INFORMATION VISUALIZATION

PERCEPTION and COLOR

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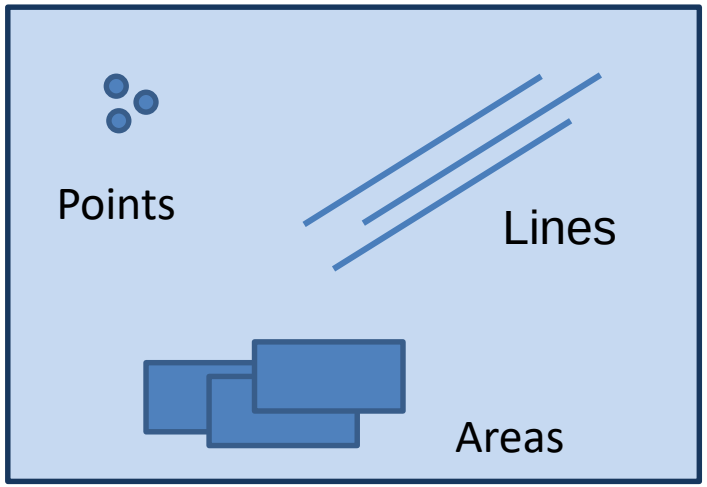
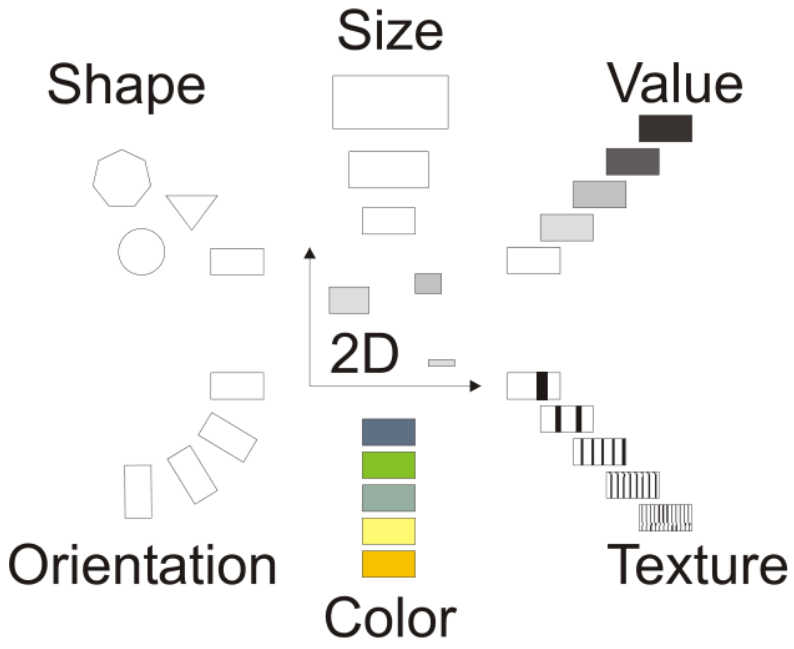
Recap

- In Lecture 1 you learned about the basic components of visualization
  - Marks and visual variables





and others

Summary

- You know that the main building blocks are **marks**
- Marks are modified by **visual variables**
- Visual variables have **specific characteristics**
- These characteristics influence how the data will be **perceived**

Today you will

- Learn details about the **perception of color** and **other visual encodings**
- See that the vision system is **quicker and better** at detecting certain visual encodings

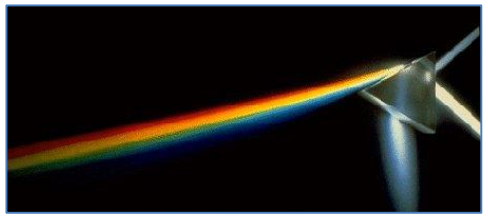
WHAT IS COLOR?

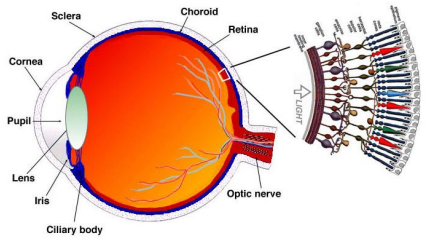
Experiment

What is Color?

- Color is a **human reaction** to light (change)

What is Color?





"Yellow"

Physical World → **Visual System** → **Mental Models**

Lights, surfaces, objects

Eye, optic nerve, visual cortex

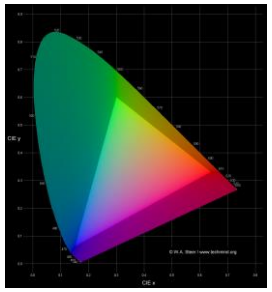
Red, green, brown

Bright, light, dark, vivid, colorful, dull

Warm, cool, bold, blah, attractive, ugly, pleasant, jarring

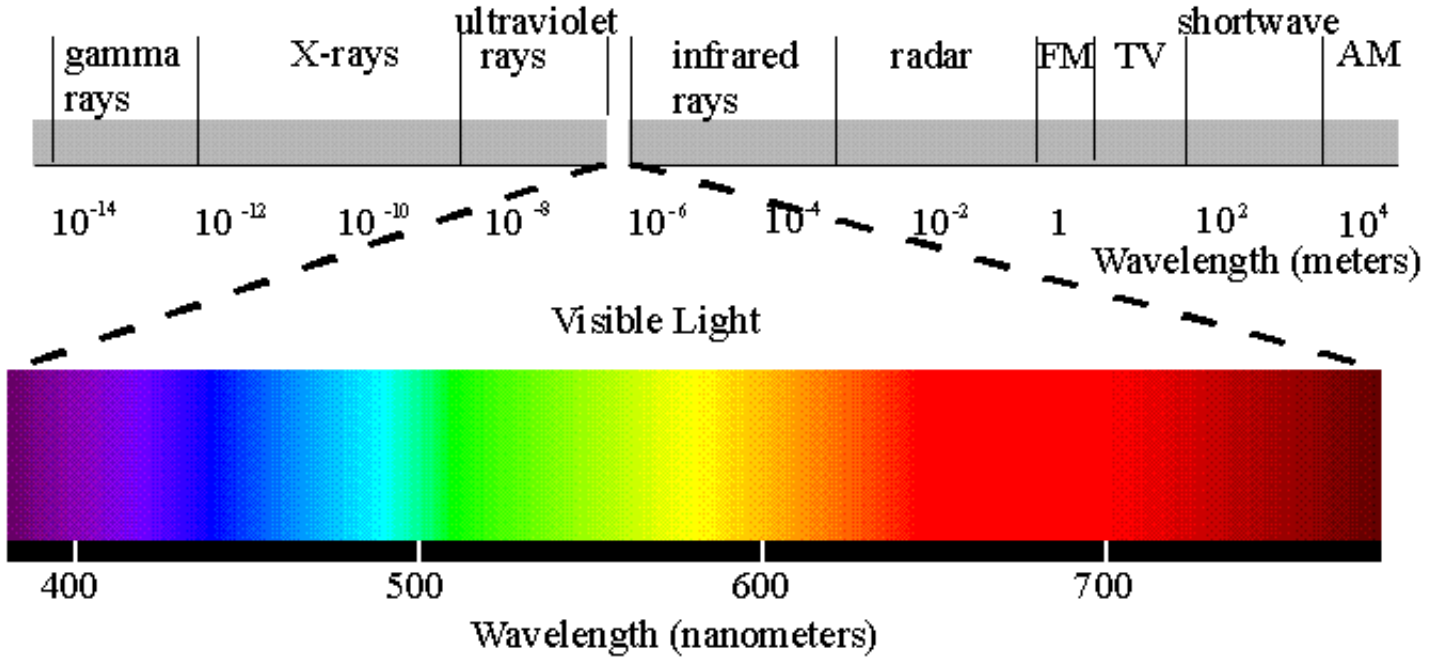
Color Models

RGB, CMYK, CIE XYZ, …



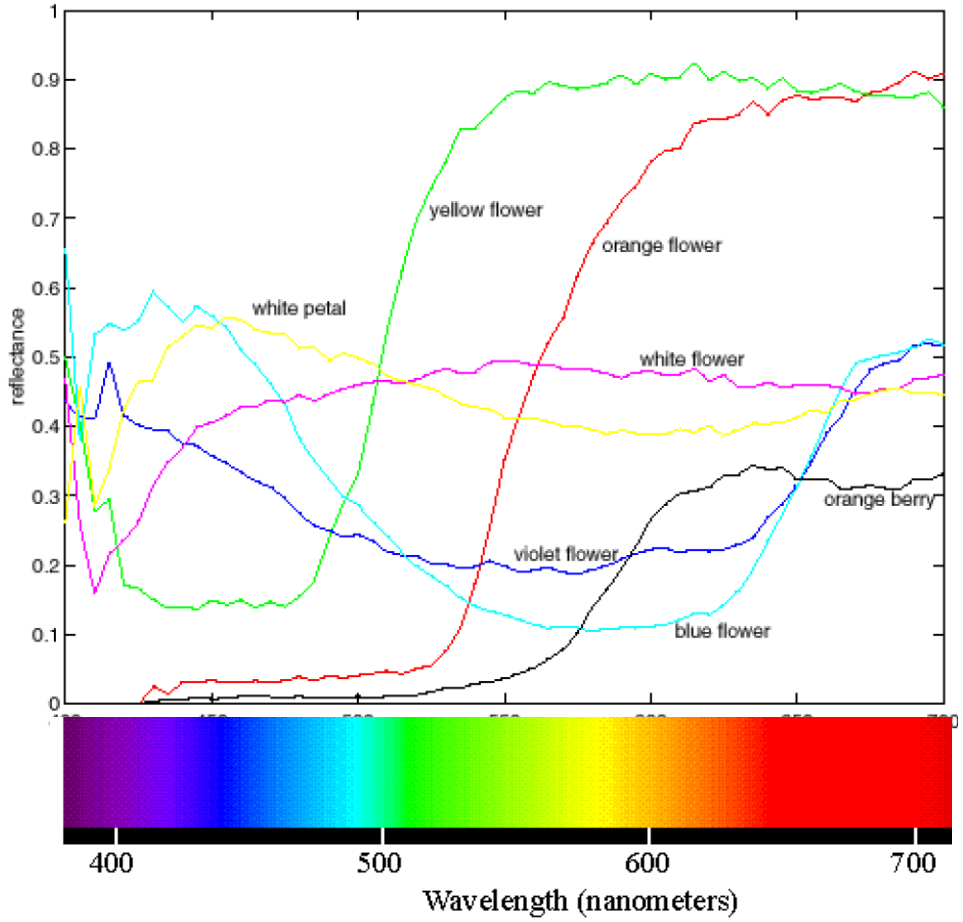
Physical World

- Light is **radiation** in a range of wavelengths: 370–730 nm
- Light of a single wavelength is **monochromatic**

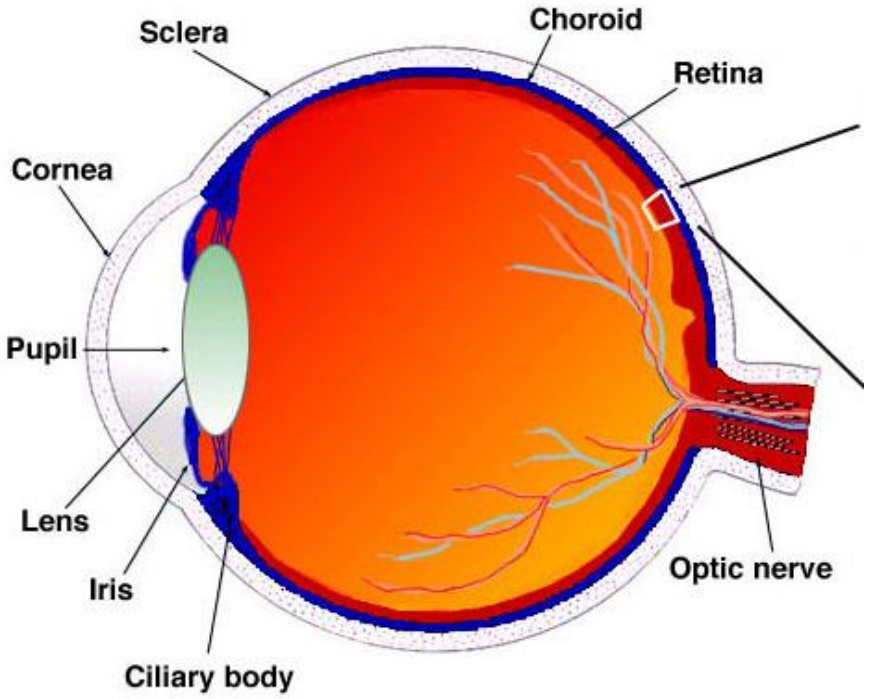


Physical World

- Light is **radiation** in a range of wavelengths: 370–730 nm
- Light of a single wavelength is **monochromatic**
- Most **colors are not** monochromatic



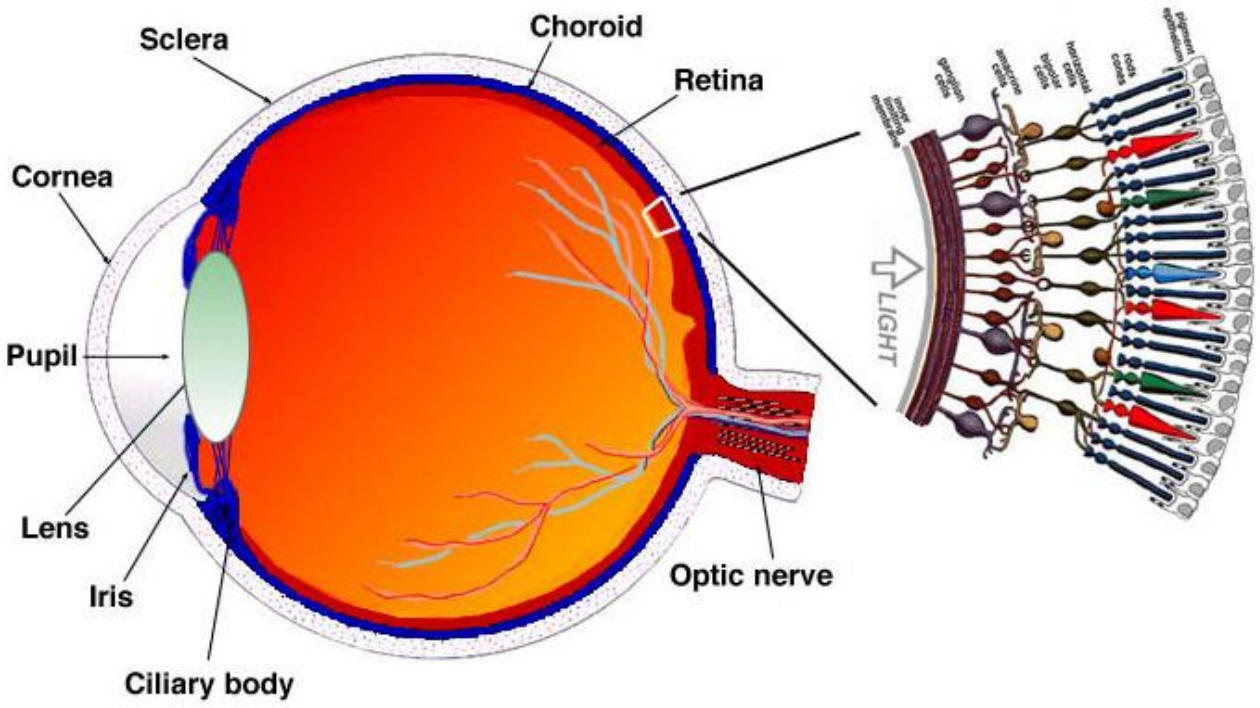
Physical World➡Visual System



- You **do not** see the spectrum of light
- Eyes make limited measurements
- Eyes physically adapt to circumstance
- You brain adapts in various ways

Simple Anatomy of the Retina, Helga Kolb

Physical World➡Visual System



Rods

- No color (sort of)
- All over the retina
- More sensitive

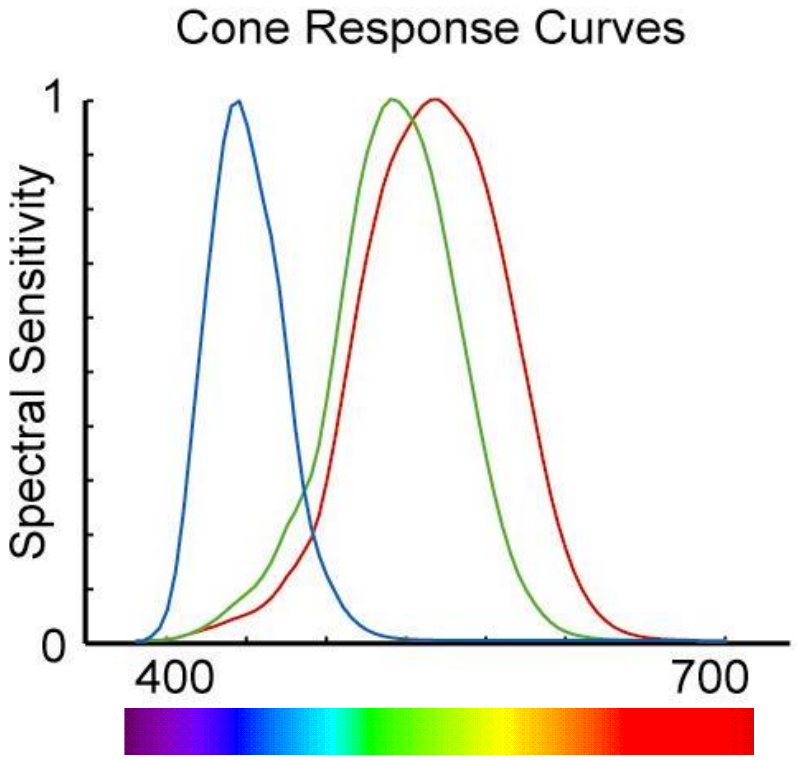
Cones

- Three different kinds of “color receptors”
- Mostly in the center
- Less sensitive

Simple Anatomy of the Retina, Helga Kolb

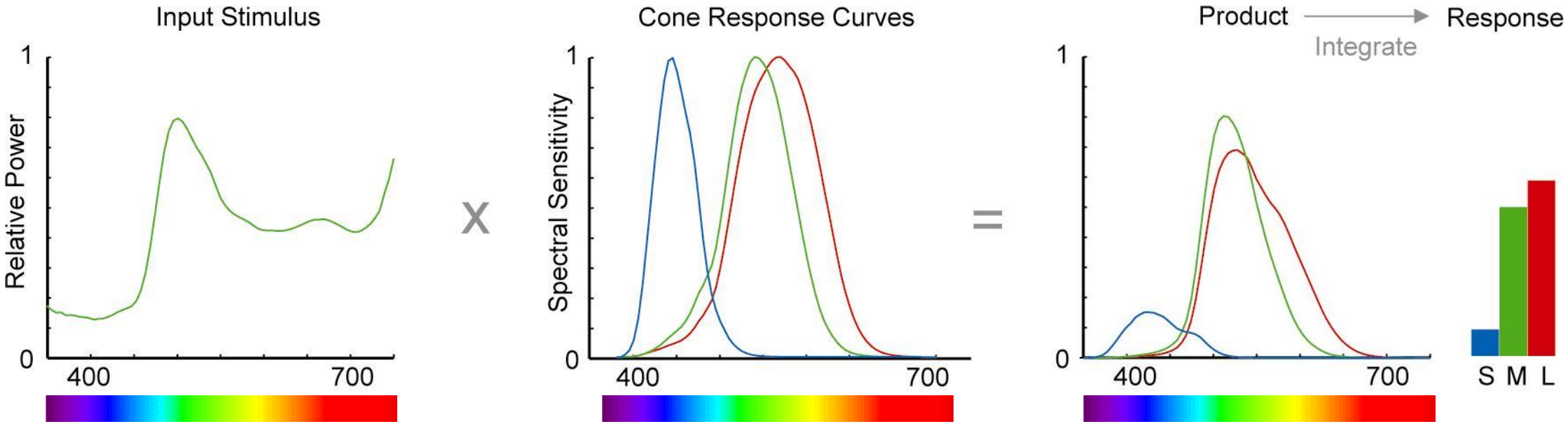
Cone response

- Three different types of cones
  - Long cones (red)
  - Middle cones (green)
  - Short cones (blue)
- Sensitive to different wavelengths



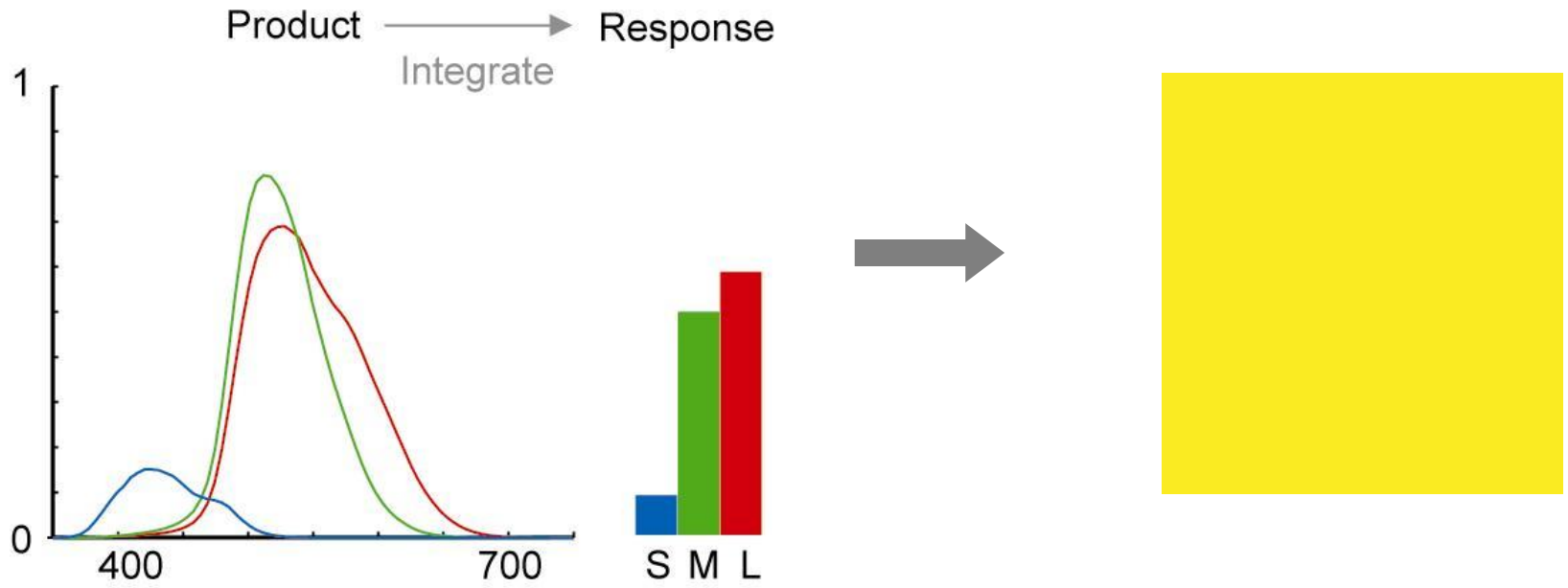
A Field Guide to Digital Color, Maureen Stone (2005)

Cone Response



A Field Guide to Digital Color, Maureen Stone (2005)

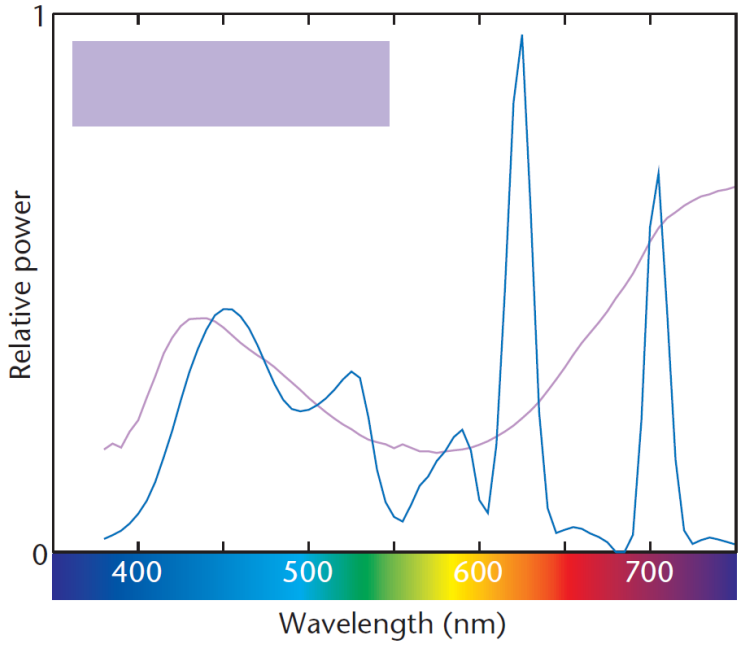
Visual System ➞ Color Models



A Field Guide to Digital Color, Maureen Stone (2005)

Two Principles of Color Perception

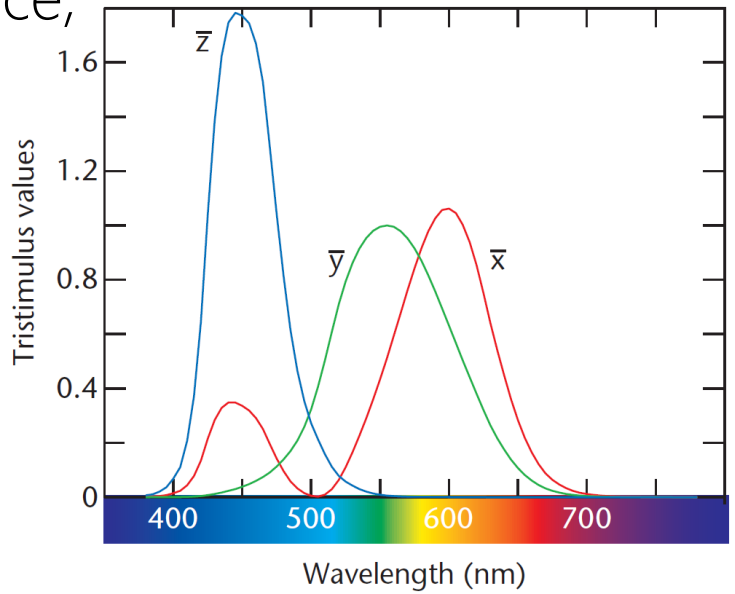
- Trichromacy
  - Representation of all spectral distributions possible with **three values** without information loss (w.r.t. the visual system)
    → essential for CS!
- Metamerism
  - Different spectra exist that produce the same trichromatic response



A Field Guide to Digital Color, Maureen Stone (2005)

XYZ Color Model

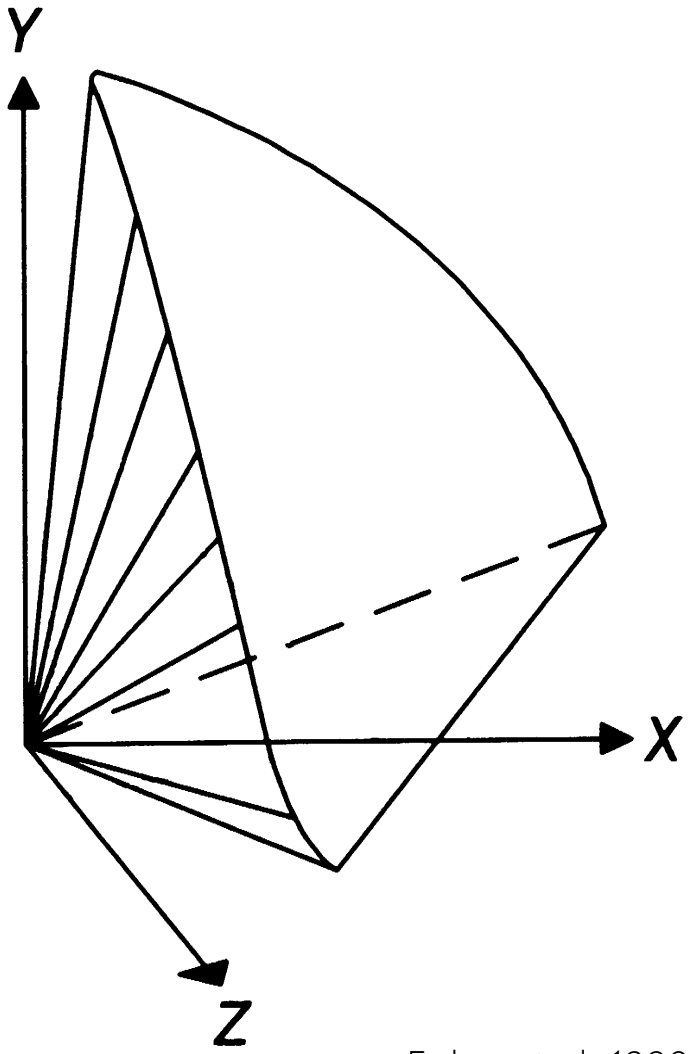
- Definition of three primary colors: X, Y, Z
- Color-matching functions
  - The numerical description of the chromatic response of the *observer*
  - Non-negative
  - Mathematically derived from color matching experiments
- Y follows the standard human response to luminance, i.e., the Y value represents perceived brightness
- Can represent all perceivable colors



A Field Guide to Digital Color, Maureen Stone (2005)

XYZ Color Model

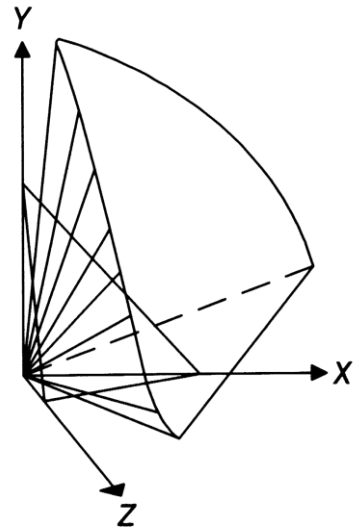
- XYZ CIE Color Space
  - Plotting XYZ space in 3D
  - All colors that are perceivable by humans form a deformed cone
  - *X*, *Y*, and *Z*-axes are outside this cone

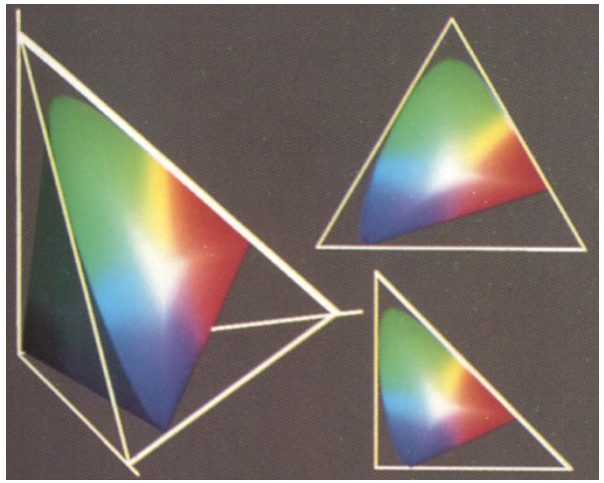


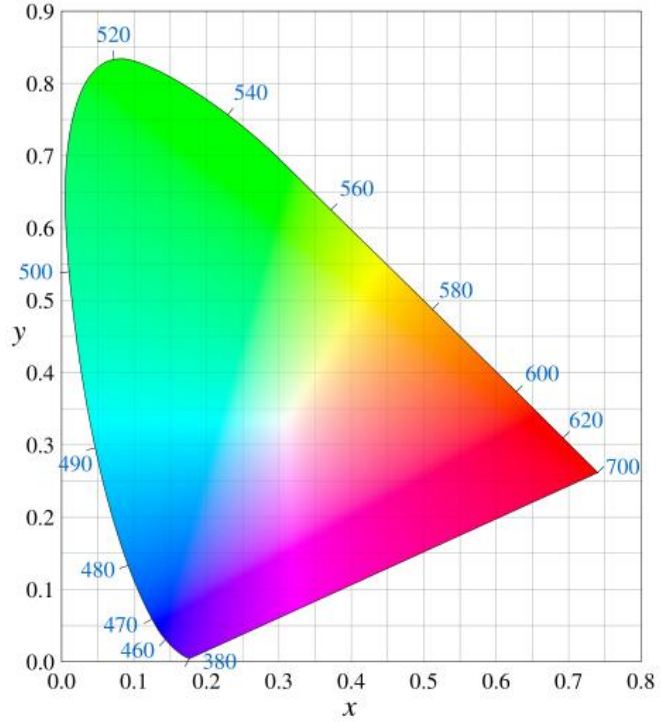
Foley et al. 1990

CIE Chromaticity Diagram

- Projection of XYZ space onto X+Y+Z = 1
  - To factor out a color's brightness: x = X/(X+Y+Z) y = Y/(X+Y+Z)
- Monochromatic colors on curved boundary



