Output

Perception

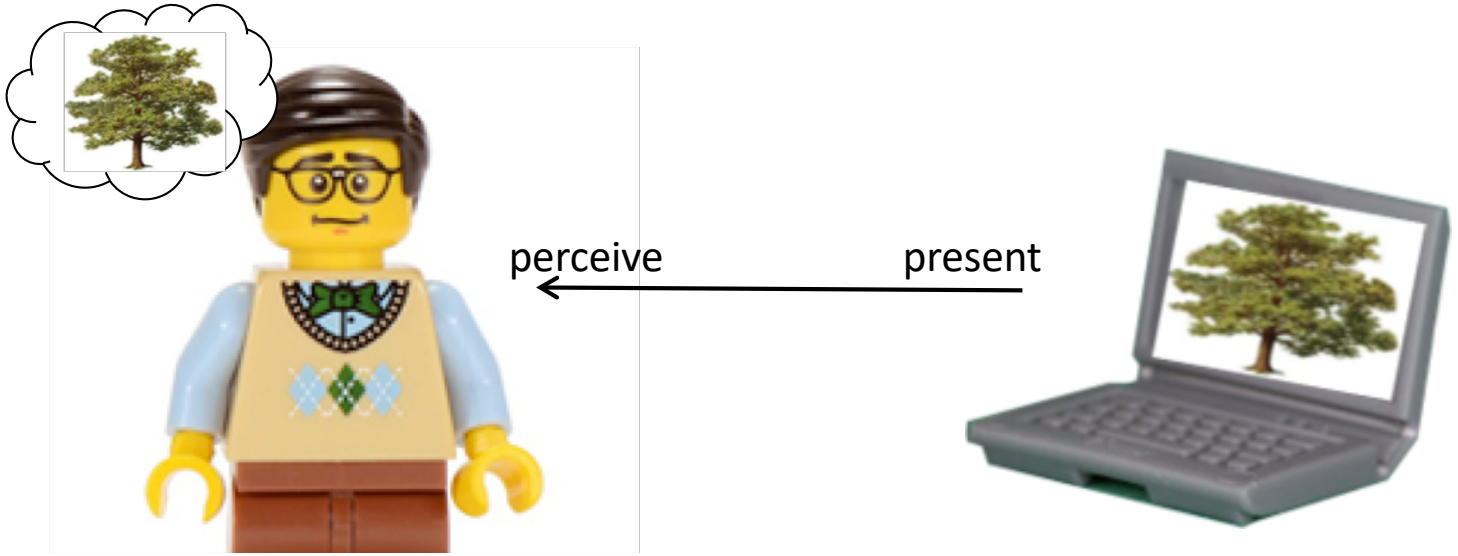
Managing output

Human Elements of Graphical Output

Psychophysics: “out there” vs. “in here”

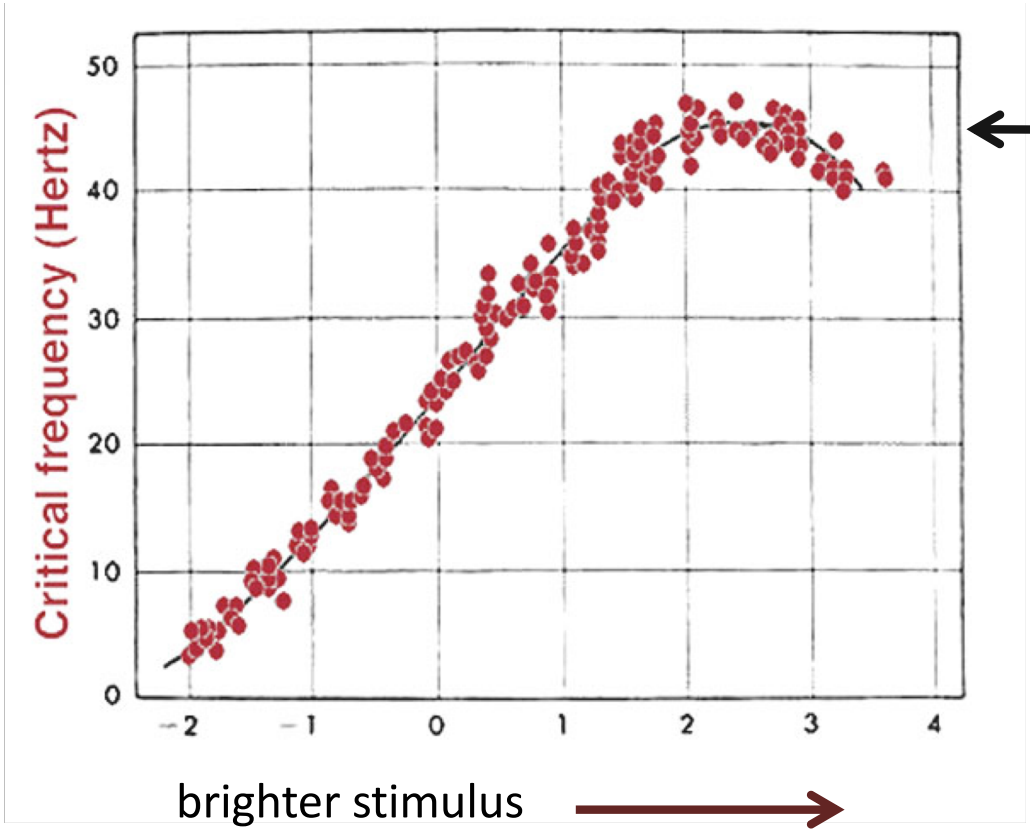
Relationship between external stimuli and internal sensations

- Temporal and spatial resolution
- Vision and color perception
- Interpretation of visual elements



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 …



~ 45 Hz

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

Temporal Resolution: Flicker into Motion

- CFF can also create perception of continuous motion
  - 24 FPS film, 60 FPS NTSC video, HFR video 120 FPS -> motion effect
  - motion blur required to make scenes look “real”

