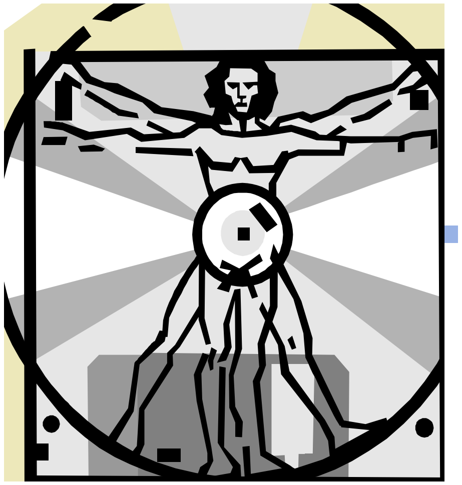


Color Vision

Ebony, and ivoryyyy

Overview

- Color vision in nature
- Color mixture
- Effects
- Theories
- Defective color vision

Questions

- Why do we perceive blue dots when a yellow flash bulb goes off?
- What does someone who is “color-blind” see?
- What colors does a honeybee perceive?

Color vision in nature

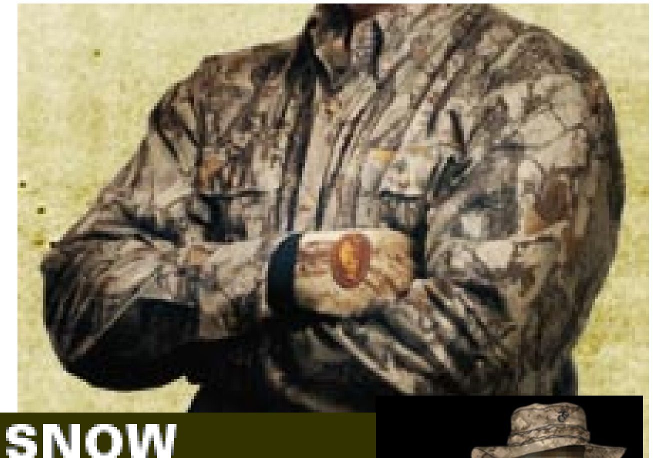
- Utility
  - Evolutionary advantages
- Prevalence
  - No clear phylogenetic trends
  - Primates -- good
  - Birds -- better
  - Fish -- better
  - Dogs -- worse

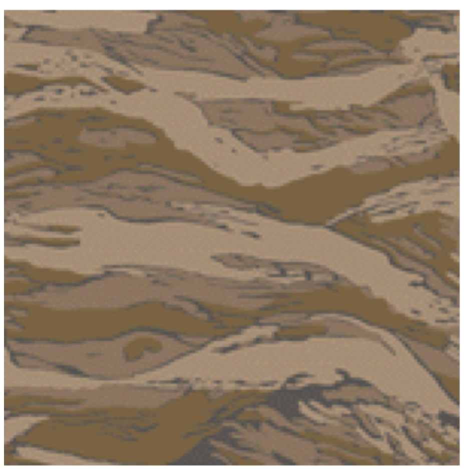
Camouflage

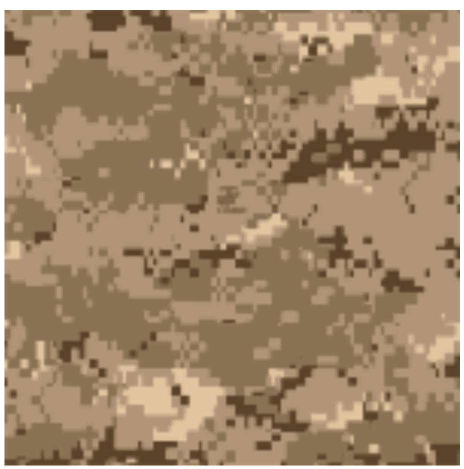
- Natural

Camouflage

- Man-made
  - Often imitate natural (but not always)



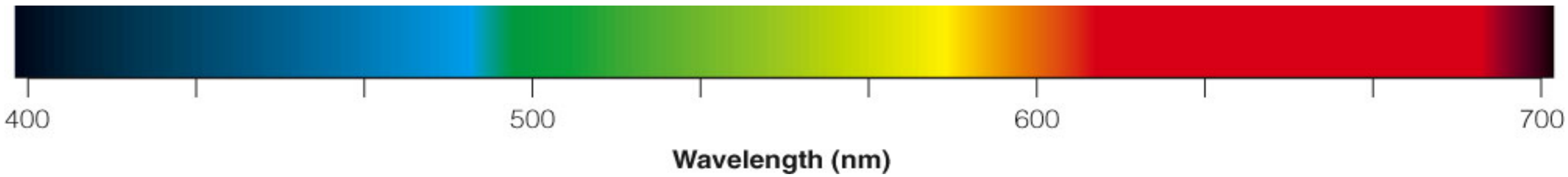




Describing Color

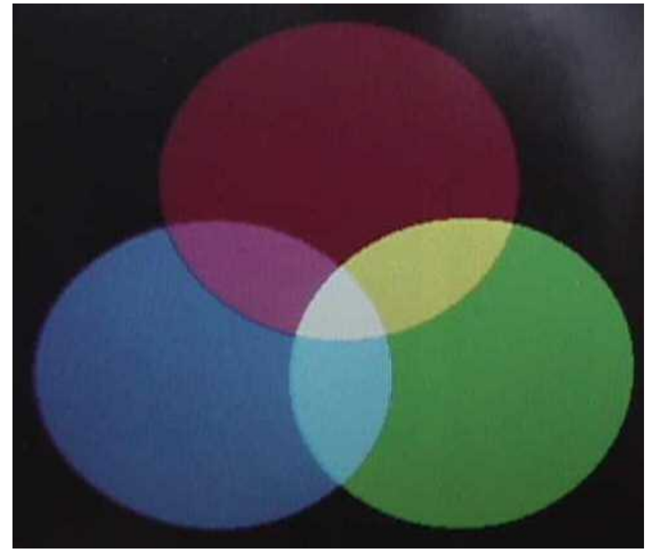
- Hue
  - Perception of wavelength
    - Why is the sky blue, anyway?
    - Why is the sky reddish at dusk?
      Note Martian sunset is blue
    - Rainbow, ROYGBIV & Newton

- Brightness
  - Perception of intensity
  - Brightness/intensity relationship depends on hue (wavelength)
  - Similar to loudness/intensity depends on frequency
  - Bezold-Brucke shift: change in hue with intensity
- Saturation
  - Perception of purity (like timbre)
  - A pure light is monochromatic



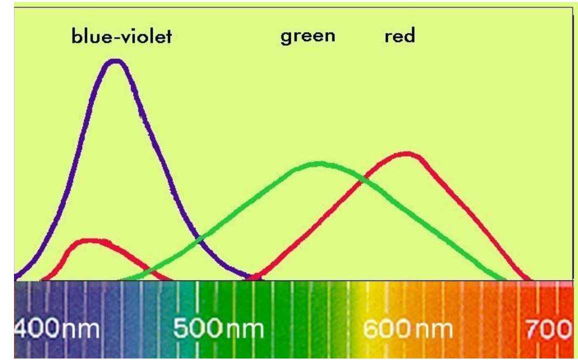
Colors

- Primary colors
  - Red, green, blue
    - Are these 3 colors "special" because of something in our visual system?
    - Why 3 primary colors? Why not 4, 5?