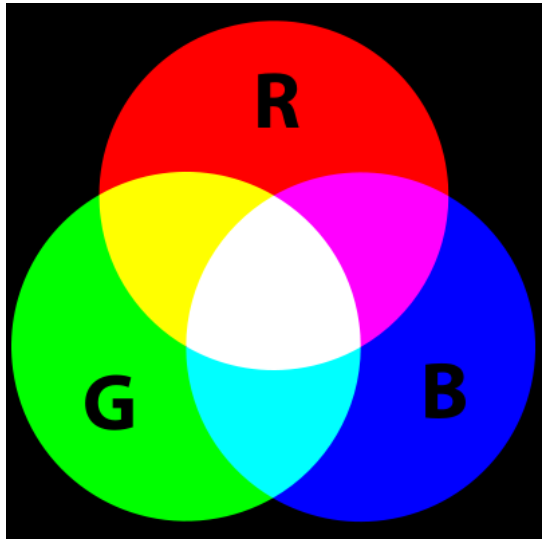


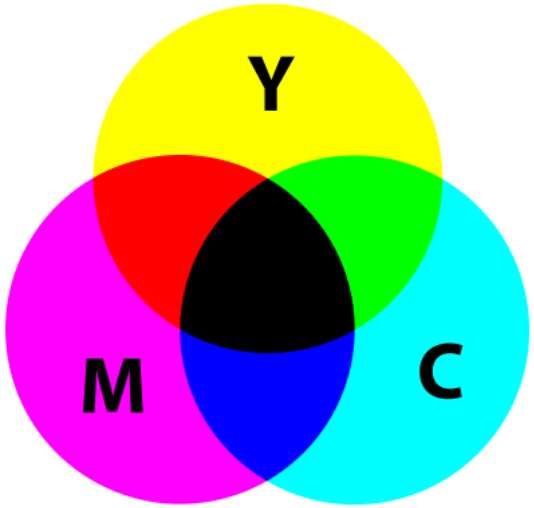


Foley et al. 1990

RGB & CMYK

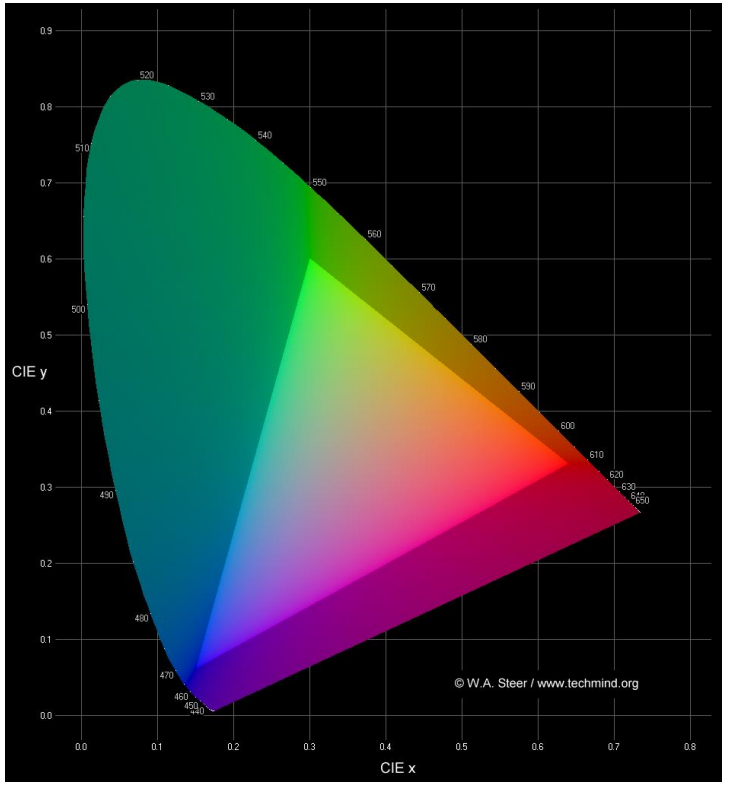
- (Physical) color mixing depends on color production process
  - Light emission: additive mixing (e.g., CRTs)
    - **RGB model** (red, green, blue)
  - Light absorption: subtractive mixing (e.g., printing process)
    - **CMY(K) model** (cyan, magenta, yellow)





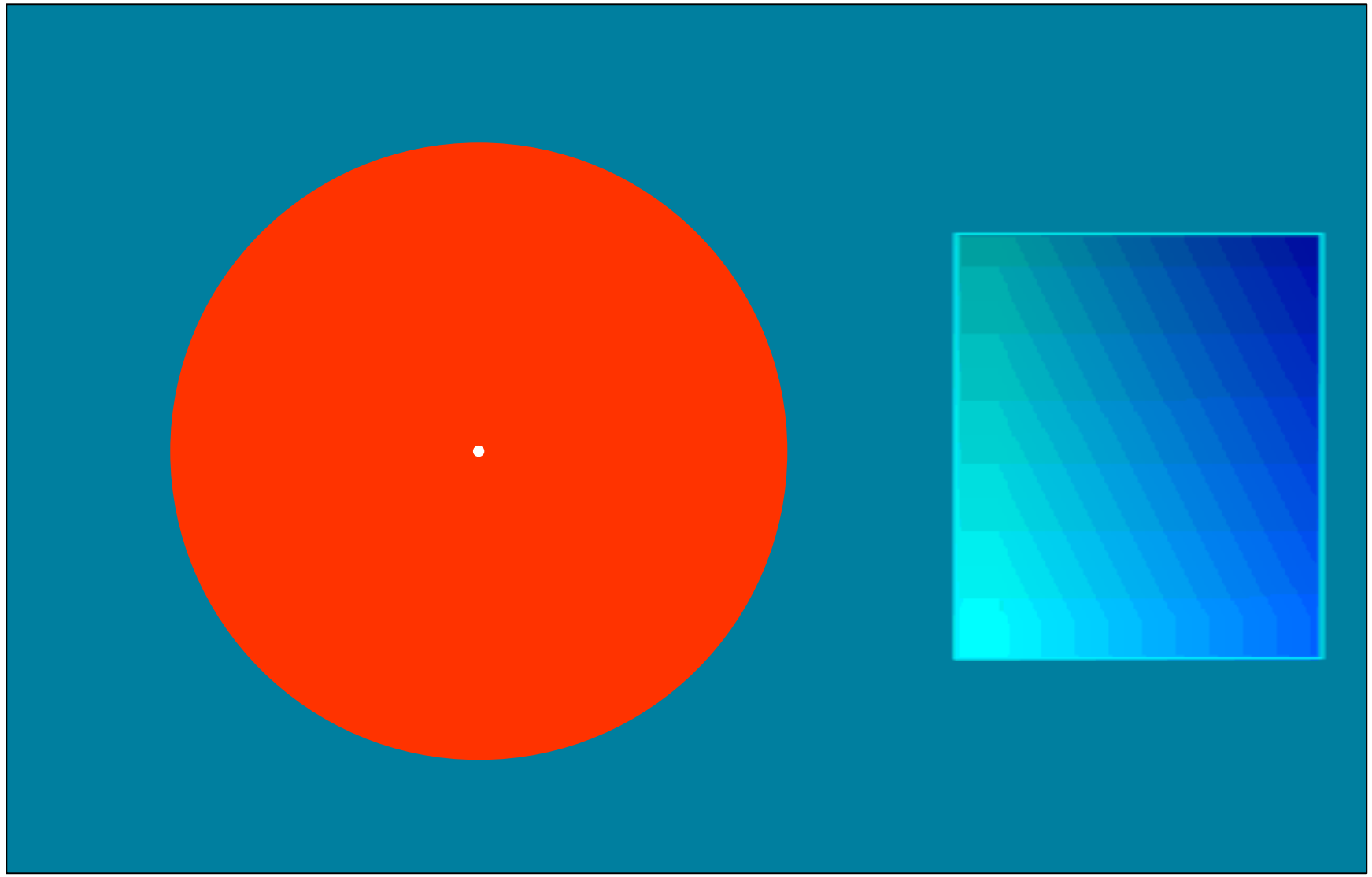
RGB

- Can RGB Represent All Visible Colors?
  - No, because all colors form horseshoe shape in CIE chromaticity diagram and RGB gamut is triangular
  - But my shiny new 30" UHD OLED is state-of-the-art, it can surely show all colors!"
    → Let's see a color that it cannot show …



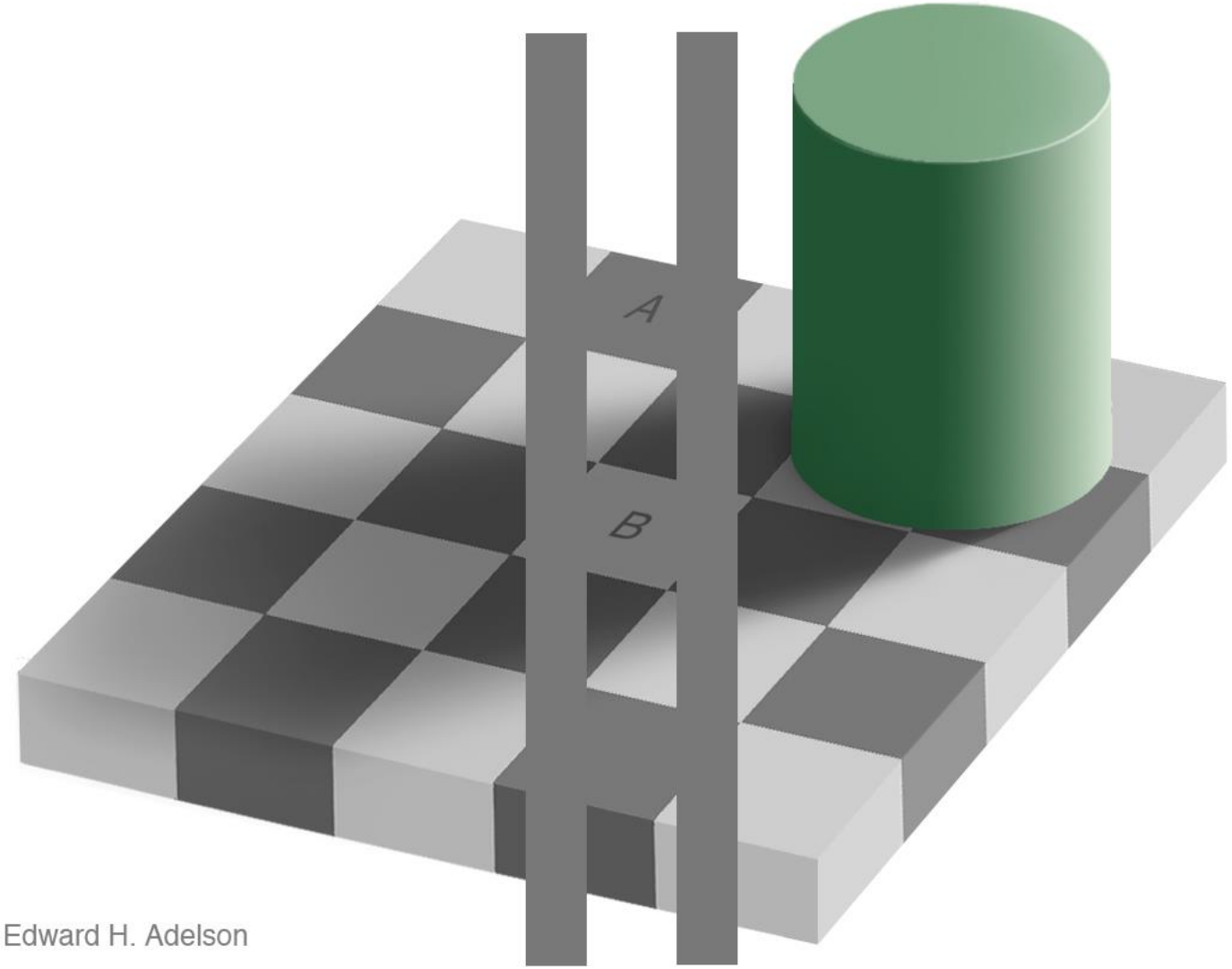
http://www.techmind.org/

REAL Cyan



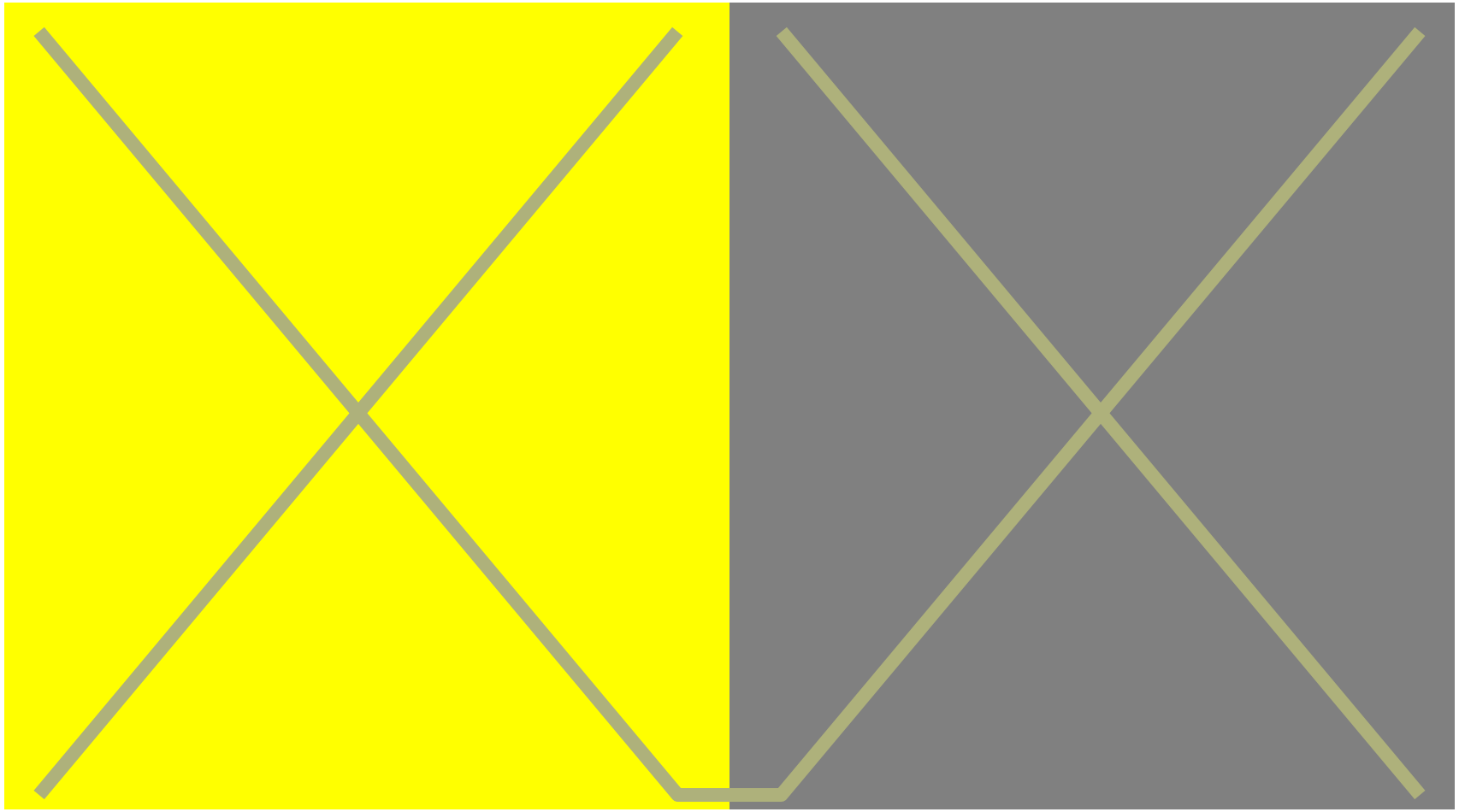
COLOR PERCEPTION

Visual System ➞ Color Perception



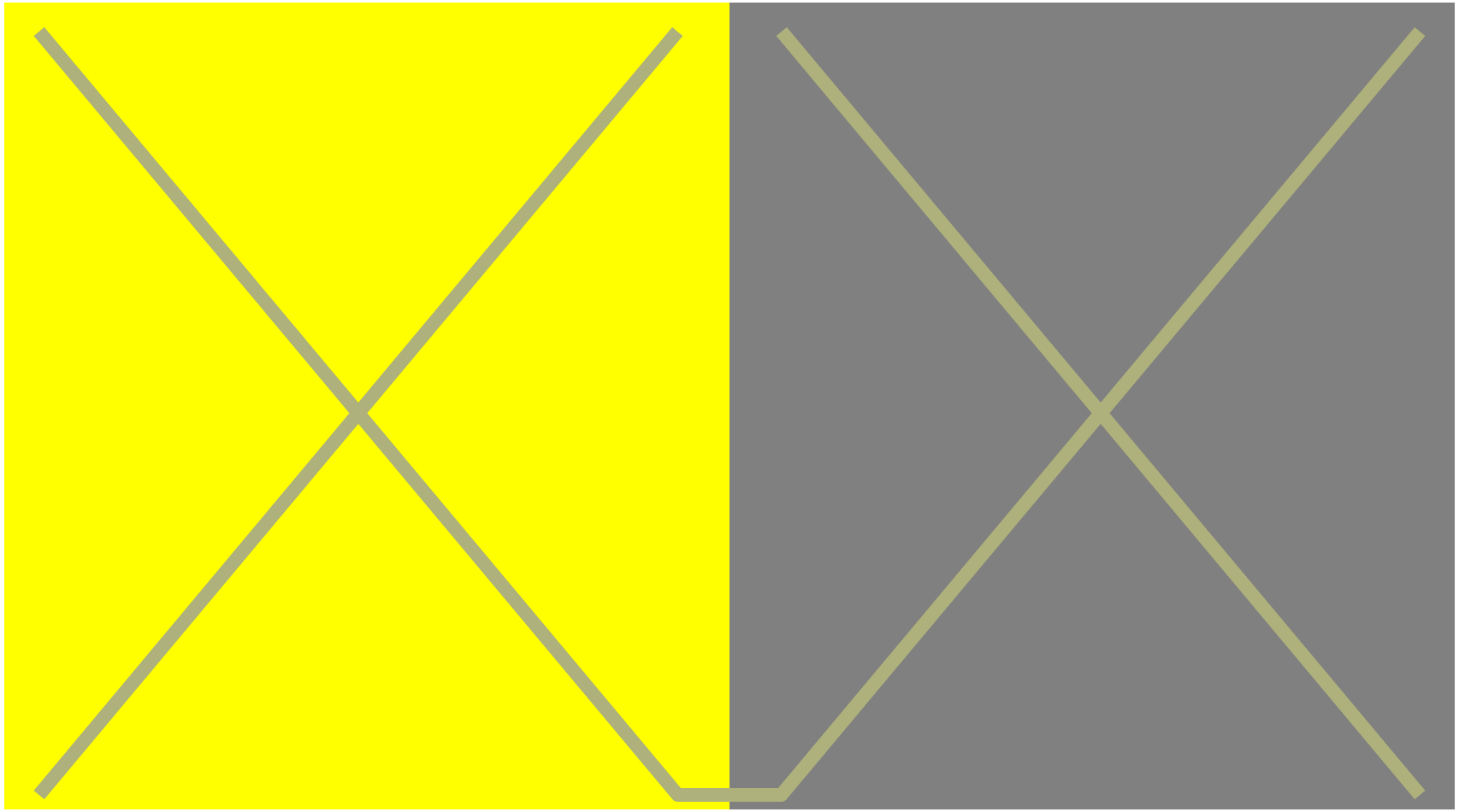
Slide adapted from Stone & Zellweger

Visual System ➞ Color Perception



Josef Albers

Simultaneous Contrast

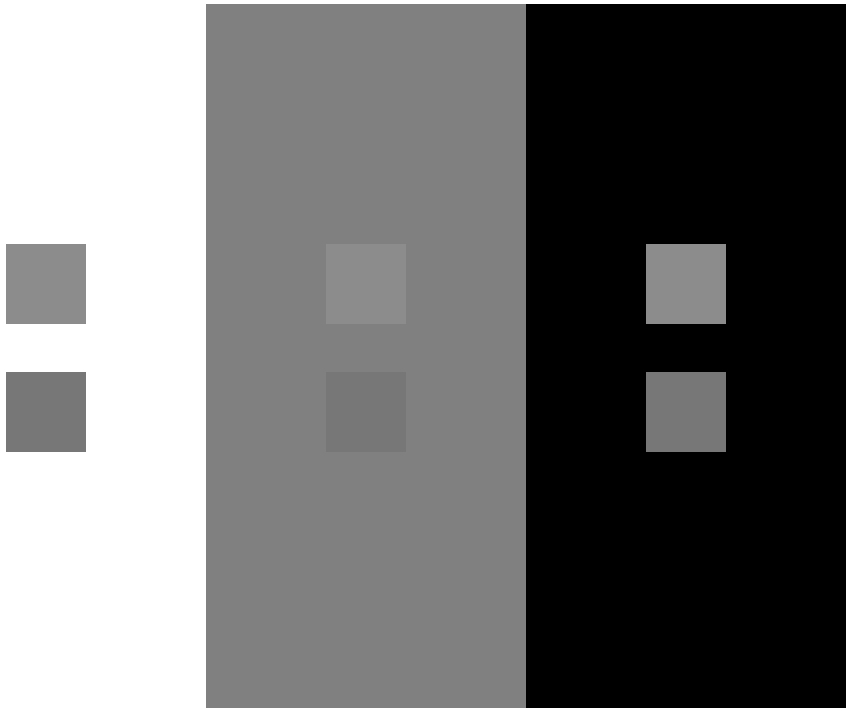


Josef Albers

Bezold Effect

Crispening

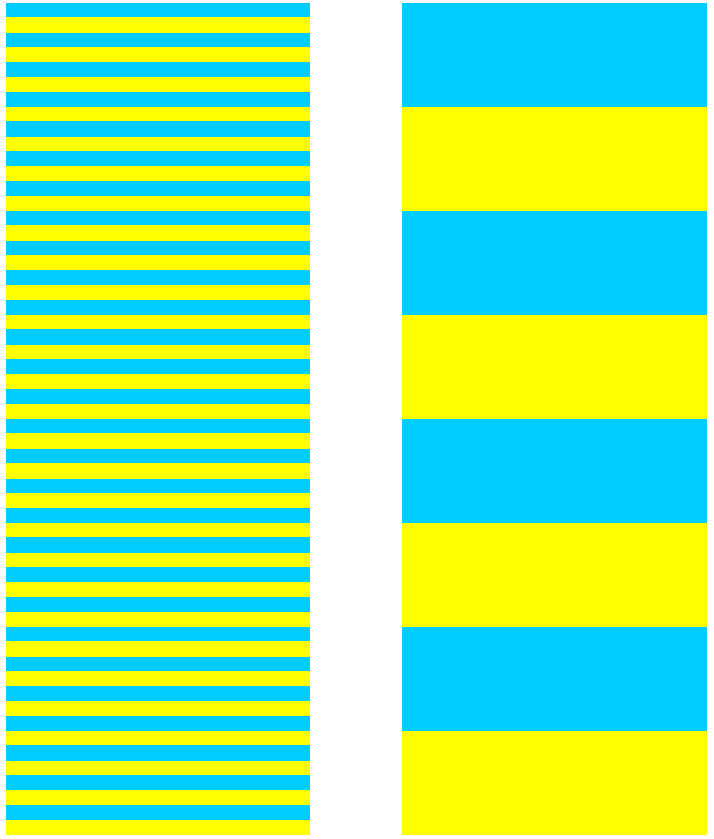
- Perceived difference depends on background



Color Appearance Models, Fairchild

Spreading

- Spatial frequency
  - Small text, lines, glyphs
  - Image colors
- Adjacent colors blend



Redrawn from *Foundations of Vision*

Color Perception ➞ Color Naming

What color is this?

"Yellow"

Color Perception ➞ Color Naming

What color is this?

"Blue"

Color Perception ➞ Color Naming

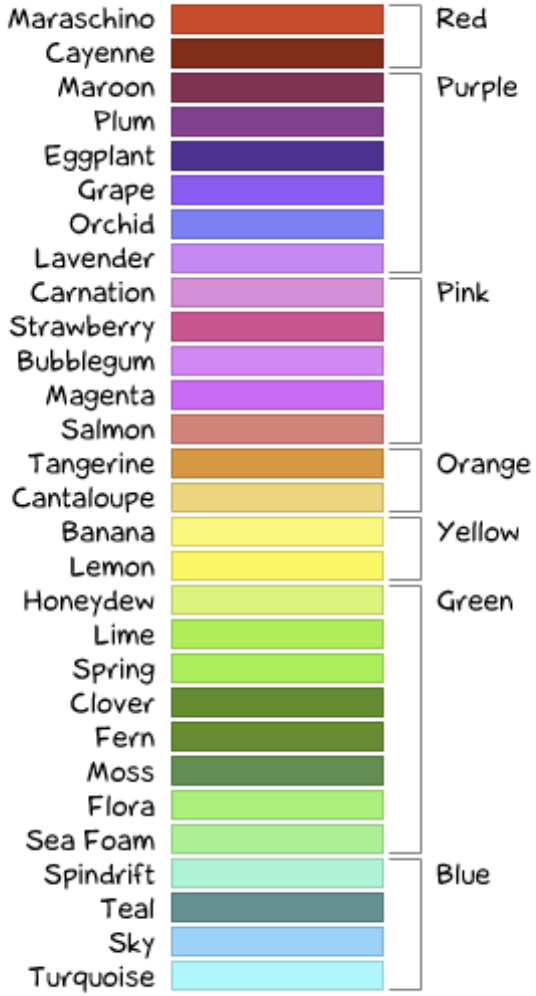
What color is this?

"Teal?"

"Turquoise?" *"Blue-Green?"* *"Sarcelle?"*

Color according to gender?

Color names if you're a girl...



Color names if you're a guy...

Doghouse Diaries
"We take no as an answer."

xkcd

Color according to XKCD

A crowdsourced color-labeling game

~5 million colors

~222,500 user sessions

http://blog.xkcd.com/2010/05/03/color-survey-results/

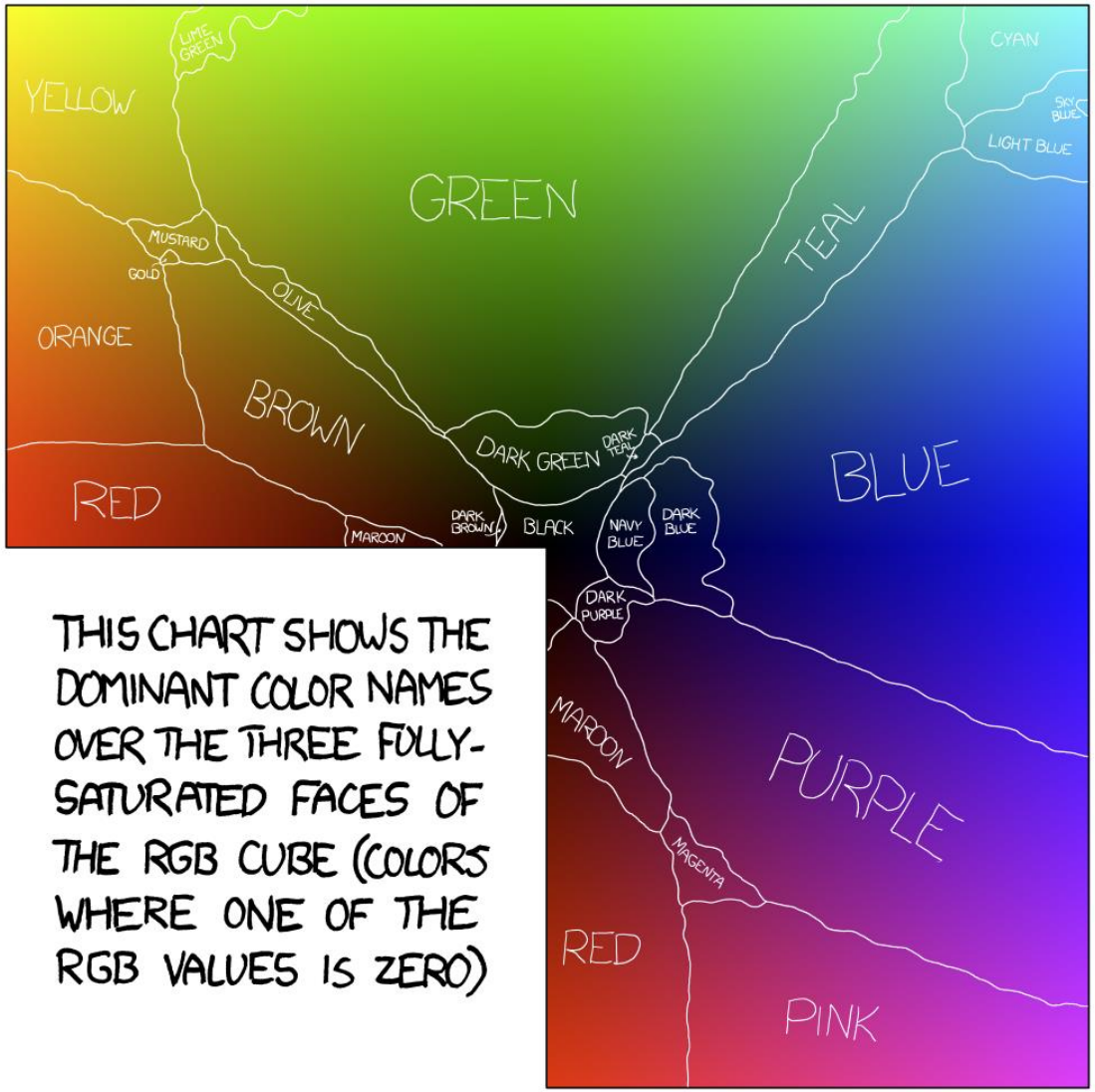
Color according to XKCD

xkcd

Color Naming

- We associate and group colors together
- We often use the same name for different colors

