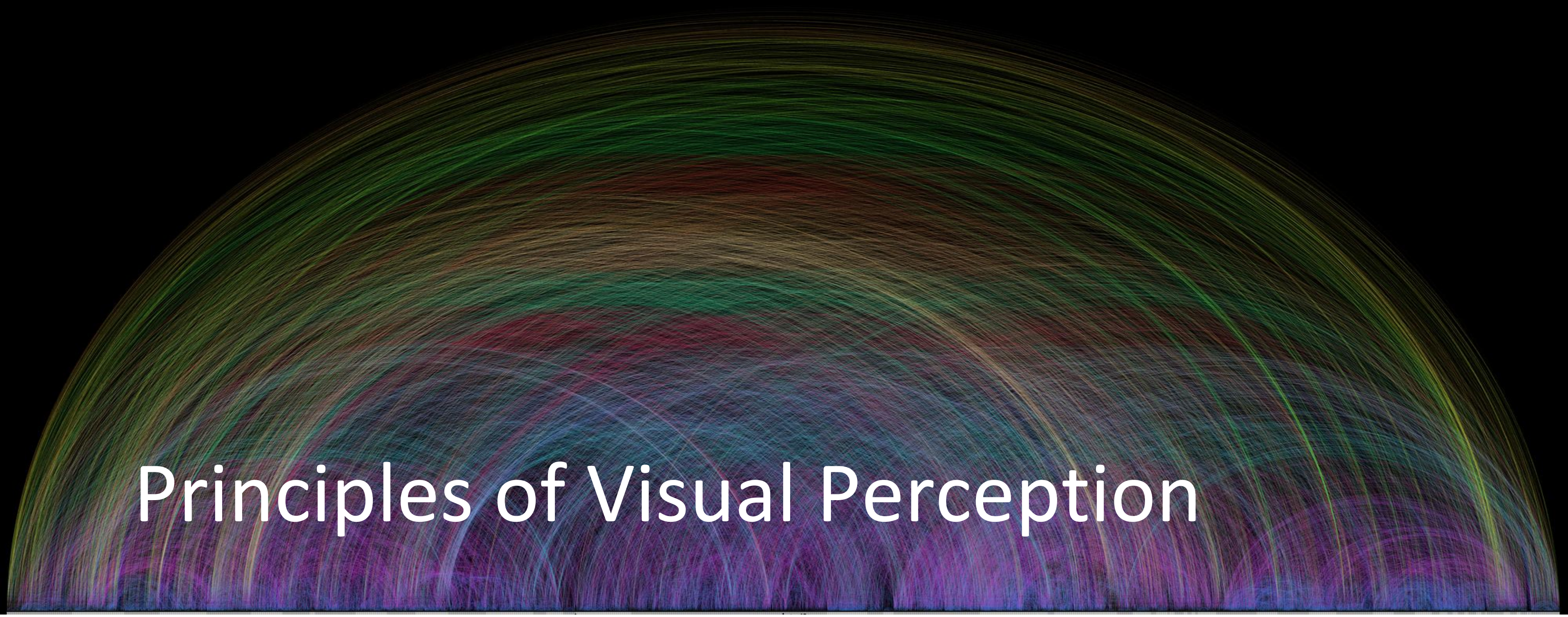


# Principles of Visual Perception

BAIS 6140 – Information Visualization

L. Miguel Encarnação

# Agenda

- Sensation & Perception
- Principles of Perceptual Organization
- Human Visual Physiology
- Color Perception
- Motion (brief)

# SENSATION & PERCEPTION

# Sensation and Perception

- *Sensations* occur when a physical event in the world stimulates receptors (such as those at the back of the eye, in the ear, and on the skin), which then send signals to the brain.
- We detect events that are over a threshold (a difference threshold to distinguish them from similar stimuli; an absolute threshold to see if they are present at all)
  - but our sensitivity to stimuli must be distinguished from our bias to classify input as signal versus noise.
- *Perception* occurs when input is organized and interpreted as indicating that a particular object or event is present.

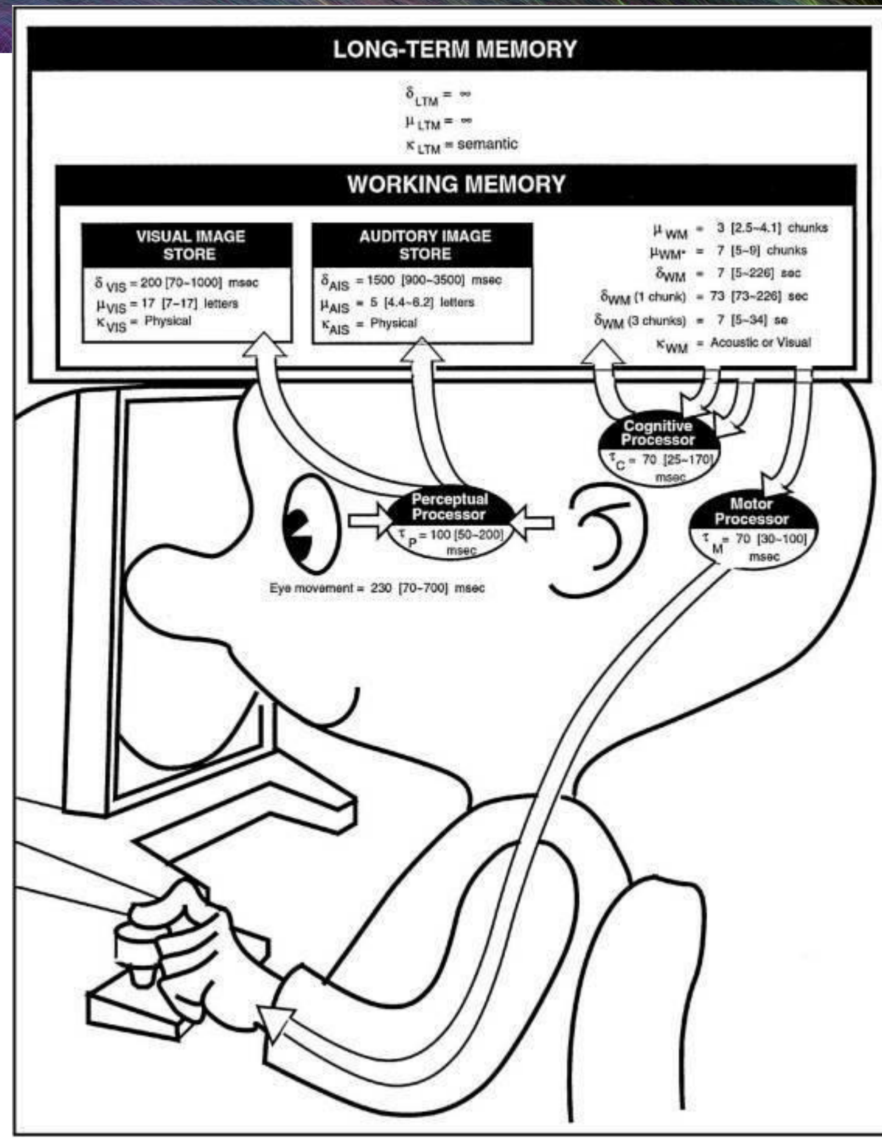
# Sensation and Perception

*

- *Sensation* is the immediate experience of basic properties of an object or event.
  - requires receptor stimulation
- *Perception* is the act of organizing and interpreting sensory input as signaling a particular object or event.
  - Brain
- Can have sensation without perception and perception without sensation, when there is brain abnormalities.

# Sensation and Perception

- There are three levels of processing involved in the sensory and perceptual processes:
  - Early processing, which is the registering of sensation when receptors are physically <u>stimulated</u>.
  - Intermediate processing, which is when the sensory information is <u>organized</u> into coherent units.
  - Late processing, which is when your perceptual processes <u>interpret</u> the meaning of these units.



# Sensation and Perception

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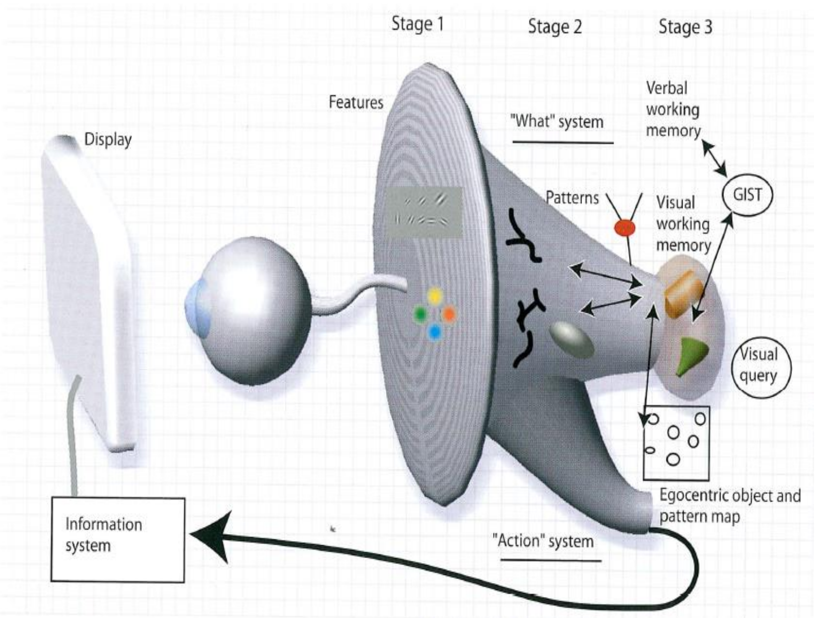


# Sensation, Perception and Cognition

- Processing may be initiated by one of two ways:
  - Bottom-up processing which is initiated by stimulus input
  - Top-down processing which is initiated by knowledge, expectation, or belief

# The Stroop Effect (1)

Red

Blue

Green

Yellow

Brown

Pink

# The Stroop Effect (2)

Green

Red

Brown

Yellow

Blue

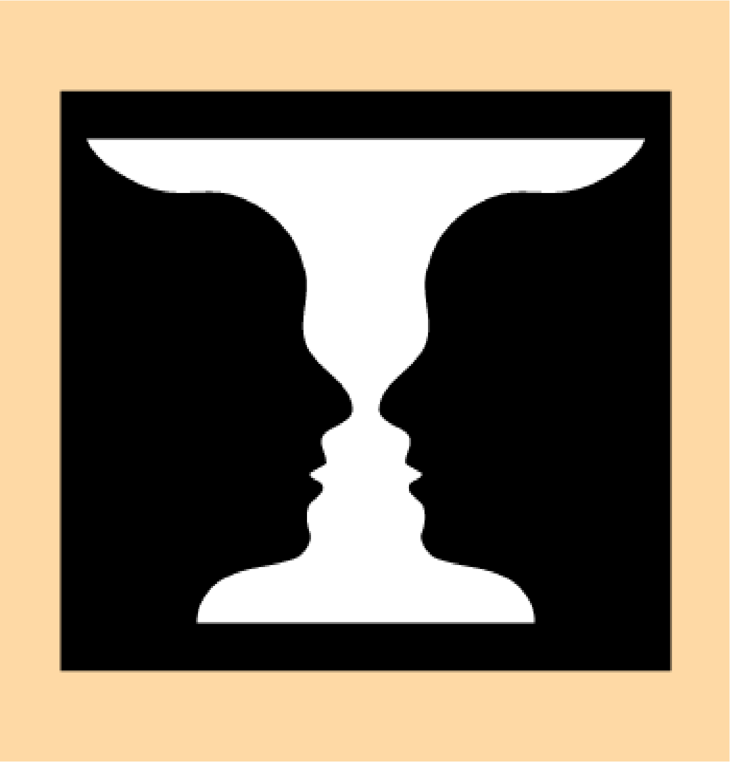
Pink

# PRINCIPLES OF PERCEPTUAL ORGANIZATION

# Principles of Perceptual Organization

- Figure/ground refers to our tendency to lock into a figure as the object of interest by distinguishing it from the background.
  - Camouflage makes it difficult to do this by making the figure blend into the background

# Figure Ground



# Principles of Perceptual Organization

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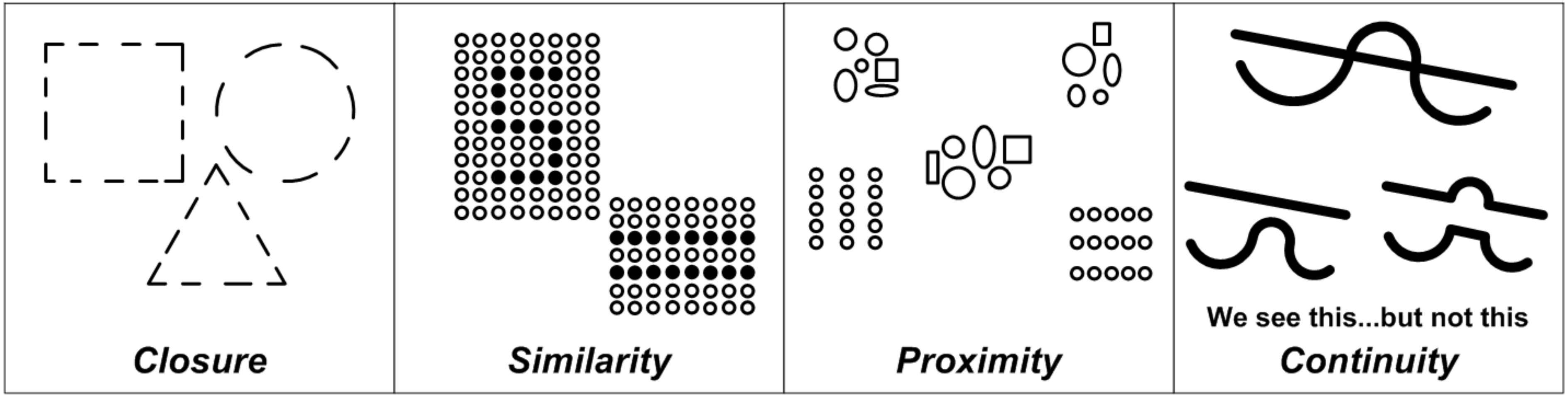
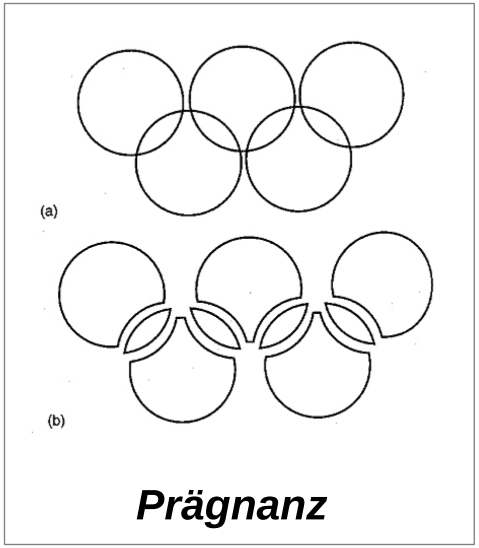



- There are 5 main Gestalt laws of grouping
  - *Closure*: we tend to close any gaps in a figure and see a complete figure.
  - *Similarity*: objects that look alike tend to be grouped together.
  - *Proximity*: objects that are near each other tend to be grouped together.
  - *Continuity*: marks that fall along a smooth curve or a straight line tend to be grouped together.
  - *Prägnanz (good form)*: marks that form a single shape tend to be grouped together



# Principles of Perceptual Organization



- Additional Gestalt laws of grouping
  - *Symmetry*: objects that are symmetrical to each other tend to be grouped together.
  - *Common fate*: objects that have the same trend of motion tend to be grouped together.
  - *Past experience*: objects tend to be grouped together if they were together often in the past experience.

# Principles of Perceptual Organization

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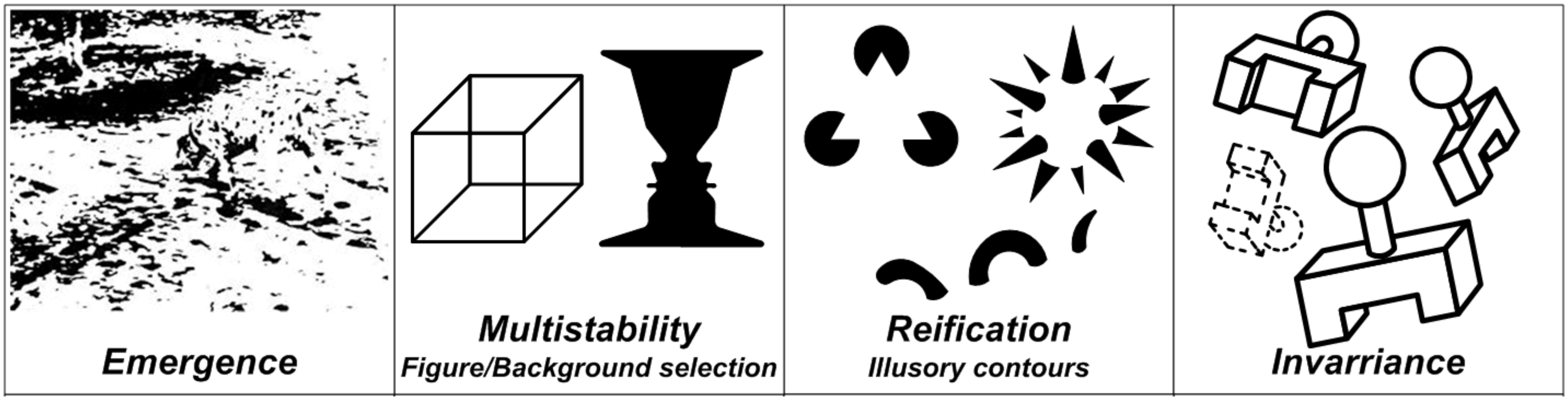
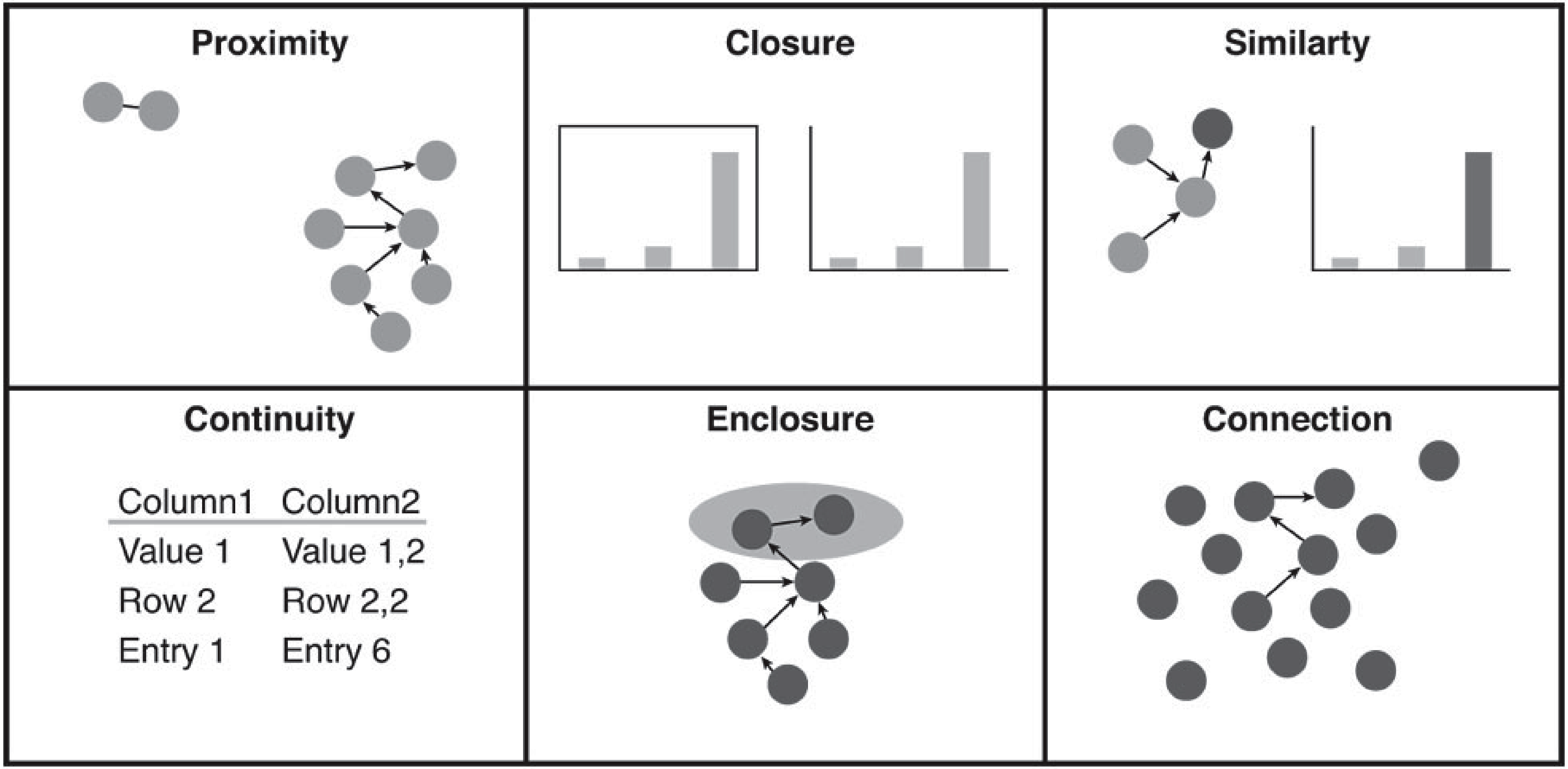
- Key principles of gestalt systems



