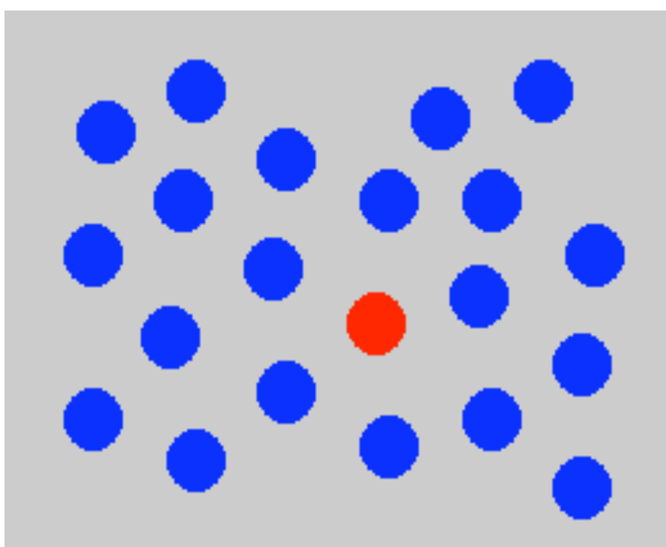
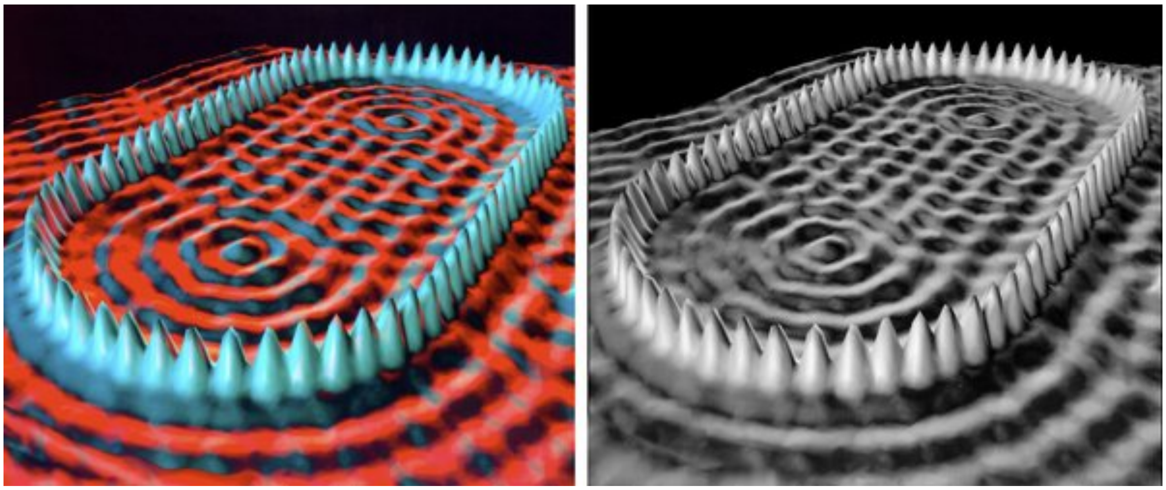
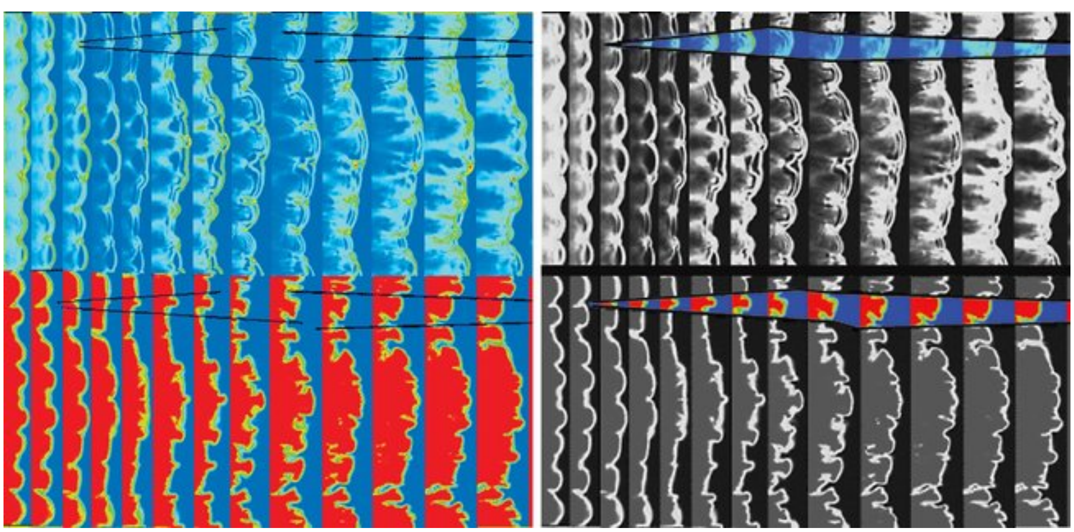
Color



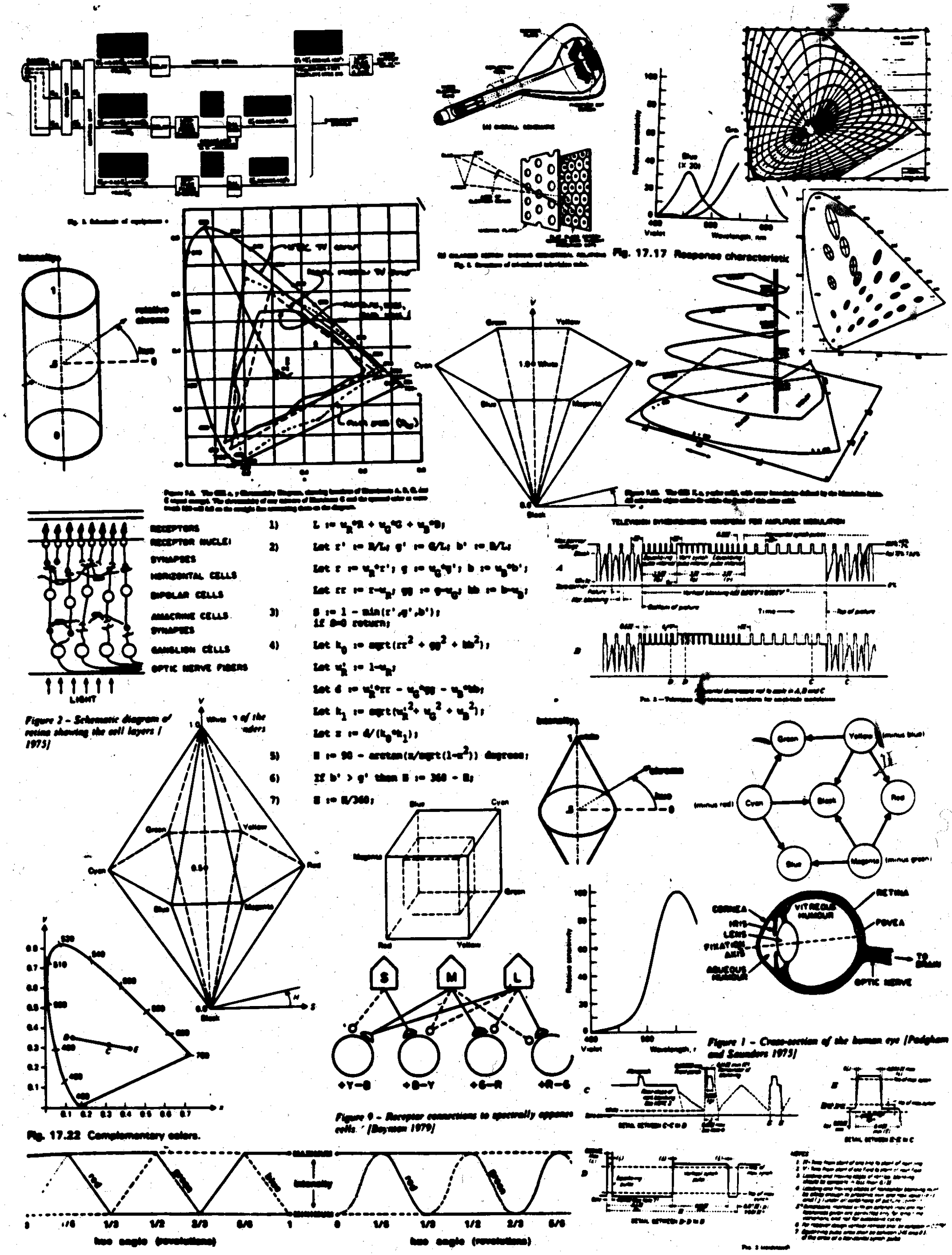
Make Me Look, But Be Responsible



NY Times, Sept. 4th 2012, Images by Felice Frankel, MIT: Top: A "corral" of carefully placed atoms on a surface, left, was visualized by researchers using false colors. Felice C. Frankel and Angela H. DePace suggest that eliminating the colors gives equal visual weight to important features within the corral. Bottom: Characteristics of explosions are visualized in sections for comparison. The authors say that would be easier if the irrelevant areas were gray.

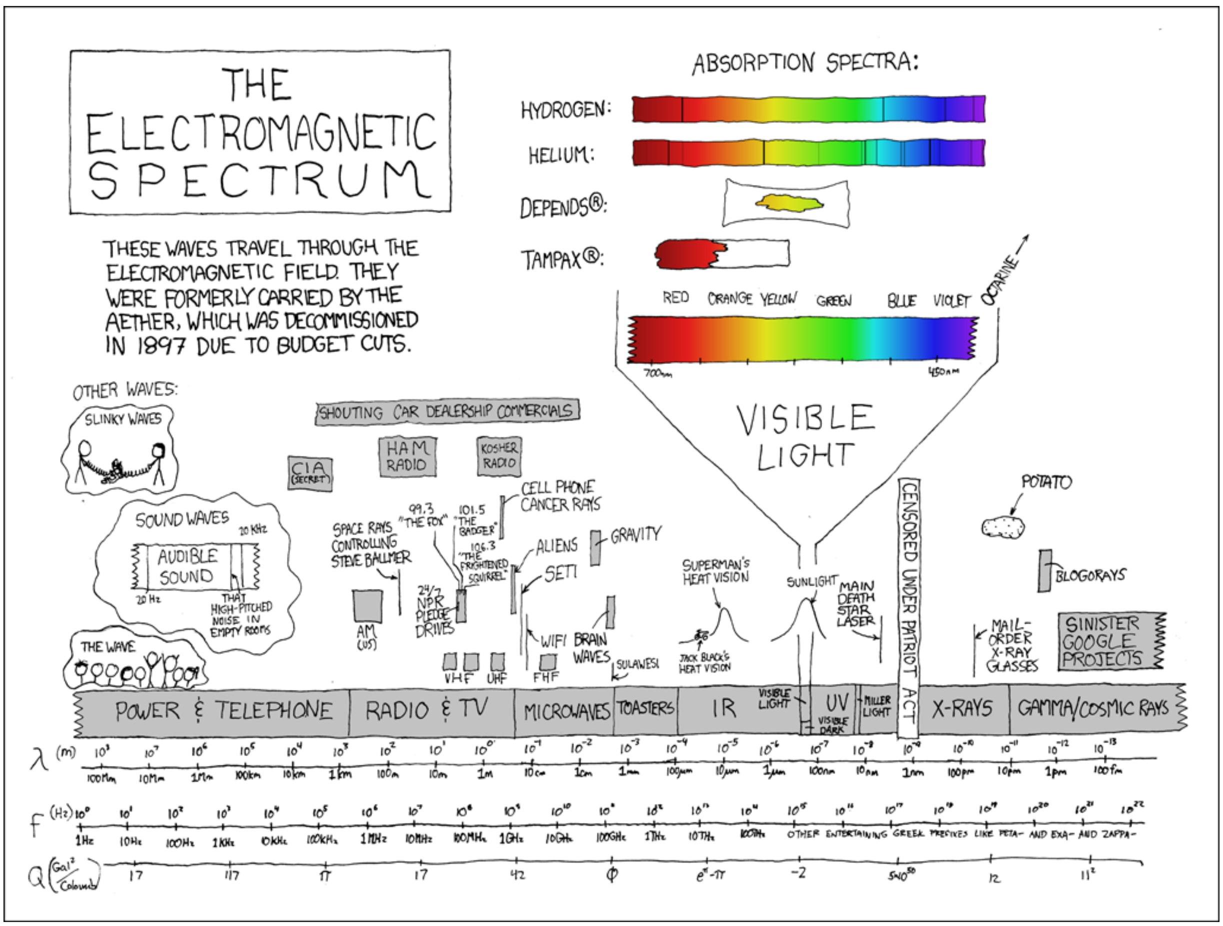


All You Need to Know About Color ☺



Color Is a Perception

- Color is a perception and *not* visible EM radiation (light waves are not colored)
- Wavelengths don’t look the same to everyone
  - *most* people experience the sensation “blue” with wavelengths near 400nm