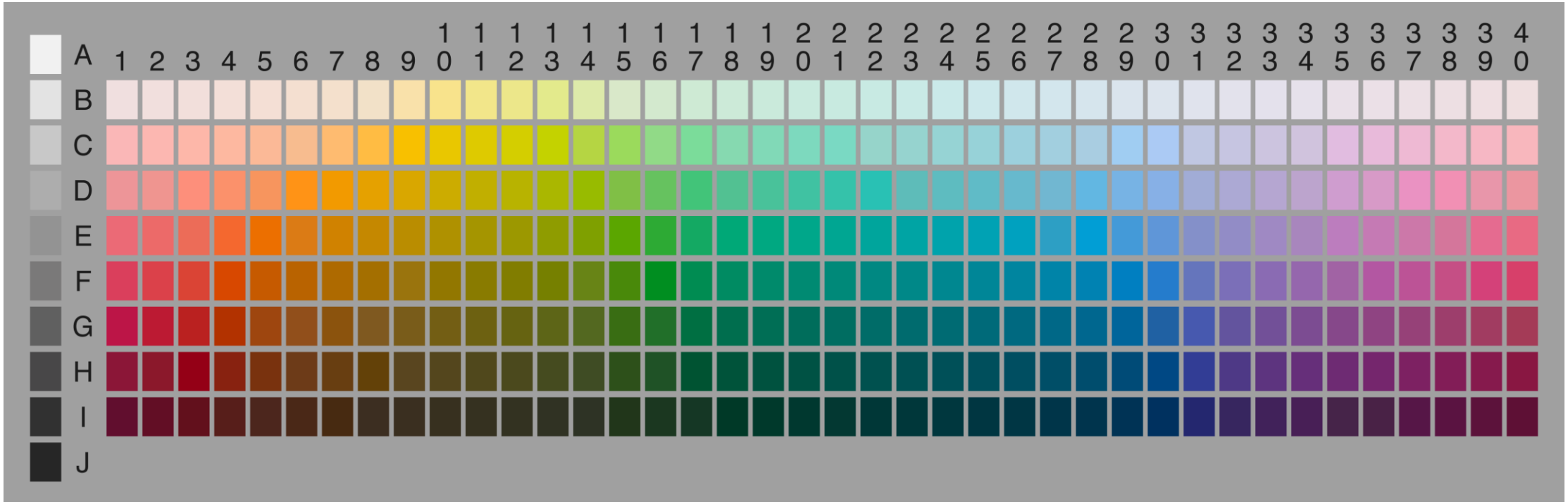
Are there natural boundaries?



xkcd

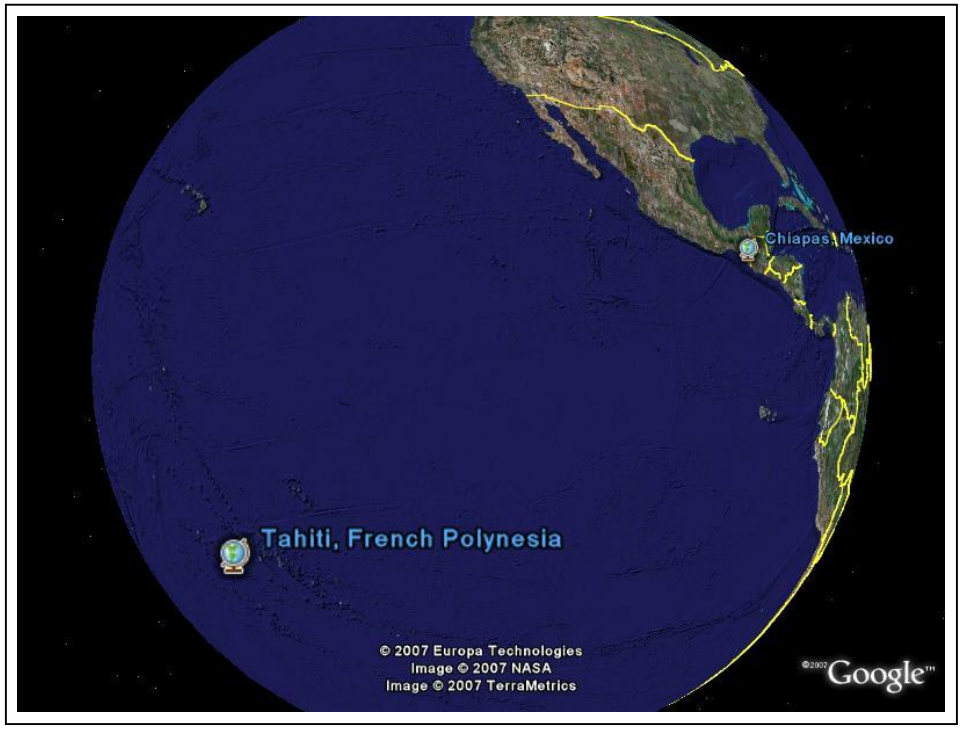
World Color Survey

- Brent Berlin & Paul Kay 1969
- Basic color terms
- Surveyed 2616 speakers of 110 languages using 400 different color chips



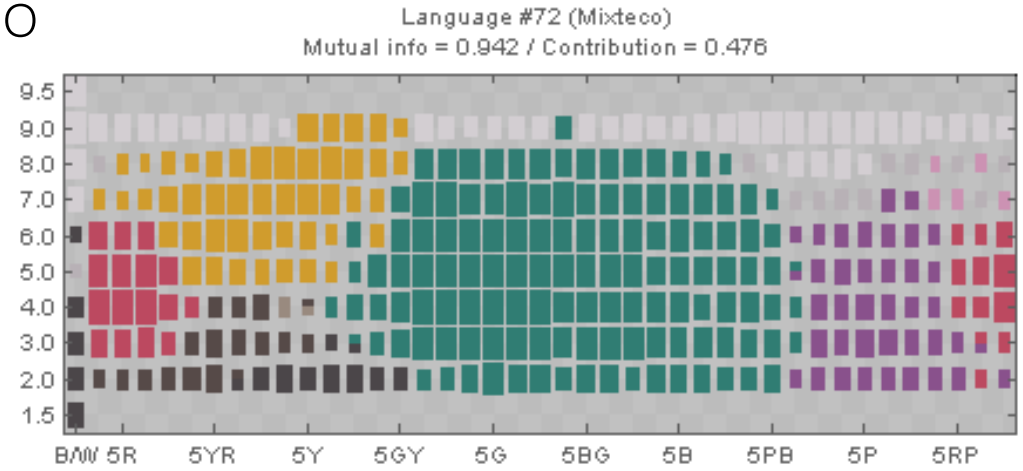
World Color Survey

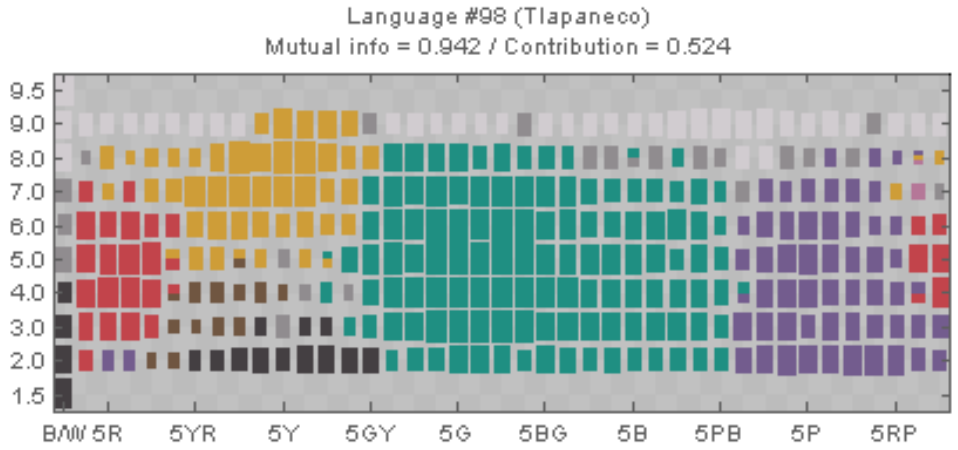
- Comparison of two specific places: Mexico and South Pacific



World Color Survey

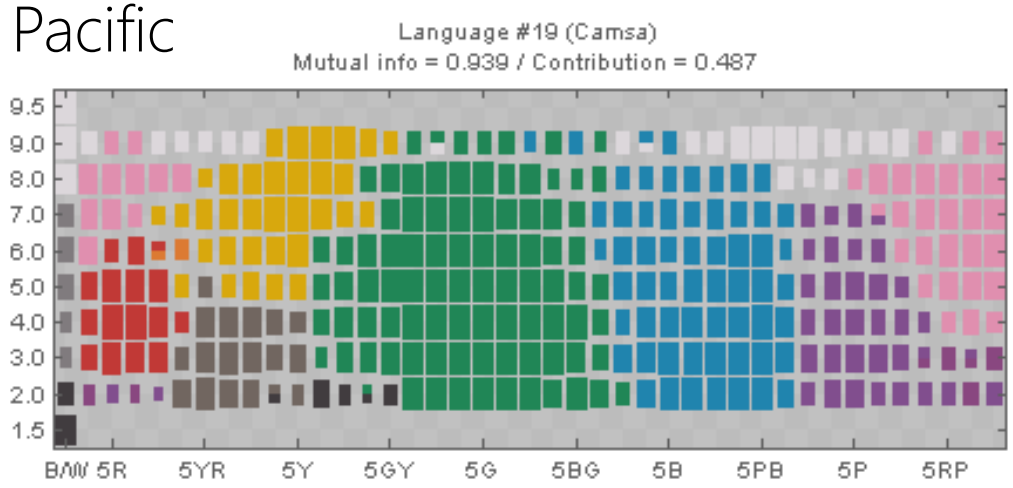
- Results from Mexico

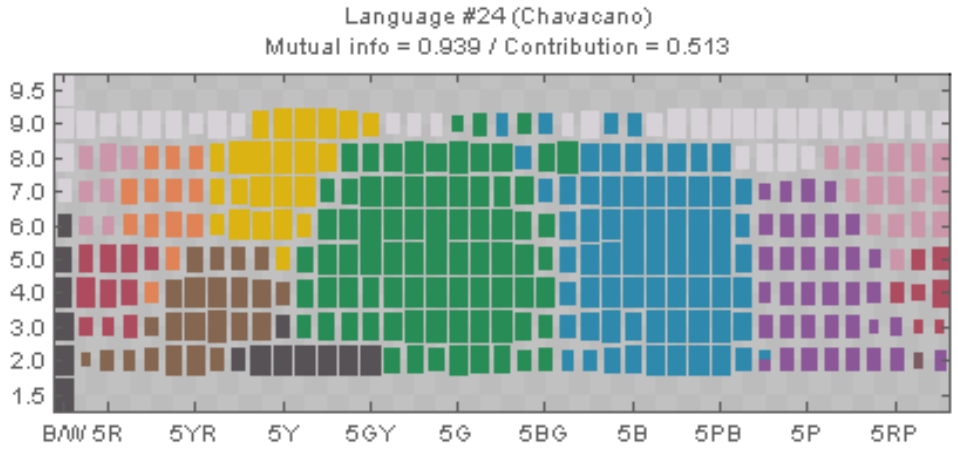




World Color Survey

- Results from South Pacific



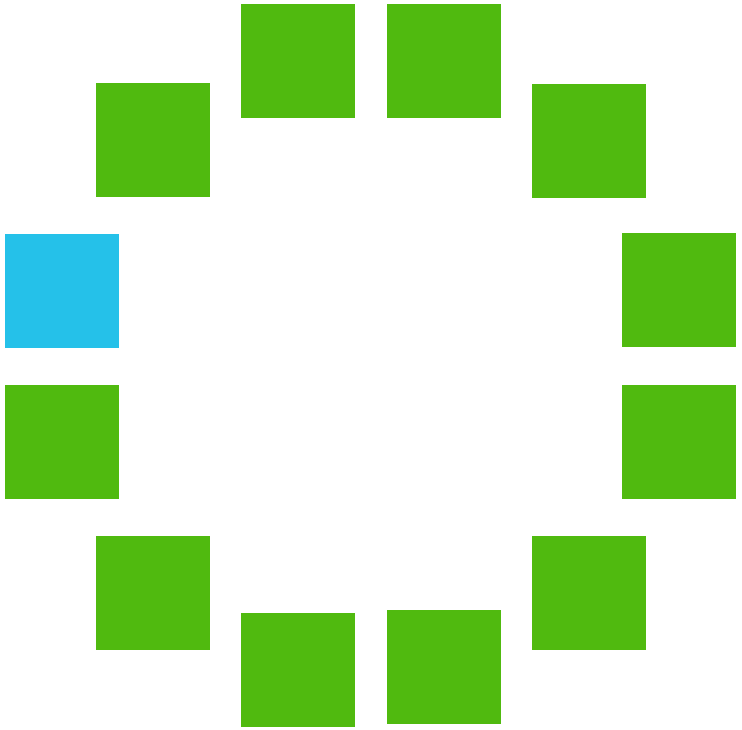


Language-color Interaction

- Himba tribe in Namibia – only few color words
  - **zoozu**: most dark colors (red, blue, green, violet)
  - **vapa**: white, also some yellow
  - **borou**: some green and blue colors
  - **dumbu**: many green but also red colors

Language-color Interaction

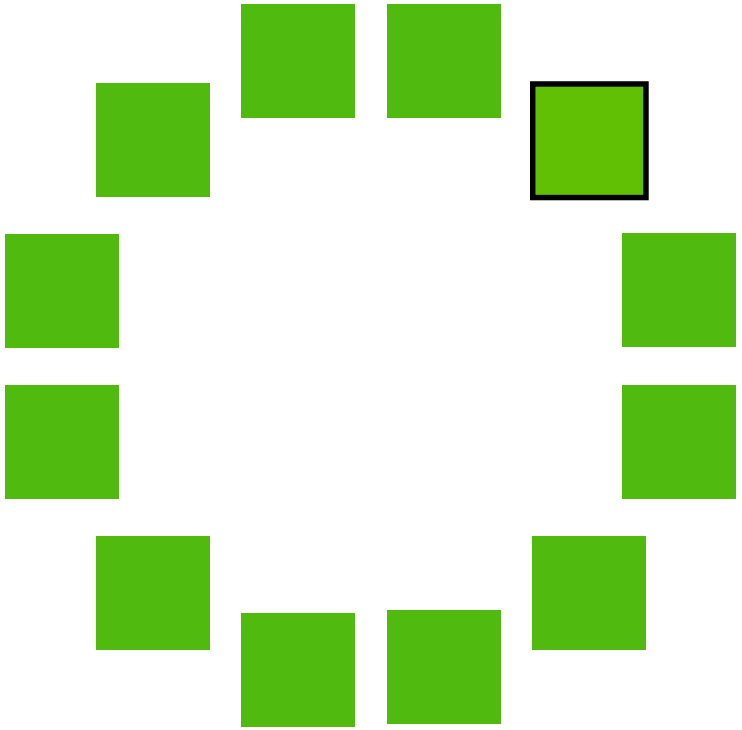
- Experiment: how long to find a differing color?

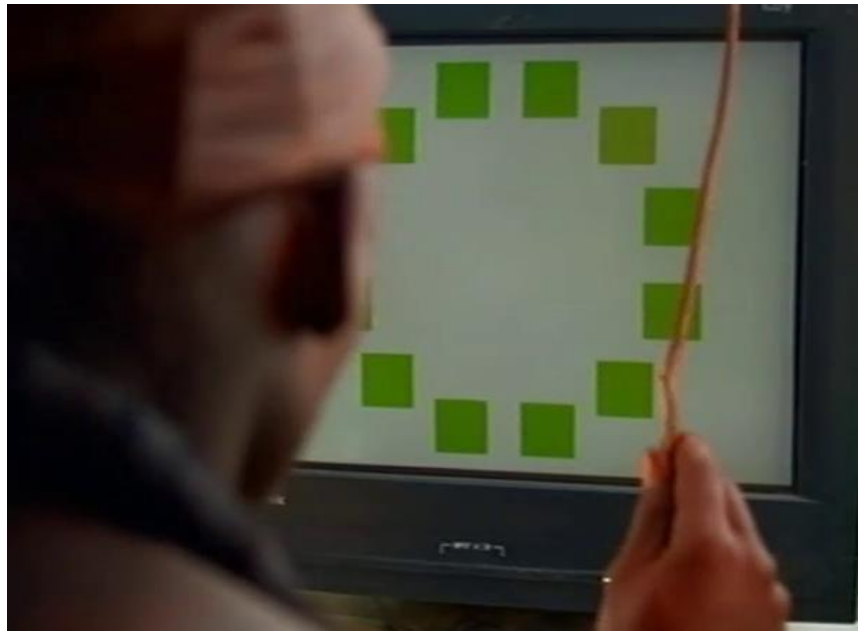


Difficult to impossible for Himba people

Language-color Interaction

- Experiment: how long to find a differing color?

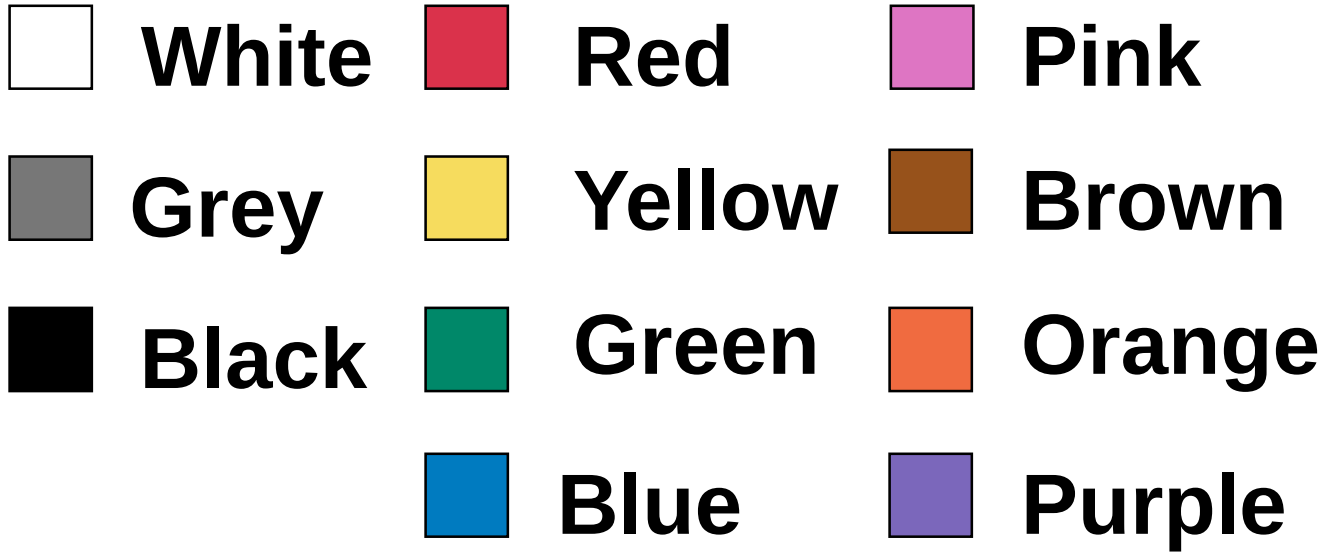




Easy for Himba people: different words for both types of green

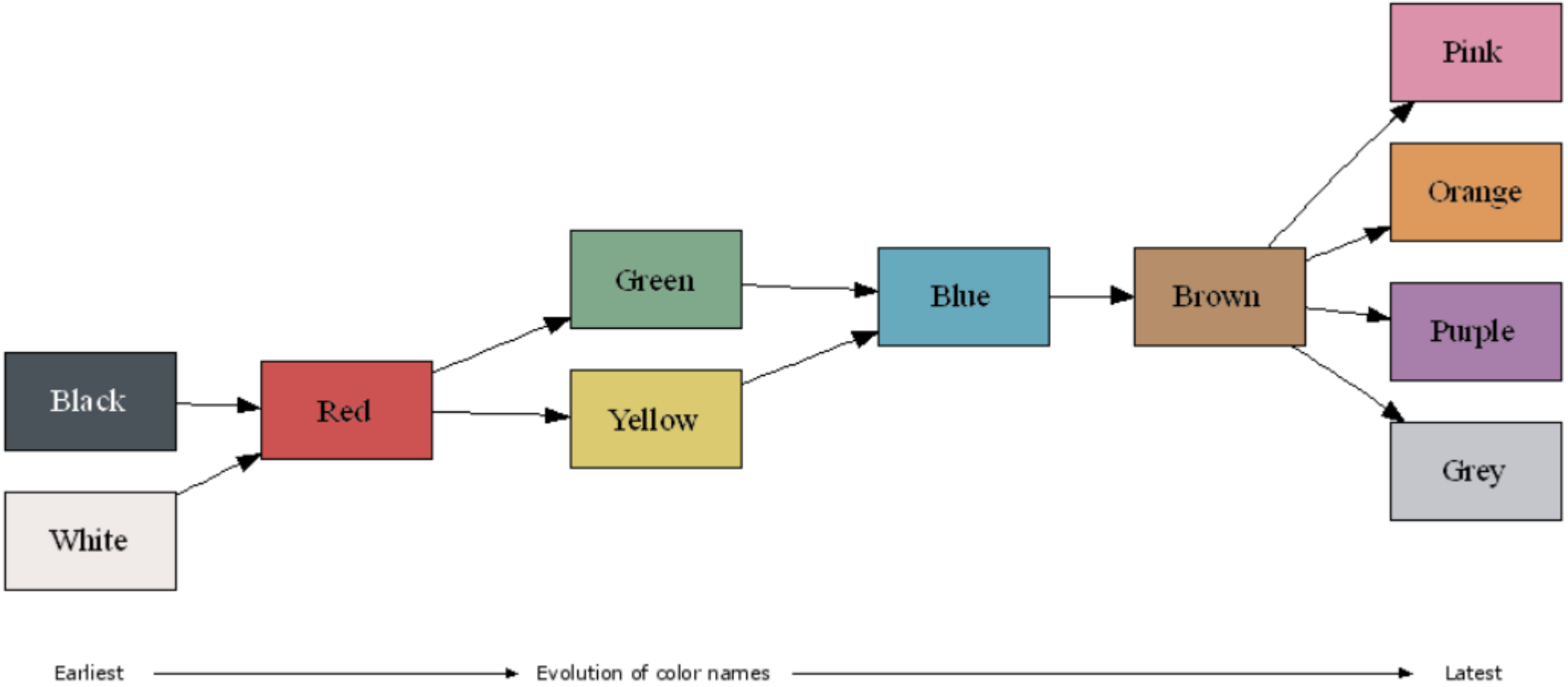
Basic Color Terms

- Universal (?)
- Basic color terms recur across languages



Basic Color Terms

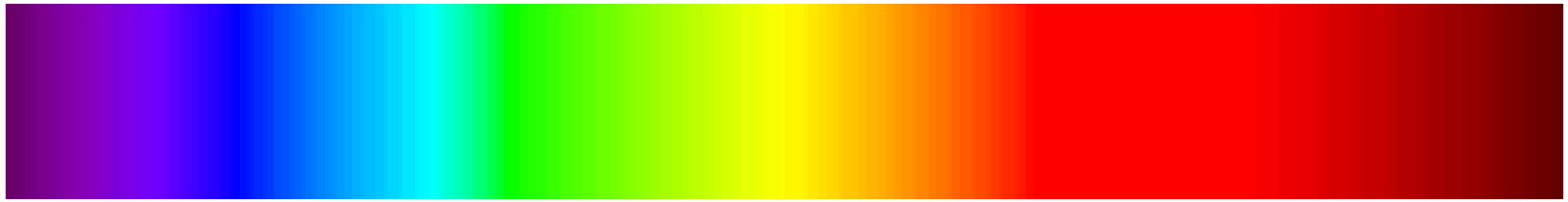
- Proposed universal evolution of color names across languages



COLOR FOR VISUALIZATION

Choosing Colors

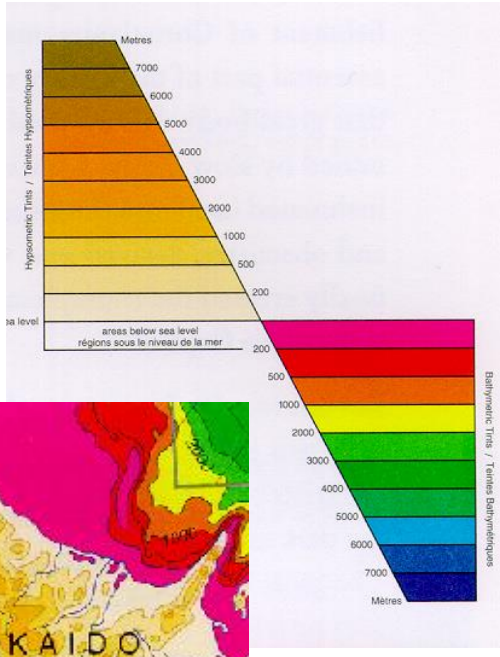
- Why are color choices important?
- Example: The Rainbow Color Scale
  - Represent data by varying hue across (approximately) the full range of visible wavelengths
  - One of the most common color scales in use today



- And it's (usually) a huge mistake!

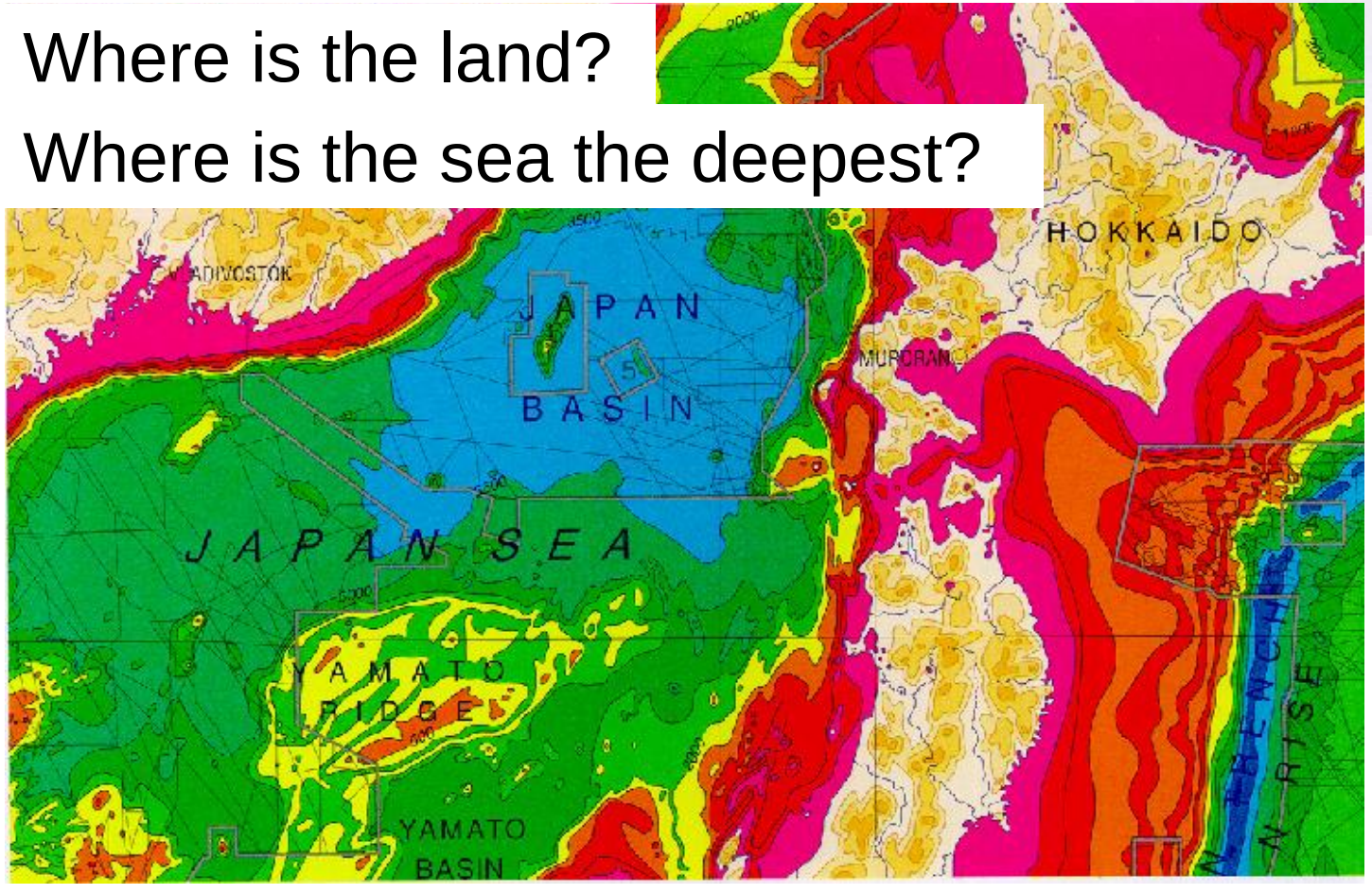
Choosing Colors

- General Bathymetric Chart of the Ocean
- Every color mark signals: longitude, latitude, sea/land depth/altitude



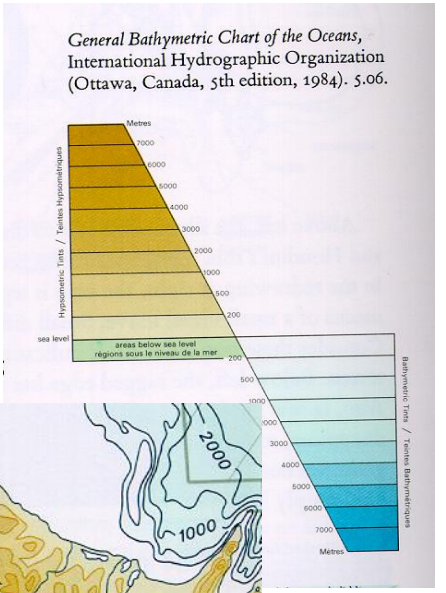
Where is the land?

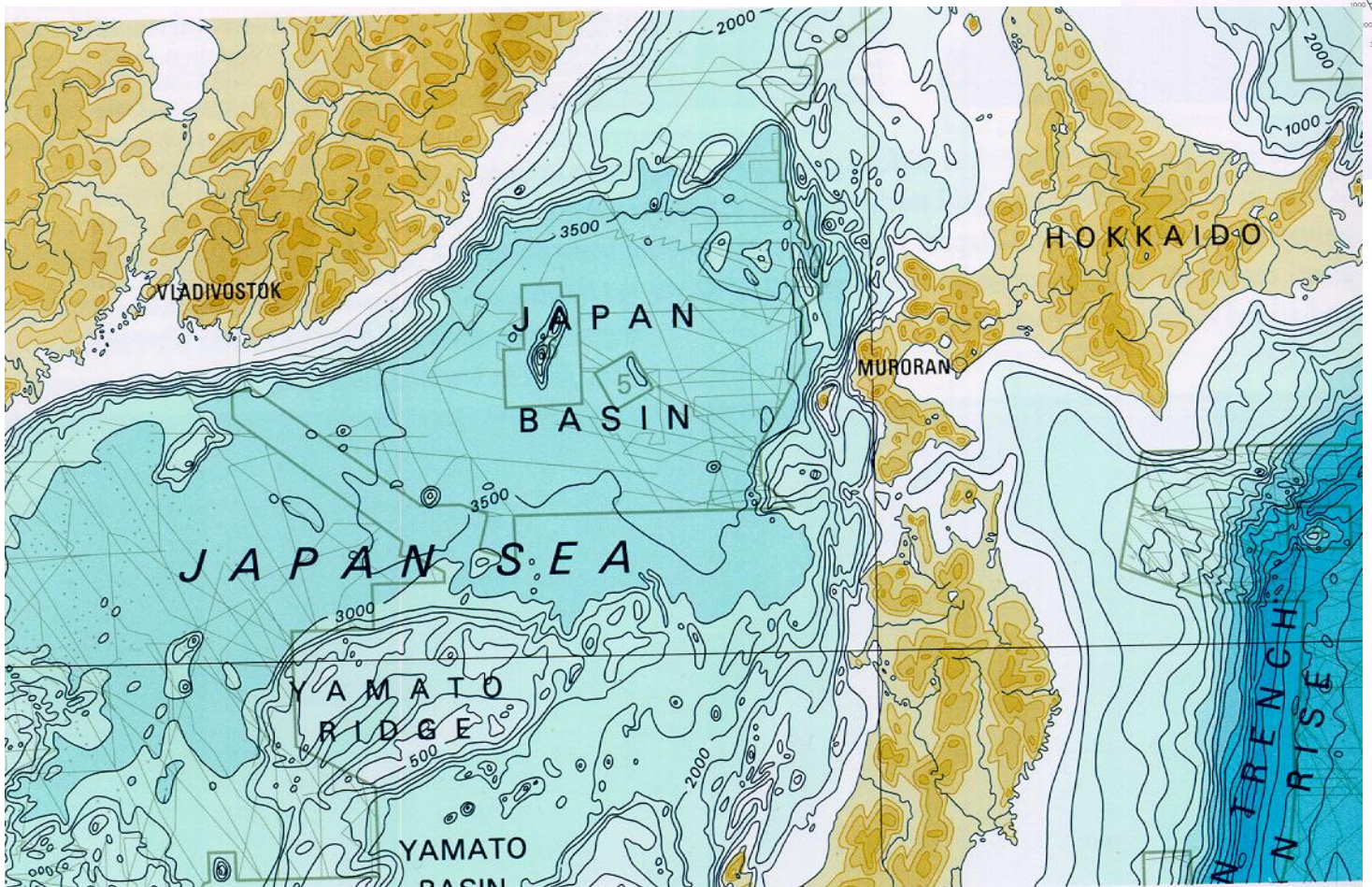
Where is the sea the deepest?