- Secondary colors
  - Mixture of primary colors
  - Yellow, cyan, magenta (between two rainbows)
  - Brighter (two sets of cones stimulated)
  - Key for mixes, paints, printing (CYMK, not RGB)
- Tertiary colors
  - Mixture of primary and secondary
  - Orange raspberry aquamarine purple lime cobalt

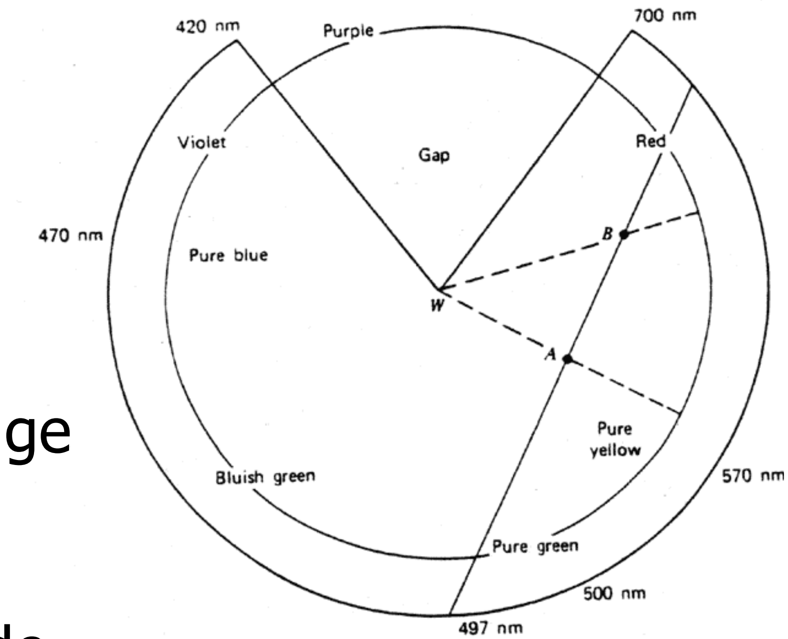
Color Phenomena

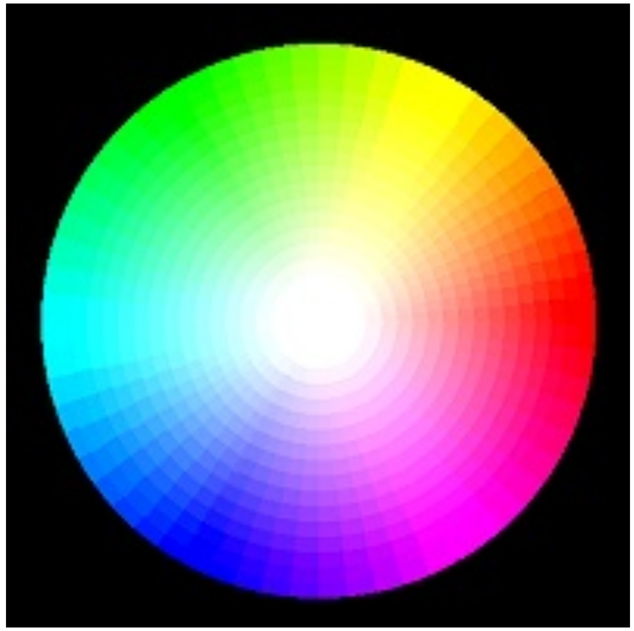


- At a given light level, blue seems less bright than red or green
- Yellow light seems particularly bright
  - Stimulates two cone types
- Eye cannot focus all light at the same time
  - Focus is particularly difficult for blue
  - Implication for Web color choices (among other things)
- Overlap of sensitivities
  - Note some red cones respond to blue light, so some blues seem to have some red in them (violet)

Color mixture

- Additive color mixture
  - Color circle
  - Complementary colors
    - Adding even amounts of two colors results in a different color on the edge of the wheel
    - Adding different amounts of colors results in an intermediate color inside the wheel
    - Reducing intensity of each component leads to gray
  - Metamer
    - Light produced via a combination that is perceptually the same as a single-wavelength light
    - Compare yellow to magenta





