

Information Visualization PERCEPTION and COLOR



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Let's do an experiment ...



What is Color?

= the set of **perceptions** elicited by the spectral distribution of light

Color Vision

- What we call color is generated by the visual brain
- There is no one to one relationship between the colors seen and wavelengths

Functions of Color Perception

Color helps us to:

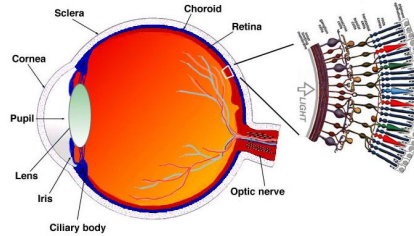
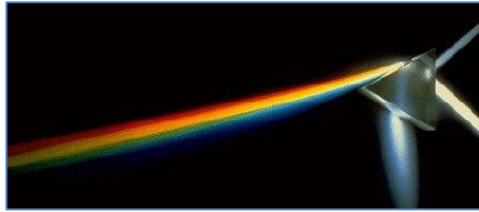
- Identify things
- Classify things

Through

- Grouping
- Background segregation



How do we describe color?



“Yellow”

**Physical
World**

Lights, surfaces,
objects

**Visual
System**

Eye, optic nerve,
visual cortex

**Mental
Models**

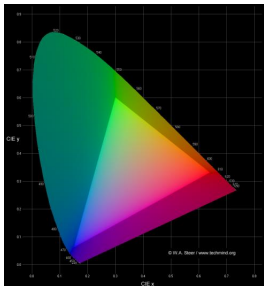
Red, green, brown

Bright, light, dark, vivid,
colorful, dull

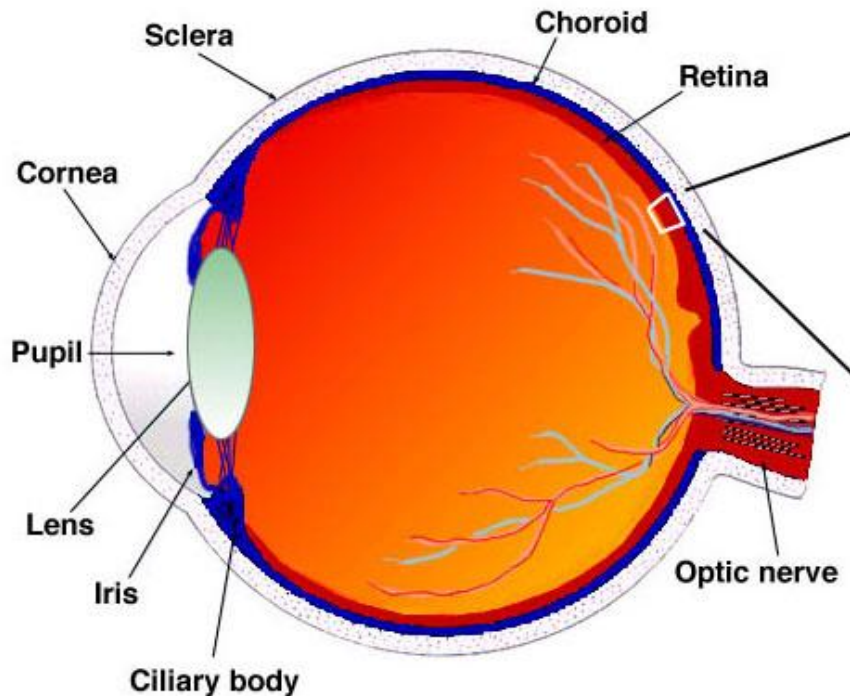
**Color
Models**

RGB, CMYK,
CIE XYZ, CIE Lab
HSV/HSB, ...

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



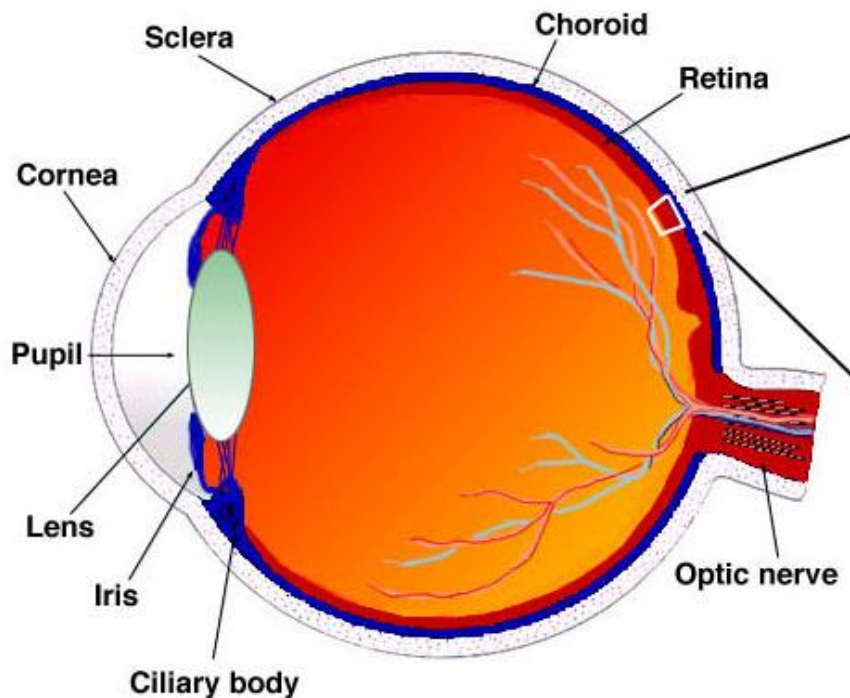
Physical World → Visual System



Retina is stimulated by three factors:

- illumination (light source)
- reflectance (from object)
- transmittance (atmosphere)

Physical World → Visual System



You do not see individual photons or light waves

- Eyes make limited measurements
- Eyes physically adapt to circumstance
- Your brain adapts in various ways
- Weird stuff happens

Example: Lightness vs. Luminance

- **LUMINANCE:** an objective measurement of light intensity per unit area (e.g. cd/m^2 ; physical)



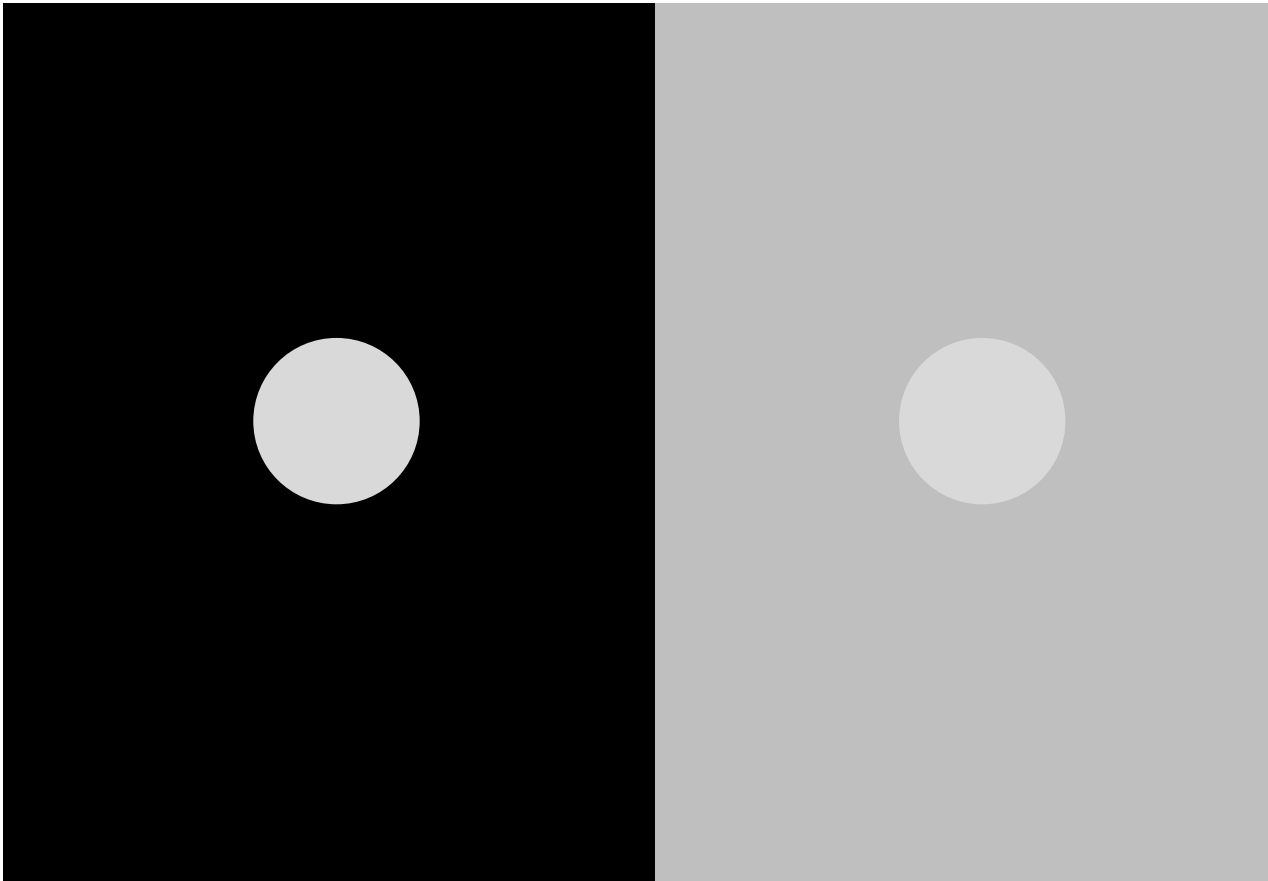
- **LIGHTNESS:** a subjective impression of the intensity of light reflected from on object surface (no units; psychophysical)

Lightness experiment



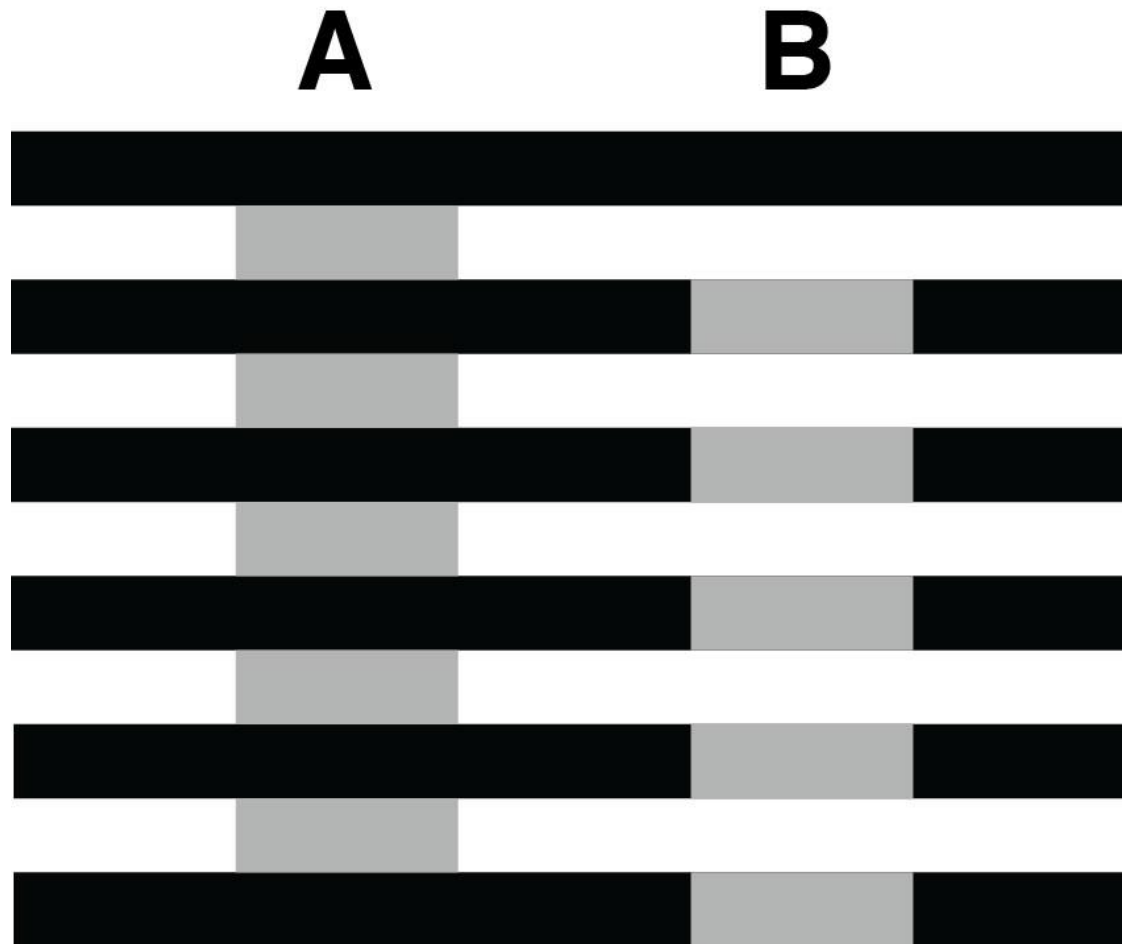
The two circles are physically the same

Lightness experiment



The two circles are still physically the same, but the lightness you perceive is not

White's illusion: the opposite effect



A is surrounded by more black but seems darker than B, which is surrounded by more white

The Cornsweet Edge

As a result of two gradients, but why does this happen?

