

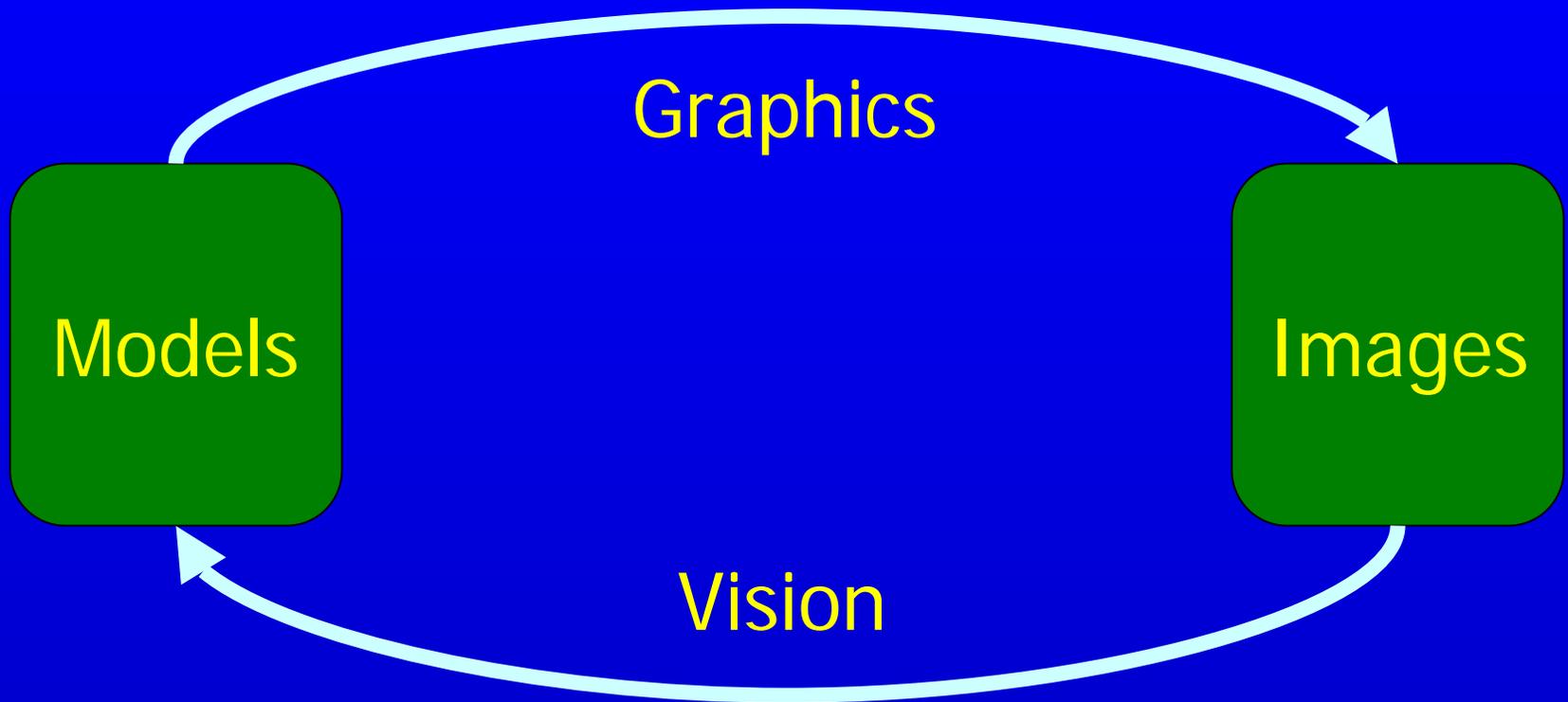
# Computer Graphics and the Visual System

Bobby Bodenheimer

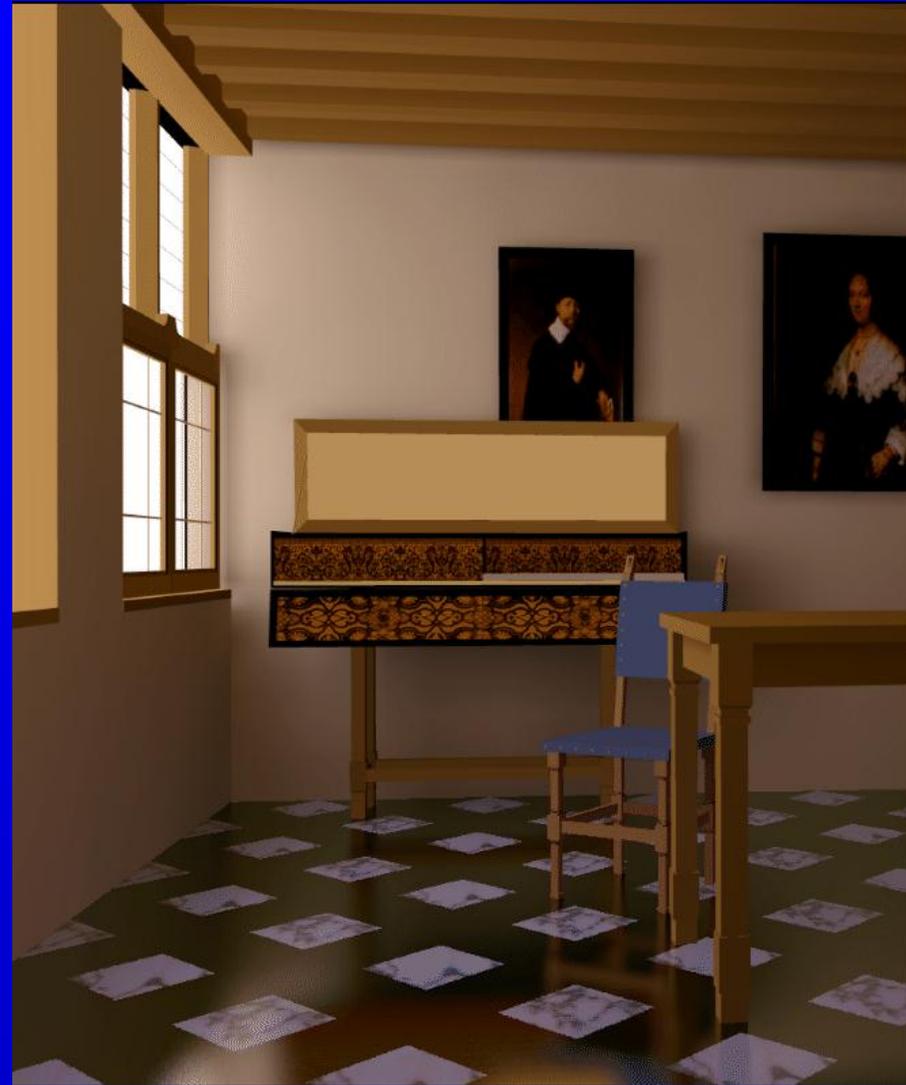
Electrical Engineering and Computer Science