Color mixture, cont’d

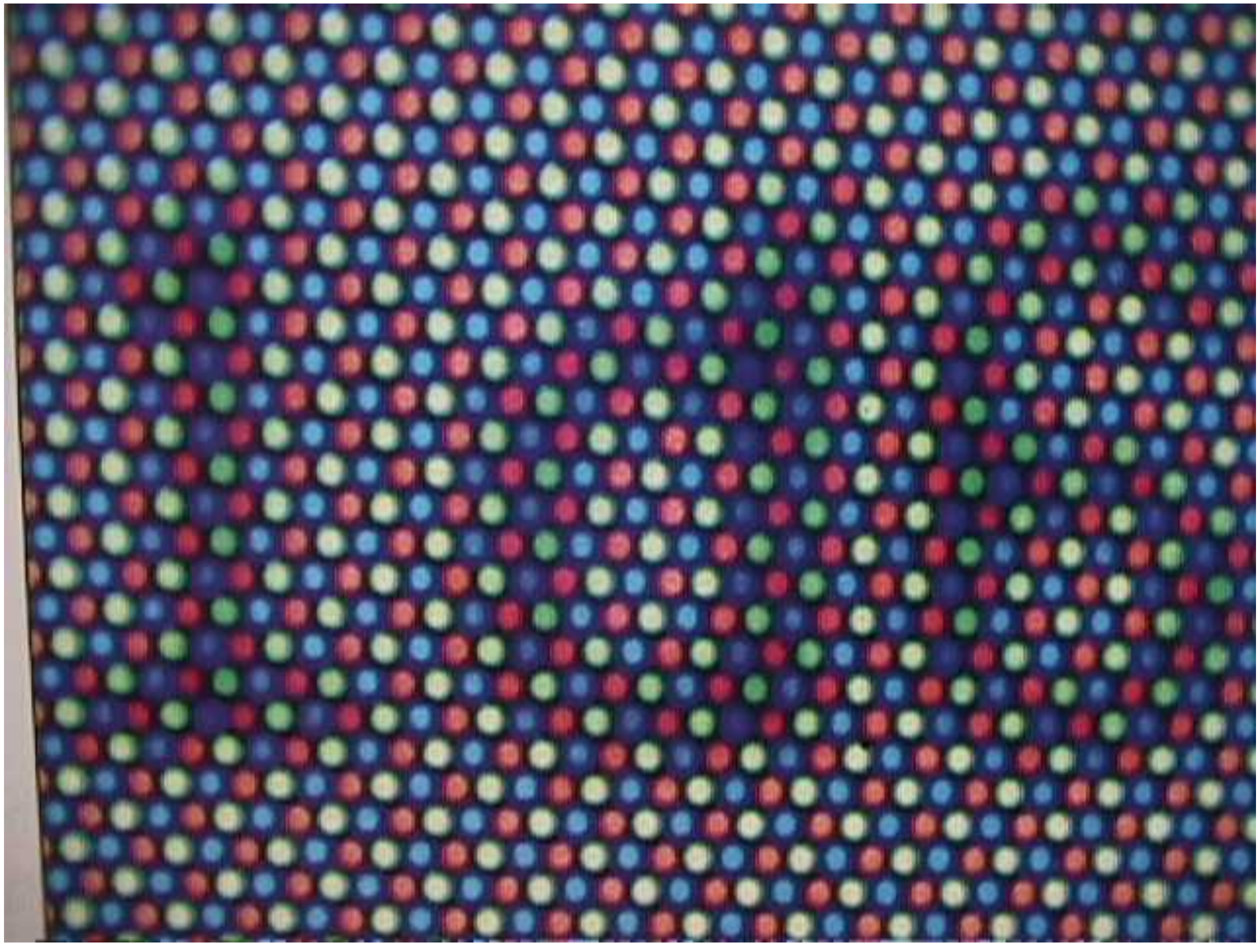
- Pointillism (Seurat, Pissarro, Signac)
  - Painting technique using little dots

Color mixture, cont'd

- Pointillism (Seurat, Pissarro, Signac)

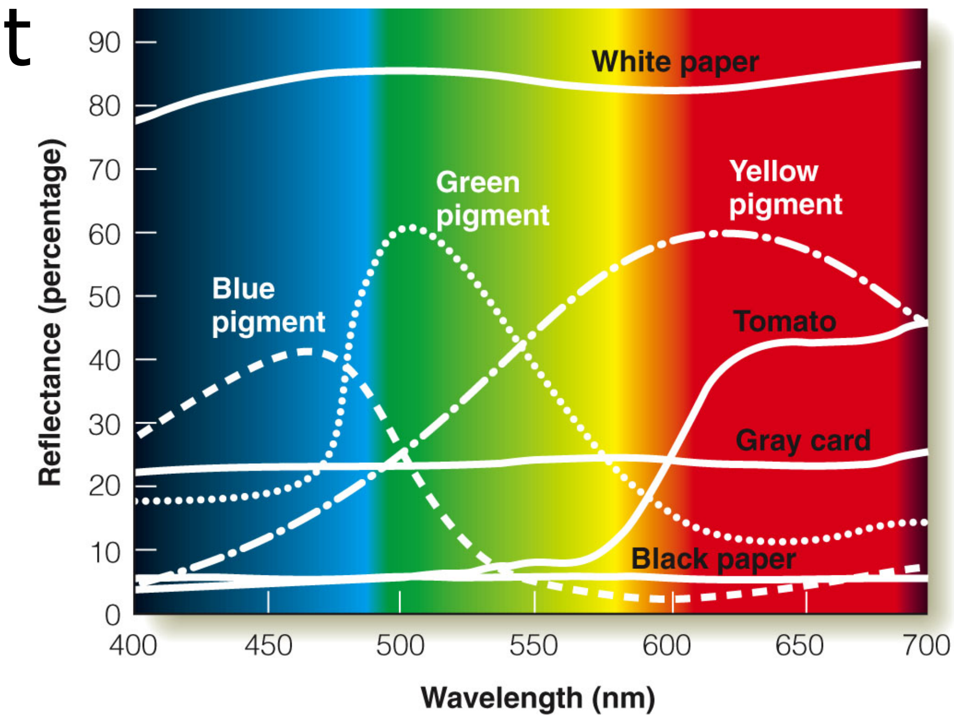
Color mixture, cont' d

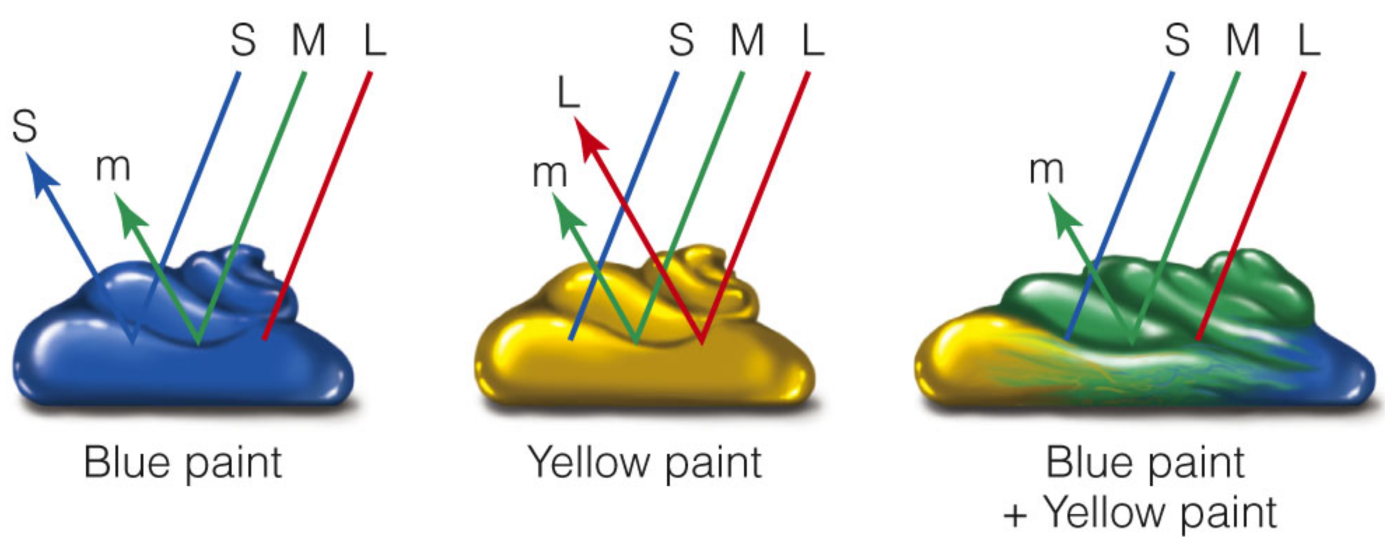
- Television/Computer Monitors
  - Use three colors of phosphors