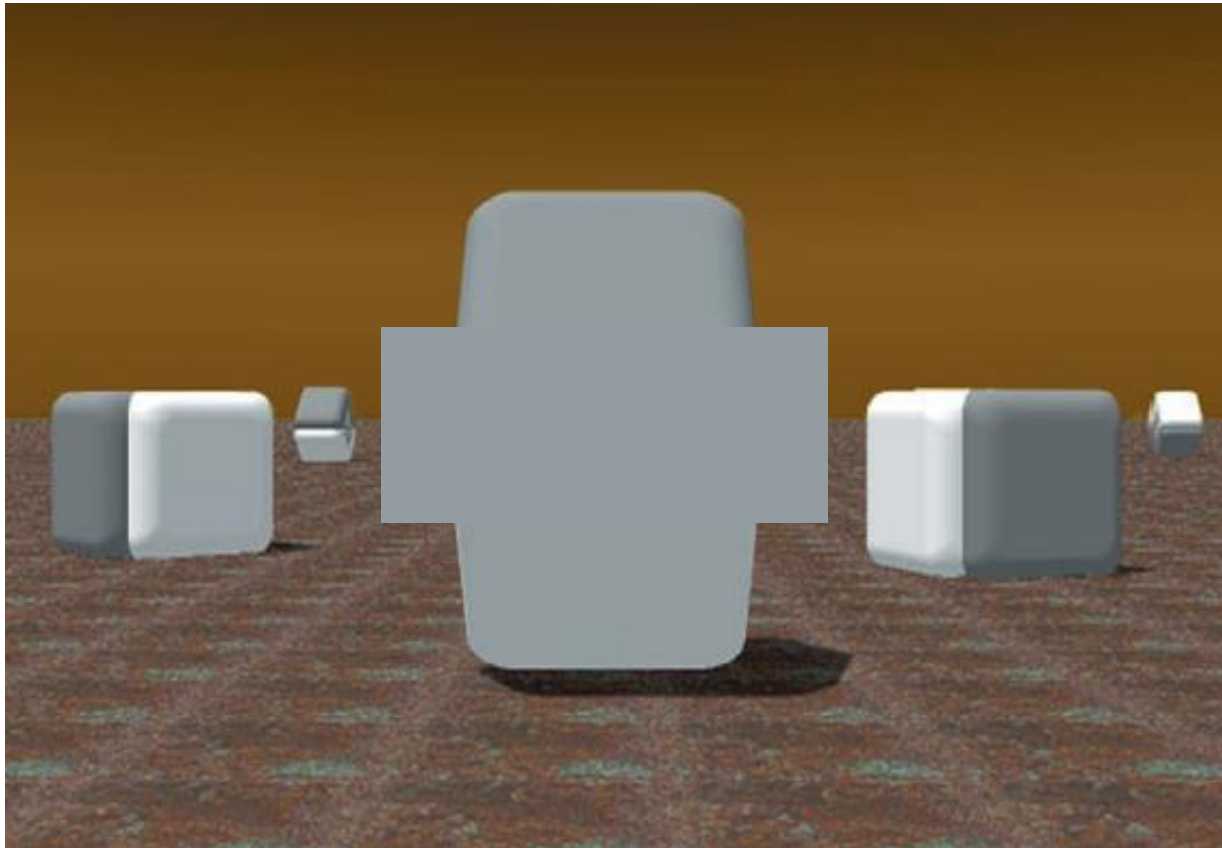
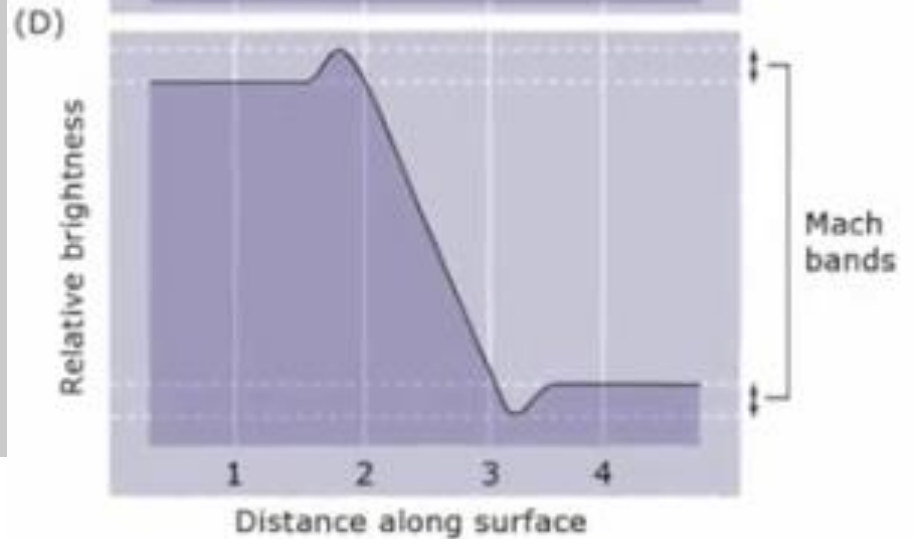
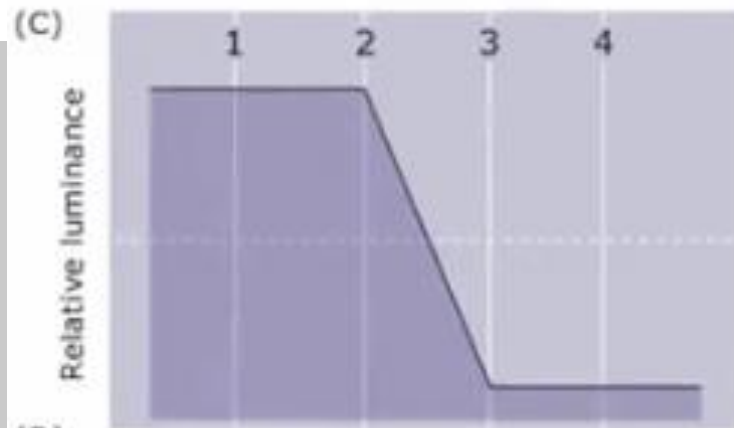
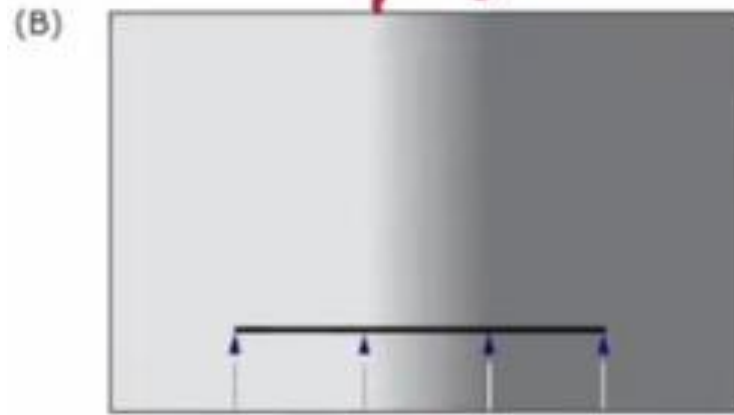
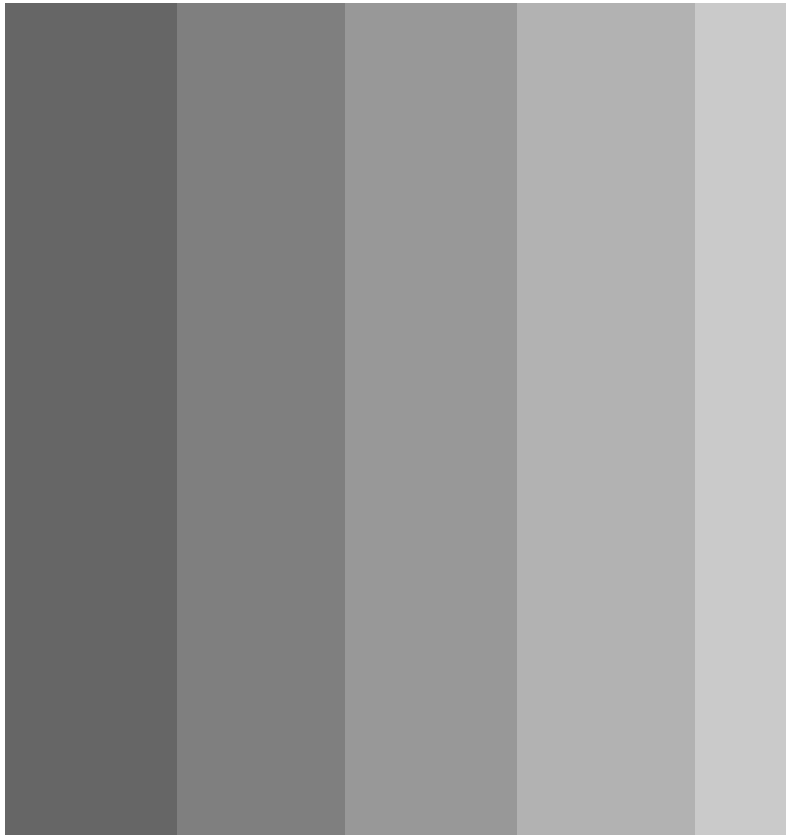


Image source: The Journal of Neuroscience, October 1, 1999, 19(19):8542–8551 [An Empirical Explanation of the Cornsweet Effect.](#)

Mach bands

Even harder to explain:



WHAT IS GOING ON?

The Inverse Problem

- What the retina receives as input (stimulus) is a combination of photons/light waves
 - From illumination sources
 - From reflectance of objects
 - From transmittance through objects
 - How do we know who contributed what?
- We have learned what the relationships are between the physical world and our perceived information are, to solve this problem

WHAT IS **COLOR**?

Some definitions

Physical measurement:

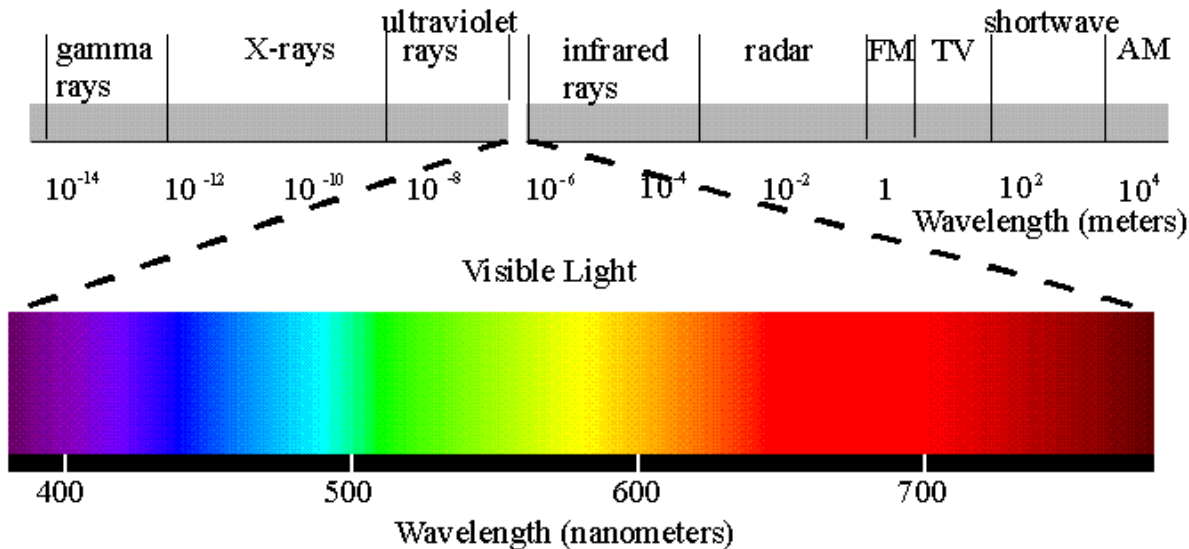
the relative intensities of wavelengths in light measured with a spectrophotometer

Psychophysical measurement:

report of the **color** seen by a normal subject, typically made by comparison

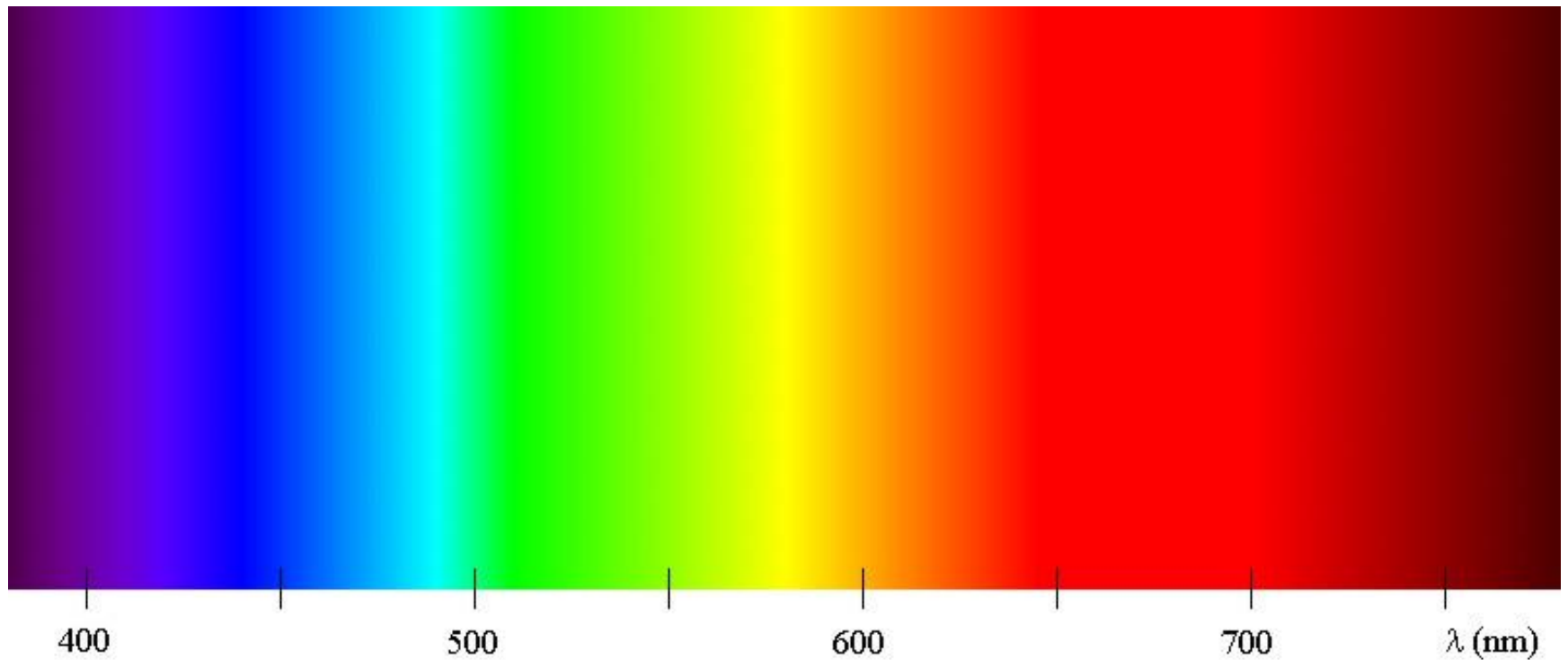
Physical World – The Nature of Light

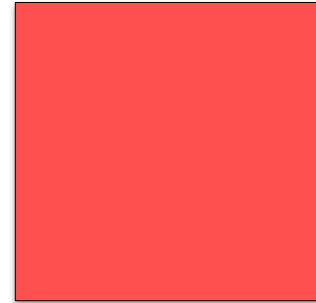
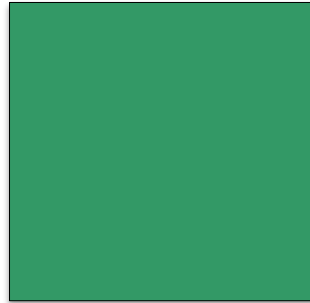
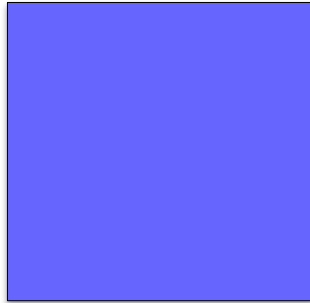
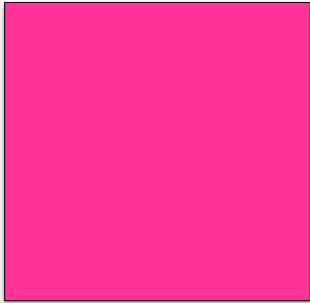
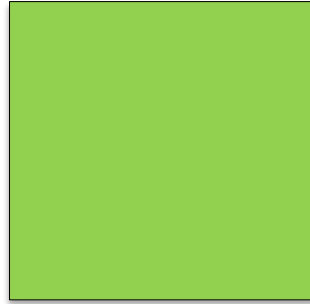
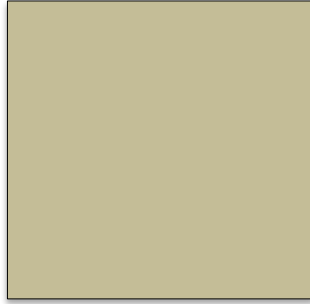
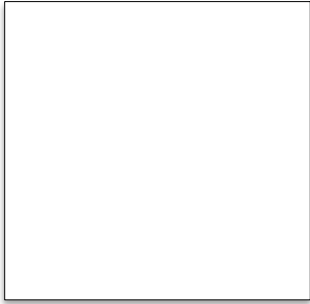
We have evolved to see a range of wavelengths: ~400 - 700nm



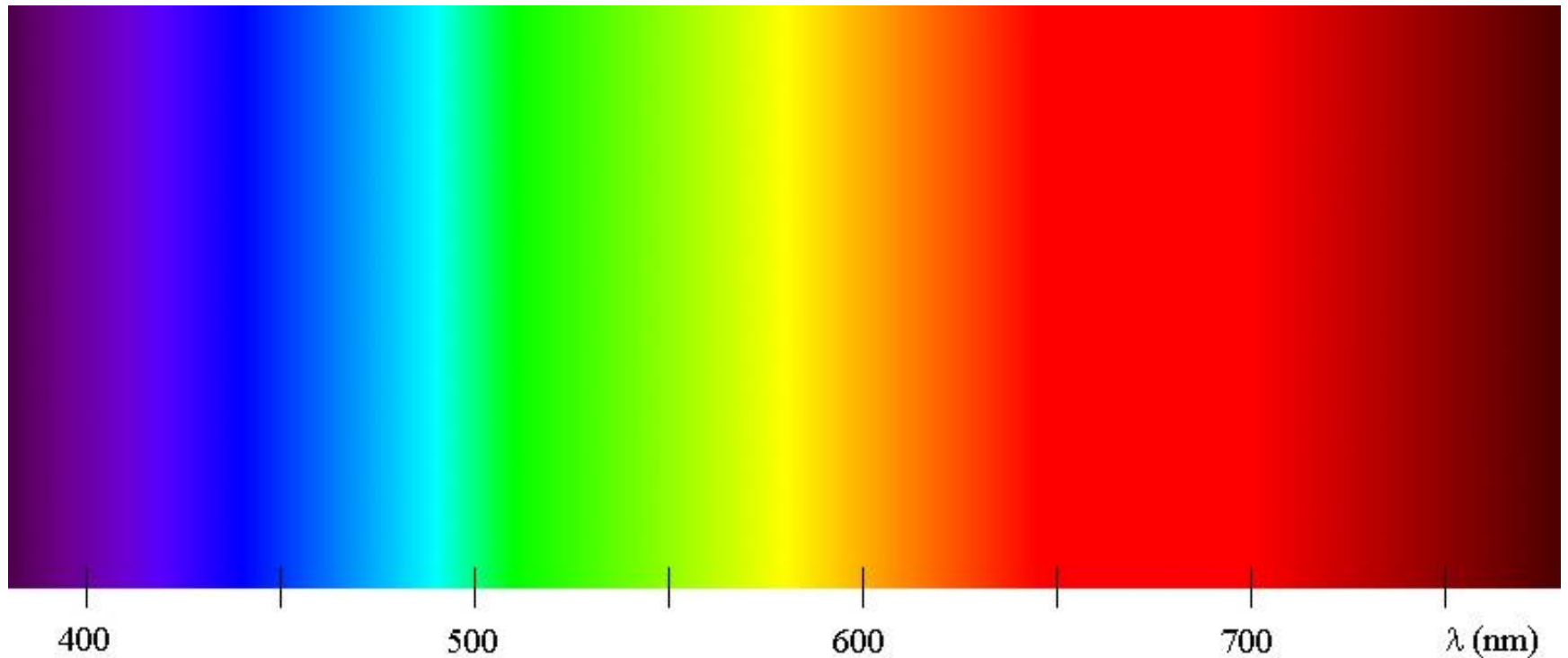
Light of a single wavelength is *monochromatic*

What do you notice?





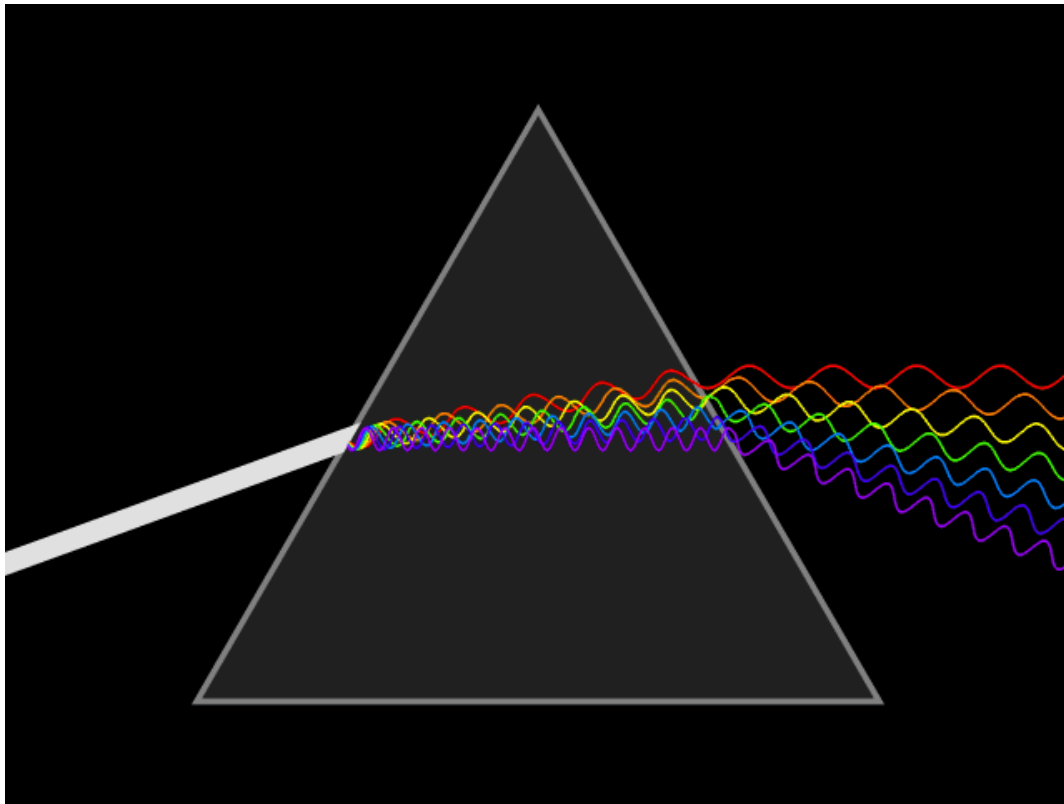
Monochromatic colors



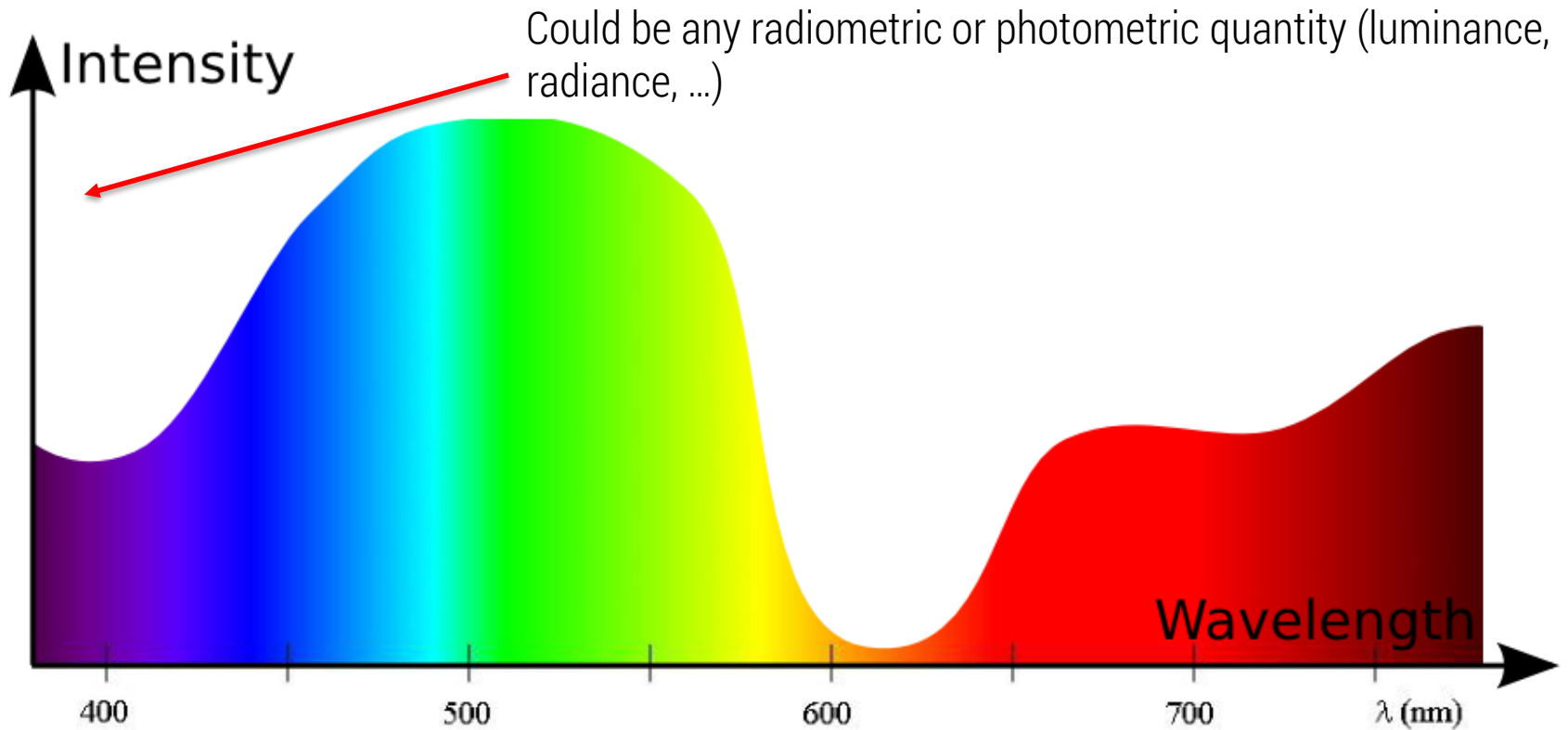
Can be obtained with one or more rays of light with a single wavelength

BUT...

