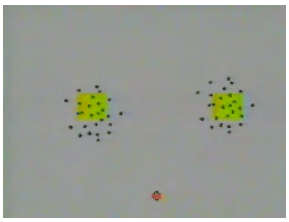
Announcements

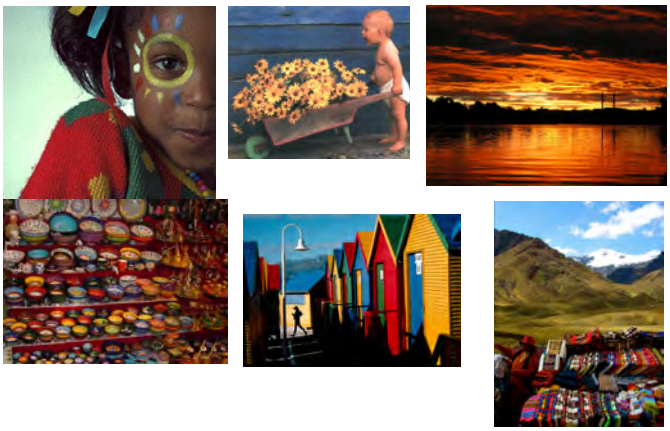


Color capture

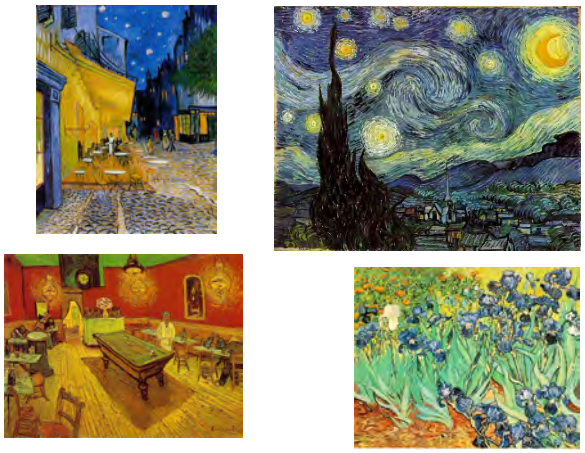
Color

- Why color?
- What is color?
- Trichromatic theory
  - how we detect color: photoreceptors
  - retinal color blindness
- Opponent-process theory
  - color adaptation & afterimages
  - opponent processes
- Effects of context on color perception
- Synesthesia

Color is pleasing



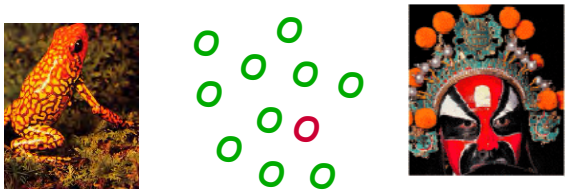
Color is pleasing



Color affects mood

- Pink visitor locker rooms (Iowa)
- Green delivery rooms
- Yellow interrogation rooms

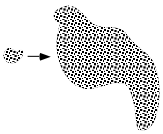
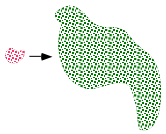
Color is useful -- it makes things conspicuous



Color is useful -- it makes things conspicuous



Color is useful -- it makes things conspicuous

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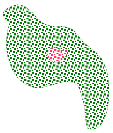
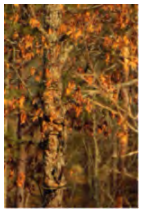
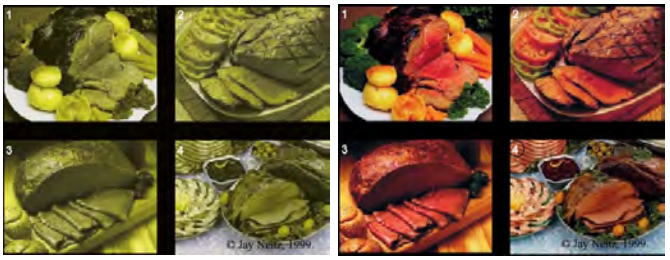