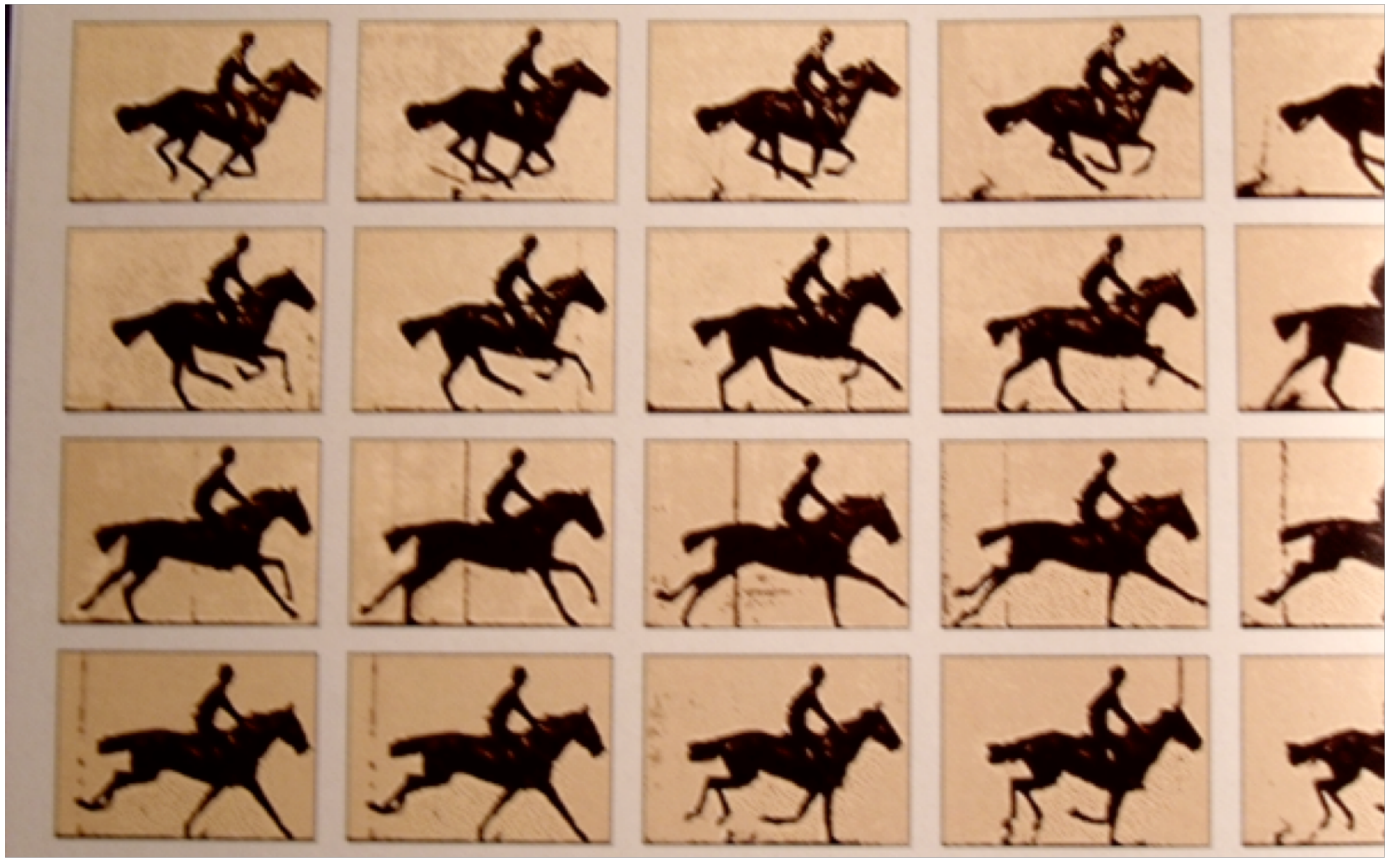


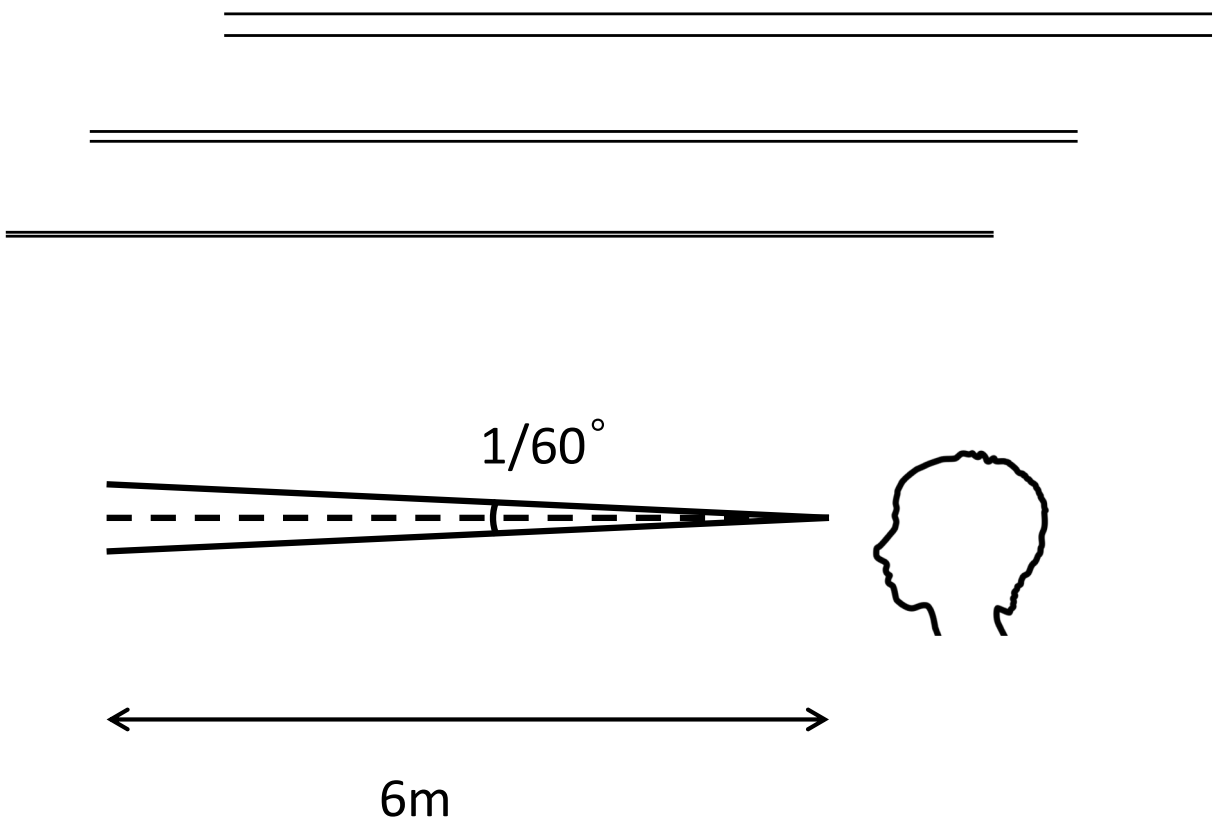
Image: http://webvision.med.utah.edu

Zoetrope, mechanical example of CFF

- https://youtu.be/-hE_fA9M580?t=5s

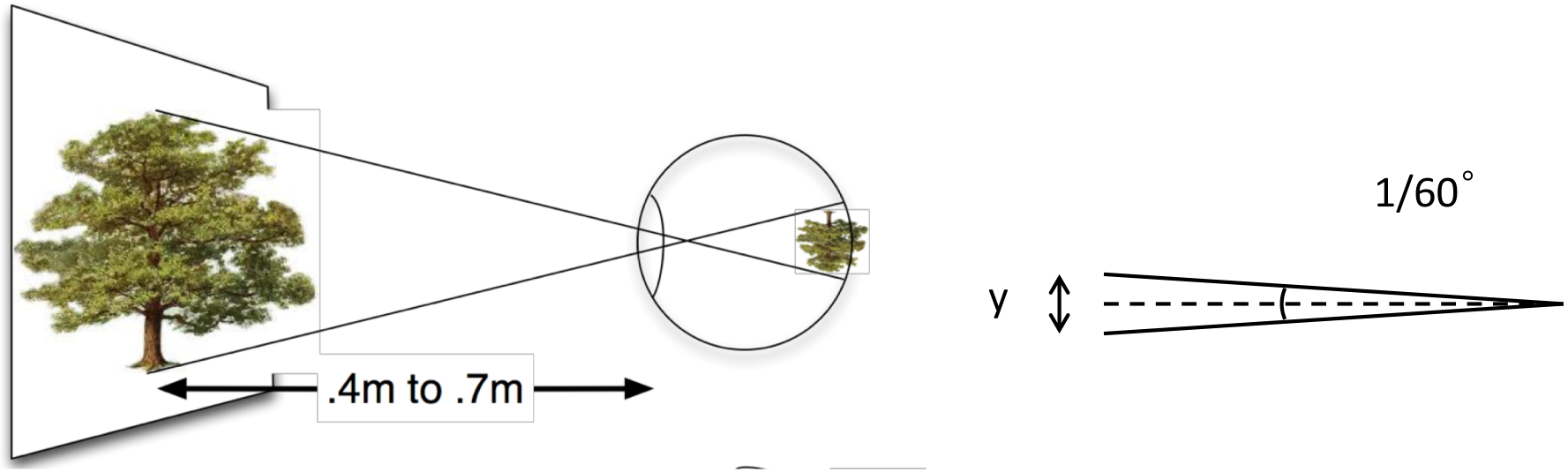
Spatial Resolution: Visual Acuity

- spatial resolution of visual processing system
  - 20/20 (6/6) vision: separate lines 1 arc minute (1/60°) apart at 20 feet (6 m)



Spatial Resolution Implications

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

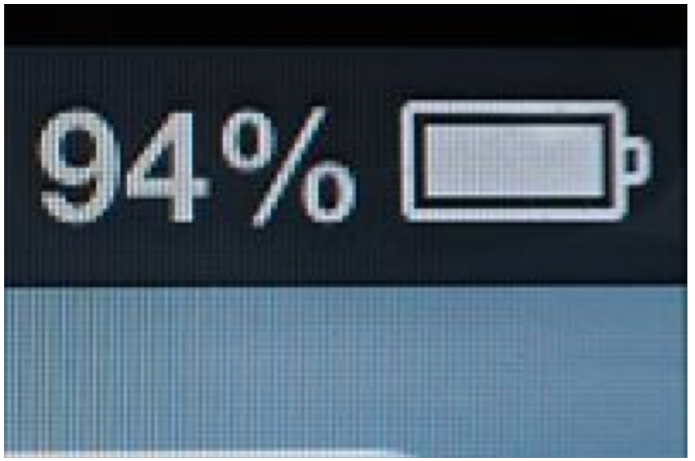


`y = 0.116mm (at .4m), y = 0.203mm (at .7m)`

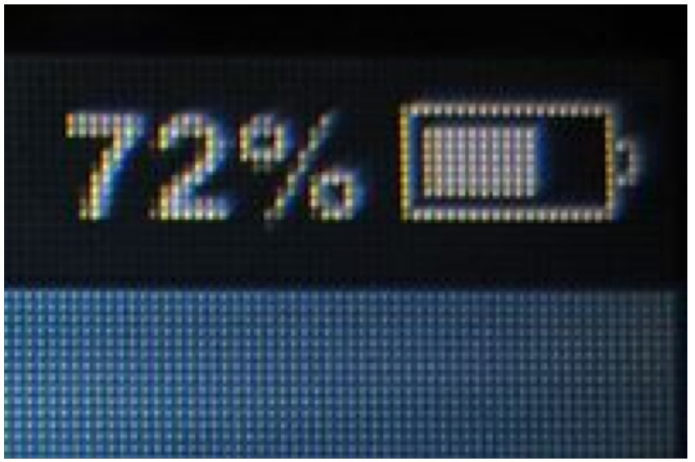
We can see individual pixels larger than about 0.116 to 0.203 mm

“Retina” Displays

- iPhone X “Super Retina”
  - 2436 by 1125 px
  - Assume held 10 to 12 inches away
  - 180 ppcm, pixel size 0.056mm
  - iPhone X: 462 pixels per inch

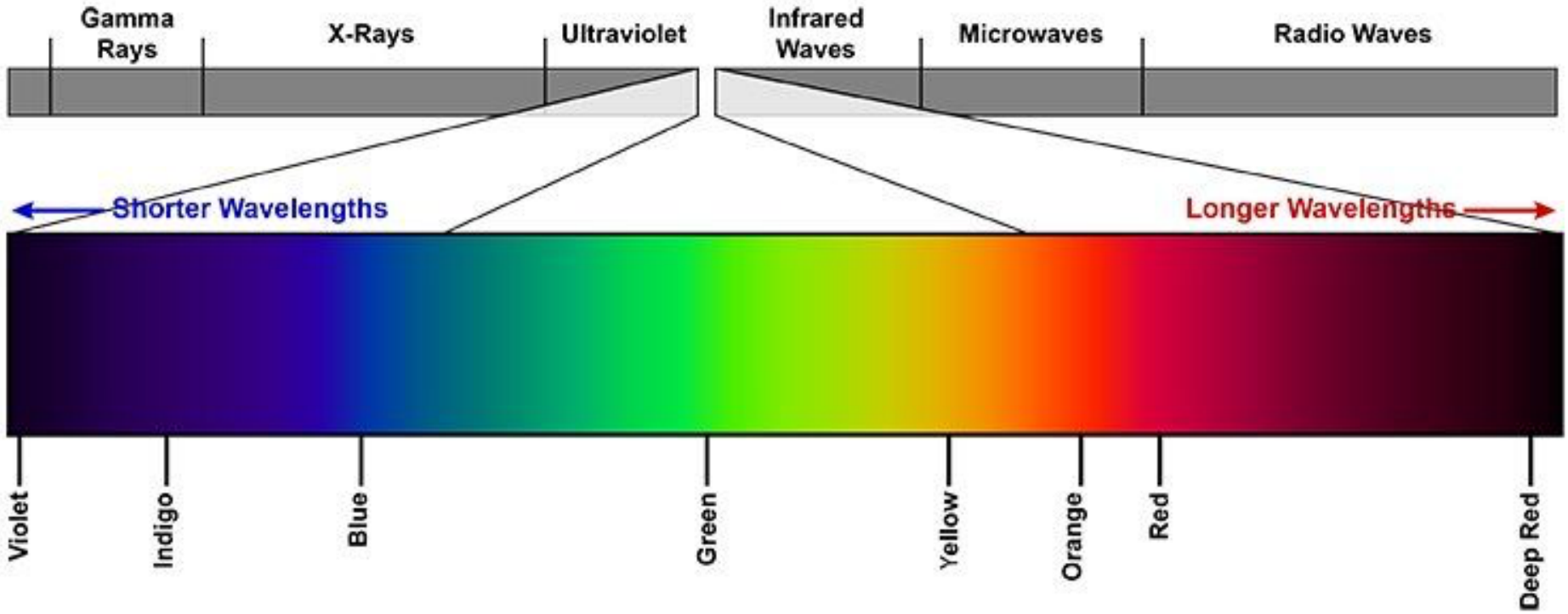


- 15 inch MacBook “Retina”
  - 2800 by 1800 px
  - 87 ppcm, pixel size 0.12 mm
  - 220 pixels per inch