Light rays are typically composed of multiple wavelengths

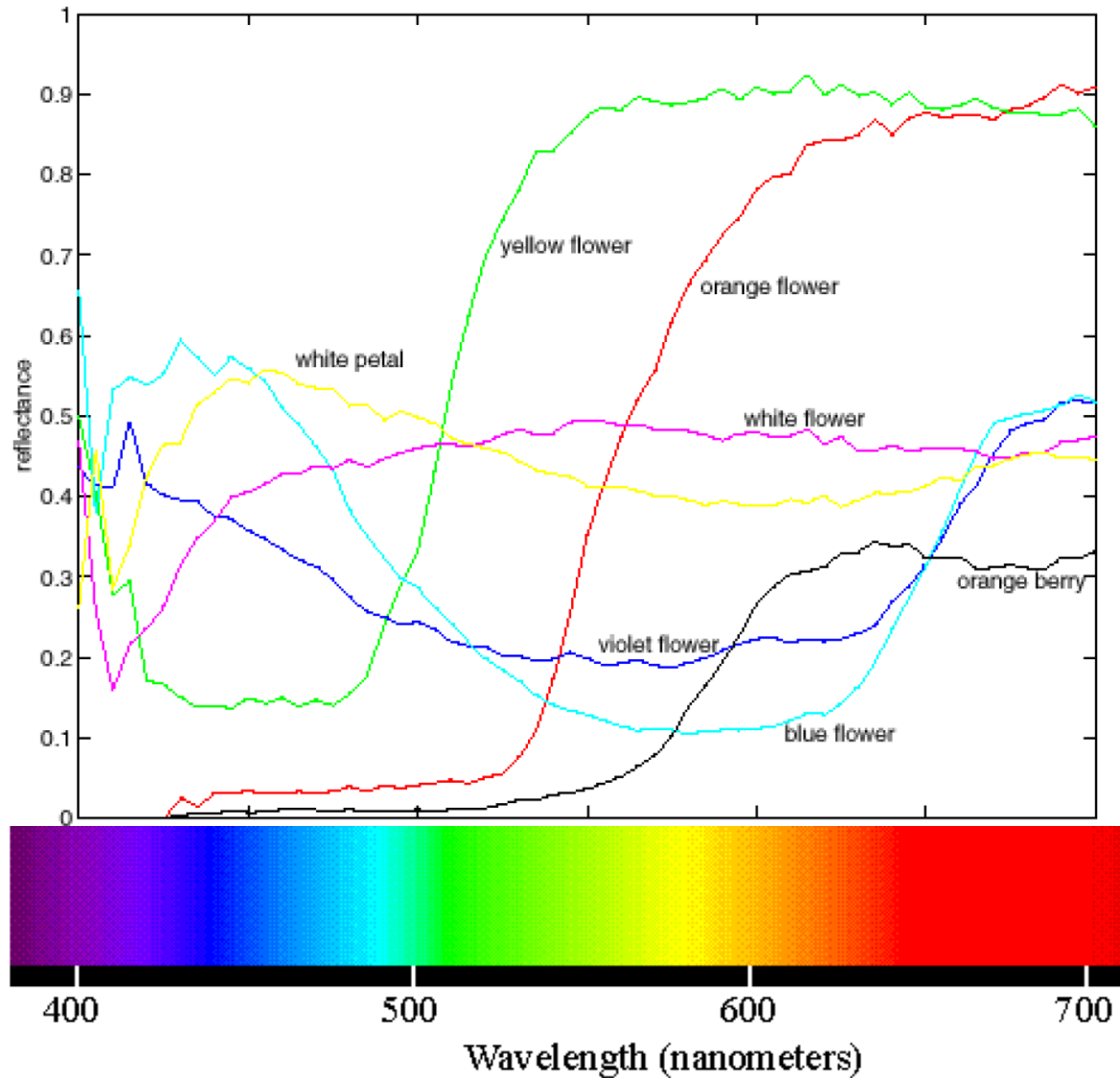


How do we describe a beam of light?

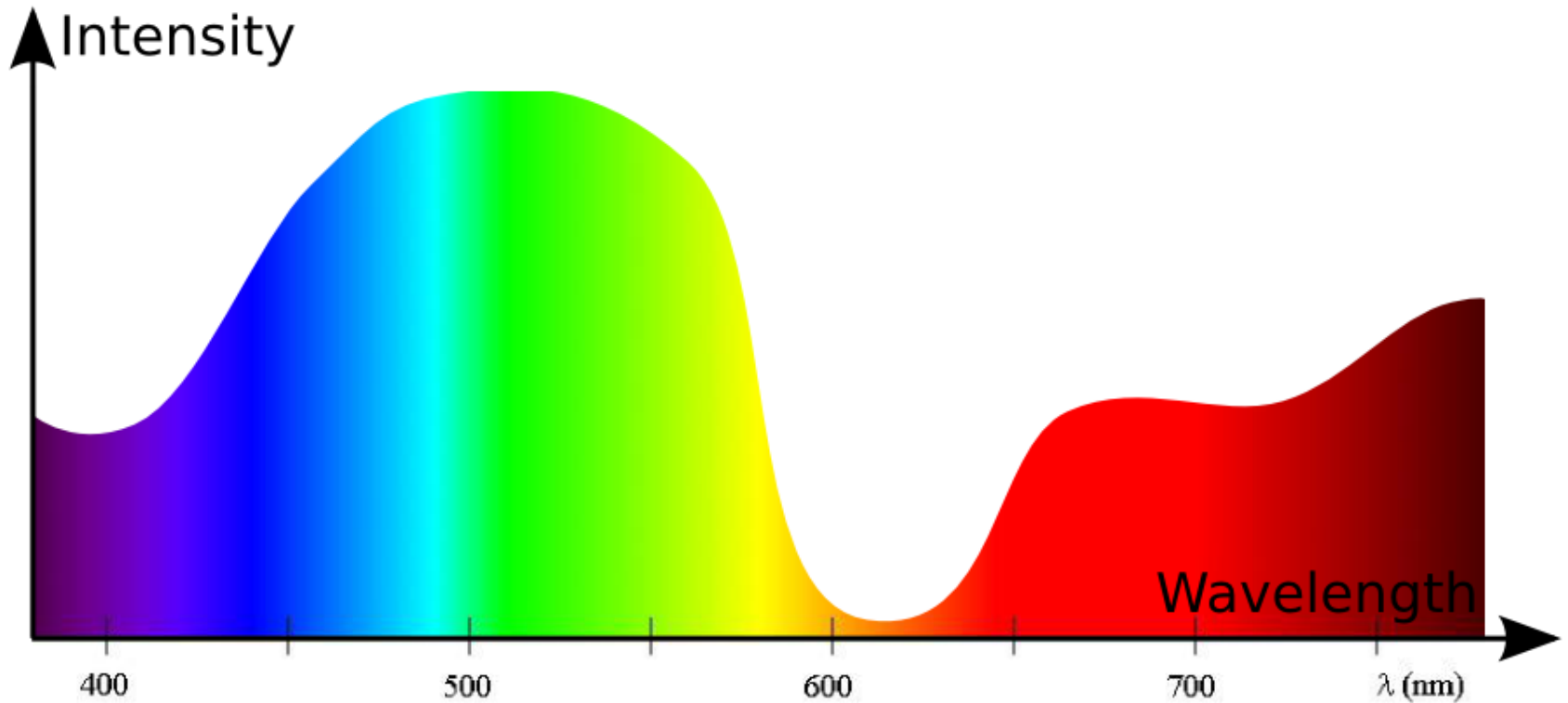


spectral power distribution (SPD)

Non-monochromatic color spectra



How do we know which color this would be?



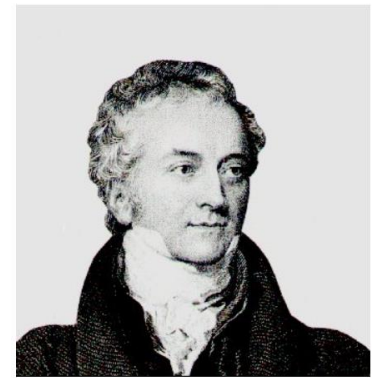
Physically speaking

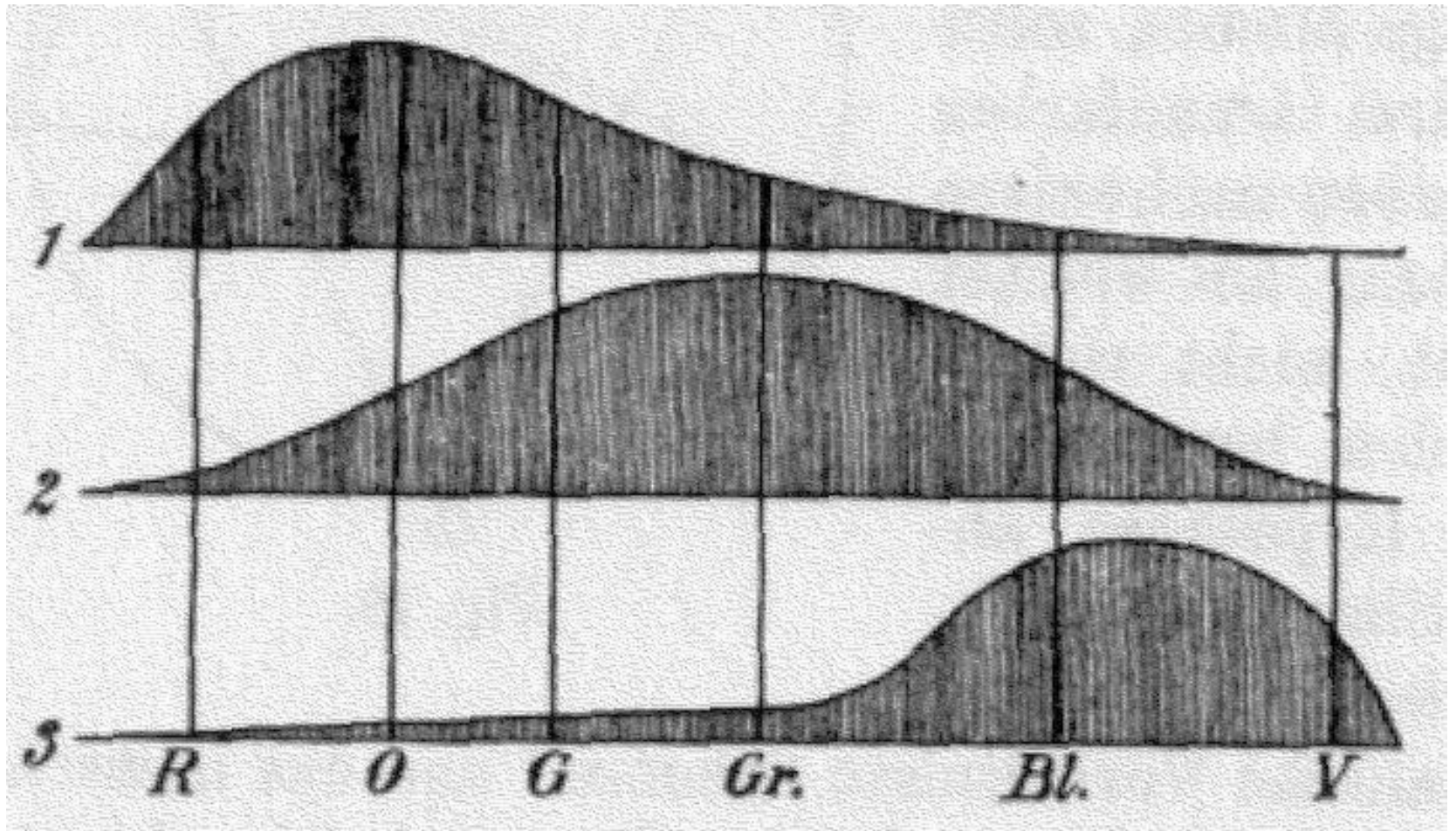
If you want to see different wavelengths at different energies across the spectrum

→ you need to have multiple photo receptors that can be compared

Trichromatic Theory

- Also called: Young-Helmholtz theory of color vision
- One of the earliest theories on how we perceive color
- Early 1800s, Young suggested that the eye contained different photoreceptor cells that were sensitive to different wavelengths of light in the visible spectrum.
- Mid-1800s: Hermann von Helmholtz suggested that the cone receptors were:
 - short-wavelength ([blue](#)),
 - medium-wavelength ([green](#)),
 - or long-wavelength ([red](#))....and the strength of the signals detected determined how the brain interpreted color in the environment.

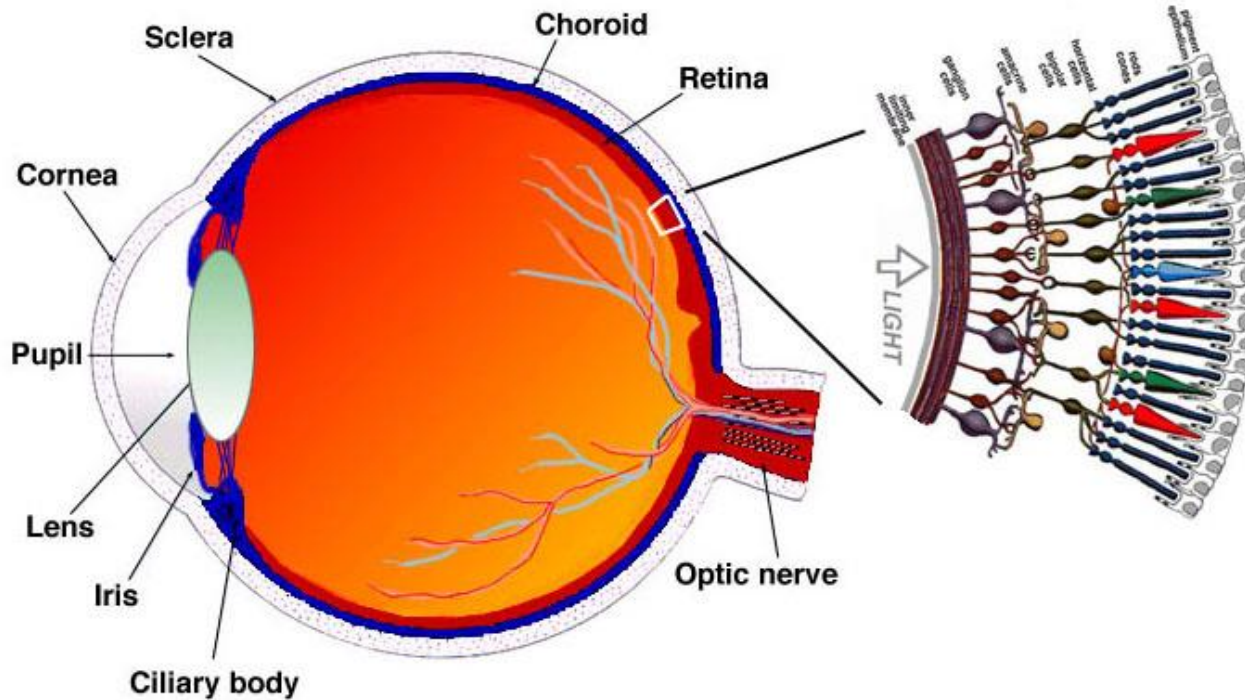




It took about another 100 years before

CONFIRMATION IN THE BODY

Physical World → Visual System



Rods

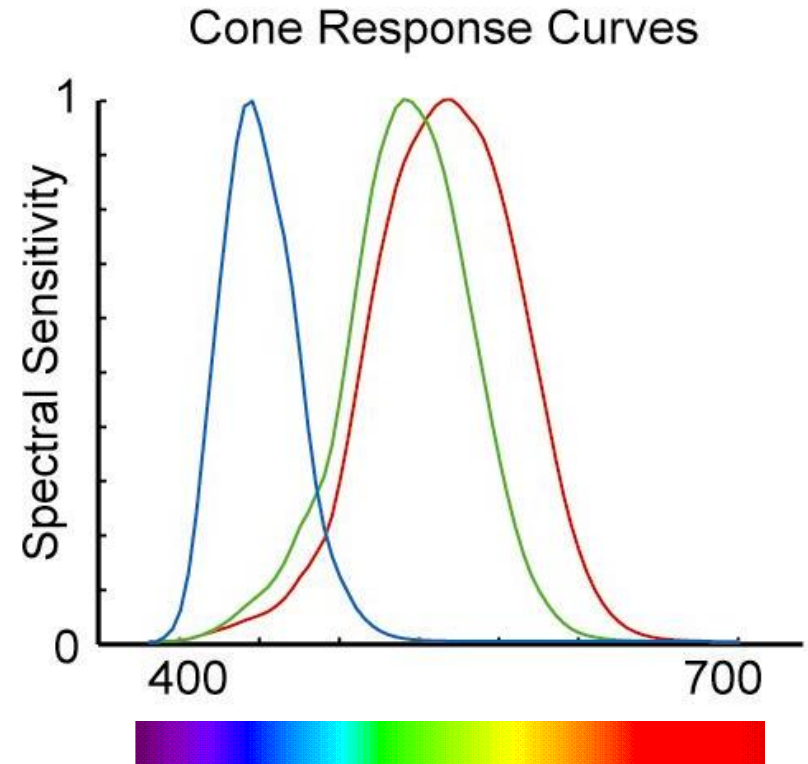
No color (sort of)
All over the retina
More sensitive