Color is useful -- it makes things **in**conspicuous

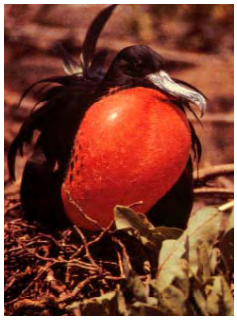




Color signals edibility/ripeness of food

Color signals edibility/ripeness of food



Color signals sexual receptiveness of animals



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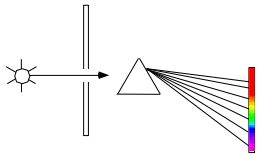
Newton's Prism Experiment: "Unweaving the Rainbow"

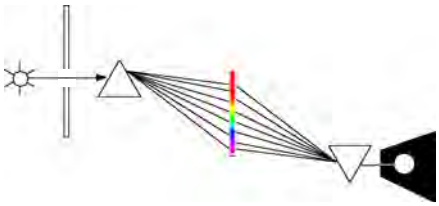


White light of the sun can be decomposed into 7 basic colors

(Newton was inclined to look for seven basics because of his knowledge of the 7 tones of the musical scale)

Just physics!

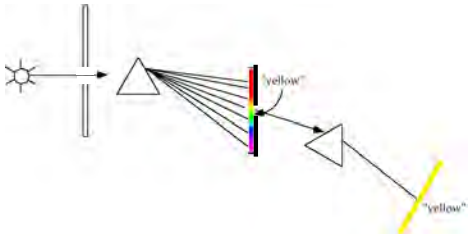
Newton's Prism Experiment: "Reweaving the Rainbow"



Colored light could be recombined to create white light (process was reversible)

Just physics!

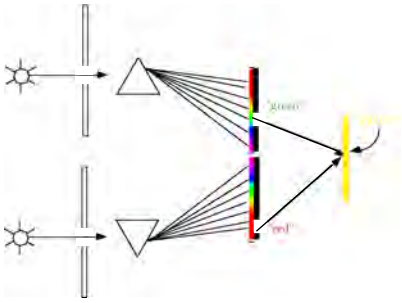
Newton's Prism Experiment: "Basic Colors"



A *basic color* is one that cannot further be decomposed upon passing through a prism

Just physics!

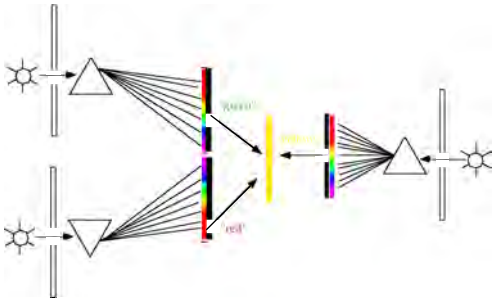
Newton's Prism Experiment: "Basic Colors"



Basic colors can be recombined to create **new** colors

Physics or Biology???

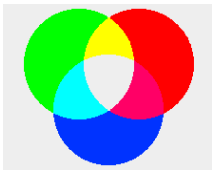
Newton's Prism Experiment: "Metamers"



Color produced by isolating light at 570 nm is **perceptually indistinguishable** from the color produced by adding light at 520 nm and 680 nm. Why?

Physics or Biology???

Additive color mixture



G + R --> Y, when G & R are roughly equal in intensity;

varying the relative amounts of R & G will vary the product from pure green, through olive, yellow, orange and, finally, red.

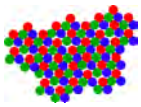
G + R + B --> white; these are known as "primary" colors

B + Y --> ???

Physics or Biology???

Additive color mixture

Color television screens are composed of tiny (≈ 0.2 mm) dots that are red, green or blue; the dots are so small that their emitted light effectively adds together; by varying the proportion of energy produced by each of the three, the television is able to reproduce most of the colors of the spectrum.