# Principles of Perceptual Organization

- Application to information visualization

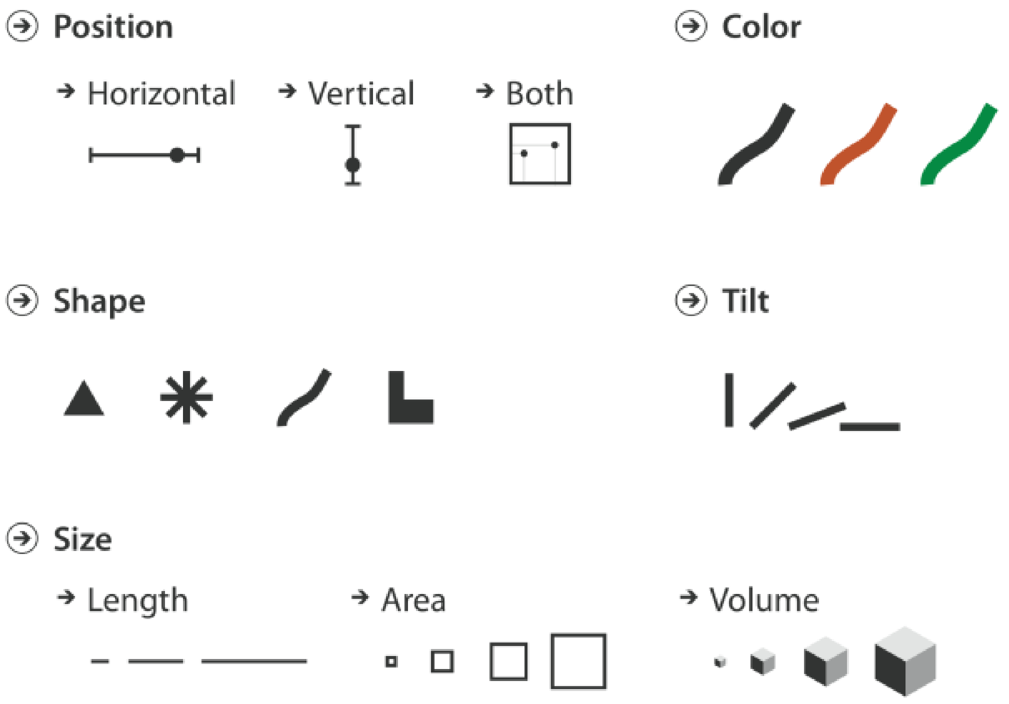


# Principles of Perceptual Organization

- Application to information visualization

## Channels (aka Visual Variables)

Control appearance proportional to or based on attributes

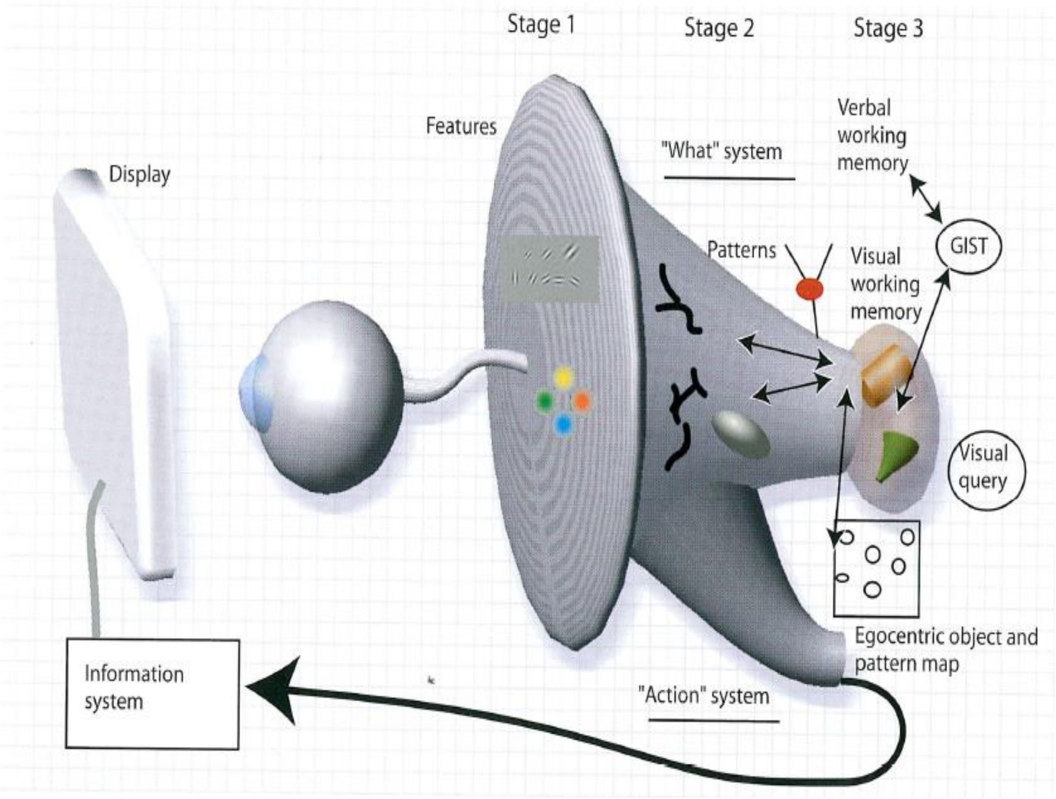


# Principles of Perceptual Organization

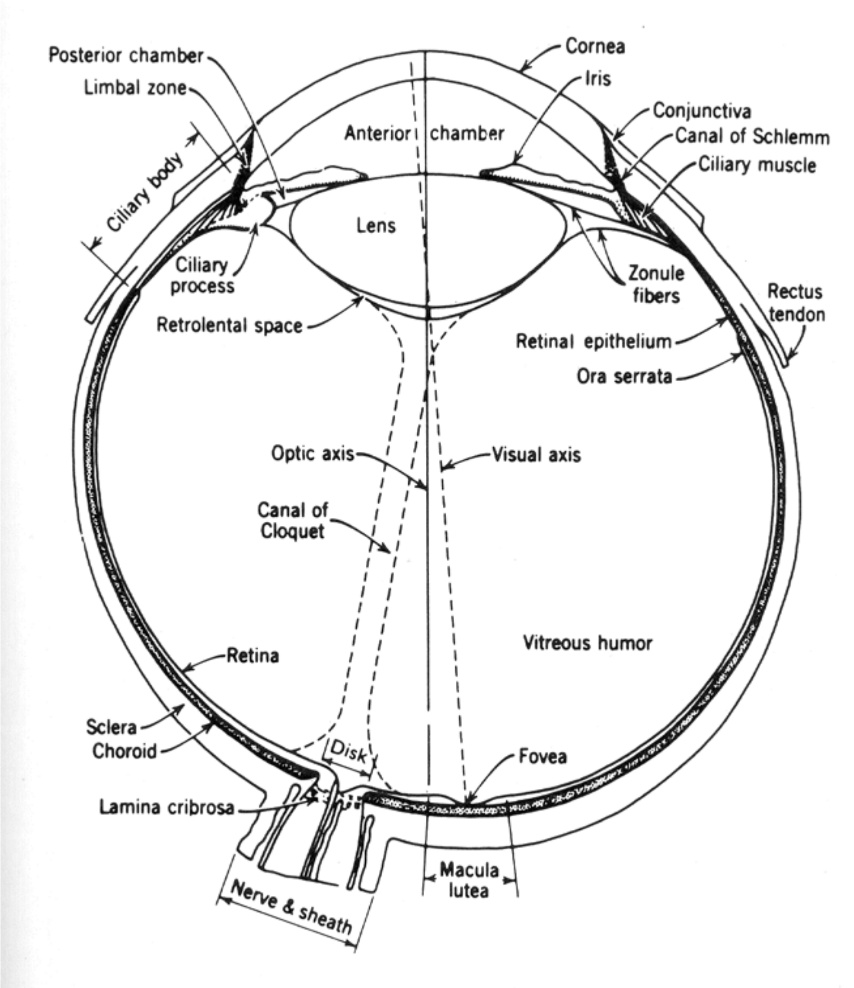
- **Perceptual constancies** occur when an object or quality looks the same even though the sensory information striking the eyes changes.
  - **Size constancy** involves seeing an object as being the same when viewed at different distances and visual angles.
  - **Shape constancy** involves seeing objects as having the same shape even when the image on the retina changes.
  - **Brightness and color constancy** involve seeing objects as having the same lightness, brightness, or color in different viewing conditions.

# HUMAN VISUAL PHYSIOLOGY

# Visual Information Processing



# Visual Physiology: the eye




Light entering the eye passes through:

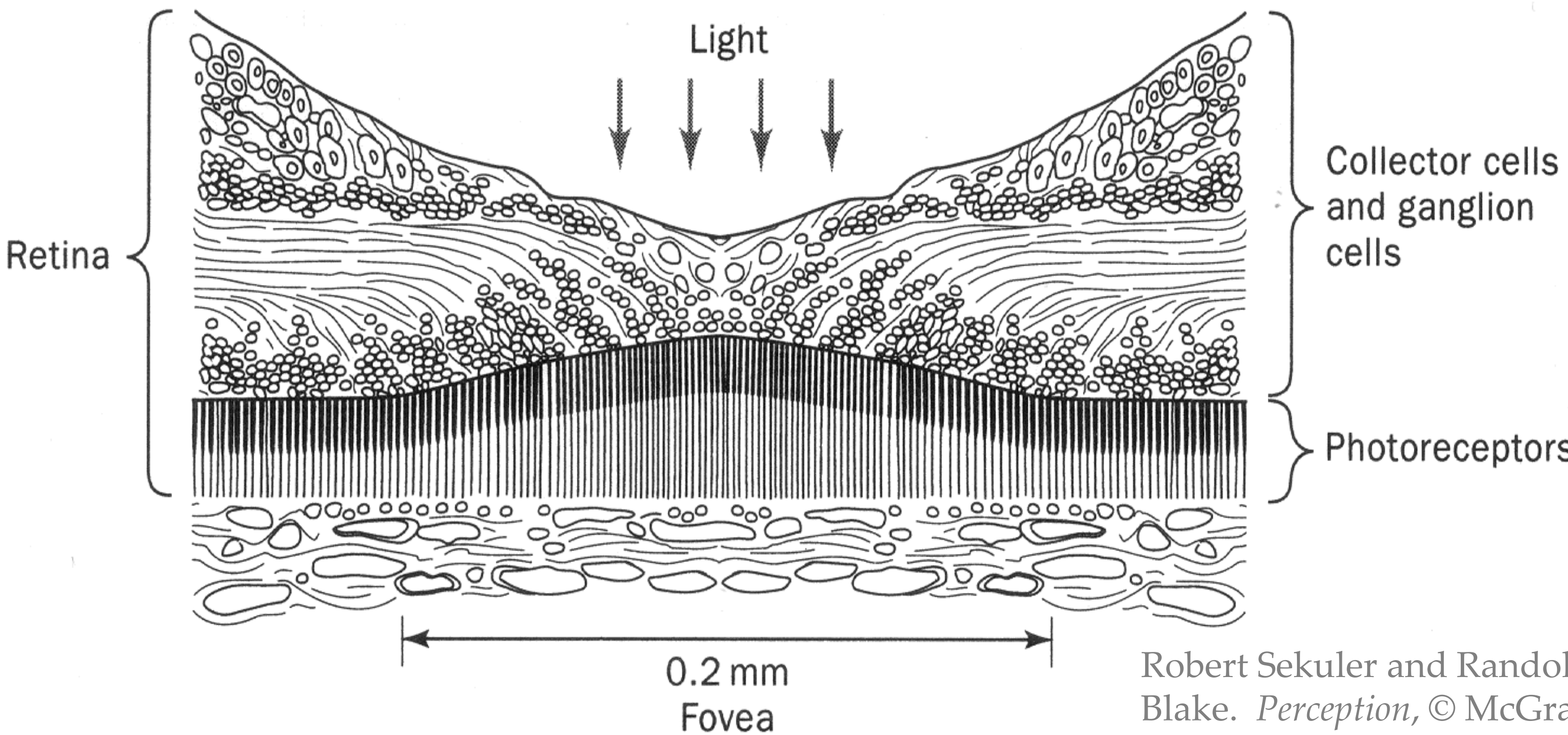
- cornea
- pupil
- lens
- vitreous chamber

and then strikes the retina

Martin D. Levine. *Vision in Man and Machine*, © McGraw-Hill, 1985.

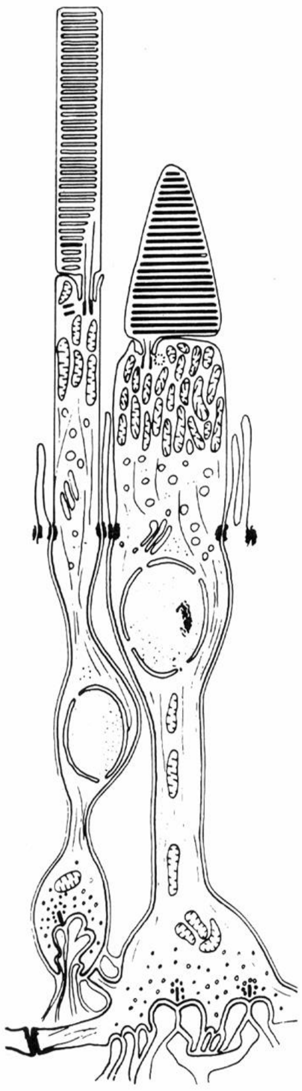
# The Retina

- Light entering the retina must pass through several layers of cells before reaching the photoreceptors




Robert Sekuler and Randolph Blake. *Perception*, © McGraw-Hill, 1994.

# Photoreceptors: where vision begins



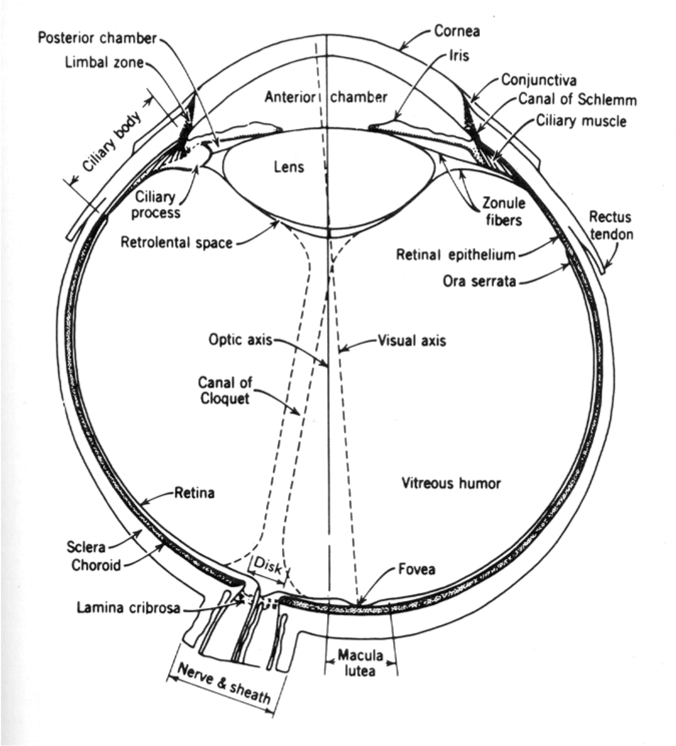
- Light is absorbed by the photoreceptors and converted into the electrical energy that initiates neural signals to the brain
- These signals pass from the photoreceptors through the collector cells to the retinal ganglion cells, and out of the eye through the optic nerve

Martin D. Levine. *Vision in Man and Machine*, © McGraw-Hill, 1985.