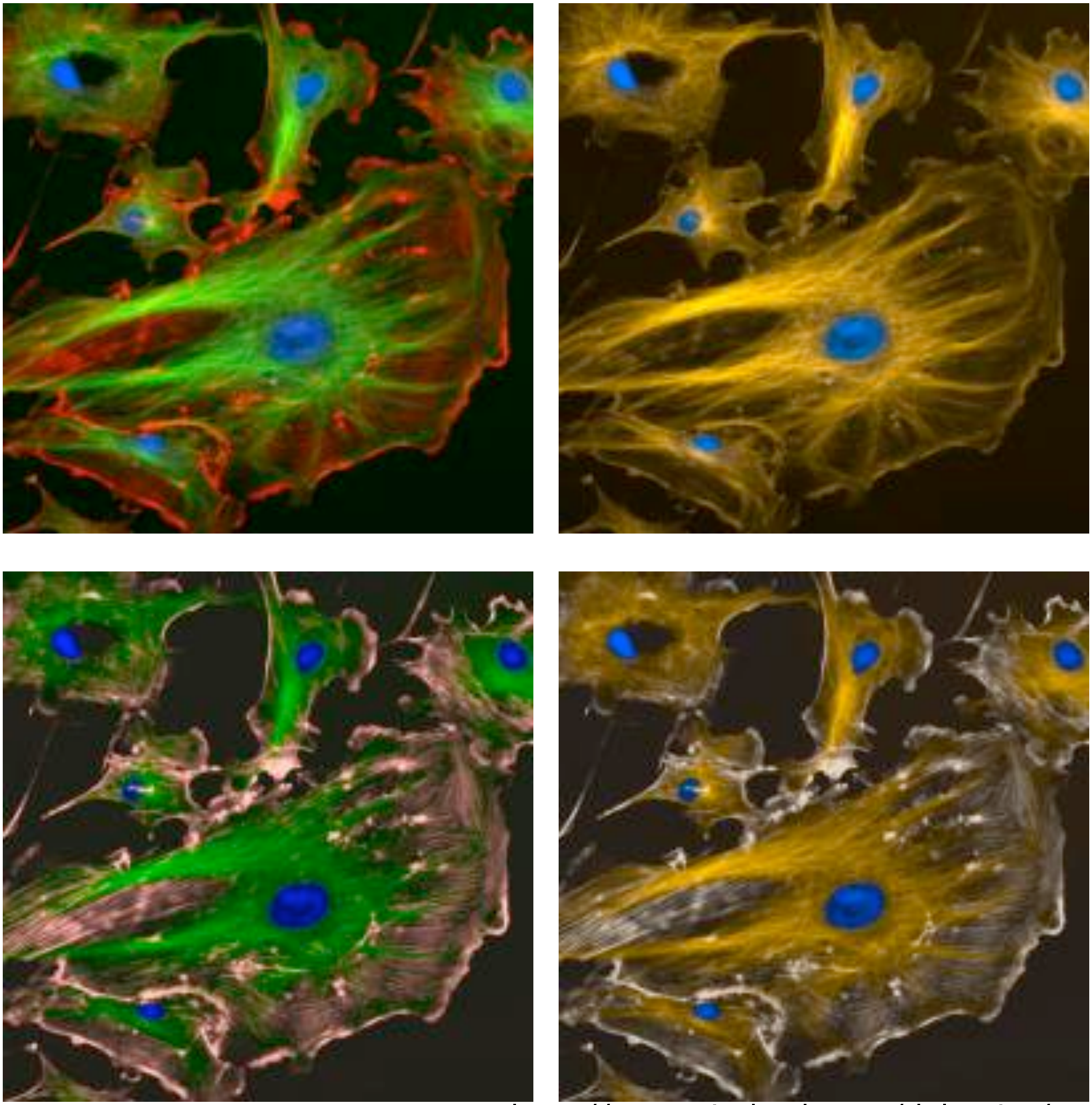


Color Is Difficult

- Perceived color of object depends not only on object material but also on light source, color of surrounding area, and human visual system (the eye/brain mechanism)
  - color perception strongly influenced by context, training, etc., abnormalities such as color blindness (affects about 8% of males, 0.4% of females)

http://www.vischeck.com/daltonize/

Color Blindness: SciVis



http://www.vischeck.com/daltonize/

Images

For our purposes, an image is:

- A 2D domain
- With samples at regular points (almost always a rectilinear grid)
- Whose values represent gray levels, colors, or opacities (or tissue density in an MRI scan)

Common image types include:

- 1 sample per point (B&W or Grayscale)
- 3 samples per point (Red, Green, Blue)
- 4 samples per point (Red, Green, Blue, and “Alpha”, a.k.a. Opacity)
- 5 samples per point (add “Depth”)

Grayscale Images

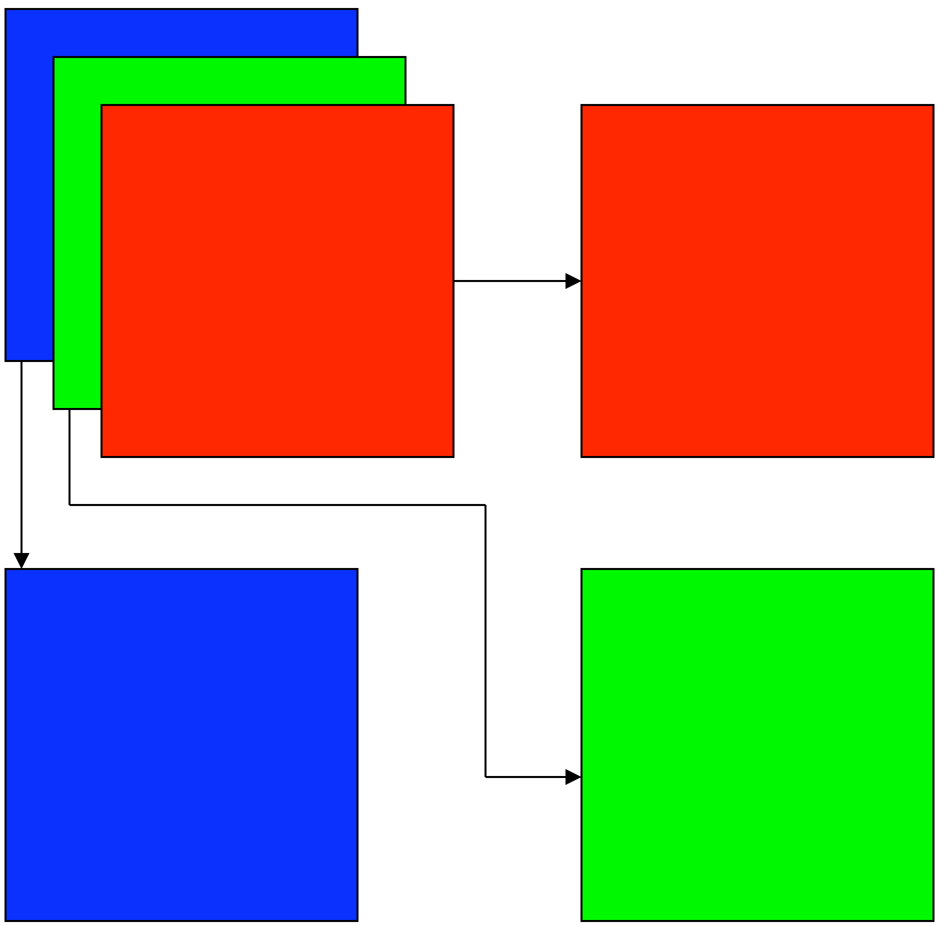
- What is a grayscale image?
  - a 2D domain
  - with samples at regular points
  - whose values represent gray levels
  - one sample (gray-level) per pixel

				49	151	176	182	179
				45	148	175	183	181
				42	146	176	185	184
				35	140	172	184	184
66	64	64	84	129	134	168	181	182
59	63	62	88	130	128	166	185	180
60	62	60	85	127	125	163	183	178
62	62	58	81	122	120	160	181	176
63	64	58	78	118	117	159	180	176

Irani and Basri

RGB Color Images

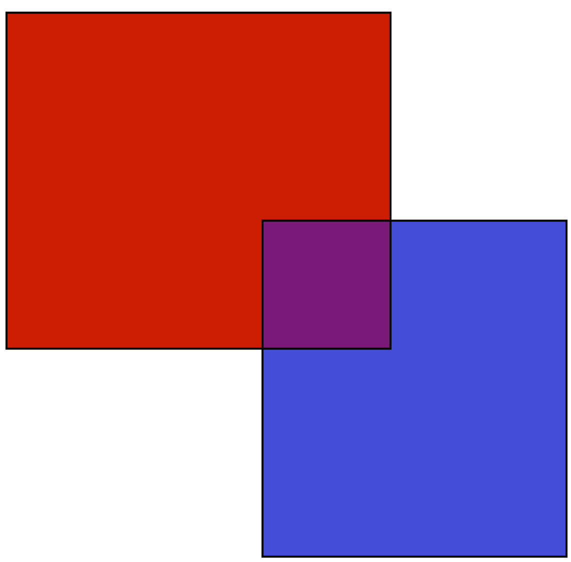
- What is an RGB color image?
  - a 2D domain
  - with samples at regular points
  - three samples per pixel