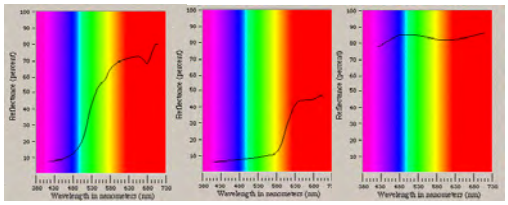


Pontillist paintings, too, are composed of tiny colored dots too small to be resolved by the eye when seen from normal viewing distance; by varying the colors of the dots, the painter is able to reproduce most of the colors of the spectrum.

(Chuck Close)

But, what makes **objects** have different colors?

Molecular structure of surface material determines the percentage of incident light absorbed by that surface and the percentage reflected from the surface to the eye (a "red" apple is everything but red)

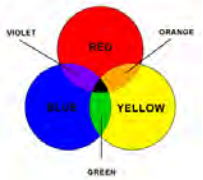


lemon tomato white paper

*The wavelengths reflected from an object characterize the **visual stimulus** and are (in part) responsible for our **subjective sensation** of **color**.*

But, what makes **objects** have different colors?

Subtractive color mixture

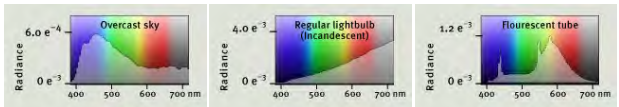


- Paints contain pigments that absorb given wavelengths of light.
- Thus, for example, "red" paint absorbs - thereby subtracting - all wavelengths but the very longest ones; these remaining long wavelengths are reflected from the surface to your eyes.
- When you mix the "red" paint with another "color" paint, the reflected light will be further limited - the greater the amount of paint added, the darker the color
- Most of the colors we perceive in the natural environment are the result of subtractive color principles, because surfaces are naturally "painted" (i.e., they have pigments that absorb light energy).

But, what makes **objects** have different colors?

But, don't forget the spectral content of ambient illumination!

A wavelength cannot be reflected if it isn't in the ambient light!!!!!!



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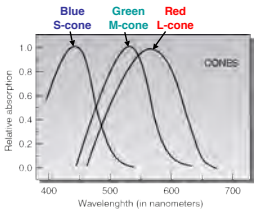
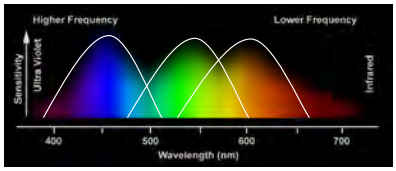
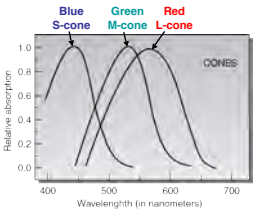
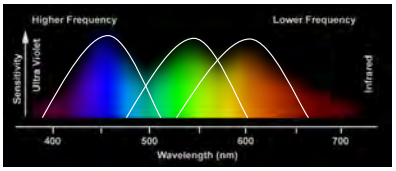


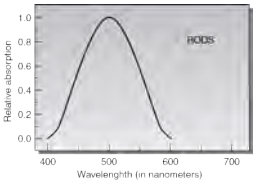


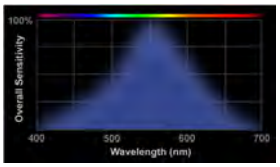
Each cone contains one of three different photopigments

The *ensemble* of cone signals carry information about wavelength of light









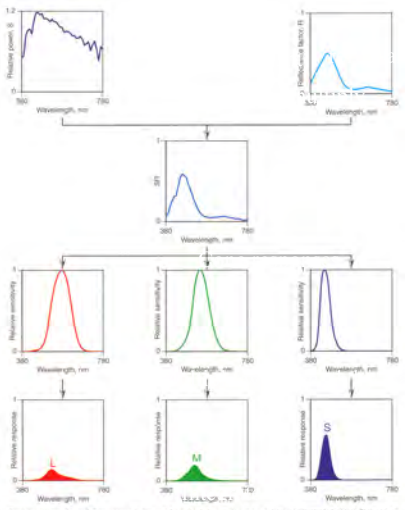
- All "rods" contain the identical photo pigment -- consequently rod signals do not code information about wavelength of light, only about the intensity of light (**univariance principle**)
  - Very long wavelength light invisible to rods = red objects hard to see at night
  - No color at night
- Normal color vision dependent on normal cone types and their distribution throughout the retina