Subtractive/reflective color mixture

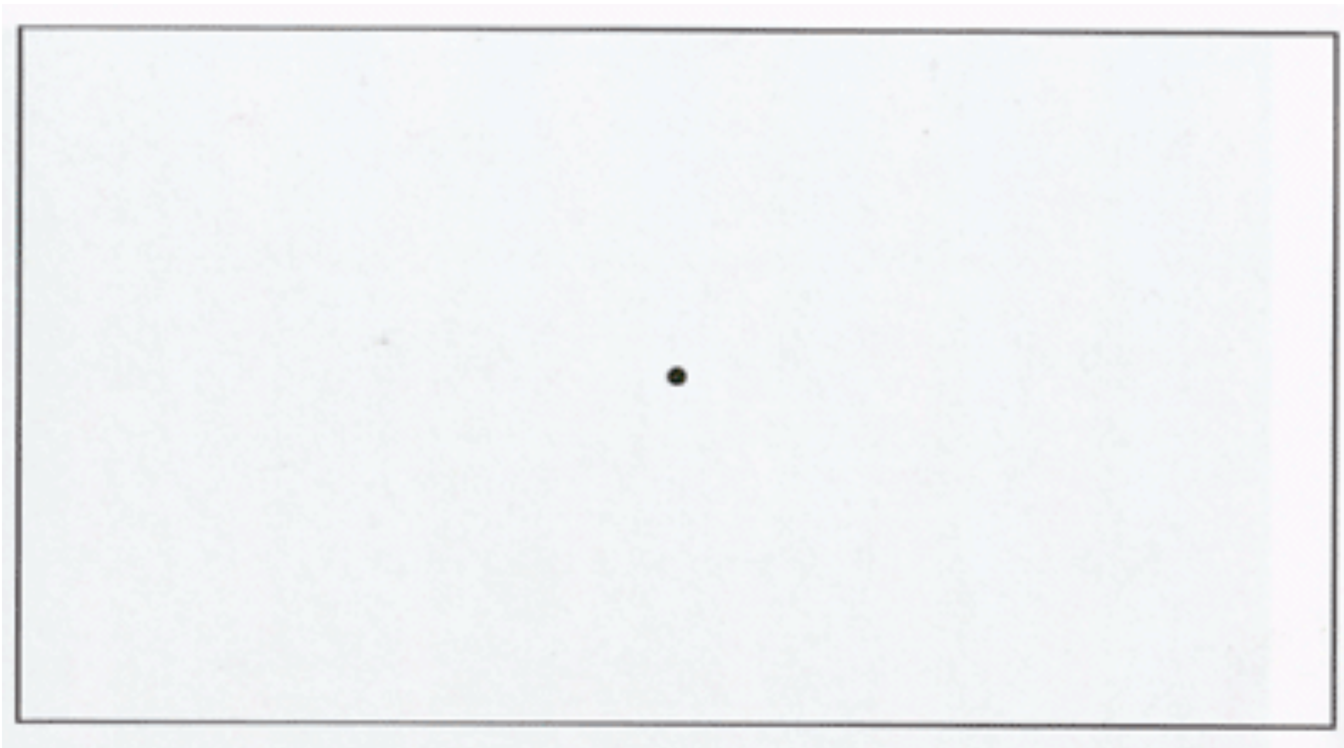
- Pigments absorb some light and reflect other light
- Reflected light is what is “seen” as the color of the paint





Effects in color vision

- After images
  - Negative after image



Effects in vision, cont’d

- Memory color
  - Top-down process (memory, expectation) influences perception of color

- Color constancy
  - Perception of an object’s color seems to remain constant across illumination types
    - e.g., white paper seems white, regardless of actual color of light reflecting off it

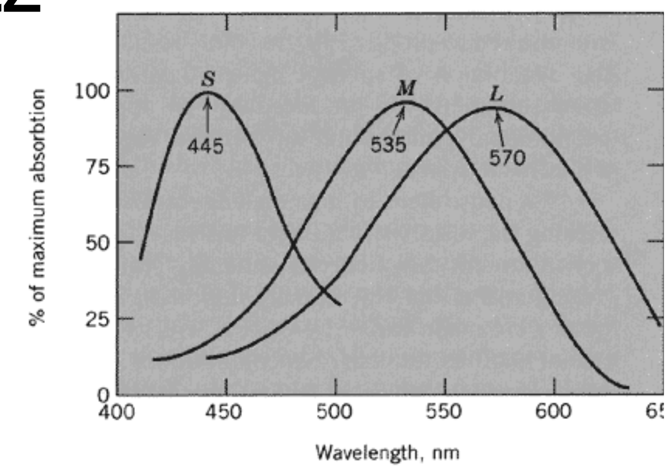
Theories of color perception

- The need for a theory (?)

- Competing (?) theories:
  - Trichromatic Receptor Theory
  - Opponent Processes Theory

Trichromatic Receptor Theory

- Young (1882) & then Helmholtz
  - Primary colors suggest three distinct receptors
- Cone types
  - S, M, L cones (=B, G, R cones)
  - Photopigments
  - Retina acts as a spectral analyzer



Blue (short wavelength) ~445 nm Cyanolabe 5-10% of cones sparse periphery of fovea	Green (medium) ~535 nm Chlorolabe 30% of cones many more center of fovea	Red (long) ~570 nm Erythrolabe 60% of cones many, many more center of fovea