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



Colour Perception

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

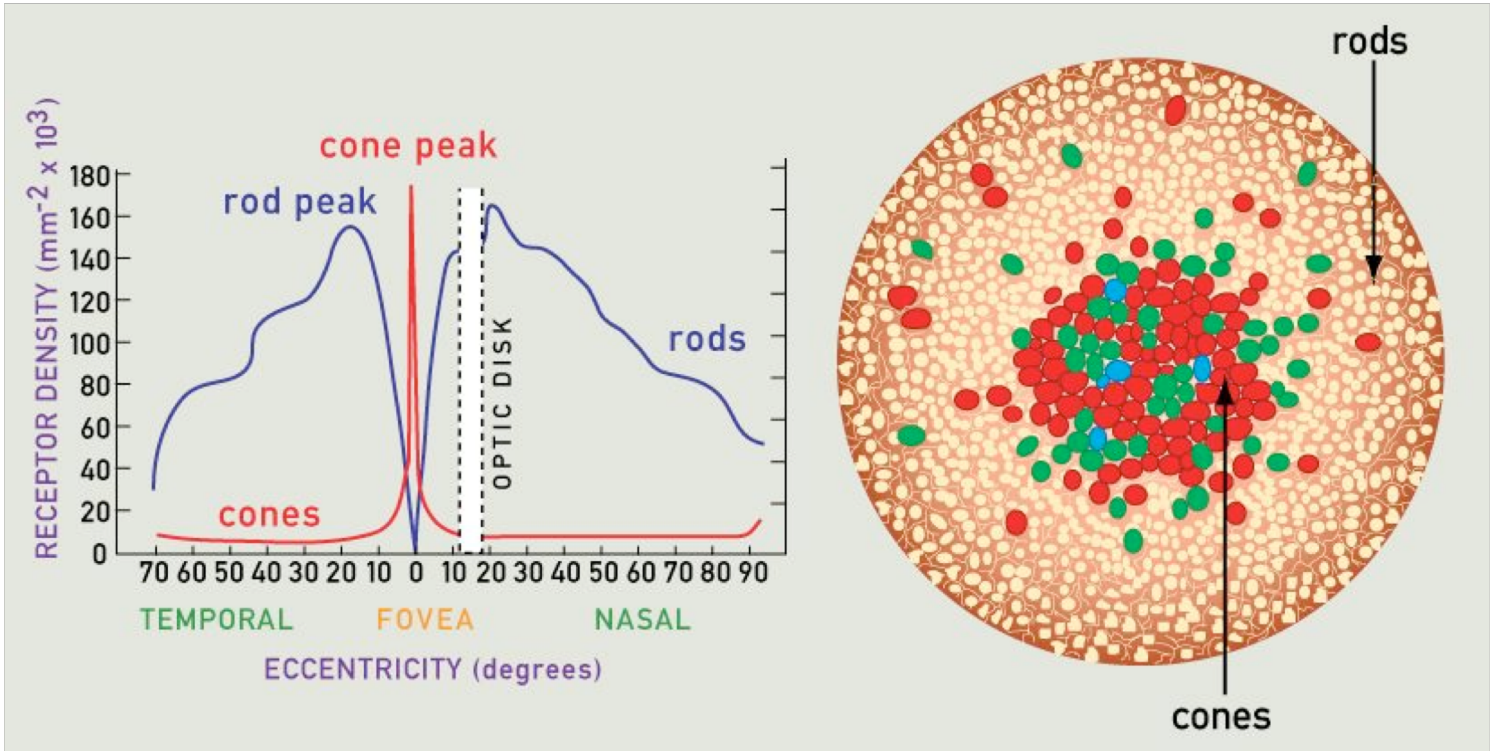


Image: www.webexhibits.org

Rod and Cone Color Sensitivity

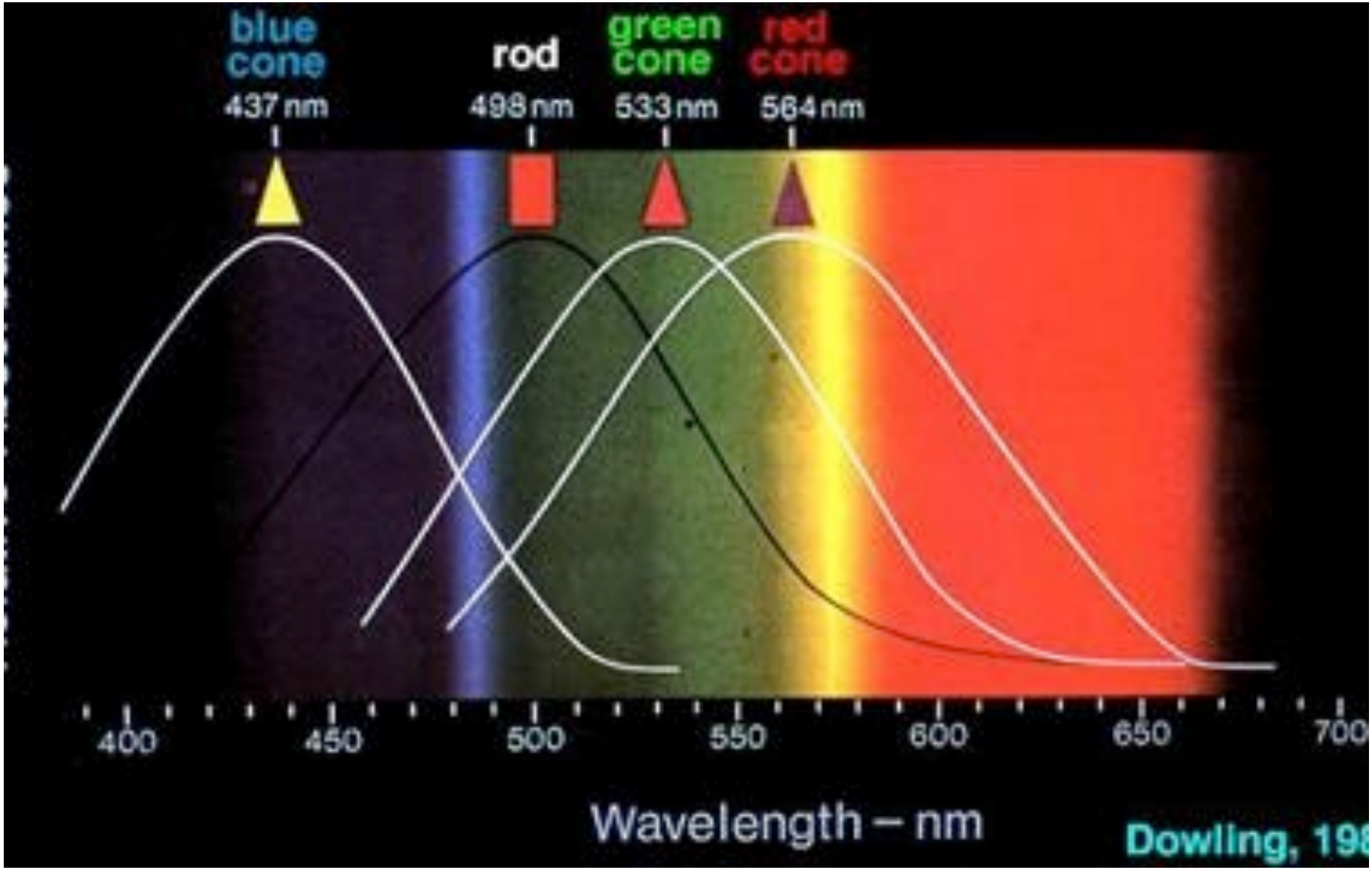
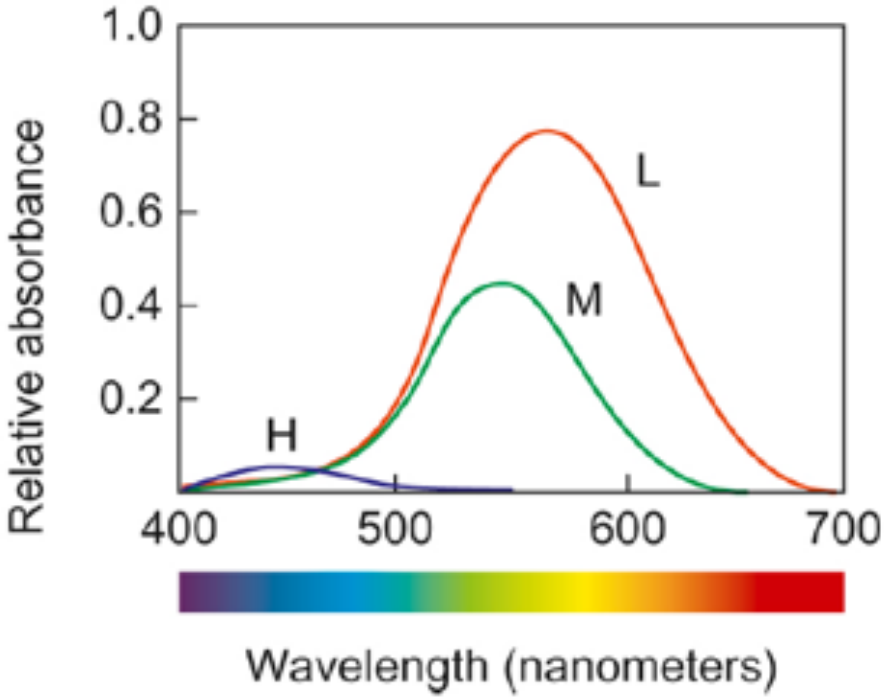


Image Credit: Fleet

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



Actual Cone Response

(Johnson, page 38)