**Figure 3.16** Human rod (left) and cone (right). (*From L. Missotten, "The Ultrastructure of the Human Retina," Editions Arscia Uitgaven, N.V., Brussels, 1965.*)

# Photoreceptor Distribution

- The Fovea:
  - a very small area of the retina, less than 1mm in diameter, directly on the line of sight
  - contains no rods
  - contains about 50,000 cones
- The Periphery:
  - extends to nearly 90° of visual angle on each side
  - rods outnumber cones in the periphery by 20:1



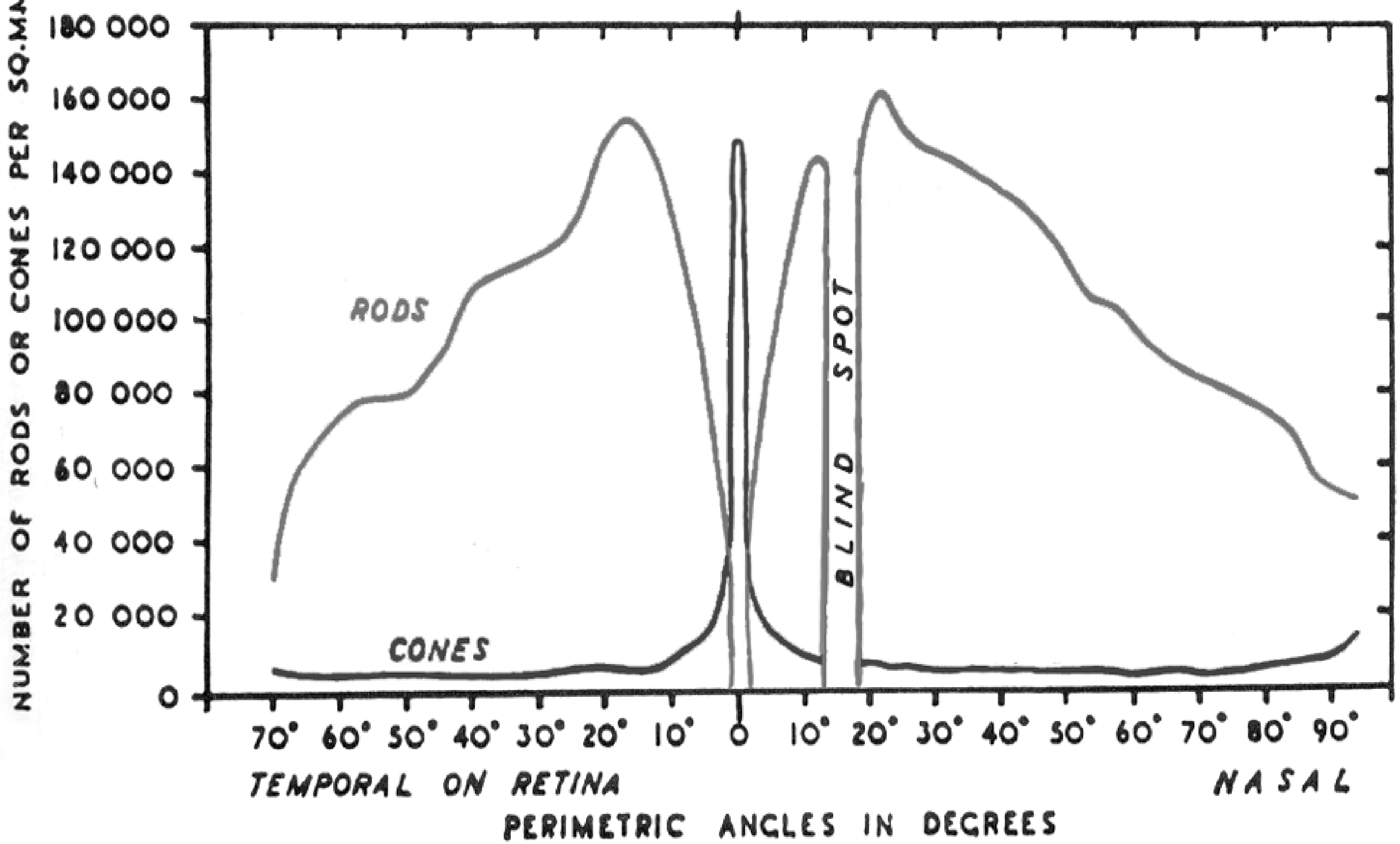
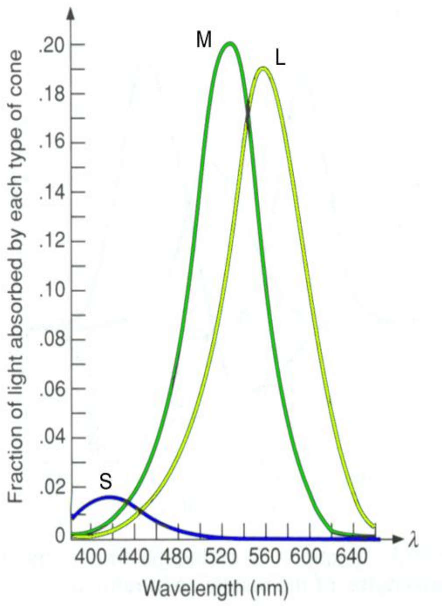



**Figure 3.15** The spatial distribution of rods and cones.
(*From M. H. Pirenne, "Vision and the Eye," 2d ed., Associated Book Publishers, London, 1967.*)

# Photoreceptors: rods and cones

*

## Summary




- **rods** (100-120 million)
  - predominate in the periphery
  - maximally sensitive to light of about 500nm
  - sensitive to very low levels of illumination
  - mainly responsible for night vision
- **cones** (7-8 million)
  - tightly packed in the fovea, present throughout the retina
  - three different types, containing different photo pigments
  - maximally sensitive to light of 420nm, 534nm, or 564nm
  - require higher levels of illumination
  - mainly responsible for color vision

# COLOR PERCEPTION

# Agenda

- Sensation & Perception
- Principles of Perceptual Organization
- Human Visual Physiology
- **Color Perception**
- **Motion (brief)**

# Functions of Color Perception

- Color vision plays an important role in perceptual organization

Image from: Heeger and Bergen (1995) "Pyramid-Based Texture Analysis/Synthesis
Computer Graphics Proceedings, Annual Conference Series, p 237.

# Functions of Color Perception

- Color vision plays an important role in perceptual organization
- Some researchers have even suggested that color vision may have evolved in our primate ancestors for the express purpose of detecting fruit in the forest

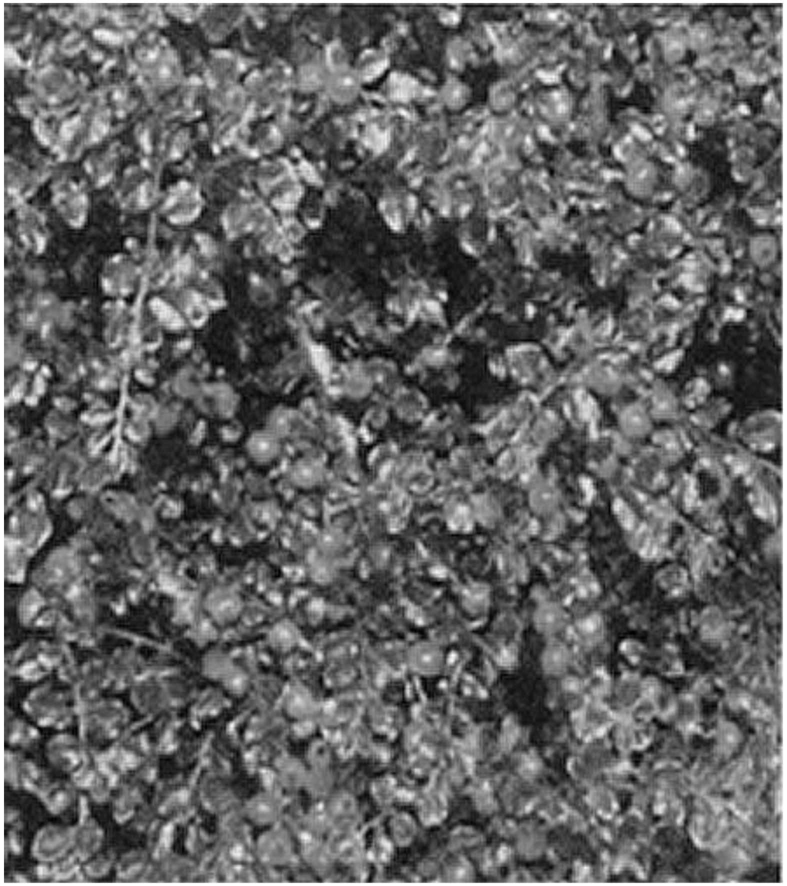


Image derived from: Heeger and Bergen (1995) "Pyramid-Based Texture Analysis/Synthes
Computer Graphics Proceedings, Annual Conference Series, p 237.

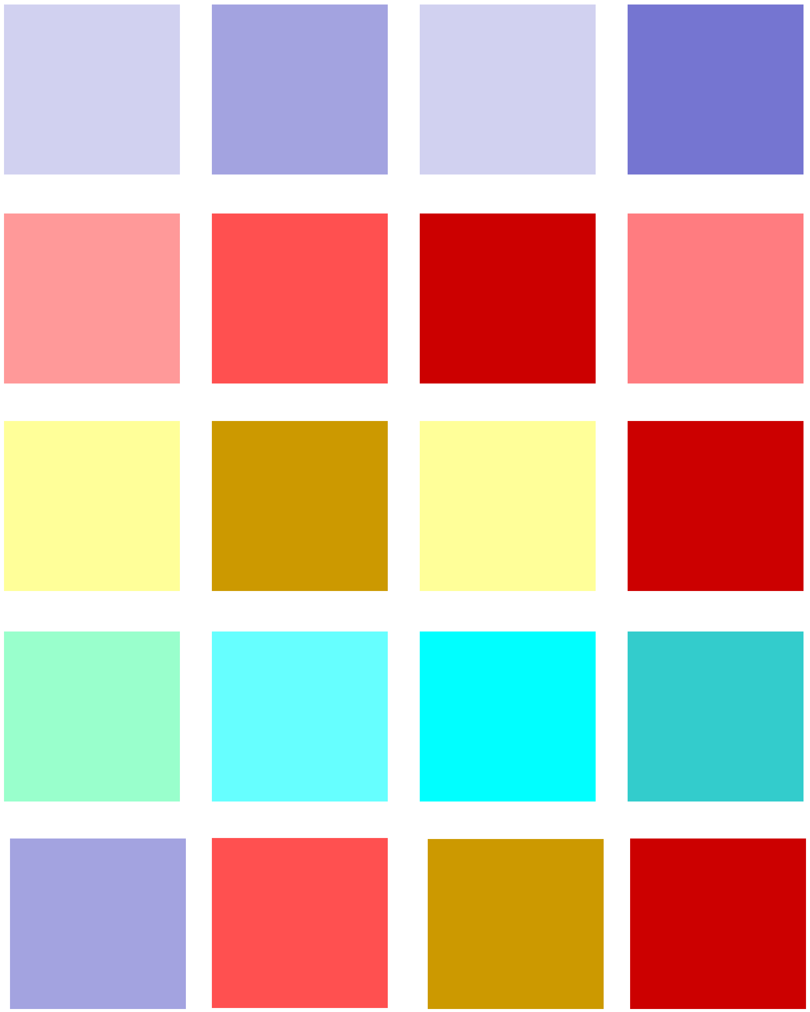
How Many Different Colors Can We See?

# How Many Different Colors Can We See?

- When color samples are placed side-by-side, people can discriminate thousands of different colors

# How Many Different Colors Can We See?

- When samples are presented individually, at an interval of several seconds, people can reliably discriminate only a few dozen



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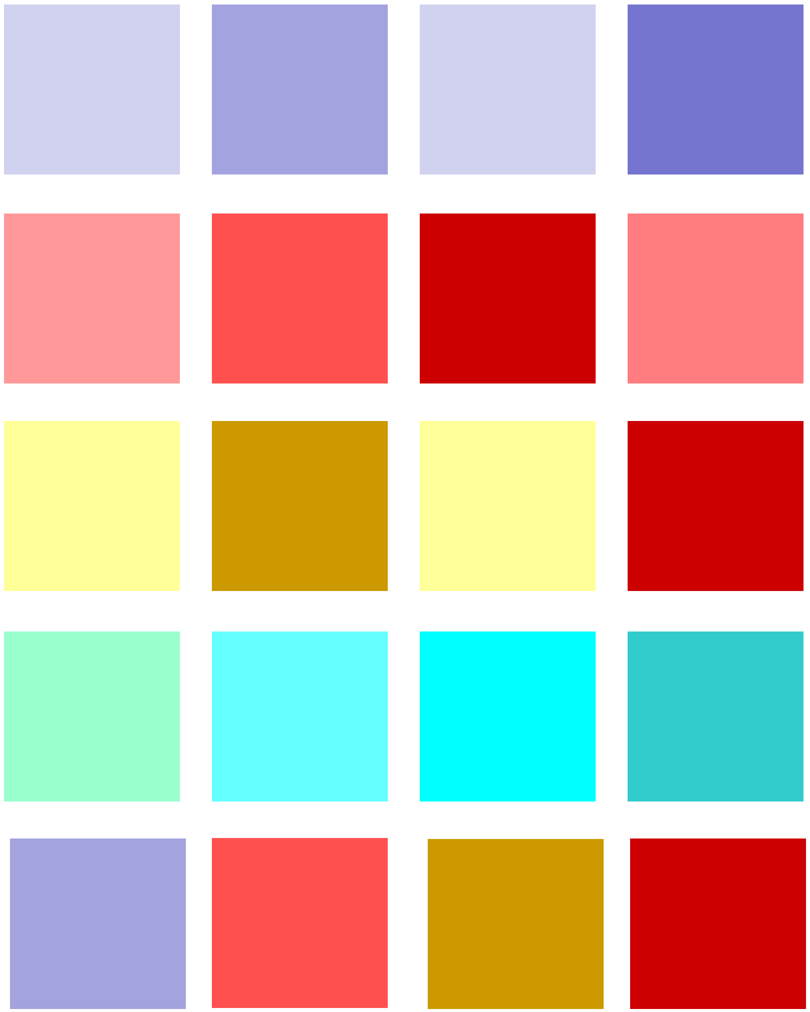


# How Many Different Colors Can We See?

- For specifying data attributes so that they can be reliably distinguished at equiluminance, the limit is about 7

# Color “Meaning”

- Color can have an emotional impact
- The information that we get from color can bias our sense of taste and smell
- Different cultures assign different meanings to specific colors
- Does this imply that our interpretation of color is arbitrary?

# Color: Cultural Influences

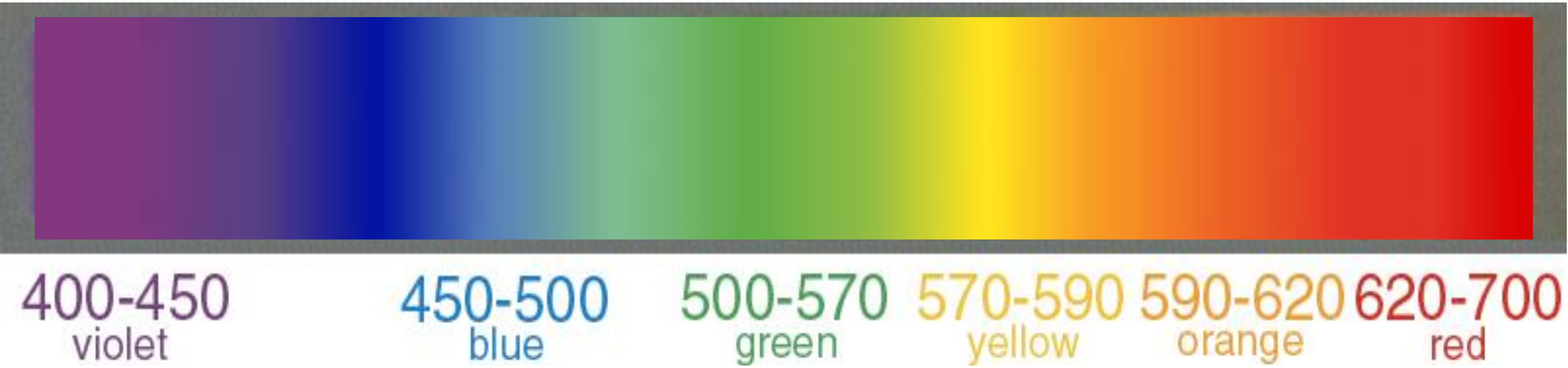
- Ethnic
  - Uniforms
  - Religion
- Domain
  - Traffic signs
  - Internet
  - Sports

# Fundamental Color Categories

- Cross-cultural studies, and studies with infants, suggest that there is an inherent neural basis for what appears to be a universal categorization of colors into:
  - » Blue
  - » Yellow
  - » Green
  - » Red

# The Spectrum of Visible Light

- Visible light occurs in the range of wavelengths between about 400 - 700nm in the electromagnetic spectrum



# “White” Light Includes All Colors

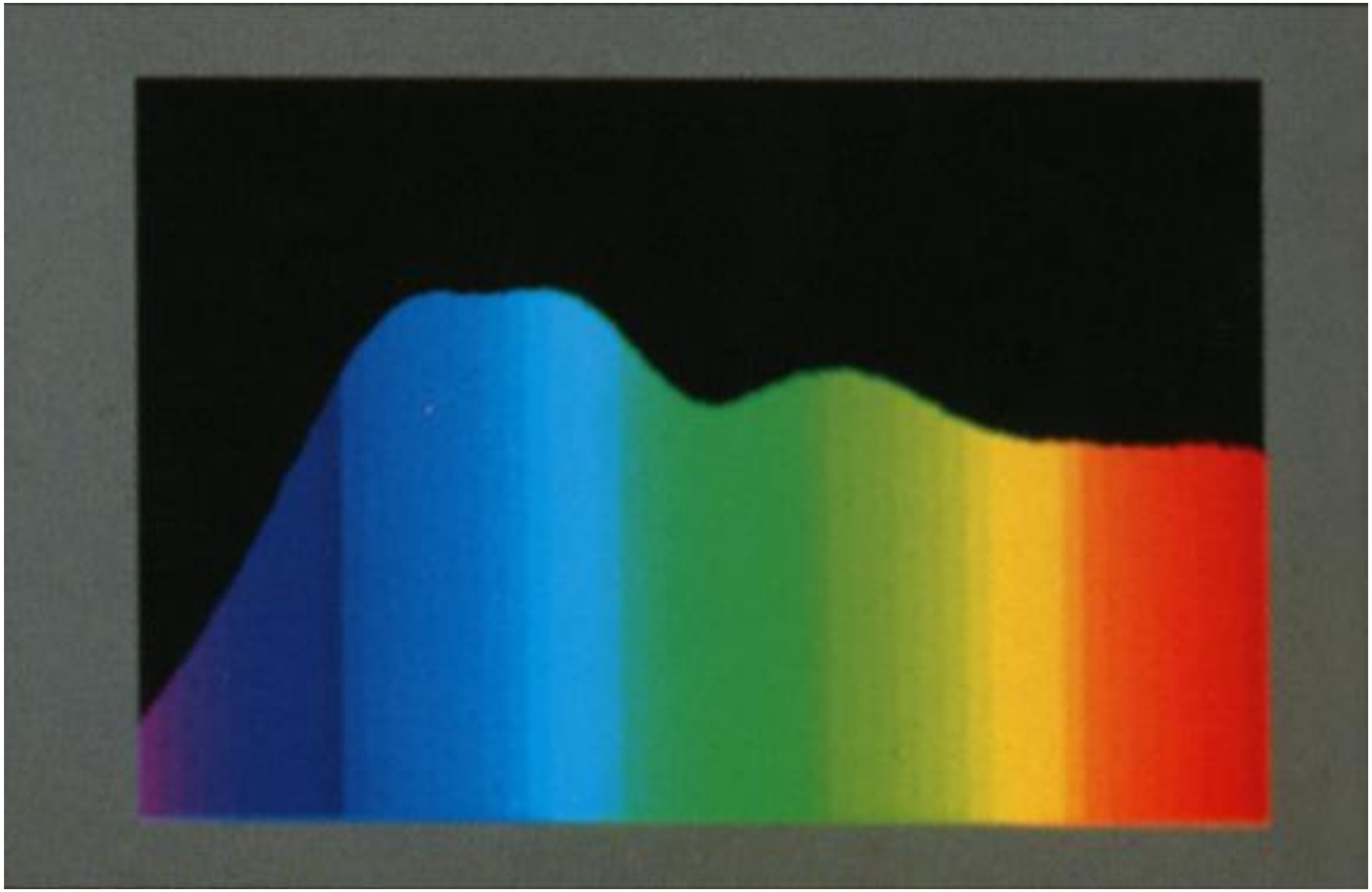
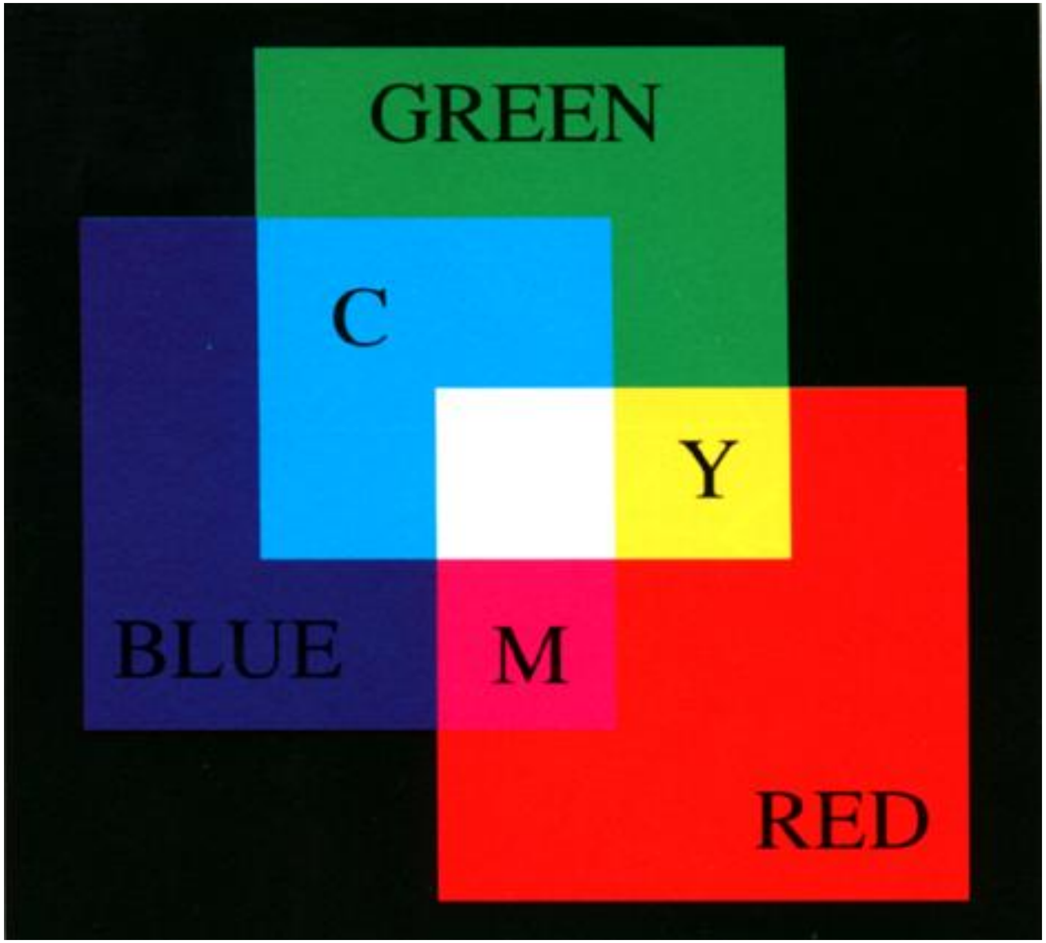