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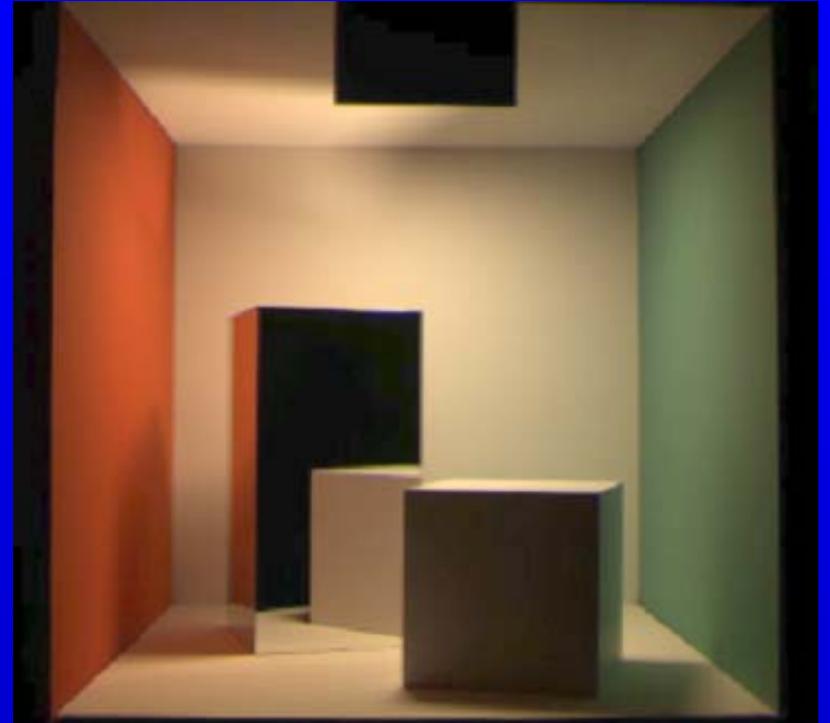
# What is Computer Graphics?



More formally, **Computer Graphics** is the study of the processes involved in converting a mathematical description of an object (model) into a visualization, a two-dimensional projection that simulates the appearance of the real object.



# Which is Real?



# The point being

that if you don't understand the human visual system, you won't understand how to make good images on a computer.



# Change Blindness Demonstration

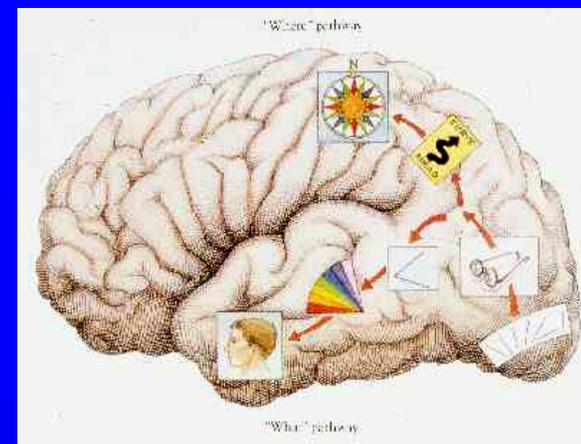
# Change Blindness Demonstration

- Based on the work of Ronald Rensink at University of British Columbia
- <http://www.usd.edu/psyc301/Rensink.htm>

# The Perceptual System

- Conflicting goals: high spatial resolution vs. wide aperture
- Organized in a “three-level hierarchy”
  - retina
  - fovea
  - receptors within fovea

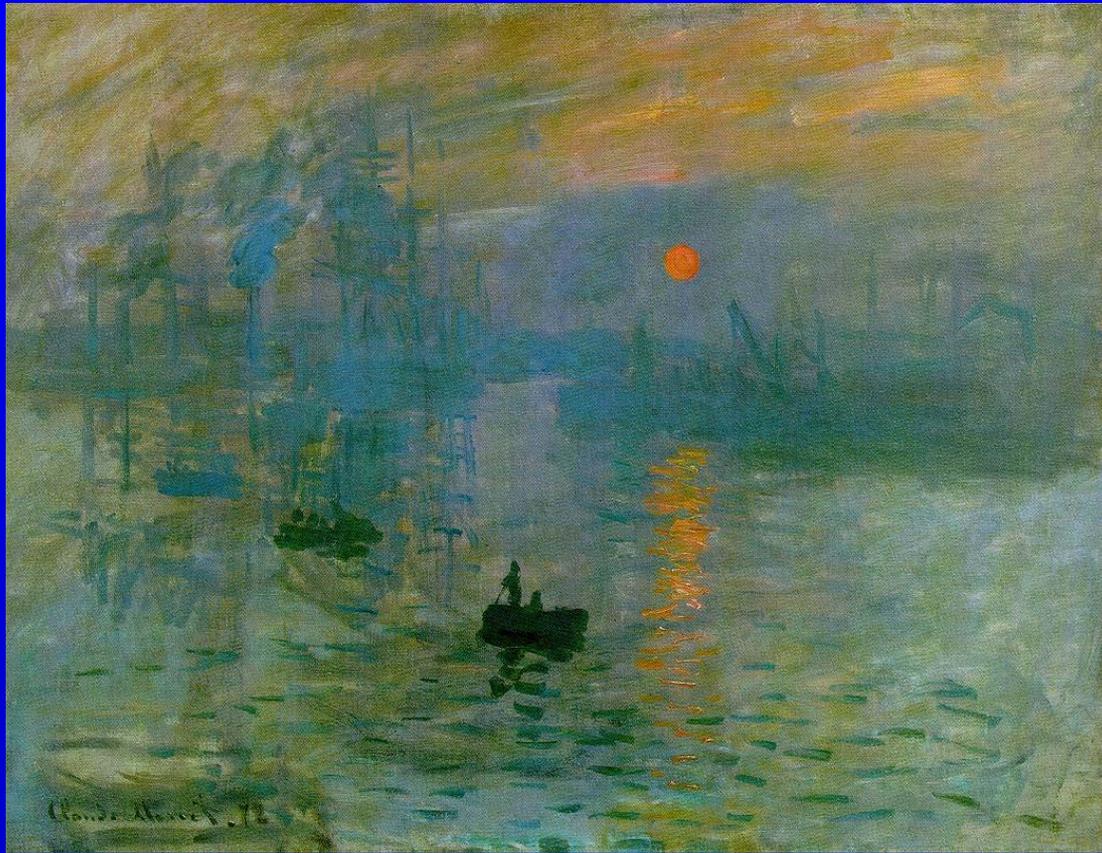
# What/Where Pathways



- What Pathway
  - Object Recognition
  - Face Recognition
  - Color Perception
- Features
  - Color Selective
  - Slow
  - Low Contrast Sensitivity

- Where Pathways
  - Motion Perception
  - Depth Perception
  - Spatial Organization
  - Figure/Background Separation
- Features
  - Color Blind
  - Fast
  - High Contrast Sensitivity