Humans, Birds, and Bees

Visible Light

UV Light

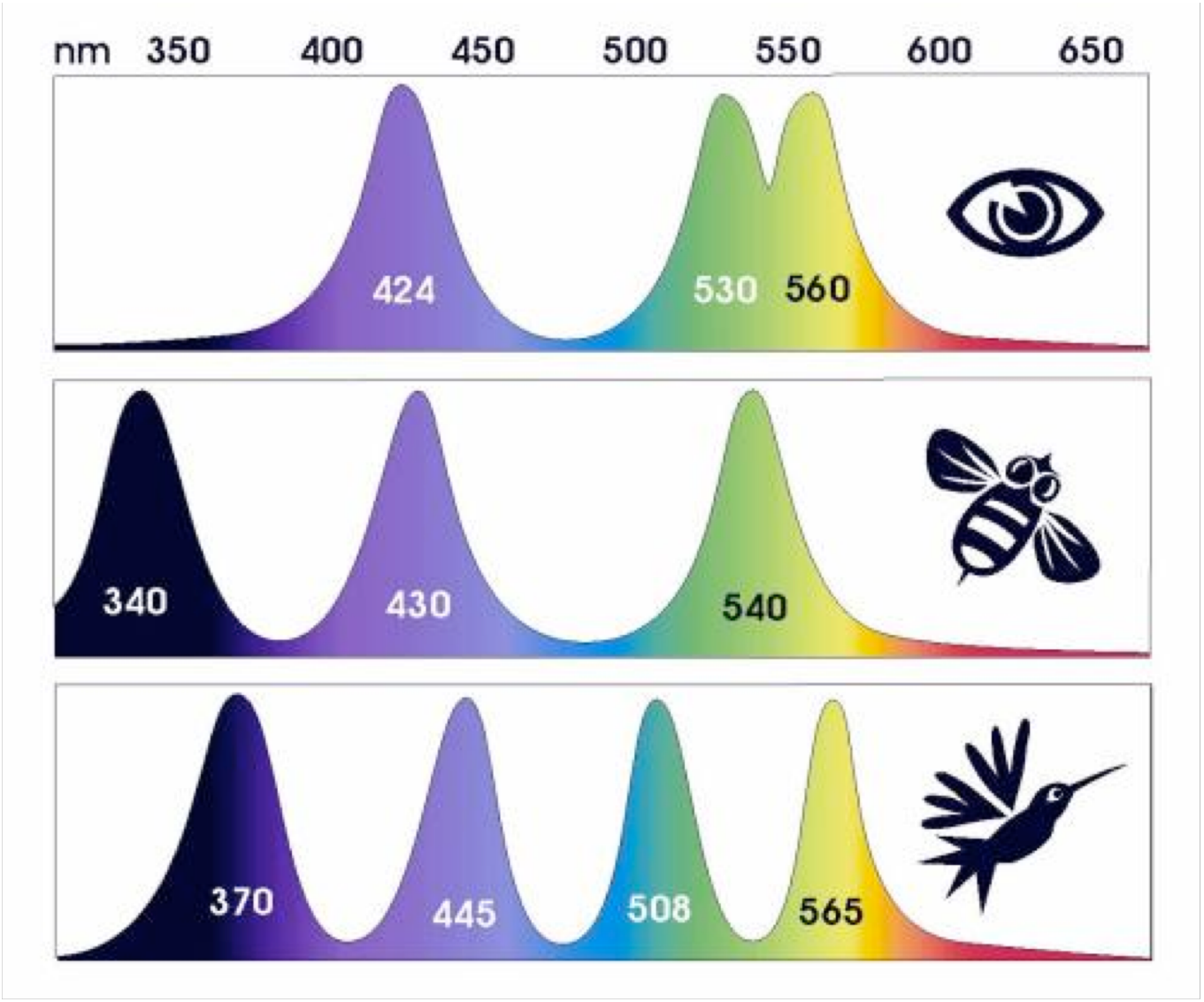
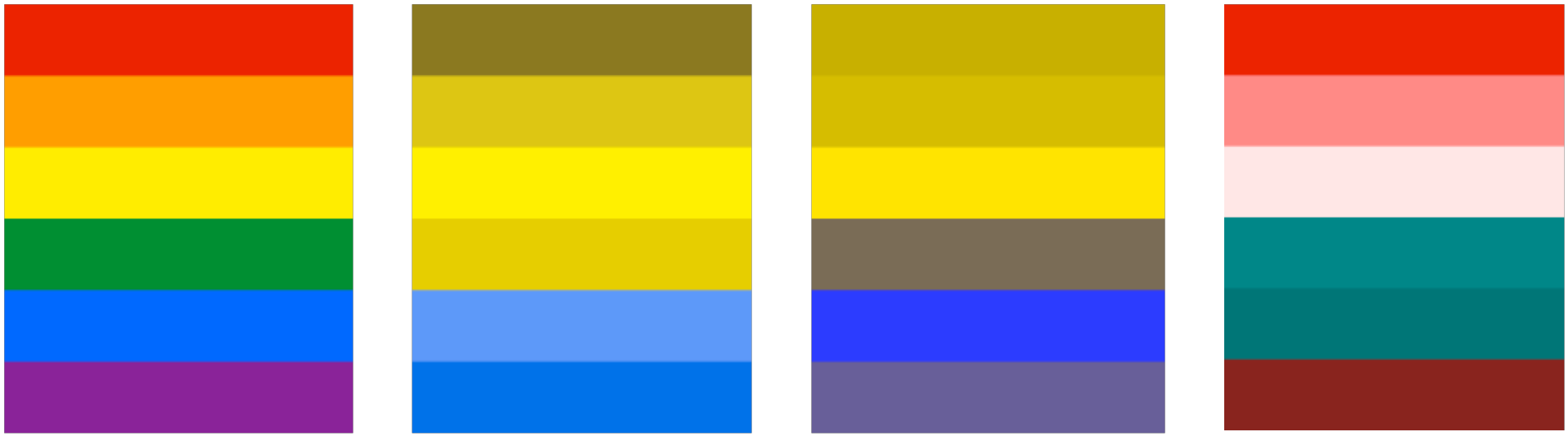


Image: http://fieldguidetohummingbirds.wordpress.com
http://www.naturfotograf.com/UV_flowers_list.html#top/

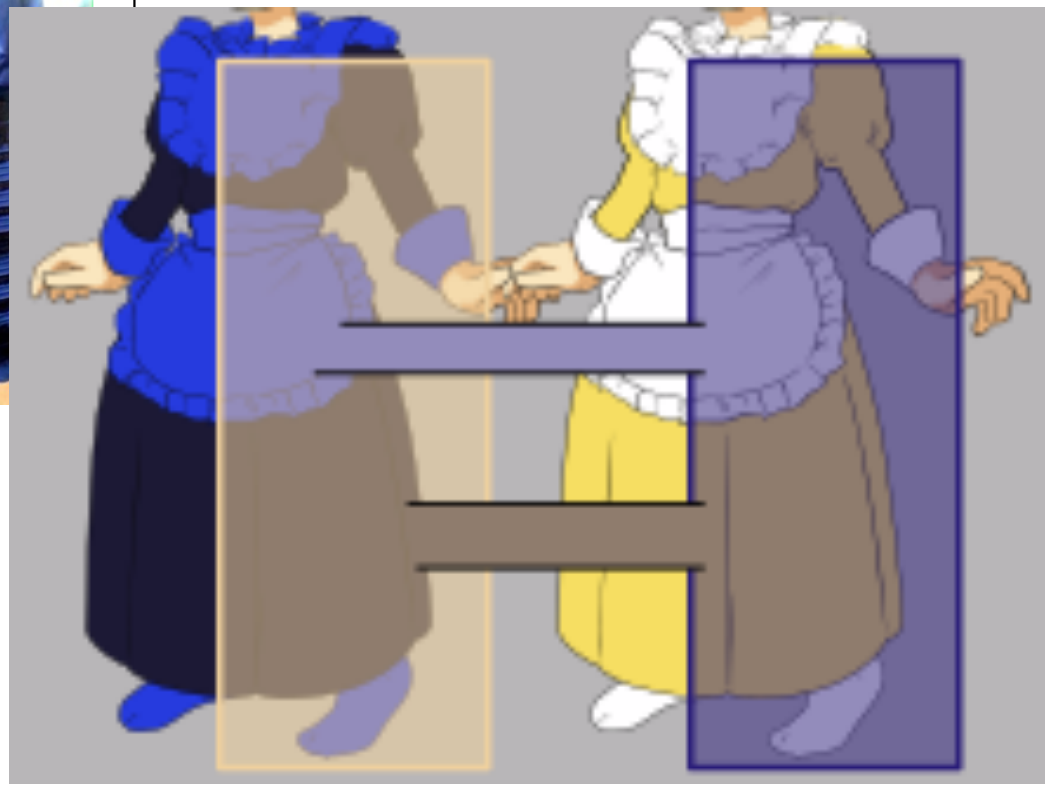
Colour Blindness

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

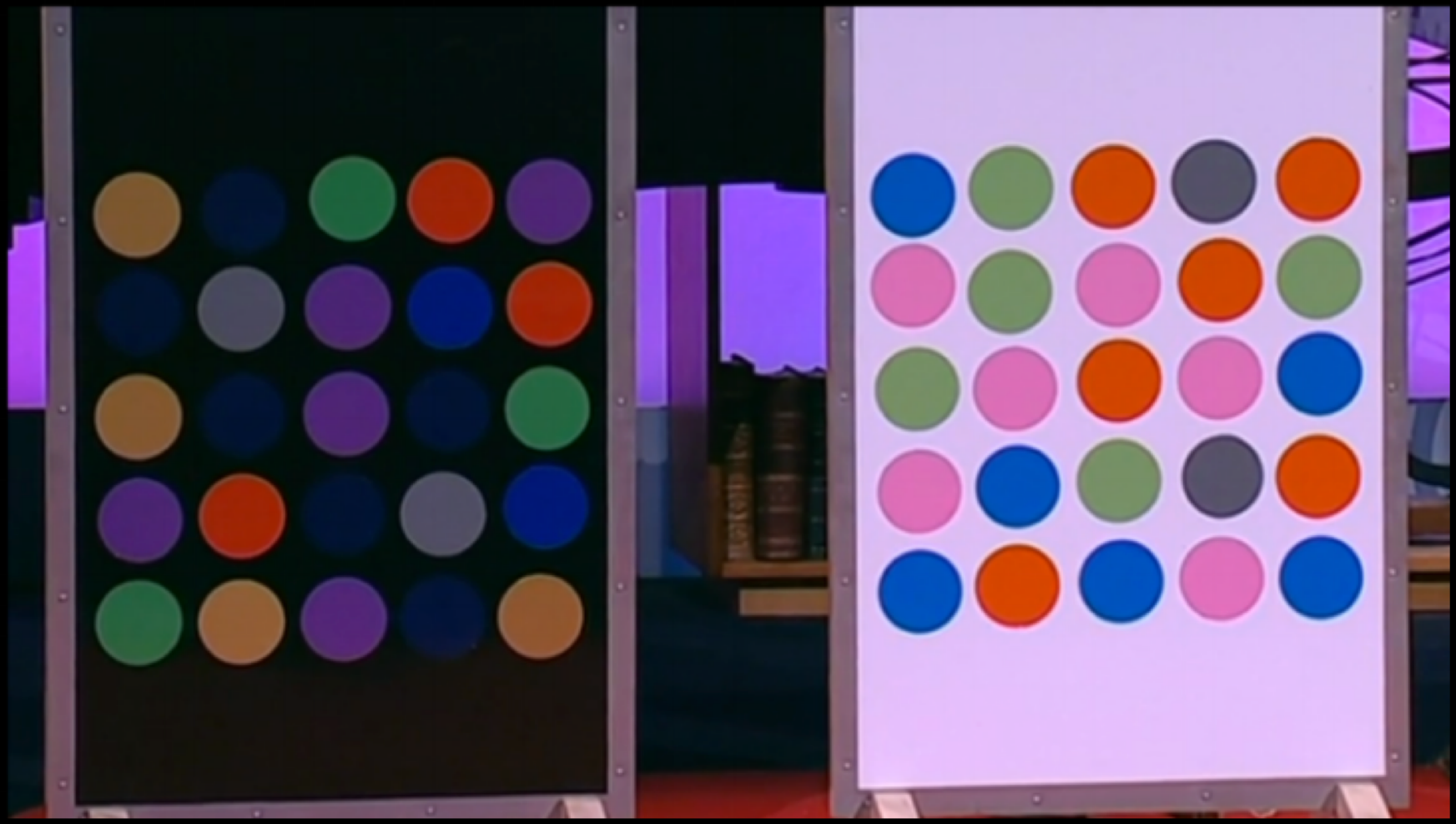


protanopia deuteranopia tritanopia

What color is the dress?



http://www.wired.com/2015/02/science-one-agrees-color-dress/
https://en.wikipedia.org/wiki/The_dress