Image from: Foley, van Dam, Feiner and Hughes (1990) *Computer Graphics, Principles and Practice*, Addison-Wesley.

# Emitted Light Combines Additively

- The sun
- Light bulbs
- A computer monitor (RGB)

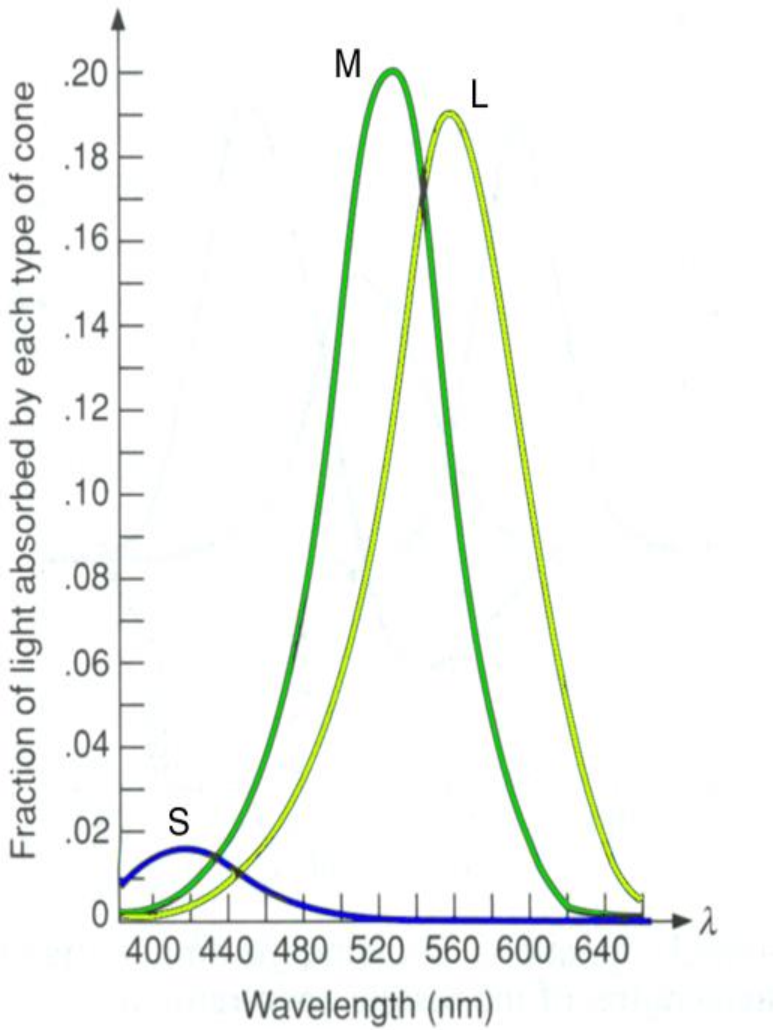


# Reflected Light Combines Subtractively

- Paints
- Printed inks (CMYK)


Image from: Foley, van Dam, Feiner, and Hughes (1990) *Computer Graphics, Principles and Practice*, Addison-Wesley.

# Three Different Types of Cones




- **S-cones:** ***peak sensitivity at 419nm***
  - distributed much more sparsely than other types of cones
  - completely absent from the central fovea
- **M-cones:** ***peak sensitivity at 531nm***
  - about 1/3 of cones are M-cones
- **L-cones:** ***peak sensitivity at 558nm***
  - about 2/3 of cones are L-cones

The relative ratio of L:M:S cones is approx. 40:20:1

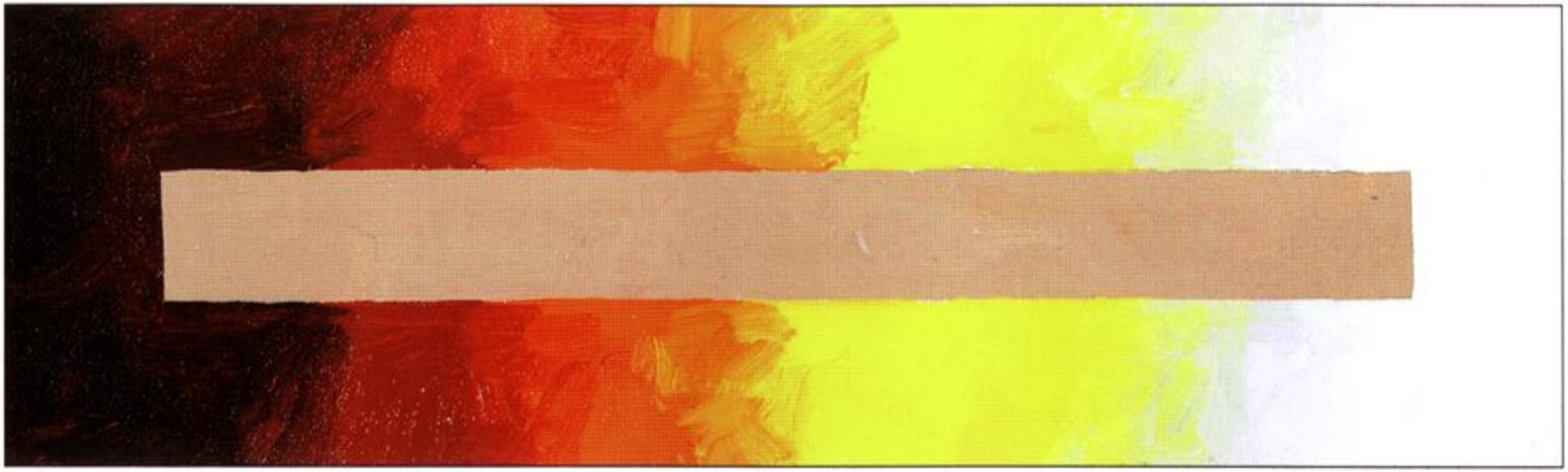
Foley, van Dam, Feiner and Hughes (1990) *Computer Graphics, Principles and Practice*, Addison-Wesley, p.577.

# Watch out for blue!

- Spatial acuity of blue targets is much poorer than spatial acuity of targets of other colors. *This means that blue objects are more prone to looking blurry*
- Sensitivity to short-wavelength (blue) light decreases with age

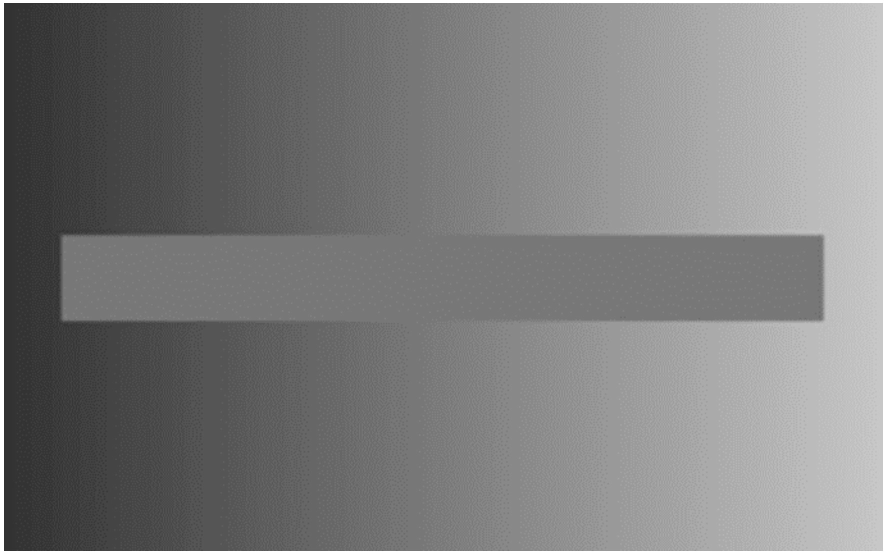
# Simultaneous Contrast

- How we perceive a color depends upon the context in which it is seen

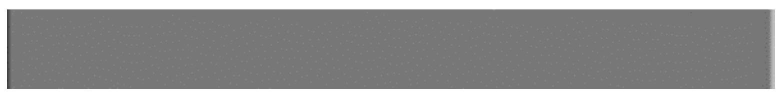


Kevin D. MacPherson, *Fill Your Oil Paintings with Light and Color,* North Light Books, 1998.

# Brightness

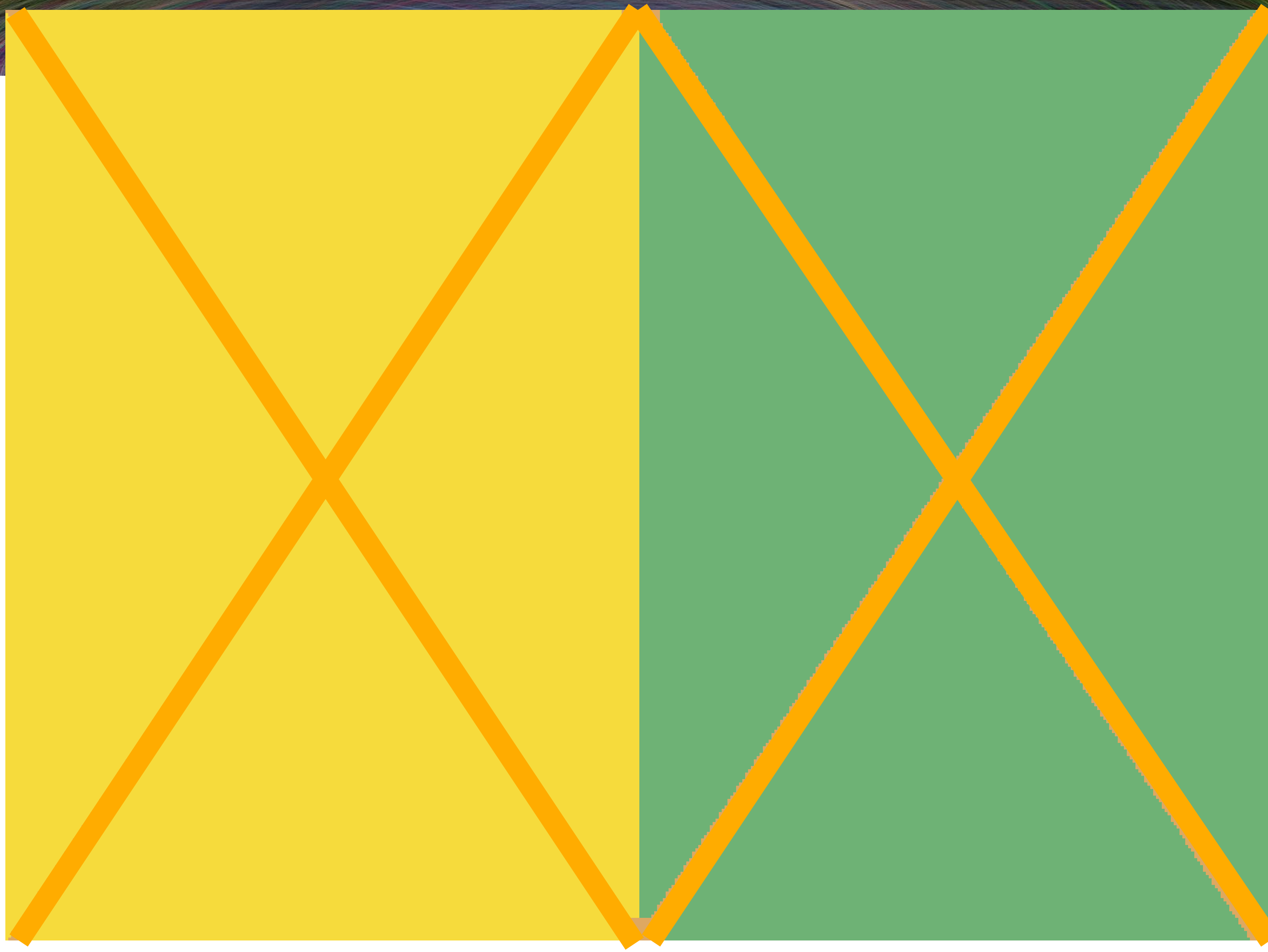


# Brightness Constancy Illusion



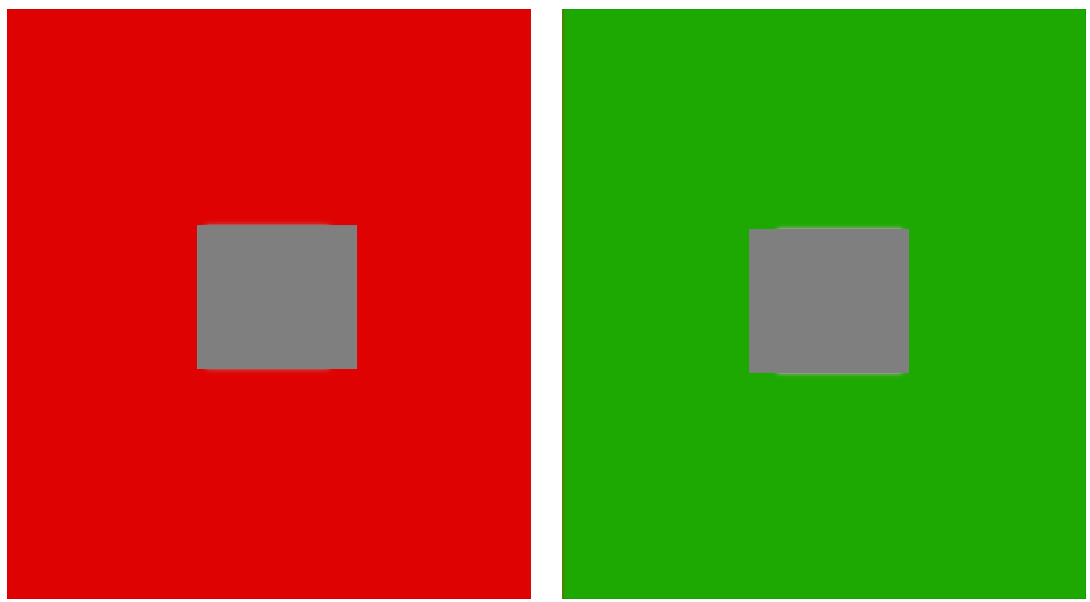
# Color and Simultaneous Contrast

- Lateral inhibition between opponent colors (red/green or blue/yellow) causes our perception of the *hue* as well as the *lightness* of a colored patch to be context sensitive



# Chromatic Induction

- An interior patch can be tinged with the opponent hue of a surrounding patch; for example a gray patch surrounded by red may appear greenish, the one surrounded by green may appear purple
- Effects are strongest when smooth gradients of color are present