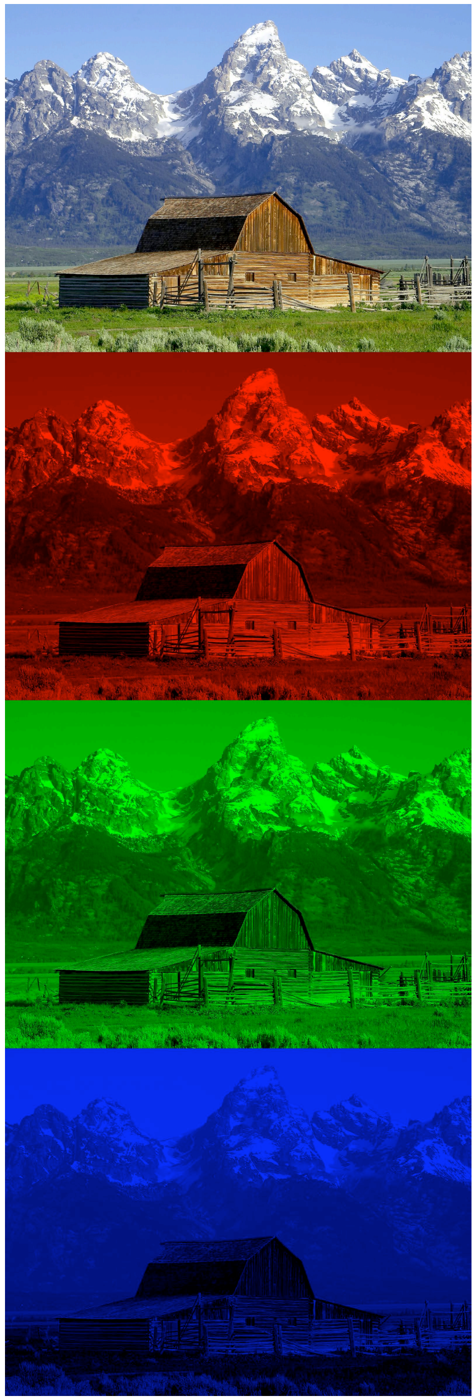
The Alpha Channel

Adding "coverage" information to pixels

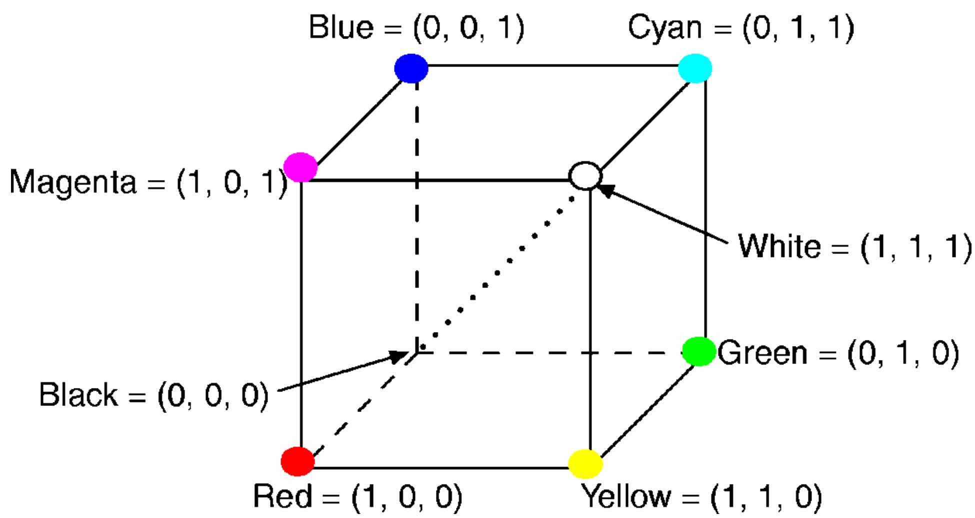
- In addition to R, G, B channels of an image, add a fourth channel, called α
- Alpha varies between 0 and 1
  - Value of 1 represents a "fully covered" pixel, one you cannot see through
  - Value of 0 is a completely transparent pixel
- Useful for blending images
  - image with higher alpha value "shows through" more



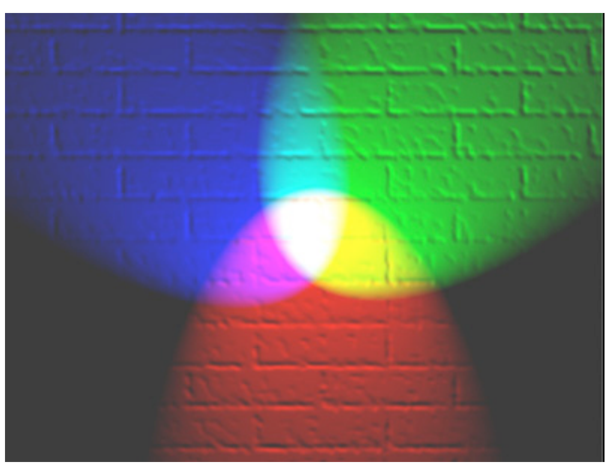
RGB Decomposition



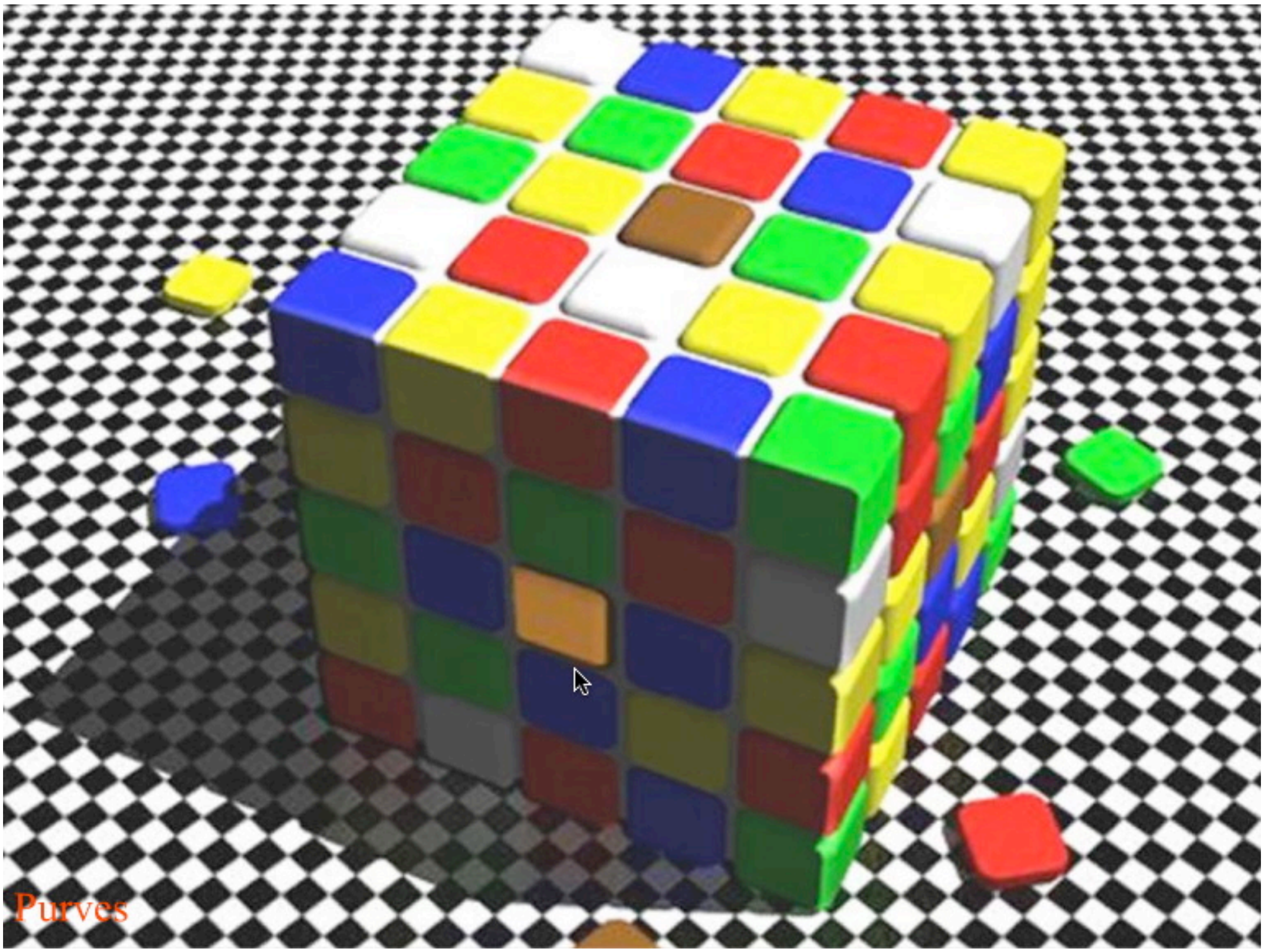
"Display" Color Terms



The RGB cube (grays are on the dotted main diagonal)



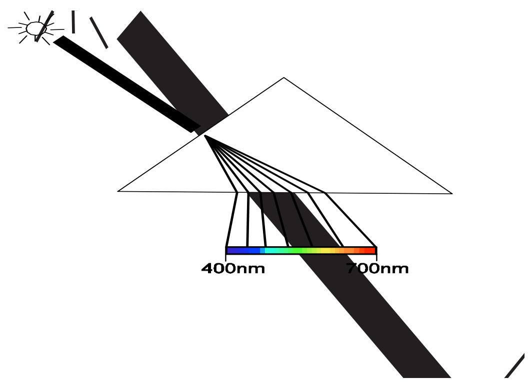
Color Perception: Example

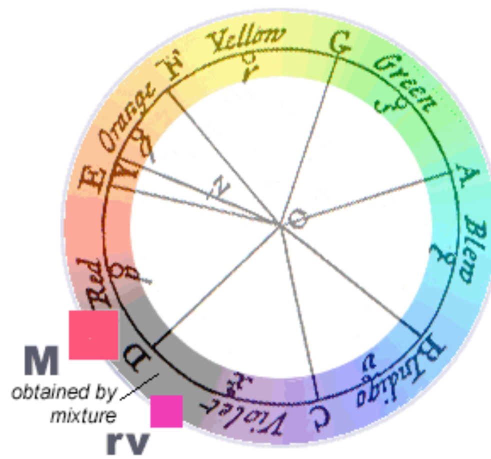


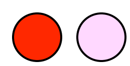
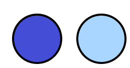
Same RGB values, different perception

"Perception" Color Terms

- *Hue* distinguishes among colors such as red, green, purple, and yellow (position in spectrum)





- *Saturation* describes how intense the color is
  - red saturated; pink unsaturated 
  - royal blue saturated; sky blue unsaturated 
  - pastels are less vivid, less intense
- *Luminance*

  Lightness: perceived brightness of reflecting object

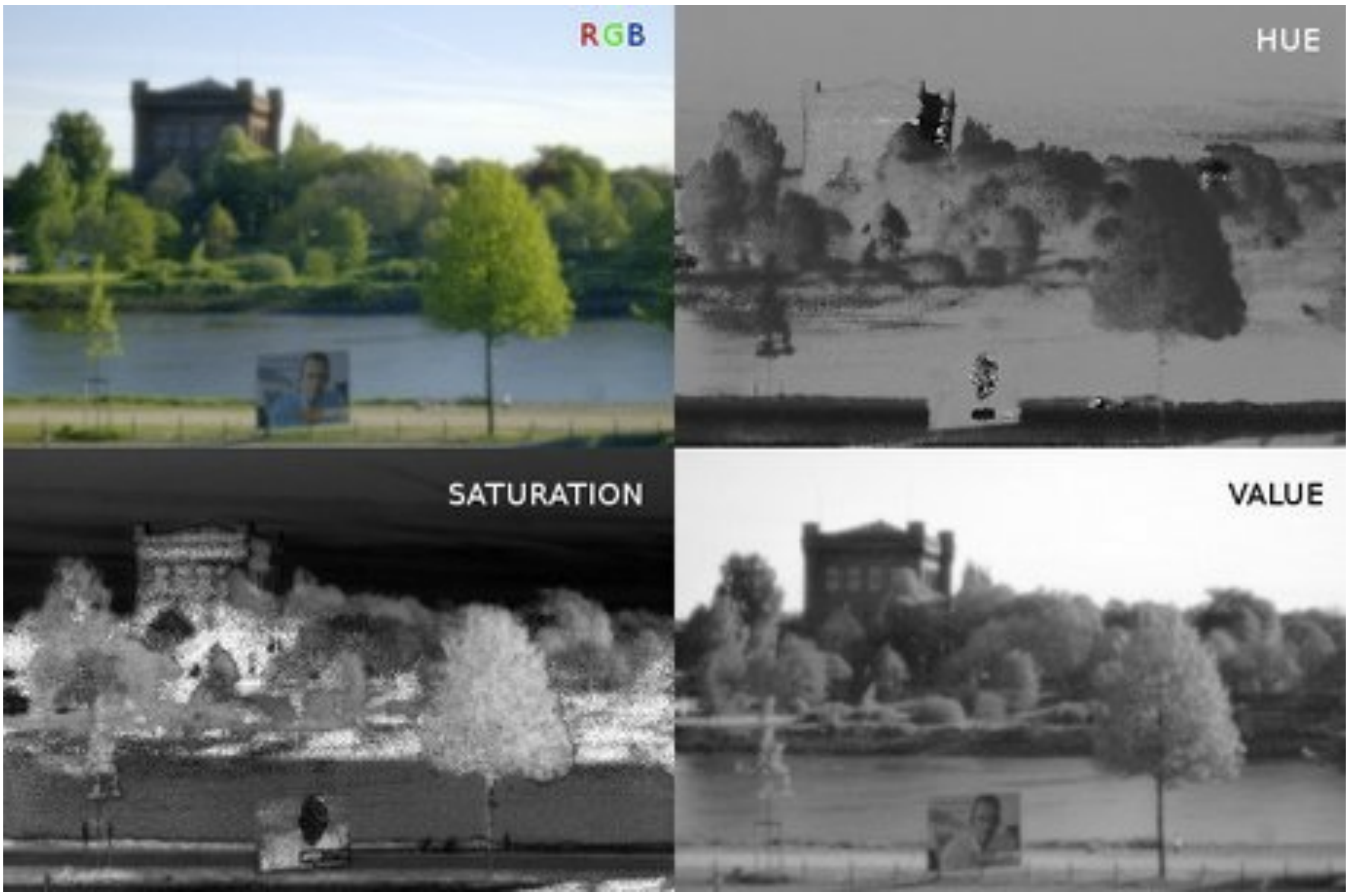
  Brightness: perceived brightness of a self-luminous object, such as a light bulb, the sun, or a CRT