Trichromatic Theory, cont'd

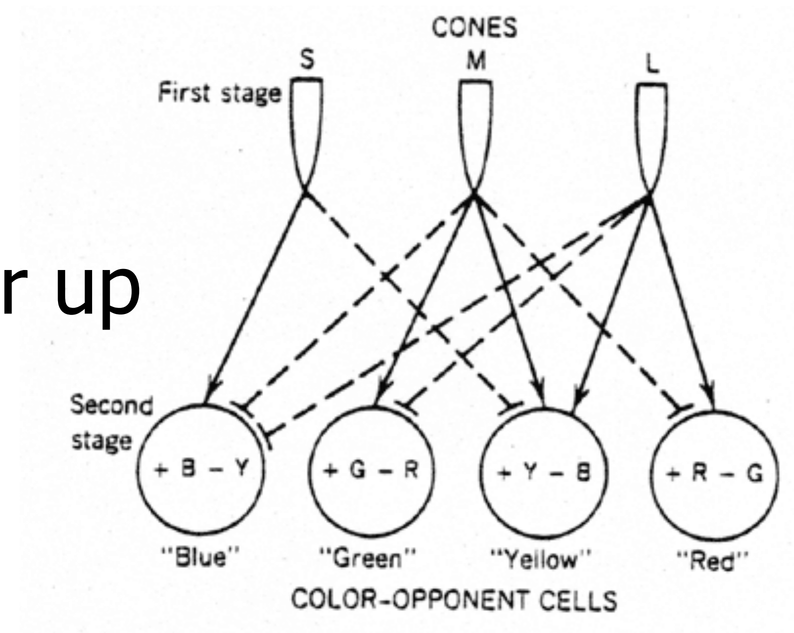
- Explanatory power
  - Adding green & red results in metamer of yellow
    - M&L cones absorb the two light wavelengths in the same way as one yellow wavelength, and produces the same neural firing
  - Sidebar: Cone functioning
  - Complementary afterimages
    - Staring at a blue image fatigues blue cones
    - Leaves only the red and green cones to function effectively
    - Then viewing a white source, the red and green cones both work, resulting in perception of yellow

Trichromatic Theory, cont’d

- Questions
  - Are there things that Trichromatic Theory cannot explain?
- Adding blue light to yellow light yields white or gray
  - The Trichromatic Theory explains this by saying that yellow is really red+green, so adding blue yields white, since all 3 primaries are involved
    - But you can have situations where adding red to green leads to grey
- Visualization: You cannot visualize reddish-green or bluish-yellow

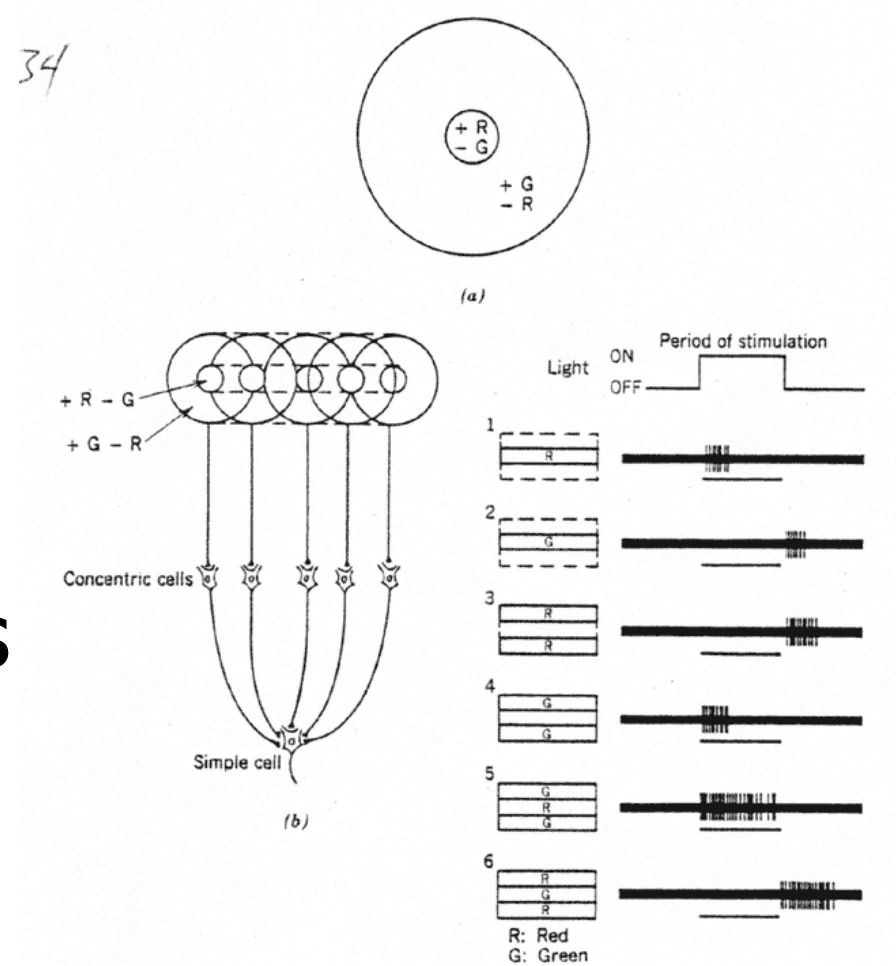
Opponent Process Theory

- Hering; Hurvich & Jameson
- Two stage process
  - 3 cones system at retina
  - 3 opponent processes higher up
    - white-black
    - blue-yellow
    - red-green
- Ganglion + LGN cells have opponent processes / center-surround with colors



Blobs in cortex

- Color-opponent neurons with *double-opponent* receptive fields
- Center surround
- A series of these cells can detect color bars, as well as patterns of green-red-green-red, etc.



