Visualization Techniques

Textbooks

- No required textbooks

- **Reference Books**:
- Information Visualization, by Colin Ware, 3nd Edition, 2013
- *The Visualization Toolkit,* by William Schroeder, Ken Martin, Bill Lorensen, 4th Edition, 2006 (for VTK users)

Prerequisites

- **1 semester object oriented programming (sophomore level or above)**
- Programming language: C++, Python, C#, JS…

====

- 1 semester statistics or probability (sophomore level or above)
- 2 semester calculus (differential and integral)
- 1 semester discrete mathematics or numerical methods (sophomore level or above)

Project

- Topics
  - Choose a topic you like
  - Start the project as early as possible
- How to choose a topic
  - Interest
  - knowledge / expertise
  - Significance
  - Application

Project

- Application oriented
  - Apply visualization techniques to real world applications
- Research oriented
  - Your current research project in visualization
  - New or enhanced visualization for your research work
  - Topics or cases from me
- Conference or journal submissions

Project

- Milestones
  - Topic, abstract
  - Designs, methods and preliminary results
  - Final results/products
- Products
  - Report
  - Software / code
  - Presentation
  - Conference / journal submission (optional)
  - Online release (upon approval)

Course Content

- Vision, Perception, Cognition
- Multidimensional visualization
- **Scientific visualization**
- Graph and tree visualization
- Text visualization
- Animation and Video

Course Content

- Introduction to visual analytics
- Basics of Graphics Review
- Scalar Visualization
- Volume Visualization
- Flow Visualization

- Medical Visualization
- Illustrative Visualization

- **Imaging:** the study of 2D images, including techniques to transform, extract information from, analyze and enhance images
- **Computer Graphics:** the process of creating images using a computer. 2D and 3D drawing (or rendering) techniques.
- **Visualization:** the process of exploring, transforming and viewing data as images to gain understanding and insight into the data.

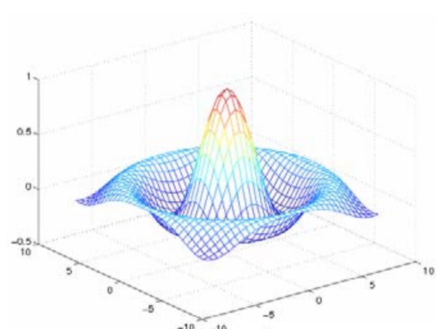
Implementation

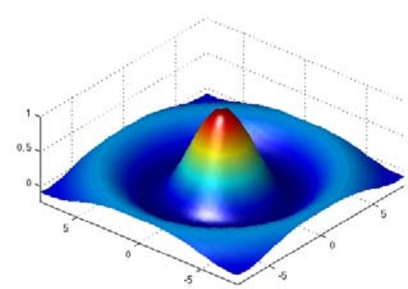
- Most visualization libraries are free
- Scientific libraries: developed in C, C++,Python
- Visualization libraries for Internet:
  - ActionScript, Silverlight, etc.. ← outdated
  - Javascript
  - Many libraries for different data types
- Visualization Packages: Free, Commercial

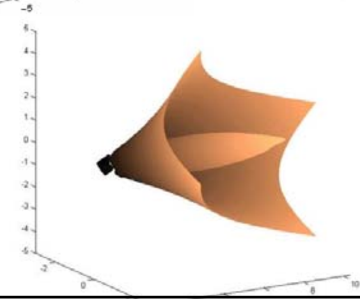
VTK: Visualization Toolkit

- Open source
- Implemented in C++
- Many wrappers
- Good documentations and examples
- Steep learning curve

Matlab

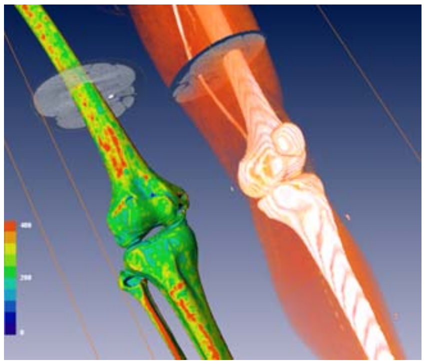






Commercial Software Amira

- Avizo and Amira



DTI:
https://youtu.be/7rNR7TQ62Wk

Data Visualization for Internet

Internet Oriented Visualization

- Web-Based Visualization
  - Download and run inside the web browser
  - No application installation

=========

- Adobe Flex
  - Mozilla Public License
  - Actionscript
- Microsoft Sliverlight
  - Any .NET programming language
  - Free but not open
- Many others. E.g. InfoVis

Internet Oriented Visualization

- Java applet (need plugin)
- Google Visualization API (GVis)
- Adobe Flash/Flex (need plugin. Apple does not like it)
- Microsoft Sliverlight (need plugin)
- JavaScript and SVG (browsers built-in)
- Server-side rendering
  - Tableau and VNC approaches

JavaScript and SVG

- The only true built-in programming language for the browser
- No relation to Java!
- Easy to learn and easy to get confused
- Dynamic internet programming: AJAX: Asynchronous JavaScript and XML
- Application development for the Web

```
<script type="text/javascript">
document.write('<b>Hello World</b>');
</script>
```

```
<input type="button" id="hello-world2"
value="Hello" onClick="alert('Hello World!');"
/>
```

JavaScript and SVG

- Most flexible way to create graphics in browers → SVG from W3C
- Royalty-free, freely available
- XML-based
- Microsoft support since IE9

JavaScript and SVG

```
<?xml version="1.0"?>

<svg xmlns="http://www.w3.org/2000/svg">

  <rect x="20" y="20" width="300" height="250"
       style="fill:none;stroke:blue;stroke-width:2"/>

  <g style="stroke:green;">
    <line x1="50" y1="200" x2="100" y2="60"
          style="stroke-width:5; stroke-linecap:round;"  />

    <line x1="100" y1="200" x2="150" y2="60"
          style="stroke-width:10; stroke-linecap:butt;"  />

    <line x1="150" y1="200" x2="200" y2="60"
          style="stroke-width:15; stroke-linecap:square;"  />

    <line x1="200" y1="200" x2="250" y2="60"
          style="stroke-width:20; stroke-linecap:round;"  />

    <line x1="250" y1="200" x2="300" y2="60"
          style="stroke-width:25;"  />
  </g>
</svg>
```

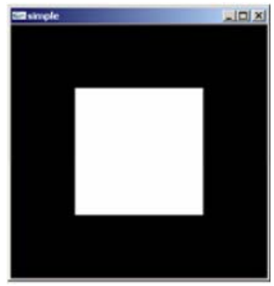
http://croczilla.com/bits_and_pieces/svg/sample

OpenGL

- OpenGL
  - Platform independent
  - Easy to use
  - Excellent performance
  - Focus on rendering
  - Not object oriented (Developed by SGI in 1980s)

OpenGL Utility Toolkit

```
#include <GL/glut.h>
void mydisplay() {
glClear(GL_COLOR_BUFFER_BIT);
glBegin(GL_POLYGON);
glVertex2f(-0.5, -0.5);
glVertex2f(-0.5, 0.5);
glVertex2f(0.5, 0.5);
glVertex2f(0.5, -0.5);
glEnd();
glFlush();
}
int main(int argc, char **argv) {
glutCreateWindow("simple");
glutDisplayFunc(mydisplay);
glutMainLoop();
}
```



Visualization Programming

- Appropriate tools
- Visualization performance
- Minimized dependencies

- If the performance is the only criterion → OpenGL

Visualization Programming

- Other factors to consider:
  - Platform support (mobile device, web browser, VR)
  - Programming language (learn a new language?)

echarts

- https://ecomfe.github.io/echarts-doc/public/en/index.html

Google Chart

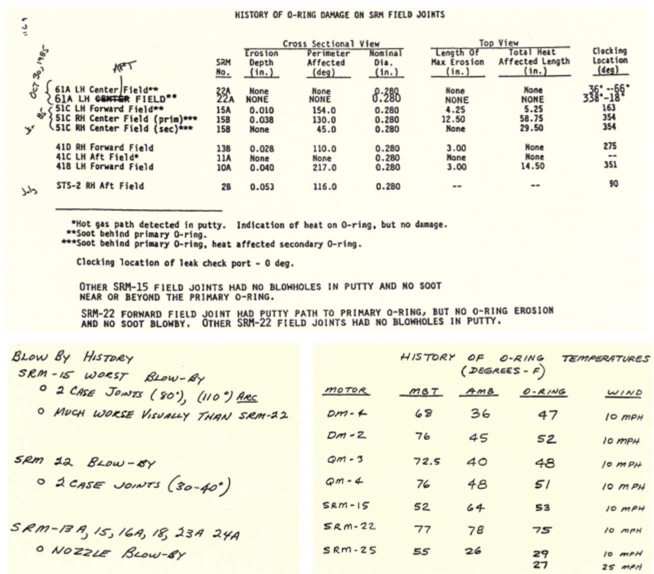
- https://developers.google.com/chart/interactive/docs/gallery

The Functions of Visualization

- **Record: store information**
  - Photographs, blueprints, …
- **Analyze: support reasoning about information**
  - Process and calculate
  - Reason about data
  - Feedback and interaction
- **Communicate: convey information to others**
  - Share and persuade
  - Collaborate and revise
  - Emphasize important aspects of data

Jeffrey Heer

Support Reasoning



HISTORY OF O-RING DAMAGE ON SRM FIELD JOINTS

Oct 30, 1985

AFT

	SRM No.	Cross Sectional View: Erosion Depth (in.)	Perimeter Affected (deg)	Nominal Dia. (in.)	Top View: Length Of Max Erosion (in.)	Total Heat Affected Length (in.)	Clocking Location (deg)
61A LH Center Field**	22A	None	None	0.280	None	None	36°-66°
61A LH ~~CENTER~~ FIELD**	22A	NONE	NONE	0.280	NONE	NONE	338°-18°
51C LH Forward Field**	15A	0.010	154.0	0.280	4.25	5.25	163
51C RH Center Field (prim)***	15B	0.038	130.0	0.280	12.50	58.75	354
51C RH Center Field (sec)***	15B	None	45.0	0.280	None	29.50	354
41D RH Forward Field	13B	0.028	110.0	0.280	3.00	None	275
41C LH Aft Field*	11A	None	None	0.280	None	None	--
41B LH Forward Field	10A	0.040	217.0	0.280	3.00	14.50	351
STS-2 RH Aft Field	2B	0.053	116.0	0.280	--	--	90

*Hot gas path detected in putty. Indication of heat on O-ring, but no damage.
**Soot behind primary O-ring.
***Soot behind primary O-ring, heat affected secondary O-ring.