Luminance vs. "Color"

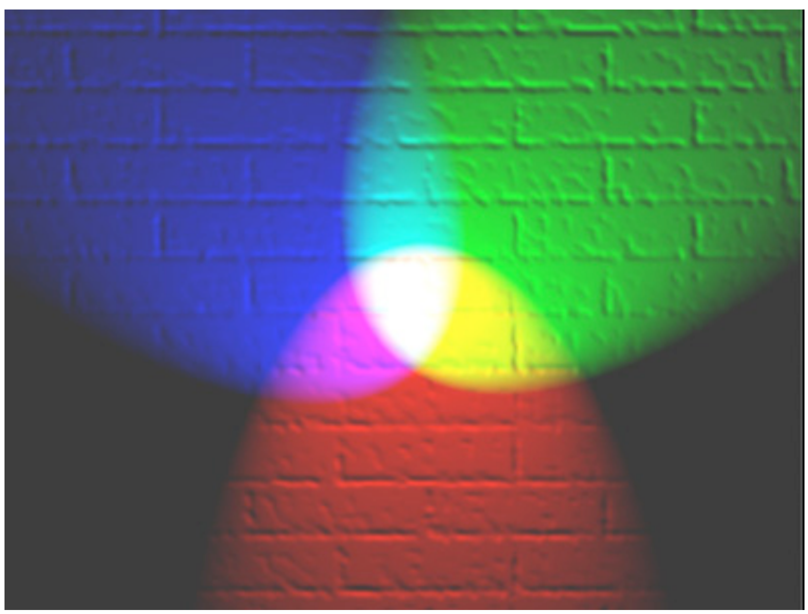
- Human vision much more sensitive to slight changes in luminance (intensity) of light than slight changes in color (hue)
  - "Colors are only symbols. Reality is to be found in luminance alone…" (Pablo Picasso)

  - Picasso's Poor People on the Seashore: the melancholy blue color serves an emotional role, but does not affect our recognition of the scene.
  - color and luminance: analyzed by two different subdivisions of the visual system. The parts of our brain that process information about color are located several inches away from the parts that analyze luminance -- as anatomically distinct as vision is from hearing.

Converting RGB to HSV

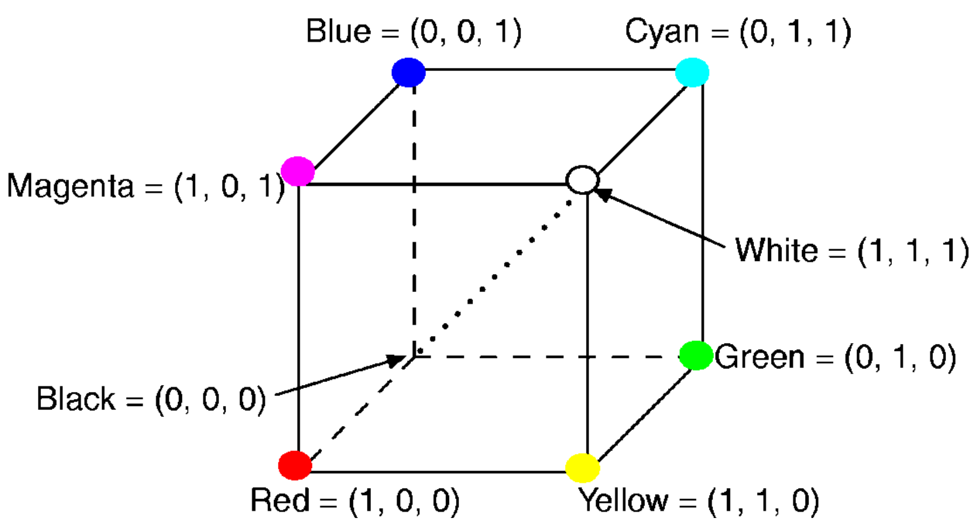


Describing Color for Graphic Displays: Color Spaces



The RGB Color Model

- used to mix additively R, G, B in displays
- R, G, B choice is related to the physiology of the human eye



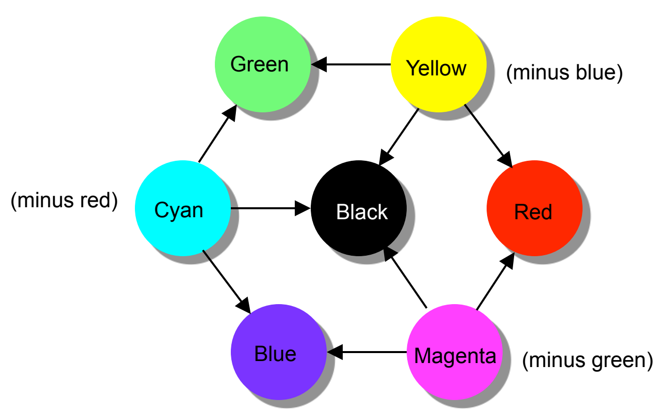
The RGB cube (grays are on the dotted main diagonal)

- Main diagonal => gray levels
  - black is (0, 0, 0)
  - white is (1, 1, 1)

The CMY(K) Color Model

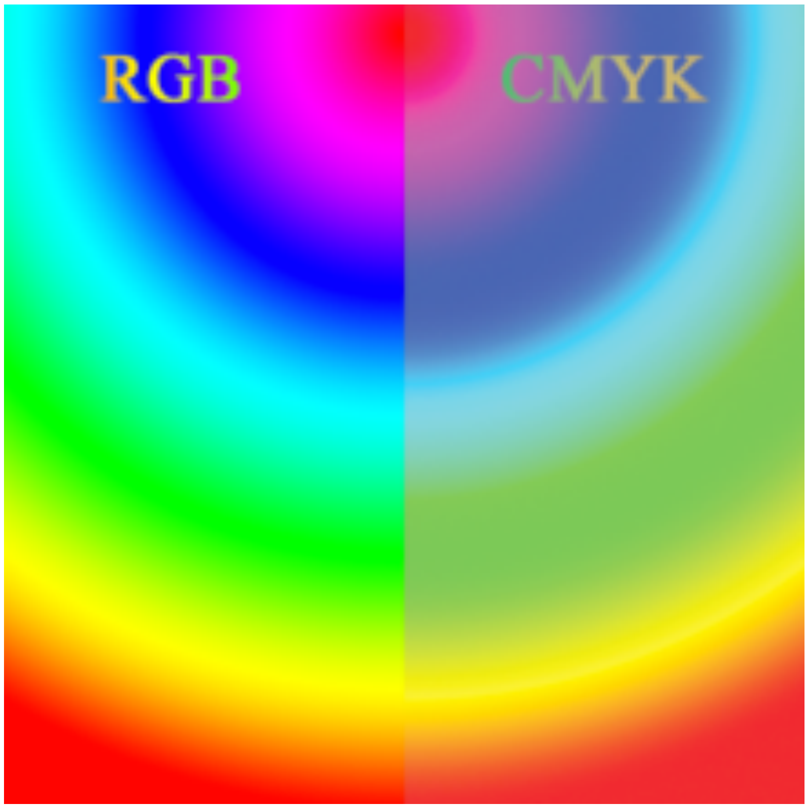
- Used in electrostatic and in ink-jet plotters that deposit pigment on paper
- Cyan, magenta, and yellow are complements of red, green , and blue
- *Subtractive primaries*: colors are specified by what is removed or subtracted from white light, rather than by what is added to blackness
- Cartesian coordinate system
- Subset is unit cube
  - white is at origin, black at (1, 1, 1):

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



subtractive primaries (cyan, magenta, yellow) and their mixtures

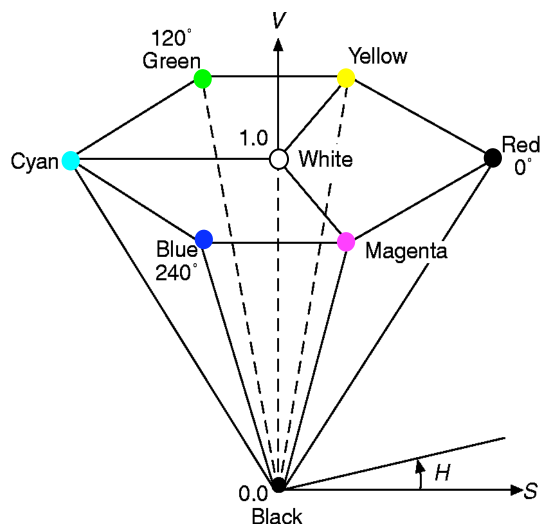
RGB and CMY(K)



This image demonstrates the difference between how colors will look on a computer monitor (RGB) compared to how they will reproduce in a CMYK print process. (wikipedia.org/wiki/Color_Spaces)

The HSV Color Model (1/2)

- Hue, saturation, value (luminance)

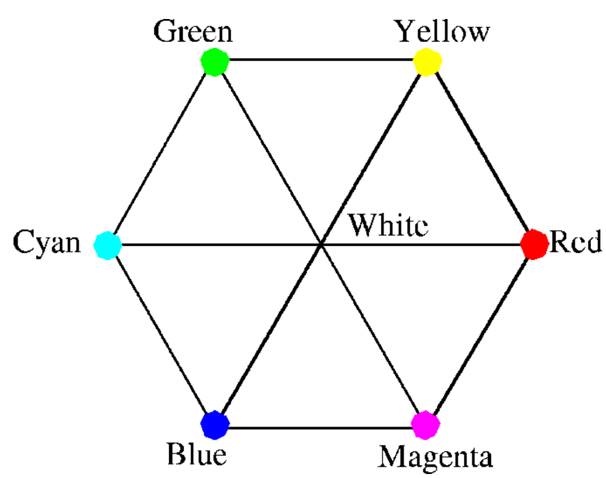


Single hexcone HSV color model.
(The V = 1 plane contains the RGB model's R = 1, G = 1, B = 1, in the regions shown)