Stages of Color Perception

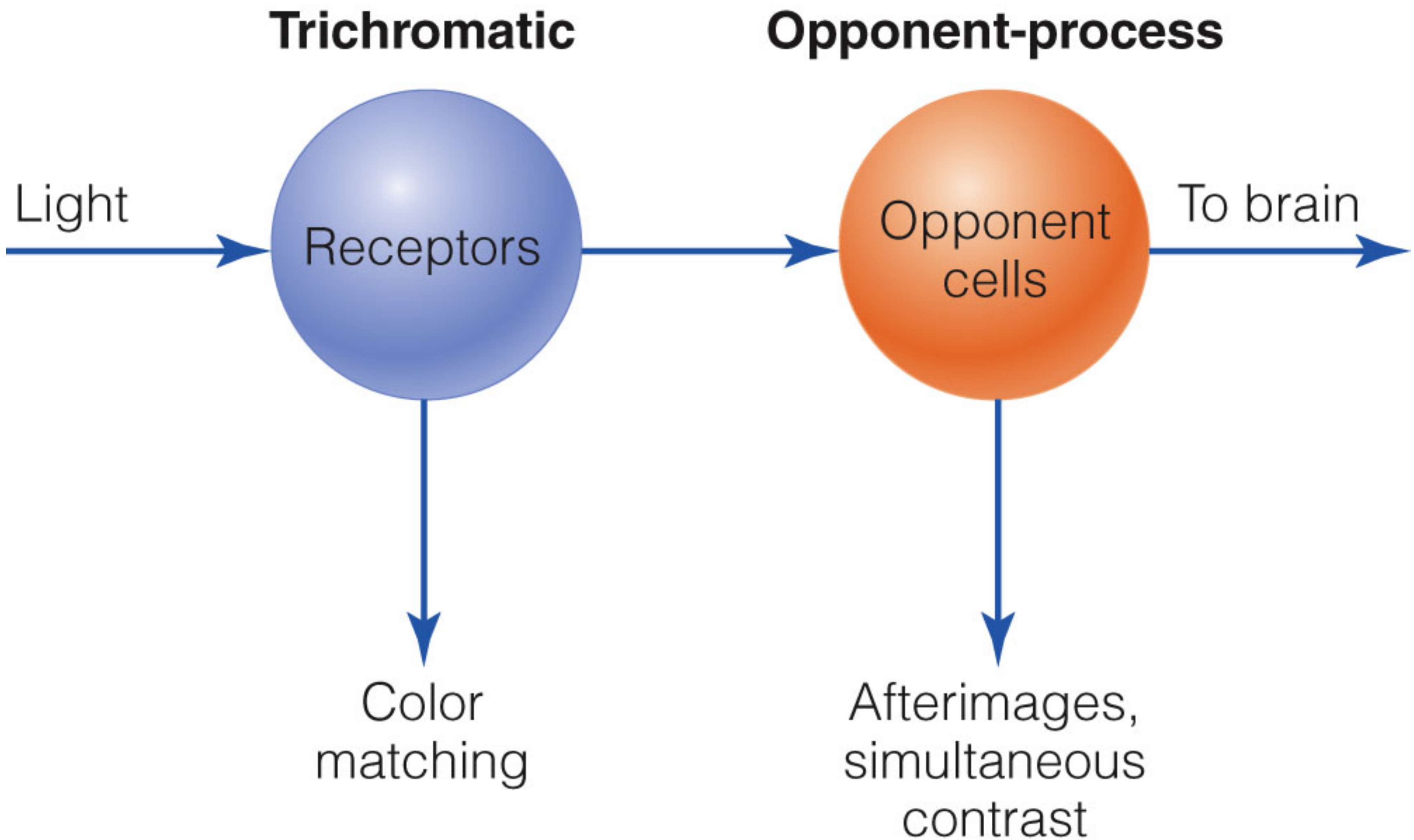


Figure 9.21 Our experience of color is shaped by physiological mechanisms, both in the receptors and in opponent neurons.

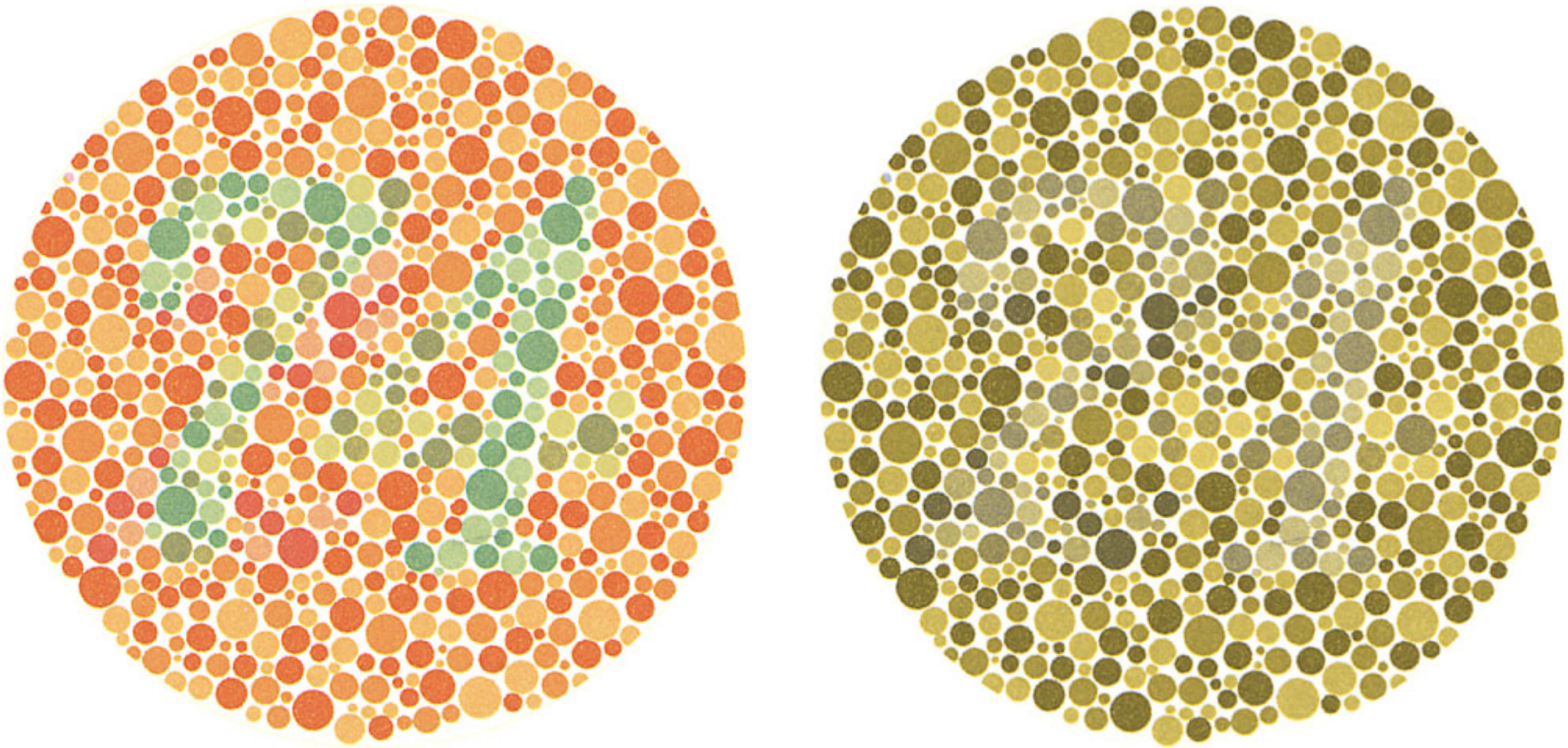
Defective color vision

- Monochromatism
  - Only one cone
  - True color blindness - only shades of light/dark
- Dichromatism
  - Protanopia
    - Lack L (red) cone
  - Deuteranopia
    - Lack M (green) cone
    - Both protanopes & deuteranopes confuse red & green
  - Tritanopia
    - Lack S (blue) cone
    - Sees only reds & greens
    - Confuse shades of yellows, grays, blues
    - Note: this is evidence for opponent processes