Clocking location of leak check port - 0 deg.

OTHER SRM-15 FIELD JOINTS HAD NO BLOWHOLES IN PUTTY AND NO SOOT NEAR OR BEYOND THE PRIMARY O-RING.

SRM-22 FORWARD FIELD JOINT HAD PUTTY PATH TO PRIMARY O-RING, BUT NO O-RING EROSION AND NO SOOT BLOWBY. OTHER SRM-22 FIELD JOINTS HAD NO BLOWHOLES IN PUTTY.

BLOW BY HISTORY
SRM-15 WORST BLOW-BY
- 2 CASE JOINTS (80°), (110°) ARC
- MUCH WORSE VISUALLY THAN SRM-22

SRM 22 BLOW-BY
- 2 CASE JOINTS (30-40°)

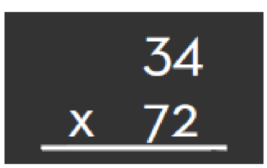
SRM-13A, 15, 16A, 18, 23A 24A
- NOZZLE BLOW-BY

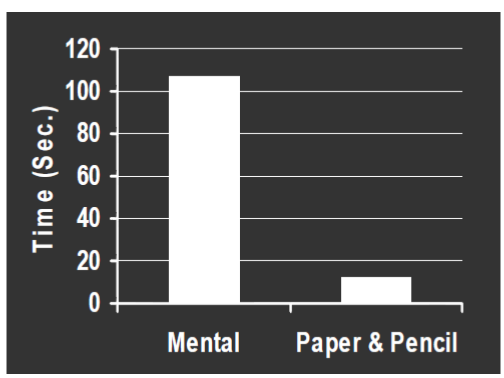
HISTORY OF O-RING TEMPERATURES (DEGREES - F)

MOTOR	MBT	AMB	O-RING	WIND
DM-4	68	36	47	10 MPH
DM-2	76	45	52	10 MPH
QM-3	72.5	40	48	10 MPH
QM-4	76	48	51	10 MPH
SRM-15	52	64	53	10 MPH
SRM-22	77	78	75	10 MPH
SRM-25	55	26	29 27	10 MPH 25 MPH

Jeffrey Heer

Expand Memory





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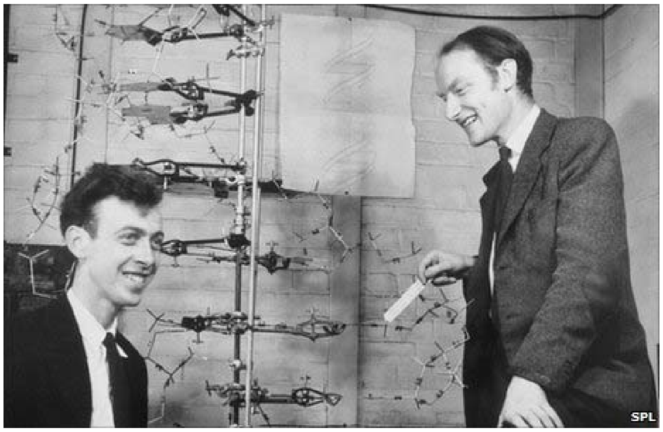
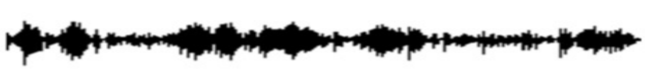
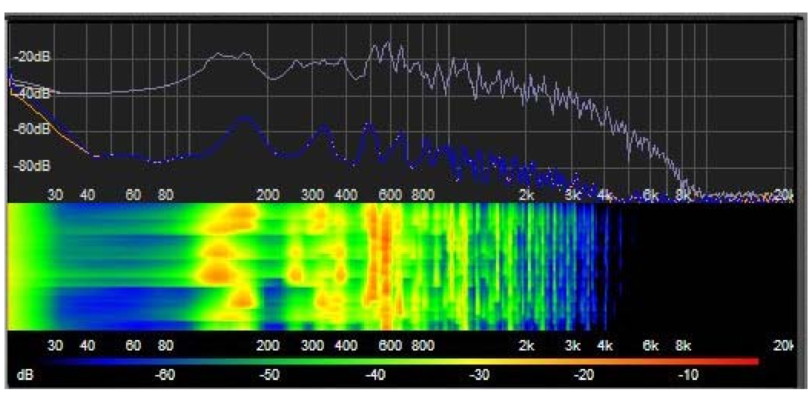
Inspire



Double helix model [Watson and Crick 1953]

Pattern Detection





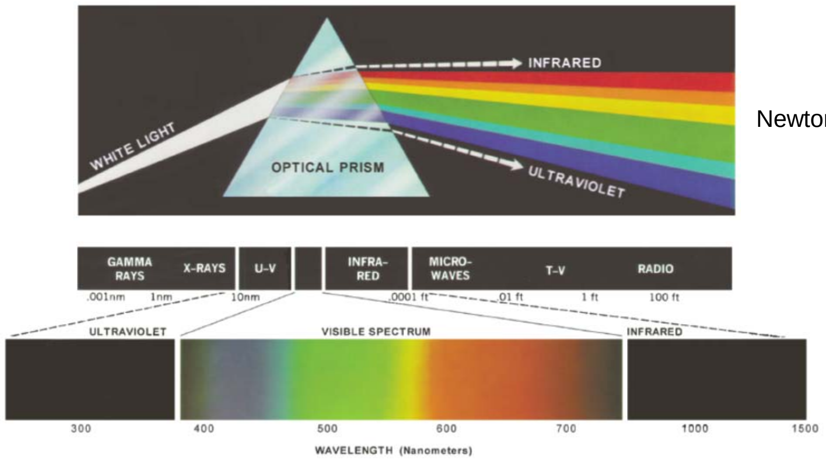
The Value of Visualization

- Answering questions
- Confirm the expected
- Discover the unexpected
- Making decisions
- Expand memory
- Find patterns
- Tell a story
- Inspire others

Color

Color Fundamentals

- Physical nature of color



Newton 1666

Color Fundamentals

The complexity of Color

- wavelength of light/color
- perception and interpretation of color

Color Fundamentals

Human can discern

- ~ 24 shades of gray

- Question: Number of colors distinguishable by the human eye? (Magnitude)

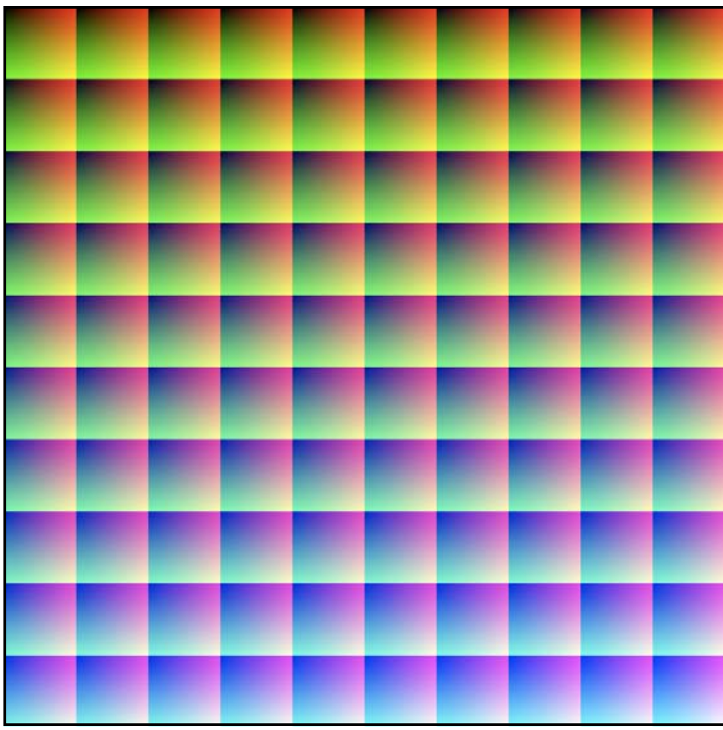
Number of Distinguishable Colors

Reference	Quote	Number
Calkins, David J. *Mapping color perception to a physiological substrate*. The Visual Neurosciences Volumes 1 and 2 The MIT Press, 1993.	"The tremendous variability in the spectral composition of light reflected from surfaces lends itself to eliciting a daunting gamut of more than 100,000 discriminable colors, and the variation in the names we assign these colors is limited only by scope of human experience."	100,000
Kleiner, Kurt. *What we gave up for colour vision*. "New Scientist." January 24, 2004: 12.	"Humans, other apes, and Old World monkeys have trichromatic vision, with eyes containing three colour receptors, sensitive to blue, green, and yellow-red. They allow us and our Old World relatives to distinguish around 2.3 million colours."	2.3 million

http://hypertextbook.com/facts/2006/JenniferLeong.sht

Number of Distinguishable Colors

Reference	Quote	Number
Myers, David G. *Psychology*. Michigan: Worth Publishers, 1995: 165.	"Our difference threshold for colors is so low that we can discriminate some 7 million different color variations (Geldard, 1972)."	7 million
Color. Wikipedia. 2006.	"It has been **estimated** that humans can distinguish roughly 10 million different colors, although the identification of a specific color is highly **subjective**, since even the two eyes of a single individual perceive colors slightly different."	10 million



This image (when viewed in full size, 1000 pixels wide) contains **1 million pixels, each of a different color**. The human eye can distinguish about **10 million** different colors.

Ref: Judd, Deane B.; Wyszecki, Günter (1975). *Color in Business, Science and Industry*. 3rd Ed. P388.

- Question: 10M color in the visible spectrum,

calculate Δλ, Δγ

color	wavelength interval	frequency interval
red	~ 700–635 nm	~ 430–480 THz
orange	~ 635–590 nm	~ 480–510 THz
yellow	~ 590–560 nm	~ 510–540 THz
green	~ 560–490 nm	~ 540–610 THz
	~ 490–450 nm	~ 610–670 THz
violet	~ 450–400 nm	~ 670–750 THz

Characterization of Light

- If the light is **achromatic** (void of color), its only attribute is **intensity**.