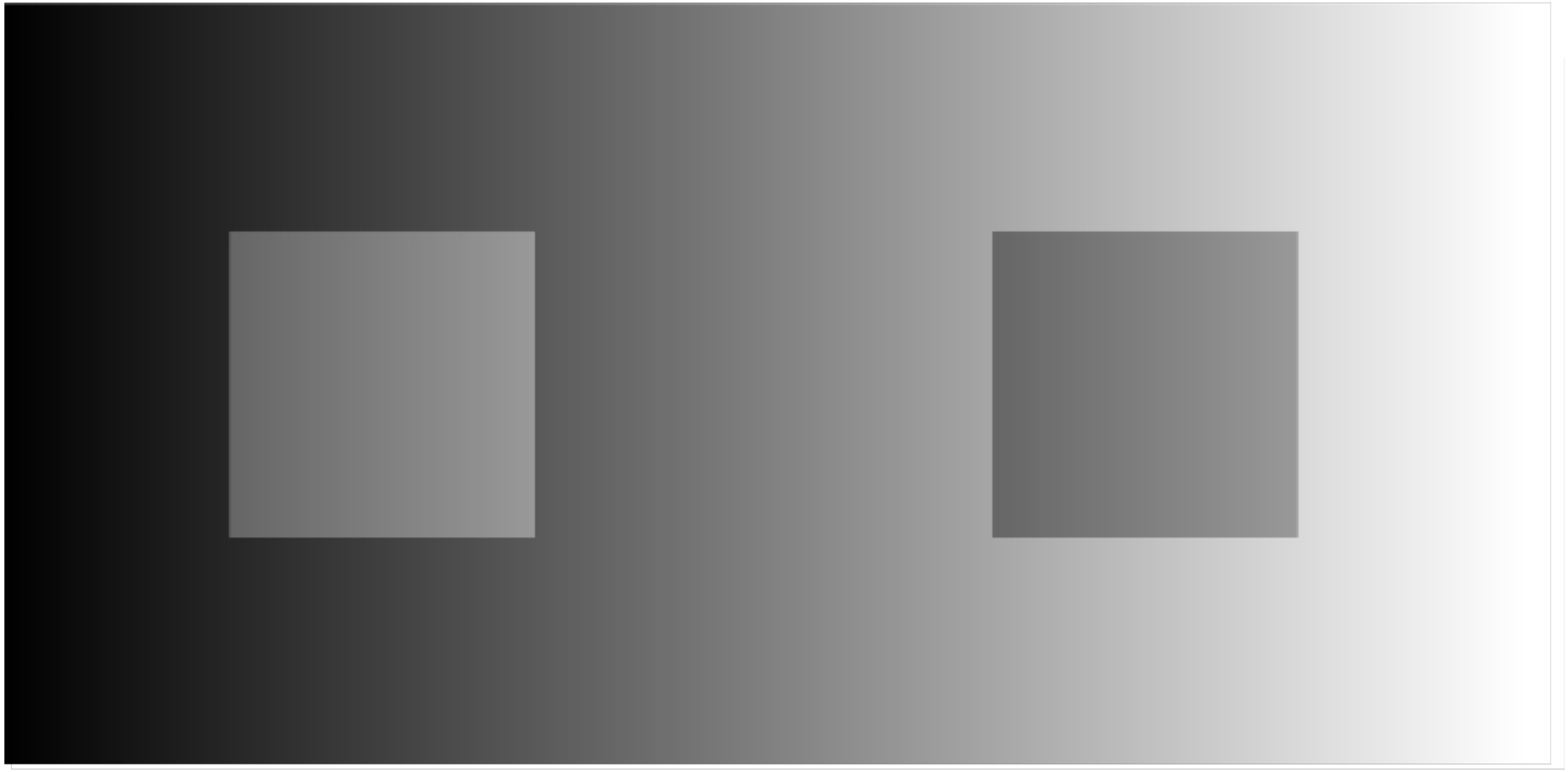


Beau Lotto, **Optical illusions show how we see (Ted 2009)**

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

Design Implications: 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

Design Implications: Colour Presentation Matters

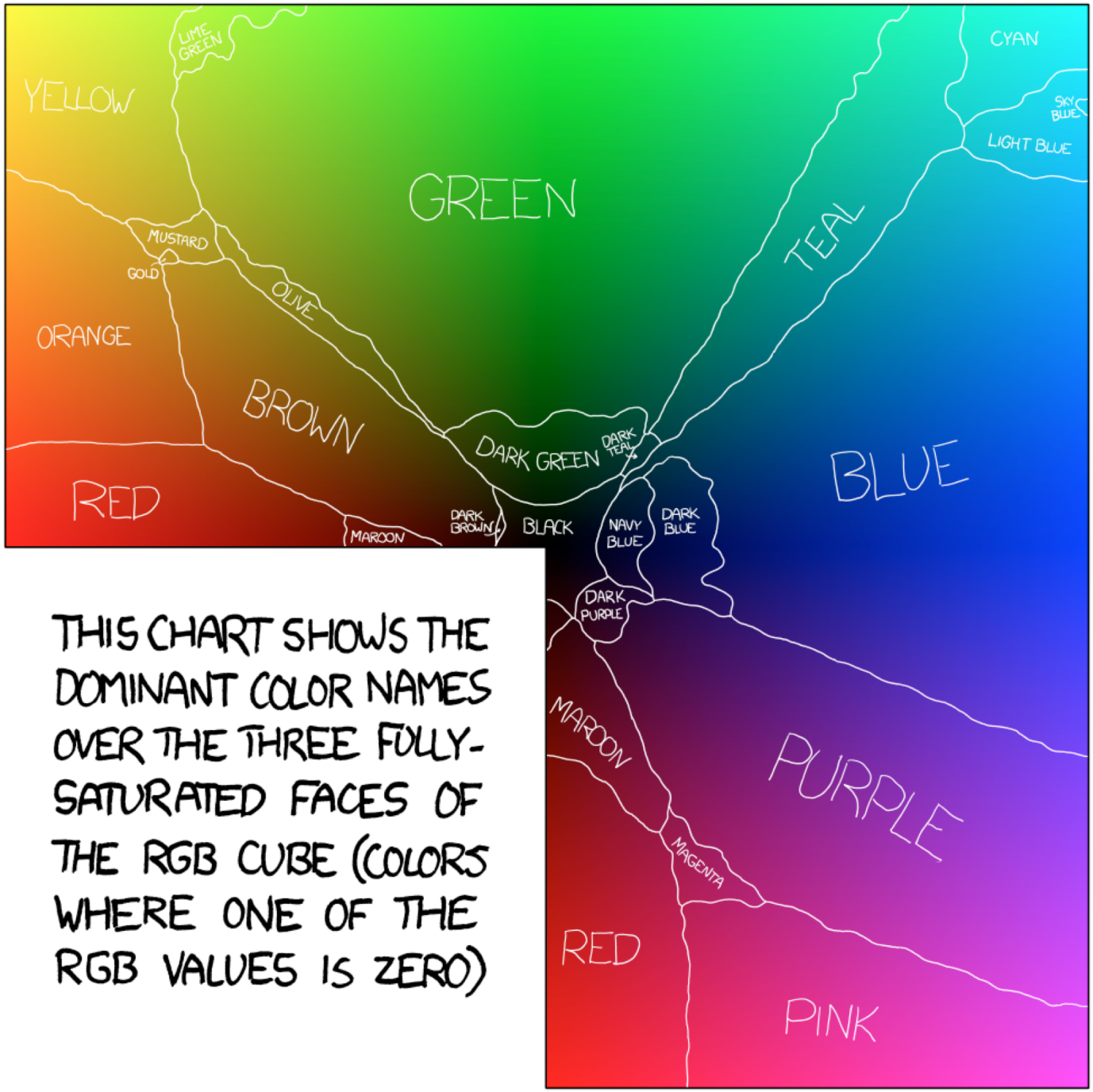
- Our ability to discriminate colours depends on presentation
- Example: it's harder to tell two colours apart when
  - the colours are pale
  - the object is small or thin
  - the colour patches are far apart

FIGURE 5.4

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

(Johnson, page 41)

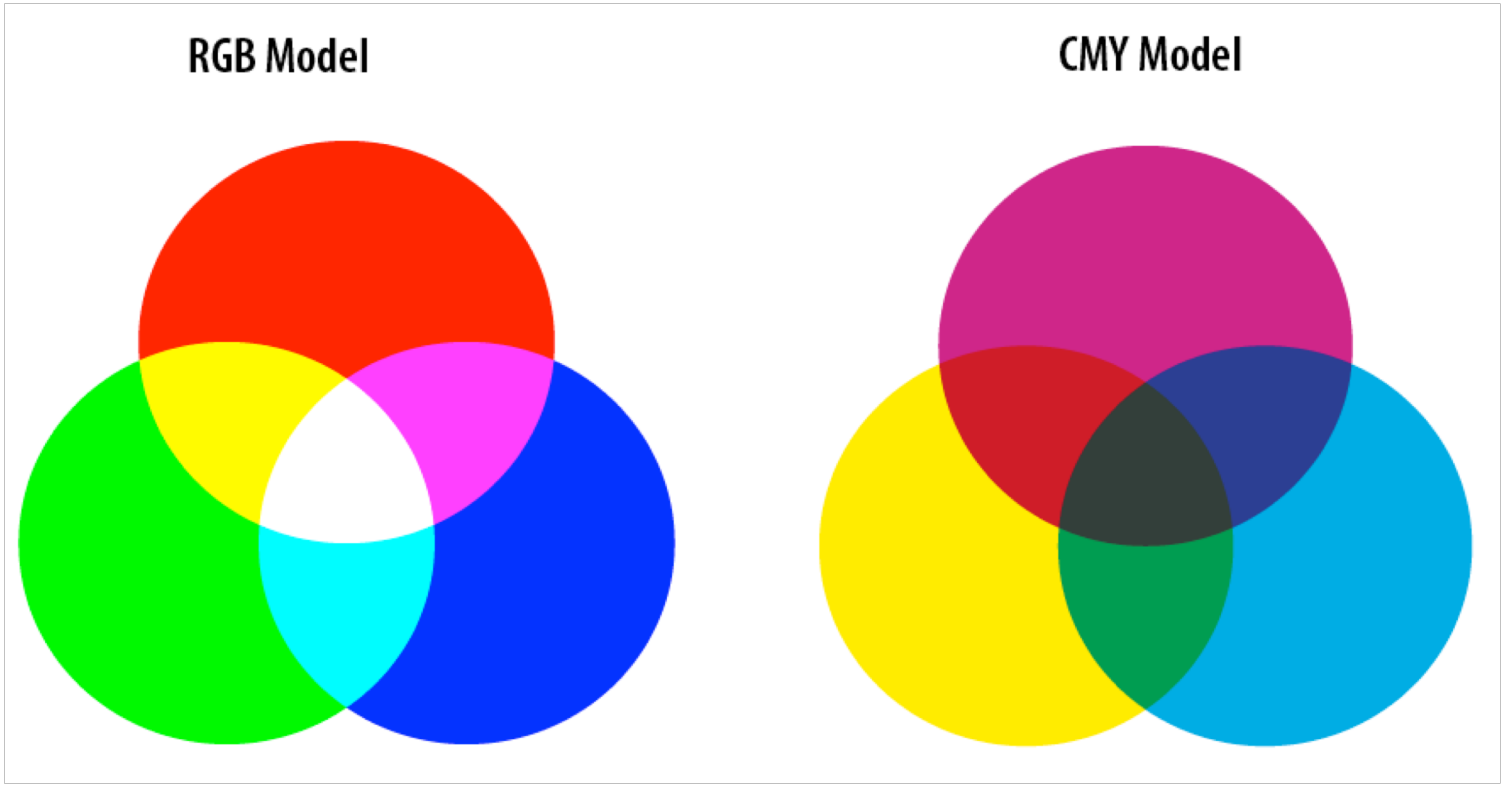
Representing Images and Colour


LIME GREEN
YELLOW
GREEN
CYAN
SKY BLUE
LIGHT BLUE
TEAL
MUSTARD
GOLD
OLIVE
ORANGE
BROWN
DARK GREEN
DARK TEAL
BLUE
RED
MAROON
DARK BROWN
BLACK
NAVY BLUE
DARK BLUE
DARK PURPLE
MAROON
PURPLE
MAGENTA
RED
PINK
THIS CHART SHOWS THE DOMINANT COLOR NAMES OVER THE THREE FULLY-SATURATED FACES OF THE RGB CUBE (COLORS WHERE ONE OF THE RGB VALUES IS ZERO)