Defective color vision, cont’d

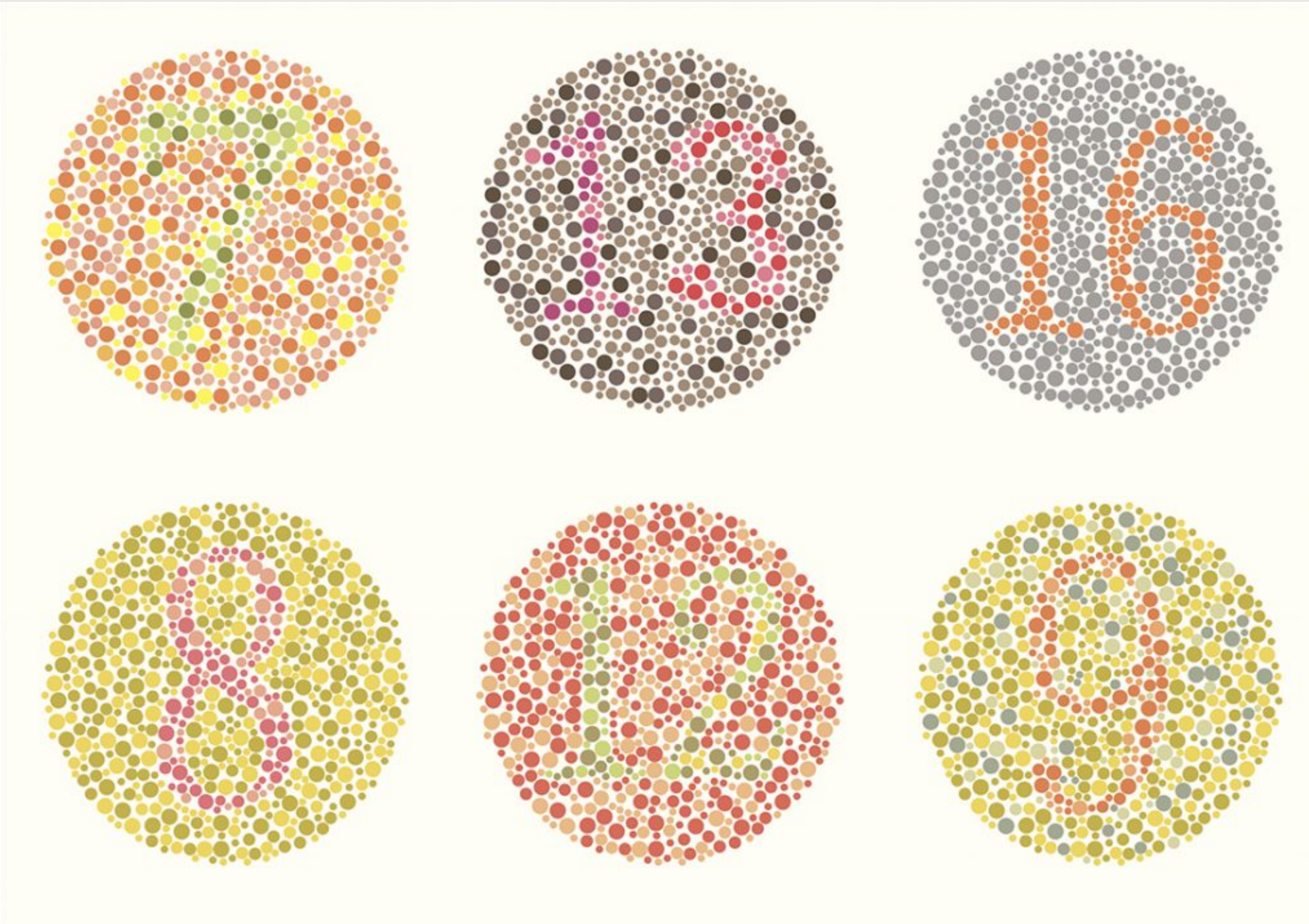
- Trichromatism anomaly
  - Have all three cone types, but sensitivity of one is deficient
  - Protoanomaly
    - Deficient L (red) sensitivity
  - Deuteranomaly
    - Deficient M (green) sensitivity
- Achromatopsia
  - Cortical color blindness (rare)
  - Congenital (retinal) achromatopsia (1 in 33,000)

Ishihara Color Tests



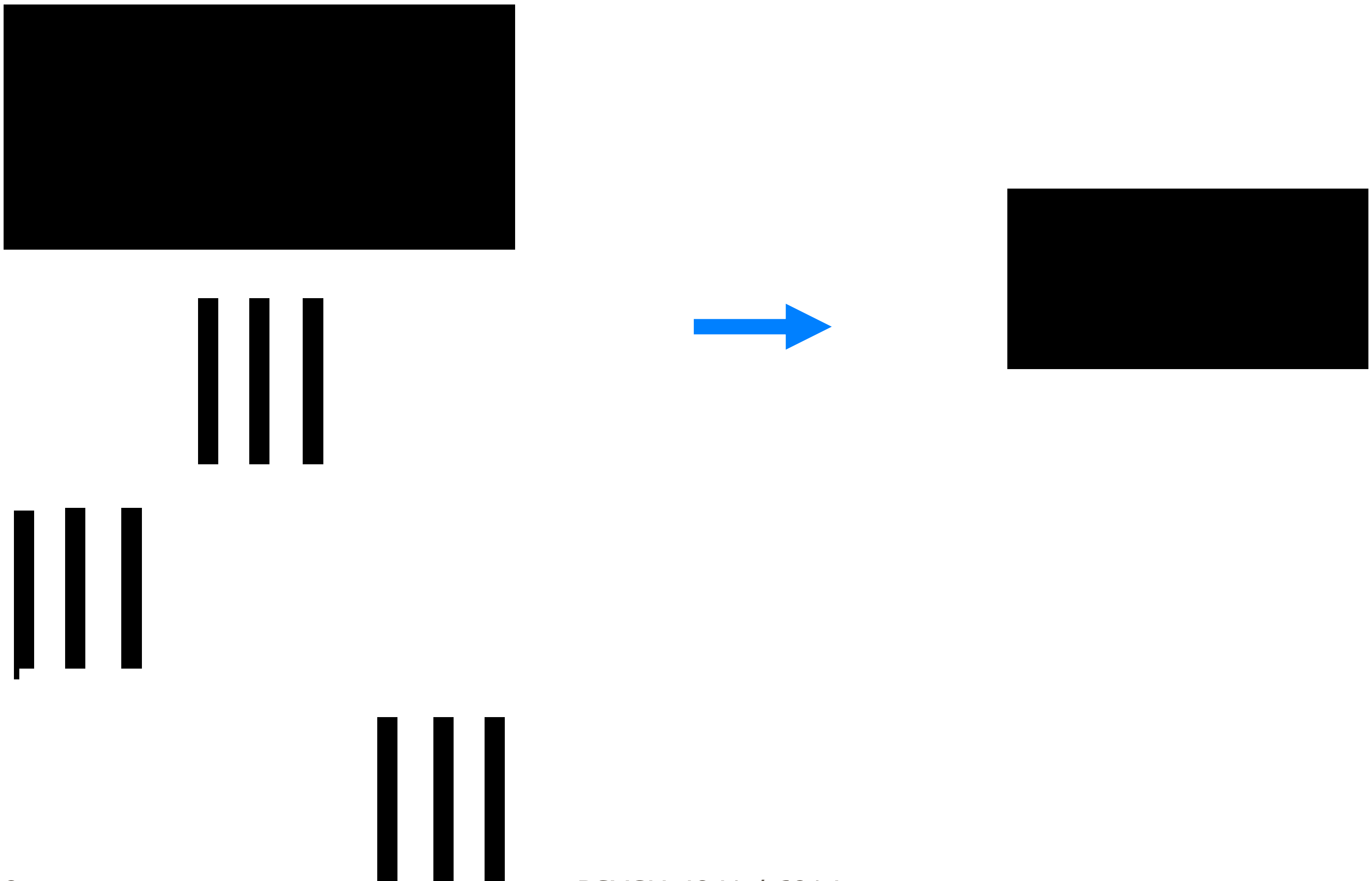
(a) (b)