Cones

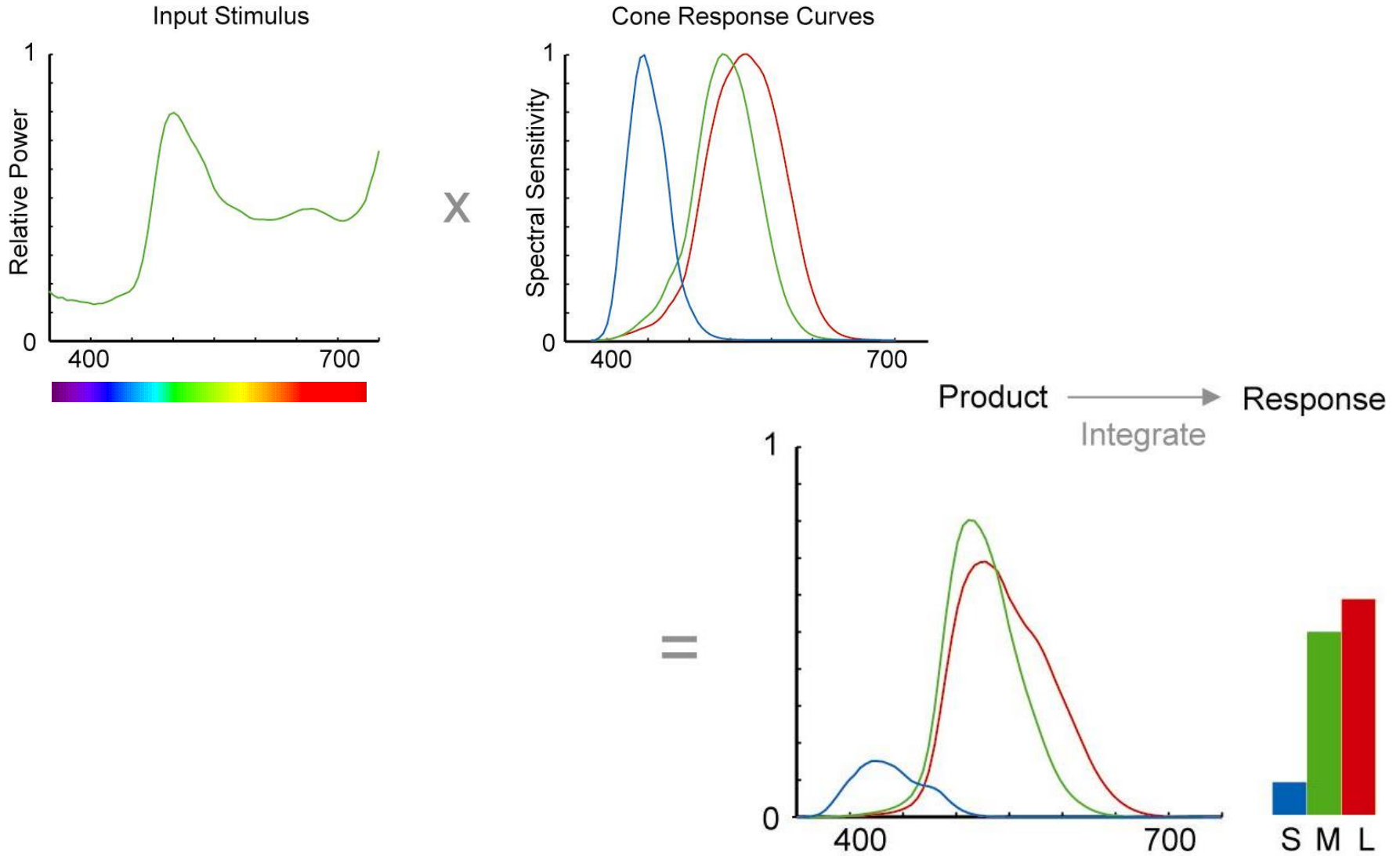
Three different kinds of
“color receptors”
Mostly in the center
Less Sensitive

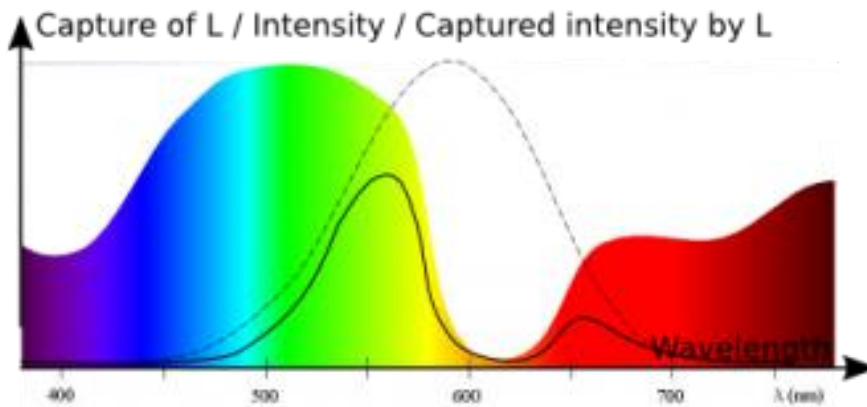
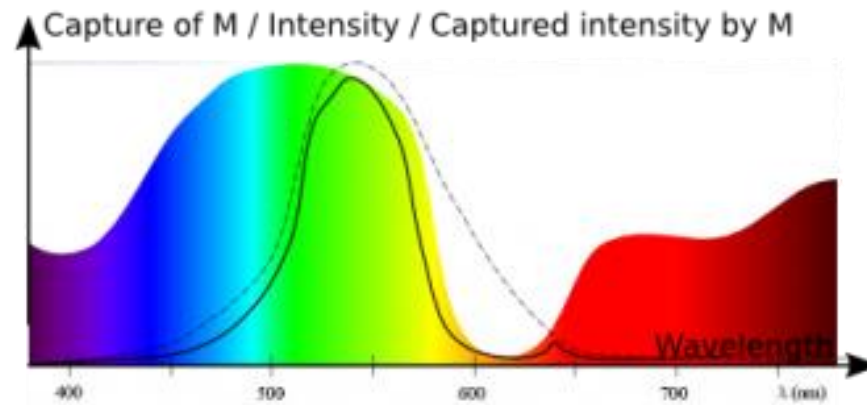
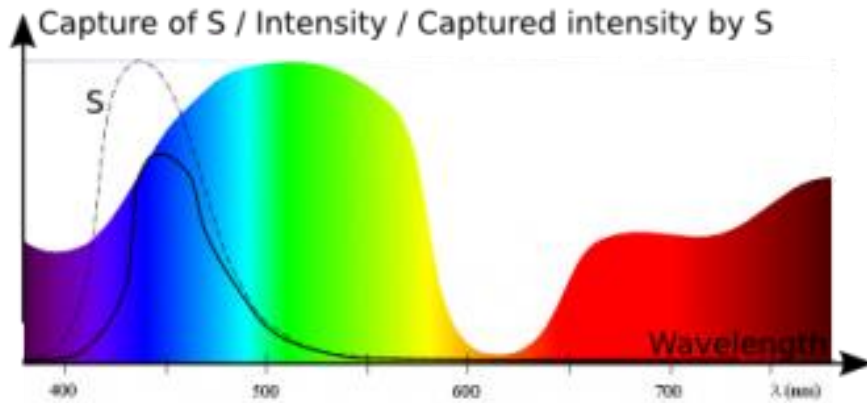
Cone response

- LMS (Long, Middle, Short) cones
- Capture different wavelengths (some better than others)
- Transmit a signal to the brain



Cone response



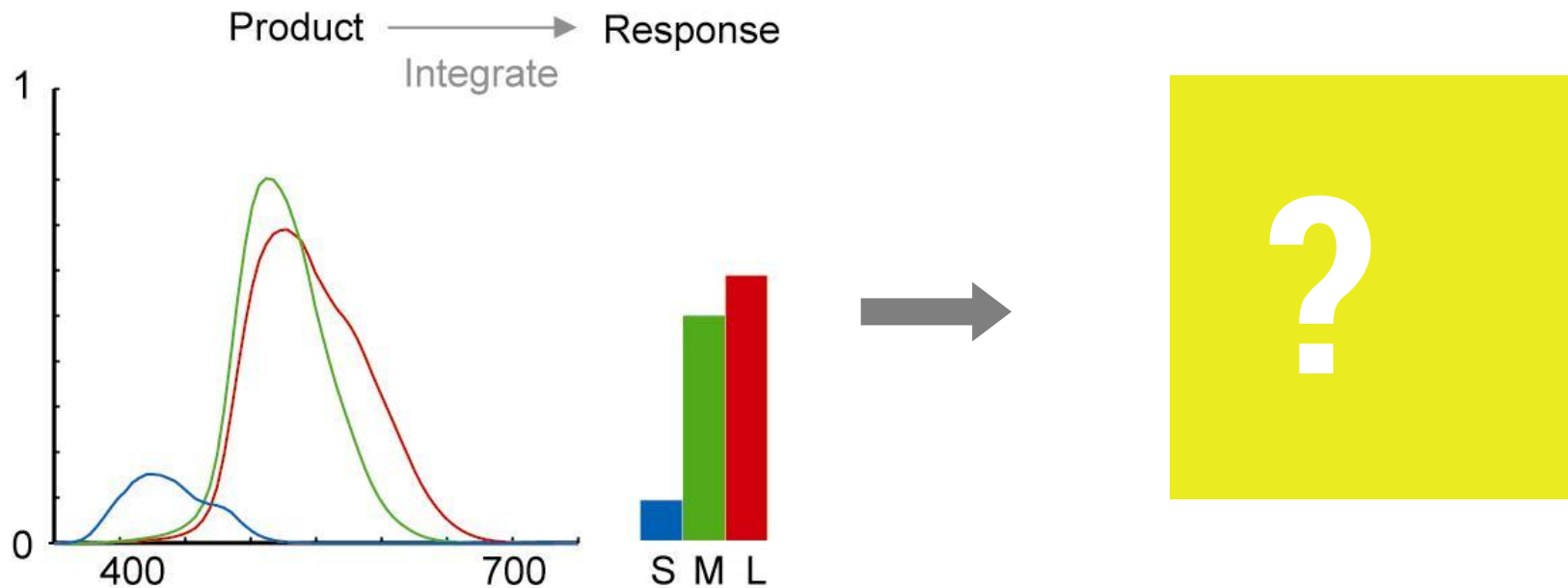


Cumulated intensities detected



SML decomposition

Visual System → Color Models



This is the color the eye sees
This is not necessarily the color the brain sees!

