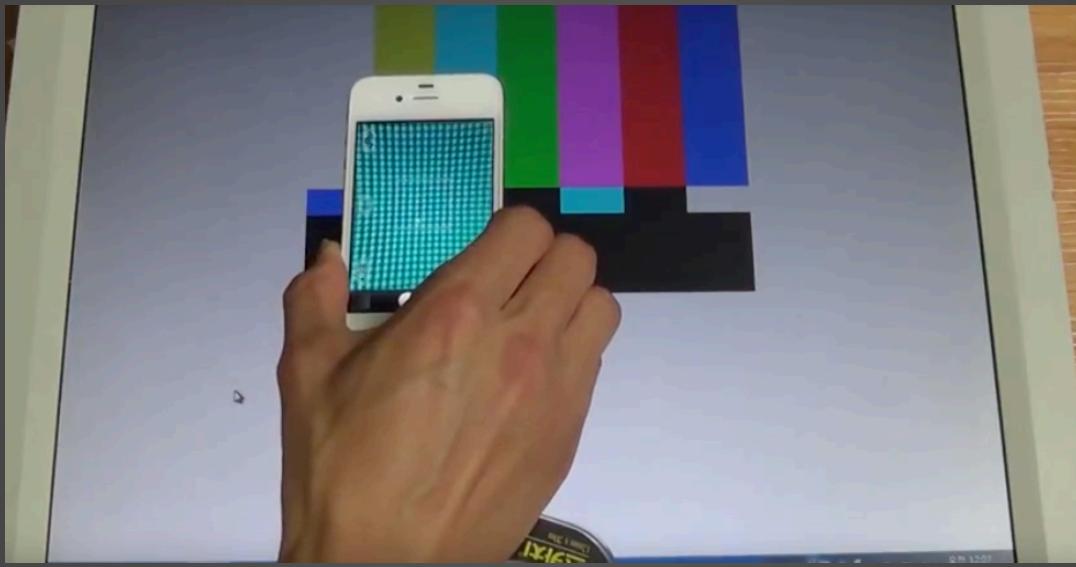
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Graphic Display Technology

- Common idea
 - Each pixel is actually 3 RGB sub-pixels: red, green and blue
 - Pack subpixels very close together so they seem to be co-located
 - Vary amounts of red, green, blue to excite cones in eyes