# Artists Exploit These Paths



Claude Monet

# Artists Exploit These Paths



Claude Monet

# Artists Exploit These Paths



Abraham Walkowitz



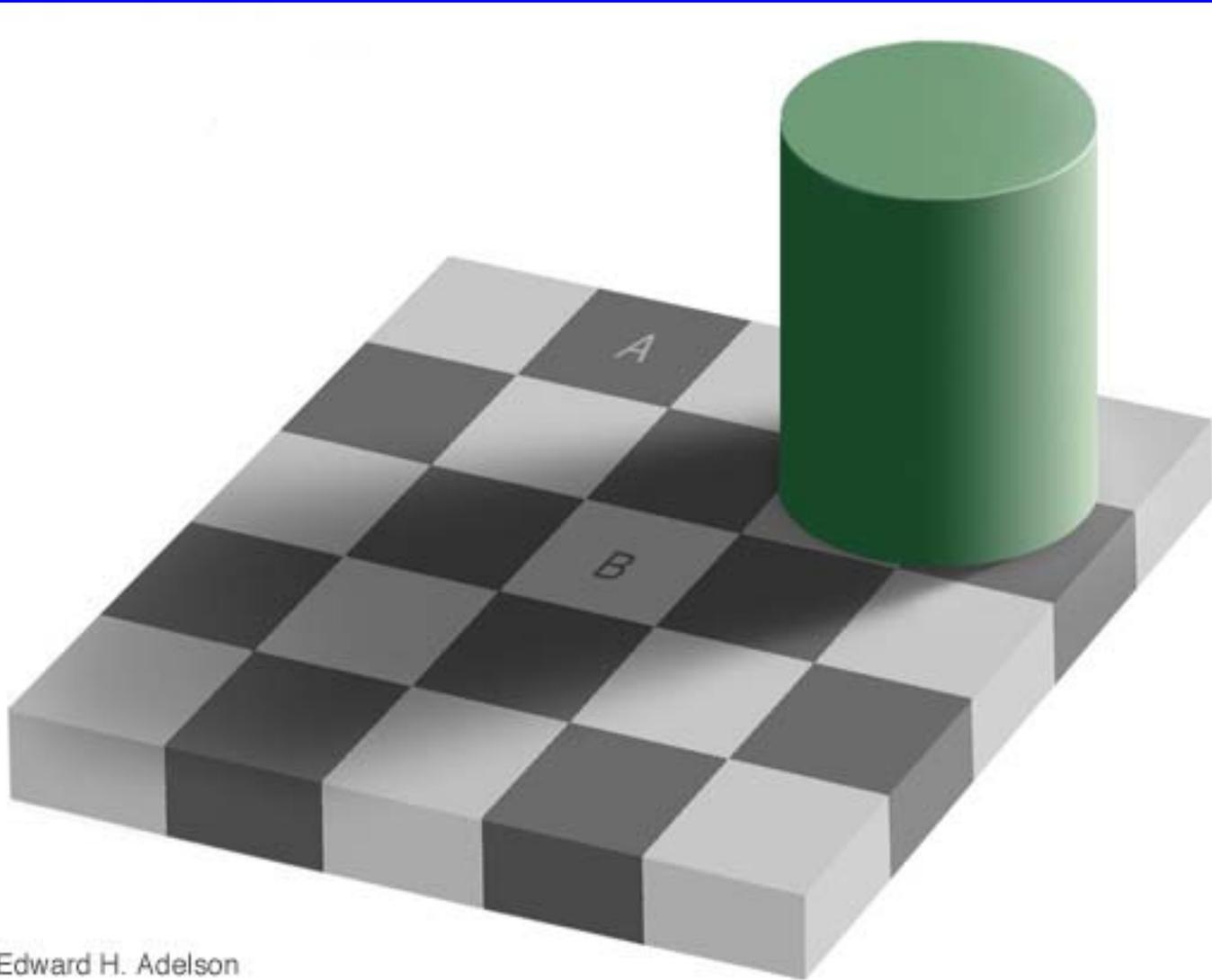
Raoul Drufy

# The visual system impacts visualization in two primary ways

- Color
  - Reproducing
  - Using
- Brightness
  - Simulating the levels of the real world