**HOW IS THE CAPTURED COLOR
INFORMATION PROCESSED?**

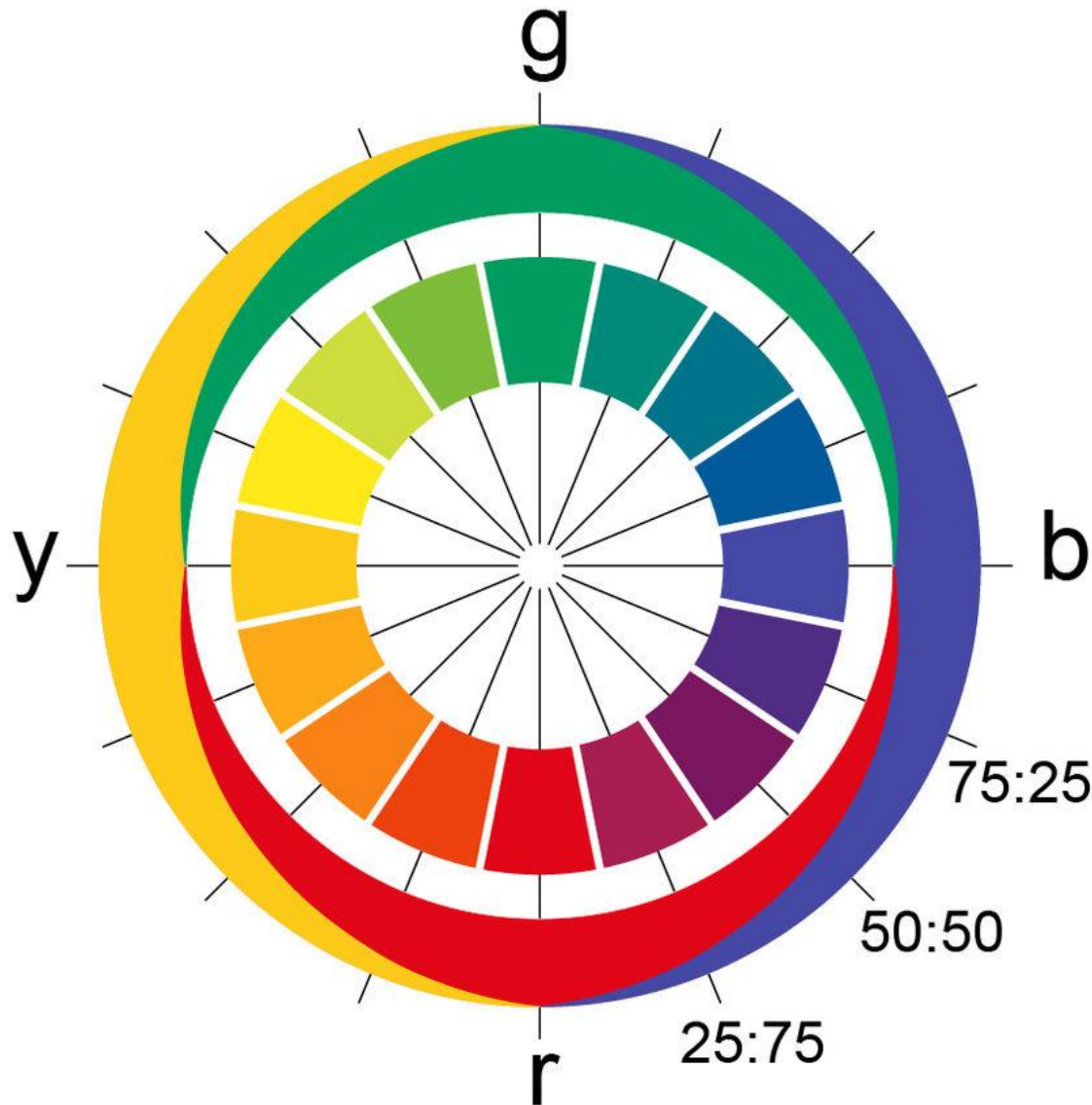
Color Opponency Theory

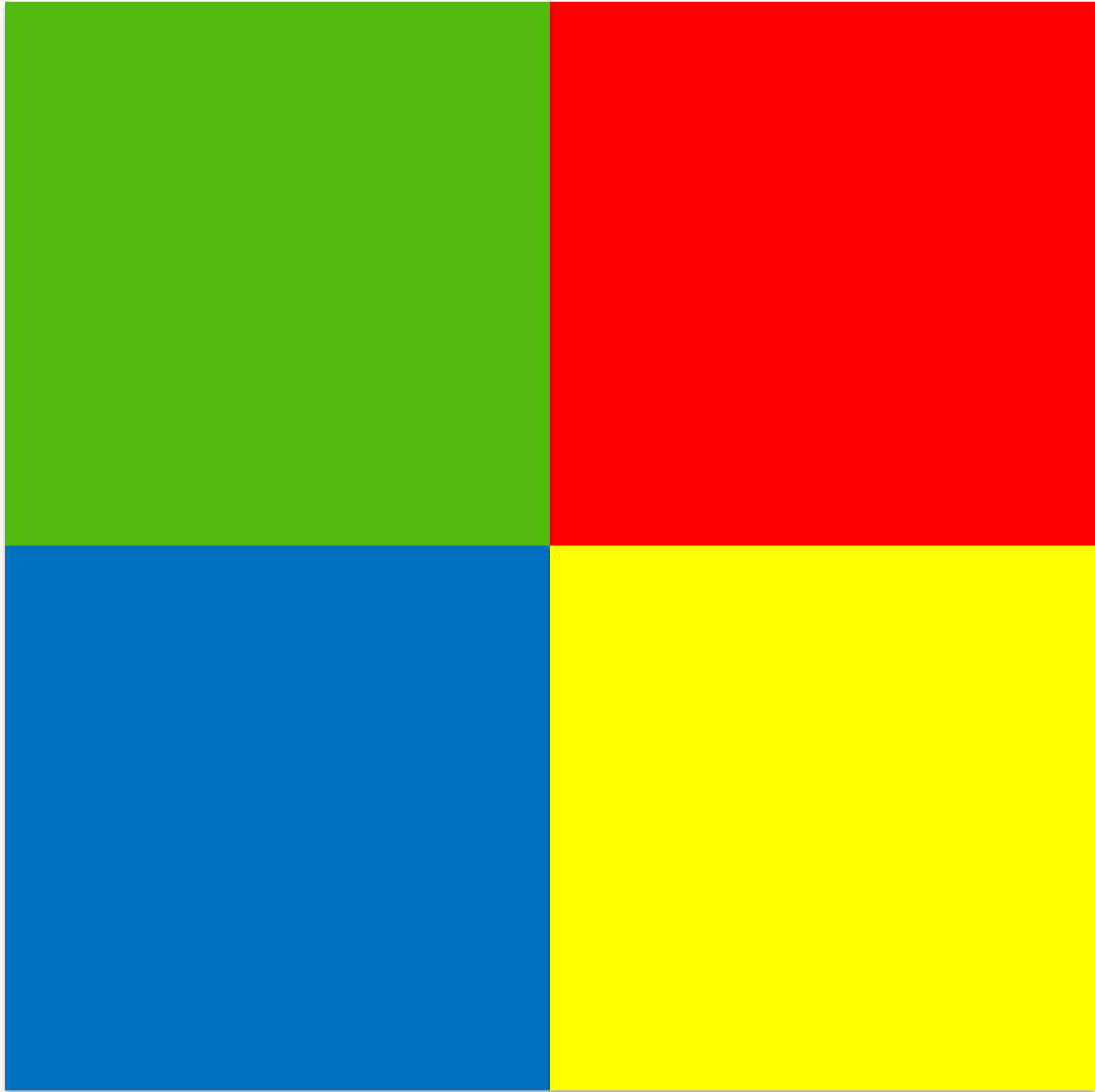
Ewald Hering 1878

Proposal:

Color experience is built from 4
primary chromatic colors

Arranged in opponent pairs





Color Opponency

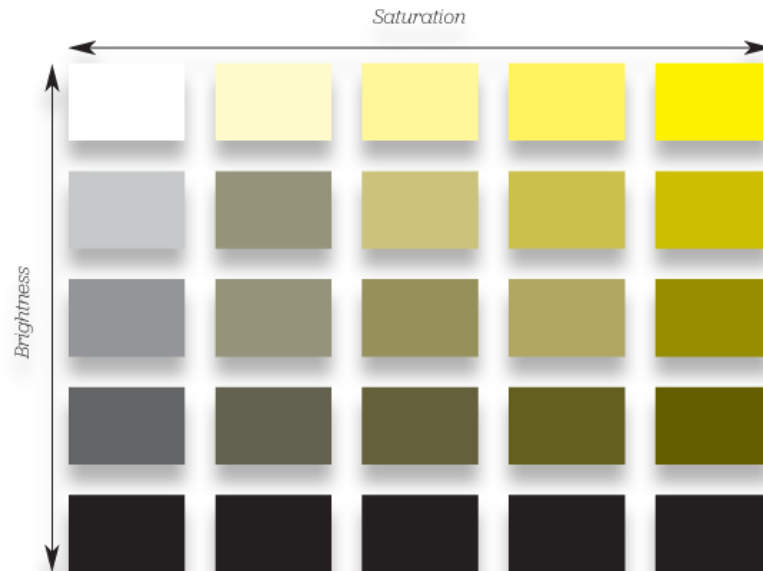
The experiment was taken as evidence for color opponency

- Now we know do with cells whose center of the receptive field is sensitive to green and the surround to red = color opponent cells (also exists for blue and yellow)
- (too much detail for our purposes)

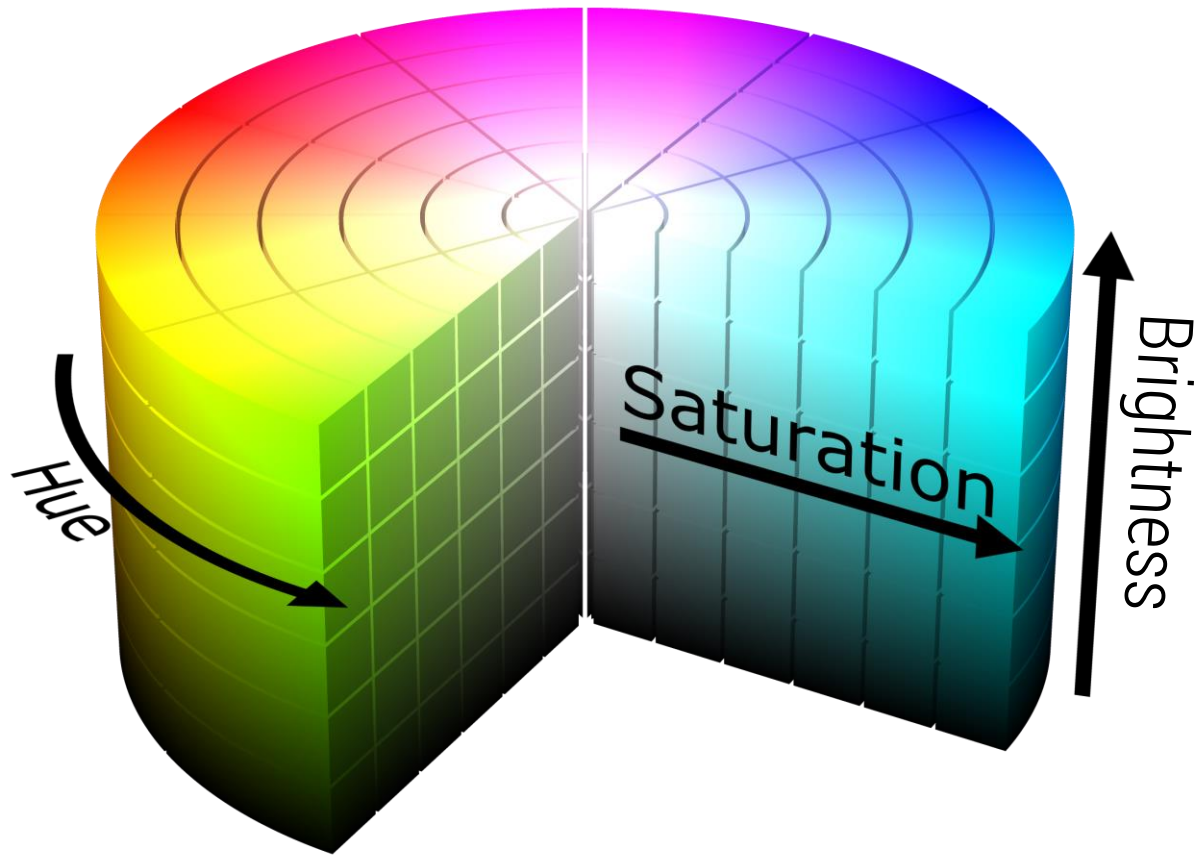
HOW TO DESCRIBE COLOR PERCEPTION

Color Terms

- Hue: Color we see (red, green, blue, ...)
- Saturation: degree to which hue differs from neutral gray
- Lightness/Brightness: the intensity of a colored surface or source



Color Spaces



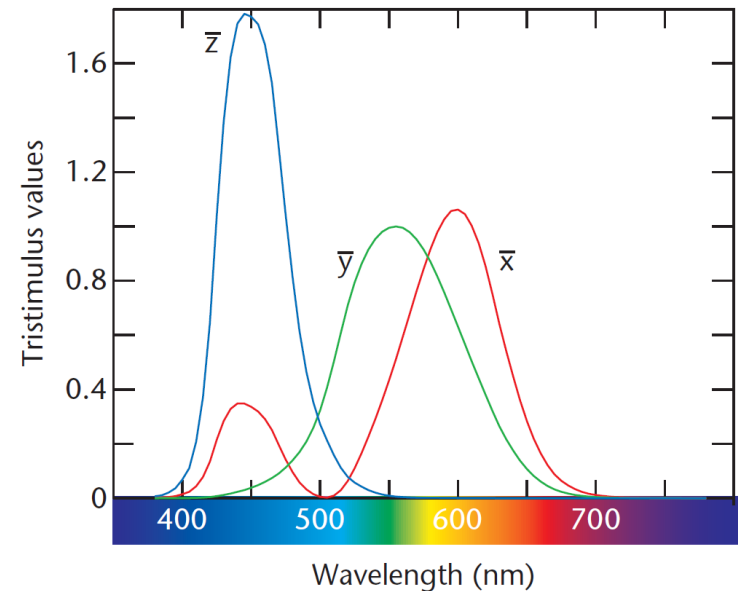
XYZ Color Model

- created by the International Commission on Illumination (CIE) in 1931
- Derived from color perception experiments
 - Relates physical wavelengths to physiologically perceived colors in human color vision.
- Seldom used directly but acts as a basis for color descriptions and transformations

XYZ Color Model

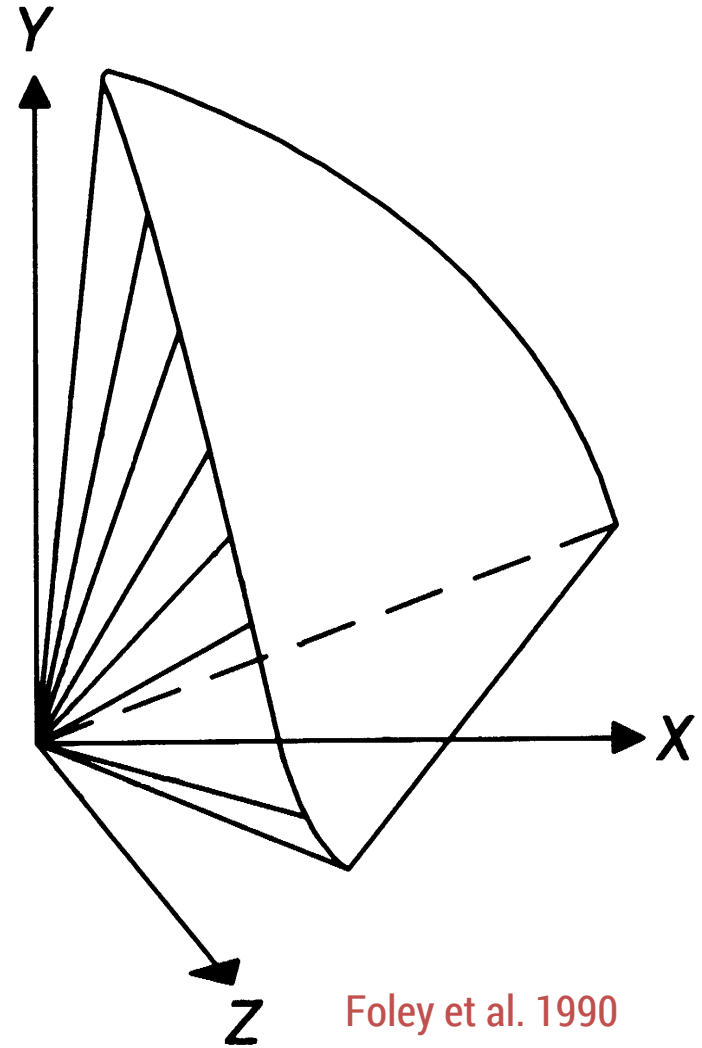
definition of three primary colors: X, Y, Z