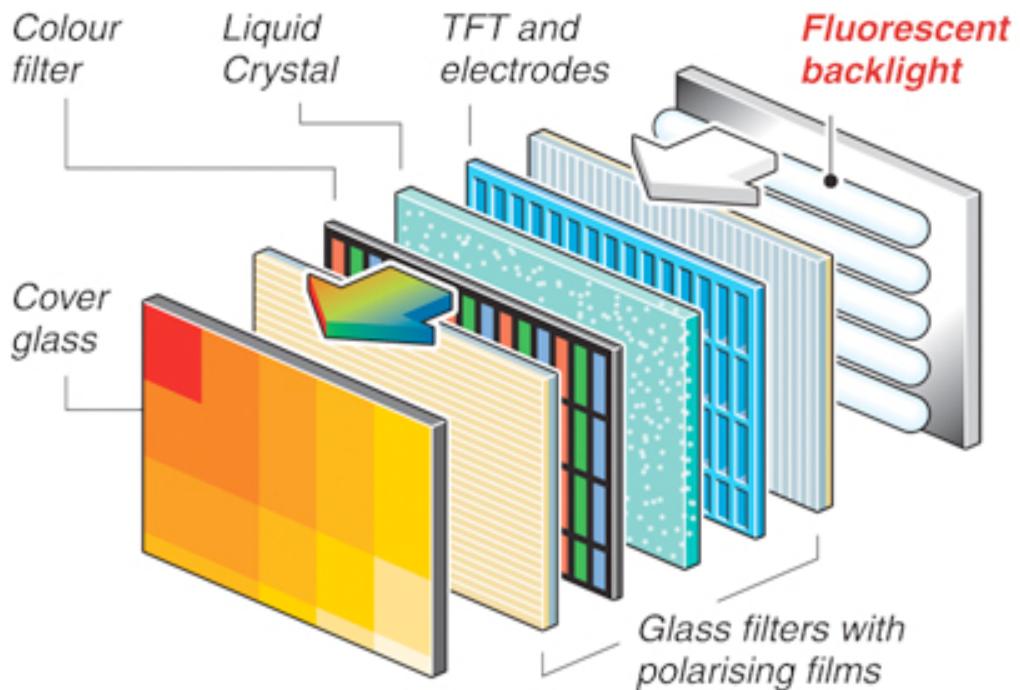


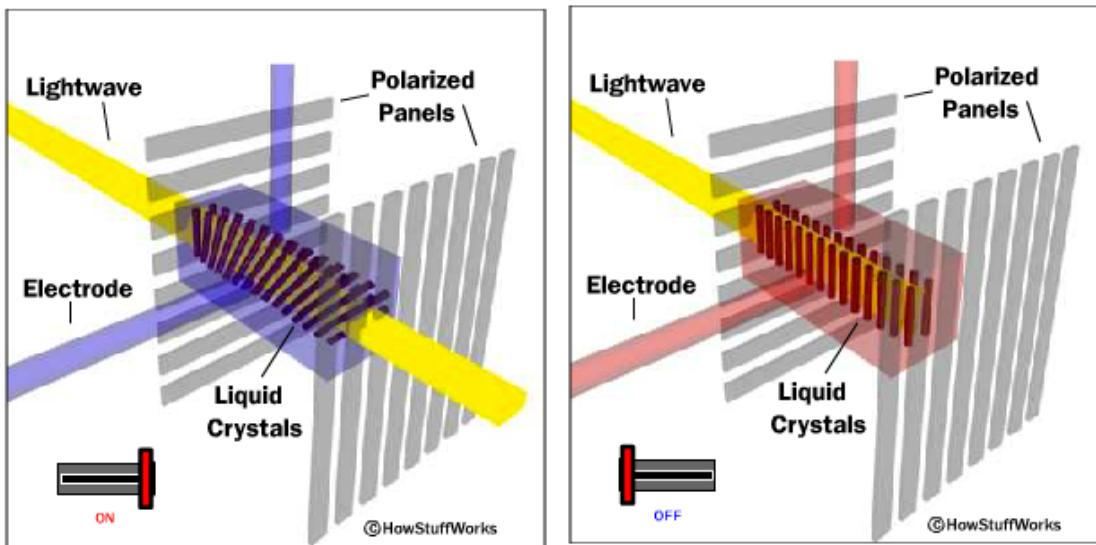
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How to see your monitor subpixels
- https://youtu.be/_O66qHq1YS4