- based on perceptual variables vs. monitor phosphor colors
  - pure red = **H** = 0, **S** = 1, **V** = 1; pure pigments are (I, 1, 1)
  - HSV <-> RGB

The HSV Color Model (2/2)

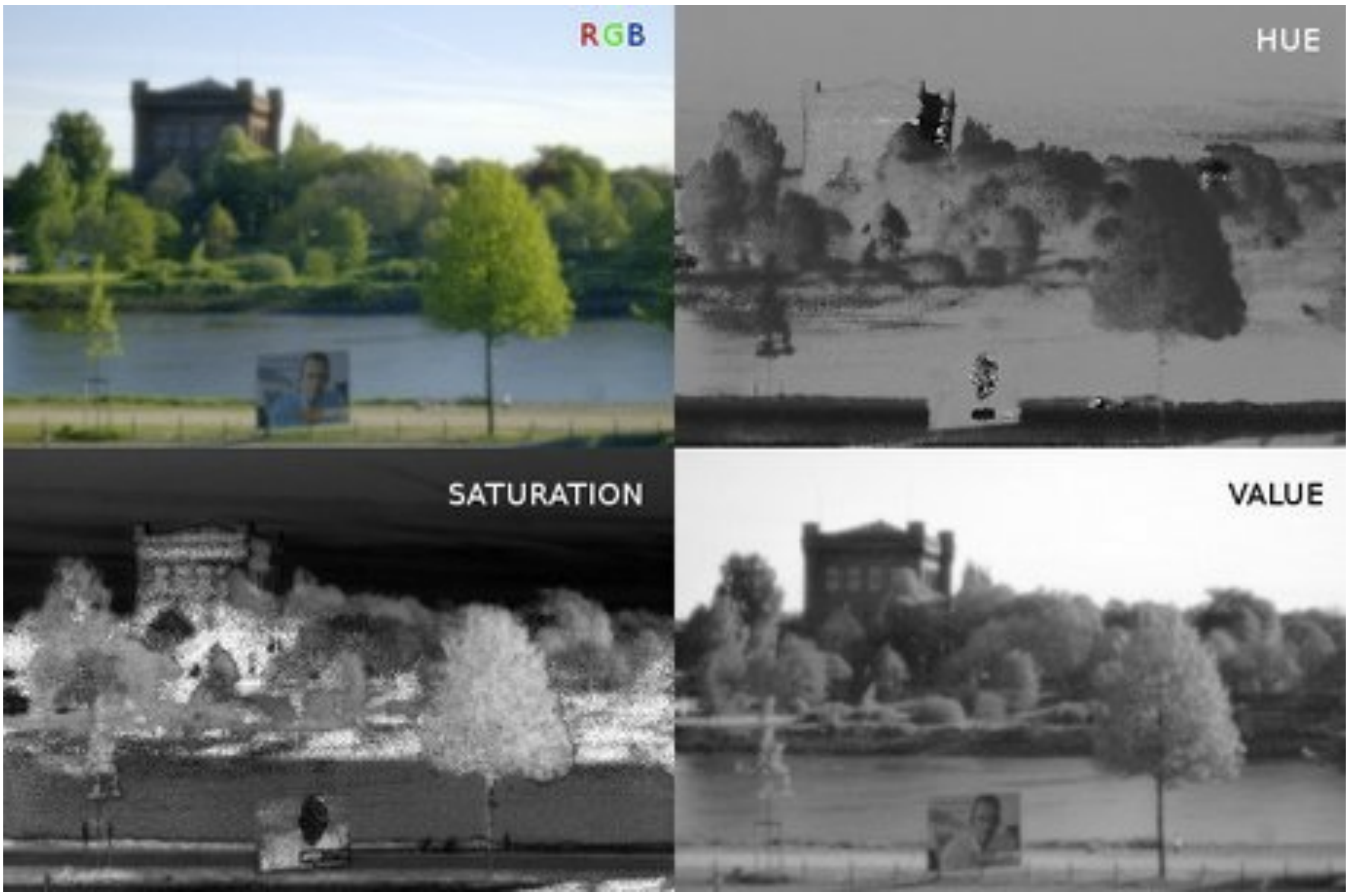
- Colors on V = 1 plane are not equally bright
- Complementary colors 180° opposite
- Top of HSV hexcone is projection seen by looking along principal diagonal of RGB color



RGB color cube viewed along the principal diagonal

- RGB ⇔ HSV

RGB <-> HSV



Converting RGB to HSV

- Let r, g, b in [0,1] be the red, green, and blue coordinates, respectively, of a color in RGB space.
- Let max be the greatest of r, g, and b, and min the least.
- To find the hue angle h in [0, 360] for HSV space, compute:

$$h = \begin{cases} 0 & \text{if } \max = \min \\ (60^\circ \times \frac{g-b}{\max - \min} + 0^\circ) \bmod 360^\circ, & \text{if } \max = r \\ 60^\circ \times \frac{b-r}{\max - \min} + 120^\circ, & \text{if } \max = g \\ 60^\circ \times \frac{r-g}{\max - \min} + 240^\circ, & \text{if } \max = b \end{cases}$$

- The values for *s* and *v* are defined as follows:

$$s = \begin{cases} 0, & \text{if } \max = 0 \\ \frac{\max - \min}{\max} = 1 - \frac{\min}{\max}, & \text{otherwise} \end{cases}$$

$$v = \max$$

Converting HSV to RGB

- Given a color defined by (*h*, *s*, *v*) values in HSV space, with *h* in 0 to 360, and with *s* and *v* varying between 0 and 1, a corresponding (*r*, *g*, *b*) triplet in RGB space can be computed:

$$h_i = \left\lfloor \frac{h}{60} \right\rfloor \mod 6$$

$$f = \frac{h}{60} - \left\lfloor \frac{h}{60} \right\rfloor$$

$$p = v \times (1 - s)$$

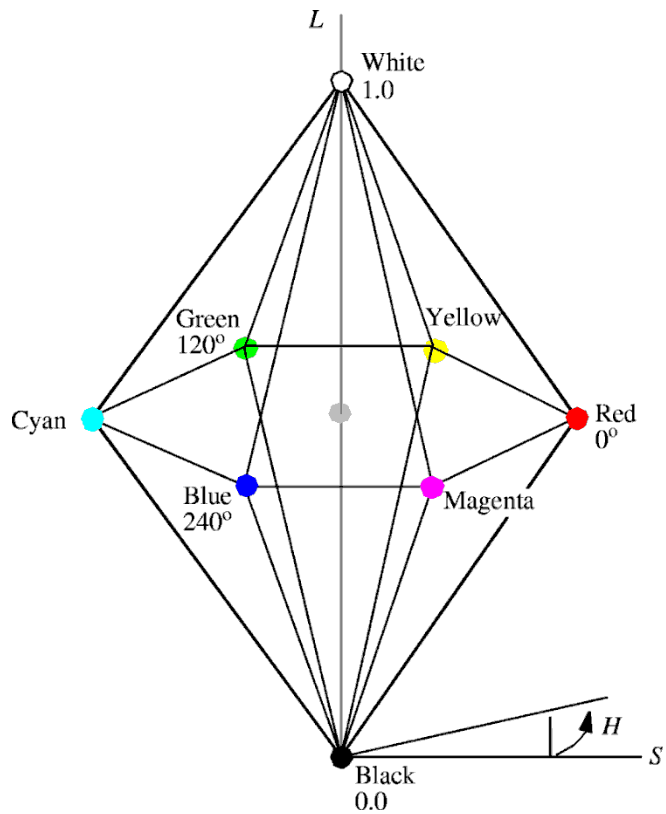
$$q = v \times (1 - f \times s)$$

$$t = v \times (1 - (1 - f) \times s)$$

$$(r, g, b) = \begin{cases} (v, t, p), & \text{if } h_i = 0 \\ (q, v, p), & \text{if } h_i = 1 \\ (p, v, t), & \text{if } h_i = 2 \\ (p, q, v), & \text{if } h_i = 3 \\ (t, p, v), & \text{if } h_i = 4 \\ (v, p, q), & \text{if } h_i = 5 \end{cases}$$