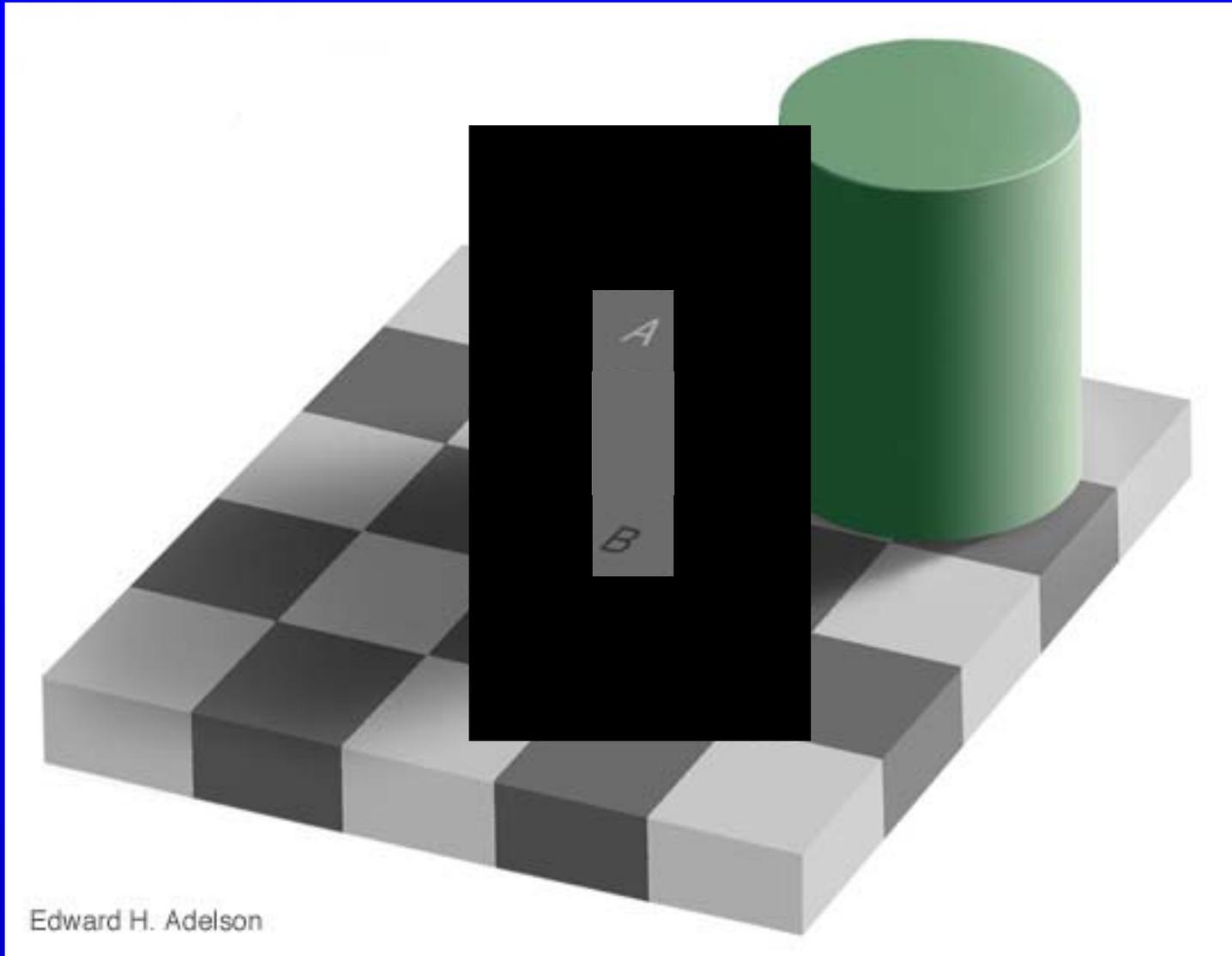


# What is Color?



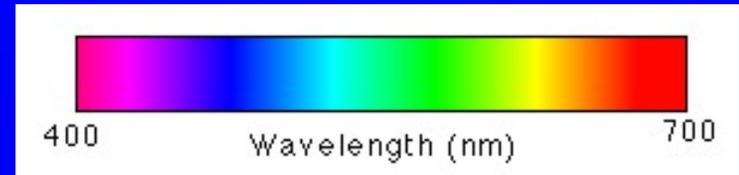
Edward H. Adelson

# What is Color?



Edward H. Adelson

# Color Terms



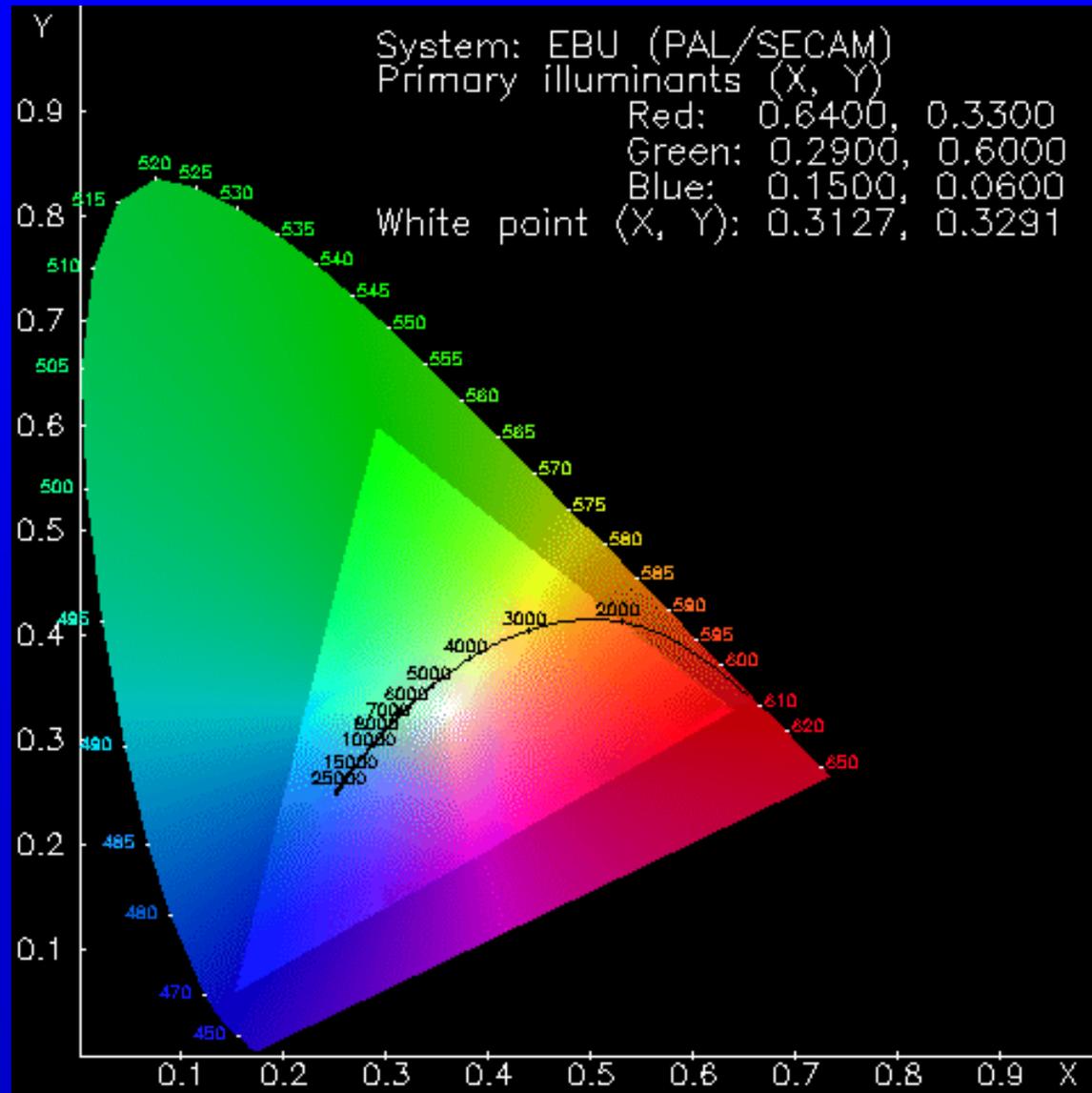
- **Hue** – dominant wavelength (red, blue, ...).
- **Saturation** – Purity (red = fully saturated; pink = not full (add white light)).
- **Luminance** – intensity of light (brightness, but brightness is subjective).

Artists start with a "pure color or hue", then add black pigment to produce different *shades*. The more black pigment the darker the *shade*. They add white pigment and get different *tints*. Adding both black and white pigments gives different *tones*.

# How many colors can we see?

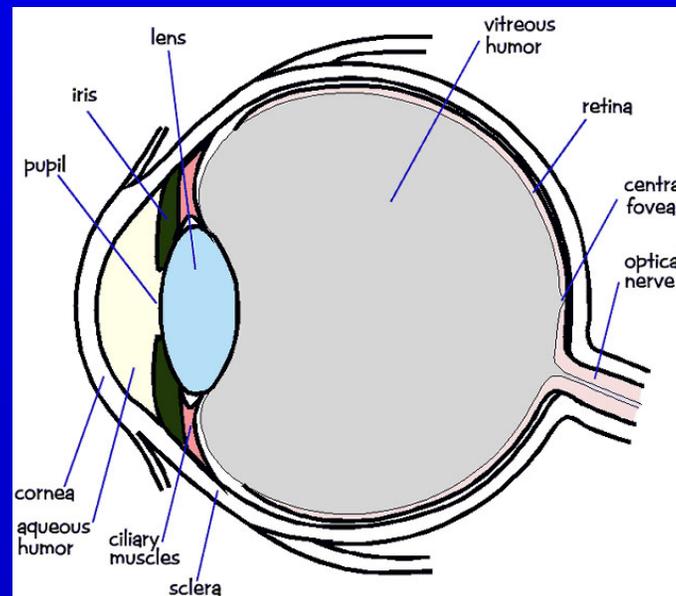
The human eye can distinguish about 128 different hues, 130 different tints (saturation levels), and from 16 (blue part of spectrum) to 23 (yellow part of spectrum) different shades. So we can distinguish about  $128 \times 130 \times 23 = 380,000$  colors.

Computers can't do this well.



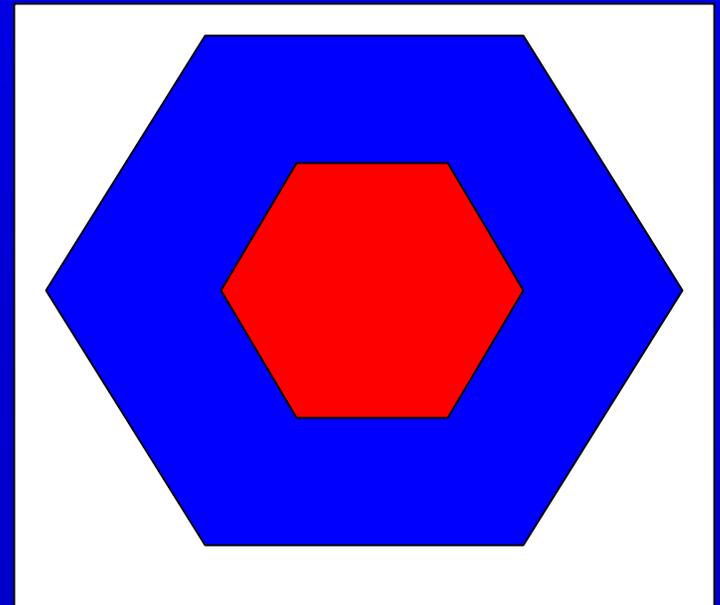
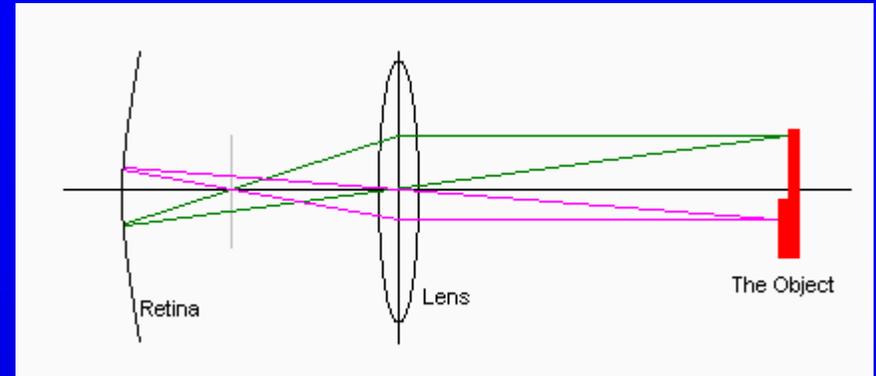
# Using Color

How does the physiology of the eye impact us if we're trying to create images or communicate information (visualization)?