Figure 9.14 (a) Ishihara plate for testing for color deficiency. A person with normal color vision sees a “74” when the plate is viewed under standardized illumination. (b) Ishihara plate as perceived by a person with a from of red-green color deficiency.



Subjective colors

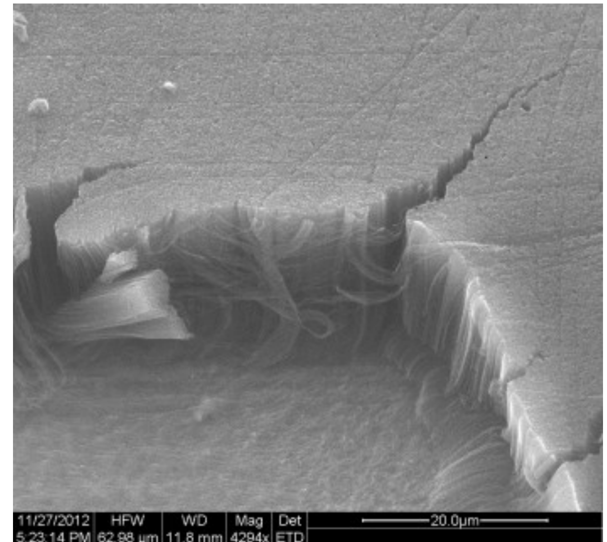
- Benham's top (http://www.michaelbach.de/ot/col-Benham/index.html)
  - "pattern-induced flicker colors"



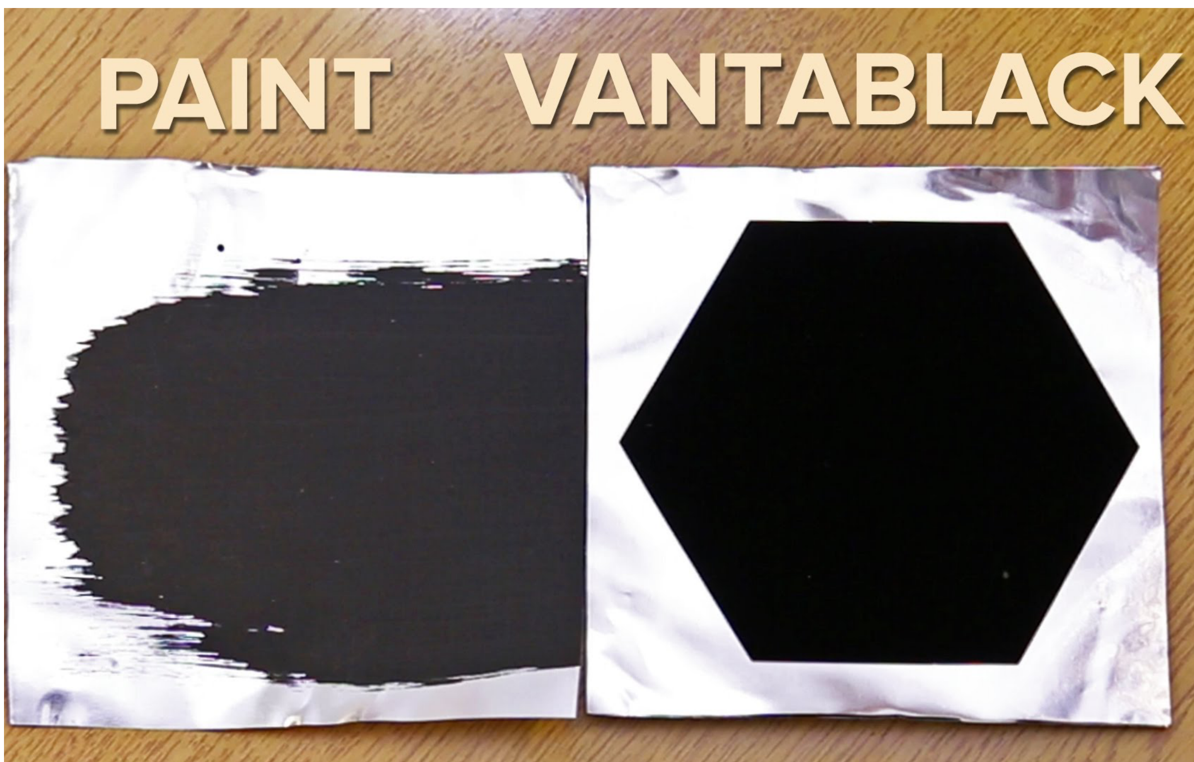
Subjective colors, cont’d

- Kinetic art (e.g., Jesus Soto)

Vantablack: Blackest Black



- https://en.wikipedia.org/wiki/Vantablack
  - Vertically Aligned Carbon Nanotube Arrays
  - Absorbs 99.965% of visible light



Upcoming

- Depth perception
- Constancy & illusions
- Camouflage