LCD Displays





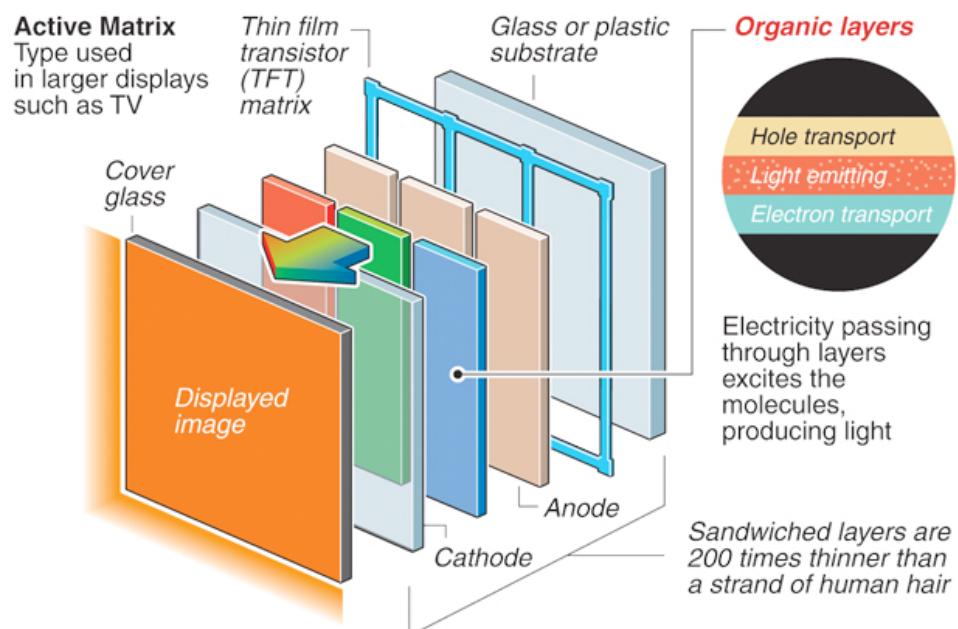
How Liquid Crystals “twist” light

- <http://electronics.howstuffworks.com/lcd2.htm>

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OLED (Organic LED)

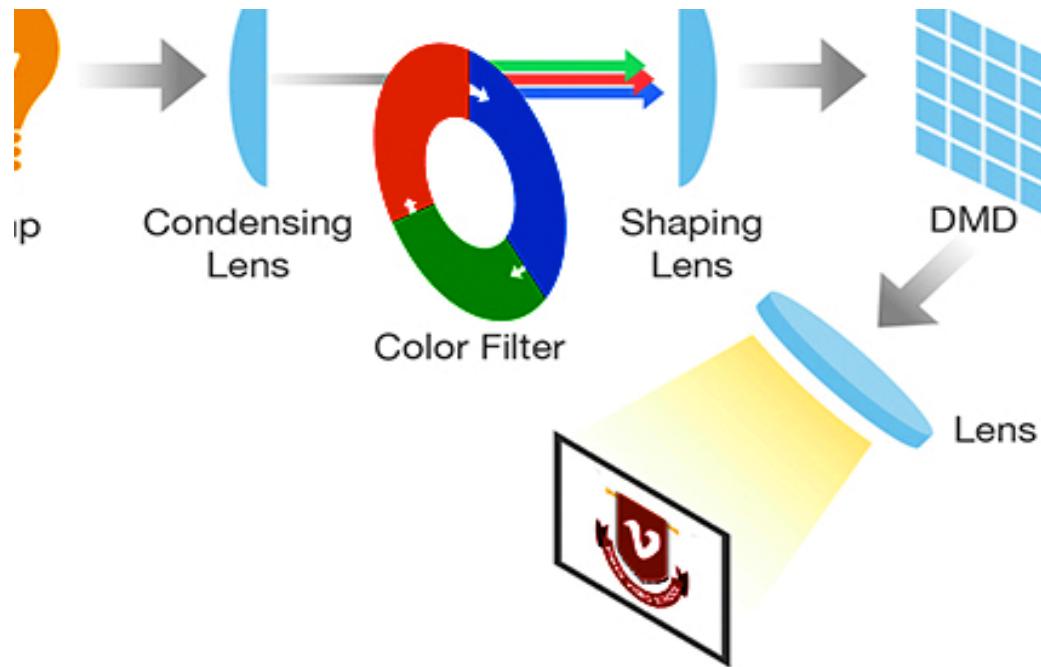
- no backlight, bendable, more expensive to produce



Visual Perception 30

Digital Light Processing (DLP) Projectors

- digital micromirror device (DMD)



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Digital Light Processing (DLP) Projectors

- light source
 - metal halide, LED, laser
- colour using single chip or 3 chip DMD
 - single chip needs way to cycle light → colour filter wheel
 - rainbow effect (spinning wheel, different light sources)
- wobulation
 - form of interlacing to double display resolution
 - 960×1080 mirror array to produce a 1920×1080 pixel picture