# The Lens – combining colors

The function of the lens is to focus the incoming light on the retina, which contains the photo receptors. Different wavelengths of light have different focal lengths so, for pure hues, the lens must change its shape so that the light is focused correctly.



# Chromostereopsis

- A related effect in which pure colors at the same distance away from the eye appear to be at different distances, red appears closer, blue further.
- Pure blues sometimes focus in front of the retina and thus appear unfocused (at night, a blue sign may appear fuzzy).

# The effects of age

- Lens absorbs more (about twice) as much blue as red. As we age, the lens yellows, absorbing more shorter wavelengths.
- People are more sensitive to yellows and oranges, and this increases with age.
- The vitreous humor also absorbs light, and this increases as we age – apparent brightness and sensitivity to blue decreases.

# Monet's Cataracts



# Monet's Cataracts II

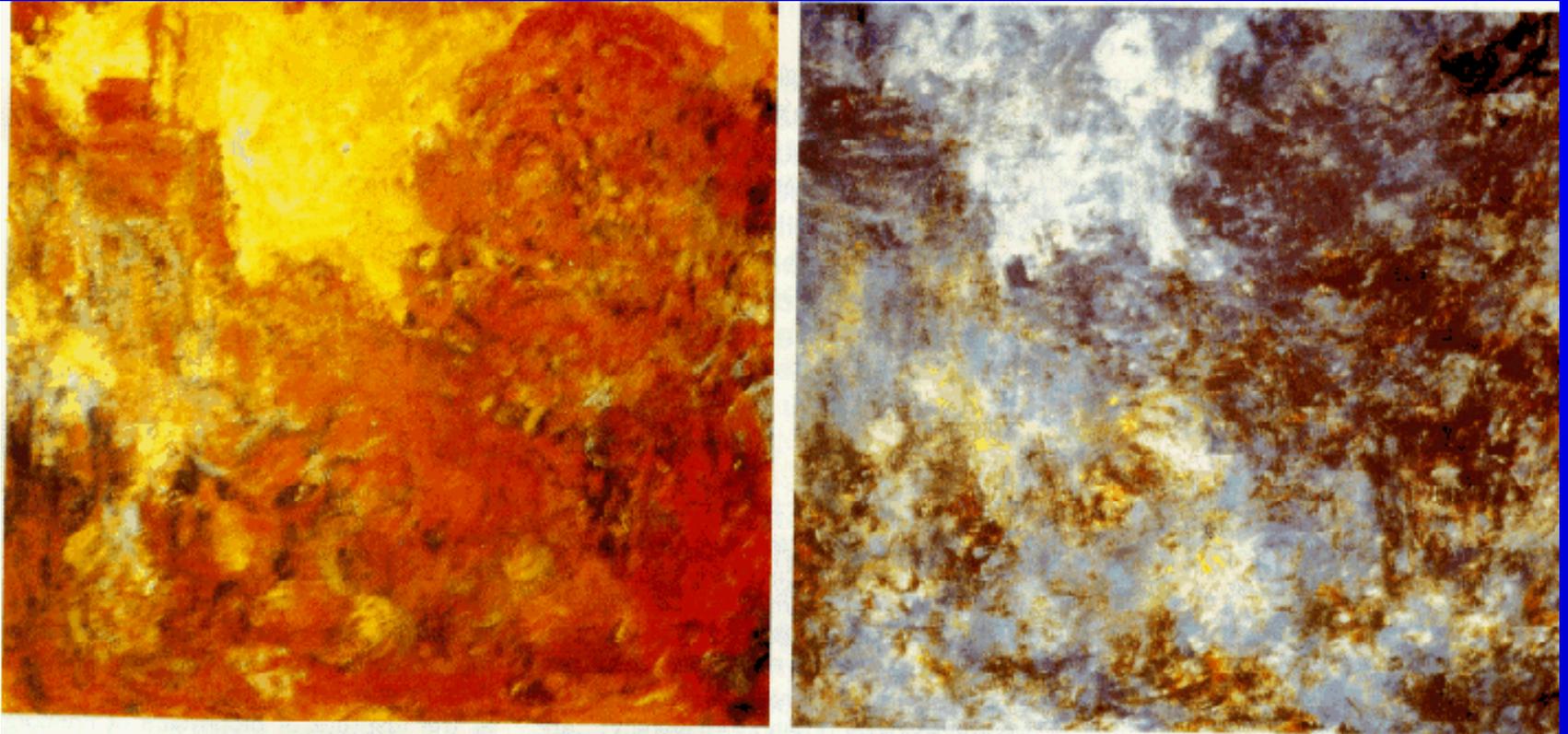
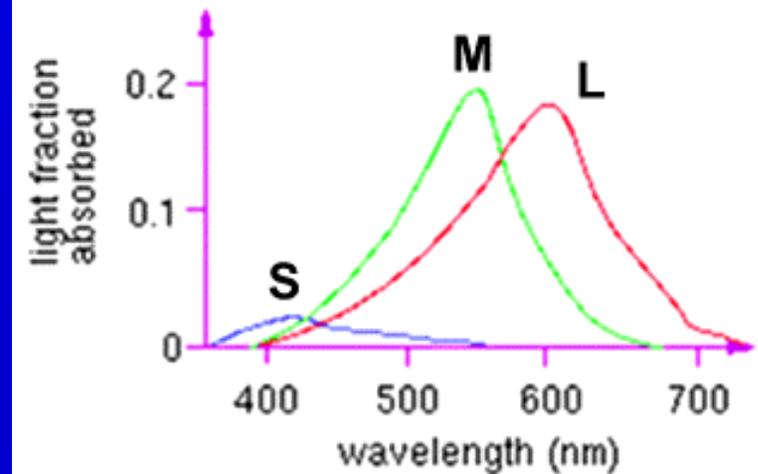
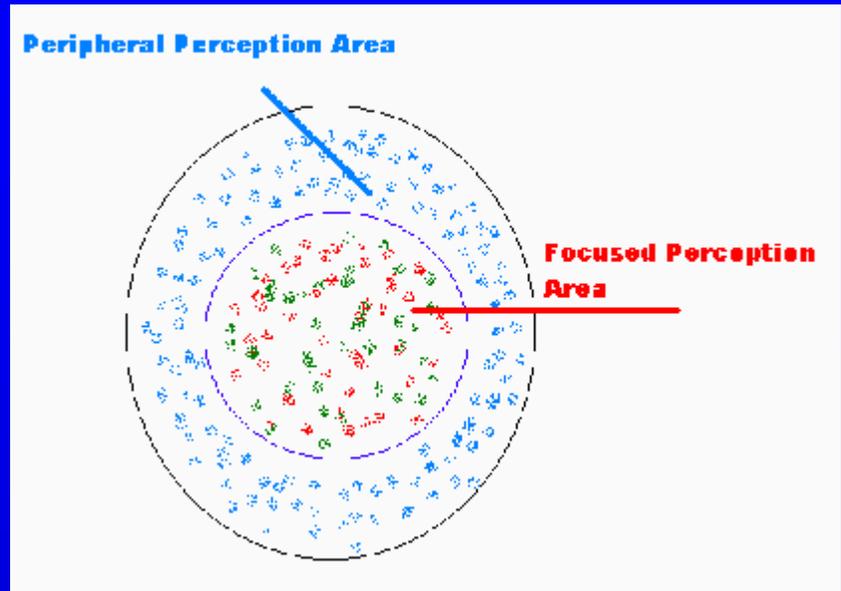


Figure 14. Left: Claude Monet (1925) *La maison vue du jardin aux roses*. [House seen from the Rose Garden]. Oil on canvas, 81 x 92 cm. Musée Marmottan, Paris. Right: Claude Monet (1925) *La maison vue du jardin aux roses*. Musée [House seen from the Rose Garden]. Oil on canvas, 89 x 100 cm. Musée Marmottan, Paris.