# Chromatic Induction

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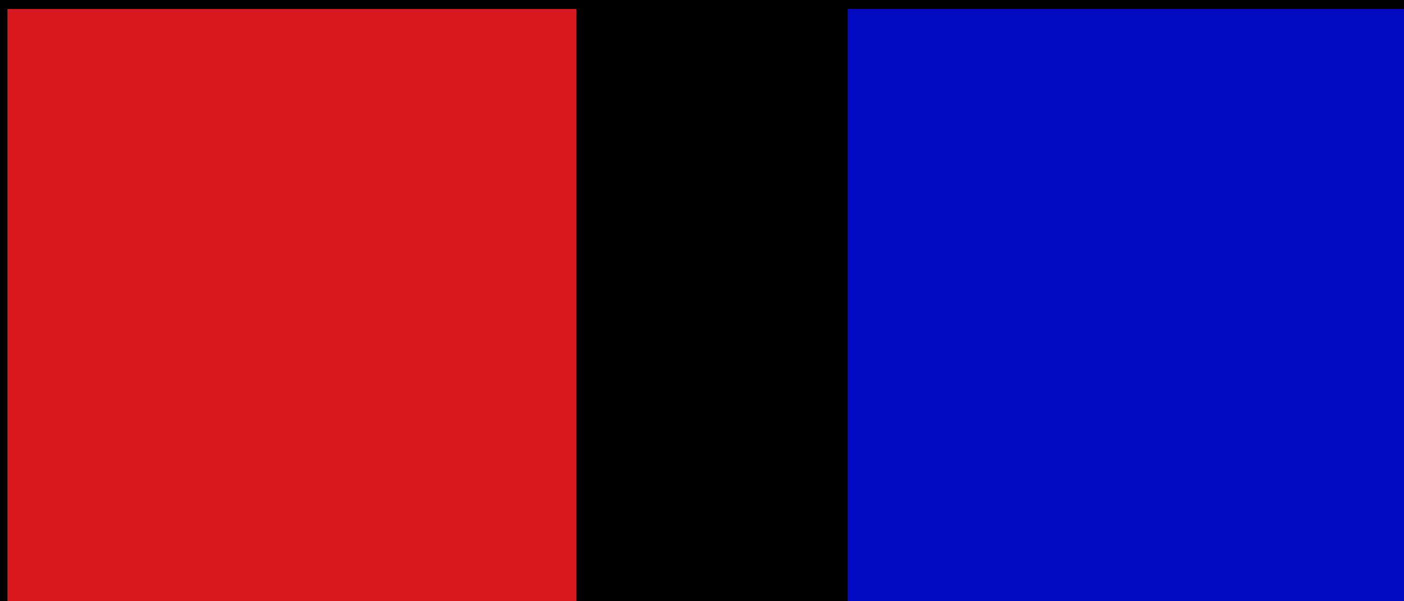
# Chromostereopsis

- Light slightly diffracts as it passes through the cornea
- The eye normally accommodates to bring the yellow wavelengths (598nm) into sharpest focus
- The longer red wavelengths converge behind the retina
- The shorter green and blue wavelengths converge in front of the retina

Longer wavelength colors appear to come forward;
Shorter wavelength colors appear to receed



# Chromostereopsis

- **This is a demo for chromostereopsis**
- **This is a demo for chromostereopsis**
- **This is a demo for chromostereopsis**
- **This is a demo for chromostereopsis**

# Color Deficiency

**approx. 8% of males and < 1% of females suffer from some kind of anomalous color vision**

- Monochromatism
  - possess only <u>one</u> type of cone or no cones at all
- Dichromatism
  - possess only <u>two</u> types of cones (two photopigments)
  - three major forms of this deficiency:
    - Protanopia - missing the *long*-wavelength pigment
    - Deuteranopia - missing the *medium*-wavelength pigment
    - Tritanopia - missing the *short*-wavelength pigment
- Anomalous Trichromatism
  - possess three cone pigments, but do not see colors in the same way as normal trichromats

# Test your color vision

- https://www.buzzfeed.com/jamedjackson/only-people-with-perfect-color-vision-can-pass-this-quiz

# Some color guidelines

- Use compatible color combinations. Avoid green-red, blue-yellow, green-blue, red-blue
- Use colors with high contrast for text and background
- Limit the number of colors (4 for novices and 7 for experts)
- Use clear blue only as background
- Do not forget that 8 to 10% of the male population have problems perceiving color!

# Summary: Color Vision

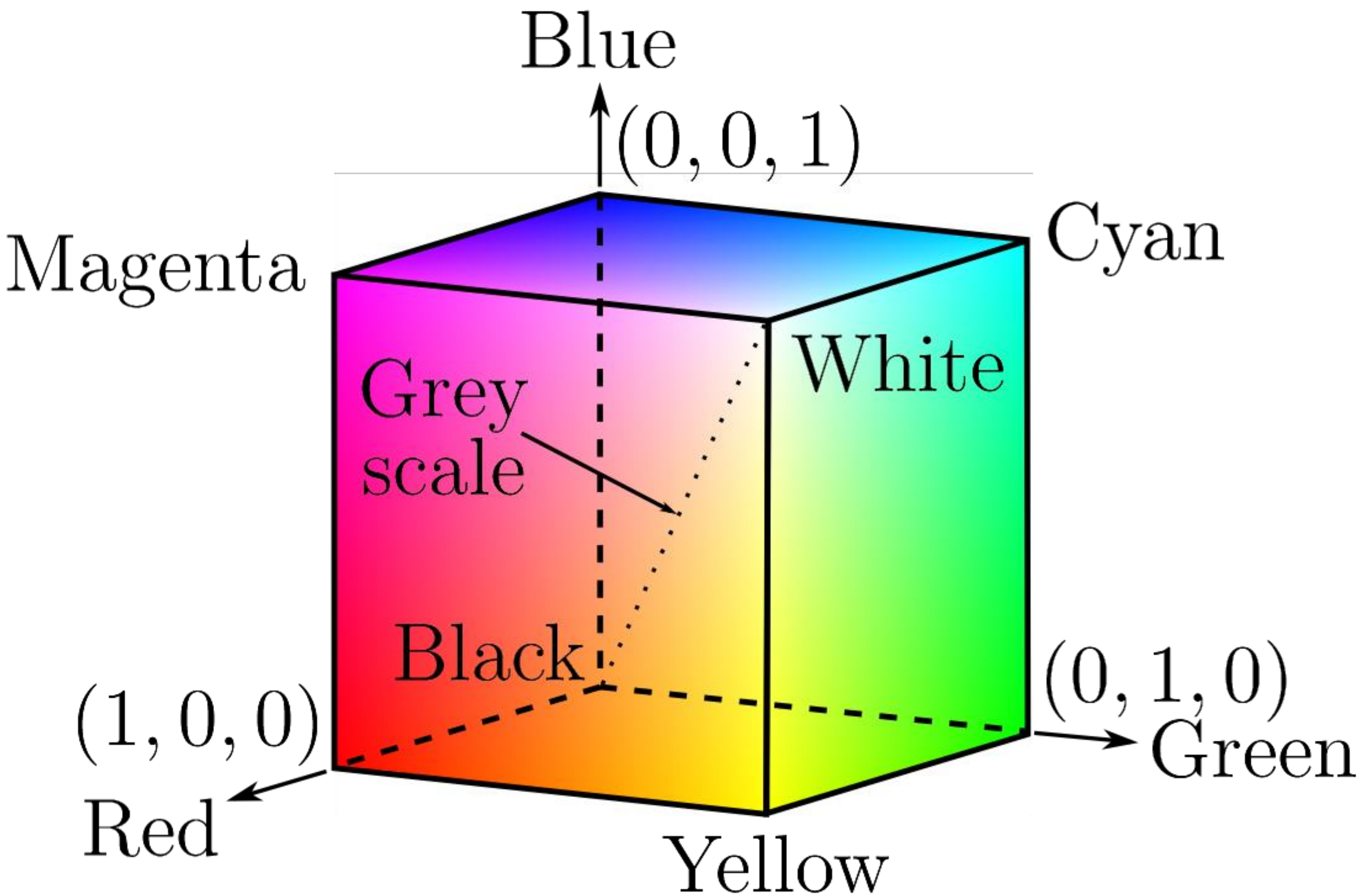
- Color vision is a result of a complicated process that mixes and inhibits.
- Different wavelengths produce the sensation of different colors (red, blue, and so on) this is hue.
- Purity of the input (the amount of white that's mixed in with color) produces the perception of saturation or how deep the color is.
- The amplitude of the light waves produces the perception of lightness or brightness.
- Color blindness-most are red-green blind, because cones don't respond appropriately or are missing
  - Red-green most common then blue-yellow
  - 10-8% of males, .5% females, X-Linked

# Representational Color Spaces

- The most common: RGB
  - Designed to be compatible with the way computer monitors work: with three kinds of phosphor
  - It can be difficult to model desired colors using RGB primaries

Foley, van Dam, Feiner and Hughes (1990) *Computer Graphics, Principles and Practice*, Addison-Wesley.

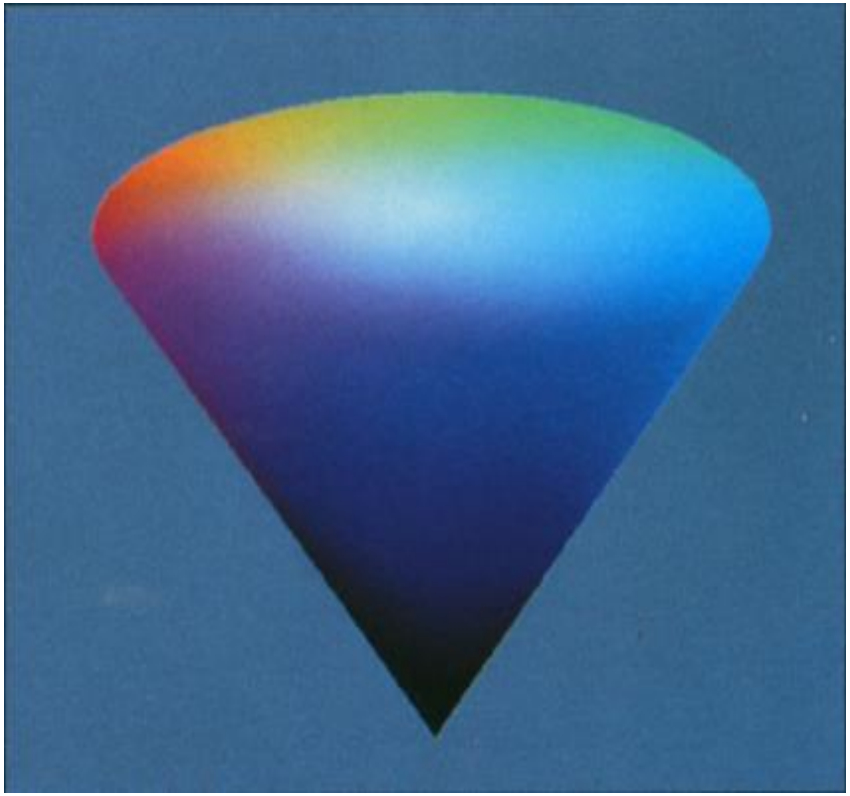
# RGB Color Space



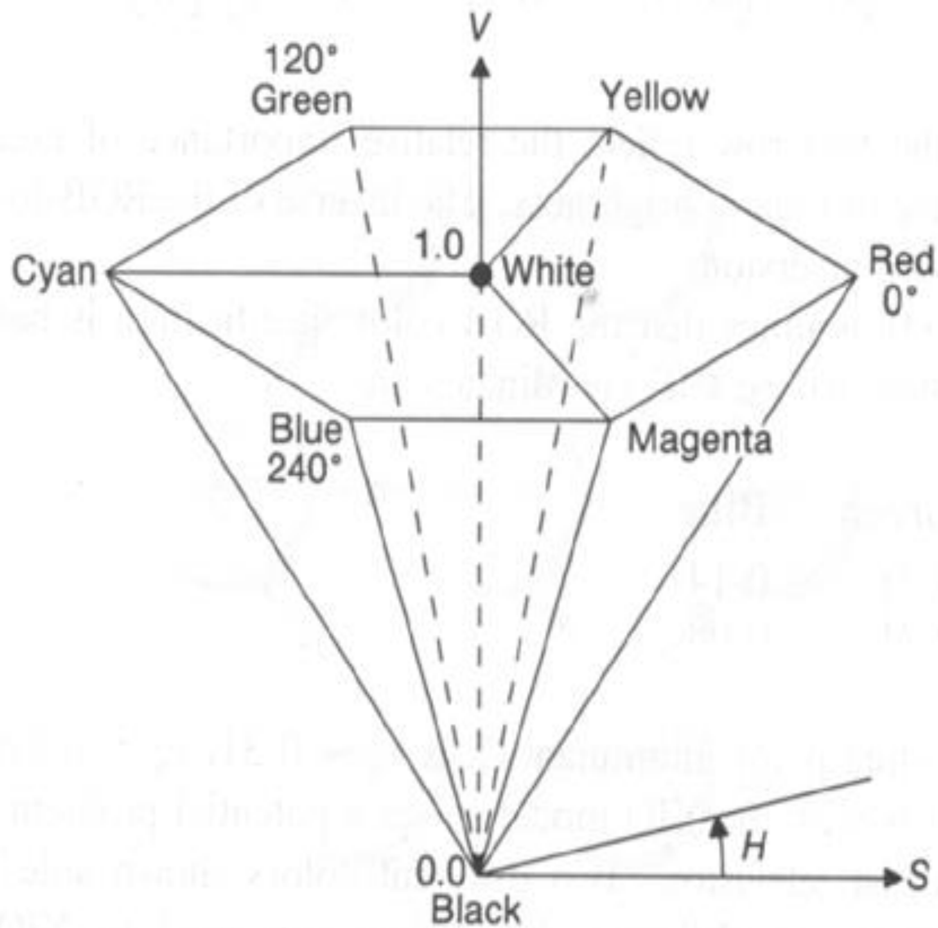

Foley, van Dam, Feiner and Hughes (1990) *Computer Graphics, Principles and Practice*, Addison-Wesley.

# HSV Color Space

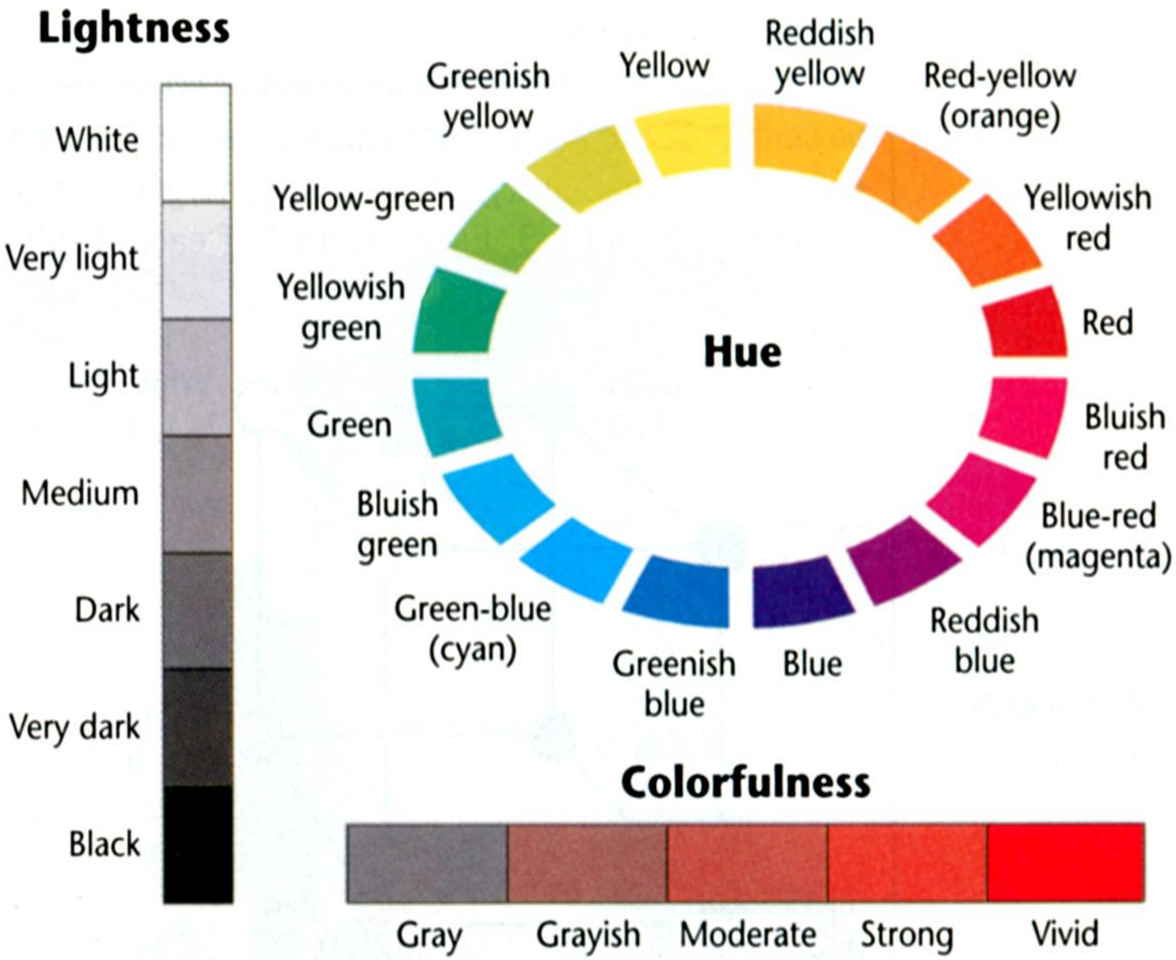
- Hue, Saturation, Value
  - Designed to be more intuitive for the computer user
  - Perceptually based variables for color definition:
    - hue:
      quality by which we distinguish one color family from another
    - saturation:
      quality of color by which we distinguish a strong or weak one (color intensity)
    - value:
      quality by which we distinguish a light color from a dark one
  - 1:1 mapping between RGB and HSV
  - Color interpolation can be more intuitive in HSV space



Foley, van Dam, Feiner and Hughes (1990) *Computer Graphics, Principles and Practice*, Addison-Wesley.




Foley, van Dam, Feiner and Hughes (1990) *Computer Graphics, Principles and Practice*, Addison-Wesley.

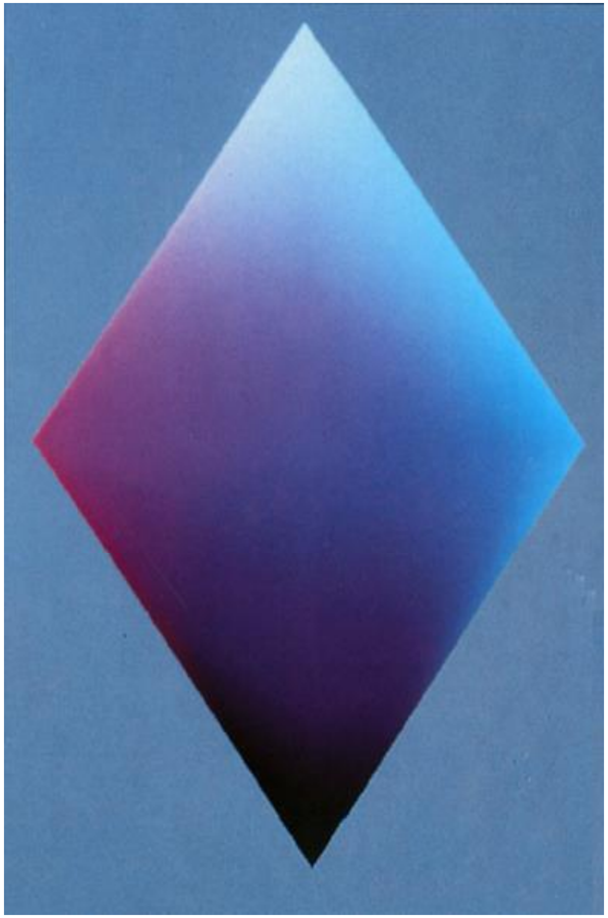



Lindsay W. MacDonald (1999) "Using Color Effectively in Computer Graphics"

# HLS Color Space

- Hue, lightness (luminance), saturation
  - Can be understood as a transformation of the RGB color cube
  - Similar to HSV, but primary colors at L=0.5
  - More intuitive than HSV since only white has absolute lightness

*All of these color spaces are designed for the computer user*



Foley, van Dam, Feiner and Hughes (1990) *Computer Graphics, Principles and Practice*, Addison-Wesley.