Ambient illumination

Surface reflectance

Cone type sensitivities

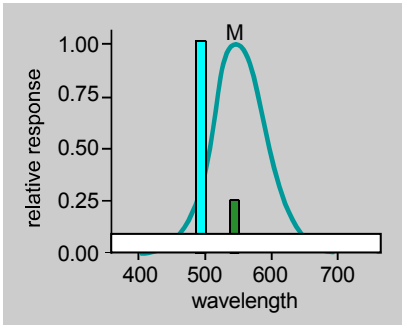
Cone type responses



Surface color

Individual cones do not "see" colors

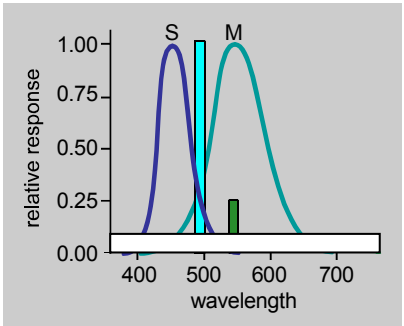
- **Univariance principle**
  - A response of a single cone type cannot tell you about the color of the stimulus!!!
  - It confounds intensity and wavelength!



These 2 colors are **metameric** with the white light

Individual cones do not "see" colors

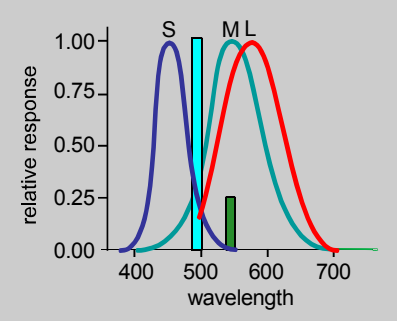
- **Univariance principle**
  - A response of a single cone type cannot tell you about the color of the stimulus!!!
  - It confounds intensity and wavelength!
  - Two cone types is better.



In this 2-cone system is there any single wavelength of light that is metameric with white light?

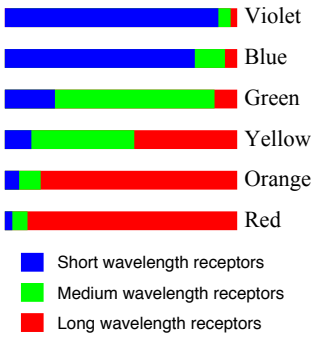
Individual cones do not “see” colors

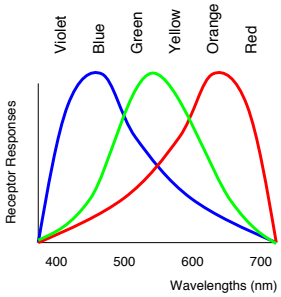
- **Univariance principle**
  - A response of a single cone type cannot tell you about the color of the stimulus!!!
  - It confounds intensity and wavelength!
  - Two cone types is better. Three is necessary to conclusively signal color.



In this 3-cone system is there any single wavelength of light that is metameric with white light?