# The Retina

- Cone distribution not symmetrical:
  - blue (4%)
  - green (32%)
  - red (64%)
- The fovea is primarily green cones with very few blue.



# Consequences

- Edges seen by different color or brightness.
- Different colors alone produce fuzzy, unfocussed edges.
- Photoreceptors have a minimum intensity to respond
  - blues and reds need higher intensities than greens and yellows to be perceived.

# The Brain

Cells process color to

$$A = M + L$$

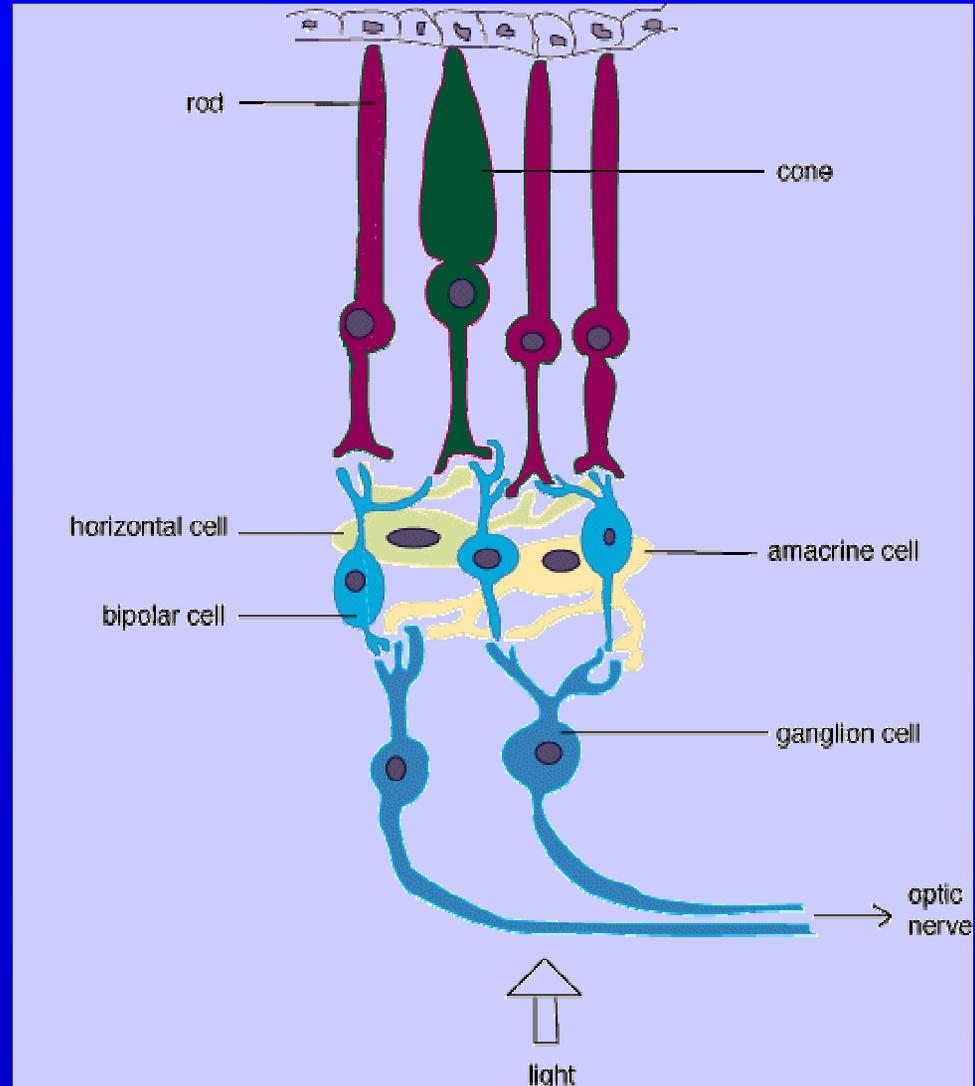
$$R/G = M - L$$

$$B/Y = S - A$$

So, transmitted in 3 axes:  
achromatic, red/green,  
blue/yellow.

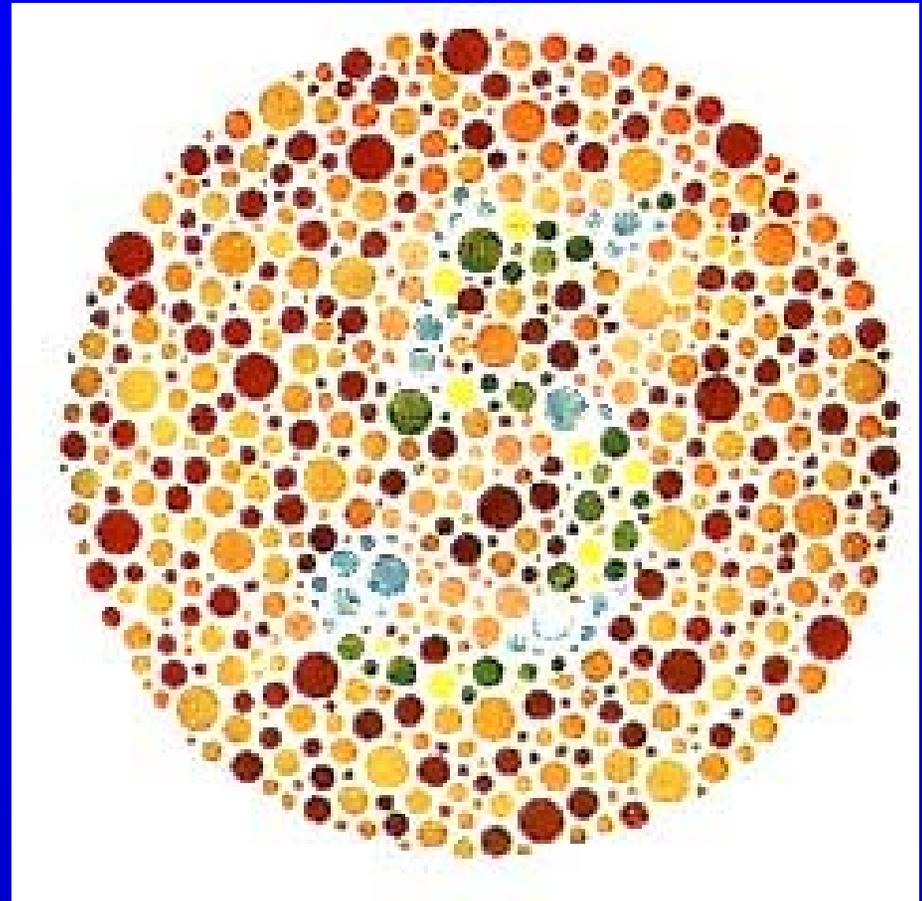
Can't have blueish yellow or  
reddish green.

Blue plays no part in brightness  
– things differing only in  
amount of blue produce fuzzy  
edges.