- color-matching functions (the numerical description of the chromatic response of the *observer*)
 - here non-negative
- Y follows the standard human response to luminance, i.e., the Y value represents perceived brightness
- can represent all perceivable colors



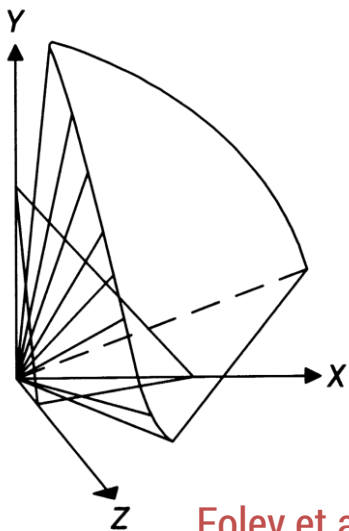
XYZ CIE Color Space

- 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

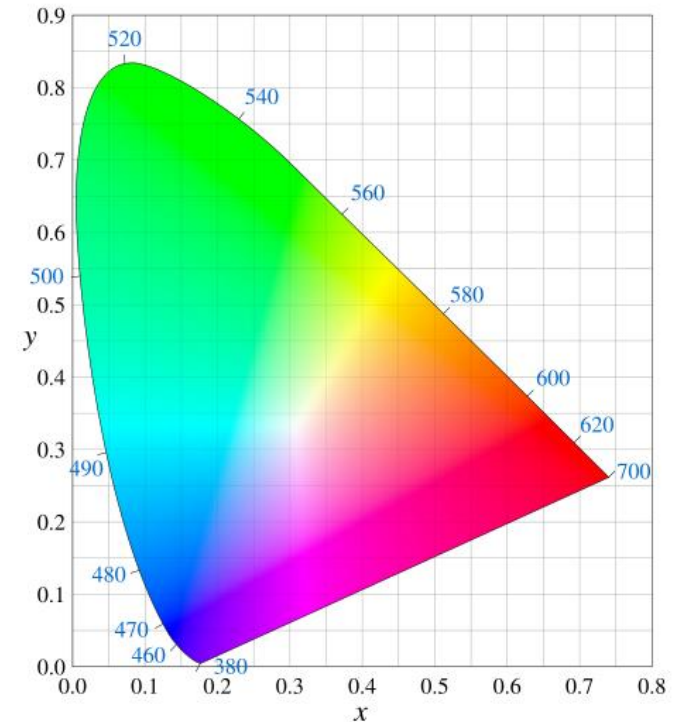
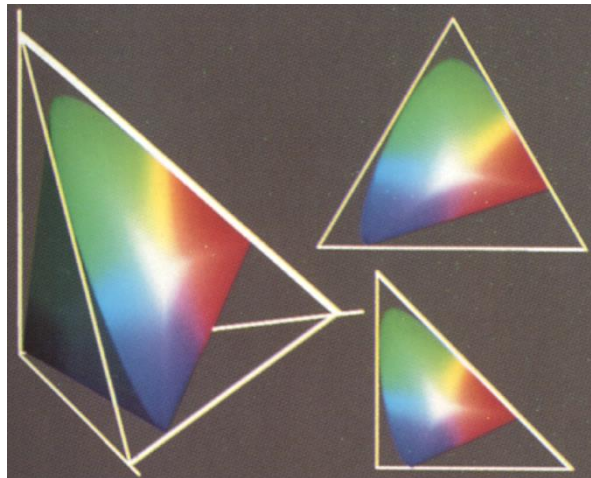


CIE Chromaticity Diagram

- 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

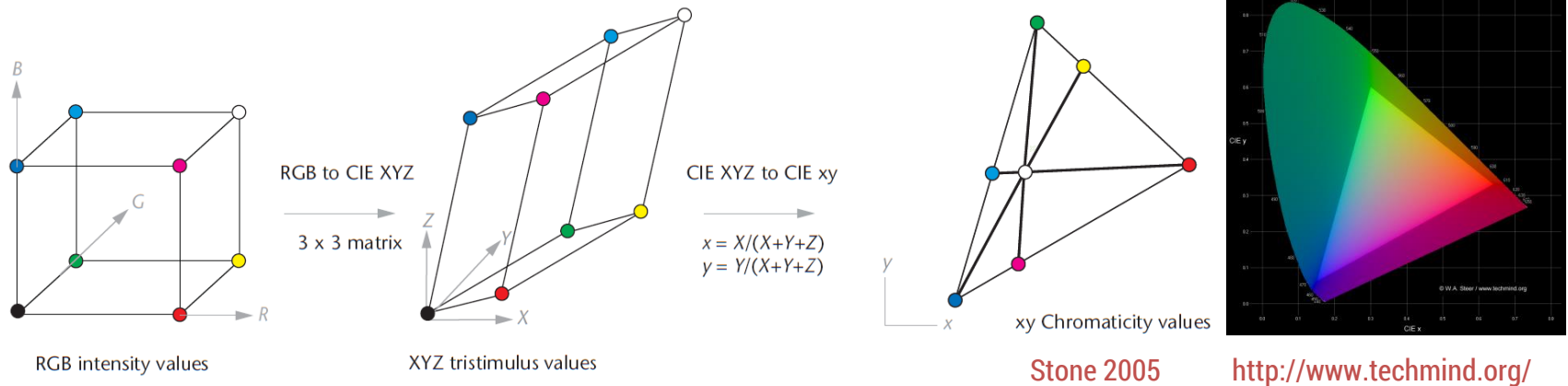


Foley et al. 1990

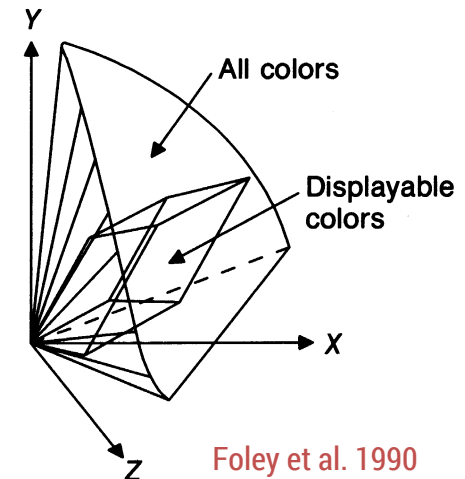


RGB and XYZ

- RGB to XYZ conversion

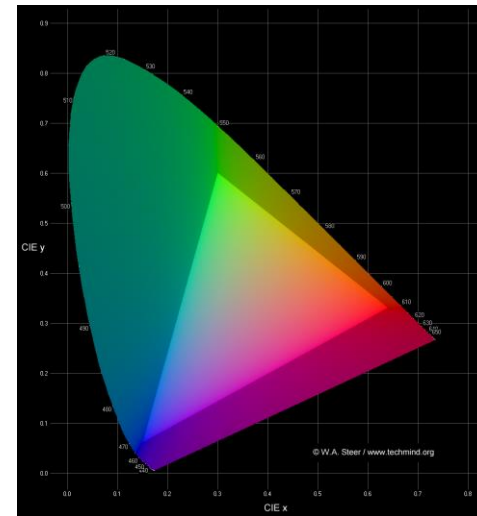


- RGB space: distorted cube
- black: origin of XYZ and projection center
- RGB projected to triangle



Can RGB Represent All Visible Colors?

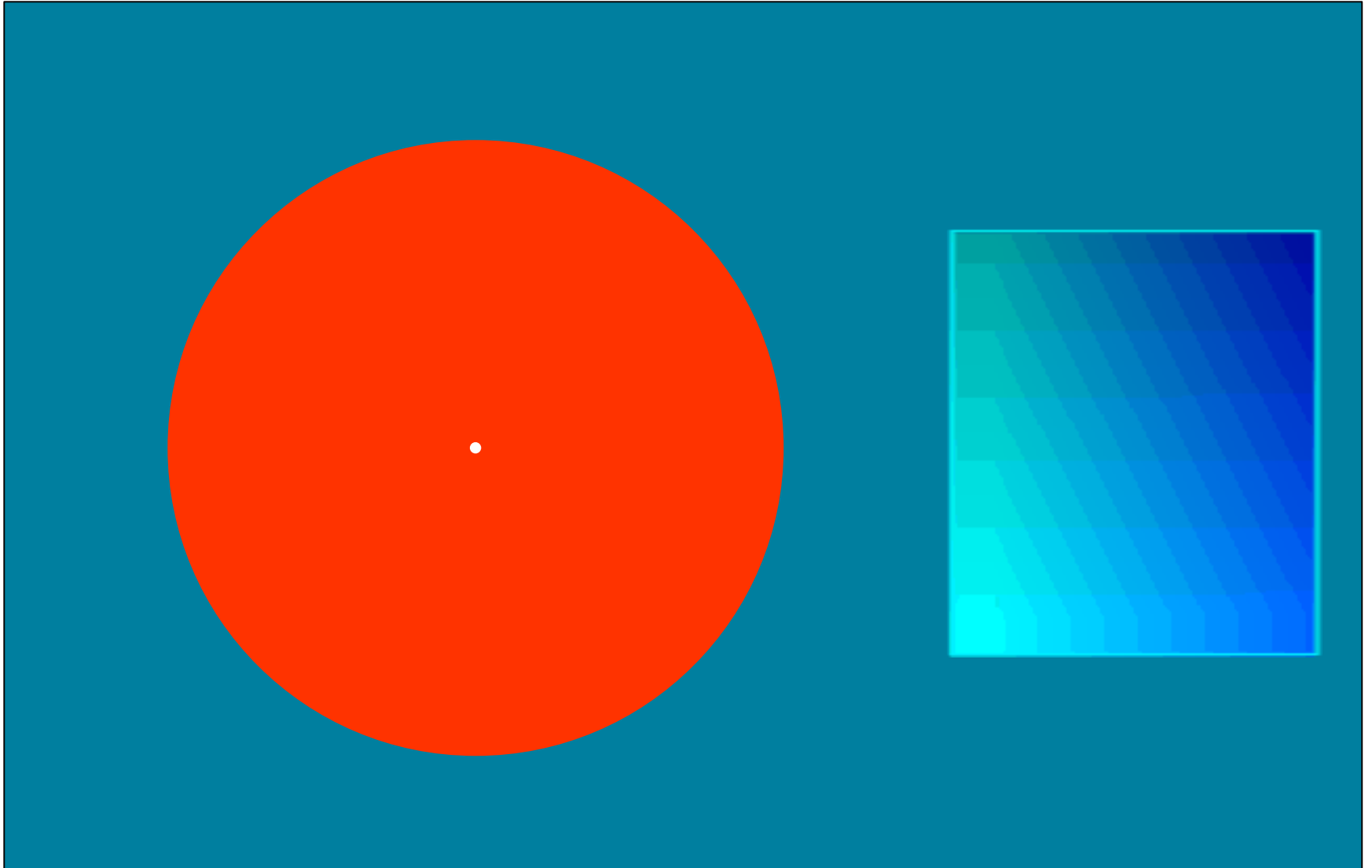
- no, because all colors form horseshoe shape in CIE chromaticity diagram and RGB gamut is triangular



<http://www.techmind.org/>

- 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 ...

Let's see REAL cyan ...



**THE STRANGE WAYS WE
EXPERIENCE COLOR...**

Color Perception → Color Naming



What color is this?
"Yellow"

Color Perception → Color Naming



What color is this?
"Blue"

Color Perception → Color Naming

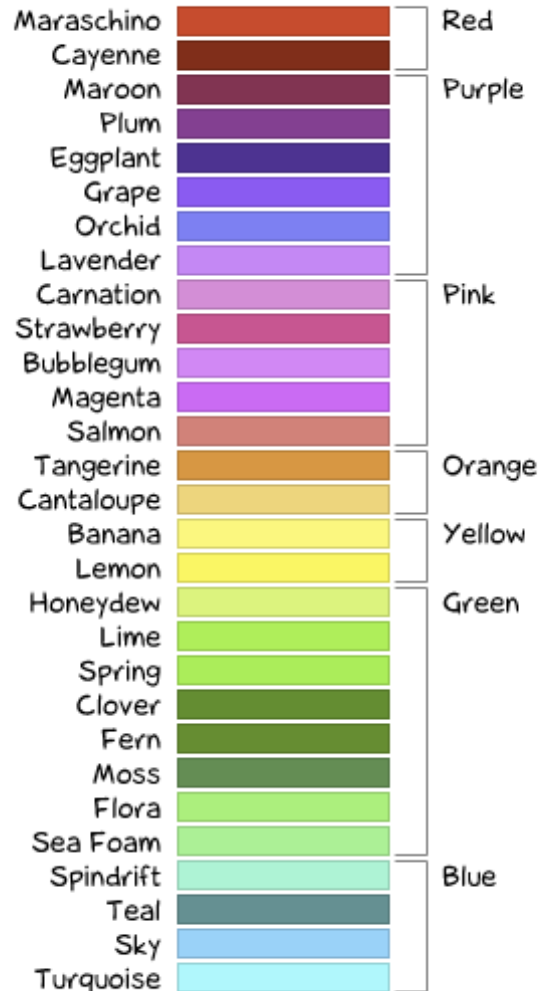


What color is this?

“Turquoise ?” “Blue-Green ?” “Sarcelle ?”

Color according to gender?

Color names if you're a girl...



Color names if you're a guy...

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

Actual color names
if you're a girl ...

Actual color names
if you're a guy ...