- A scalar measure of intensity: gray level (black to white)

Characterization of Light

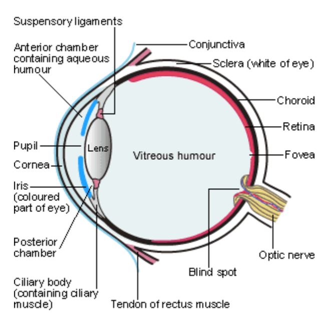
- If the light is **chromatic** (colorful, range: 400-700nm), three basic quantities to describe the light: **radiance**, **luminance** and **brightness**.

- Radiance: total energy flow from the light source. Unit: watt (w)
- Luminance: amount of energy an observer perceives. Unit: lumen (lm)
- Brightness: subjective descriptor in describing color sensation. (practically impossible to measure)

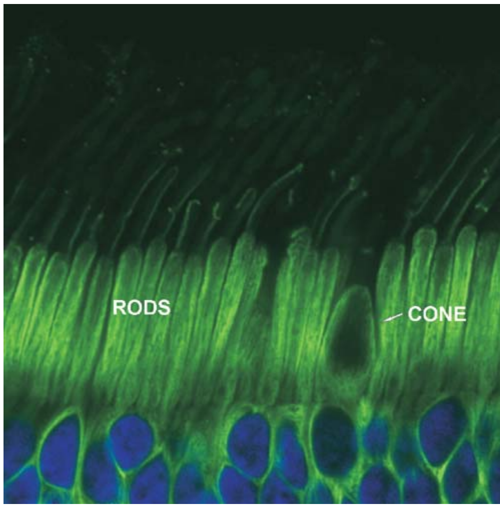
Question: Difference between Radiance and Luminance?

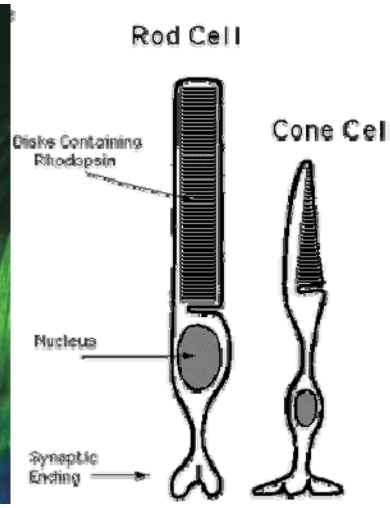
Color Response Curve

- Review
  - Light-sensitive tissue/region?
    (Retina)
  - Types of photoreceptors in retina?
    (Rods and Cones)
  - Numbers of rods and cones?
    (Rods: 75-150M. Cones: 7M)
  - Which one is more sensitive to light?
    (Rods)
  - Which one is more sensitive to color?
    (Cones)



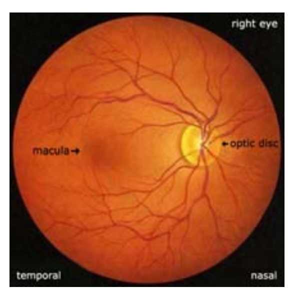
Rod and Cone Cells

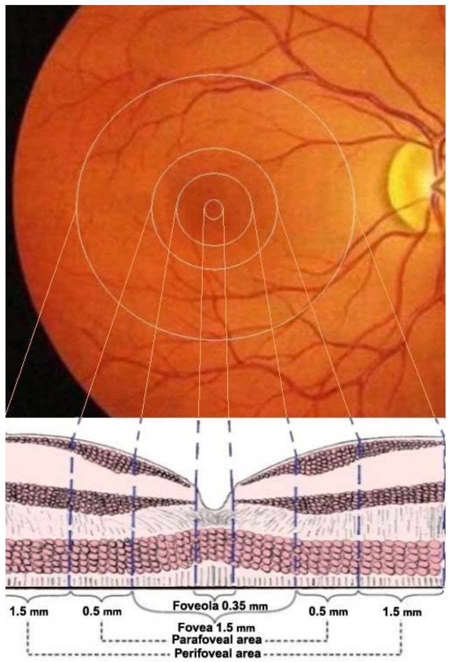


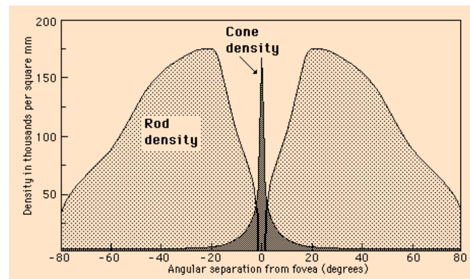


Color Response Curve

- Cones are concentrated in the macula (the central yellow spot).
- The center of macula is the fovea centralis
- Fovea diameter: 0.3 mm
- Fovea: No rods





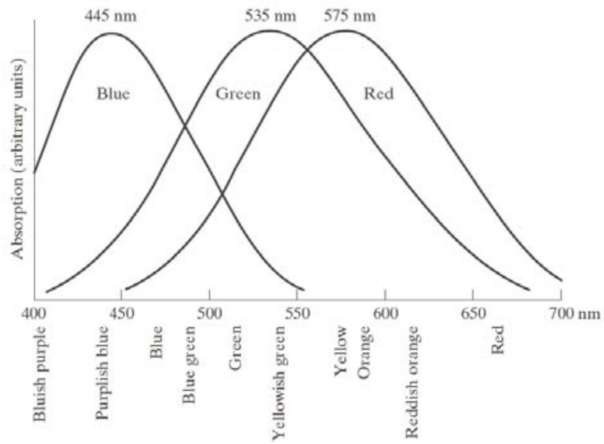


Osterberg, 1935

Color Response Curve

- 3 types of Cones
  - red cones -- 65%
  - green cones -- 33%
  - blue cones -- 2%
  - green and red cones -- concentrated in the fovea
  - "blue" cones -- the highest sensitivity
  - “blue” cones -- mostly found outside the fovea

Color Response Curve



Color Response Curve

- Blue Cones
  - 2% of the total number
  - outside the fovea where the green and red cones are concentrated.
  - much more light sensitive than the green and red cones, it is not enough to overcome their disadvantage in numbers.
  - However, the blue sensitivity of our final visual perception is comparable to that of red and green
  - Question: Why???

Primary Colors

- Due to the absorption characteristics of the human eye, colors are seen as variable combination of the so-called primary colors red (R), green (G), blue (B).
- Standard (CIE 1931)
  - Red = 700nm
  - Green = 546.1nm
  - Blue = 435.8nm

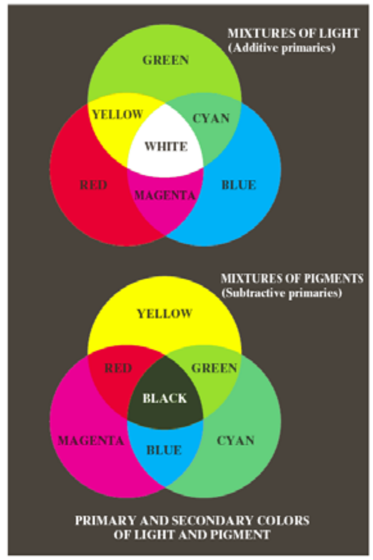
Primary Colors

- Question (True/False): Three standard primaries, when mixed in various intensity proportions, can produce all visible colors.

- Important: 3 fixed RGB components acting alone can not generate all spectrum colors unless the wavelength is allowed to vary → not fixed, standard primary colors.

Mixture of Light or Pigments

- Secondary colors (Light)
  - Magenta = R + B
  - Cyan = G + B
  - Yellow = R + G
- Pigments
  - M + Y → R
  - C + Y → G
  - C + M → B



Color Characteristics

- Three characteristics to distinguish colors:
  - Brightness, Hue, Saturation.
- Brightness → the achromatic notion of intensity
- Hue → The dominant color (wavelength) perceived by an observer.
- Saturation → Relative purity or the amount of white light mixed with a hue.

Color Characteristics

- Saturation
  - Red → pure or fully saturated
  - Pink = Red + White → less saturated

  - Violet → fully saturated
  - Lavender = Violet + White → less saturated

- Chromaticity = Hue + Saturation
- Brightness + Chromaticity → characterize a color

Trichromatic Coefficients

A color can be specified by

its trichromatic coefficients x, y, z

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

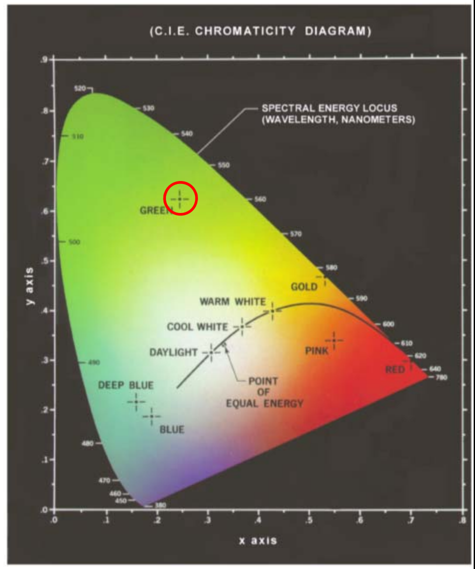
$$z = \frac{Z}{X+Y+Z}$$

$$x + y + z = 1$$

X, Y, Z are the amounts of $\mathrm{R, G, B}$

CIE Chromaticity Diagram

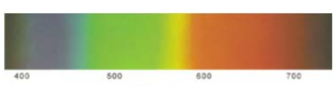
- One of the first mathematically defined color spaces for the **perception of color**.
- Created by the International Commission on Illumination (CIE) in 1931 (**Q**: why not ICI?)
- A color is specified by a function of x (red) and y (green)
  z = 1 – (x+y)



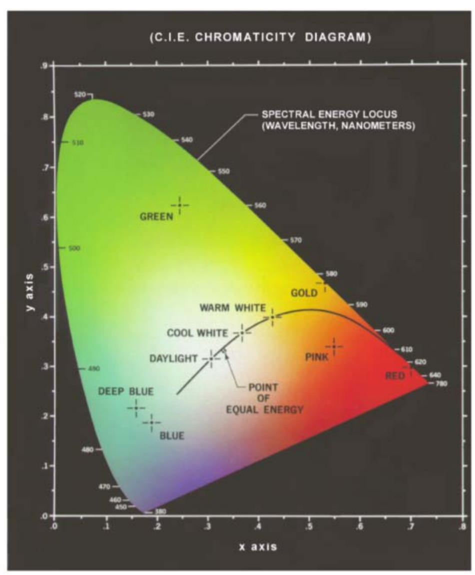
Question: x,y,z of the point?
~62%G, ~25%R
→ ~13%B