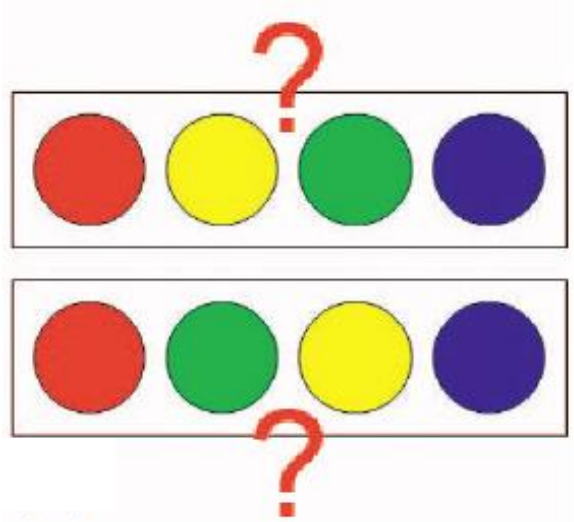
Choosing Colors

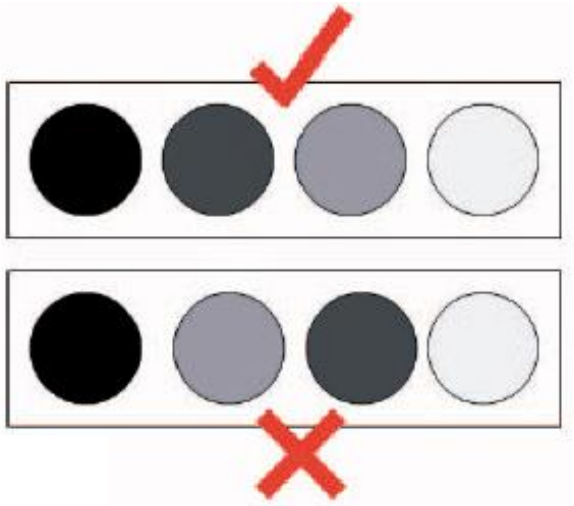
- General Bathymetric Chart of the Ocean
- Now describe what kind of color scale was possibly used here





Perceptual Ordering





Rainbow Color Scale

- Is ordered by wavelength
- Is **not** perceptually ordered

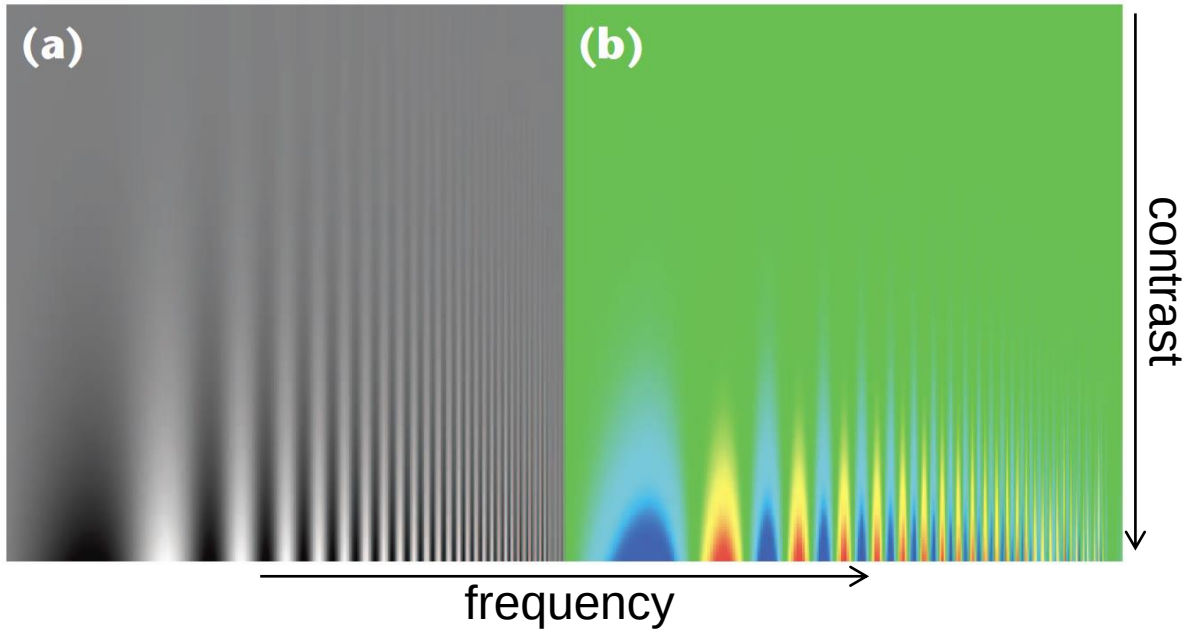
Gray Scale

- Increases luminance (value) from dark to light
- Is perceptually ordered

Rainbow Color Map (Still) Considered Harmful, Borland & Taylor, CG&A (2007)

Color Scale Luminance

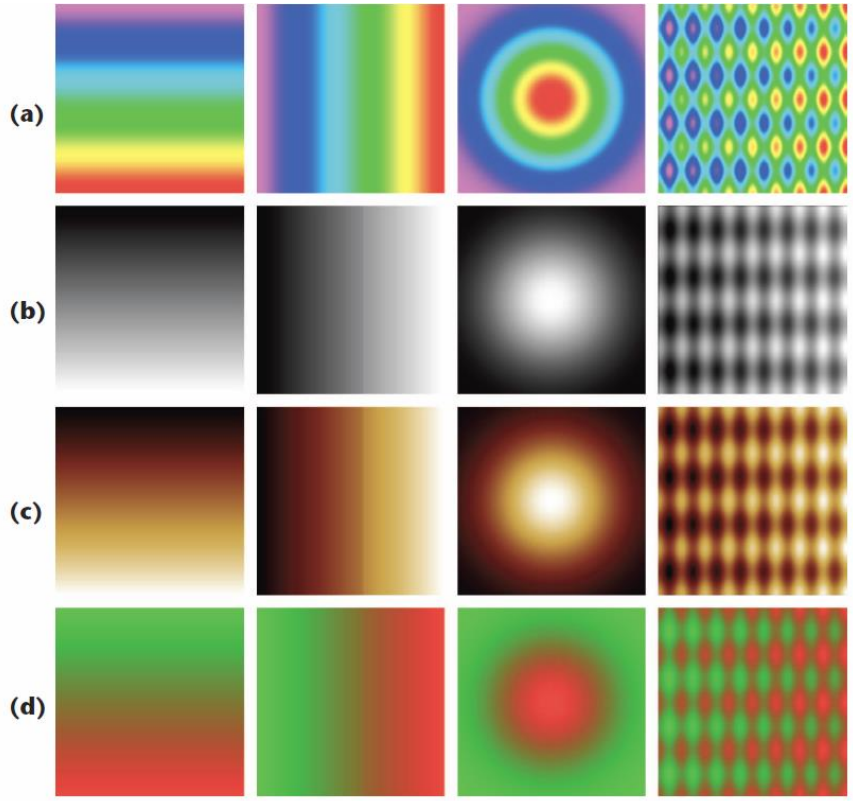
- Rainbow Color Scale
  - Visual system perceives high spatial frequencies through changes in luminance
  - RCS is isoluminant (for large portions)
    - Changes only appear at color boundaries
  - Obscures small details in the data



Rainbow Color Map (Still) Considered Harmful, Borland & Taylor, CG&A (2007)

Color Scale Transitions

- Rainbow color scale
  - Appears separated into bands of almost constant hue
  - Sharp transitions between hues are perceived as sharp transitions in the data



rainbow color scale

gray scale

heated color scale

isoluminant green-red scale

Rainbow Color Map (Still) Considered Harmful, Borland & Taylor, CG&A (2007)

CHOOSING COLORS

A Few General Rules

- Always have **high luminance contrast** between foreground and background
- Use **only a few distinct colors**
  - > 12 colors will likely not work
  - ~5 colors recommended

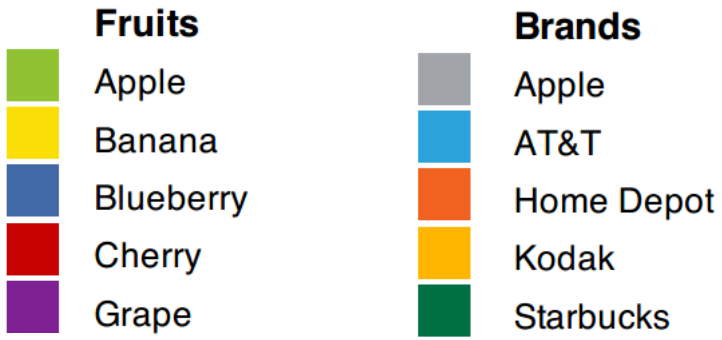
Information Visualization using Vision to Think, Colin Ware

Using Color to Label (For groups, categories, highlights, etc.)

- Colors should be distinctive and named

"Blue" "Blue-er?" "Other Blue???"

- Use cultural conventions & appreciate symbolism



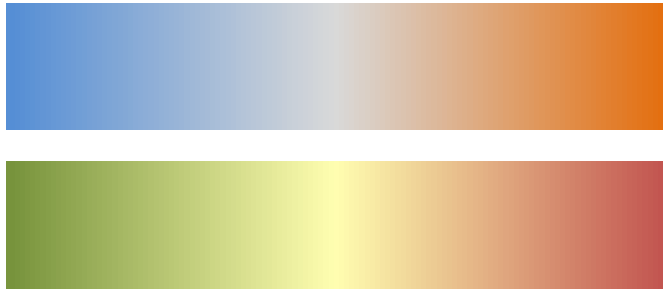
Selecting Semantically-Resonant Colors for Data Visualization, *Lin et al.* (2013)

- Beware of bad interactions (red/blue etc.)

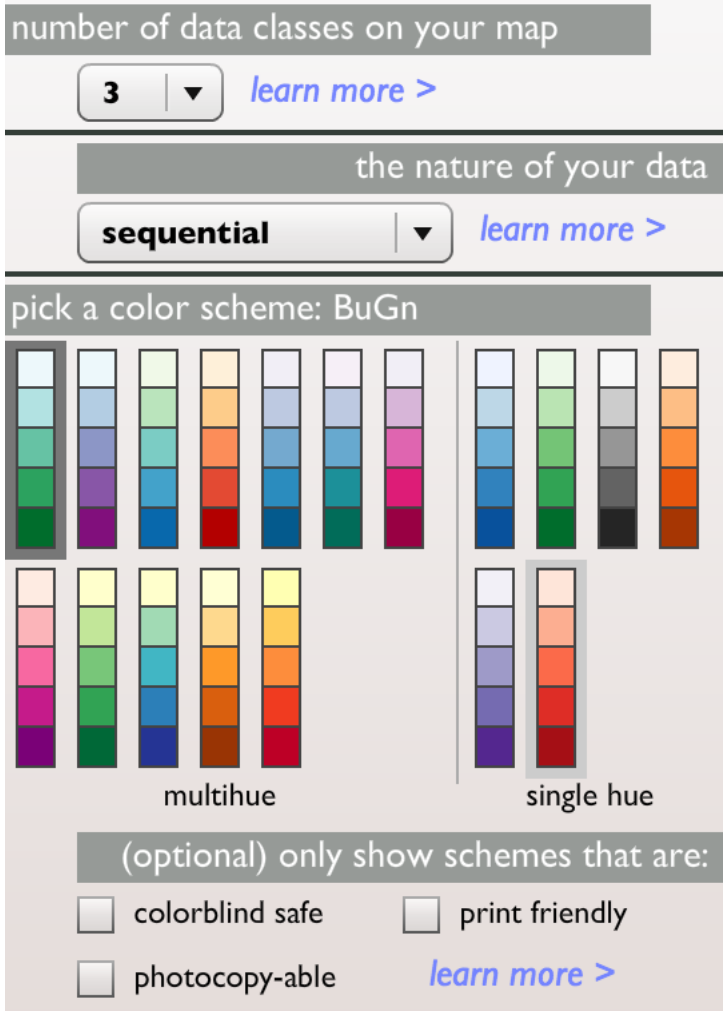
Using Color for Scales (For ordinal or quantitative data)

- Use a scale that varies **lightness** in addition to color
- Shades of **gray** or shades of **a single color** are easiest

- For **diverging scales**, use a lighter, desaturated value for the critical mid-point and darker hues for the ends



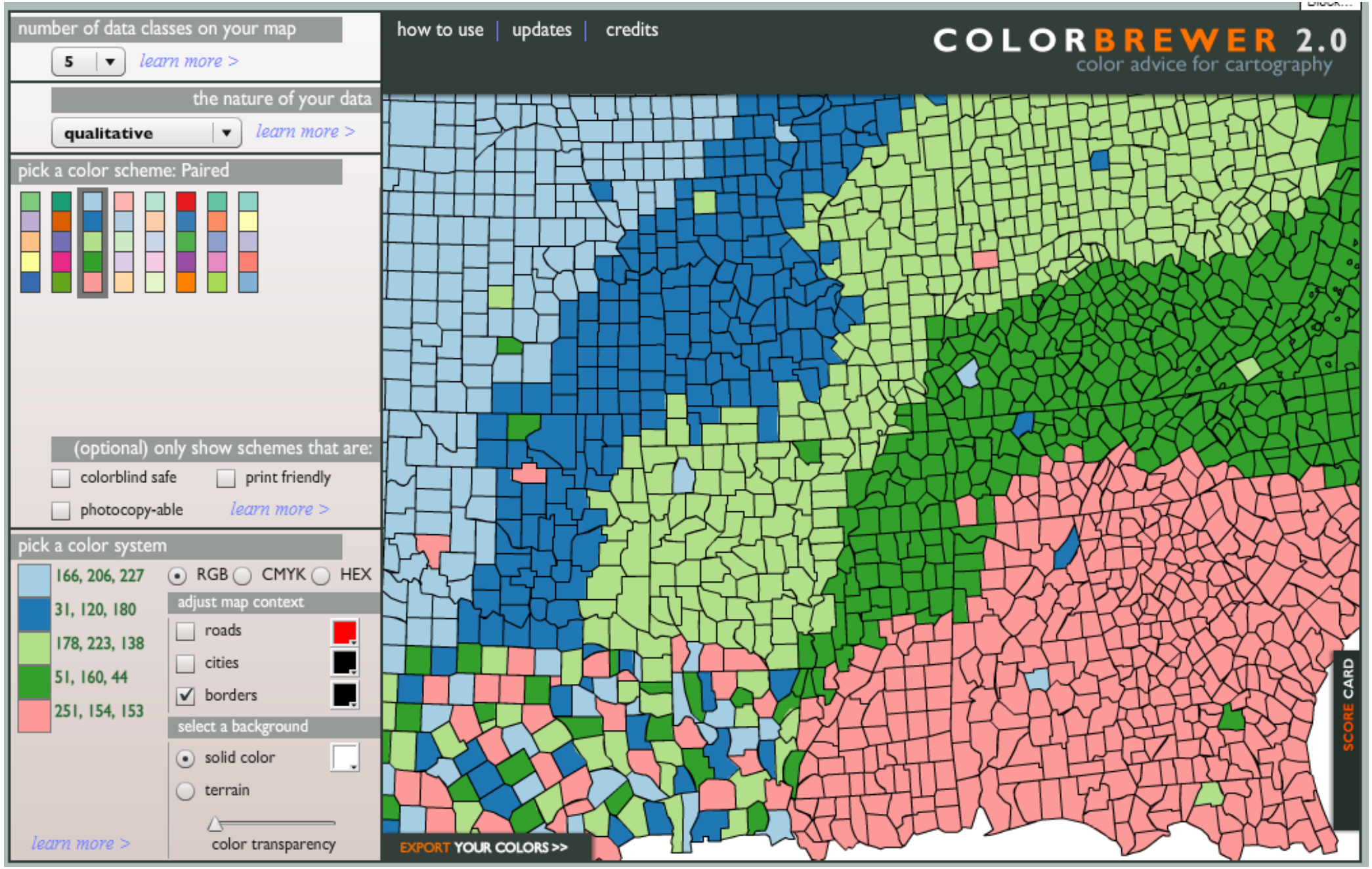
ColorBrewer



Highly recommended!

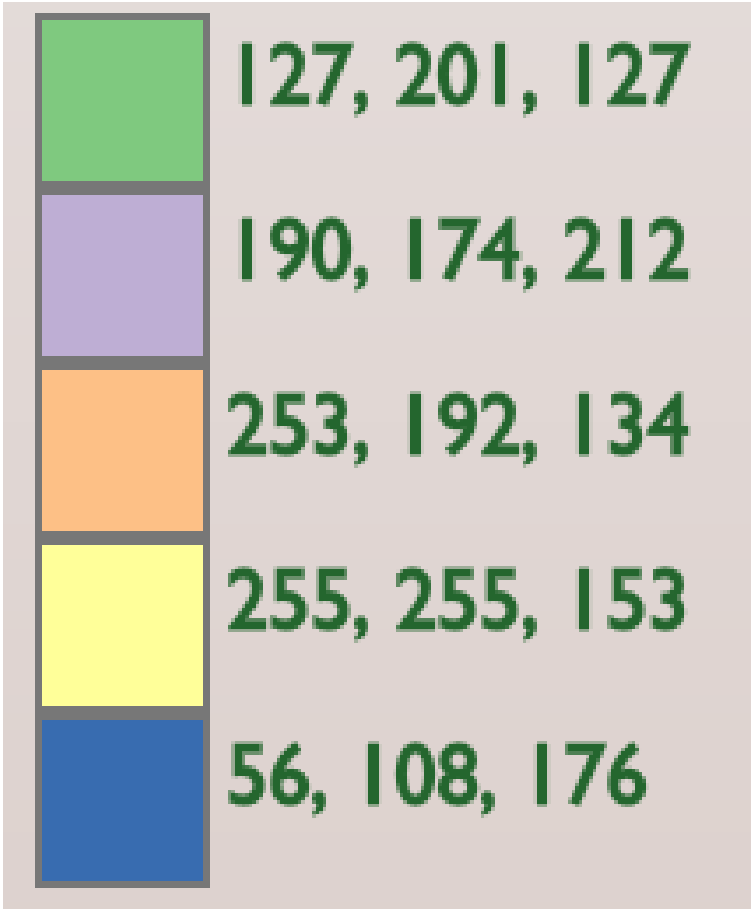
Designed originally for maps, but will also work well for other types of visualizations

http://colorbrewer2.org/

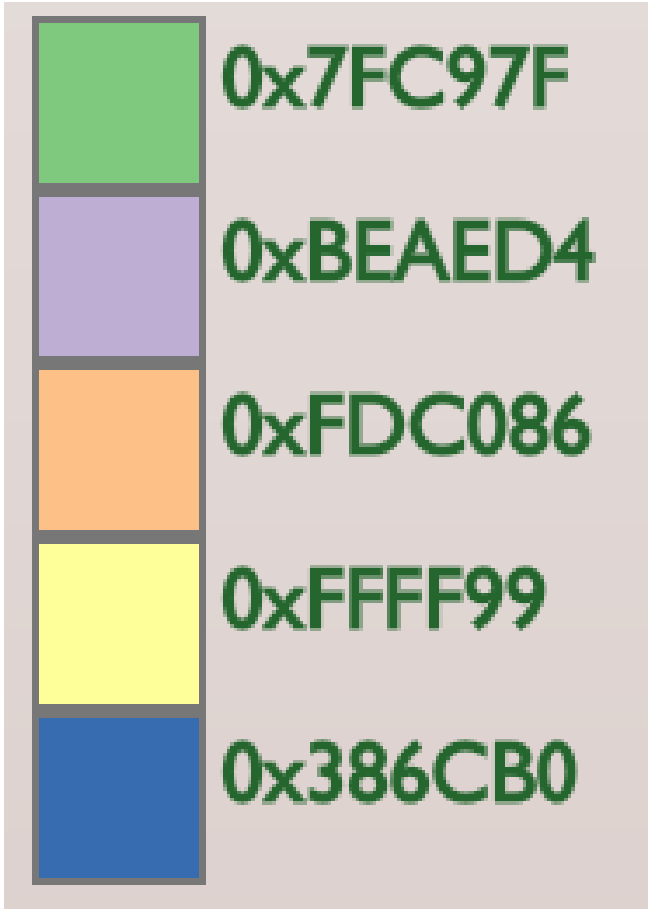


http://colorbrewer2.org/

ColorBrewer



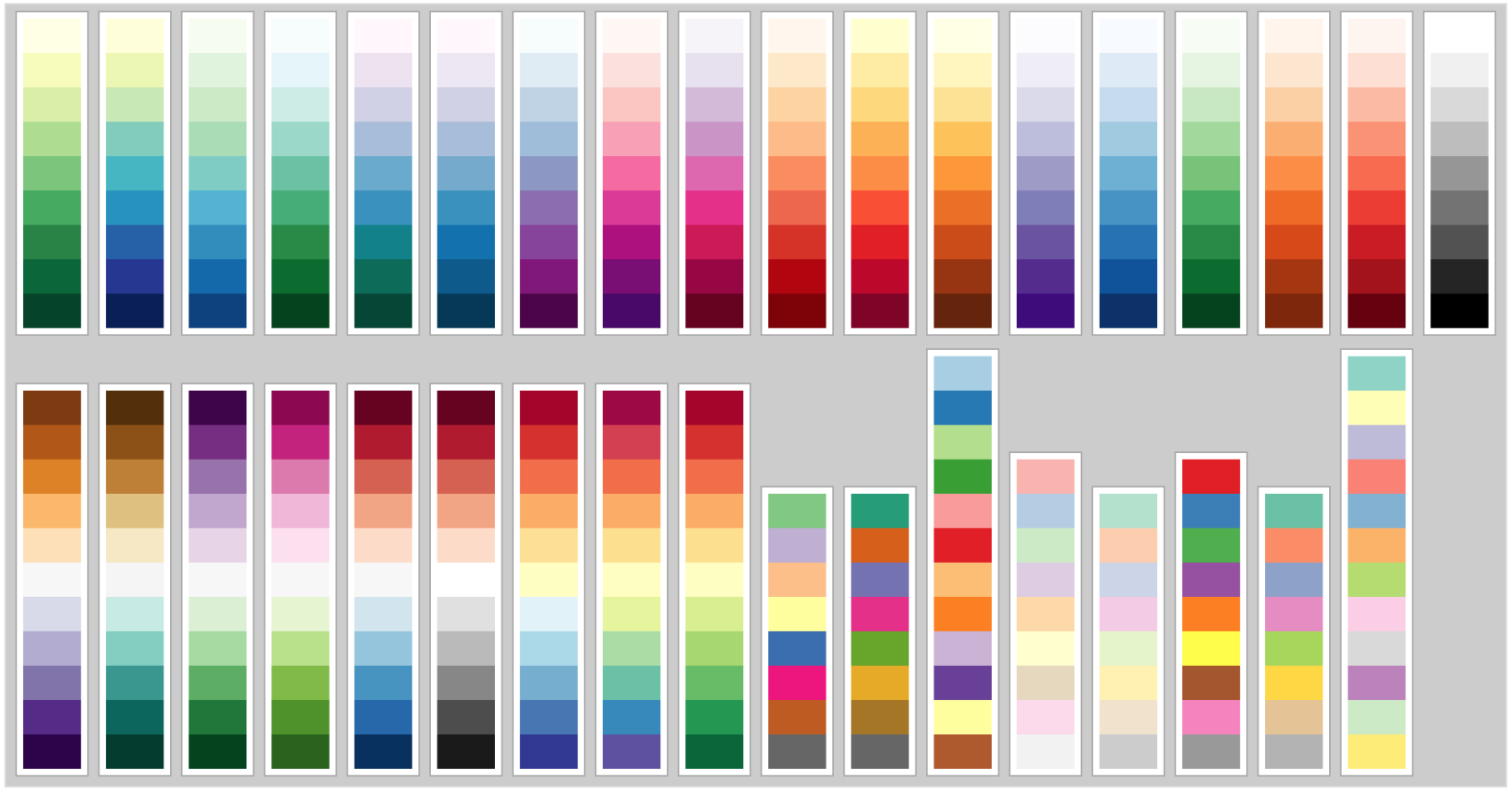
(RGB)



(Hex)

Color Brewer

- Every ColorBrewer Scale
- For CSS and JavaScript (by Mike Bostock)
  http://bl.ocks.org/mbostock/5577023



COLOR VISION DEFICIENCY

The following slides on the topic are adapted from Tobias Isenberg

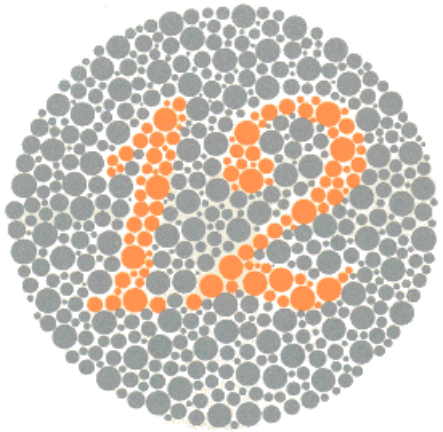
Color Vision Deficiency

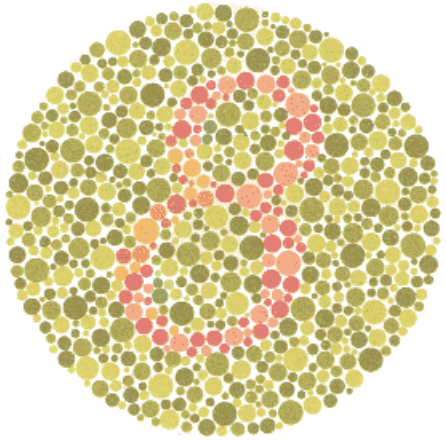
- Approx. 7% of male population color-deficient
- Mostly red-green color deficiency (deuteranopia or protanopia) – but other forms exist as well

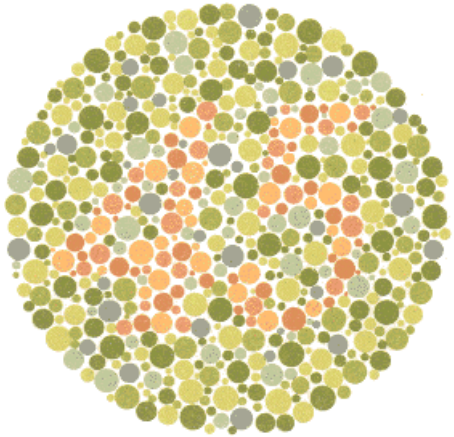
normal color vision

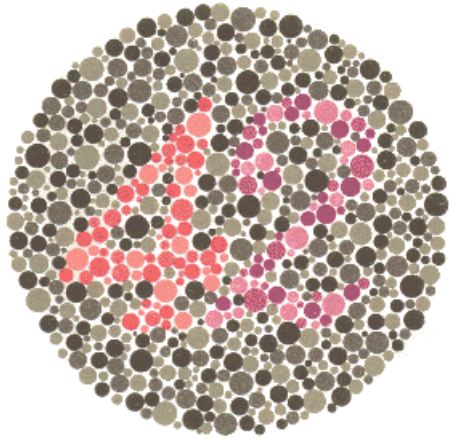
simulation of color contrast
for deuteranopic color vision
(green receptors absent)

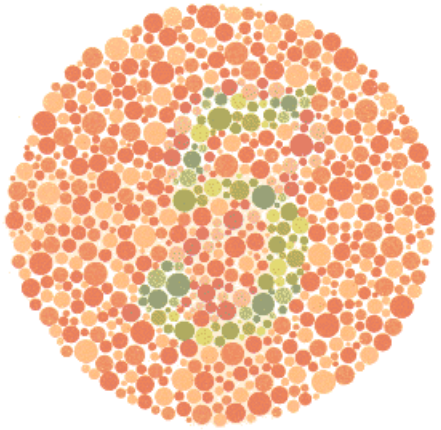
Color Vision Deficiency (Ishihara Test)