Colour Models

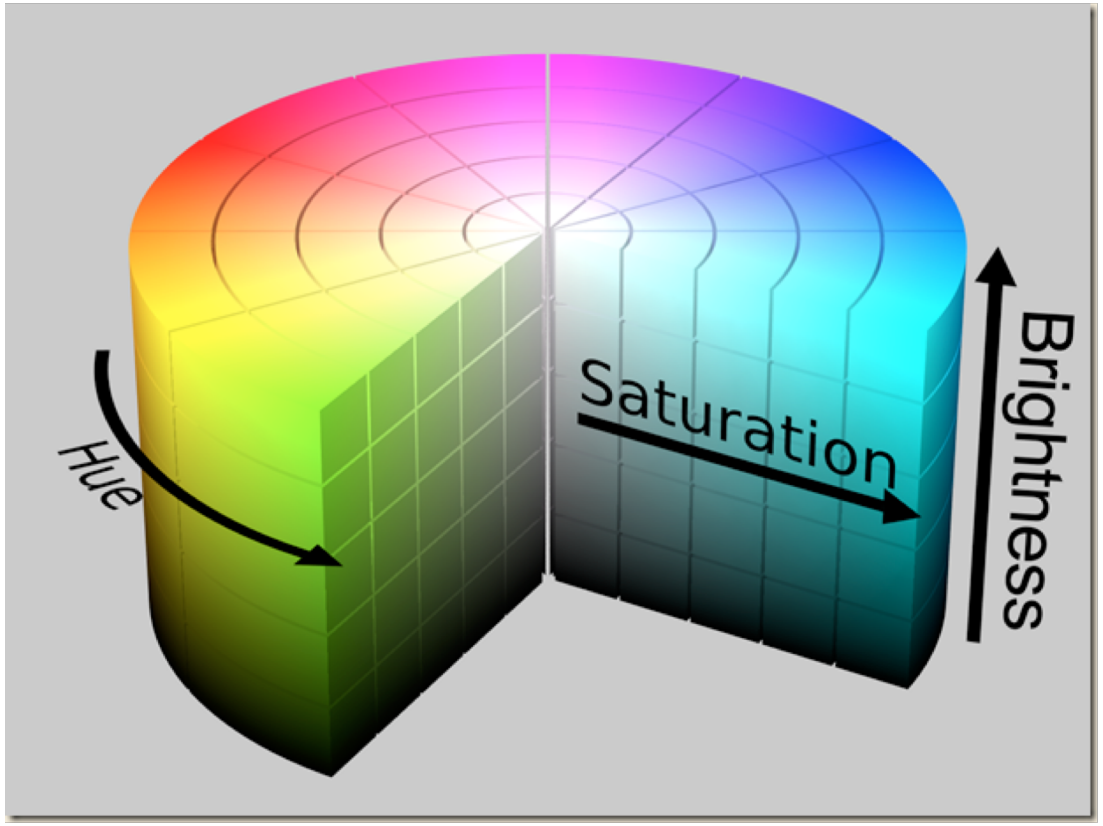
- **Additive**
  - coloured light (i.e. emitted light) is added to produce white
- RGB for displays (emit light)
- HSV/HSB to describe colour

- **Subtractive**
  - coloured light is absorbed (by colored material) to produce black
- CMY/CMYK – printing (colored ink is blended on a surface)



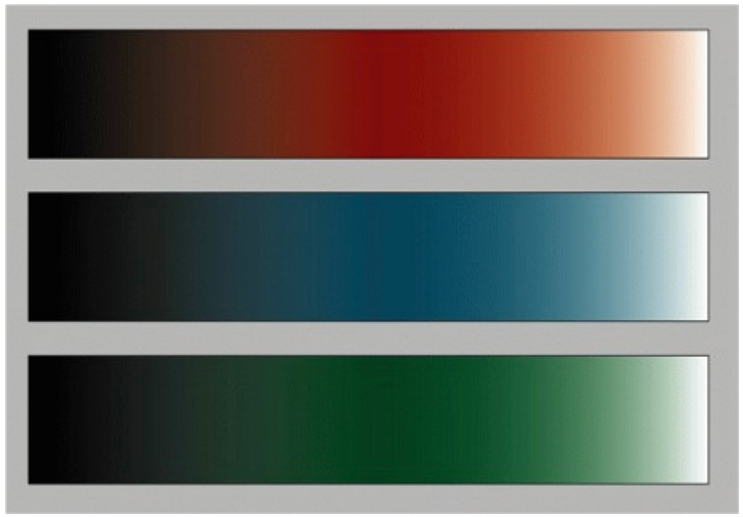
HSV/HSB Color Model (Additive)

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



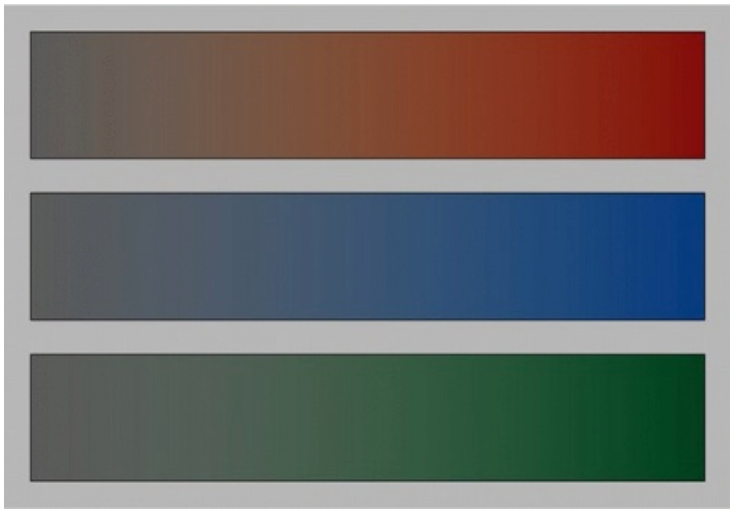
Value/Brightness vs. Saturation

- **Value/Brightness**
  - Reflecting less to more light



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

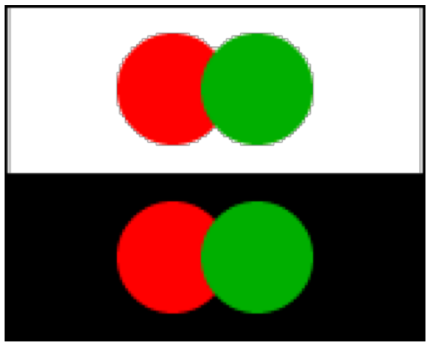
- **Saturation**
  - Containing less to more hue



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

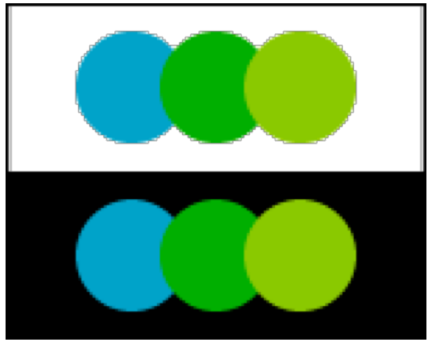
Colour Harmony

Complementary



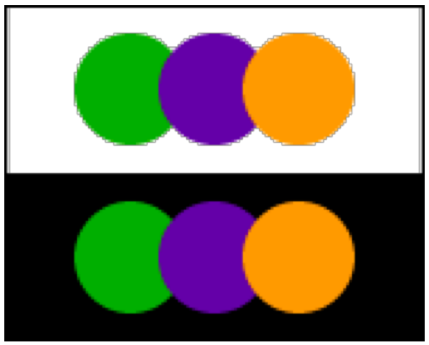
High contrast, “opposing”

Analagous



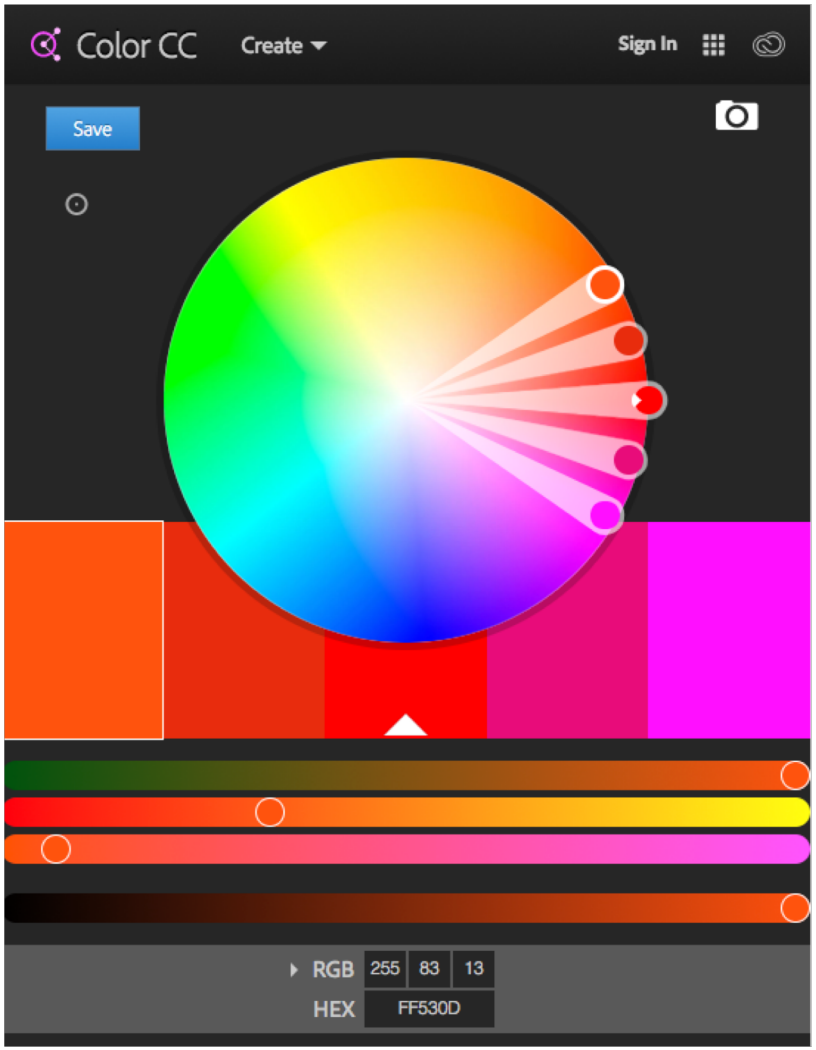
Harmonious, ”pleasing”