CIE Chromaticity Diagram

- Boundary points are pure colors

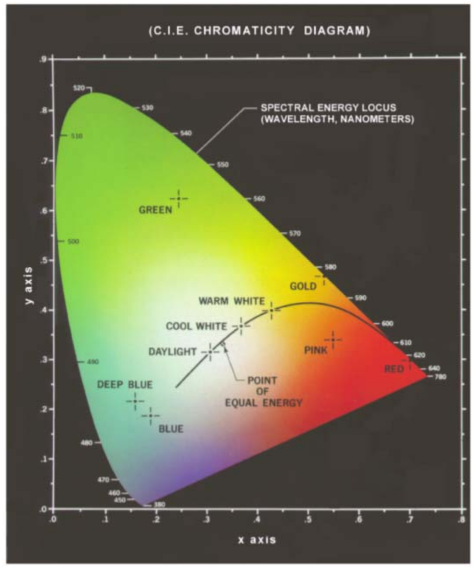


- Inside of the tongue→ mixture of color
- White →point of equal energy → equal fraction of the three primary colors

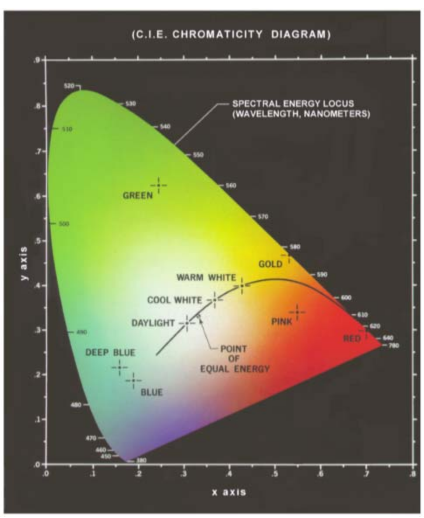


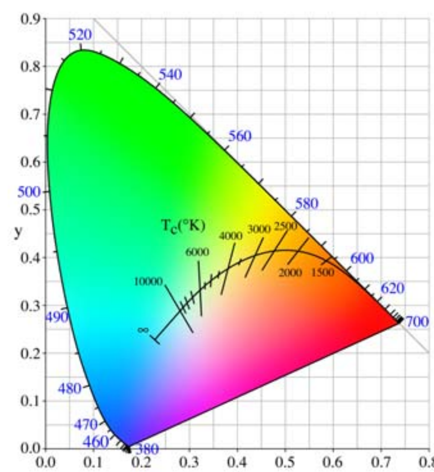
CIE Chromaticity Diagram

- Boundary points are fully saturated
- Inside of the tongue→ less saturated
- Point of equal energy → saturation=0
- Q: Find the saturation line of Red?



Color Temperature



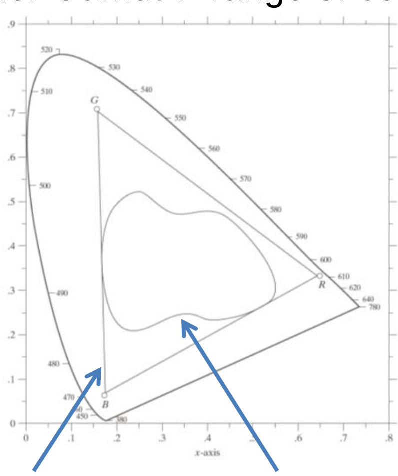


Color Temperature

- Equal to white balance in photography
- 6500K
  - Digital cameras, web graphics, DVDs, etc. are normally designed for a 6,500 K color temperature.
  - The sRGB standard commonly used for images on the internet stipulates (among other things) a 6,500 K display white point.

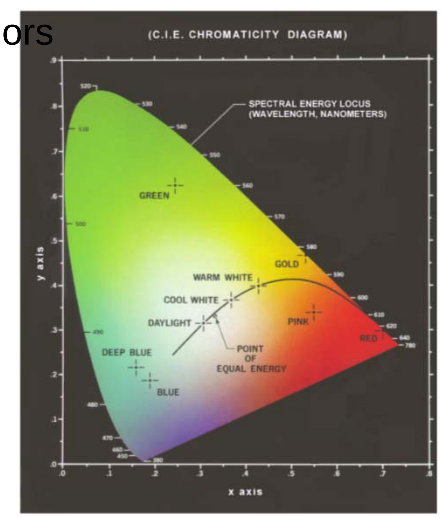
Color Gamut

Color Gamut→ range of colors



color monitors

color printing



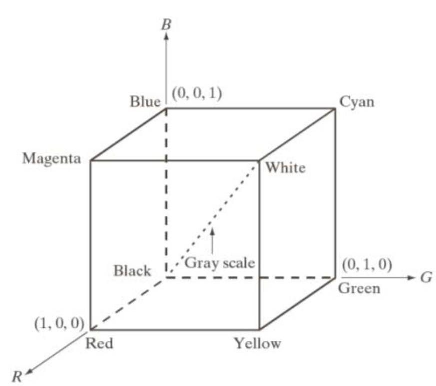
Color Space

- Also called Color Model, Color System.
- RGB space → Hardware oriented model for color monitors, cameras, etc.
- CMY and CMYK spaces → color printing
- HSV, HSI, HSL space → human perception.
- …
- …

RGB Color Space

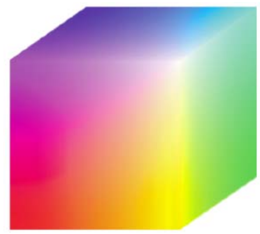
- Cartesian coordinates (normalized)
- 8 Corners:
  - Red, Green, Blue
  - Cyan, Magenta, Yellow,
  - Black, White
- Gray scale: Black, white diagonal.

  (**Q**: why?)



RGB Color Space

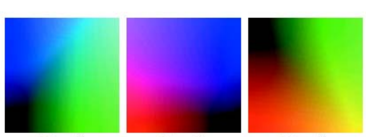
- Pixel depth: The number of bits used to represent each pixel in RGB space.
- Full color image → 24bits → 8bits in each channel
- Total number of colors in a full color image = $(2^8)^3 = 16{,}777{,}216$



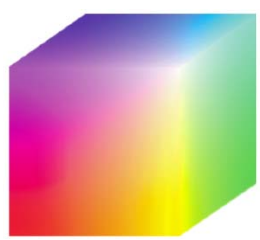
RBG 24bit color cube.

RGB Color Space

- How to select a color in the cube?
- Typical way: fix one color → 3D to 2D



$(R = 0)$ $(G = 0)$ $(B = 0)$



RBG 24bit color cube.

CMY and CMYK Color Space

- Recall
- Primary colors of light: RBG
- Primary colors of pigments: CMY
- Pigment colors are reflected colors.

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

CMY and CMYK Color Space

- Pigment colors are reflected colors.

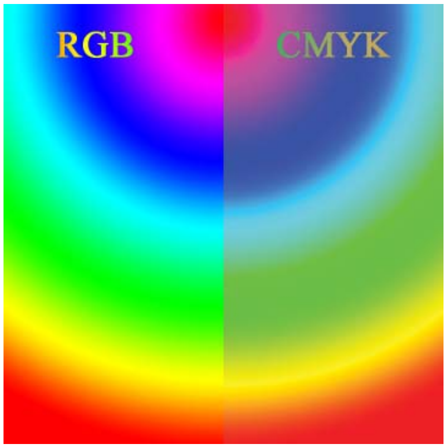
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- Question: Which color is not in the light reflected from a surface coated with pure cyan?

CMY and CMYK Color Space

- Theoretically, CMY can produce black
- In practice, muddy-looking black by mixing CMY for printing
- Solution: Add black into printing to produce true black. (Black is the predominant color in printing. Check the usage of your printer cartridges).
- Four color printing → CMYK
- Question: How to get black from CMY?

CMY and CMYK Color Space



RGB colors on a computer monitor vs. Reproduce in a CMYK print.

http://en.wikipedia.org/wiki/Color_space

HSV Color Space

- RGB and CMY color spaces are ideally suited for hardware implementations.
- Not suited for human interpretation.

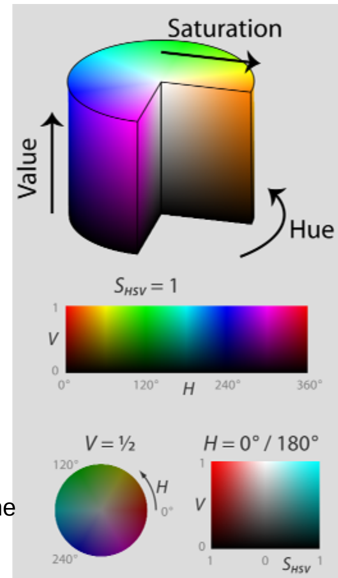
Color?

Looks like CD2626

HSV Color Space

- HSV: Hue, Saturation and Value.
- HSL: Hue, Saturation and Lightness. (similar to HSV)
- Natural and intuitive for human

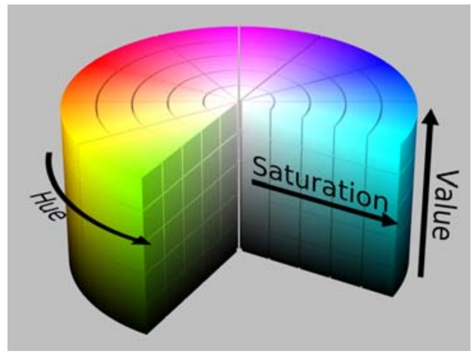
HSV Color Space



SV concentric cylinder surface

HS plane

SV plane



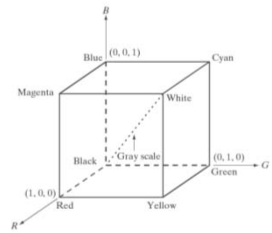
HSV Cylinder

http://en.wikipedia.org/wiki/HSV_color_space

Color Perception

Color Blindness

- ~10% of the male population
- ~1% of the female population
- Reason: the genes responsible for the most common forms of color blindness are on the X chromosome.
- Most common deficiencies
  - Protanopia: Lack of long-wavelength-sensitive cones
  - Deuteranopia: Lack of medium wavelength sensitive cones
  - Difficult to distinguish Red and Green



Daltonize

Red green color blindness

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

Daltonize

Use image processing techniques to make information in pictures available to color blind people.