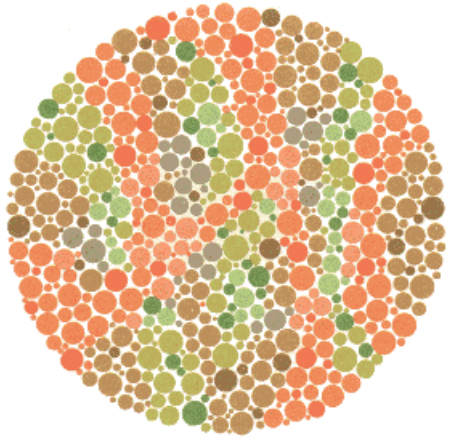




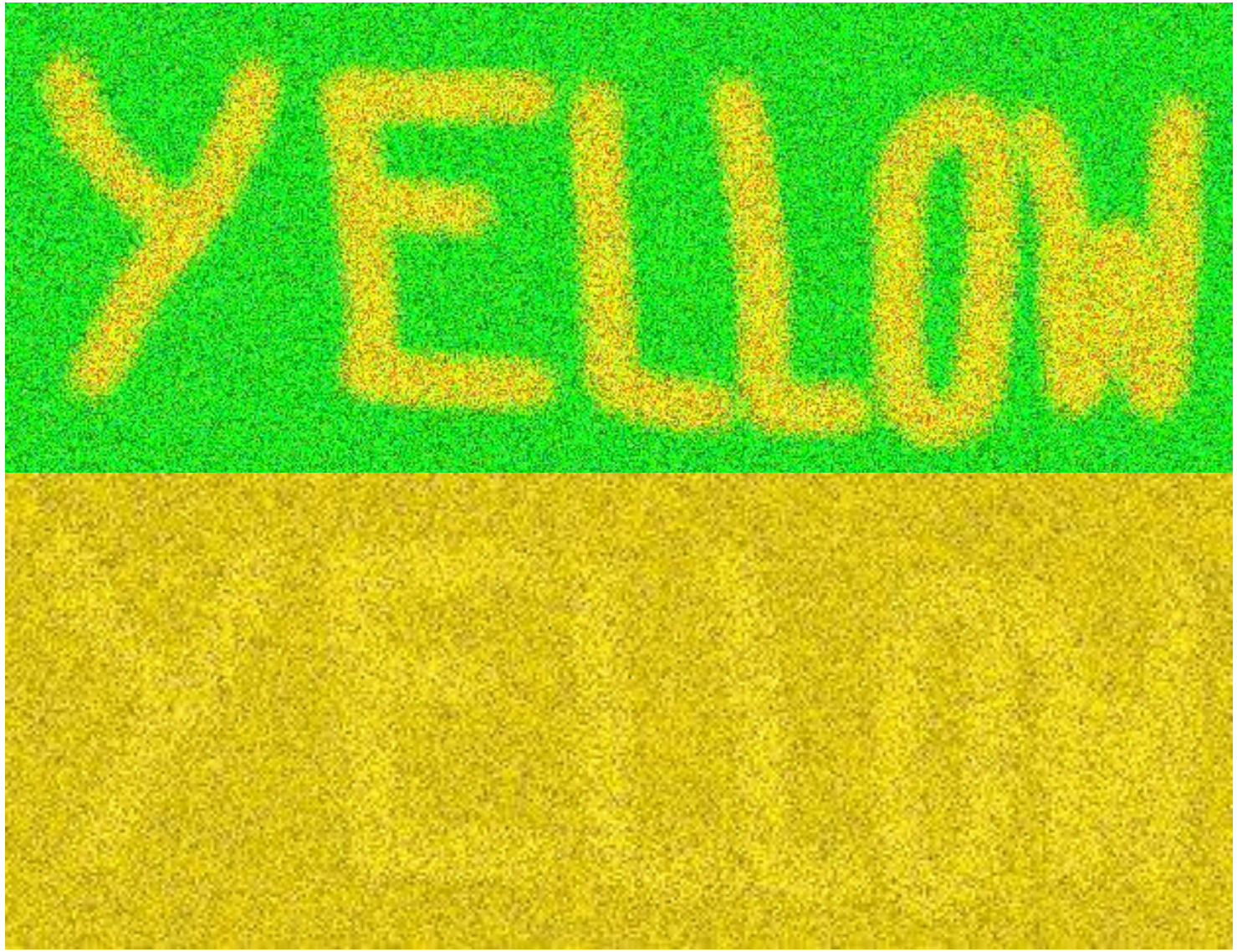




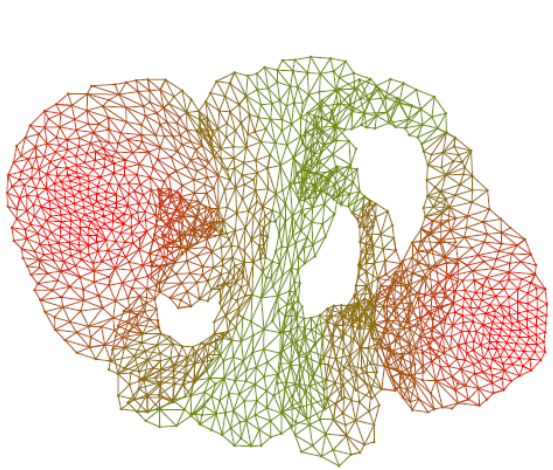


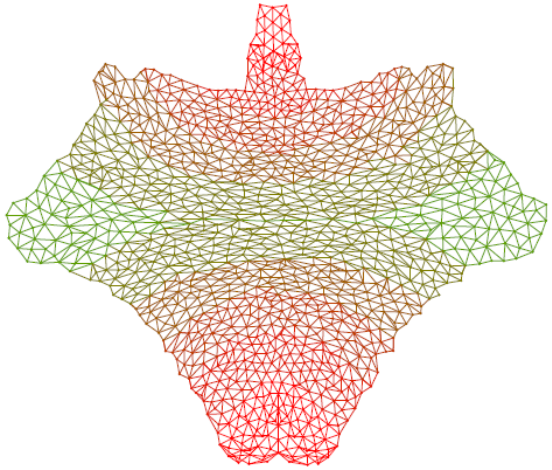


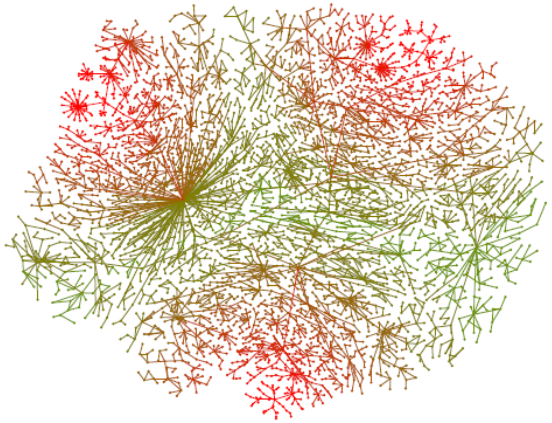
Color Vision Deficiency

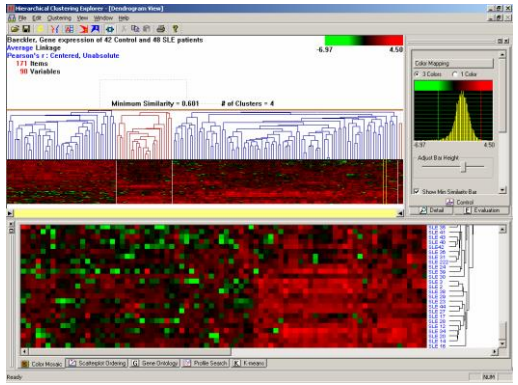


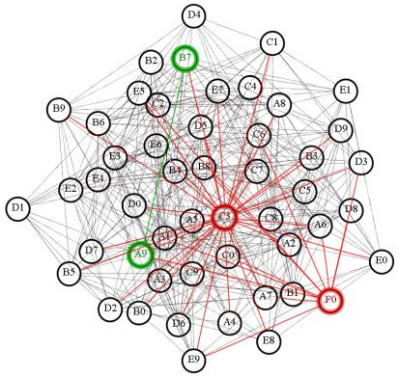
Examples from VIS/InfoVis 2004

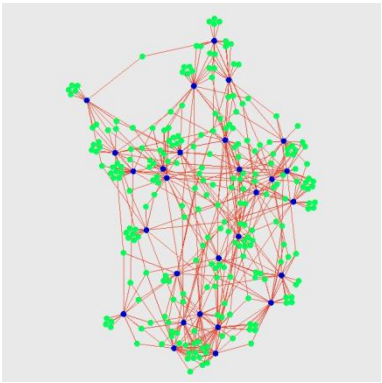


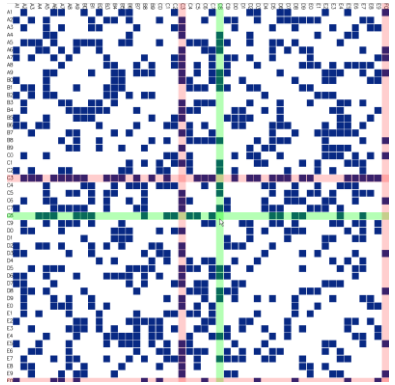




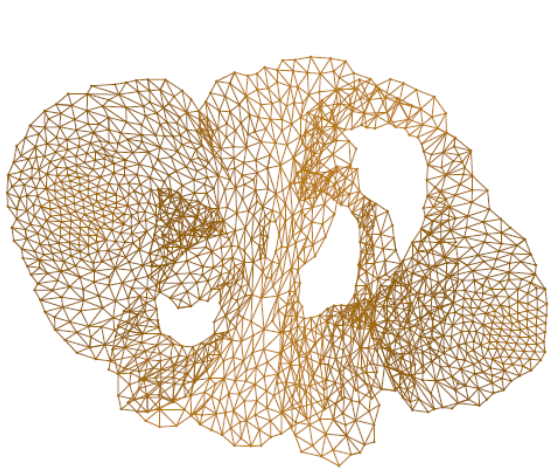


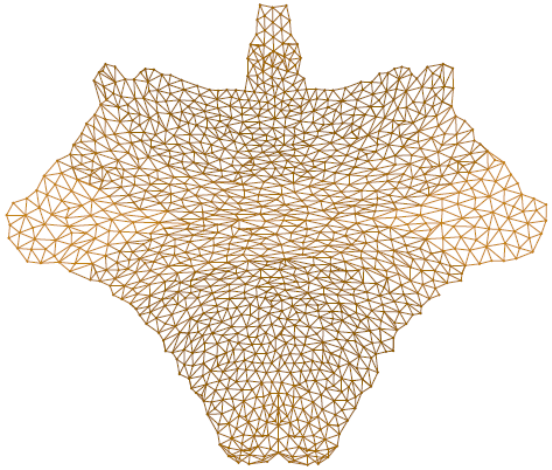


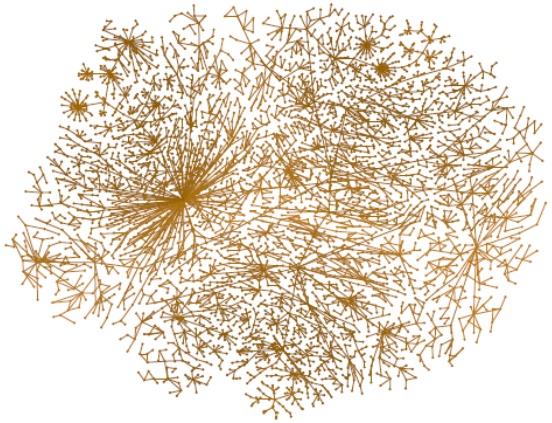


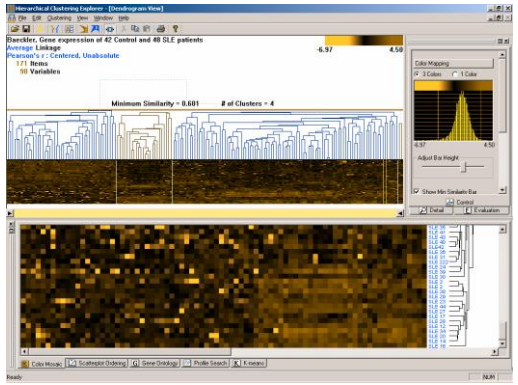


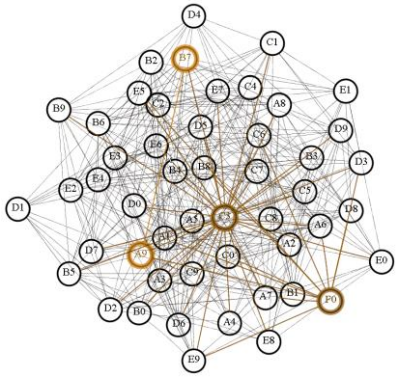
Examples from VIS/InfoVis 2004

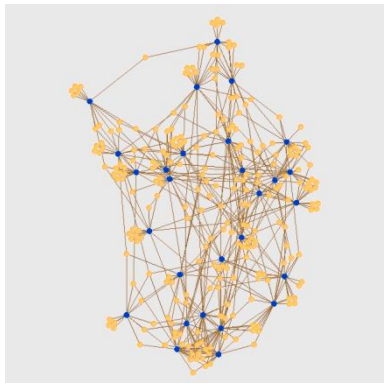






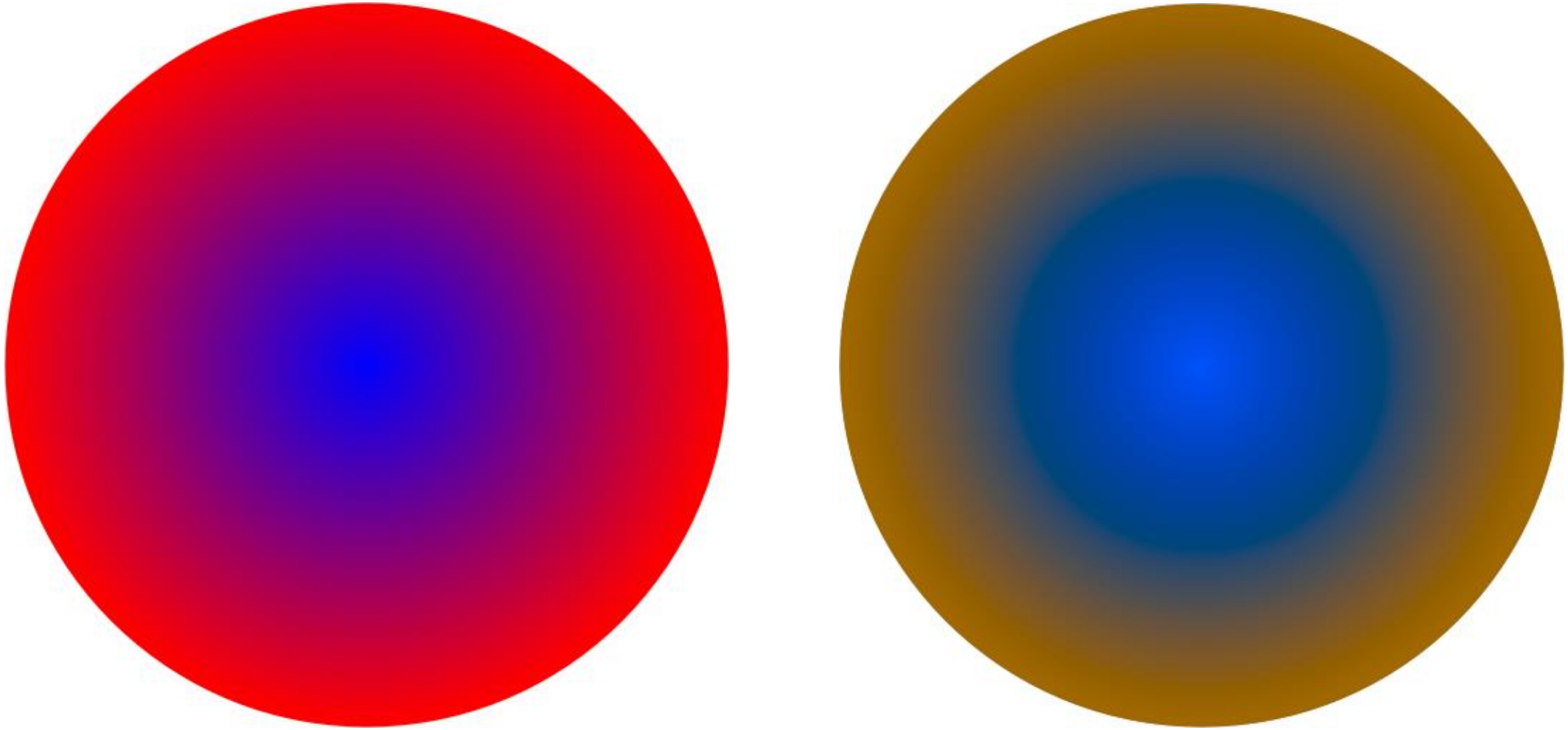






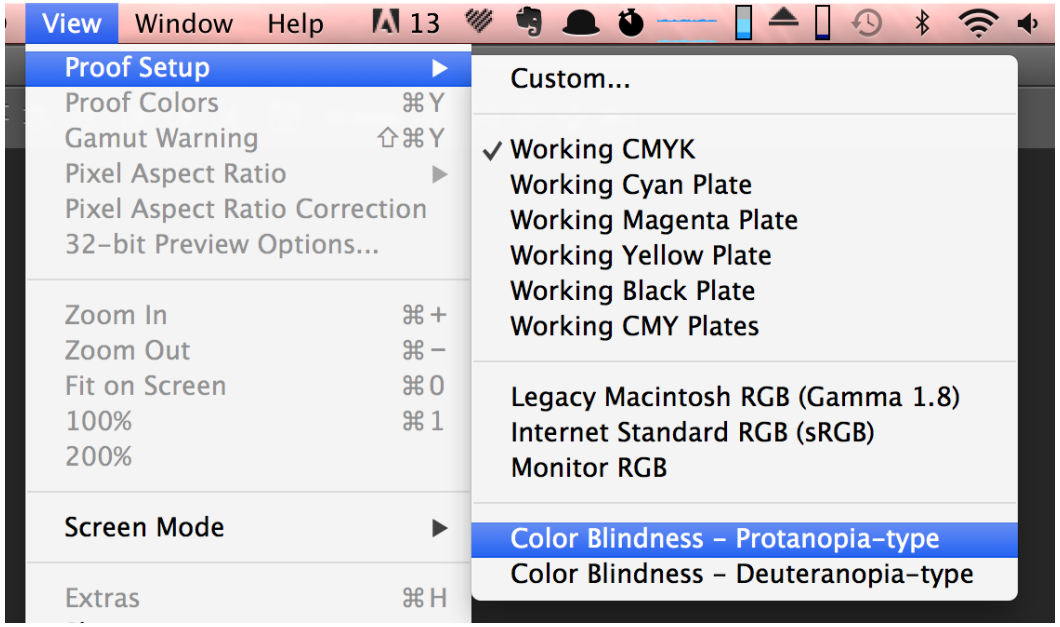
Color Vision Deficiency

- Better: Red-Blue Contrast

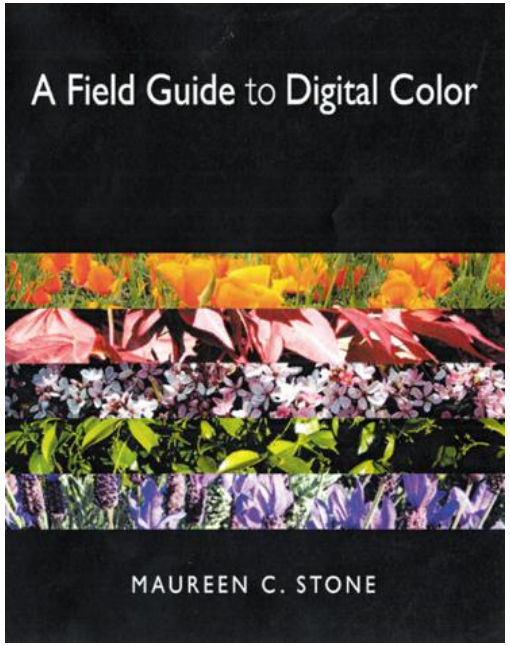


Color Vision Deficiency

- Check your visualizations!
- When possible, avoid red-green color contrasts for visualization purposes
- To test your visualizations, use proofing modes in PhotoShop and GIMP, or try VisCheck http://www.vischeck.com/



Color Resources



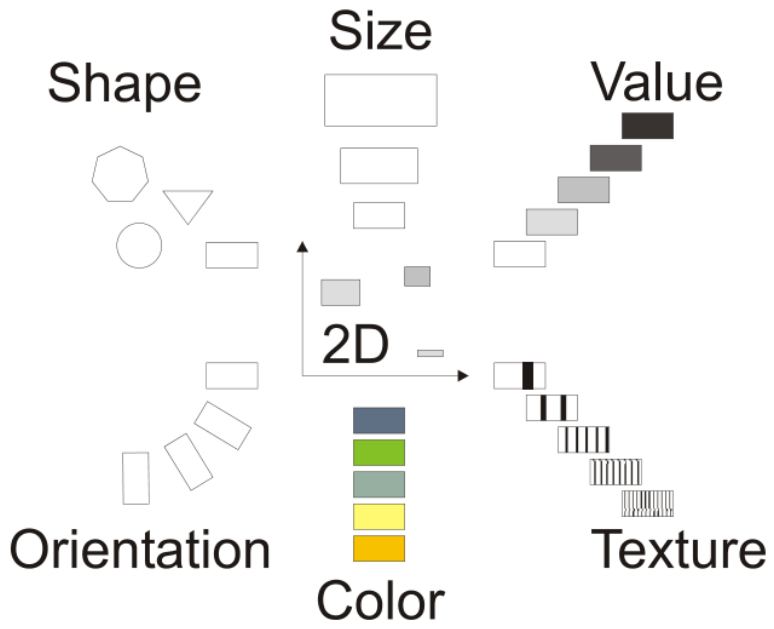
Maureen Stone's Resources
A Field Guide to Digital Color
http://www.stonesc.com

Cindy Brewer's *ColorBrewer*
http://colorbrewer2.org
For CSS and JavaScript
http://bl.ocks.org/mbostock/5577023

Community Palette Sharing
http://www.colourlovers.com
http://kuler.adobe.com

PERCEPTION OF OTHER VISUAL ENCODINGS

Perception of Visual Encodings



There are **lots** of possible visual encodings

Their **effectiveness** is related to how they are handled by our perceptual system

Elementary Graphical Perception Tasks

- William S. Cleveland (1980s)
- Performed **controlled experiments** to determine how effectively people could judge **changes in visual features**
- **Question:** What percentage in value is the right from the left?
- Focus on **quantitative information**
- **Variables**
  - angle, area (size), color hue, color saturation, density (value), length, position, slope, volume

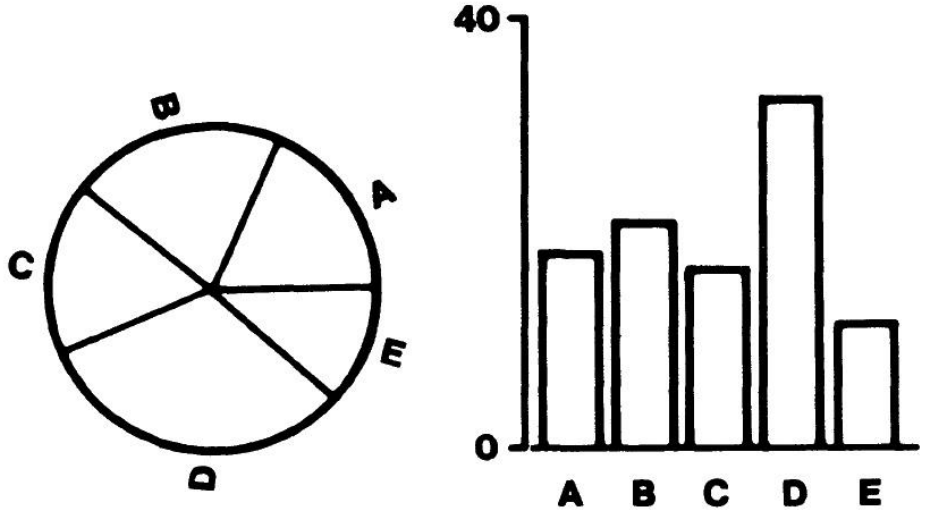
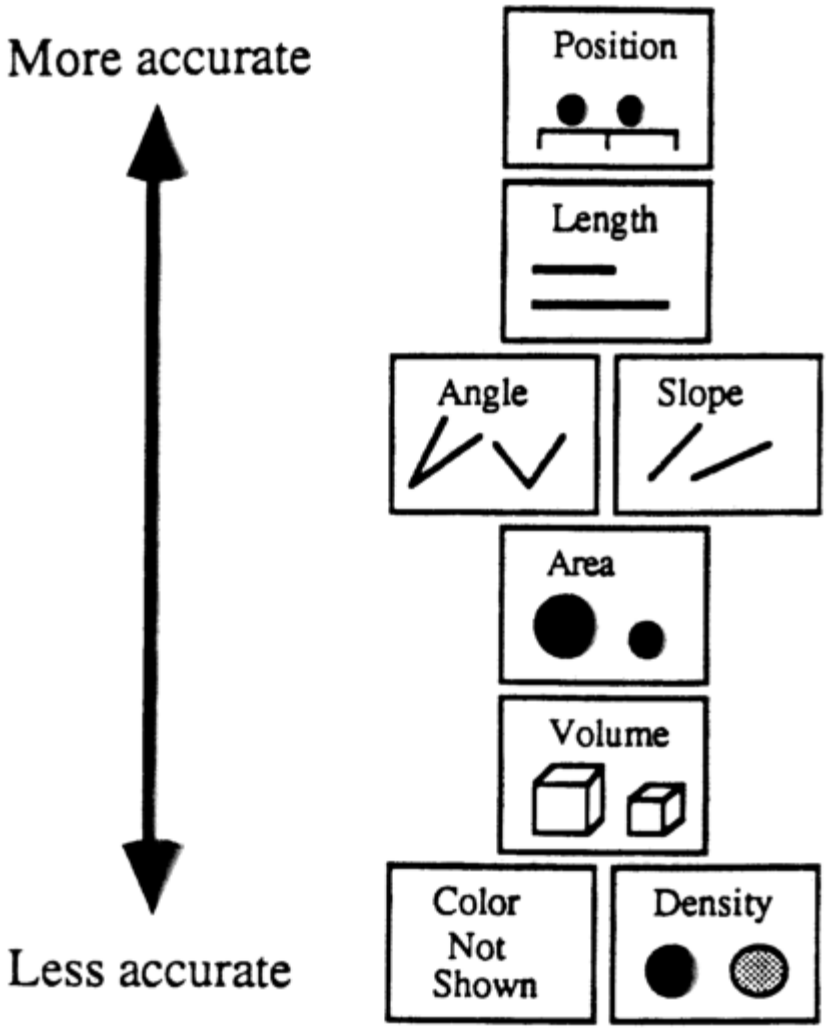


Figure 3. Graphs from position–angle experiment.

William S. Cleveland (1980s)

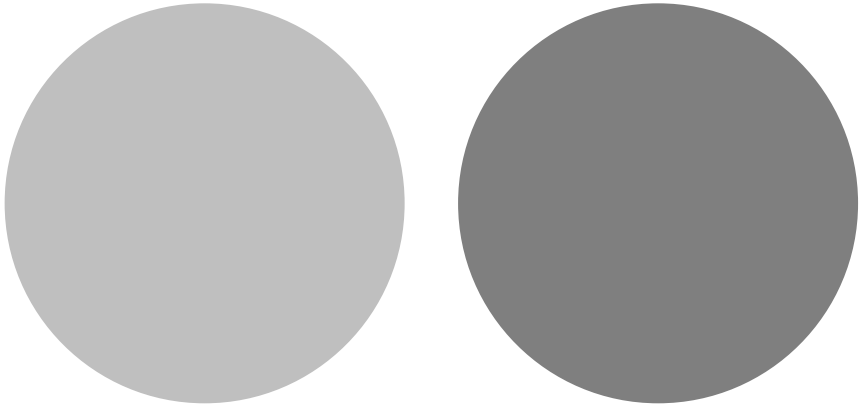
Elementary Graphical Perception Tasks



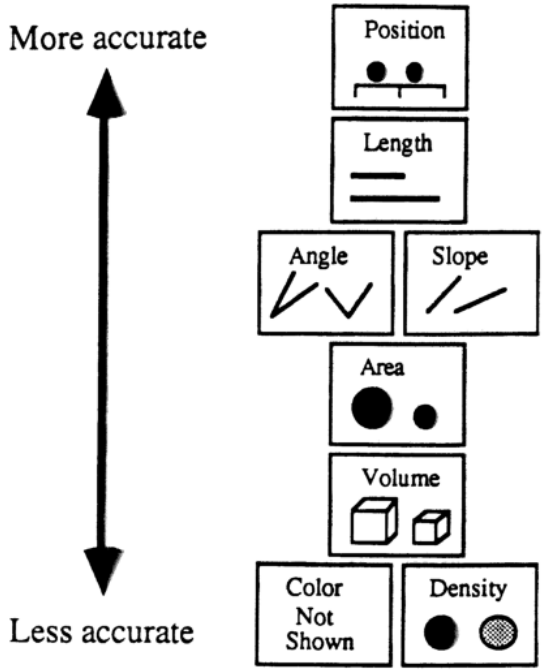
William S. Cleveland (1980s)

Elementary Graphical Perception Tasks

- Color value



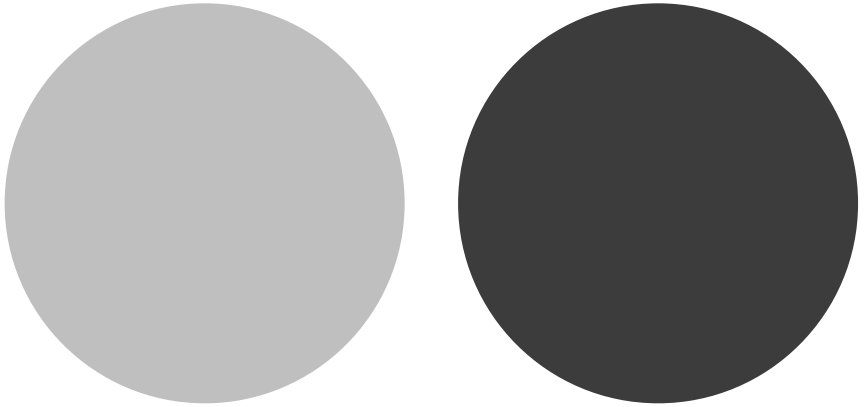
100% 66%



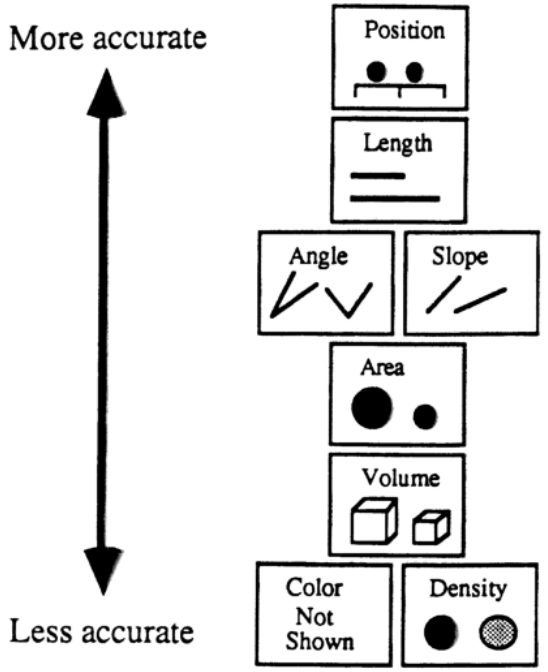
William S. Cleveland (1980s)

Elementary Graphical Perception Tasks

- Color value



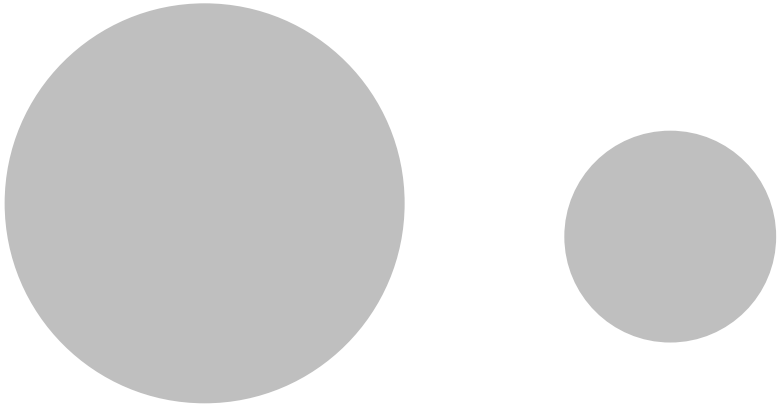
100% 60%



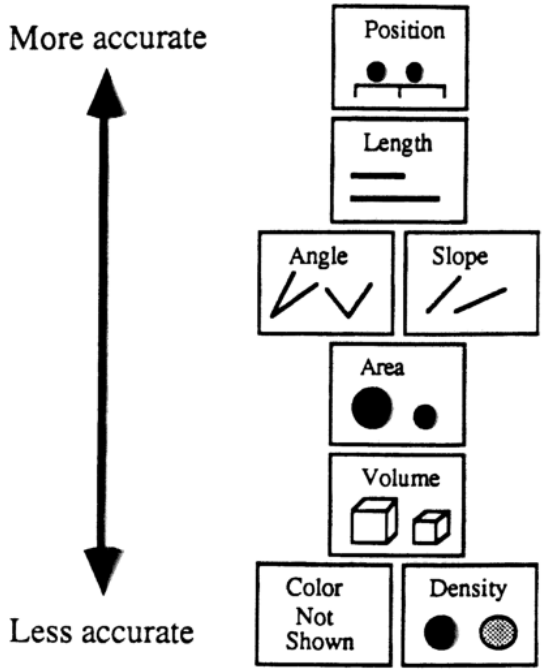
William S. Cleveland (1980s)

Elementary Graphical Perception Tasks

- Area



100% 53%

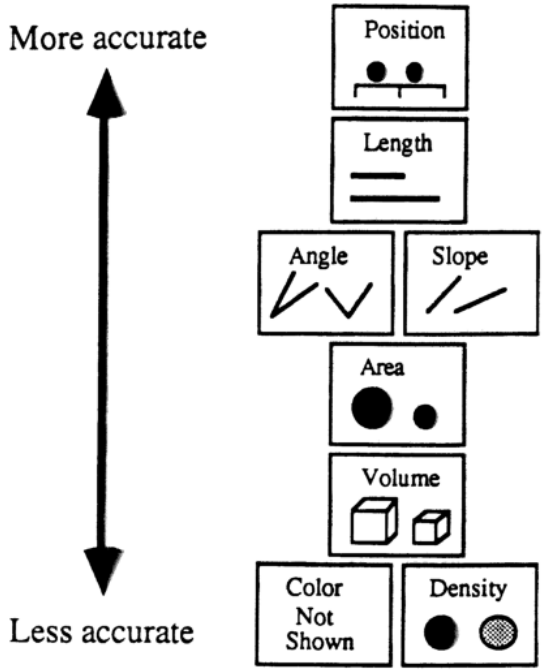


William S. Cleveland (1980s)