Relative responses of cones “see” color

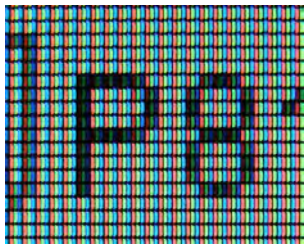


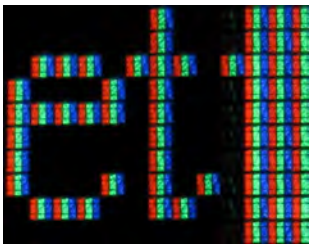


von Helmholtz 1859: Trichromatic theory

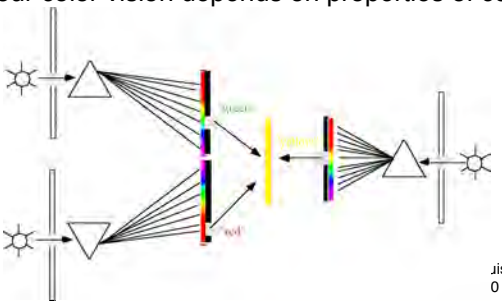
Trichromatic theory

- Researchers found that by mixing only **three** primary lights (e.g., red, green & blue) they could create the perceptual experience of all visible colors. (how TV works)
- This lead Young and Helmholtz to propose that we have **three** different types of photoreceptors, each most sensitive to a different range of wavelengths.
- The three receptor mechanisms are stimulated to different degrees by the light of a particular wavelength. This **pattern of activity** in the three mechanisms results in the perception of a certain color.

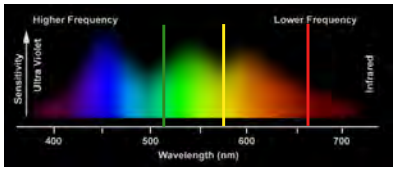




How our color vision depends on properties of cones



ıishable from
0 nm?



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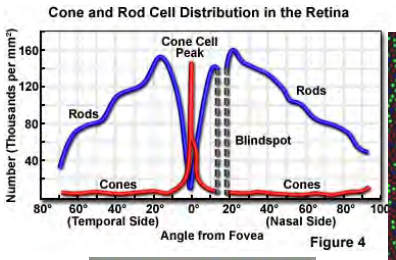
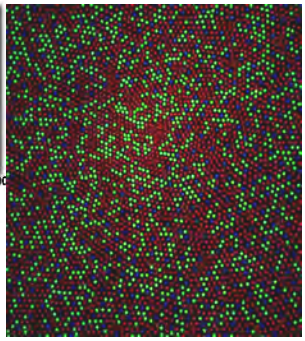
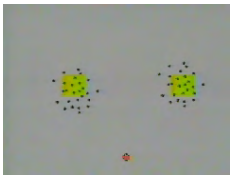
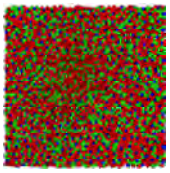






How our color vision depends on properties of cones

Color Discrimination
Measured in the Lab



Why does the moving “square” disappear at that point during the sequence when it appears faint blue?

How our color vision depends on properties of cones

Color Discrimination
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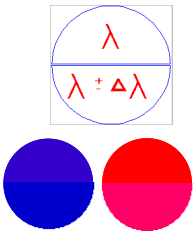
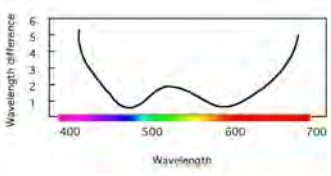
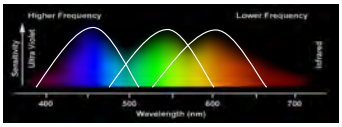
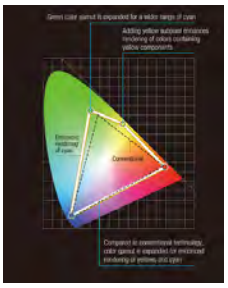






Should you buy a four-color LCD TV?



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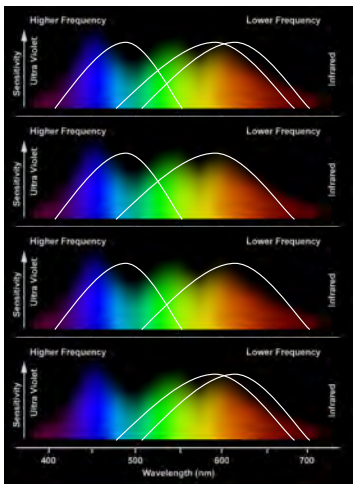
Retinal Color Blindness

Retinal Color Blindness

What Does the World Look Like
To A Dichromate?