1) Increase the red/green contrast in the image. Many color blind people have some residual red/green discrimination. Increasing the red/green contrast makes them more likely to see these types of color variations.

2) Analyze the information conveyed by variations in the red/green direction and convert these into changes in brightness and/or blue/yellow coloration.

3) Map information from a color dimension that is invisible to dichromats into those that they can see.

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

Daltonize

- Applications:
  - Digital microscope
  - Digital video recorders and display systems
  - Computer display devices
  - Print media

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

Opponent Process Theory

Opponent Process

- Ewald Hering proposed opponent color theory in 1892.
- Opposed to the leading trichromatic theory developed by Thomas Young and Hermann von Helmholtz.
- Both are now recognized as correct in different aspects of color perception.

Aug 5, 1834 -- Jan 26, 1918
German physiologist

Opponent Process

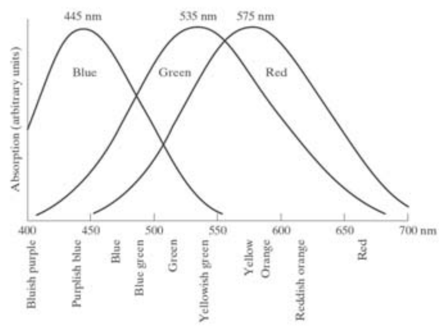
- Opponent process: Processing signals from cones and rods in an antagonistic manner.
- Six primary colors coupled in three pairs:
  - Red – Green
  - Yellow – Blue
  - White–Black
- Any receptor that was turned off by one of these colors, was excited by its coupled color.

Opponent Process Theory

- Modern opponent process theory
  - Input from the cones is processed into 3 channels
    - Luminance channel (Black-White) -- input from all wavelength cone signals
    - Red-green channel: Difference between long and middle wavelength cone signals
    - Yellow-blue channel: Difference between short wavelength cone and the sum of mid and long wavelength cone signals

Opponent Process

- The visual system to record differences between the responses of cones, rather than each type of cone's individual response.

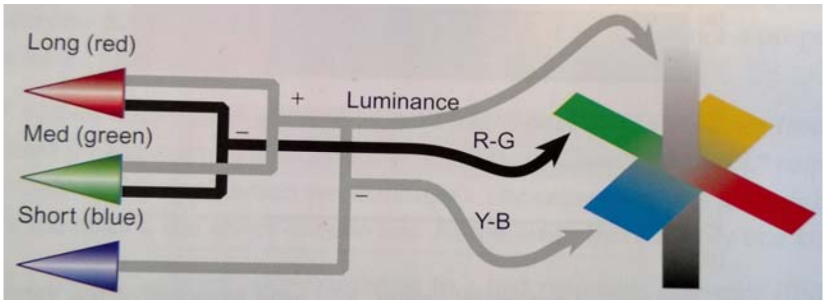


The overlap of responses

Opponent Process

- One color produces an excitatory effect and the other produces an inhibitory effect
- The opponent colors are never perceived at the same time because the visual system cannot be simultaneously excited and inhibited

Opponent Process Theory



Luminance channel (Black-White) → R + G + B
Red-green channel: |R – G|
Yellow-blue channel: |B – (R + G)|

Q: We often say *yellowish green* or *greenish blue*, but never use *reddish green* or *yellowish blue*. Why?

Q: We can see a green tree with red apples. Why?

Opponent Process

- Easy to visualize two colors if they are from different sets. Goldstein (2010)
- Never perceived: Greenish red, reddish green or yellowish blue (RGB theory: Yellow = Red + Green)
- Easy to see greenish blue, but not greenish red.

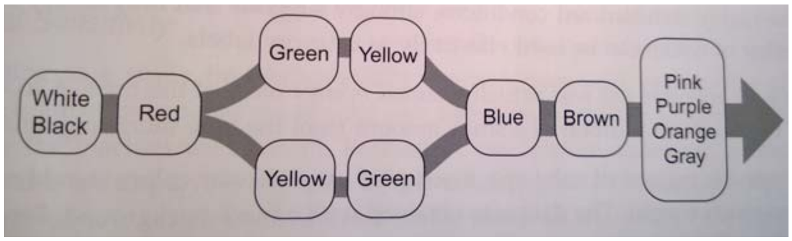
Opponent Process Theory

- Cross Cultural Naming
  - Berlin and Kay, 1969, anthropology
  - Study of >100 languages
  - Primary color terms are remarkably consistent across cultures.
    - Languages with 2 basic color words:
      - Black and white
  - Q: List the order in your mind if a third color and more present? List 10-12 colors.

Opponent Process Theory

- Cross Cultural Naming
  - Berlin and Kay, 1969, anthropology
  - Study of >100 languages
  - Primary color terms are remarkably consistent across cultures.
    - Languages with 2 basic color words: Black and white
    - If a third color is present: Red
    - 4^{th} and 5^{th}: Yellow or green
    - 6^{th}: Blue
    - 7^{th}: Brown
    - Followed by pink, purple, orange and gray in no particular order

Opponent Process Theory



The first six terms define the primary axes of an opponent color model
→Neural basis for these names are innate.
→Support the idea that certain colors – especially Red, Green, Yellow, Blue – are far more valuable in coding data than others.

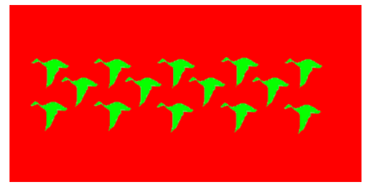
Opponent Process Theory

- Unique Hues
  - Yellow -- a special color
    - If subjects are given control over a device that changes the spectral hue of a patch of light
    - and are told to adjust it until the result is a pure yellow, neither reddish or greenish
    - → remarkable consistency and accuracy within 2nm (Hurvich, 1981)
  - Green – two greens
    - 2/3 of people set a pure green at 514nm
    - 1/3 of people → 525nm
  - Chromatic perception is independent to luminance perception

Q: Wavelength: (800-400)/1,000,000 = 4/10,000 nm
vs. 2nm accuracy in yellow. Why?

Opponent Process: AfterImage

- Opponent process theory
  - White contains all colors
  - Green receptors are worn out
  - Only red receptors are activated,
  - See red on the white wall.
- Question: How to explain afterimage with trichromatic theory



Opponent Process

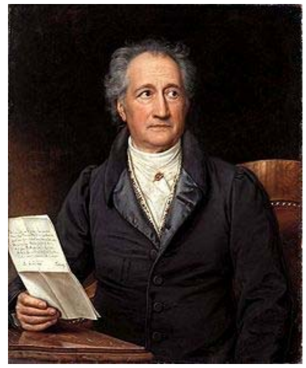
- Responses to one color of an opponent channel is antagonistic to the other color!

In your visualization project

- Do not combine opponent colors
- No reddish green, greenish red
- No bluish yellow, yellowish blue

Johann Wolfgang von Goethe

- A German writer and polymath.
- Goethe's works span the fields of poetry, drama, literature, philosophy, and science.
- Goethe in German ←→ Shakespeare in English.



Aug 28, 1749 – Mar 22, 1832

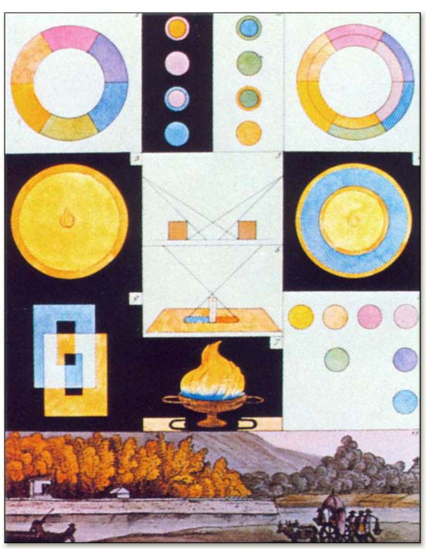
Goethe's Color Theory

- Newton → physical color
- Goethe → physiological color
  - Sensation of color
  - Perception
  - What we see depends on the object, lighting and perception

Goethe's Color Theory

- Goethe, Theory of Colors, 1810
  - 1400 pages ← good writer
  - The first to systematically study the physiological effects of color
  - Studied after-images, colored shadows and complementary colors
- Opposed to Newton's analytic treatment of color
- *"That I am the only person in this century who has the right insight into the difficult science of colors, that is what I am rather proud of, and that is what gives me the feeling that I have outstripped many."*

Goethe's Color Theory



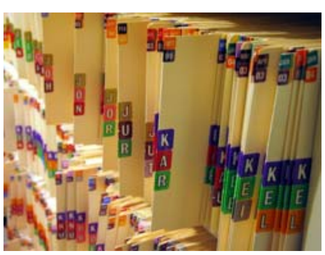
Goethe's diagrams in *Theory of Colors*
- Color wheel
- Distorted color perception.
- How a scene would look to someone who was blue-yellow color blind.

http://www.webexhibits.org/colorart/ch.html

Color Labeling

Color for Labeling

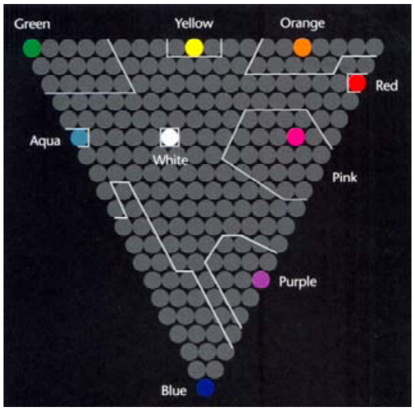
- Labeling → nominal information coding
- Color is often the best solution for labeling



Color for Labeling

- Color naming experiment by Post and Greene, 1986
- Subjects were asked to name 210 colors on a computer monitor
- Only 8 colors + white were consistently named

Question: what conclusions related to color for labeling?



Outlined regions show the colors that were given the same name with better than 75% probability.

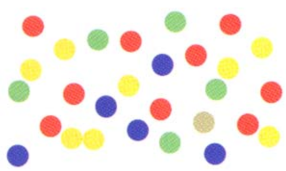
Color for Labeling

- If a color is close to an “ideal” basic color, it is easy to remember.
- only a very small number of colors can be use effectively as category labels.

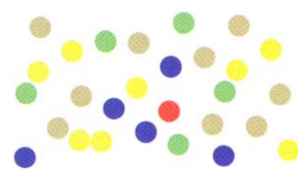
Considerations for Color Labeling

- Distinctness → the ability to distinguish a color **rapidly** from a set of other colors.