Elementary Graphical Perception Tasks

- Area

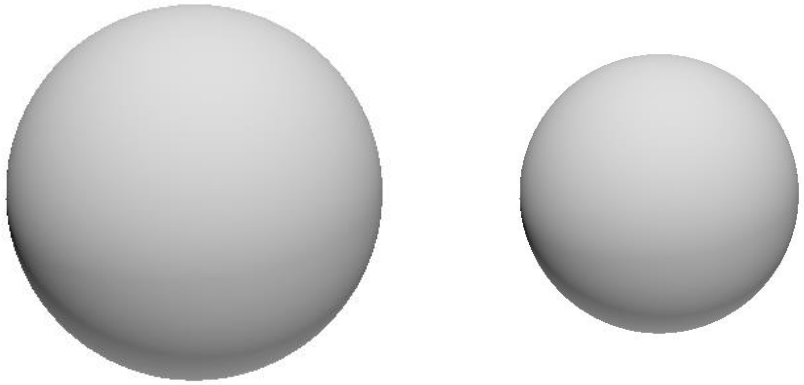
100% 35%



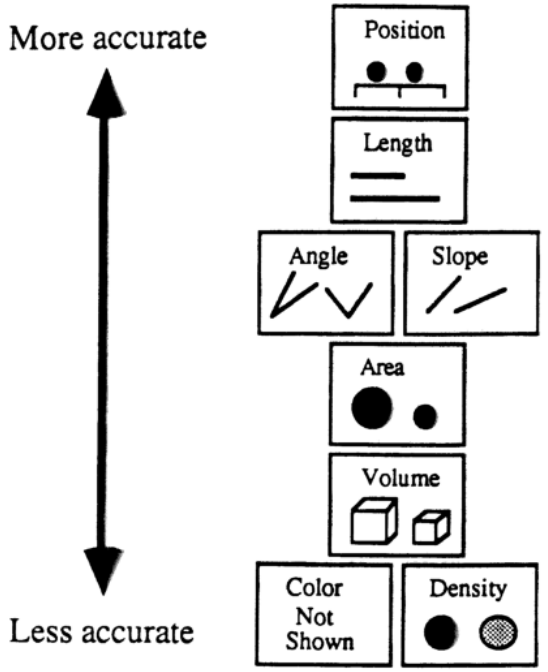
William S. Cleveland (1980s)

Elementary Graphical Perception Tasks

- Volume



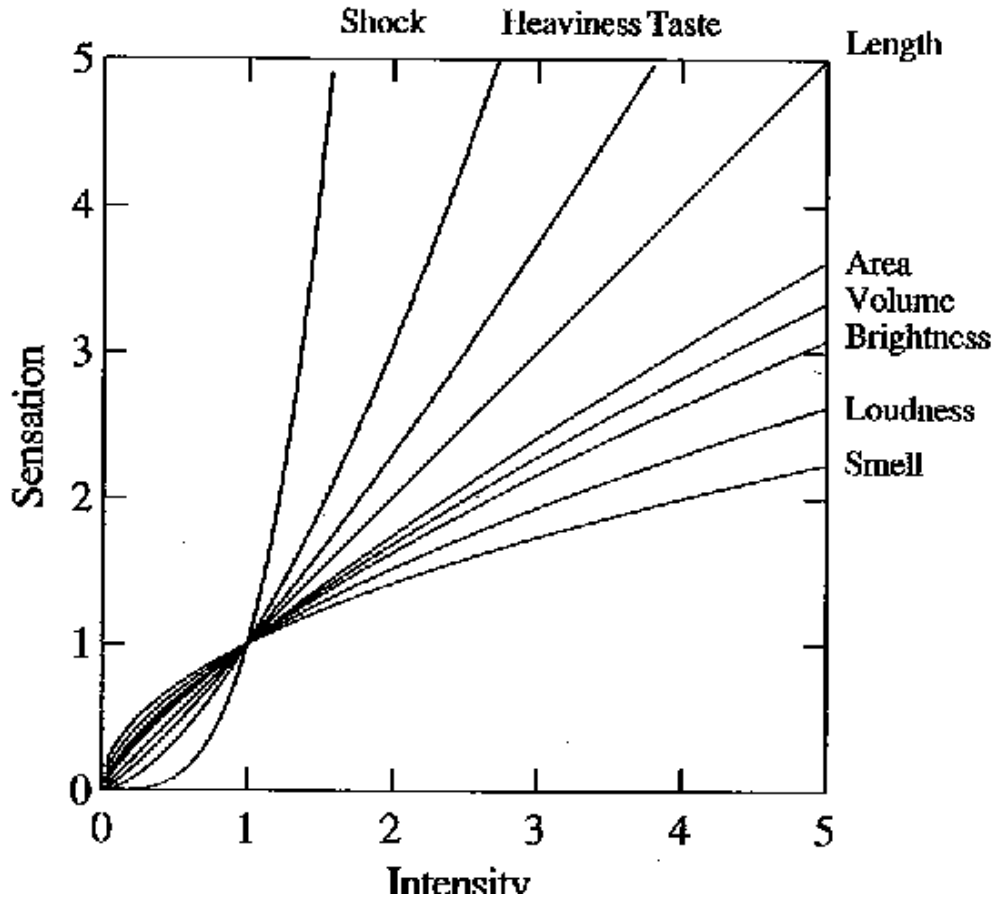
100% 40%



William S. Cleveland (1980s)

Stevens' power law

- Relationship between stimulus and perception **isn't always linear!**
- Relationship between a physical stimulus (S) and its **perceived** intensity or strength (P)

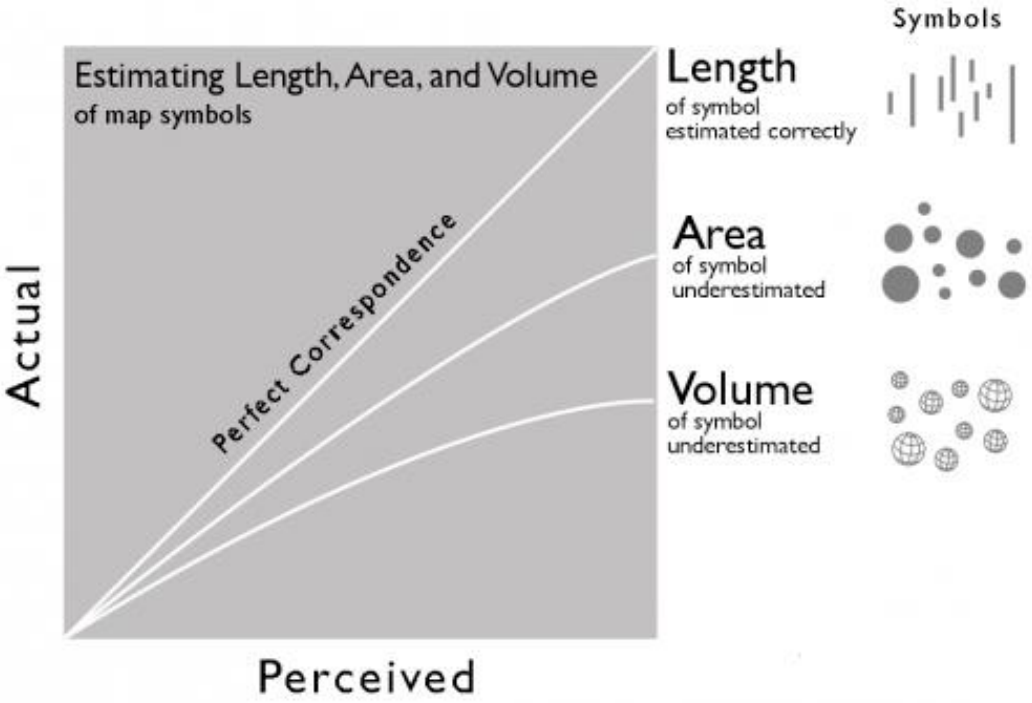


Graph from Wilkinson 99, based on Stevens 61

Perception

- People tend to **correctly estimate lengths**
- They tend to **underestimate areas and volumes**

- When asked to pick a circle **2 times** the size, people tend to pick a circle **~1.8 times** larger
- This tendency **gets worse** as area grows
- Volume **is even worse**



http://makingmaps.net/2007/08/28/perceptual-scaling-of-map-symbols/

Volume

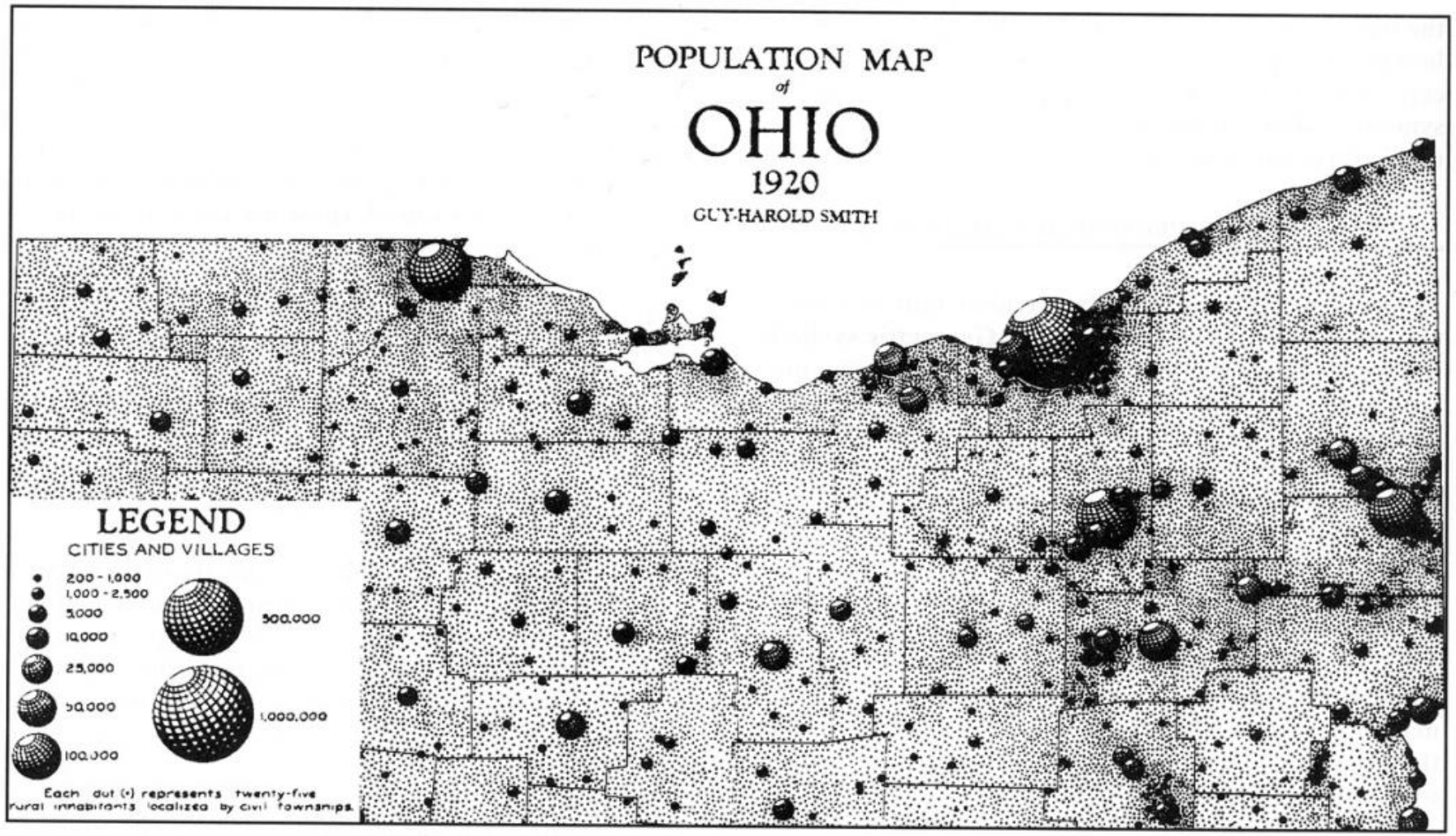
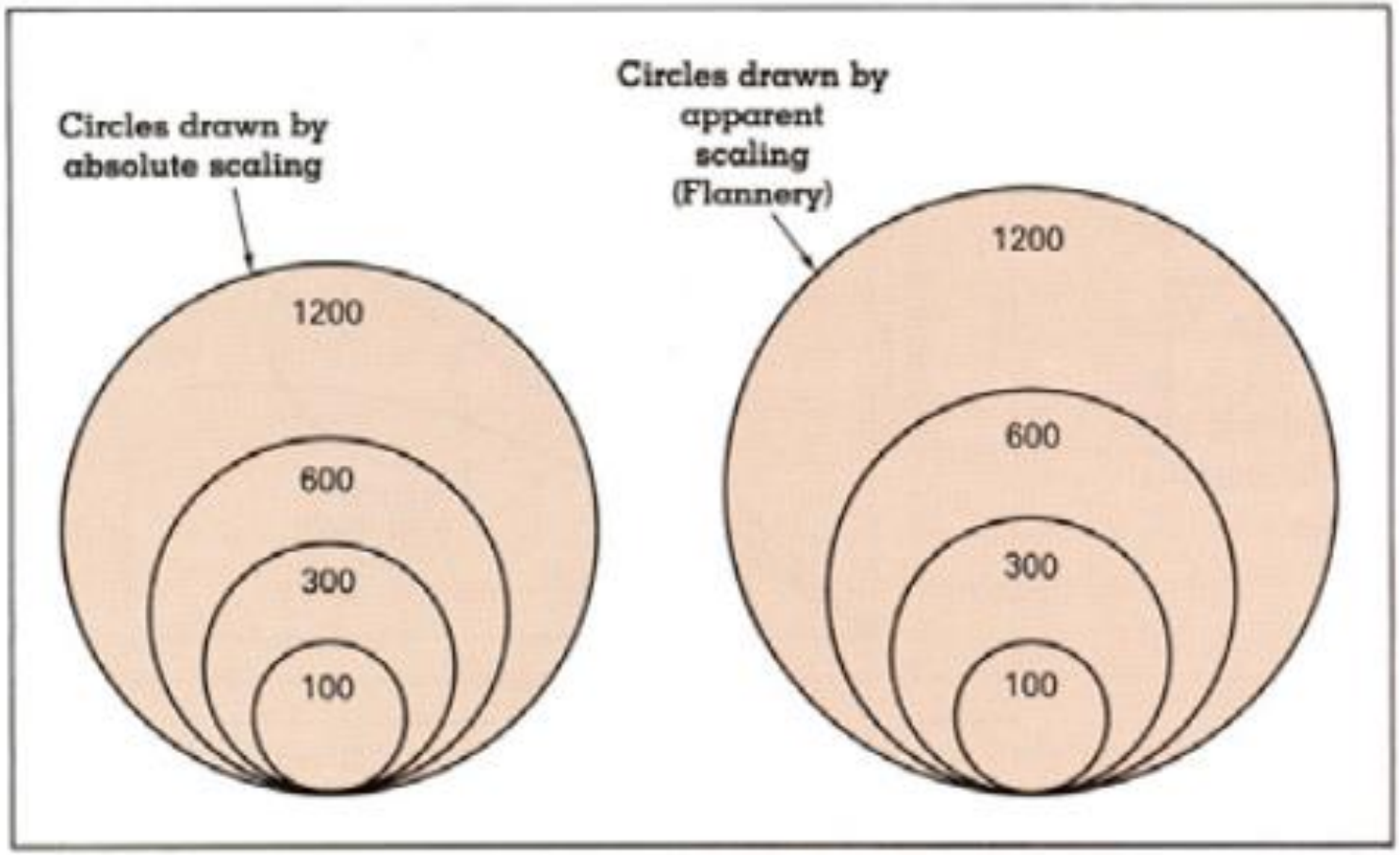


FIGURE 7.4. An eye-catching map created using three-dimensional geometric symbols. (After Smith, 1928. First published in *The Geographical Review,* 18(3), plate 4. Reprinted with permission of the American Geographical Society.)

Area

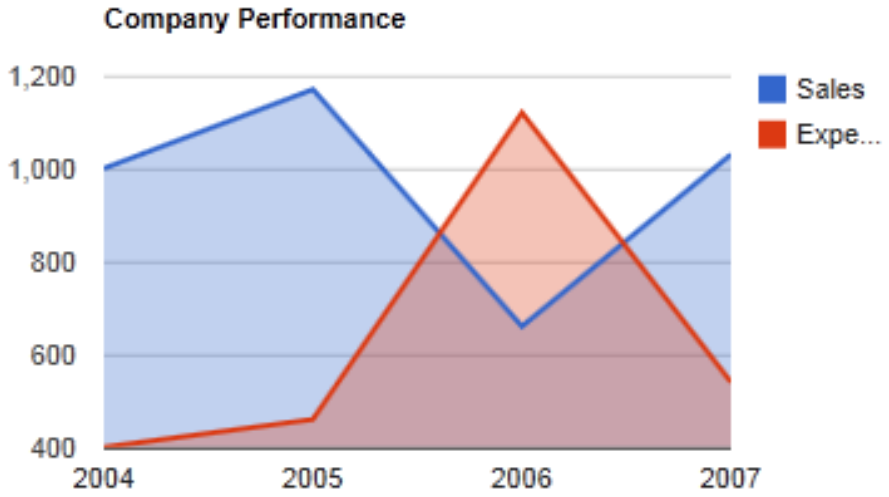


[Cartography: Thematic Map Design, Figure 8.6, p. 170, Dent, 96]

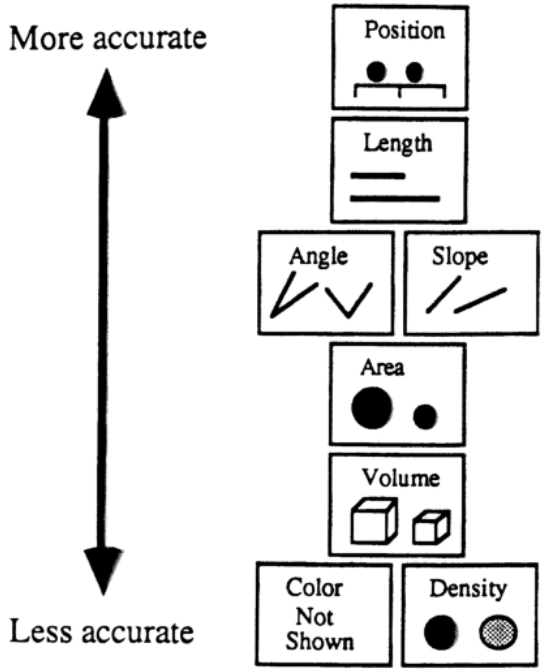
$S = 0.98A^{0.87}$ [from Flannery 71]

Area

- What percentage in size is the red from the blue (=100%)?



no idea – **this is very difficult**



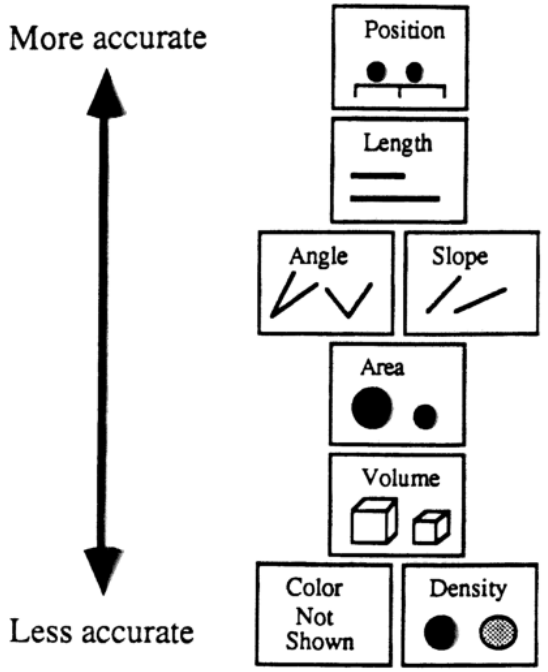
William S. Cleveland (1980s)

Length

- What percentage in length is the right from the left?

100%

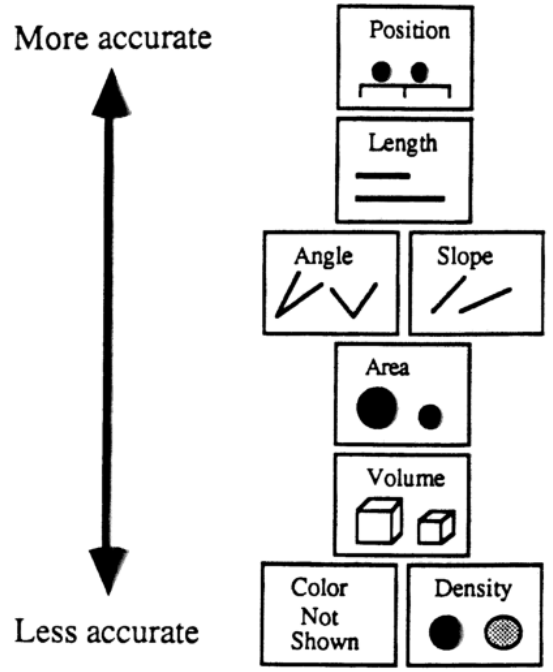
75%



William S. Cleveland (1980s)

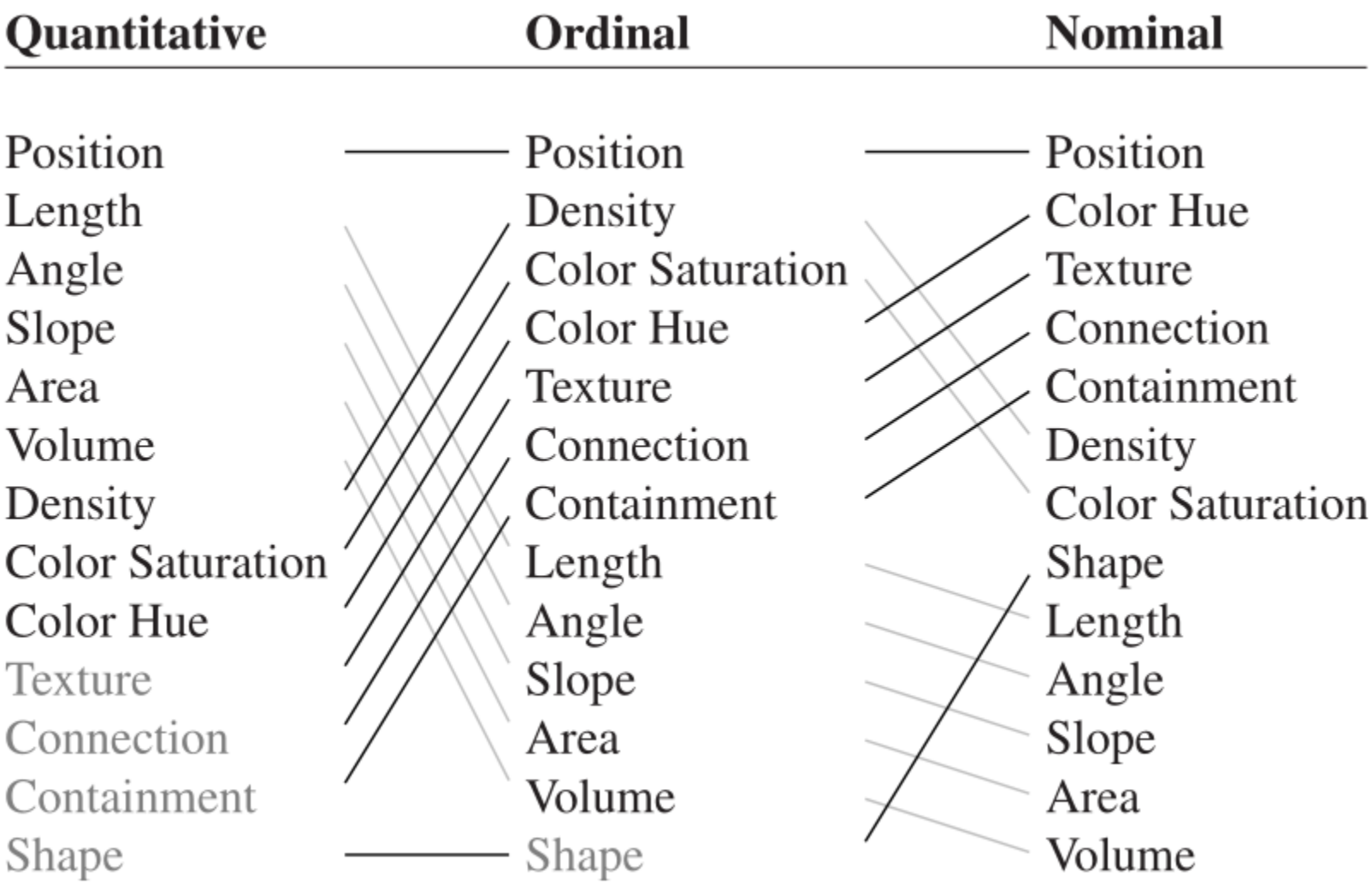
Length / Position

- What percentage in length is the top from the bottom?



William S. Cleveland (1980s)

Effectiveness of Data Encodings (Conjecture)



Mackinlay 1986

Magnitude Channels: Ordered Attributes

- Position on common scale
- Position on unaligned scale
- Length (1D size)
- Tilt/angle
- Area (2D size)
- Depth (3D position)
- Color luminance
- Color saturation
- Curvature
- Volume (3D size)

Same

Same

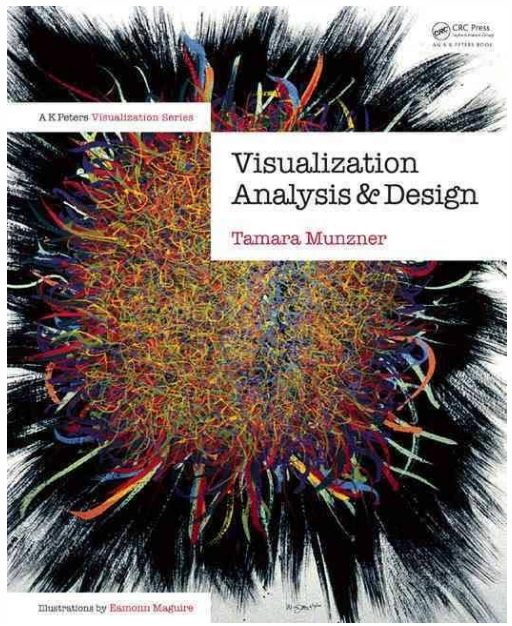
Most

Effectiveness

Least

Identity Channels: Categorical Attributes

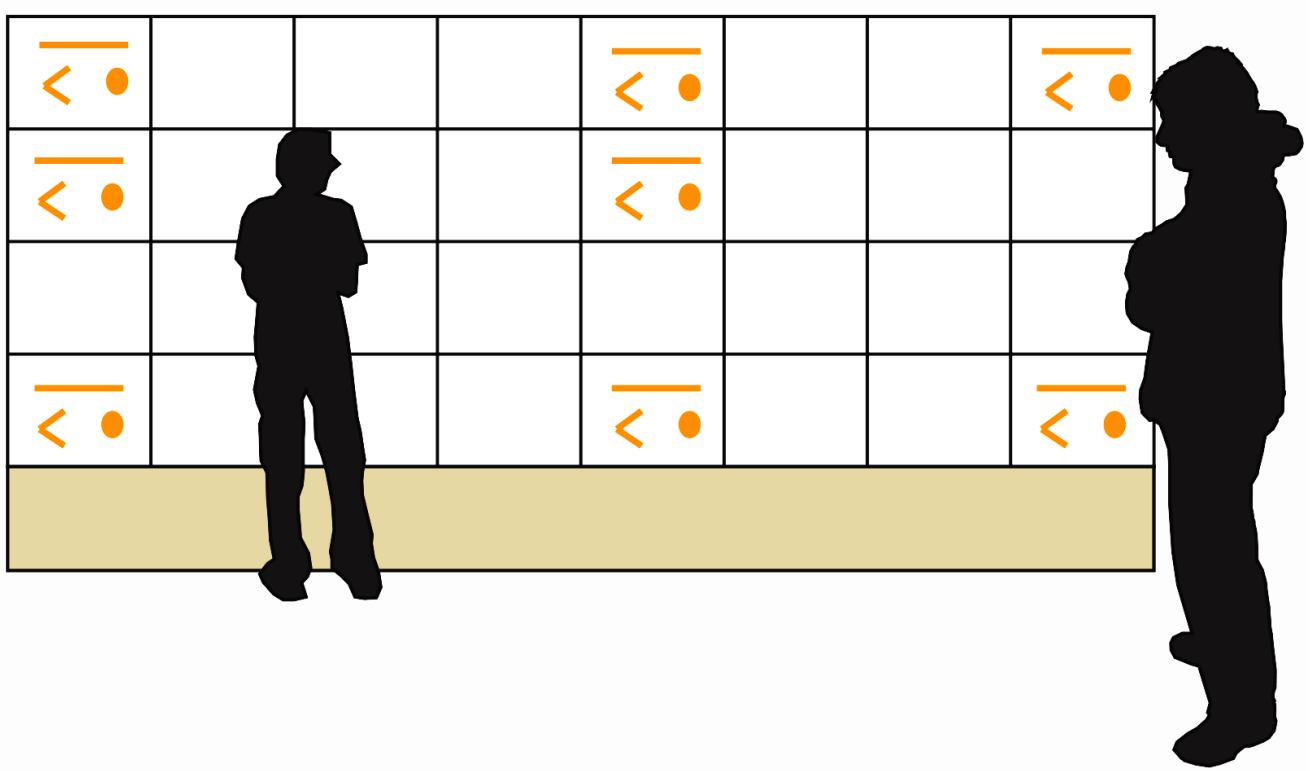
- Spatial region
- Color hue
- Motion
- Shape

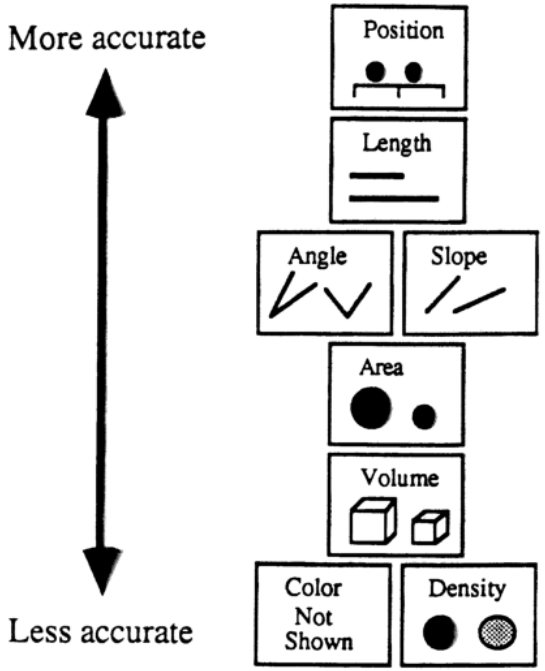


:

Elementary Graphical Perception Tasks

- Also beware of the physical presentation



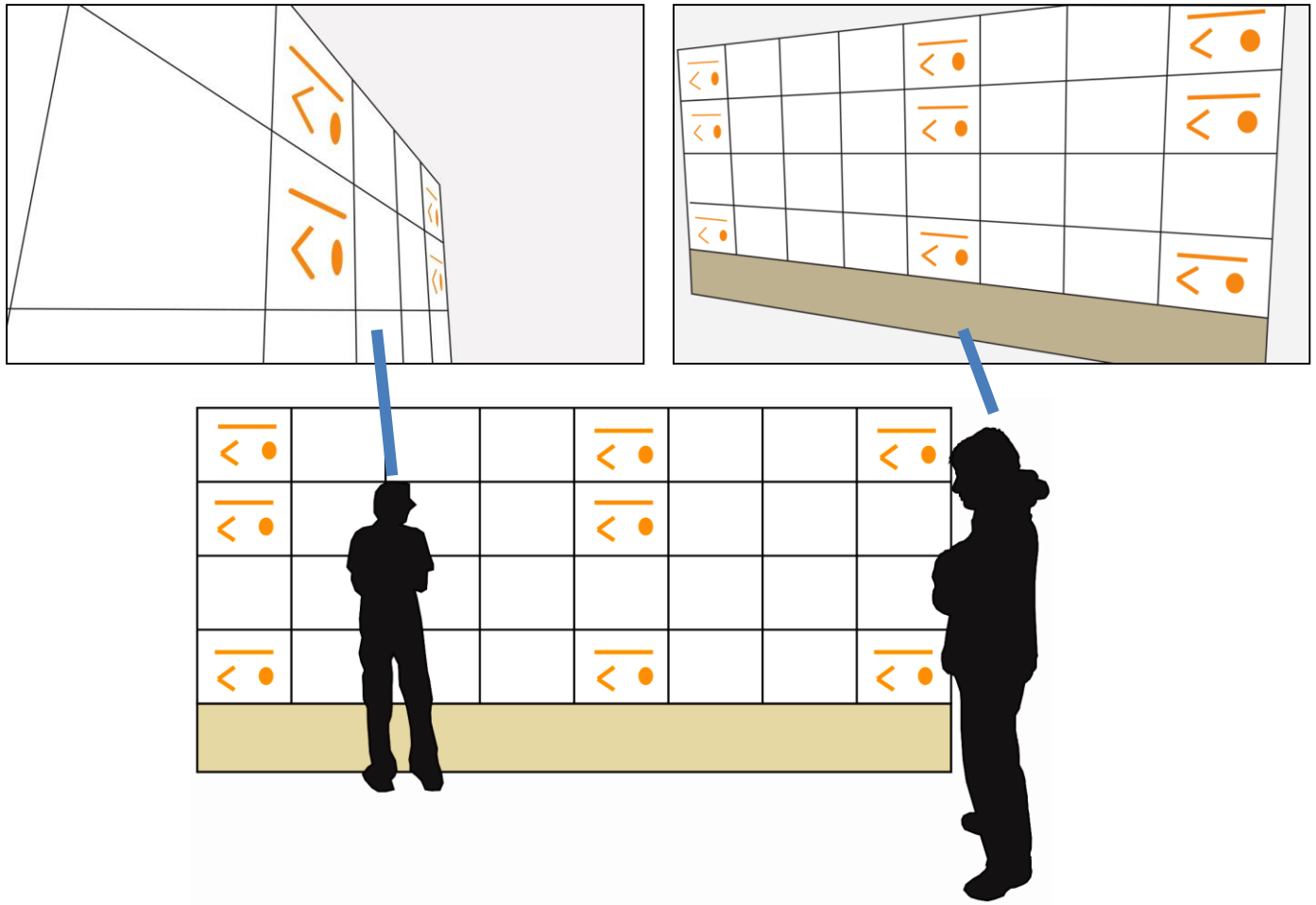


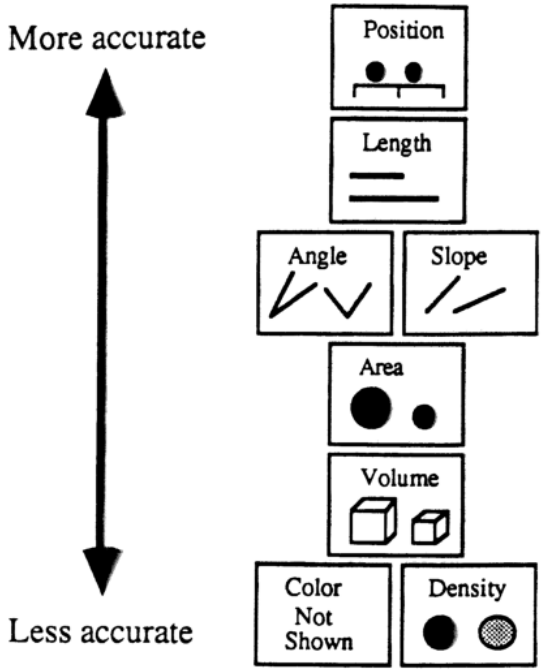
William S. Cleveland (1980s)

:

Elementary Graphical Perception Tasks

- Also beware of the physical presentation





William S. Cleveland (1980s)

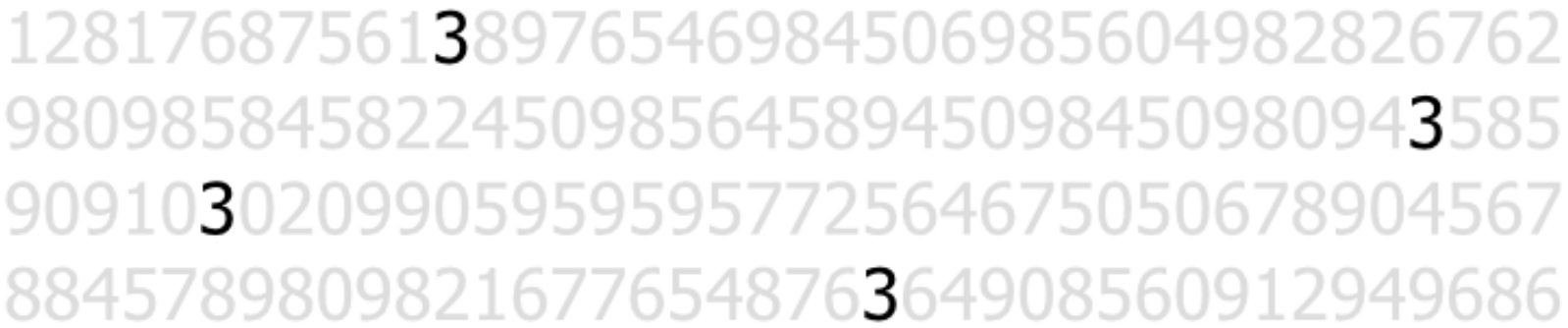
PREATTENTIVE PROCESSING

How many 3's do you see?

12817687561389765469845069856049828267629809858458224509856458945098450980943585909103020990595959577256467505067890456788457898098216776548763649085609129496869

Information Visualization using Vision to Think, Colin Ware

How about now?

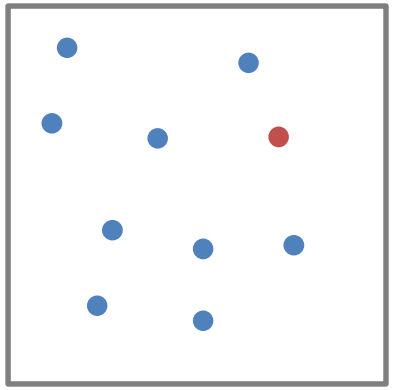
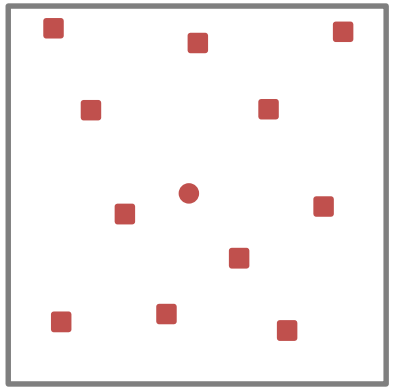
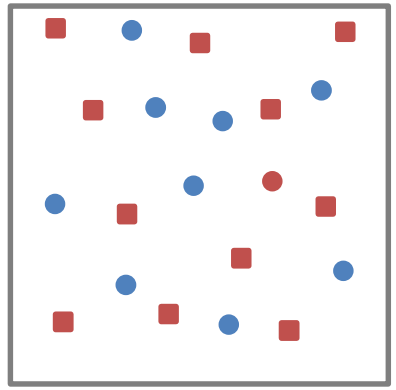
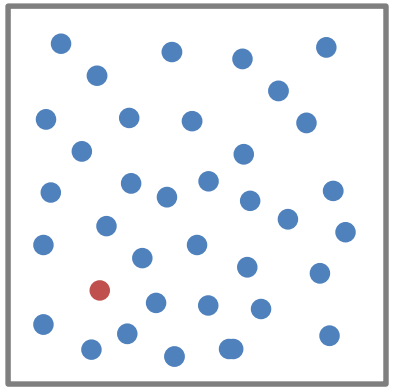
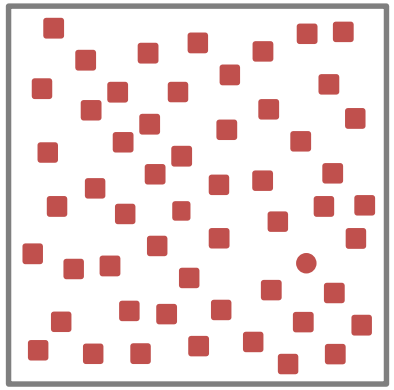
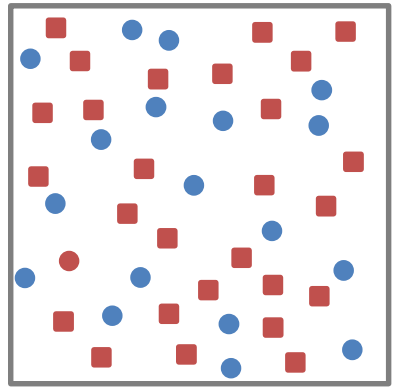


Information Visualization using Vision to Think, Colin Ware

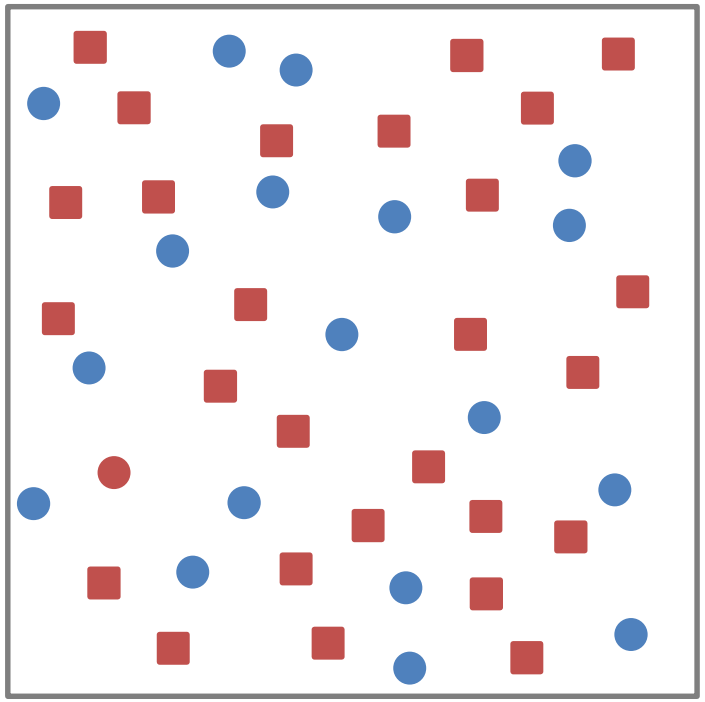
Preattentive Processing

- Some stimuli can be perceived **without** the need for focused attention
- Generally within **200-250 ms**
- Seems to be done **in parallel** by the low-level vision system
- Visual encoding has a **big** impact on this

DETERMINE IF A RED CIRCLE IS PRESENT

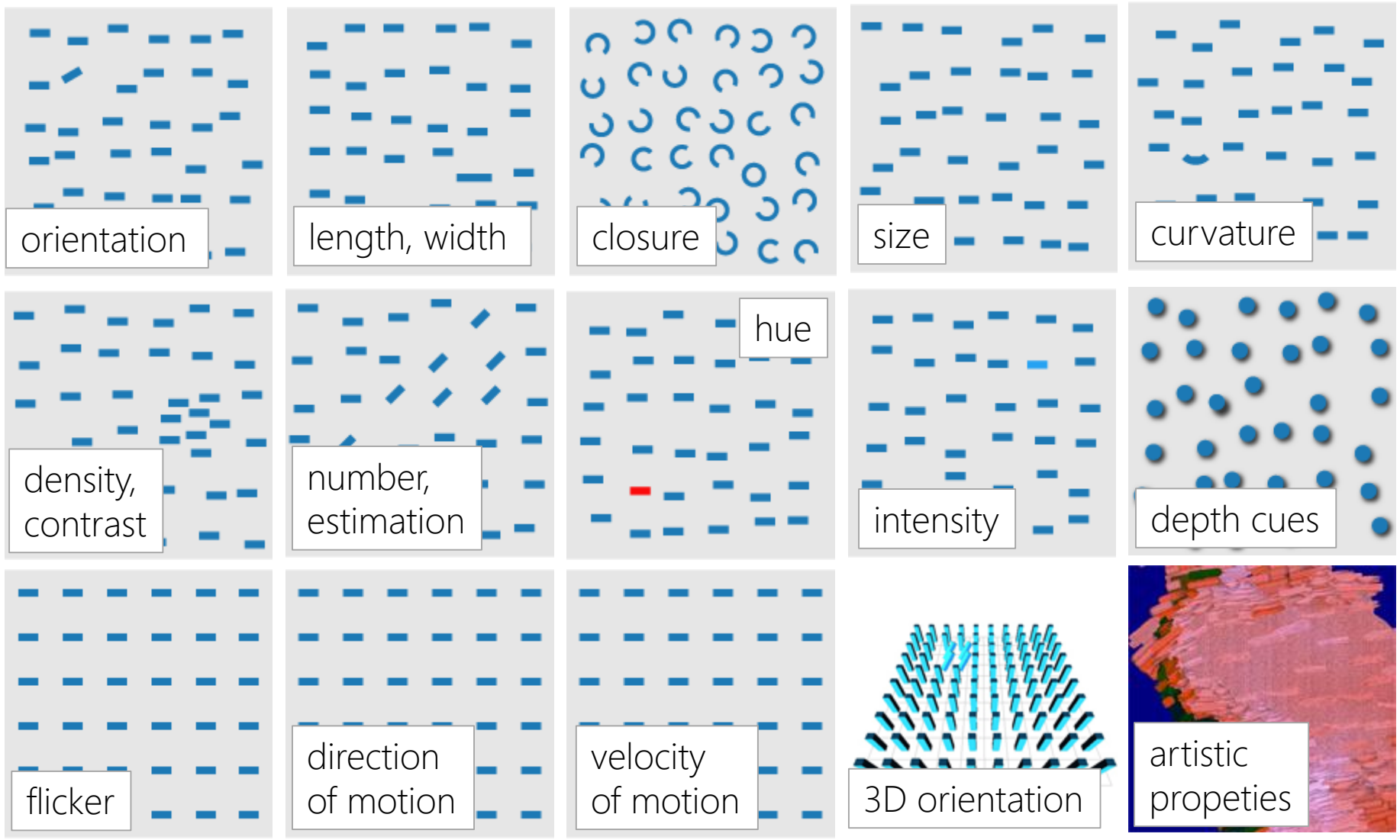
Hue and Shape



Cannot be done preattentively due to the **conjunction** of shape and hue → need to search

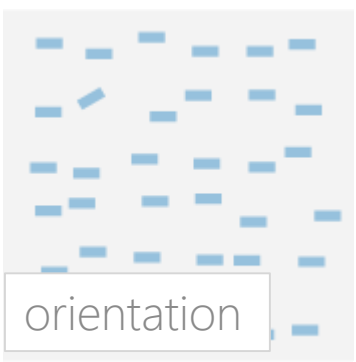
Perception in Visualization, Healey

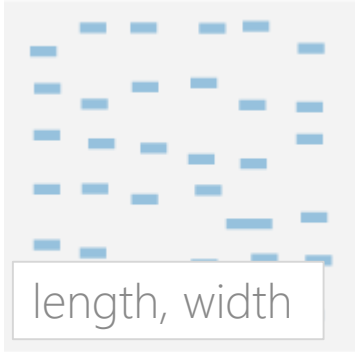
Preattentive visual features (some)

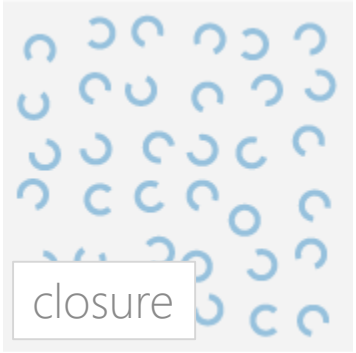


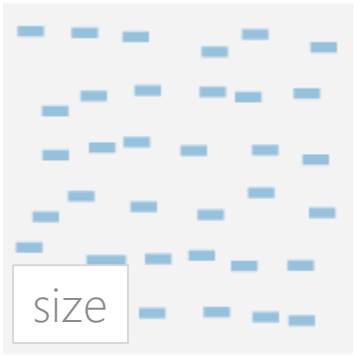
Perception in Visualization, Healey

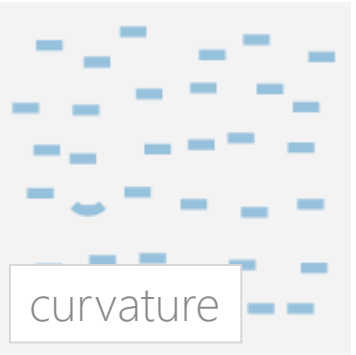
Preattentive visual features (some)

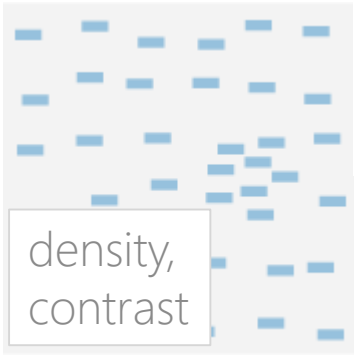




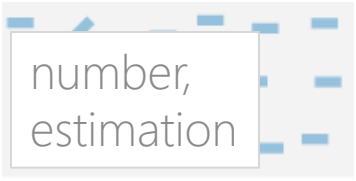


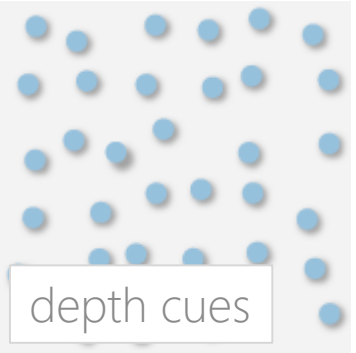


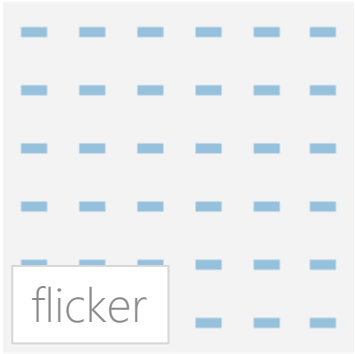


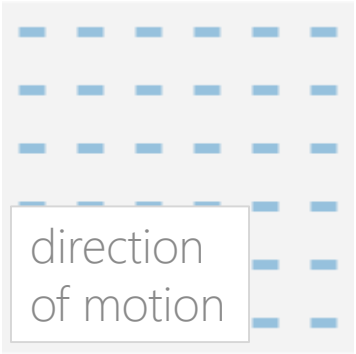


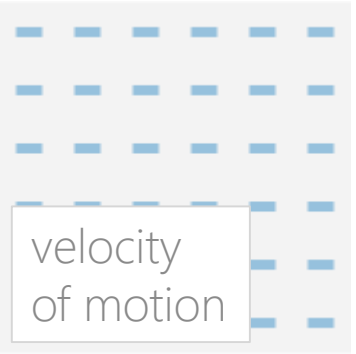
When designing visualizations, try to **use pre-attentive** features to support the **most important tasks**.

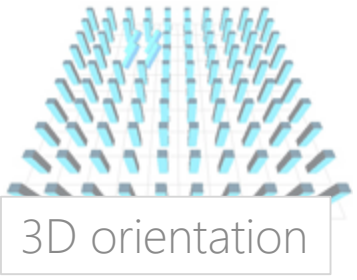






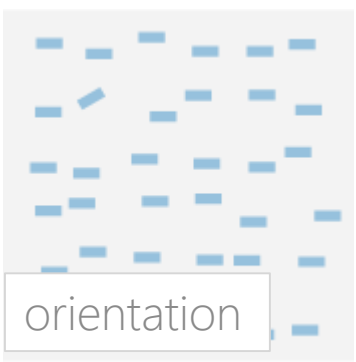


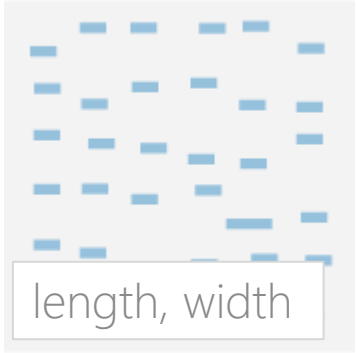


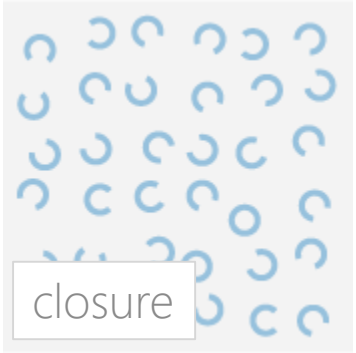


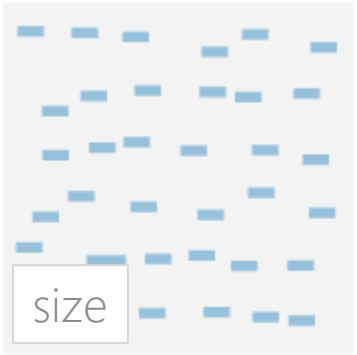
Perception in Visualization, Healey

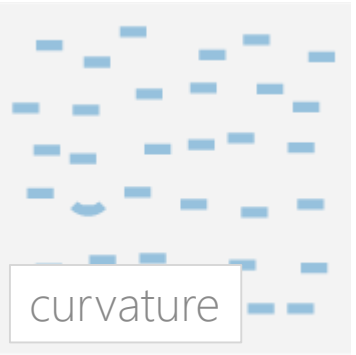
Preattentive visual features (some)

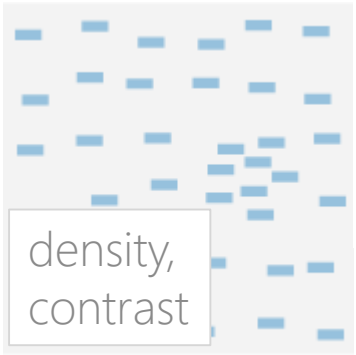






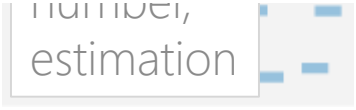


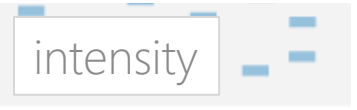


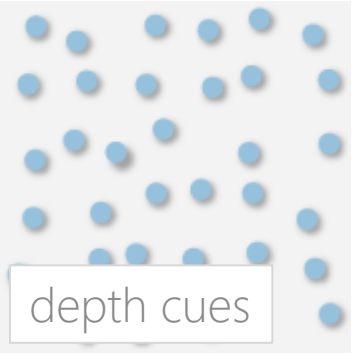


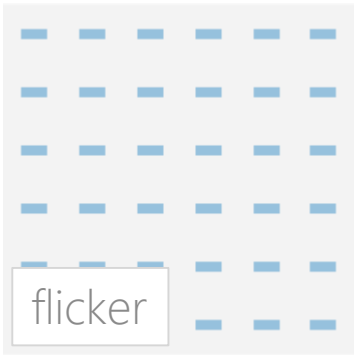
Avoid conjunctions that inhibit preattentive recognition.

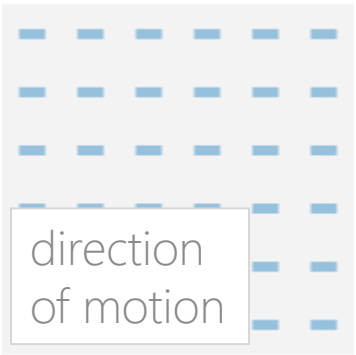
(**Most conjunctions** require search.)

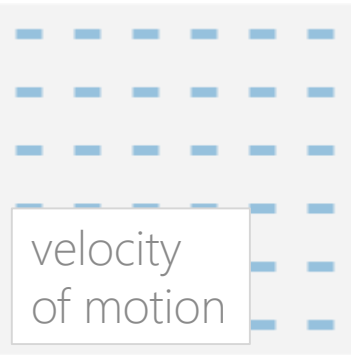


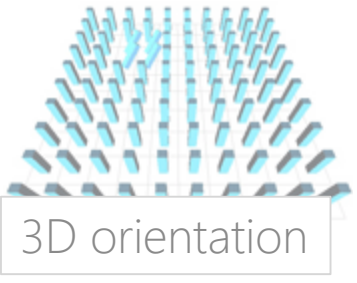












Perception in Visualization, Healey

Applying what we know to

ASSESS VISUAL REPRESENTATIONS

Let's evaluate…

Car / Nation	USA	Japan	Germany	France	Sweden
Accord		x			
AMC Pacer	x				
Audi 5000			x		
BMW 320i			x		
Champ	x				
Chevy Nova	x				
Saab 9000					x

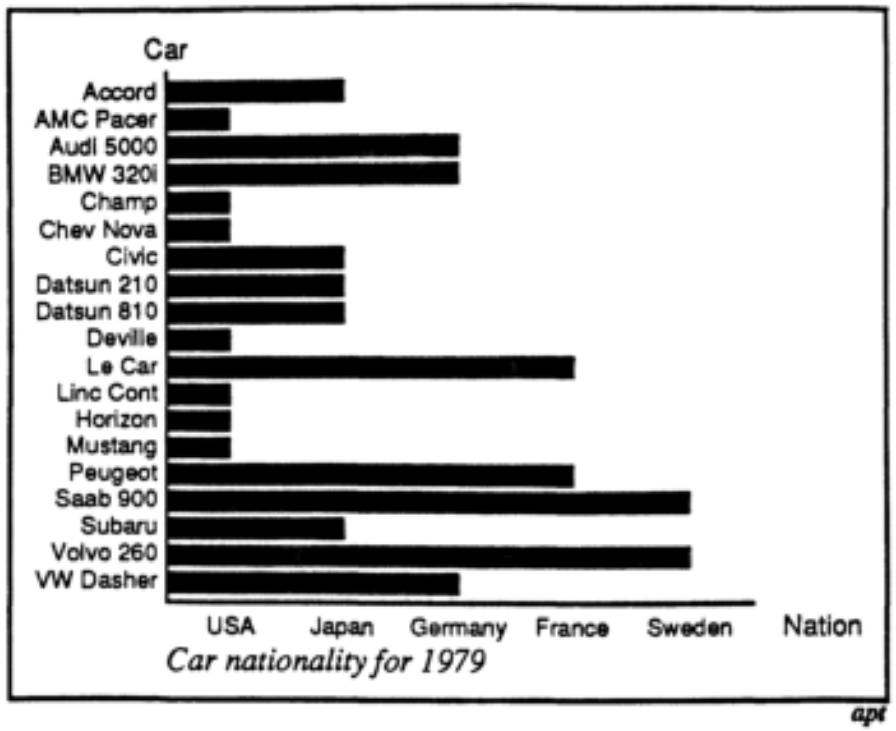
What kind of data are we looking at?

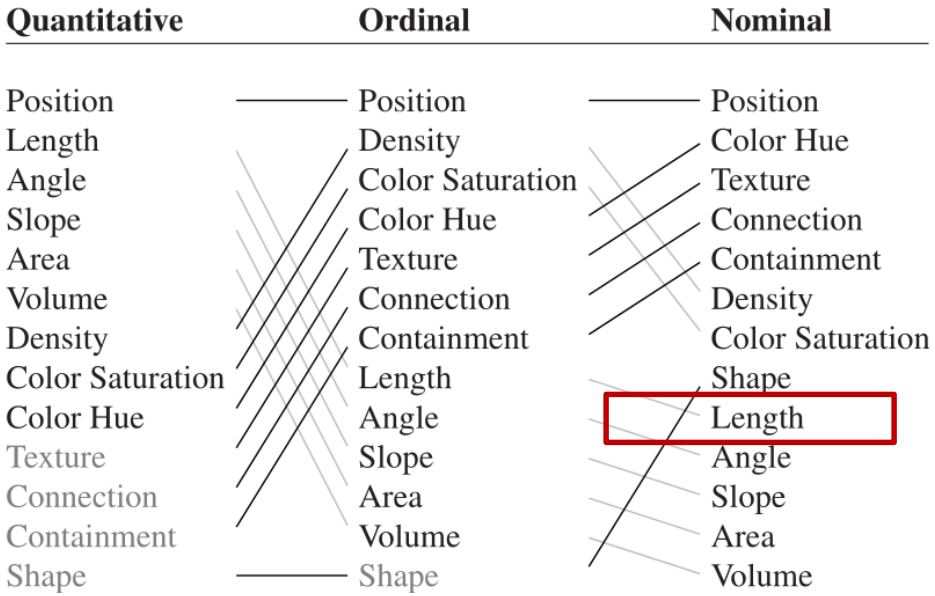
Nations: **Nominal**

Cars: **Nominal**

(Nation, Car): **Nominal**

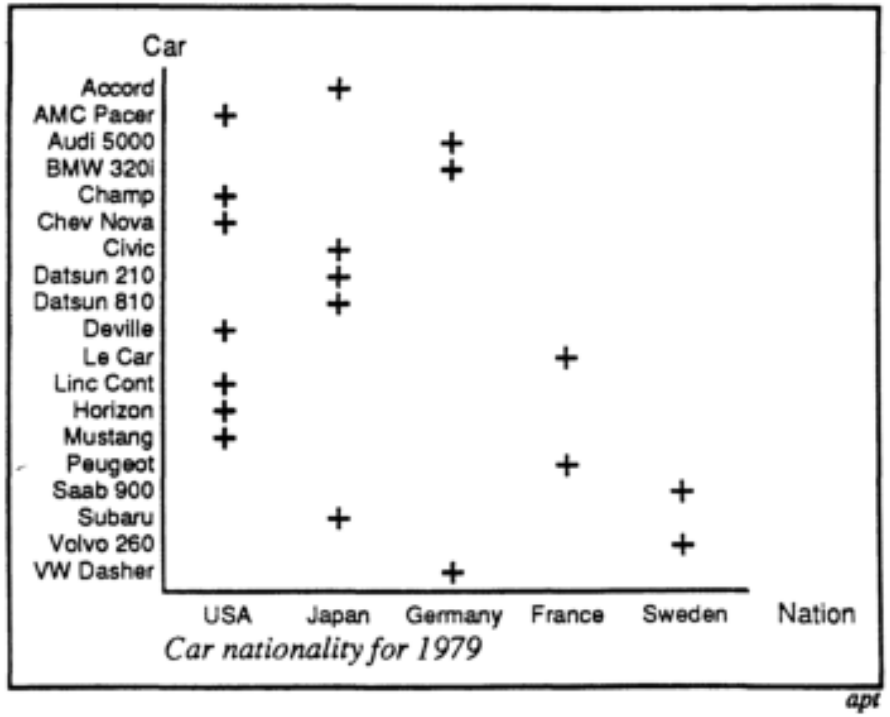
Let's evaluate…

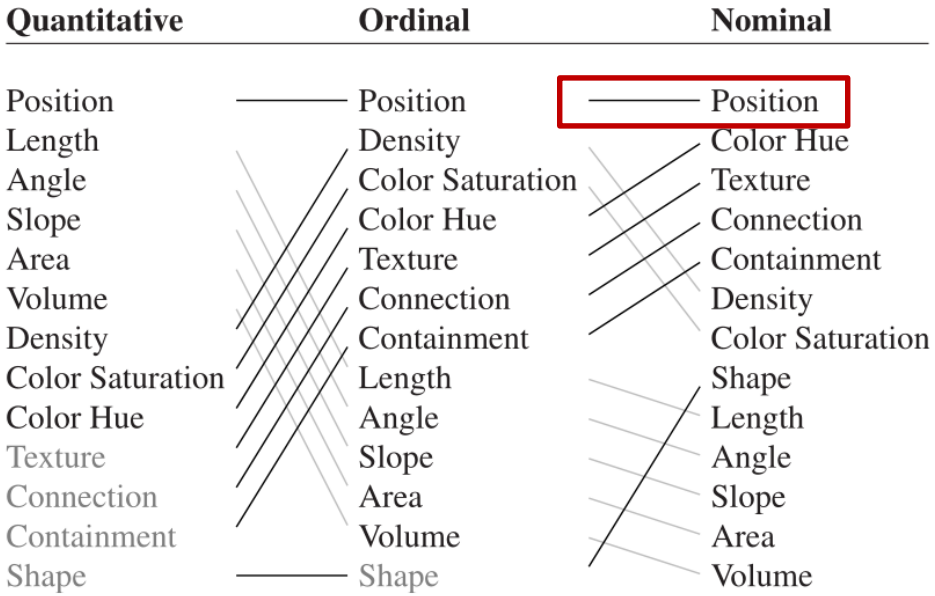




- Problem: Length of bar suggests an order or quantity (e.g. Swedish cars are better)

Let's evaluate…

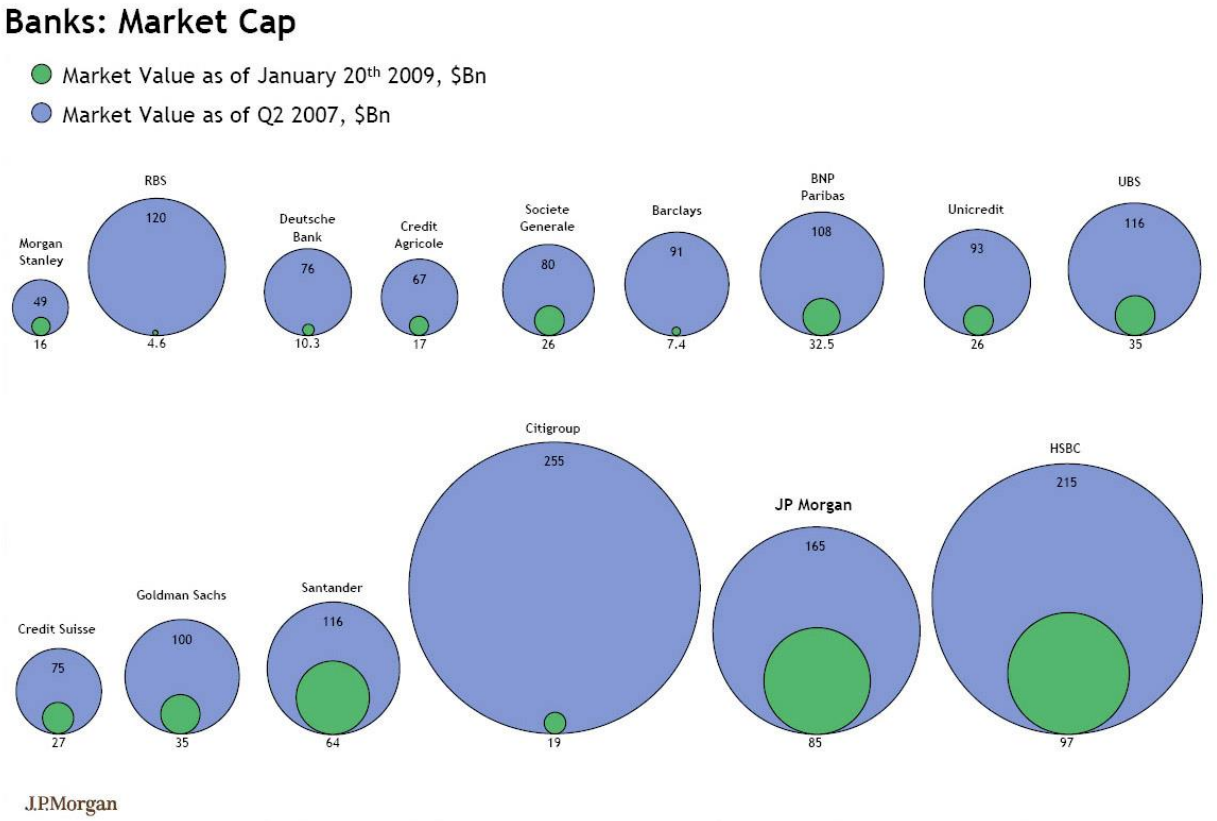




- Better!