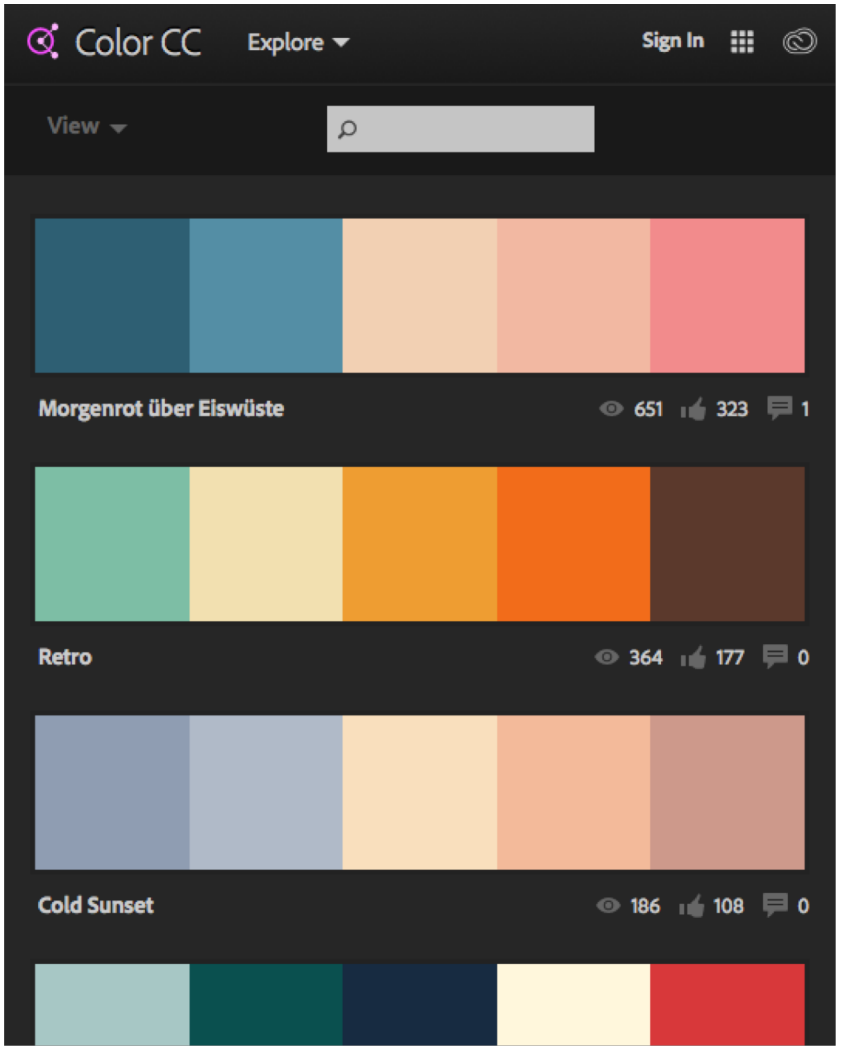
Triad



Balanced, “vibrant”

http://www.tigercolor.com/color-lab/color-theory/color-harmonies.htm



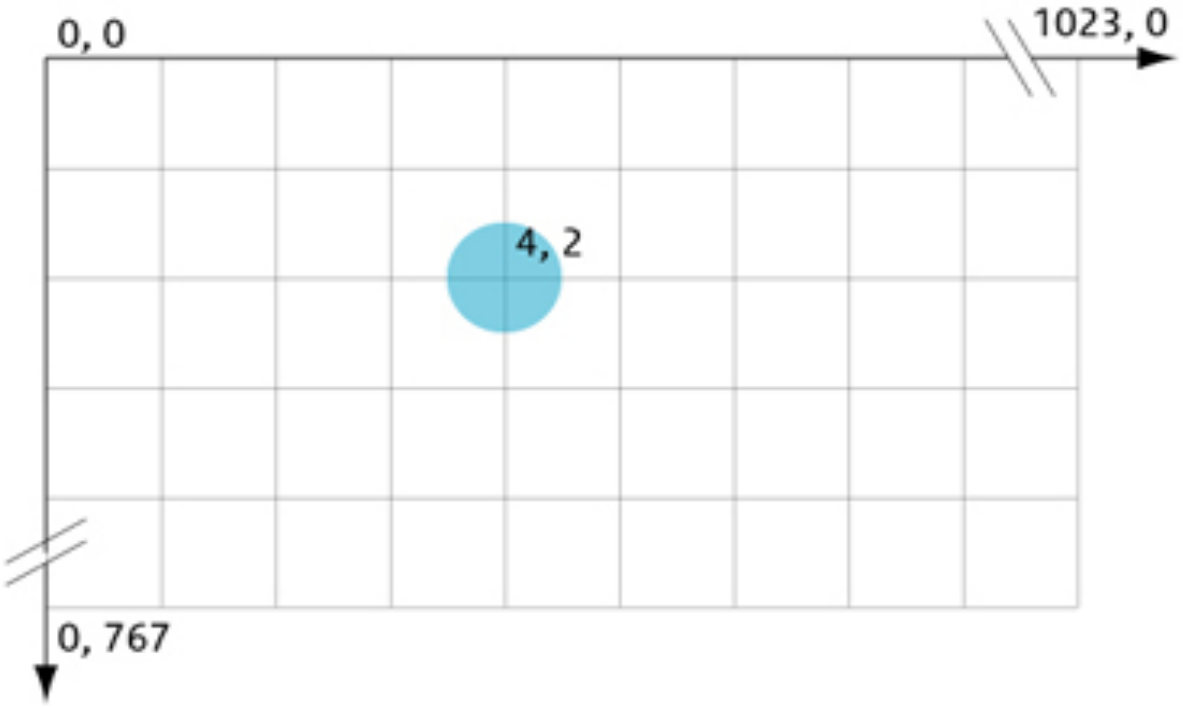


Adobe Colour Tool

- https://color.adobe.com

Coordinate Systems

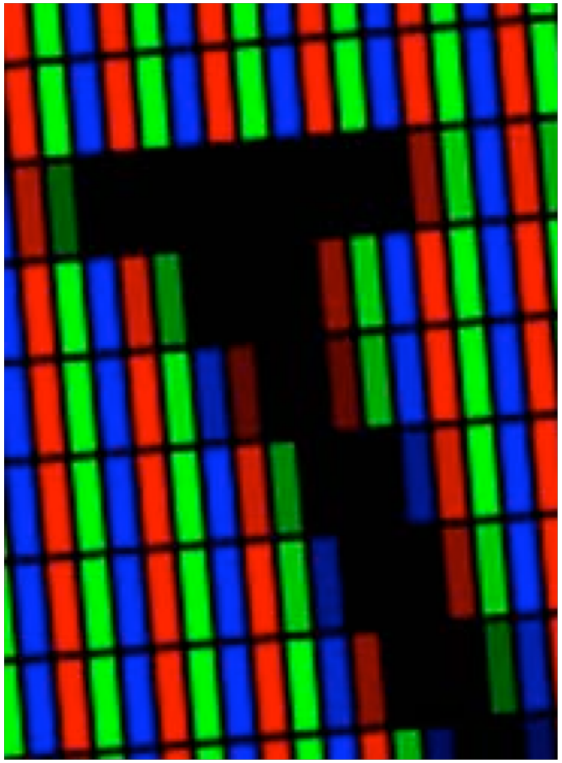
- Screen resolution refers to the number of points, or **pixels** on-screen.
- Typically we want to be able to set the color of each pixel independently.