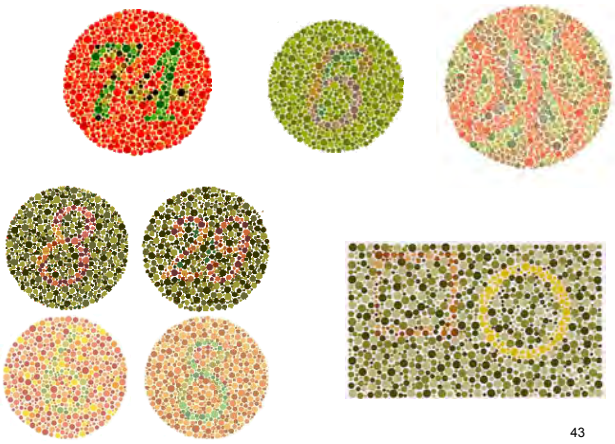
Normal color vision

Dichromacy: Missing L-type pigment
Protanopia
(red-green deficiency)

Dichromacy: Missing M-type pigment
Deuteranopia
(red-green deficiency)

Dichromacy: Missing S-type pigment
Tritanopia

Ishihara Test for color blindness



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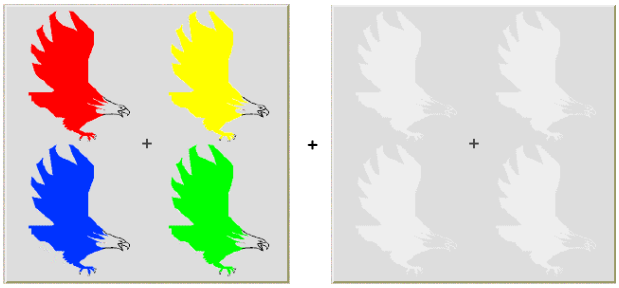

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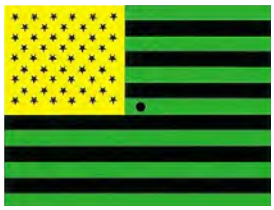
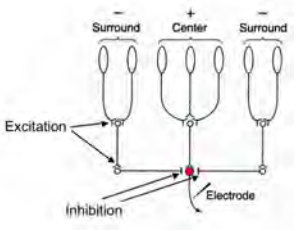
Opponent Process Theory of Color

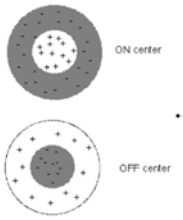
- Some aspects of our color perception are difficult to explain by the trichromatic theory alone.
- Example: afterimages
  - If we view colored stimuli for an extended period of time, we will see an afterimage in a complementary color.



Opponent Process Theory of Color

- To account for for complementary afterimages, Herring proposed that we have two types of color opponent cells:
  - red-green opponent cells
  - blue-yellow opponent cells





Opponent Process Theory of Color

- To account for for complementary afterimages, Herring proposed that we have two types of color opponent cells:
  - red-green opponent cells
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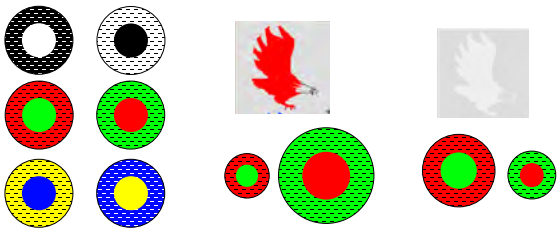
- Discovery of opponent neurons in the 1950's and 1960's
  - Neurons in the retina and LGN that respond with an excitatory response to one color and with the inhibitory response to light from another color.



Tying the Theories Together

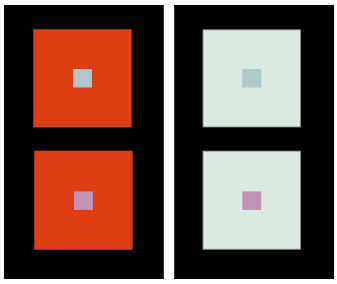
- Processing for color vision takes place in 2 stages:
  - Trichromatic theory
    - the receptors respond with different patterns to different wavelengths.
    - Trichromatic theory describes what is happening at the **very beginning** of the visual system, in the receptors of the retina. The existence of three different kinds of cone receptors is why it takes a minimum of three wavelengths to match any wavelength in the spectrum.
  - Opponent-process theory
    - neurons integrate the inhibitory and excitatory signals from the receptors.
    - Opponent-process theory describes events **later in the visual system** (from ganglion cells on….). Opponent cells are responsible for perceptual experiences such as afterimages and simultaneous contrast (see next).