Find the unique color

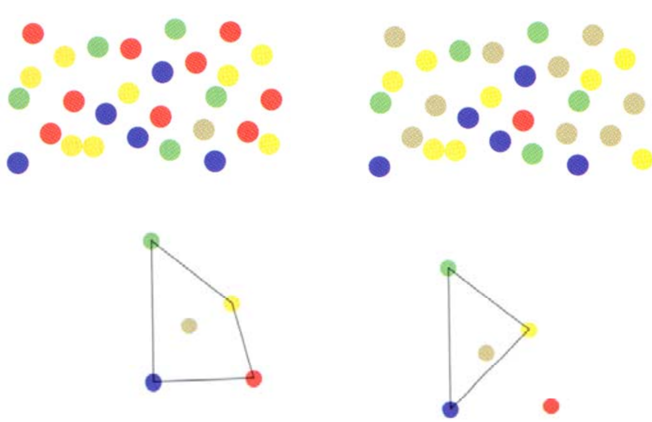


Find the unique color



- Question: Which one is easier to find the unique color? Why?

Considerations for Color Labeling



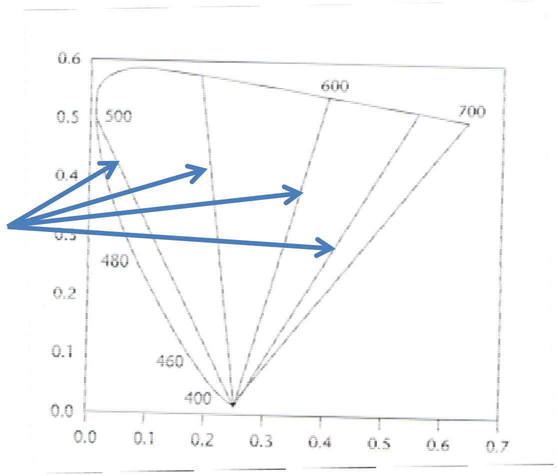
Considerations for Color Labeling

- Unique hues
  - pick colors from different categories
  - avoid using multiple shades of the same color.
- Contrast with background
  - Color coded objects can be expected to appear on a variety of backgrounds
  - Background colors can alter color appearance
  - To reducing contrast effects, place a thin white or black boarder around the color coded object.

Considerations for Color Labeling

- Number: Only a small number of codes can be rapidly perceived. (5< n < 10)
- Color blindness: Use colors that can be distinguished even by people who are color blind.
  - Question: How to pick colors for color blind? R-G, Y-B, K-W?
  - Answer: use yellow-blue direction, avoid red-green direction

Tritanopic
confusion
lines



Colors that differ along confusion lines can be distinguished by the great majority of color-blinded individuals.

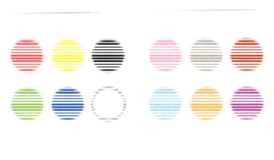
Considerations for Color Labeling

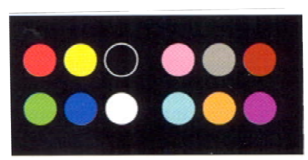
- Field size
  - Do not use very small color coded objects
  - Small object → strong, highly saturated colors
  - Large areas of color coding → low saturation, differ only slightly from one another
  - Highlight regions of black text → light, low saturation
- Conventions
  - Red → hot, danger, stop
  - Blue → life, go
  - Culture → convention

Considerations for Color Labeling

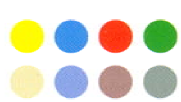
Recommended colors for color encoding

- Red
- Green
- Yellow
- Blue
- Black
- White
- Pink
- Cyan
- Gray
- Orange
- Brown
- Purple

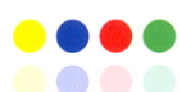




Considerations for Color Labeling



Pairs related by hue
Members differ in saturation

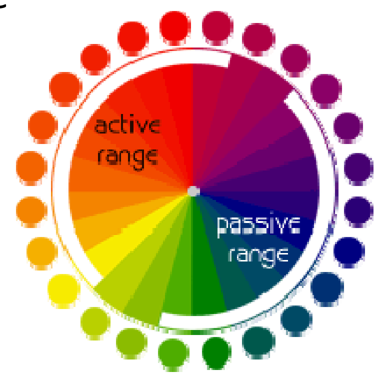


Pairs related by hue
Members differ in saturation and lightness

Warm hues and cool hues

Active vs Passive Colors

- The color wheel can be divided into ranges that are visually active or passive.
- Active colors will appear to advance when placed against passive hues. Passive colors appear to recede when positioned against active hues.



Active vs Passive Colors

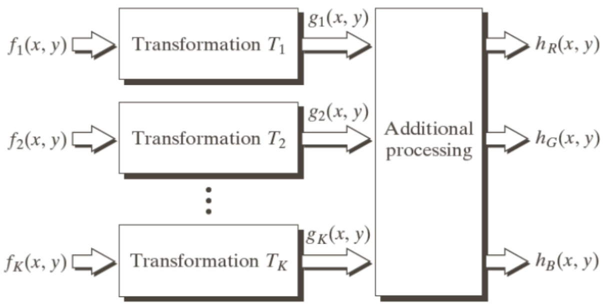
- Advancing hues are most often thought to have less visual weight than the receding hues.
- Most often warm, saturated, light value hues are "active" and visually advance.
- Cool, low saturated, dark value hues are "passive" and visually recede.
- Tints or hues with a low saturation appear lighter than shades or highly saturated colors.
- Some colors remain visually neutral or indifferent.

Pseudo Color

Pseudo Color

- Pseudo color = False color
- Application: For human visualization and interpretation of gray-scale events
- Motivations: Human can only discern ~20 shades of gray, compared to (10M?) colors.

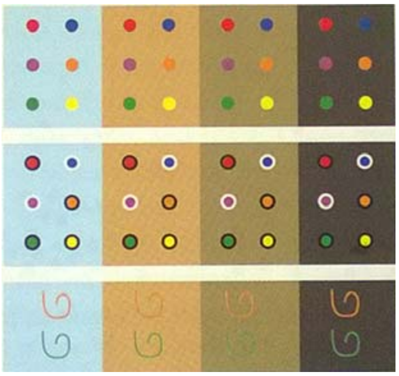
Pseudo Color



Combine several monochrome images into a single color composite

Application: multispectral image analysis.

Color Contrast

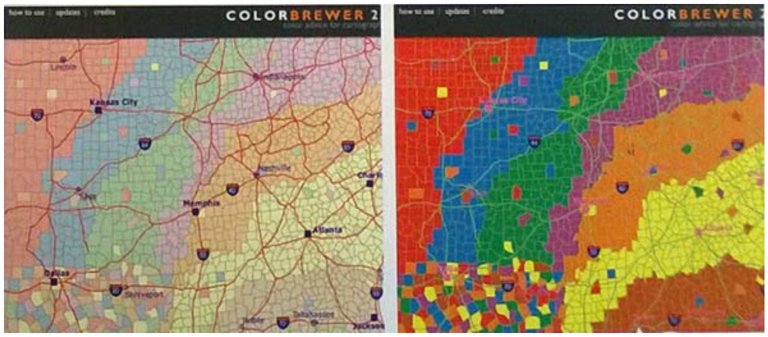


At least one of the six symbols lacks distinctness against each background

Adding a luminance contrast border for better distinctness against all background

Color coded lines can be especially problematic

Color Contrast



Low saturation light colors for area coding
High saturation dark colors for small symbols and line features

High saturation light colors for area coding
Low saturation dark colors for small symbols and line features

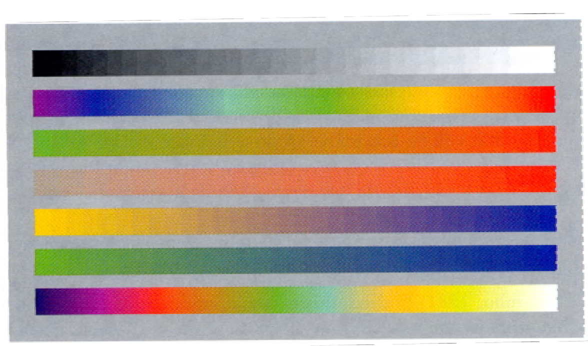
Color Labeling

- Basic rules
  - Small areas should have **high saturation colors**
  - Large areas should use **low saturation colors**
  - Luminance contrast should be maintained

Color Sequence

Color Sequence

- Possible color sequences



→ Gray scale
→ Spectrum approximation
→ Red-Green
→ Saturation
→ Yellow-Blue
→ Green-Blue
→ Lighter from left to right

Y-B and G-B sequences can be perceived by people suffering from R-G color blindness.

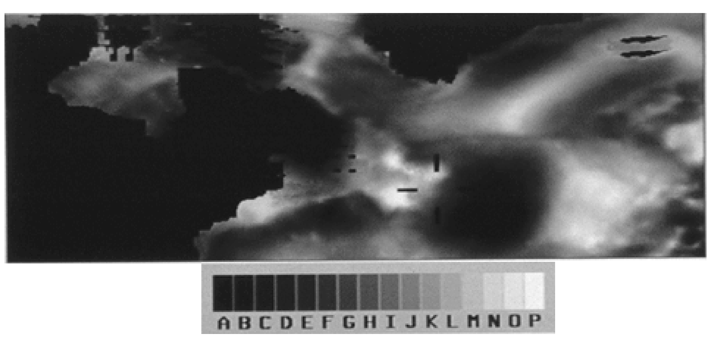
~50% papers use spectrum approximation.