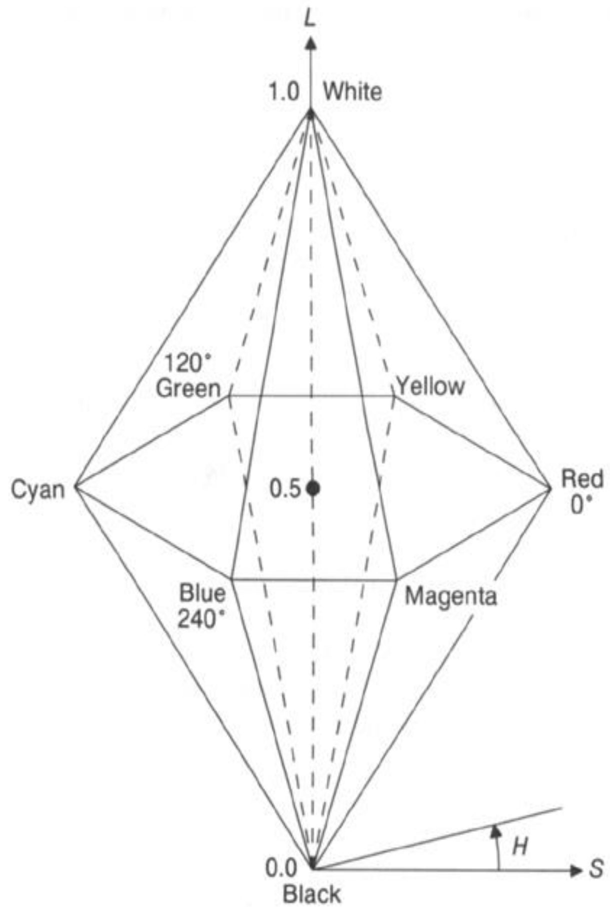
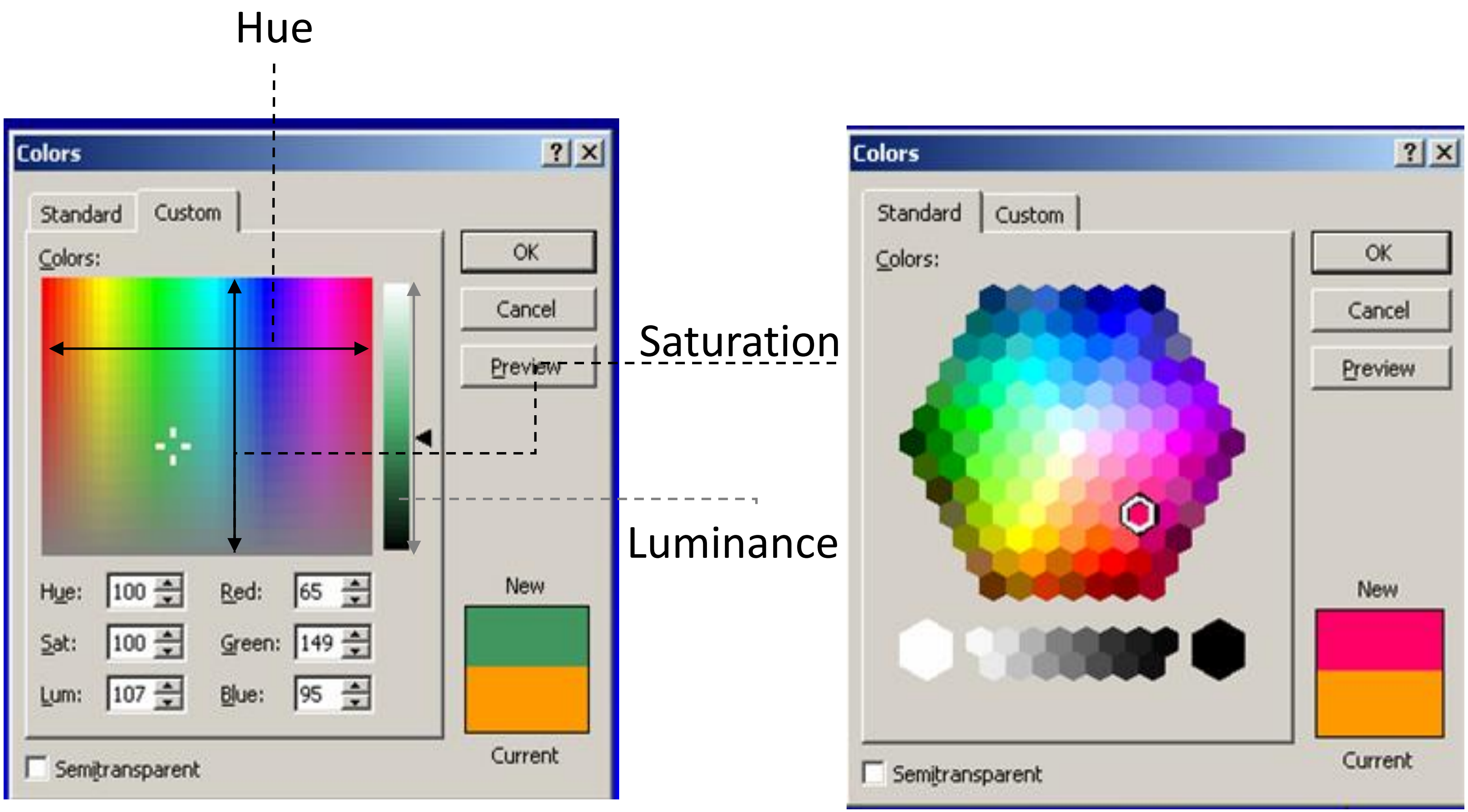


**Fig. 13.35** Double-hexcone HLS color model.

Foley, van Dam, Feiner and Hughes (1990) *Computer Graphics, Principles and Practice*, Addison-Wesley.

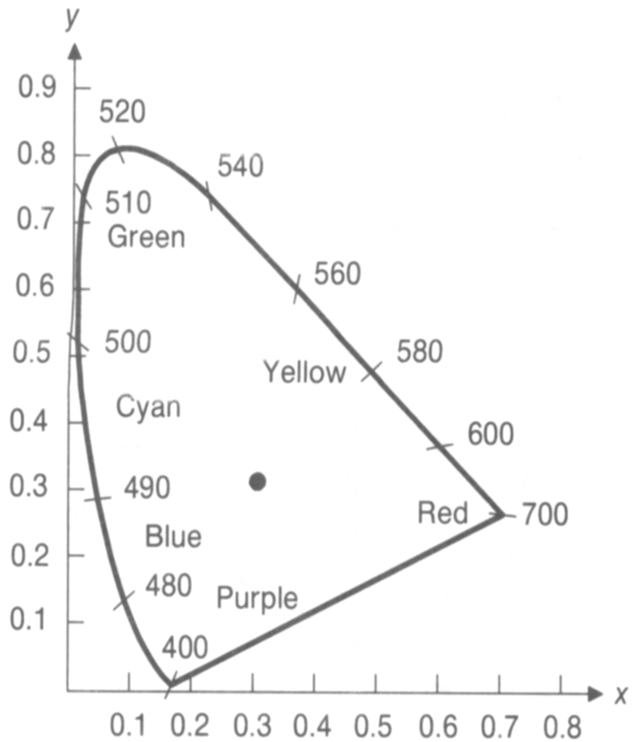
# HLS vs. RGB

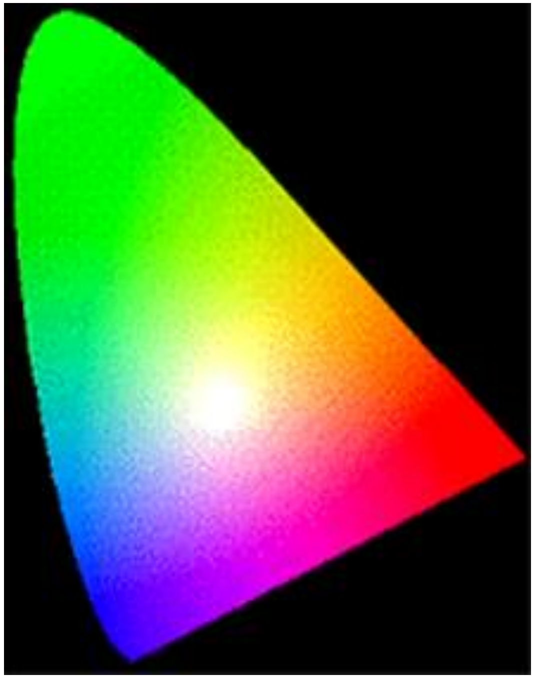



MS Powerpoint - Fill colors - More fill colors ....

# CIE Color Space

- A representation of all of the colors in the visible spectrum, using three primaries (X,Y,Z)



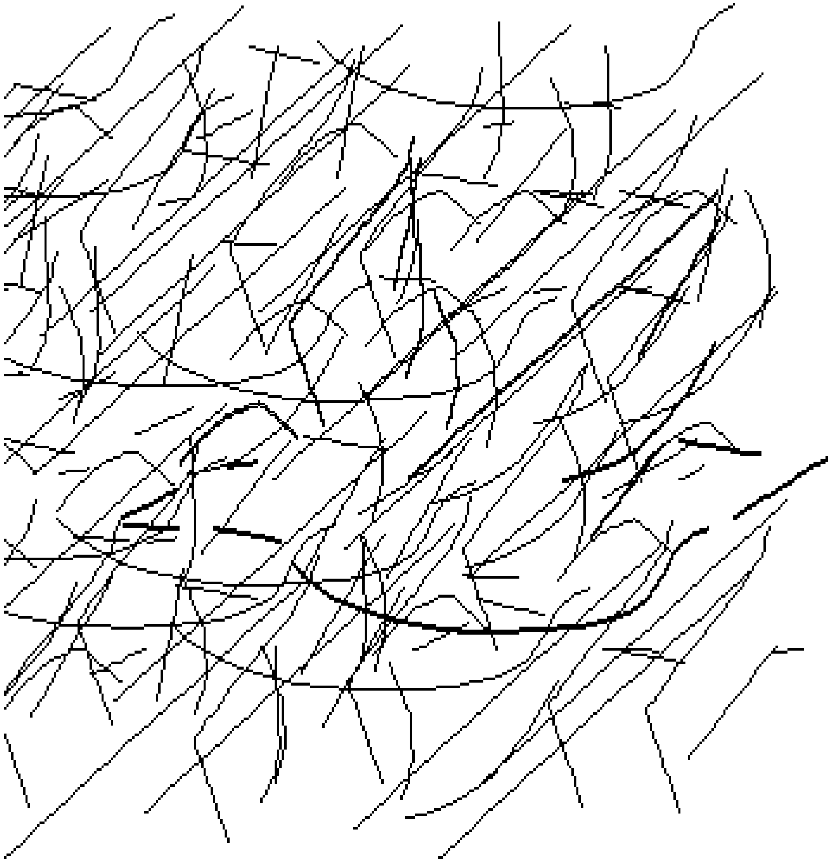
Foley, van Dam, Feiner and Hughes (1990) *Computer Graphics, Principles and Practice*, Addison-Wesley.

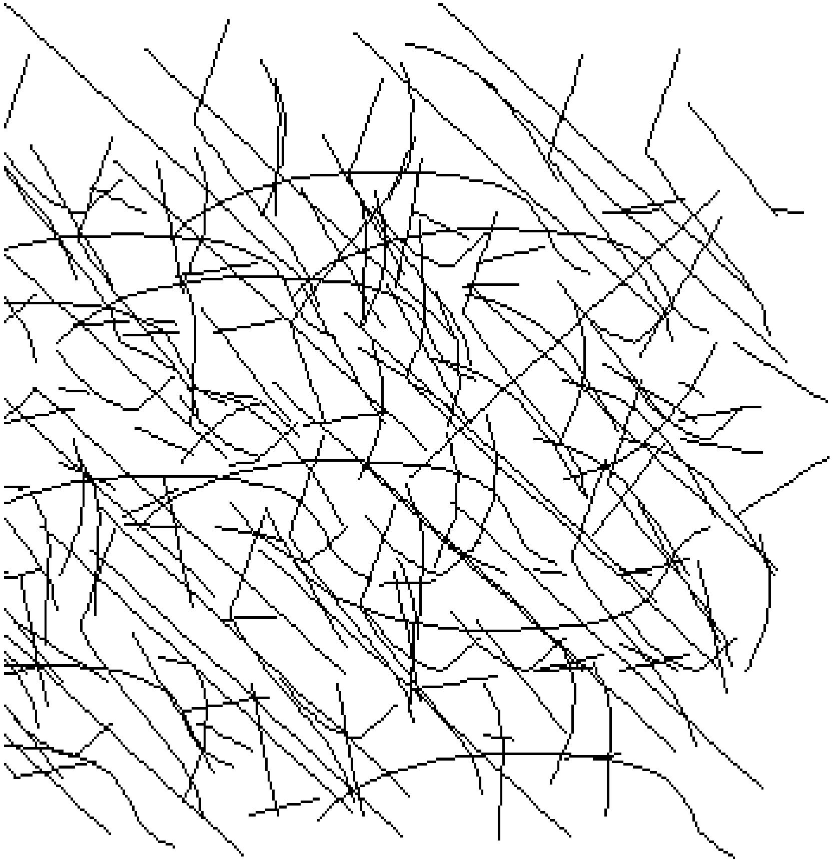
# MOTION

# Motion Perception

- Motion discriminates objects from the background
- Motion information is carried by the *magnocellular* pathway
  - insensitive to wavelength variations (color)
  - relatively large receptive fields; low spatial acuity
  - cells have faster and more transient response
  - more sensitive to low contrast stimuli


Courtesy of Penny Rheinga

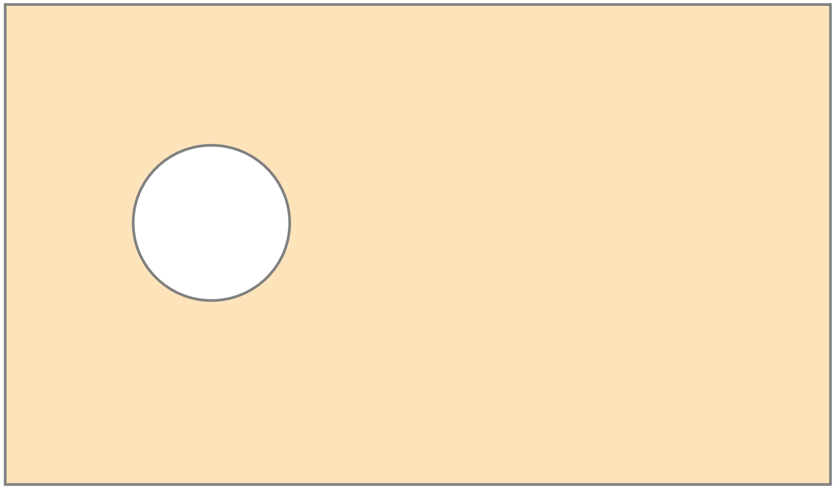


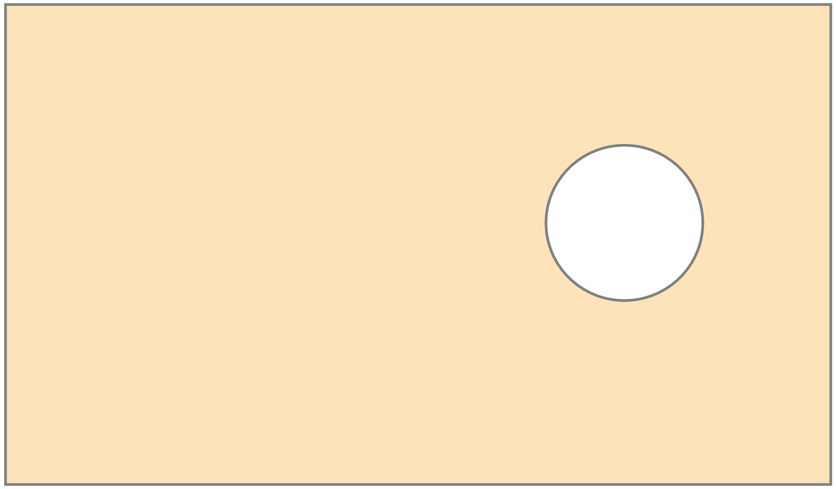


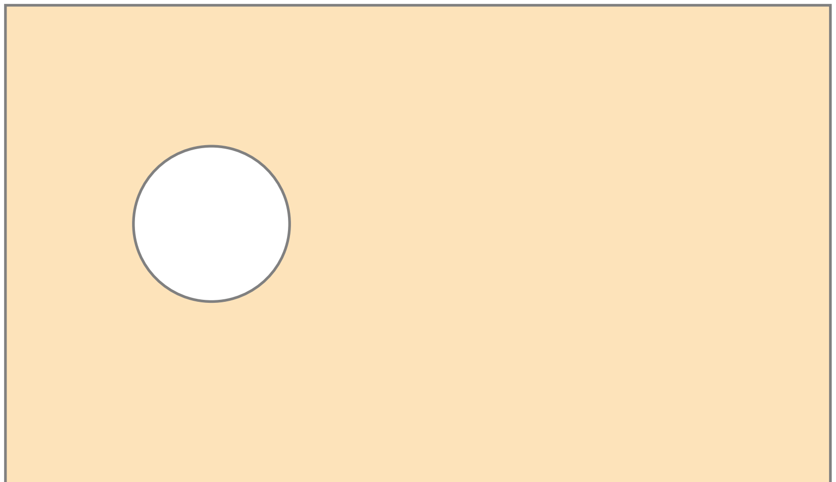
# Apparent Motion

- The perception of motion without stimulus continuity (stroboscopic and cinematic)
- Influences on apparent motion
  - spatial frequency characteristics (ex: wagon wheels)
  - global field effects
  - number of frames
  - expectations from reality
- Limitations
  - maximum of 300 msec interstimulus interval
  - decreased size constancy  (max ~8 Hz)
  - decreased sense of observer motion