Color

- Why color?
- What is color?
- Trichromatic theory
  - how we detect color: photoreceptors
  - retinal color blindness
- Opponent-process theory
  - color adaptation & afterimages
  - opponent processes
- Effects of context on color perception
- Synesthesia

Perceived colors depend on neighboring colors

Vision depends on context!



“color contrast”

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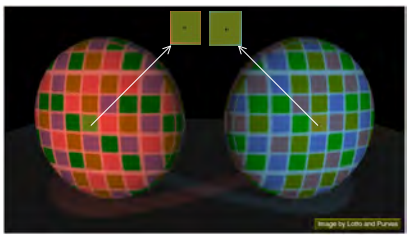

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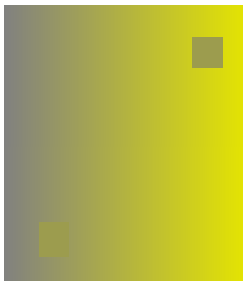

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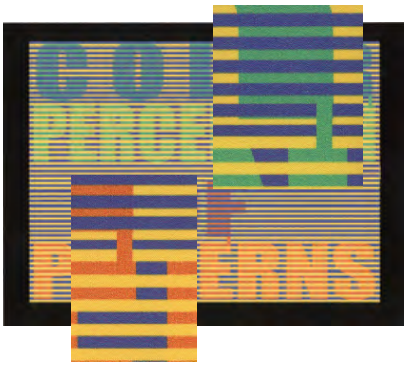

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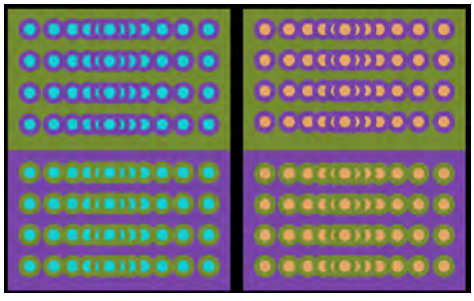

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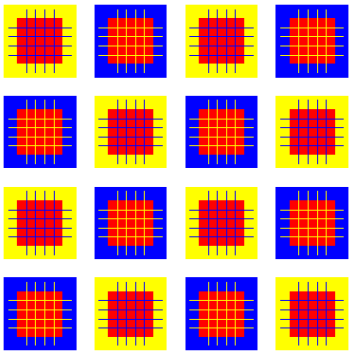

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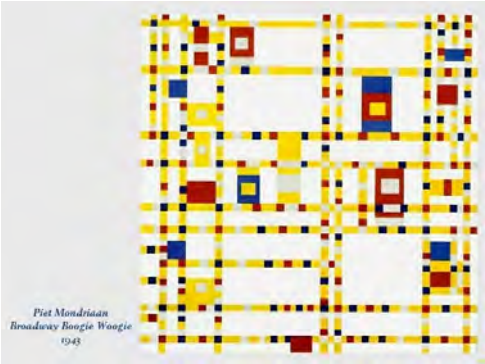

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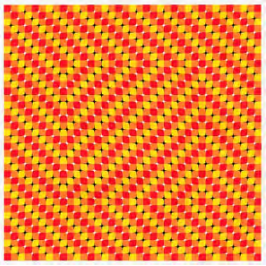

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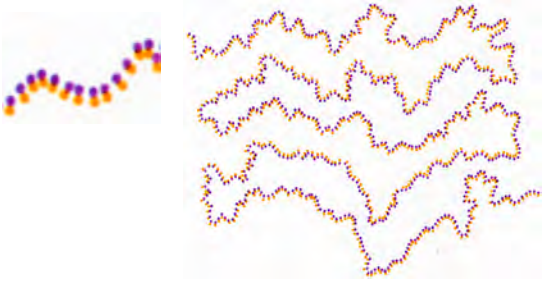