Color Sequence

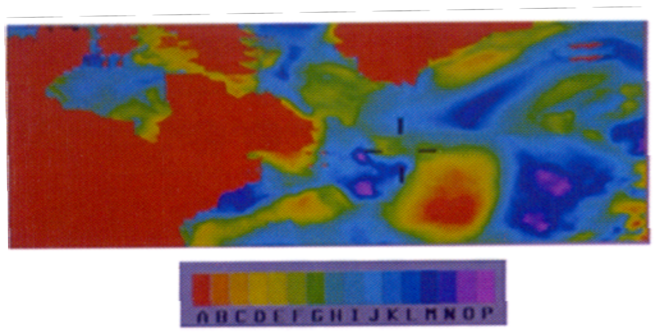
Physical map of Ukraine. Geographer's color sequence: lowlands → green. The scale continuous upwards, through brown, to white at the peaks of mountains.

http://ukrmap.su/program2009/g6/Maps/16_17.jp

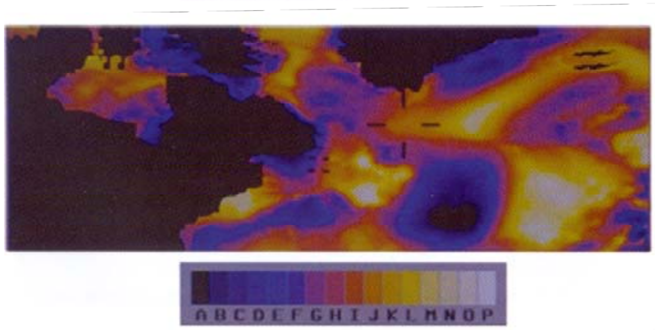
Color Sequence



Gravitational variation over the North Atlantic

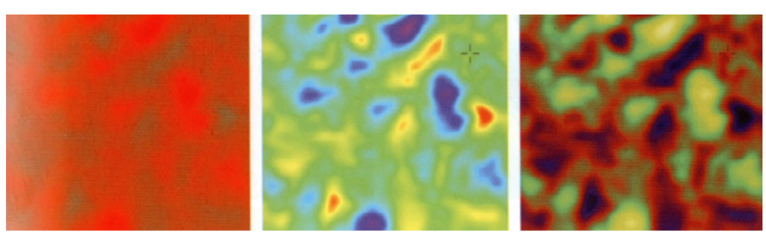


Gravitational variation over the North Atlantic using a spectrum sequence



Gravitational variation over the North Atlantic using an upward sequence;
Each color is lighter than the preceding one.

Color Sequence

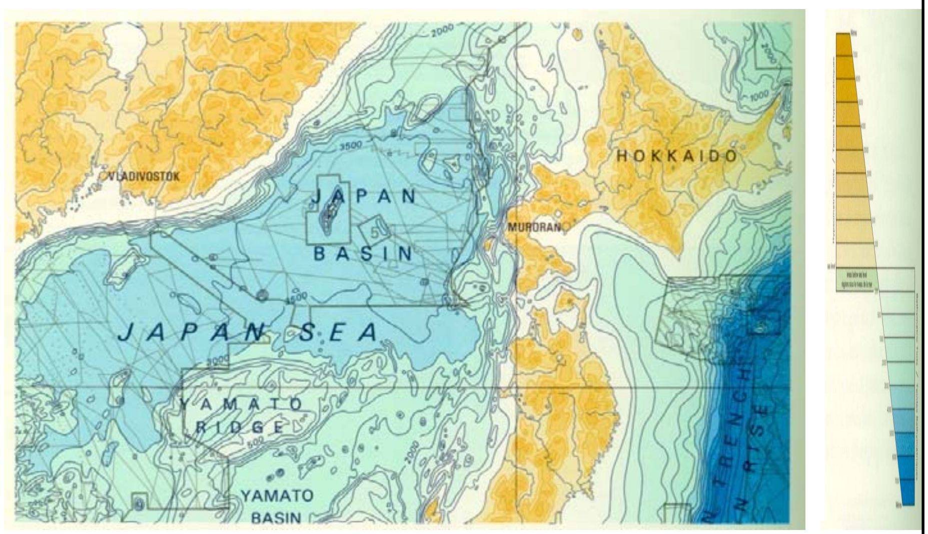


Saturation
Spiral

Spectrum

The spiral sequence makes it possible to easily see both the highs and lows, as well as values accurately from a key.

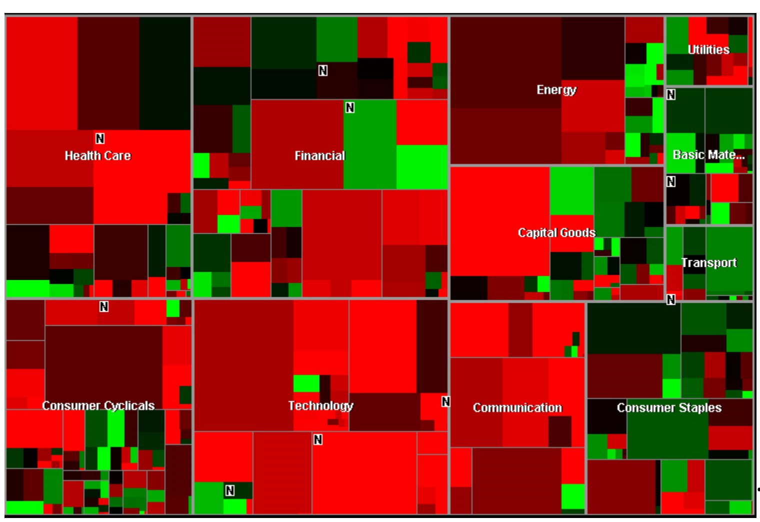
Color Sequences



Ordered and double-ended

Tufte '97, pg. 76.

Color Sequence

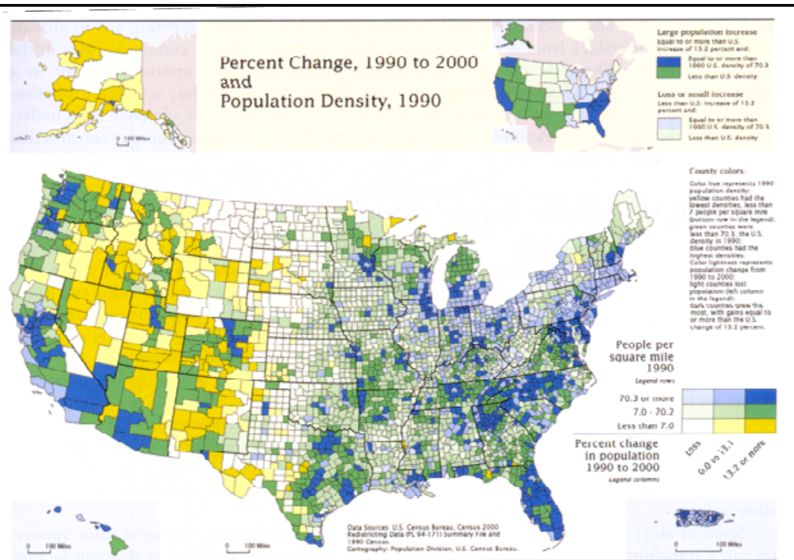


Double-Ended Income

Color Sequence

- Sequences for the color blind
  - Bivariate color sequence: use to color variables
    - Variable one → hue
    - Variable two → saturation

    OR
    - Variable one → hue
    - Variable two → lightness
  - Problem: bivariate color maps are very difficult to read.



US census data: bivariate pseudocoloring scheme.
- Variable one → Saturation and lightness
- Variable two → yellow-blue hue

Color Sequence

- Ordinal data principles
  - Order: ordered values should be represented by perceptually-ordered colors
  - Separation: significantly different levels should be represented by distinguishable colors
  - Can use uniform color spaces

  - Luminance: good for showing form
  - Many hues: useful for showing readable values

Colin Ware

Color Sequence

- Redundant Color Scales
  - Two or more color components varied together
  - Examples
    - Hue with lightness
  - Characteristics
    - Reinforces signal
    - Combines characteristics of simpler scales

Colin Ware

Basic Guidelines

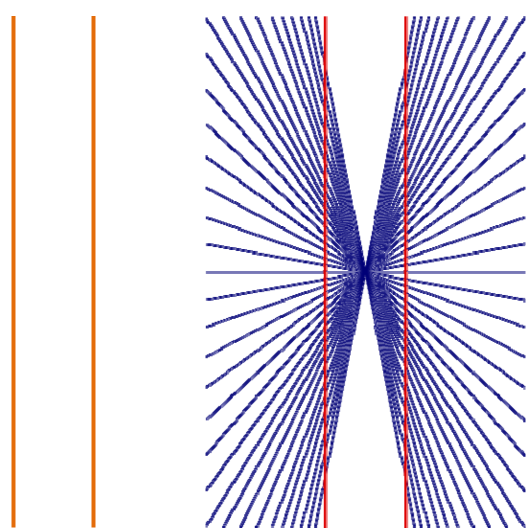
- Use only a few colors
- Use distinctive and named colors
- Use natural colors
- Follow cultural conventions
- Avoid bad interactions (e.g. red/blue)
- Be cautious in black and white
- Respect the color blind

Illusions

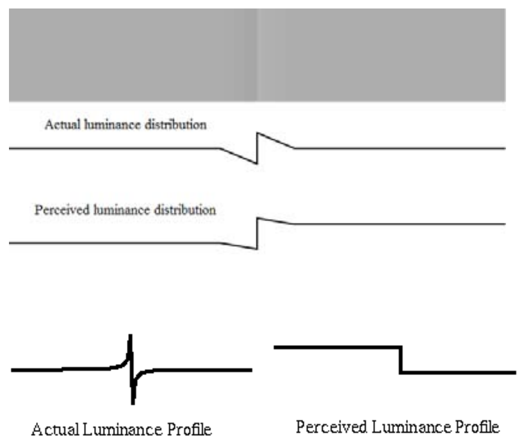
Visual Illusions

- Also called optical illusions
- Guidelines
  - Avoid or use 3D illusions
  - Be aware of gratings and grids
  - Background and shading

Hering illusion



Cornsweet Effect



Visual Illusions

- Guidelines
  - Avoid or use 3D illusions
  - Be aware of gratings and grids
  - Background and shading

Visual Attention

Attention

- Attention is a set of strategies that attempts to reduce the computational cost of the search processes inherent in visual perception (Tsotsos, 2001)

Attention

- Low-level attention (bottom-up attention)
  - Driven by the sensory input data
  - Unconscious manners to conspicuous or “salient” visual items
  - Constitutes a powerful alerting system which allows us to become aware of unexpected things
- High-level attention (top-down attention)
  - Goal-directed
  - Conscious type of attention with deliberateness
  - Powerful in orientating attention
- Bottom-up ←→ top-down

Iconic Memory

- Sperling, 1960
  - Short-term sensory buffer for visual stimuli
  - Allows us to hold the image for about 0.1-0.2 seconds while we read the symbols into our short-term memory
  - Any information that is retained longer than 3/10 seconds has been read into visual or verbal working memory for symbolic analysis.

  - Do you agree with him?