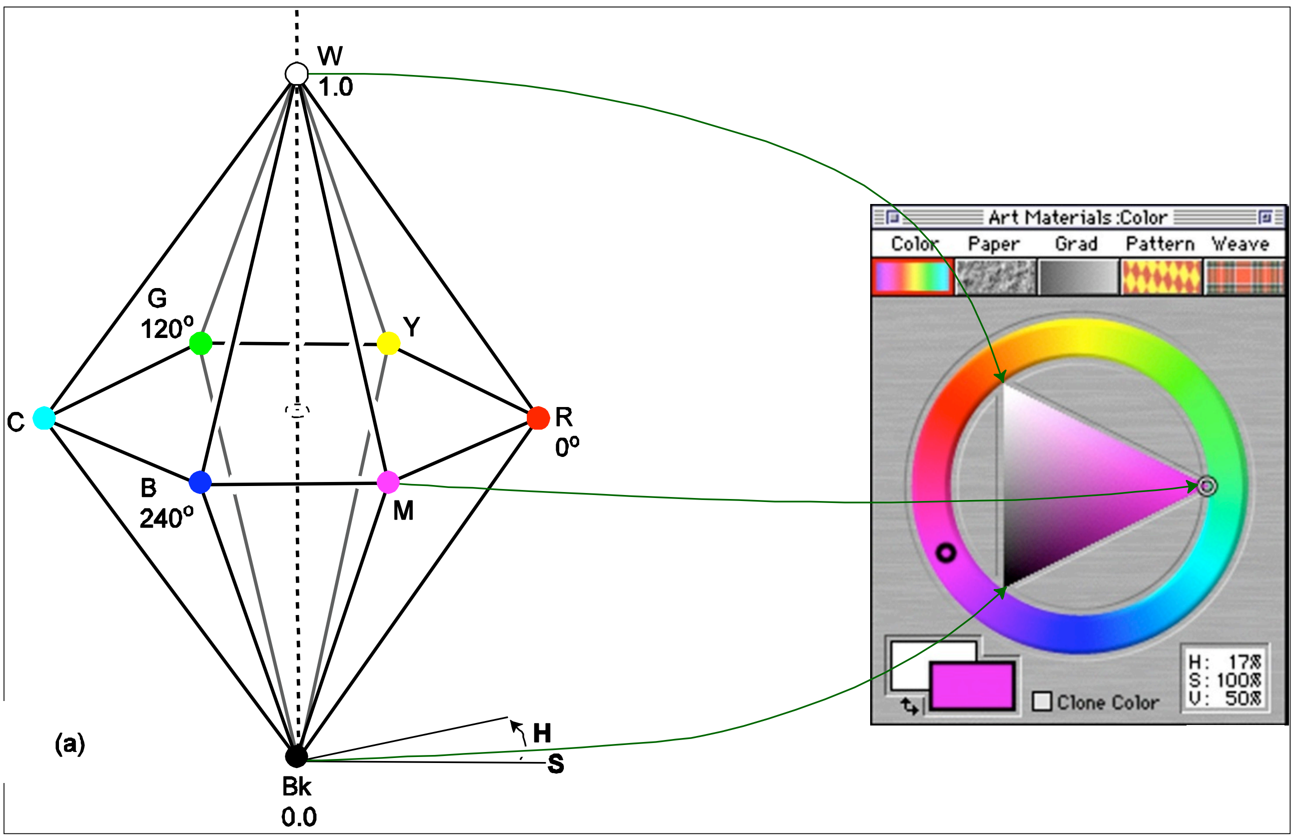
The HLS Color Model

- Hue, lightness, saturation
- Double-hexcone subset



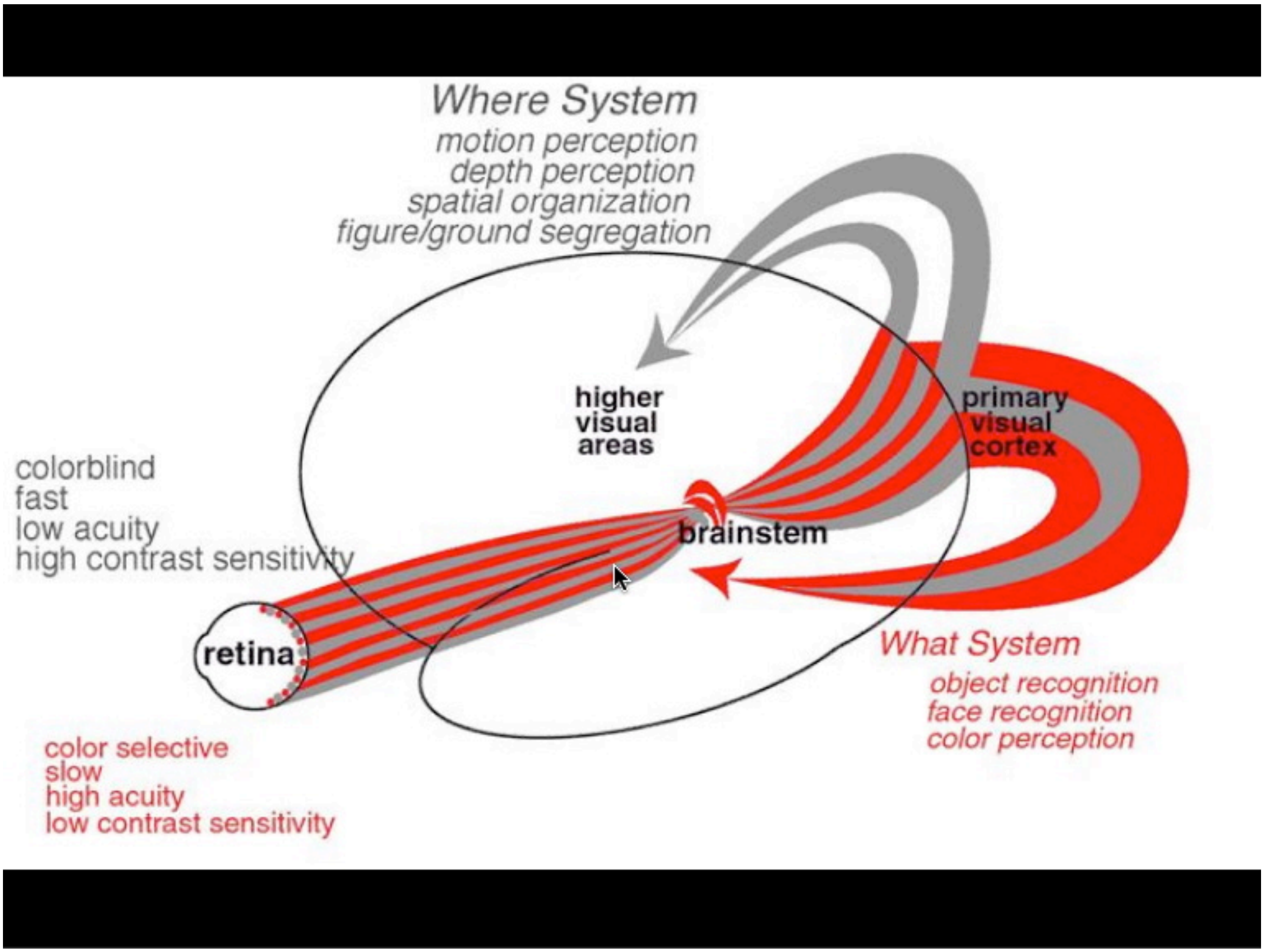
- Maximally saturated hues are at S = 1, L = 0.5
- "lightness" replaces "brightness"