Baingio Pinna (University of Sassari, Italy)

"Watercolour effect"

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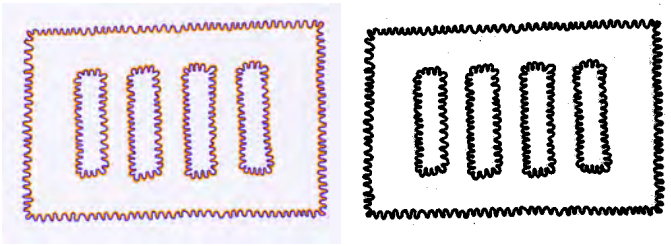

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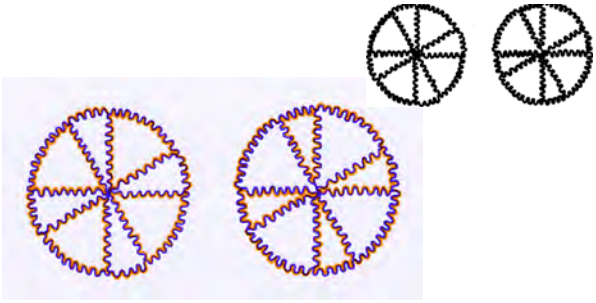

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Neon color spreading

http://www.ted.com/talks/beau_lotto_optical_illusions_show_how_we_see.html

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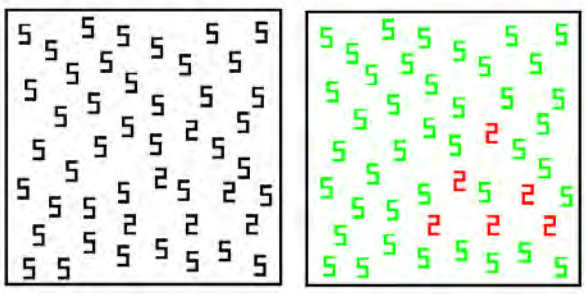

Synesthesia

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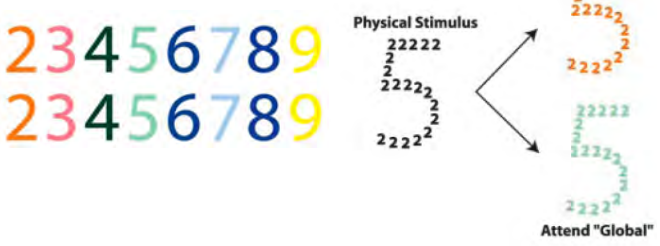
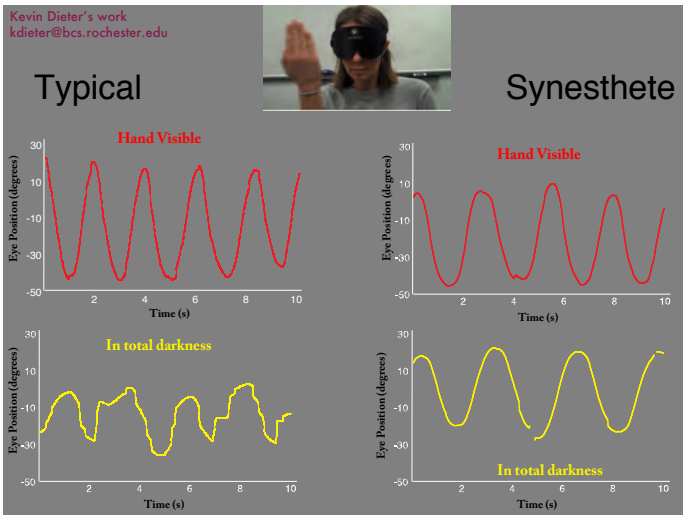


Synesthesia

http://www.youtube.com/watch?v=KApieSGIyBk


Kevin Dieter's work
kdieter@bcs.rochester.edu
Typical
Synesthete
Hand Visible
Hand Visible
In total darkness
In total darkness
Eye Position (degrees)
Time (s)