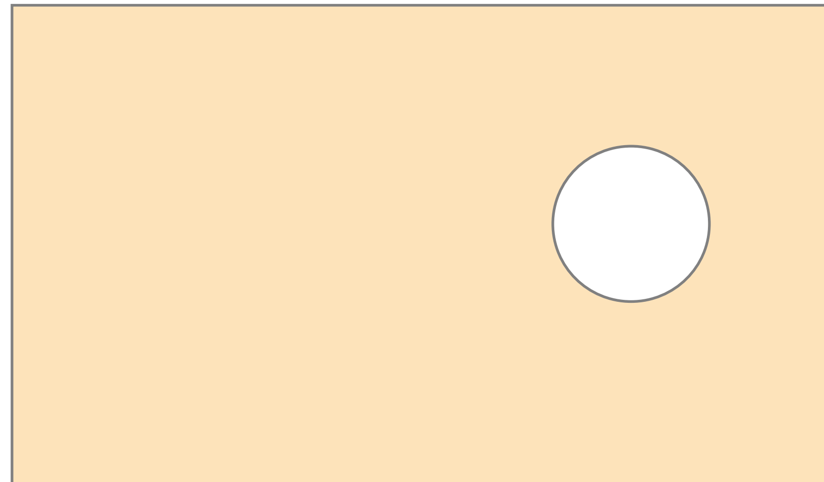

Courtesy of Penny Rheinga



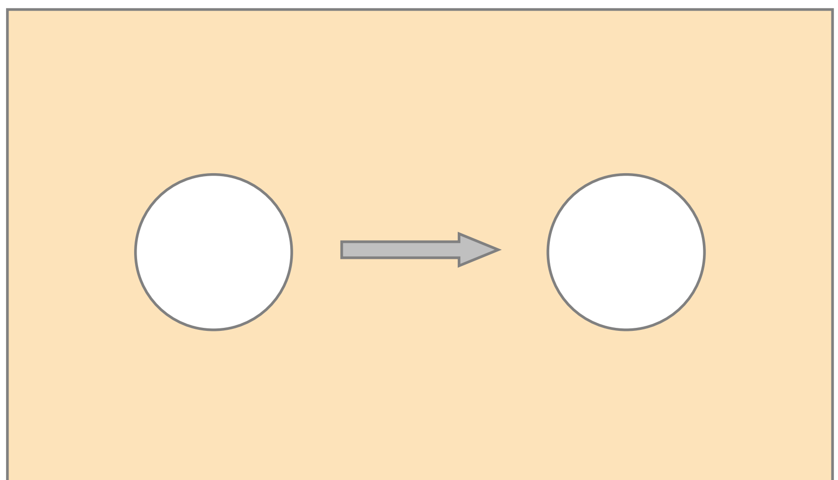




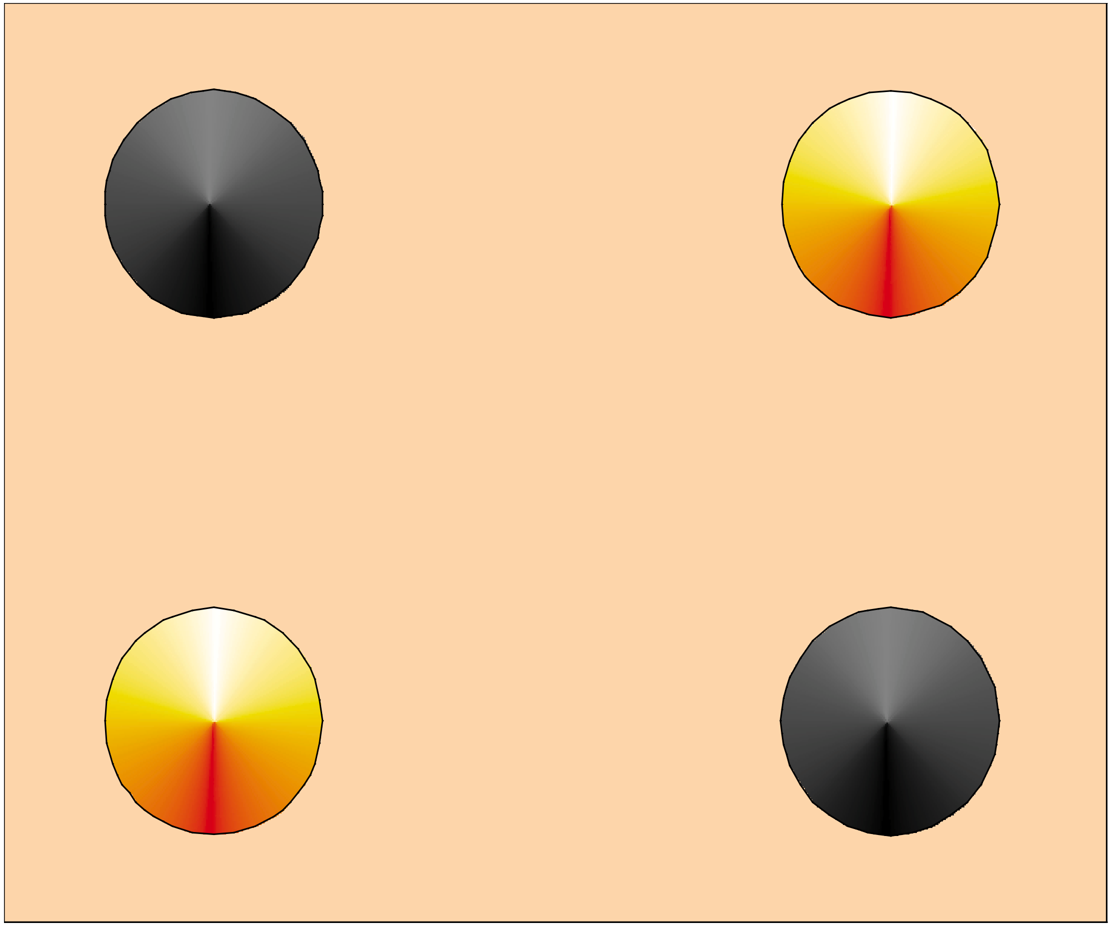
Seen at time 1

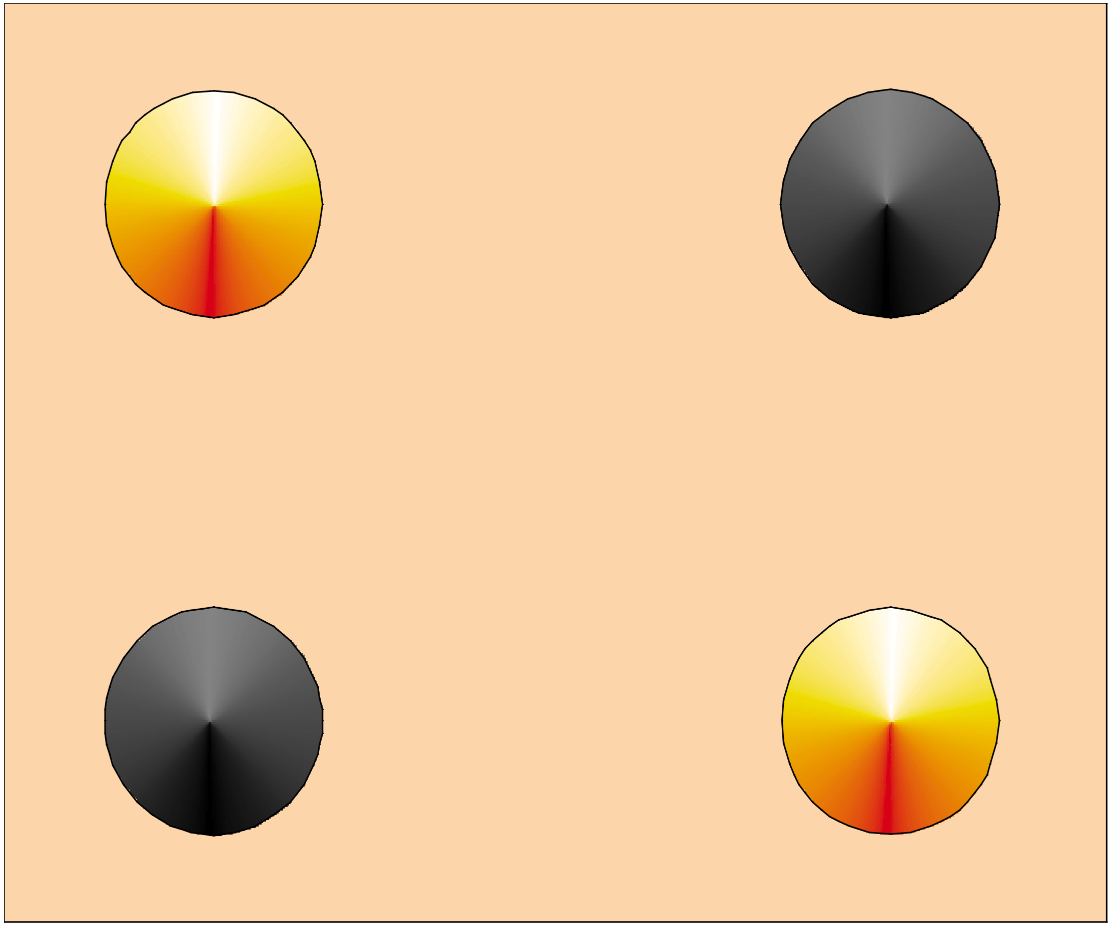


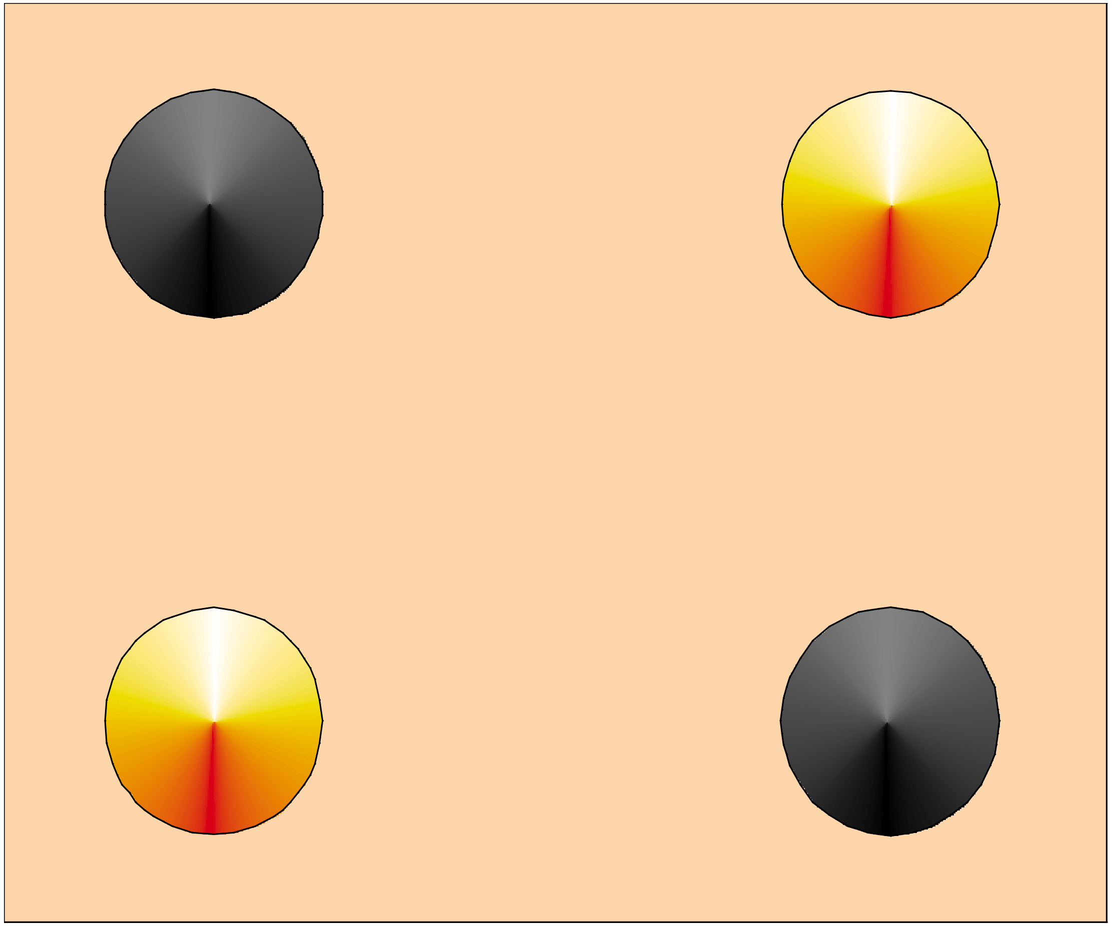
Seen at time 2

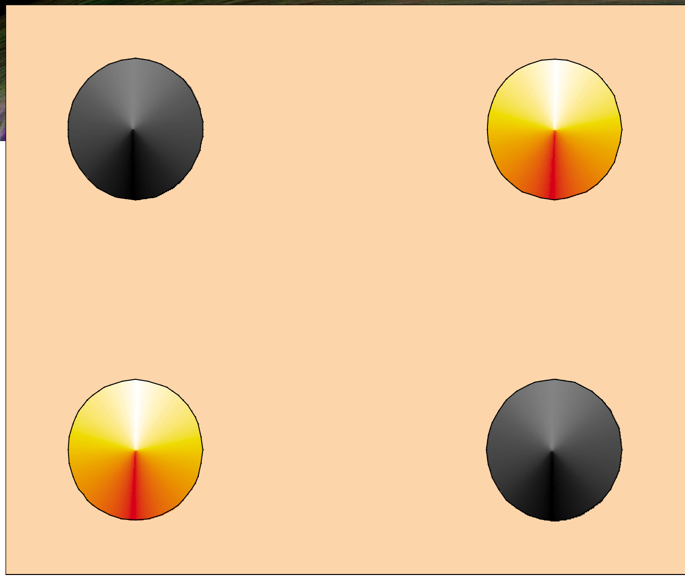


perception

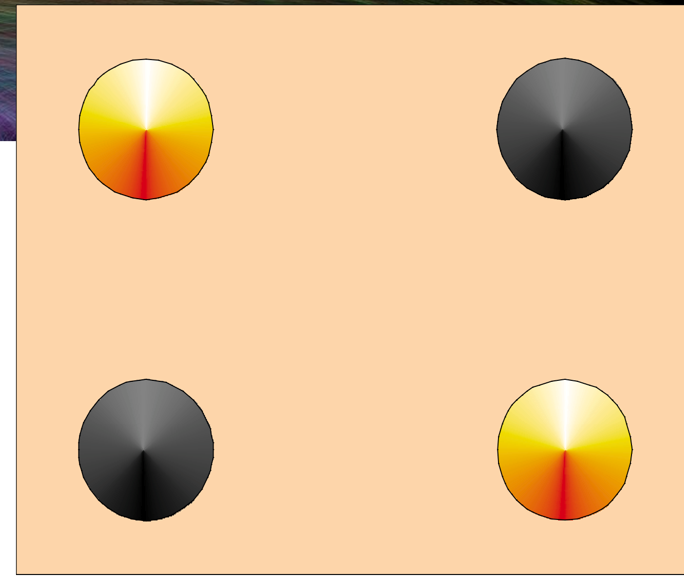




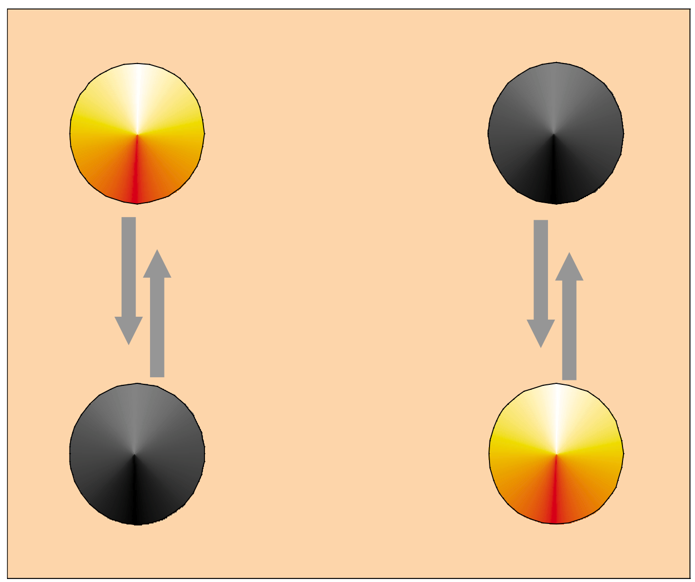




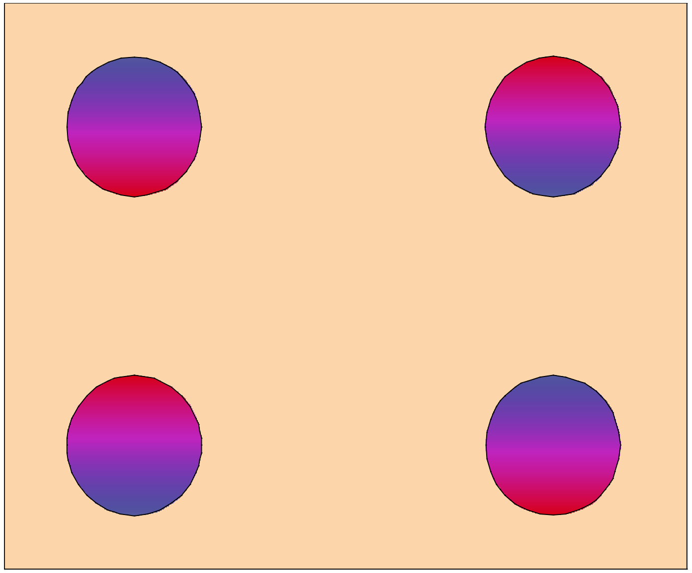
Seen at time 1

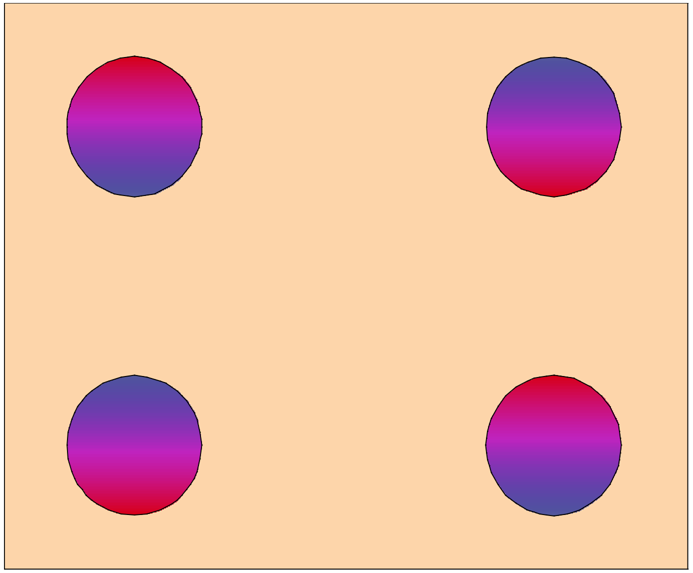


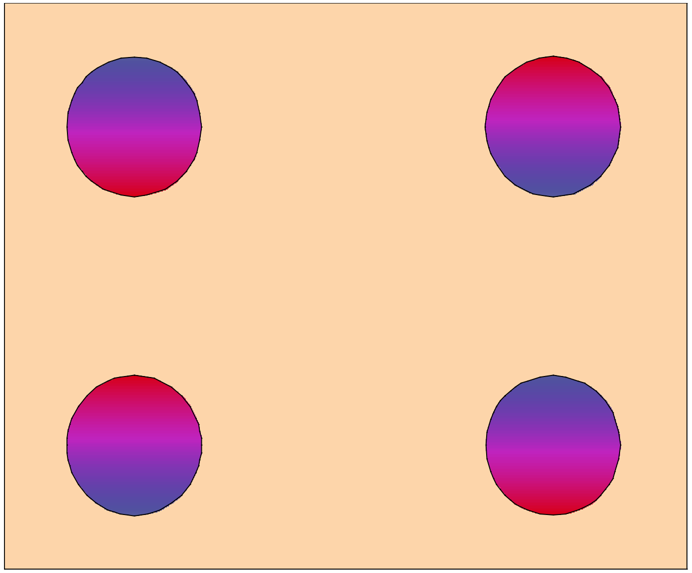
Seen at time 2



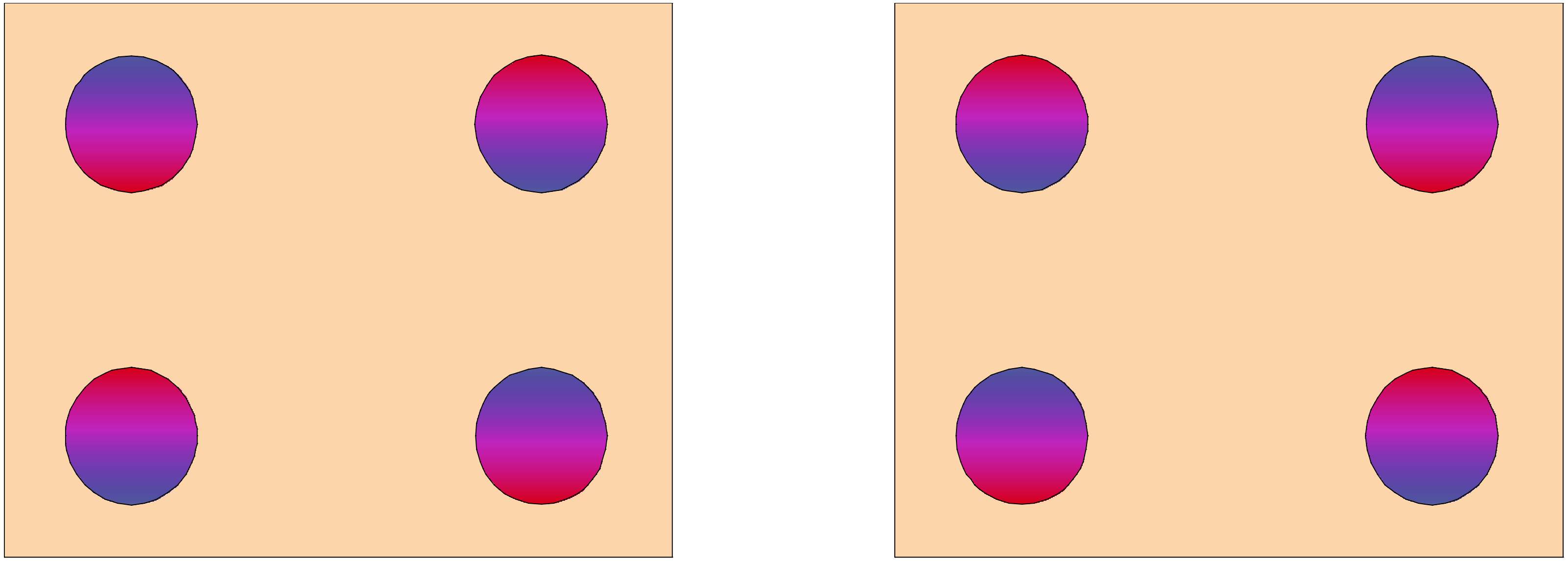
perceptio