Preattentive Processing

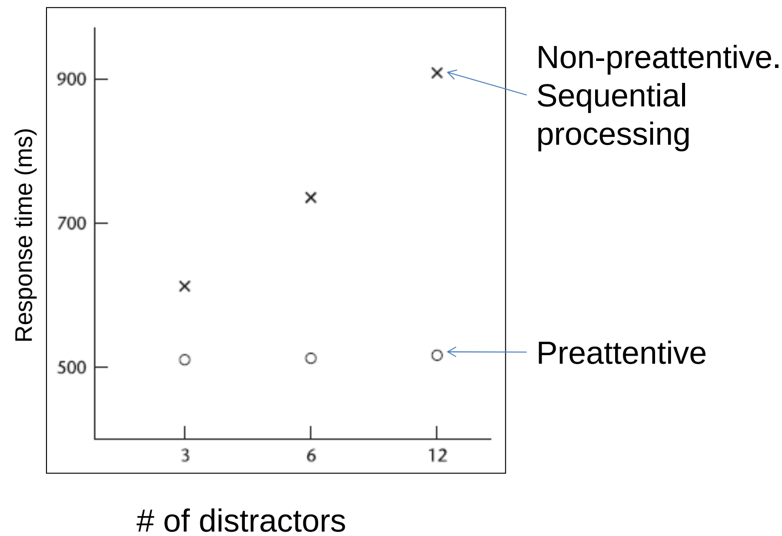
- Preattentive processing determines what visual objects are offered up to our attention.
- Visually identified after brief exposure
- “Pop out” from surroundings

Preattentive Processing

- Preattentive processing ⇔ Theory of “Pop out”
- Misleading term
  - Early researchers thought that it must occur prior to conscious attention (~1980s)
  - Modern view: attention is integral.

Preattentive Processing

- Test Preattentive Processing
  - Measure the response time to find a target in a set of distractors
  - If processing is preattentive, the time taken to find the target should be independent of the number of distractors
  - In practice,
    - Process rate > 10ms/item →preattentive,
    - Process rate > 40ms/item →non-preattentive



Preattentive Processing

- Feature categories for preattentive processing
  - Color, Form, Motion, Spatial position
- Color
  - Hue
  - Saturation
  - Intensity

Preattentive Processing

- Feature categories for preattentive processing
  - Color, Form, Motion, Spatial position
- Form
  - Line orientation
  - Line length
  - Line width
  - Line collinearity
  - Size
  - Curvature
  - Spatial grouping
  - Blue
  - Added marks
  - Numerosity

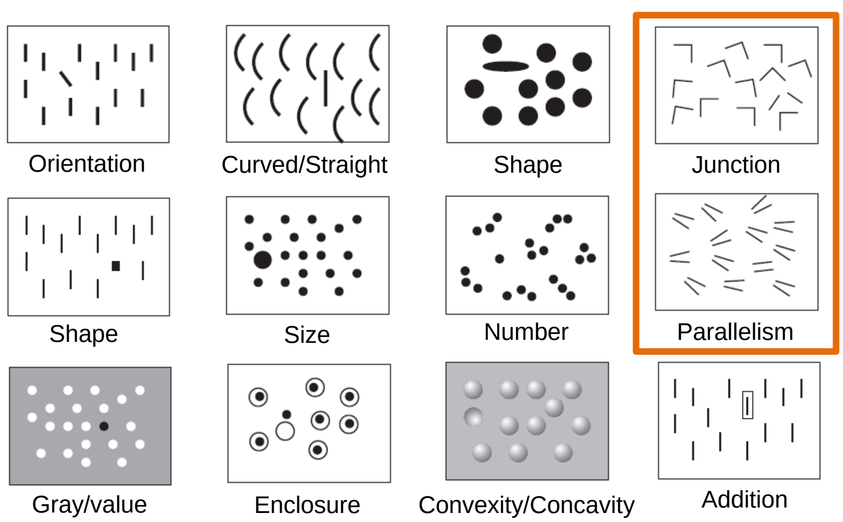
Preattentive Processing

- Feature categories for preattentive processing
  - Color, Form, Motion, Spatial position

- Motion
  - Flicker
  - Direction of motion
- Spatial Position
  - 2D position
  - Stereoscopic depth
  - Convex/concave shape from shading

Preattentive Processing

- **Question**: Find non-preattentive features?



Highlight in Practice

Use color

Use Animation. Blink??

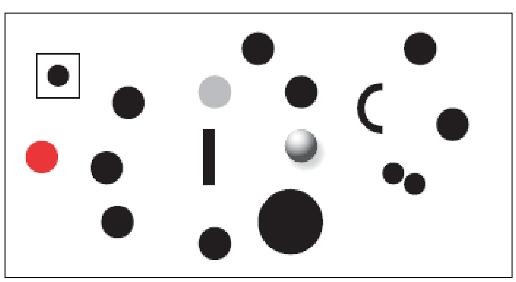
Use Animation. Fly in??

→ Use motion for orienting responses

Most PowerPoint animations are preattentive.

Multiple Preattentive Features

- Each of many symbols be preattentively distinct from all the others



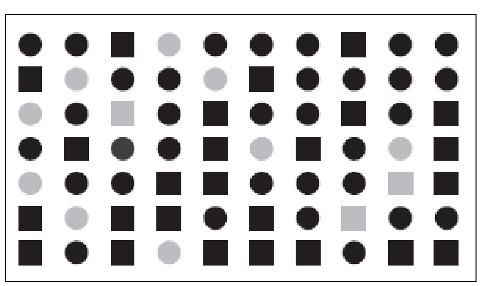
Question: List all preattentive symbols.

Preattentive Processing

- Redundant Coding
  - Choose to make something distinct on several dimensions, such as color, size and orientation.
  - Search based on any or all of the properties.
  - Redundant coding improves searching?
    - Most cases: Yes.

Preattentive Processing

- Conjunction of features
  - Search for specific conjunction of two or more features
  - Is it possible to preattentively process complex patterns?



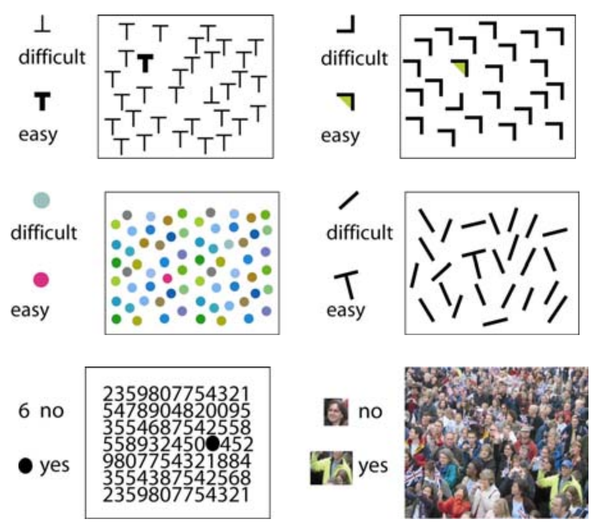
Find gray squares in a picture.
Question: Is it preattentive?
Conjunction → Gray + Square

Preattentive Processing

- Conjunction search
  - Conjunction search usually not preattentive
  - Exceptions: All related to space perception.

    E.g. Preattentive pairs
    - Spatial grouping on the XY plane (Triesman, Gormican, 1988)
    - Stereoscopic depth (Nakayama, Sliverman, 1986)
    - Convexity, concavity and color (D'Zmura, 2997)

Preattentive Processing



Preattentive Processing

- Highlighting -- one of each

- Must stand out on some simple dimensions
  – color,
  – simple shape = orientation, size
  – motion,
  – depth

Preattentive Processing

- Rapid visual search (10 msec/item)
- Makes symbols distinct
- Based on simple visual attributes
- Faces are not preattentive

Perceptual Channels

- Color → 3 channels (R, G, B)
- Shape → 2 channels (size and orientation)
- Motion → 2 channels ??
- Texture → 2 channels ??
- Position → 2 channels (X, Y)

- Total: ~ 10 channels.

Perceptual Channels

- Categories: form, color motion, spatial position.
  - Line orientation, length, width
  - Size
  - Curvature
  - Spatial grouping
  - Blur
  - Added marks
  - Numerosity (1,2, or 3 objects)
  - Color
  - Hue
    - Intensity
  - Motion
    - Flicker
    - Direction of motion
  - Spatial position
    - Two dimensional position
    - Stereoscopic depth
  - Convex/concave shape from shading

Perceptual Channels

- Not all preattentive effects are equally strong.
- The strongest effects are based on
  - Color
  - Orientation
  - Size
  - Contrast
  - Motion or blinking
  - Line curvature → weaker effects
  - "Which visual dimensions are preattentively stronger" is always depends on the strength of the particular feature and the **context.**

Perceptual Channels

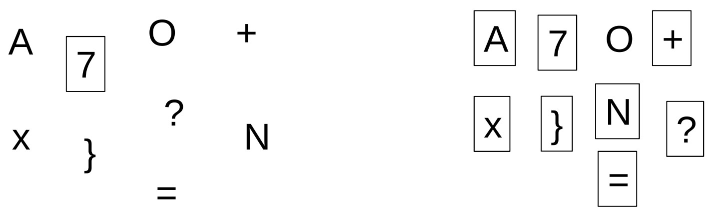
- Asymmetries
  - Adding marks to highlight a symbol is generally better than taking them away.

Insanity: doing the same thing over and over again and expecting different results. Albert Einstein

When you are courting a nice girl an hour seems like a second. When you sit on a red-hot cinder a second seems like an hour. That's relativity. Albert Einstein

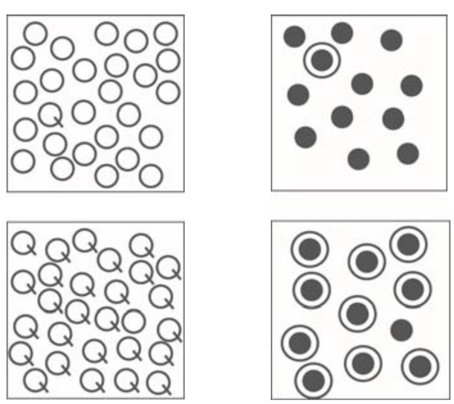
Perceptual Channels

- Asymmetries
  - Adding marks to highlight a symbol is generally better than taking them away.



Highlighting

- Asymmetries
  - Adding marks to highlight a symbol is generally better than taking them away.



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