Let's evaluate…

- Market Capitalization
  - What would it cost to buy all of a company's stock at the current price?
- Compares 15 major banks on two dates
  - January 20th, 2009
  - Q2 2007 (before banking crisis hit)

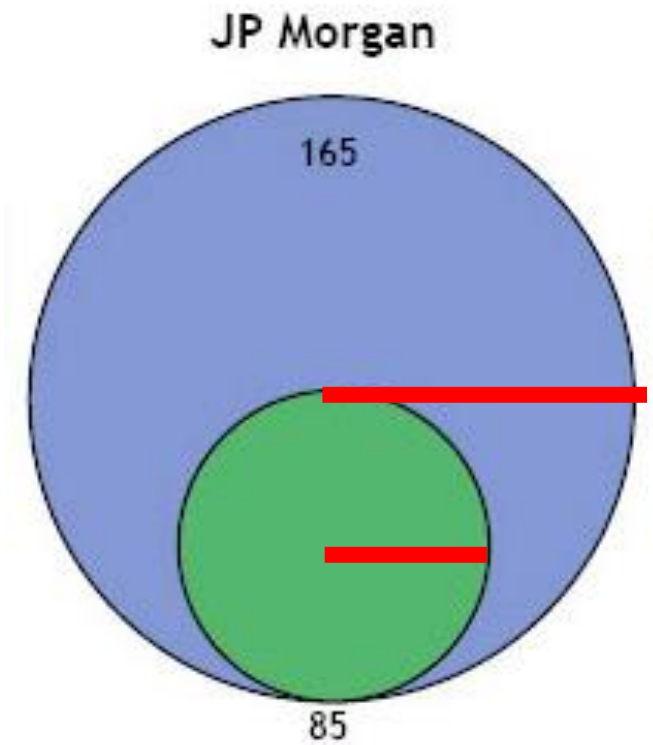


Problems here?

We are not good at comparing areas.

(And the areas here are actually misleading!)

Problems here?

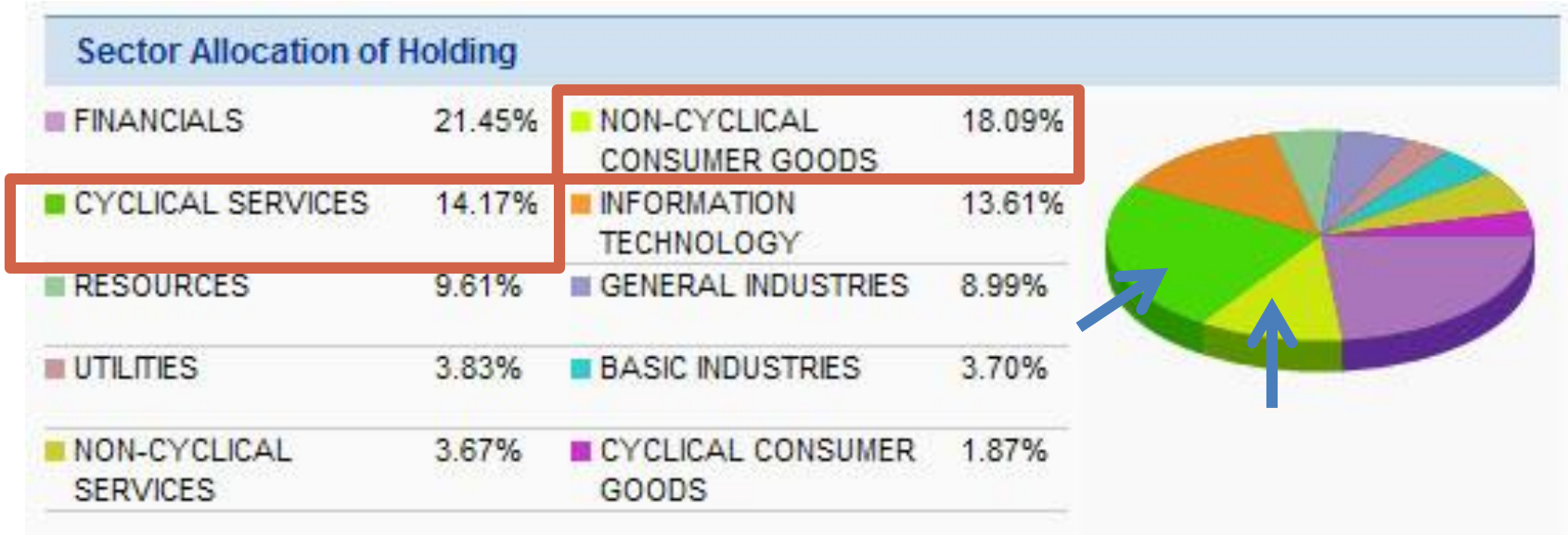


We are not good at comparing areas.

(And the areas here are actually misleading!)

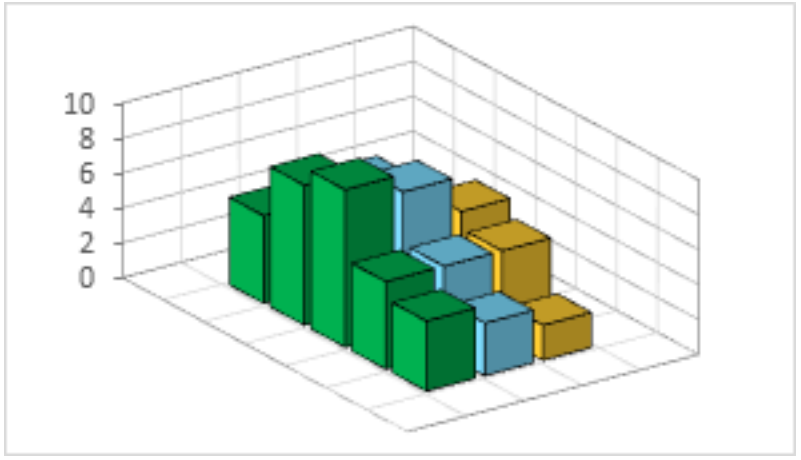
- Problem
  - 85 / 165 = ~50%
  - But this is actually the ratio of the radii, not the areas!
- Better: Bar chart

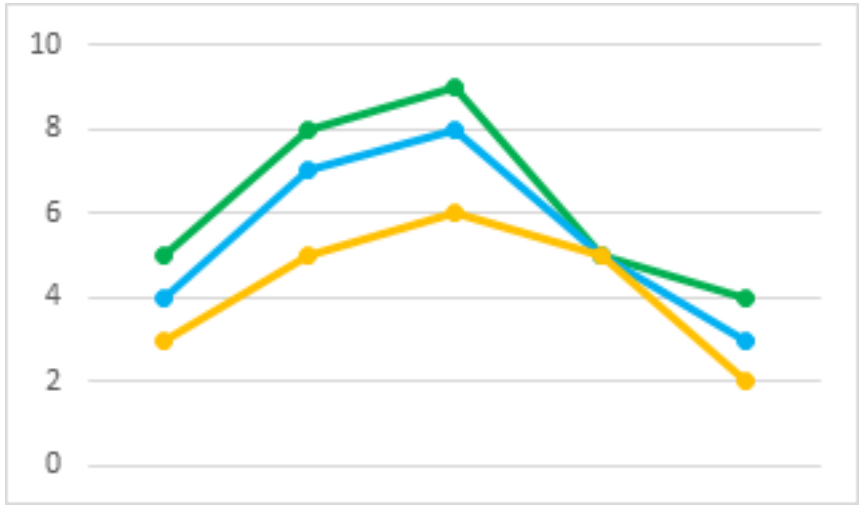
Problem here?



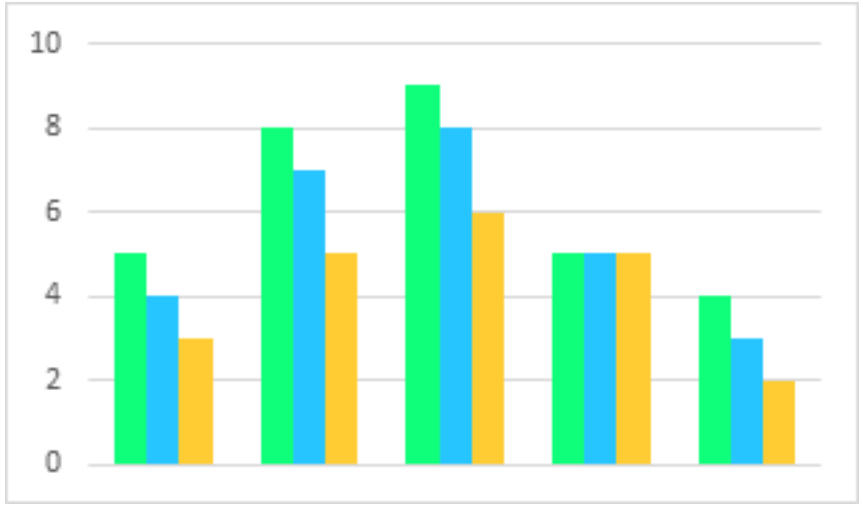
- Problems
  - There is likely a **bug or error** in the data
  - Pie slices are difficult to compare by **area** or by **angle**
  - **Similar colors** are difficult to distinguish
  - **Perspective distortion** adds to the problem

Similarly…3D bar charts are not recommended



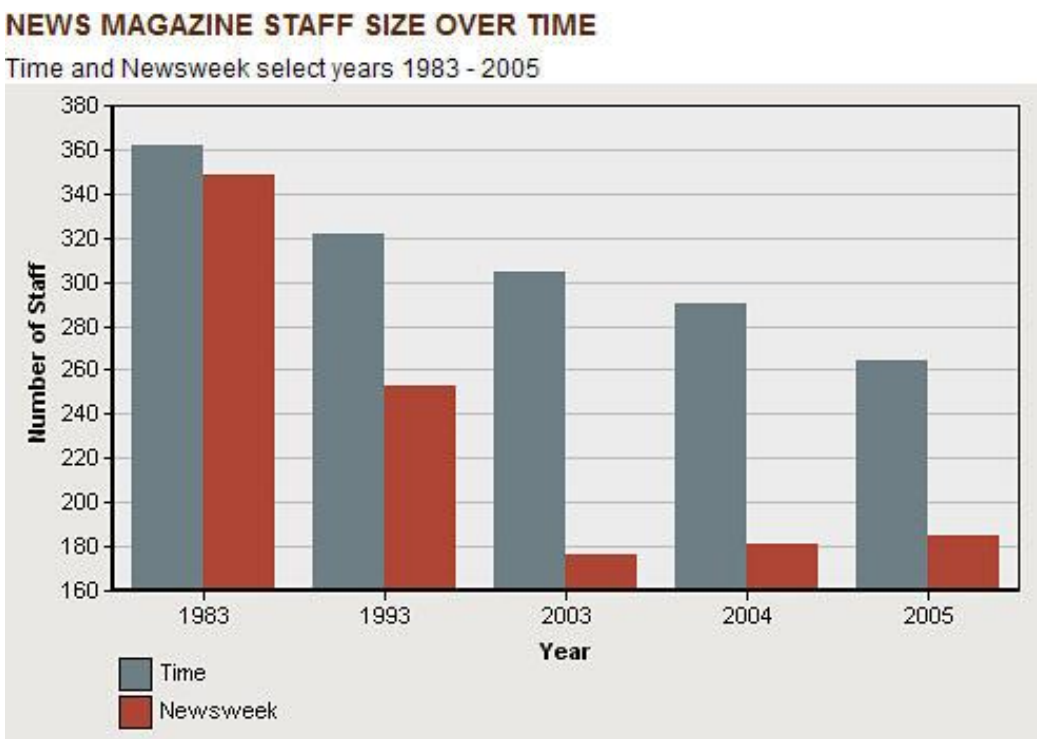


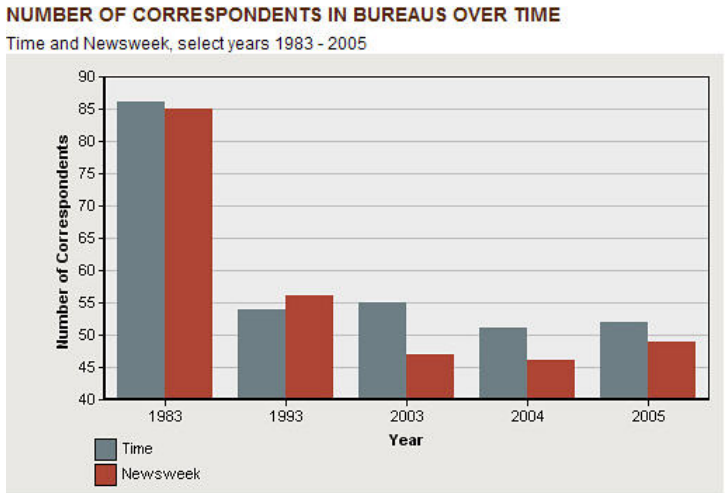
These are **much easier** to read & compare!

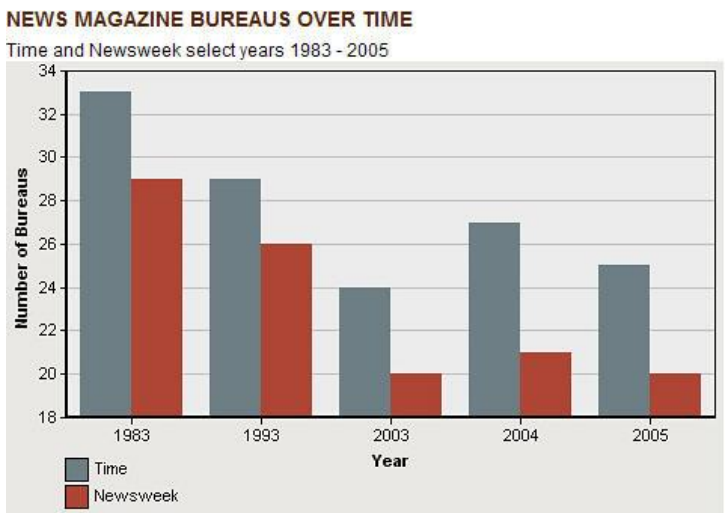


John Peltier http://peltiertech.com/WordPress/3d-bar-chart-alternatives/

Problem here?

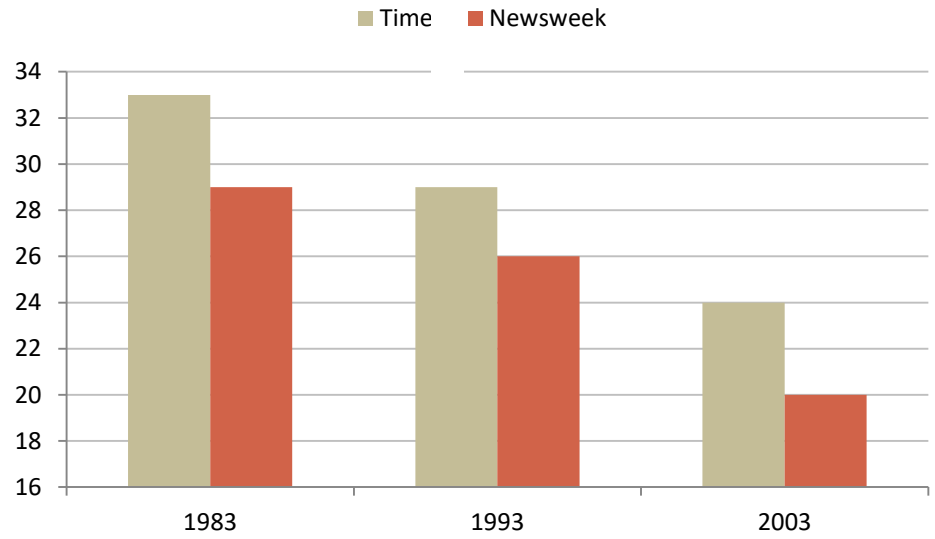






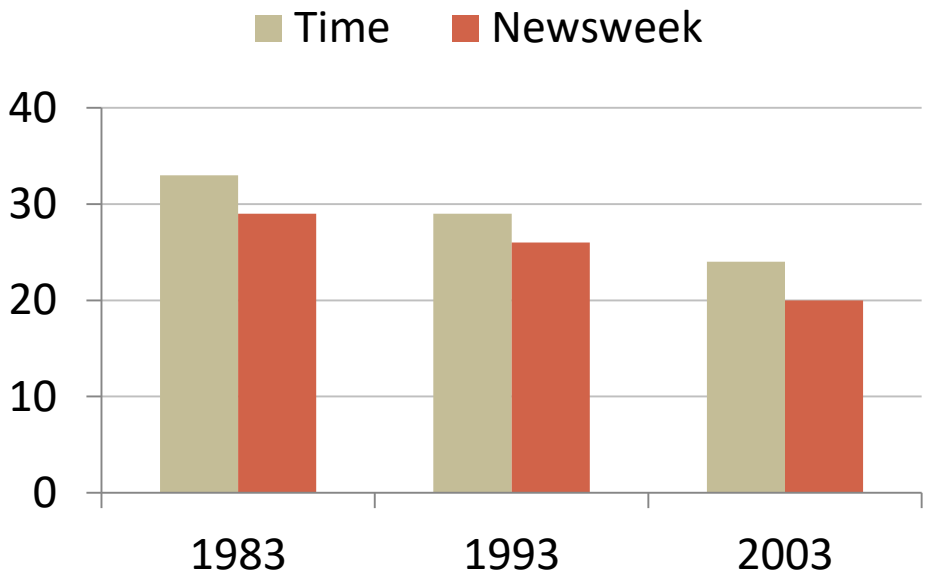
Journalism.org (via Stephen Few)

Length Comparison



At first glance:

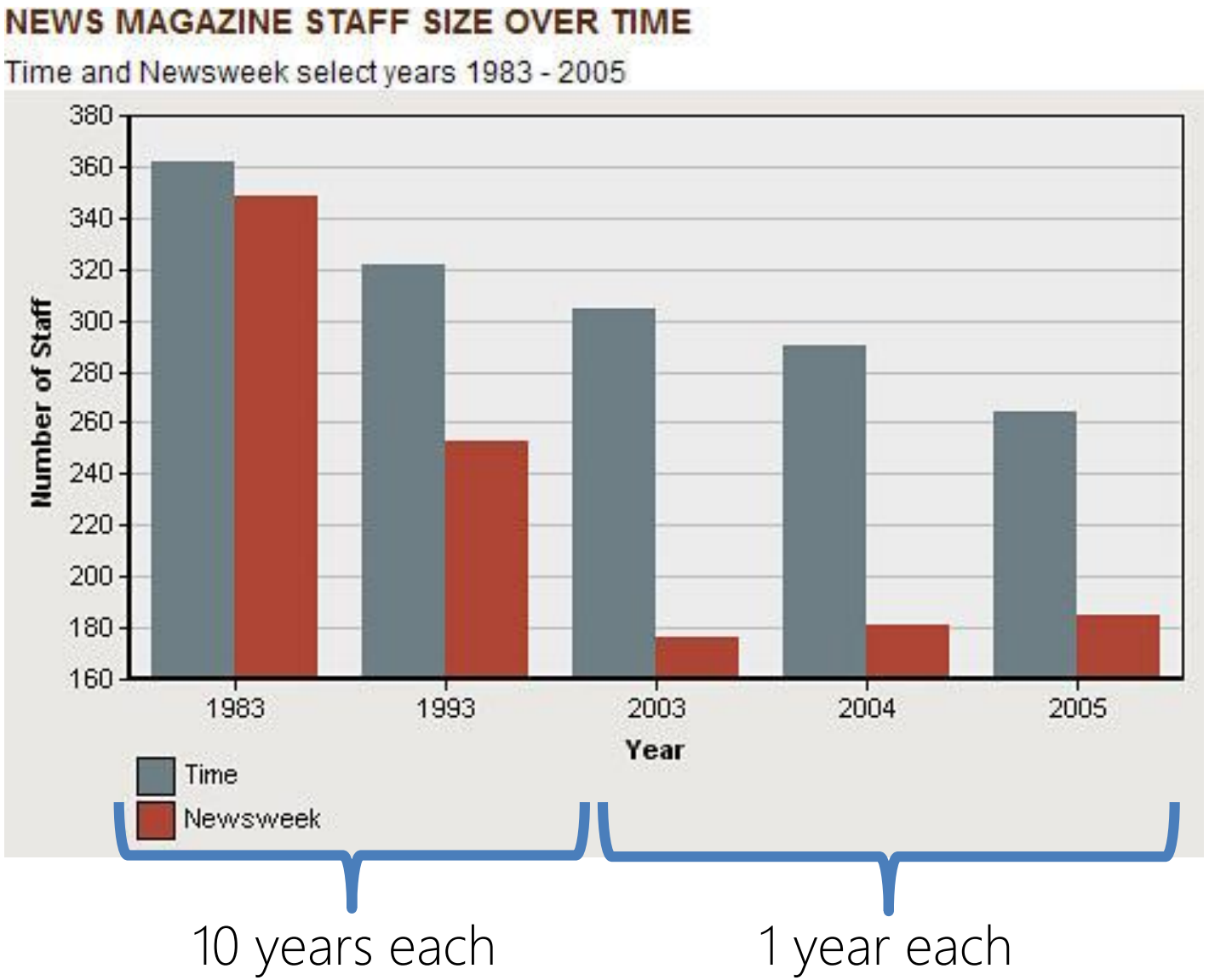
- A huge overall decline
- In 2003, Newsweek is 50% of Time



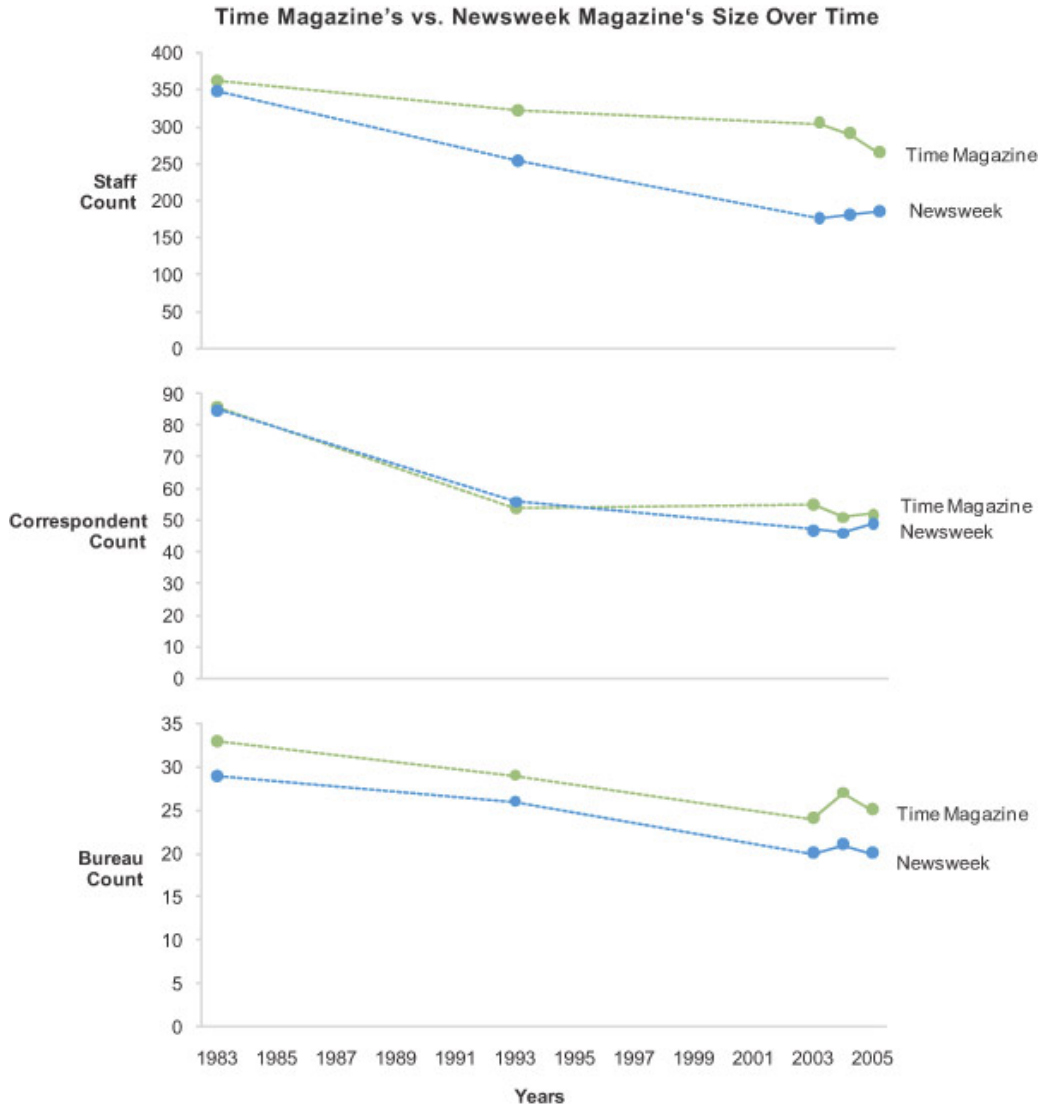
If we add a proper baseline at 0:

- The downward trend is less severe
- 2003: Newsweek is ~80% of Time

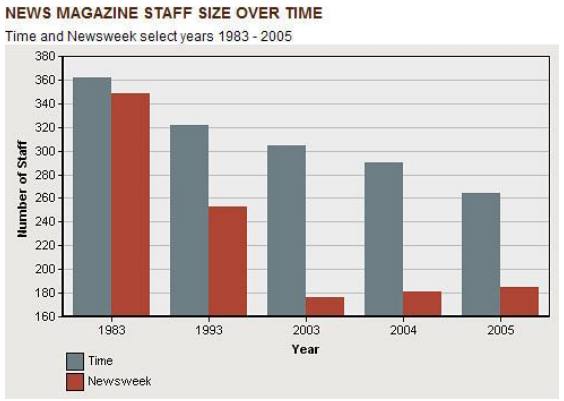
Moreover…

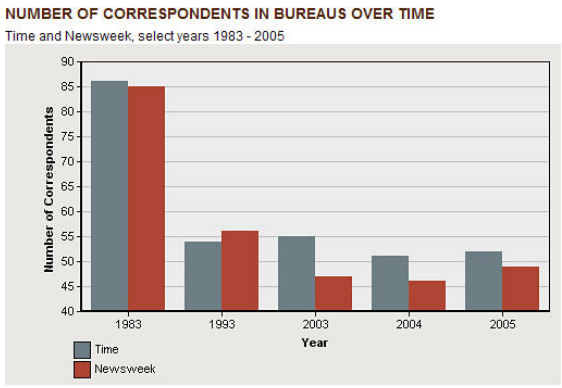

NEWS MAGAZINE STAFF SIZE OVER TIME
Time and Newsweek select years 1983 - 2005
Number of Staff
380
360
340
320
300
280
260
240
220
200
180
160
1983
1993
2003
2004
2005
Year
Time
Newsweek
10 years each
1 year each

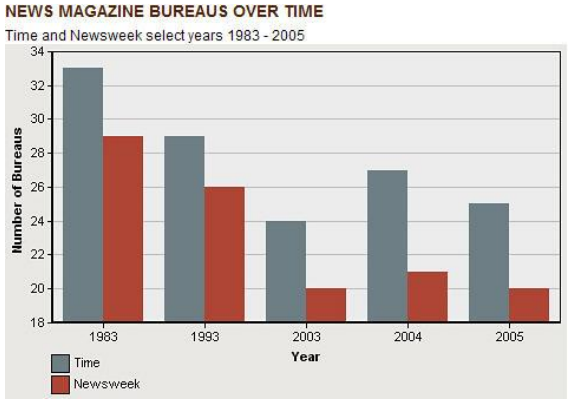
Redesign (by Stephen Few)



Note: A dashed line connecting two points indicates that there are years between the points for which values were not available. If the values were available, the shape of the lines might vary significantly.







Summary

- Today you learned
  - Details about the **perception of color** and a few **other visual variables**
  - Saw that the vision system is **quicker and better** at detecting certain visual variables
  - Learned how to **critique visualizations**