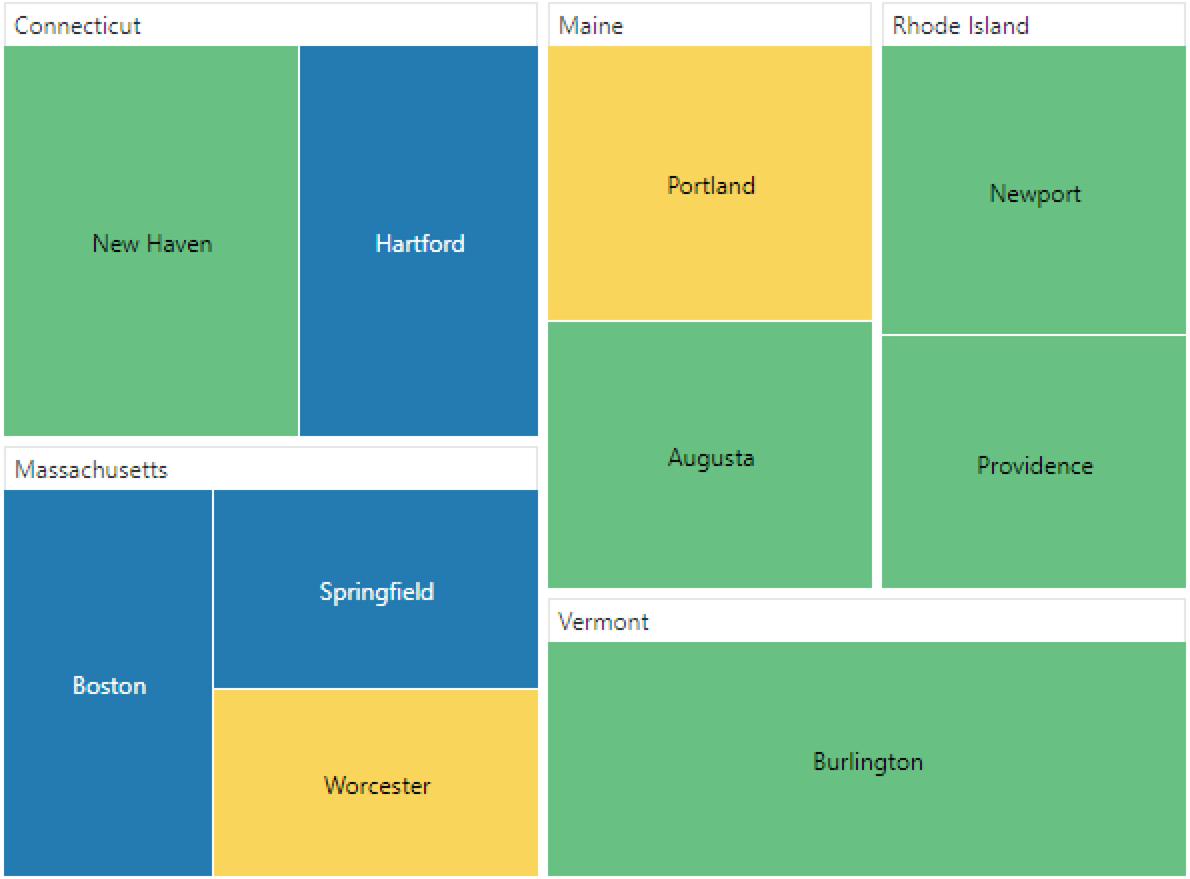


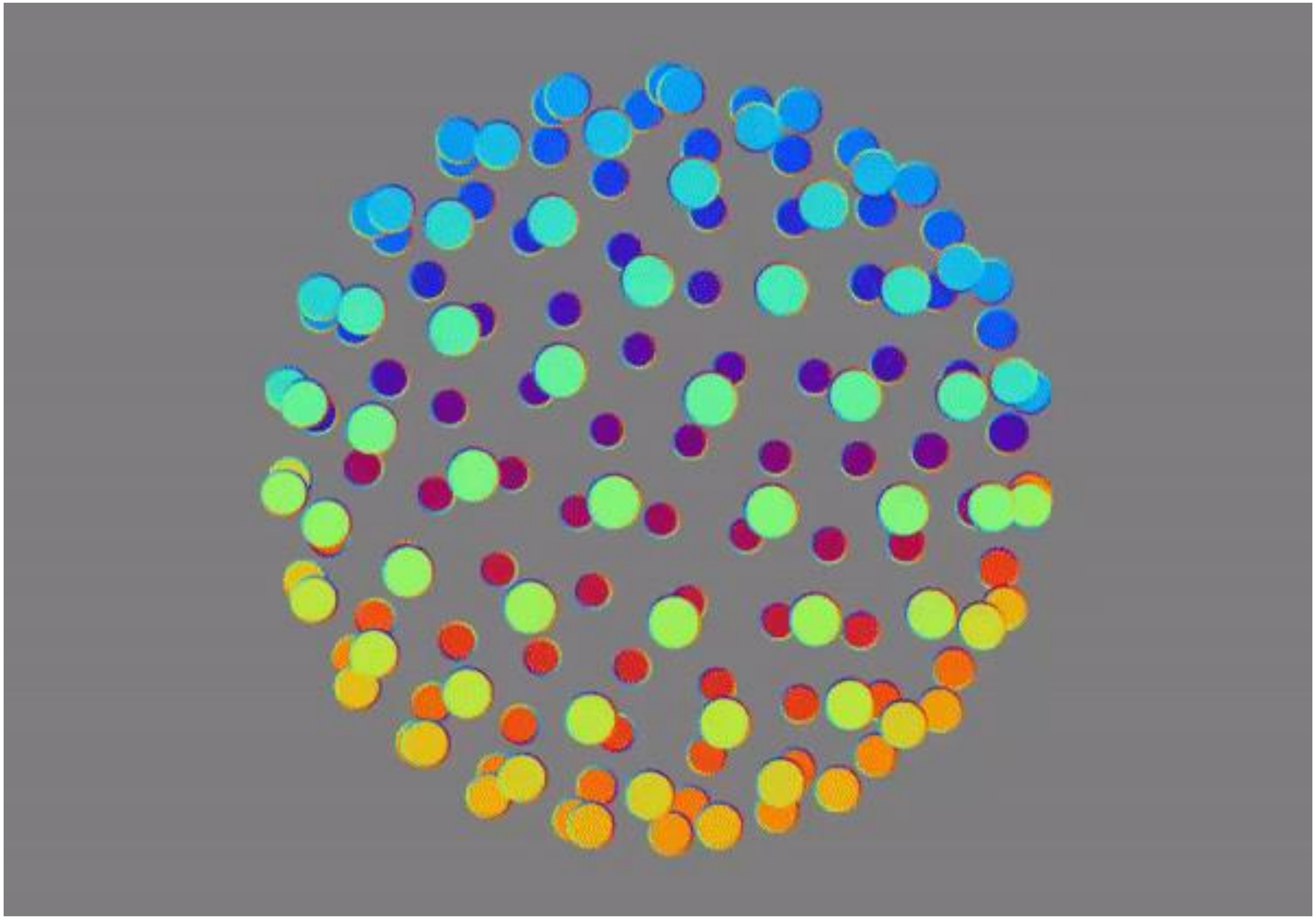


- In this case we do not perceive the dots to be moving; rather we perceive their illumination to be changing

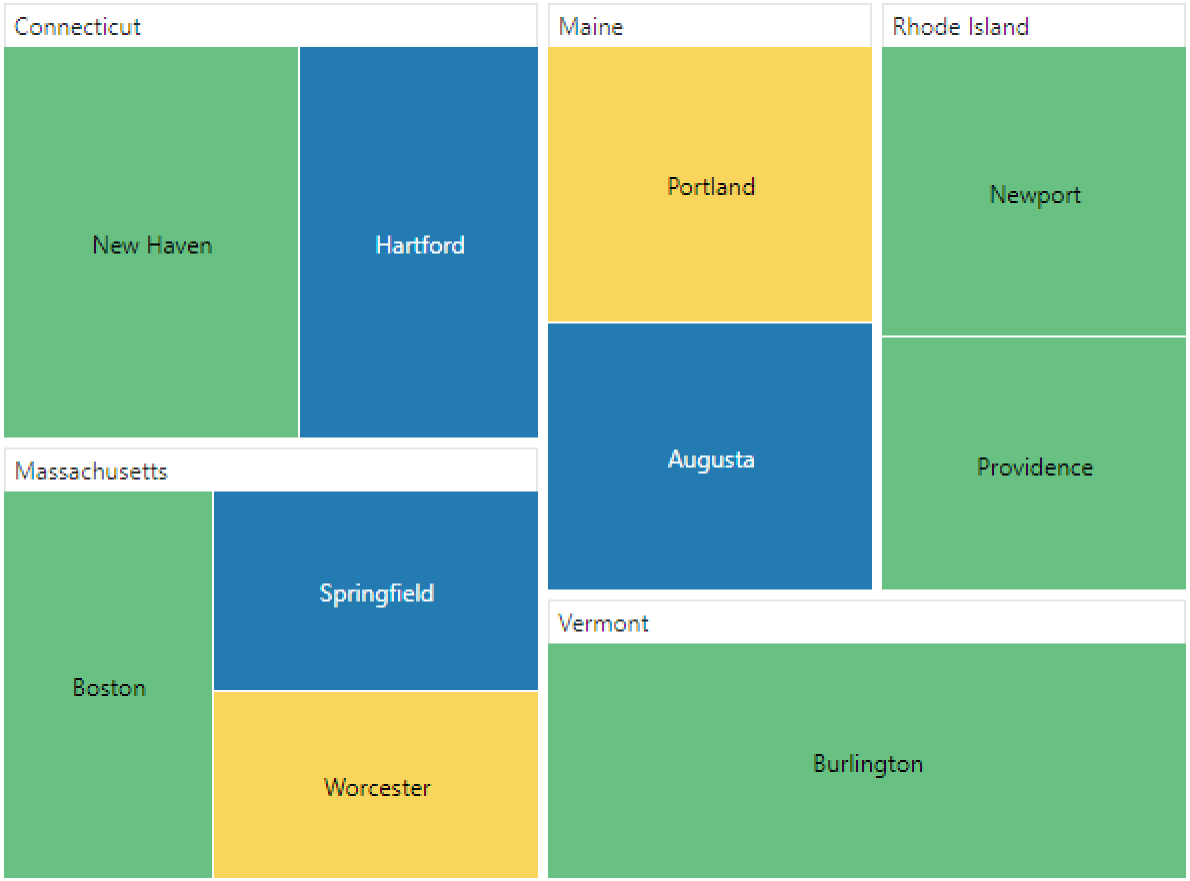


# Apparent motion in treemaps

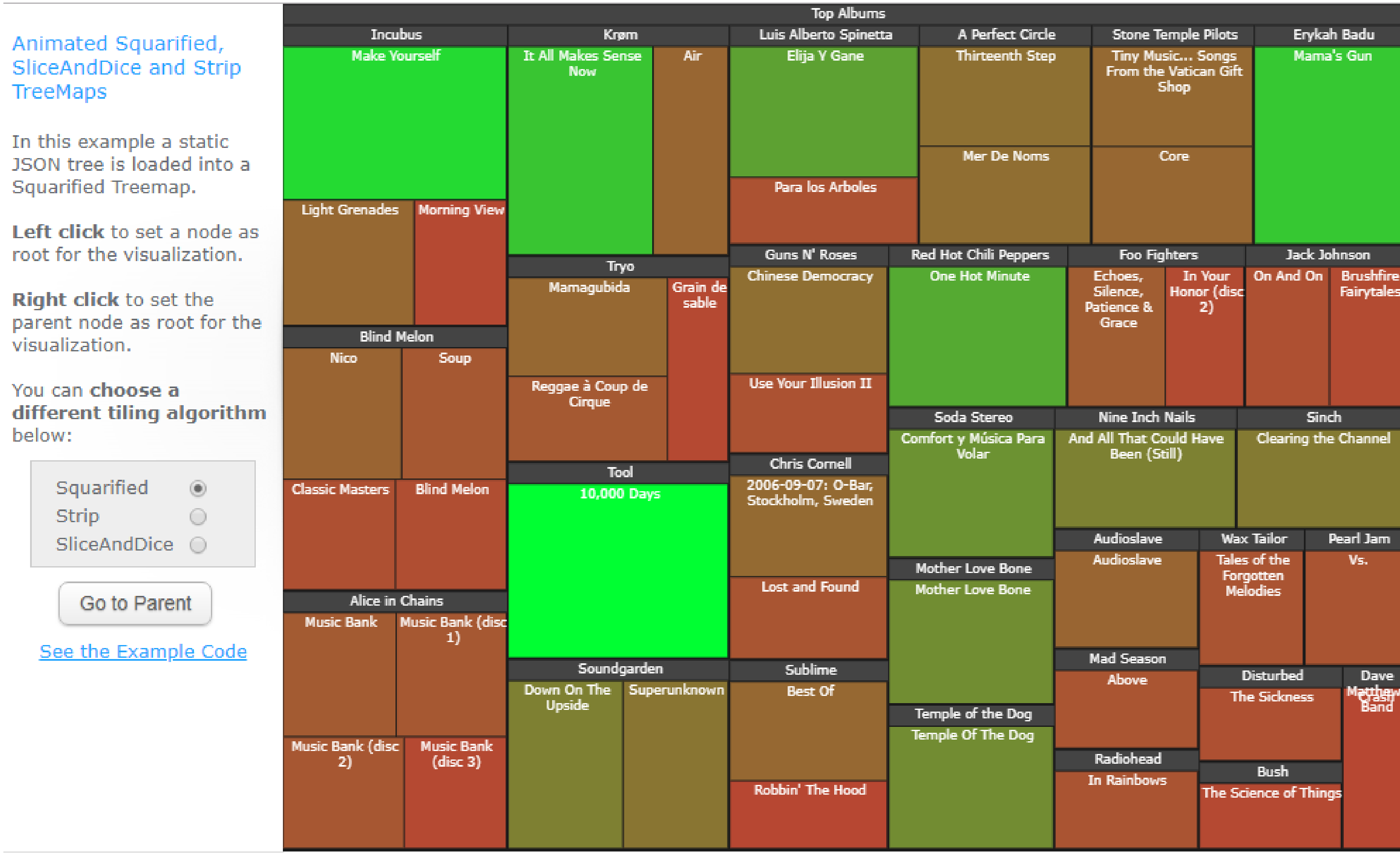




# Apparent motion in treemaps

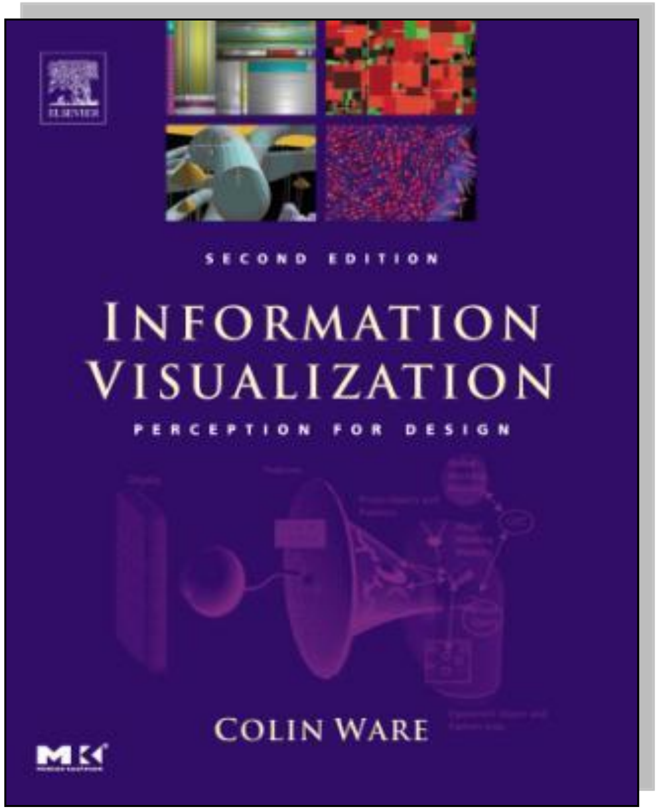


# Overcoming apparent motion in treemaps




https://philogb.github.io/jit/static/v20/Jit/Examples/Treemap/example1.html

# Book Recommendation




- *Information Visualization - Perception for Design*
  2nd edition
  Colin Ware
  Morgan Kaufmann