# Color Blindness

- 8% of the male population, 0.6% of the female population has a color deficiency
- Genetic
- Dichromats have one type of cone missing
- Anomalous trichromats
  - shifted sensitivity



# Color Blind Impressions

Original



Missing S cones



Missing L cones

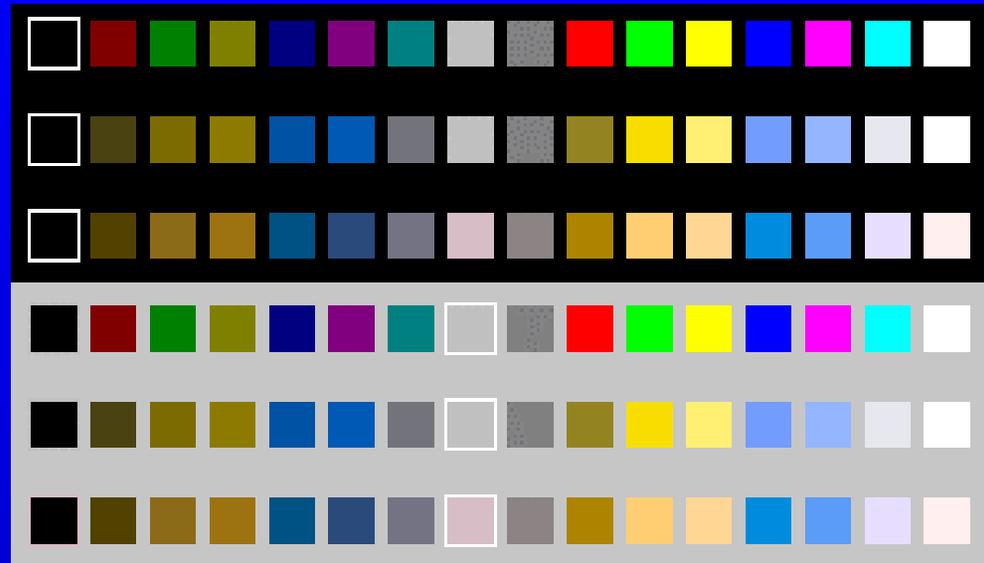


Missing M cones



# Web-Safe Palette

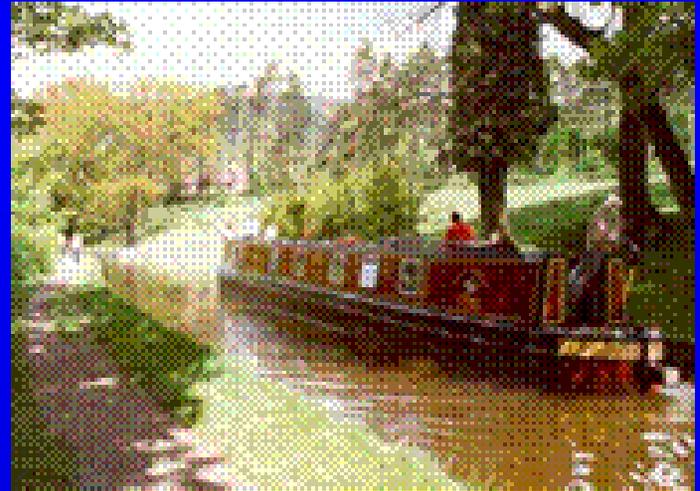
- Can change colors slightly, so that the effect is almost imperceptible, but produces gradations in shading for color-deficient vision



# Safe Web Colors



Original Color



Web-safe Color



As it appears to protanope



As it appears to deuteranope

# Guidelines

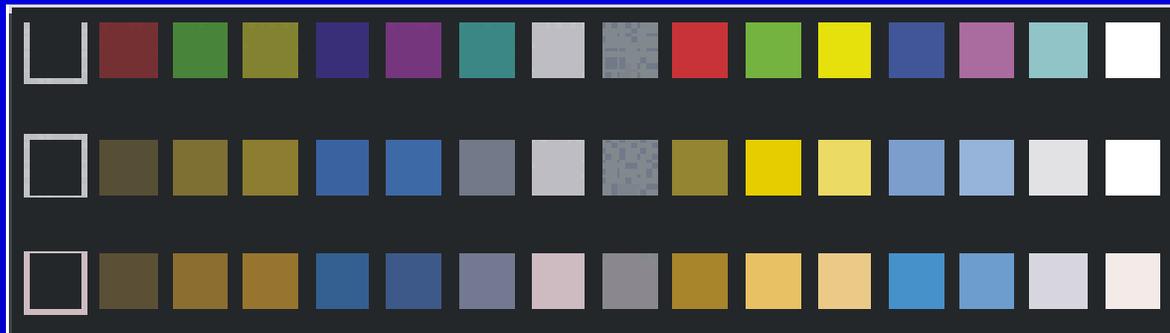
- Avoid simultaneous display of highly saturated, spectrally extreme colors: desaturate the colors or use colors close together in the spectrum.
- Avoid pure blue for text, thin lines, and small shapes. Blue makes an excellent background color (for computer displays it tends to blur the raster lines).

# Guidelines

- Avoid adjacent colors differing only in the amount of blue (fuzzy edges).
- Older viewers need higher brightness levels to distinguish colors.
- The magnitude of detectable change in color varies across the spectrum.
- It's difficult to focus upon edges created by color alone.

# Guidelines

- Opponent colors go well together.
- For color-deficient observers, avoid single color distinctions.
  - for web pages, use “web-safe” palettes



# A Little Color can be Better than a Lot



# Resolution

- The human eye can resolve small details (under 1' arc – 1/60<sup>th</sup> of a degree). This is our *visual acuity*
- Our eyes integrate detail that we cannot see, so we see an average intensity coming from small regions. This property is called *spatial integration*.

# Halftoning

- On devices with limited resolution of brightness, we can exploit this property of spatial integration
- Newspapers do this, and its name comes from there: *halftoning*



What if we only have 2 intensity levels (white and black)?