Interactive Specification of Color
Geometric Views

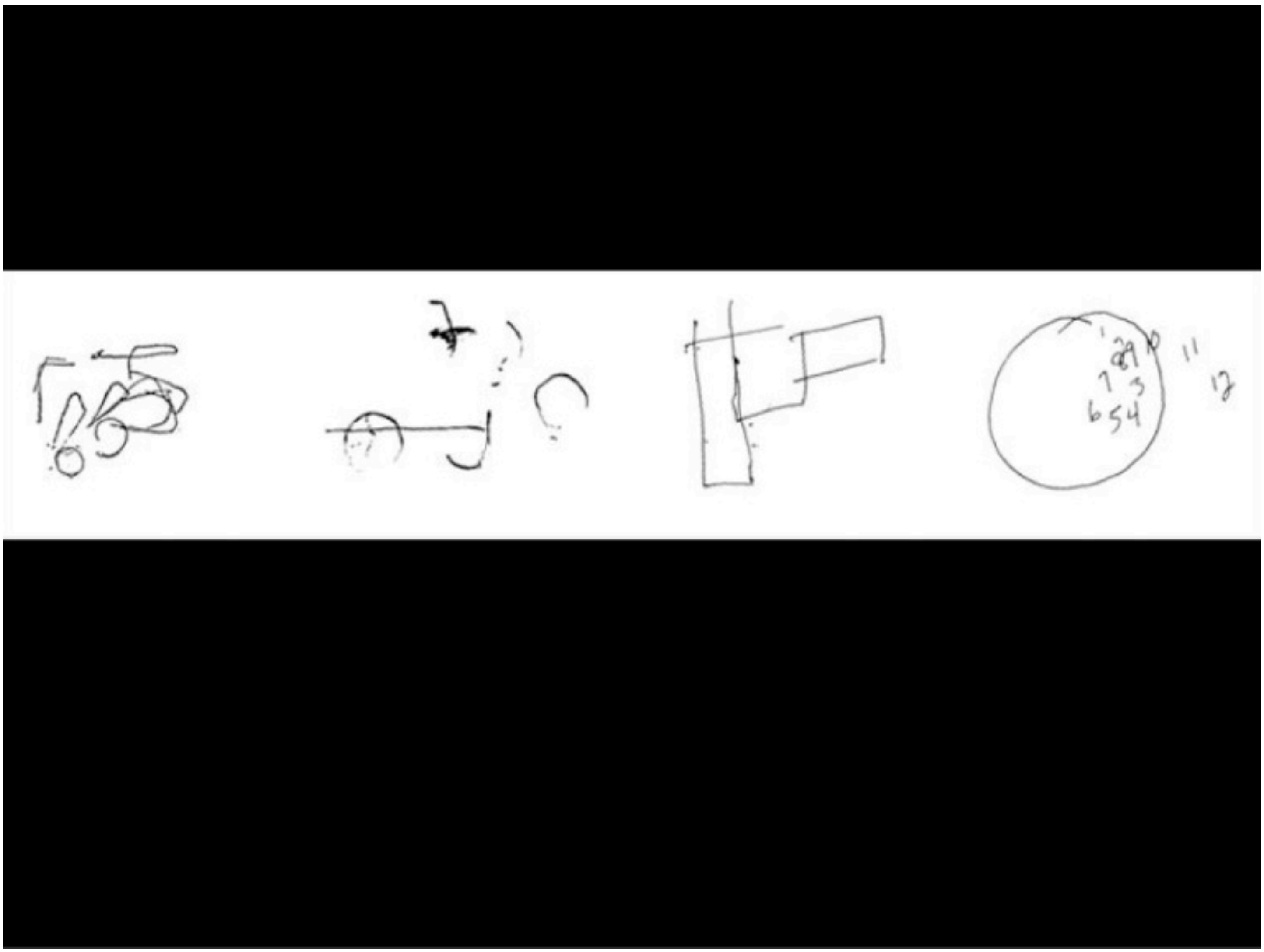


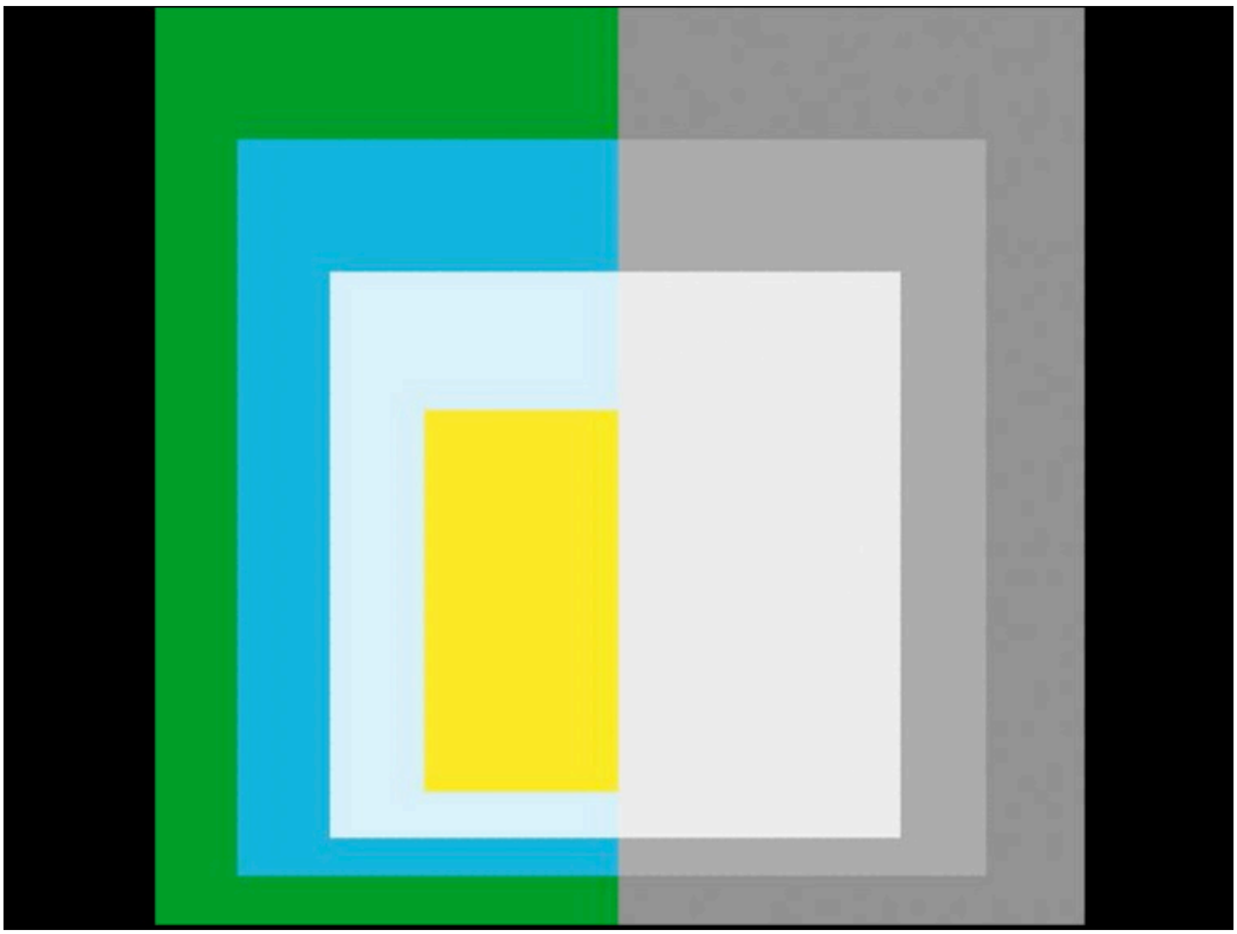
Corel Painter

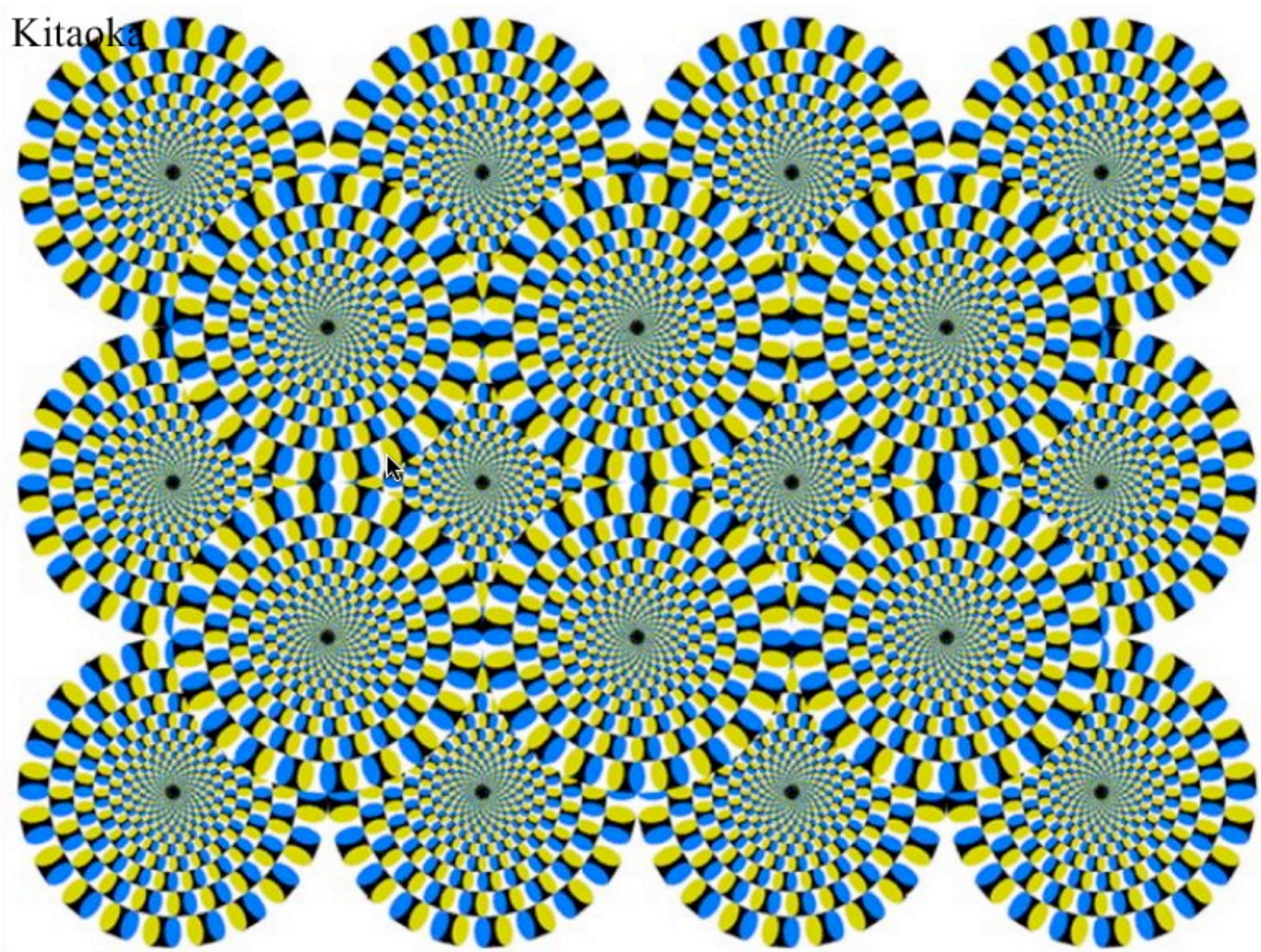
Choosing HSV over RGB: Luminance



M. Livingstone'08 (this image and all luminance images to follow)

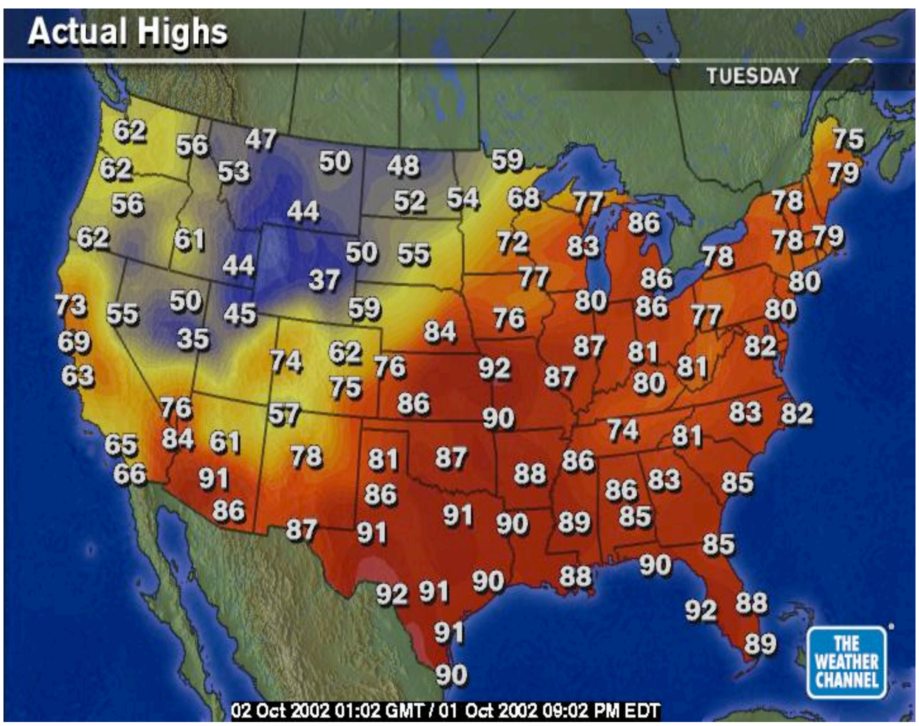





Kitaoka

This text is hard to read. It jumps around and seems unstable, because your Where system can't see it. Advertisers use equi-luminant writing because the jumpy quality is attention-getting, and the difficulty in reading it forces you to pay more attention.

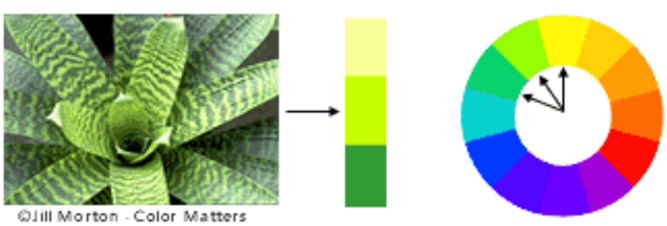
Using Color in Computer Graphics



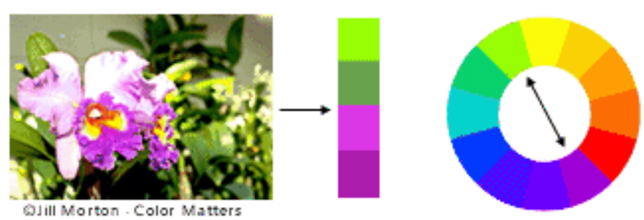
Choose Palette or Scheme

- Color harmony:
  - choose a theme color
  - choose some colors close together (analogous colors) to model light (shading) and for coloring objects that are close to each other
  - choose a complementary color for objects that should have a dynamic relationship with the theme-colored objects
  - choose contrasting colors (especially value contrast) for text and background
  - color circles can help with these choices

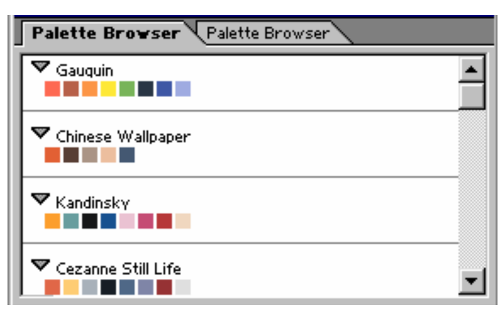
A color scheme based on analogous colors



A color scheme based on complementary colors



- Expert palettes



Contrast

- Ensure contrast of color between text and background (especially of value)
- Foreground-background colors should differ in brightness

Hello, here is some text. Can you read what it says?

Hello, here is some text. Can you read what it says?

Hello, here is some text. Can you read what it says?

Hello, here is some text. Can you read what it says?

Hello, here is some text. Can you read what it says?

Hello, here is some text. Can you read what it says?

- Use colors that have greatest contrast with the background for most important items

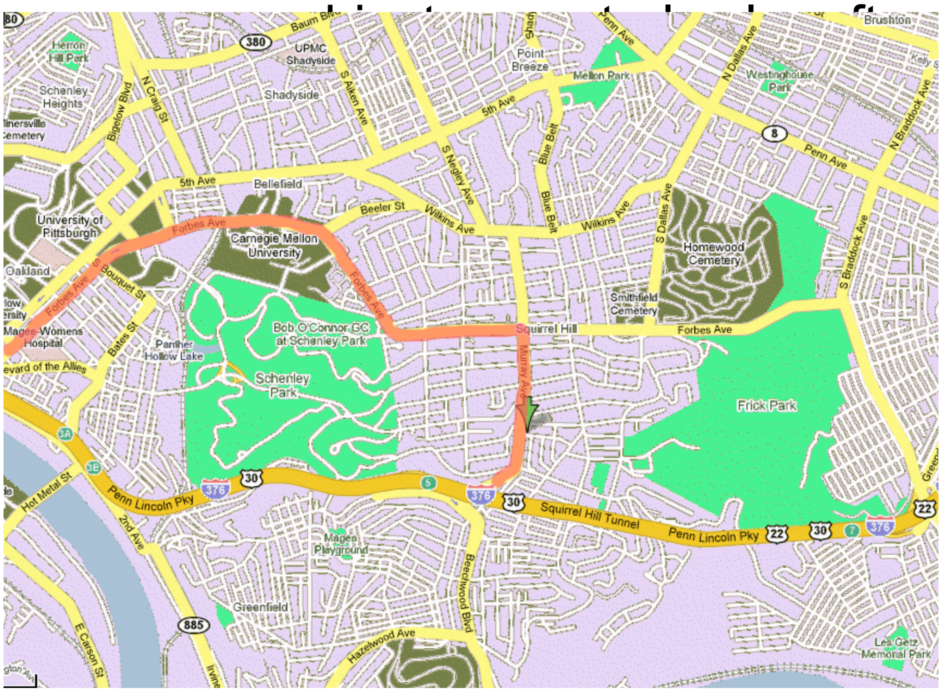
Saturation

All else being equal, areas of saturated color will draw attention

- don't use highly saturated colors of background
- large areas of intense color can lead to eye strain