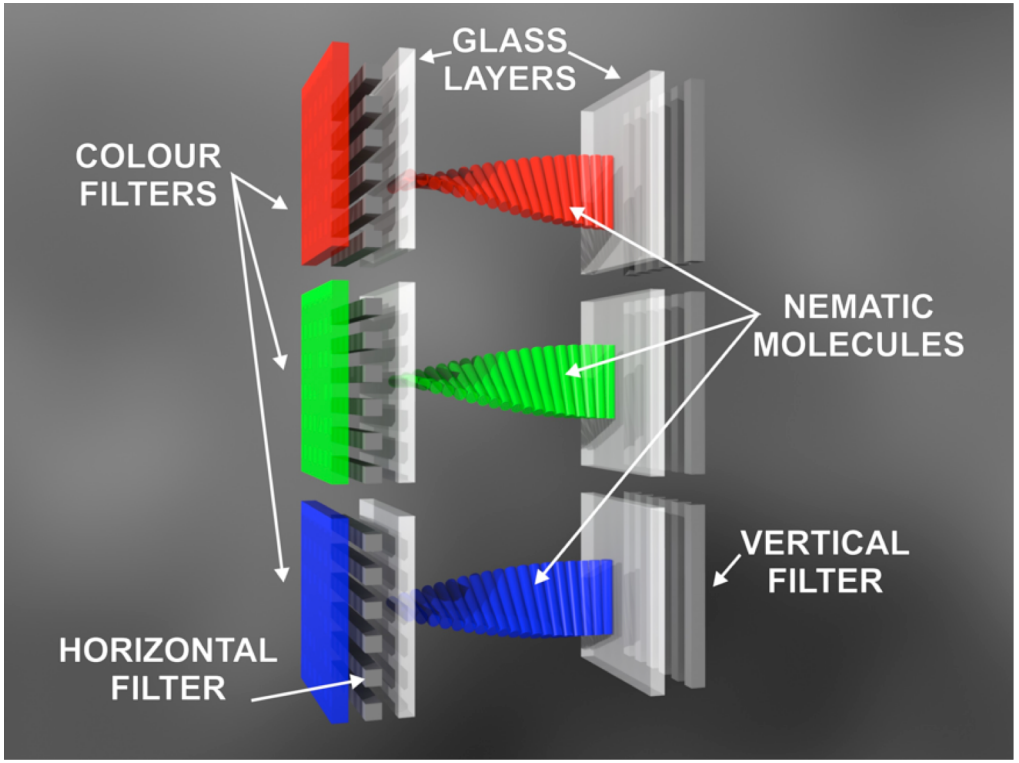


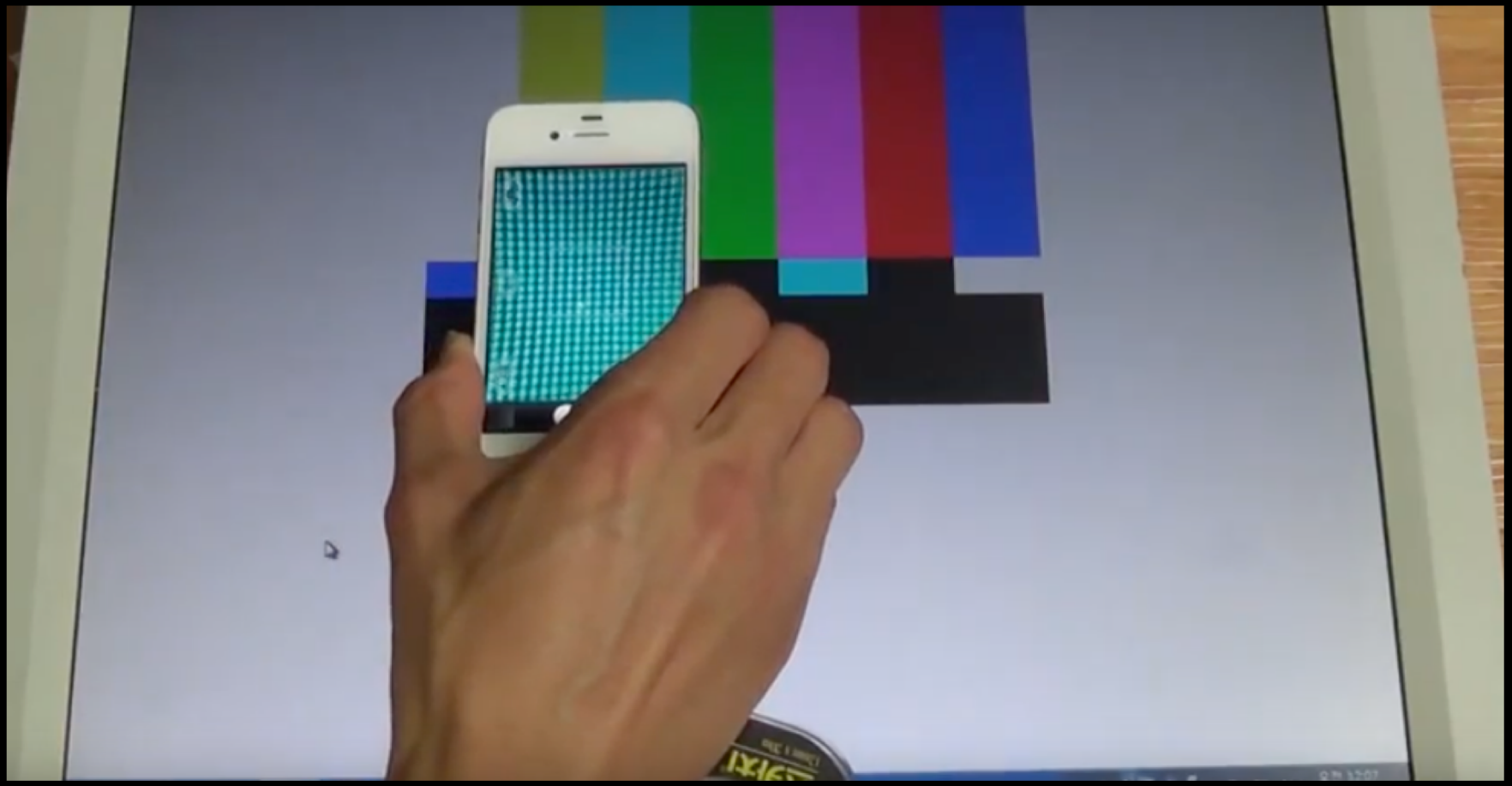
1024 x 768 screen resolution

Display Technologies

- 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



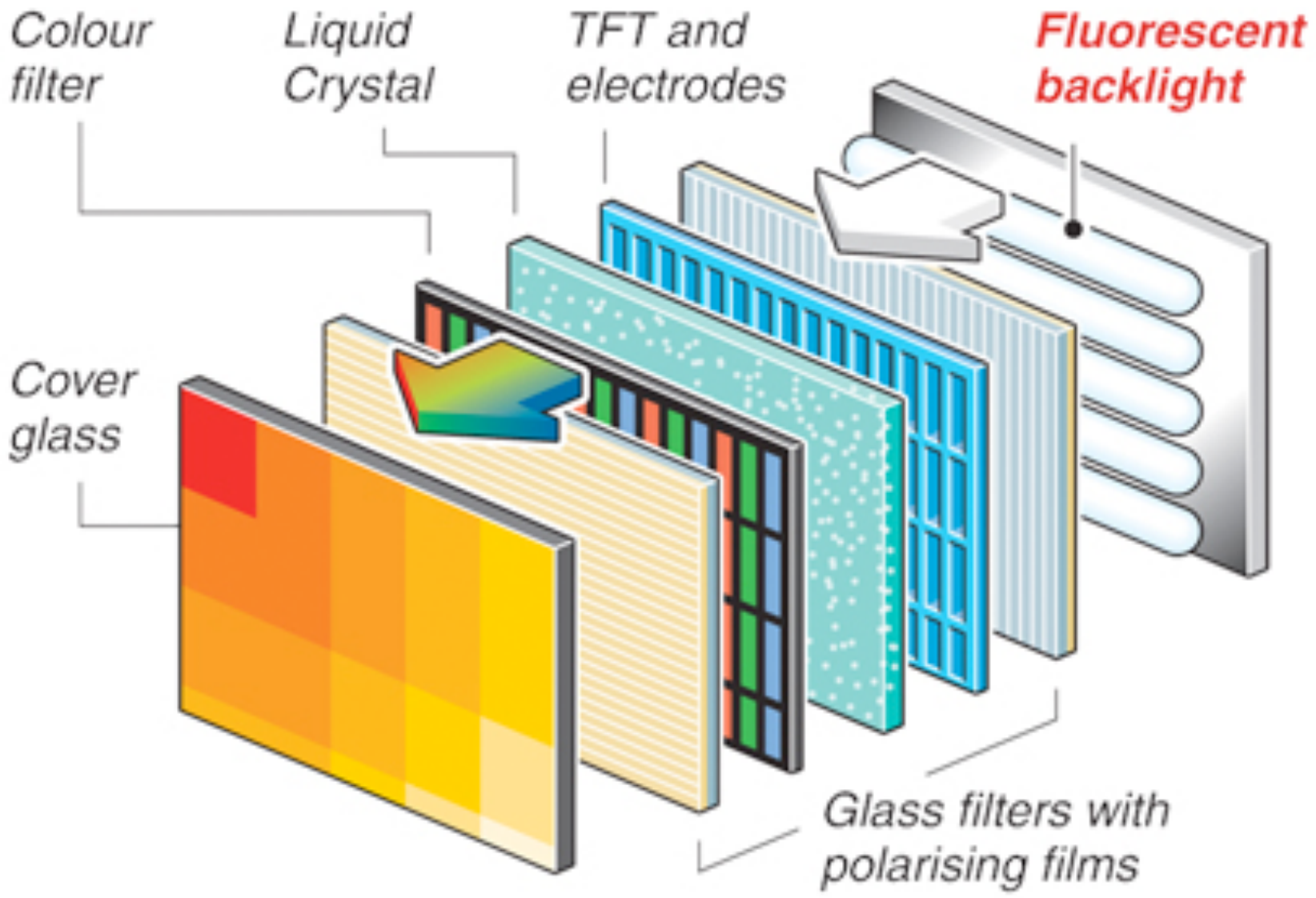


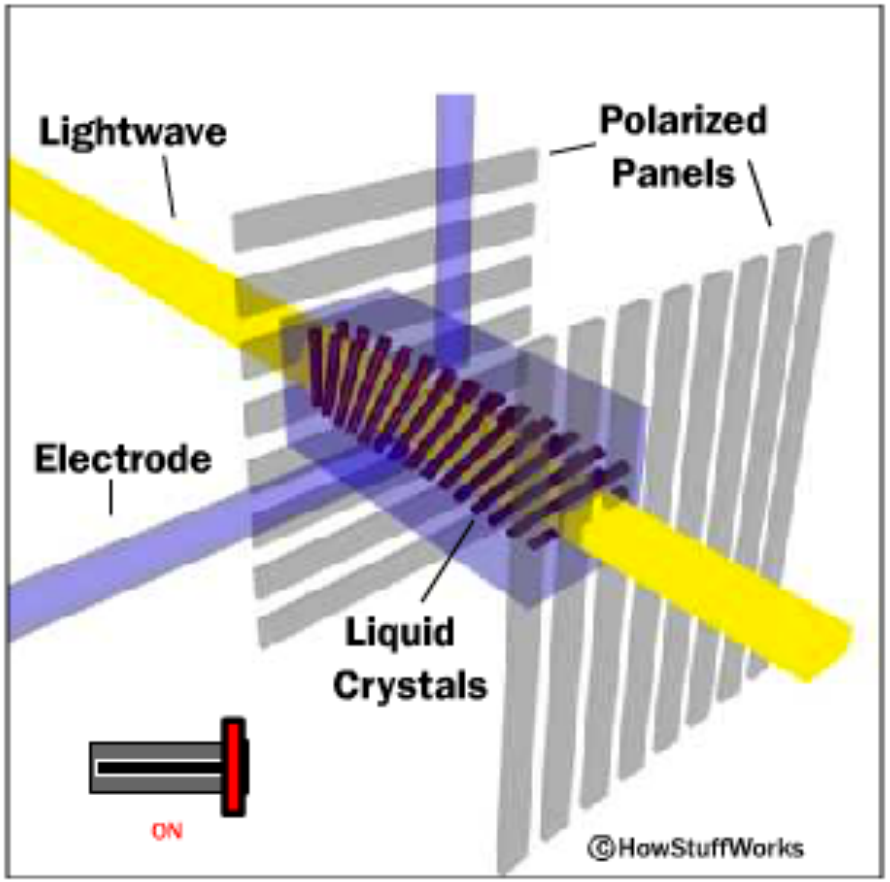


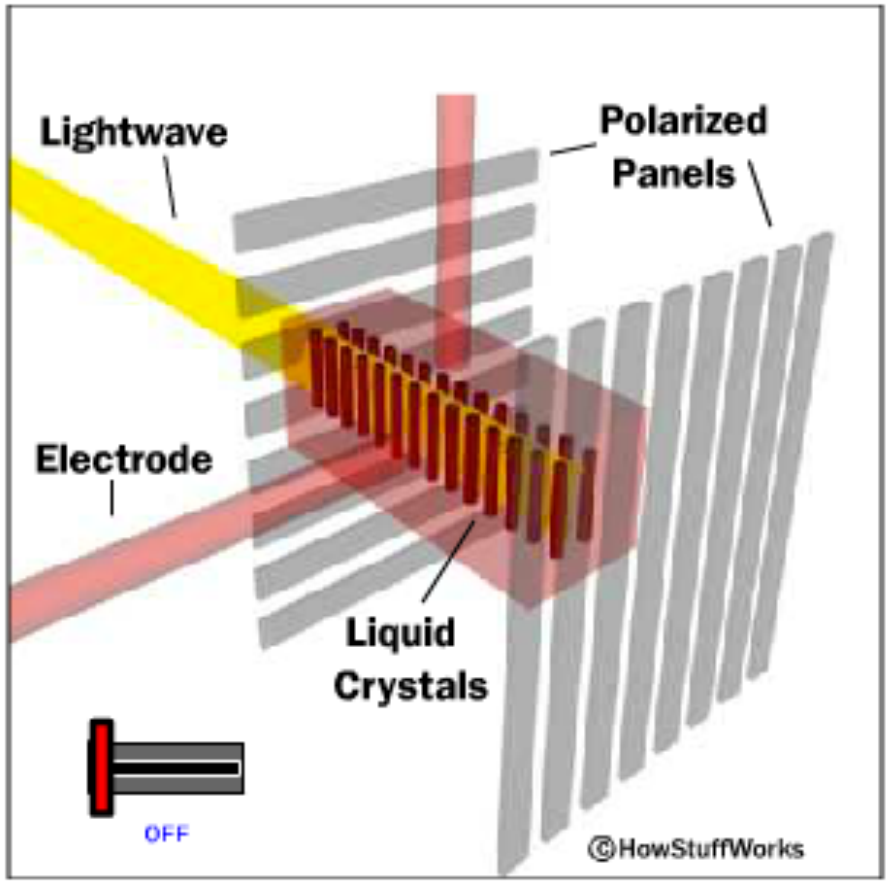
How to see your monitor subpixels

- https://youtu.be/_O66qHq1YS4

LCD Displays







How Liquid Crystals “twist” light

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