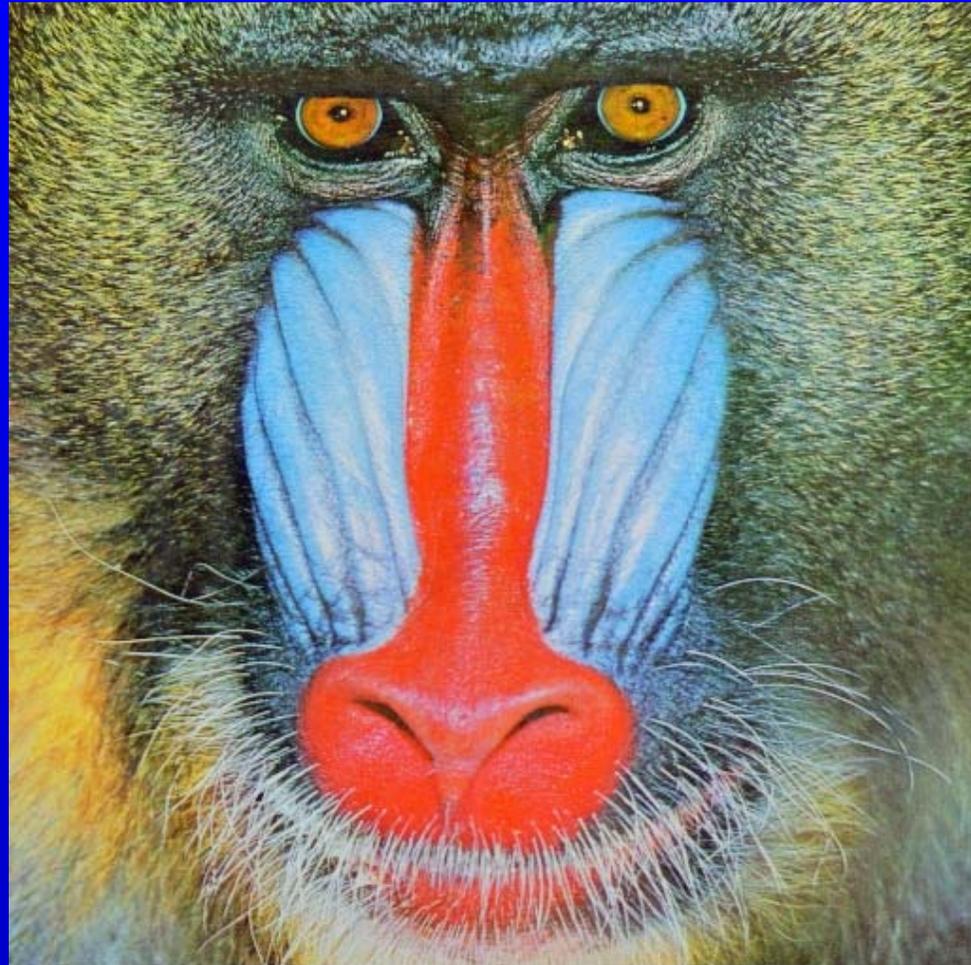
Traditional



Full dithered

# What is Dithering?

- To *dither* is to add noise to a signal
- Noise is added as a trade-off between a low-level “snow” and distortion (structured artifacts)
- Visual System is tolerant of unstructured noise; sensitive to structured noise



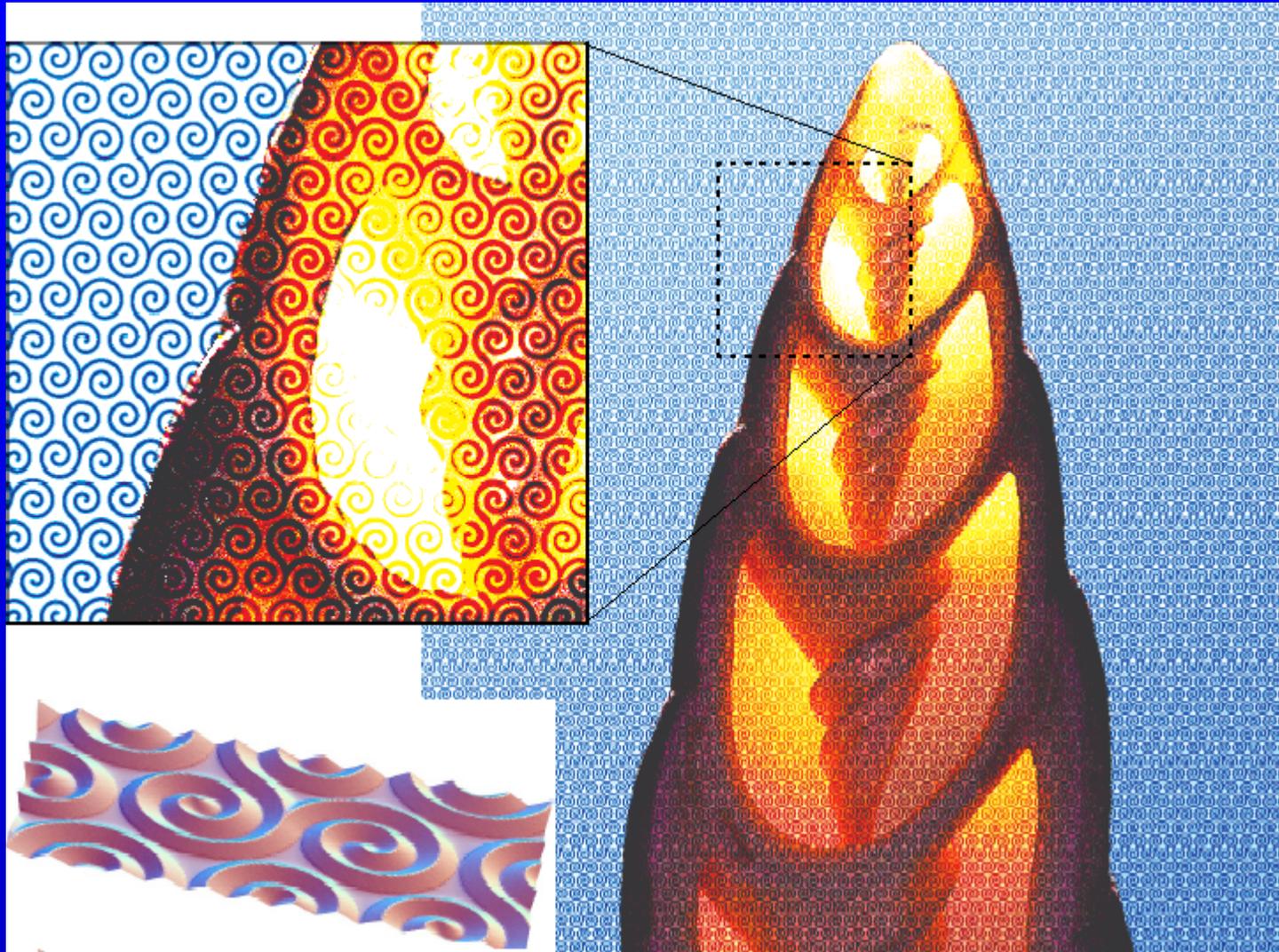
# What do Artists Do?

- Pointillism
- Reduced Color Palette



Georges Suerat

# Artistic Half-Toning



# Photomosaics



# Brightness (or Contrast)

- Computers have a fixed, linear range of brightness they can display, approximately 100 levels of contrast.
- The real world has contrast ranges of 100,000 or more, and the eye is generally capable of distinguishing them.



# Example



# Contrast ranges of common media

- Newspaper photographs 30:1
- TV 60:1
- Computer displays 100:1
- Fine quality books 200:1
- Slides 1000:1
- Real World 100,000:1

# What kinds of scenes have high contrast?

- Scenes including visible light sources, deep shadows, and specular highlights.
- How do we produce meaningful images with the limitations of our media?

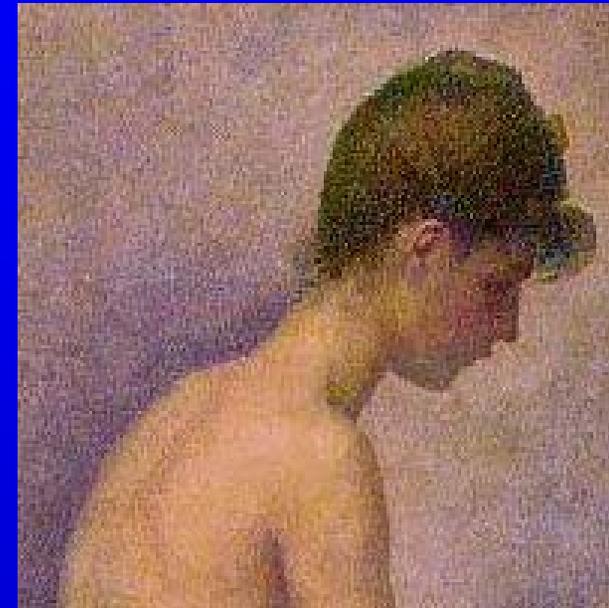
# We compress the light intensities

- Simple methods compress intensities and lose detail.
- More complicated methods can preserve detail.
  - selective compression that preserves edge and texture information.

# Example



# What do Artists Do?



Georges Seurat

# Example



# The End

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