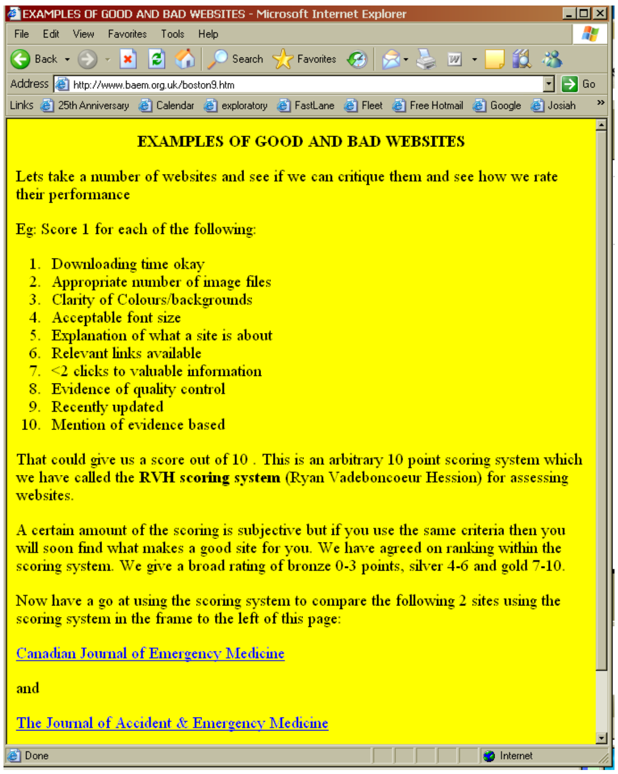
If using several colors of foreground

best for

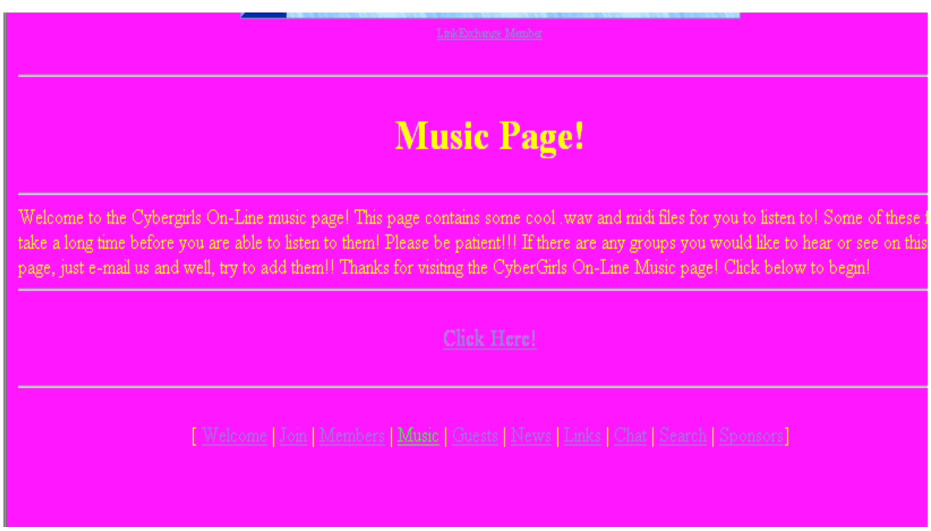


Goncharenko et al, Outdo Google If You Can, cs3610

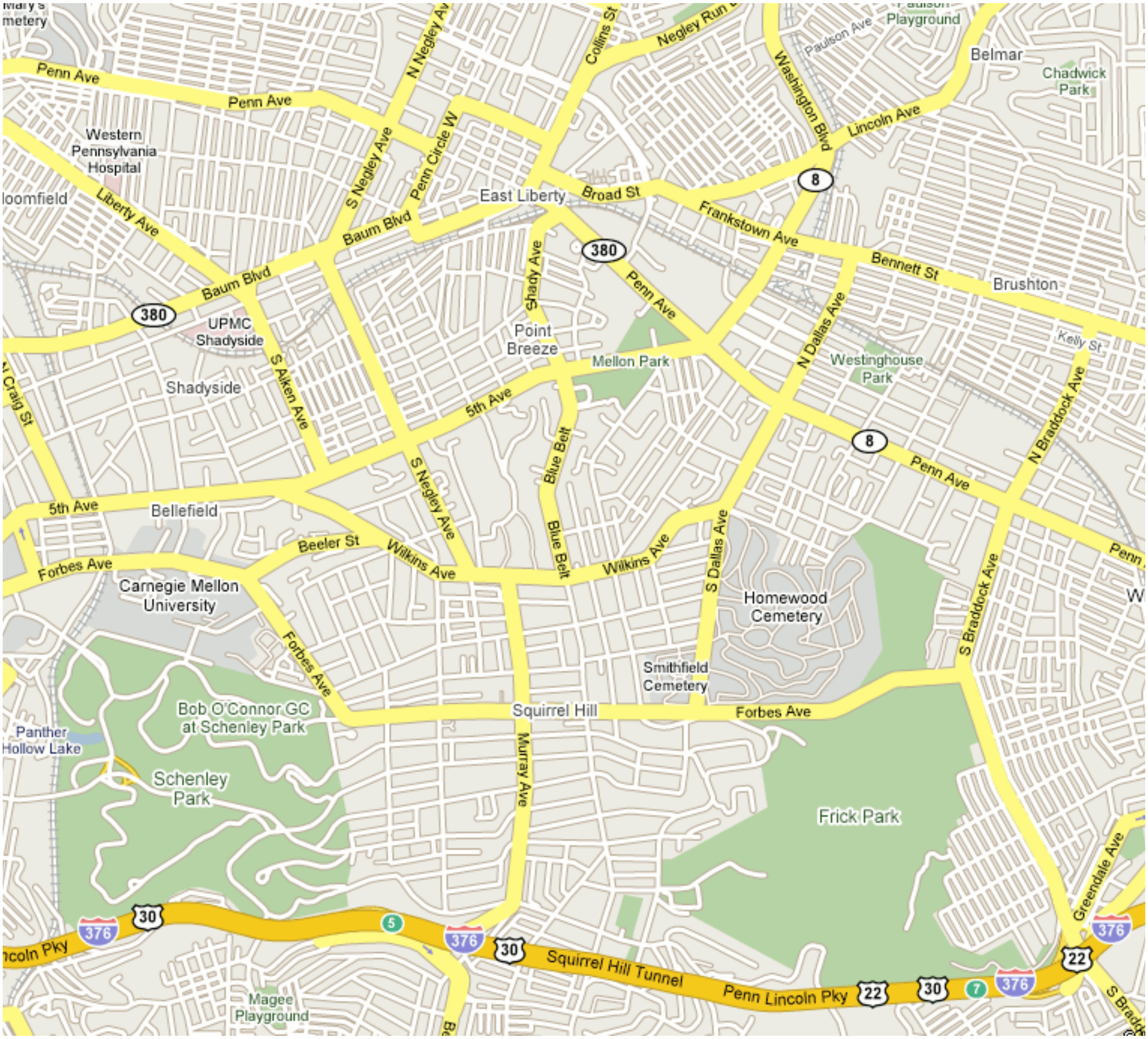
Saturation—Not Best Choice for a Background…



- Was http://www.baem.org.uk/boston9.htm (not working)
- Also http://www.angelfire.com/or/cybergirls/music.html



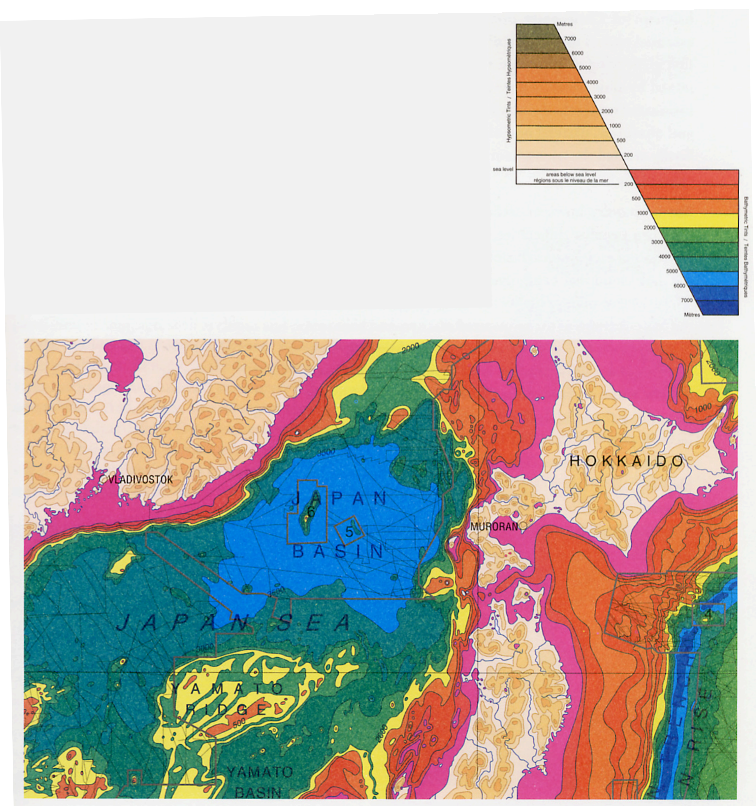
Neutral Background, Pastels

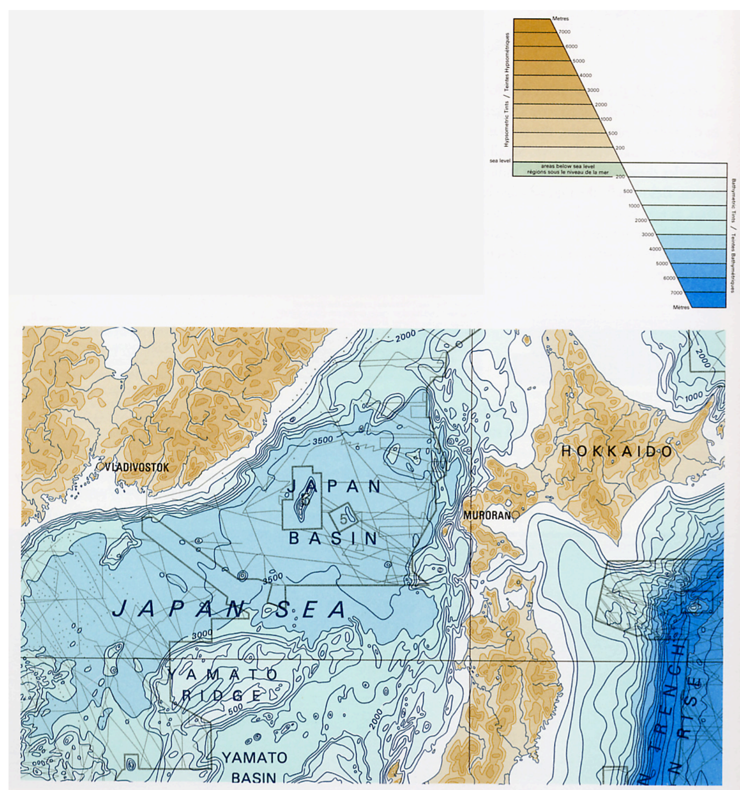


Google maps

Color Coding

- Don't
  - Use red and green for important color coding. Many people (10% men) red-green colorblind.
  - Use similar shades of green and blue for key differentiation. Often confused by viewers
  - Use rainbow/spectral scale for ordinal coding: we have no sense of whether green is more or less than red…

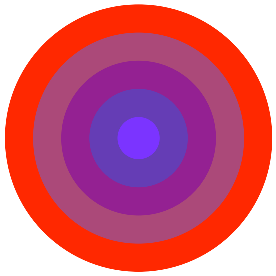




[Tufte 1]

Using Color in Computer Graphics (take home messages)

- Don't use more colors than necessary (when in doubt use less color)
- Ensure contrast of color between text and background (especially of value)
- Use colors that have greatest contrast with the background for most important items
- All else being equal, areas of saturated color will draw attention
  - don't use highly saturated colors of background
  - large areas of intense color can lead to eye strain
- If using several colors of foreground object, a neutral color often best for background
- Blue-family colors tend to recede while warmer red-family colors come forward



Recap

- Color is a perception
    - Color blindness
- Images: grayscale and RGB; transparency
- Color terms: hue, saturation, value (a.k.a. *luminance, brightness*)
- Color spaces
    - RGB: how color is stored and displayed in gfx systems; r,g,b often specified in [0,1]
    - CMYK
    - HSV: intuitive repres.; explicit access to hue (H), saturation (S) and luminance (V)
    - HSL, … (CIE Lab, YIQ, YUV, Munsell)
- Color in CG
    - Luminance: particularly important; contrast, motion etc.
    - Hue: guides construction of color palettes
    - Saturation: highlights objects of interest