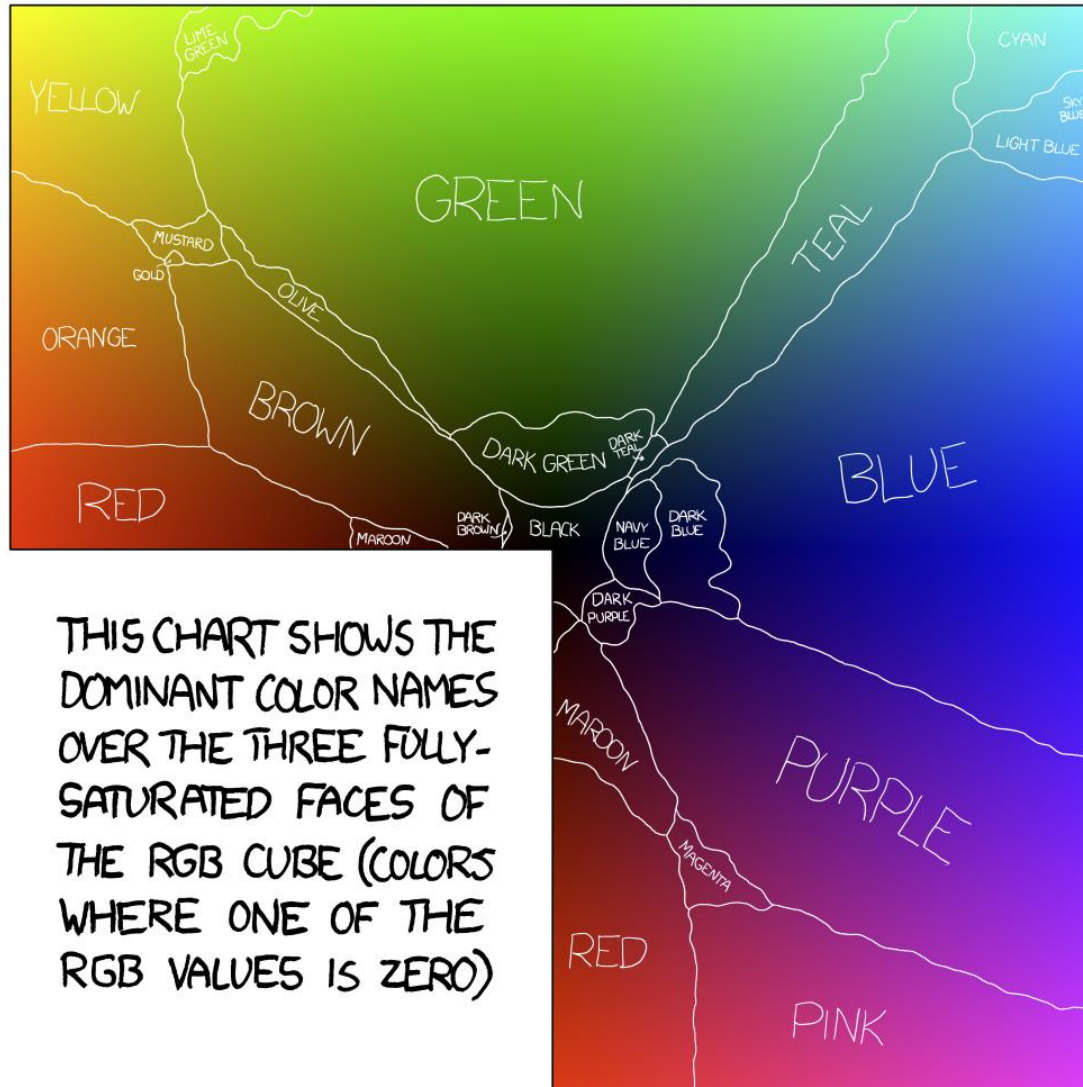


Color Naming

We associate and group colors together, often using the name we assign to the colors

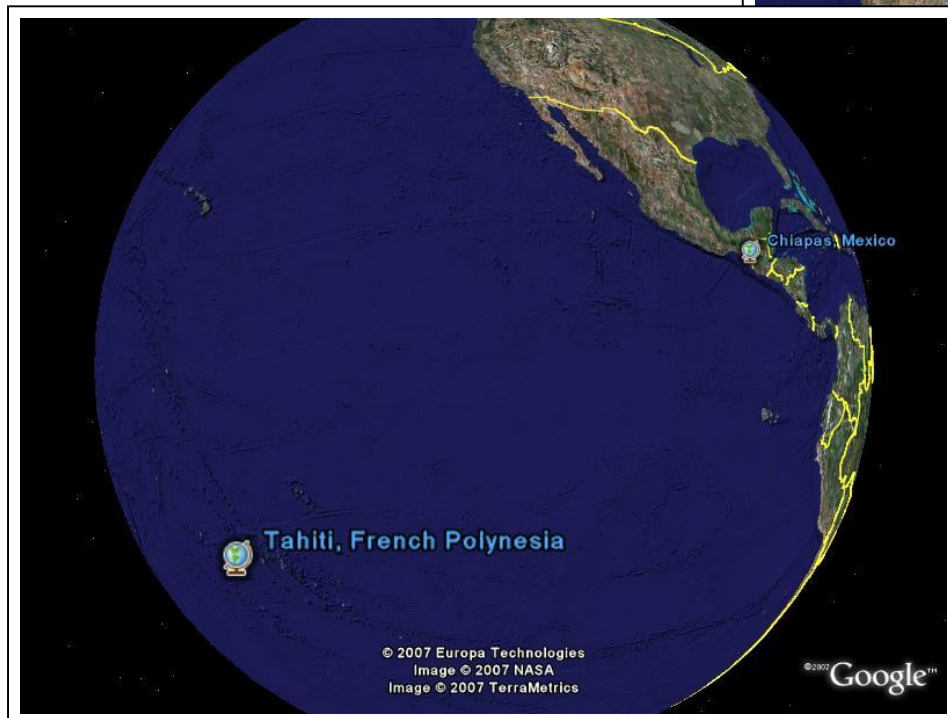


Are there natural boundaries?



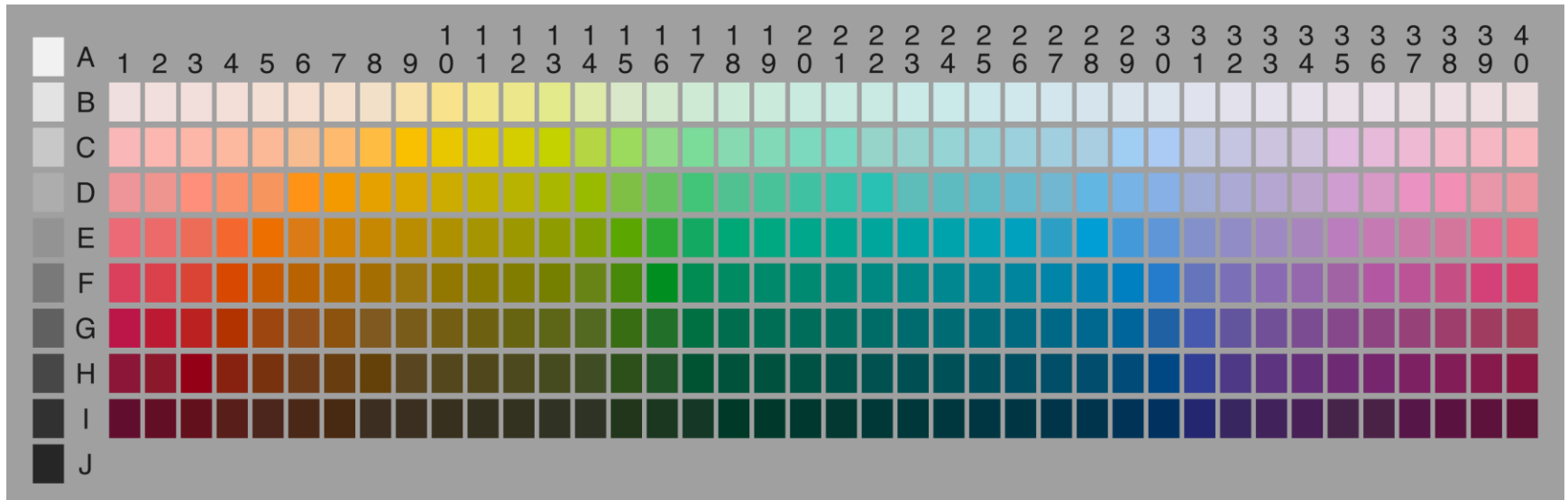
Basic Color Terms

- Brent Berlin & Paul Kay 1969
- let's look at two specific places

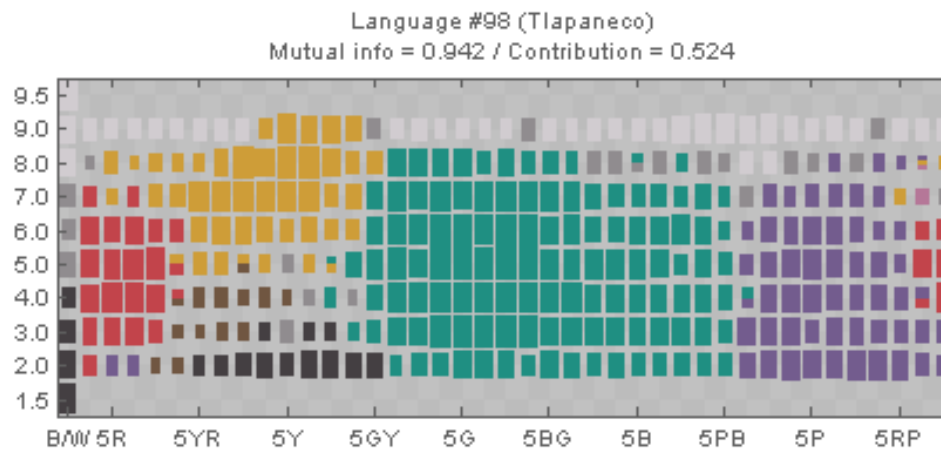
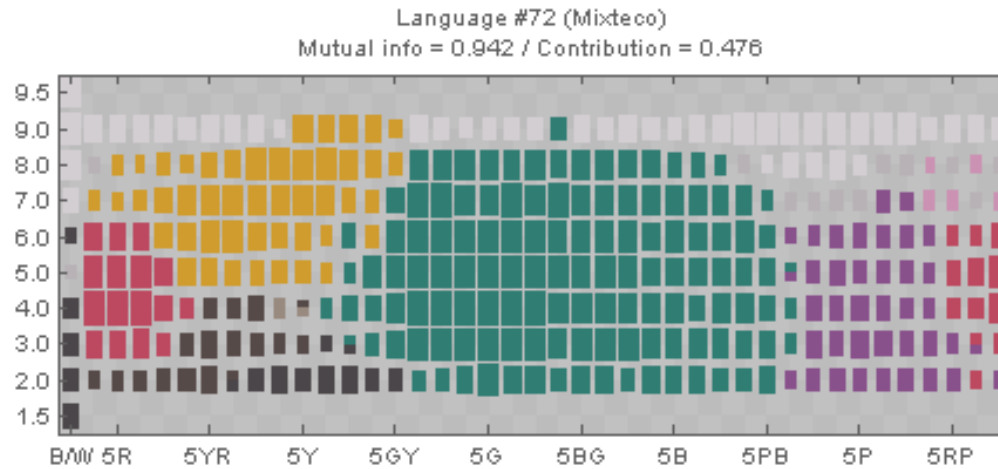


World Color Survey

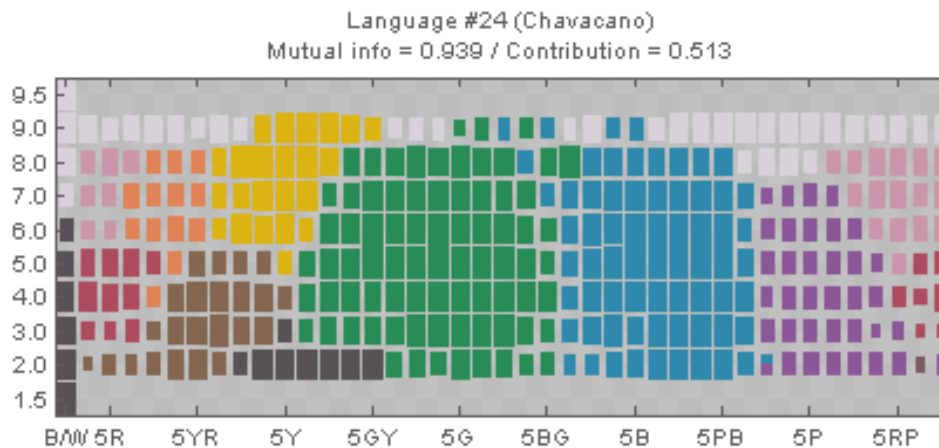
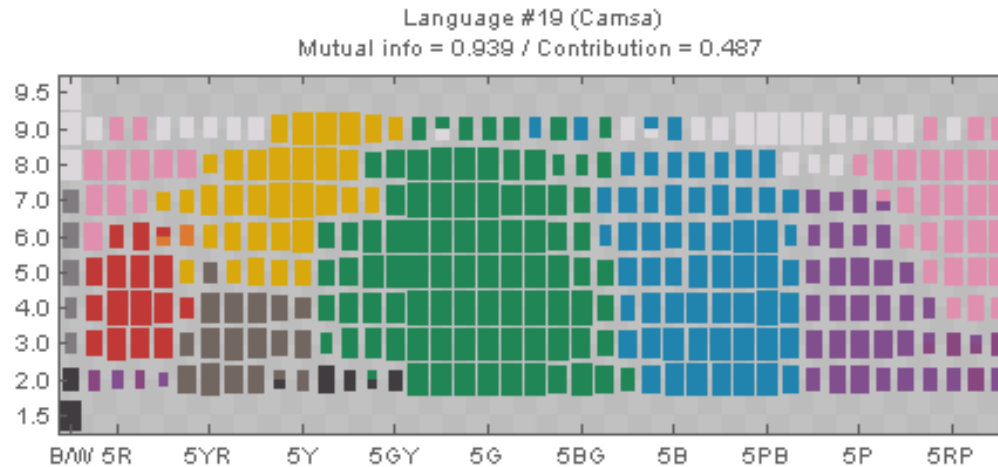
Surveyed 2616 speakers of 110 languages using 330 different color chips



Results from WCS (Mexico)



Results from WCS (South Pacific)



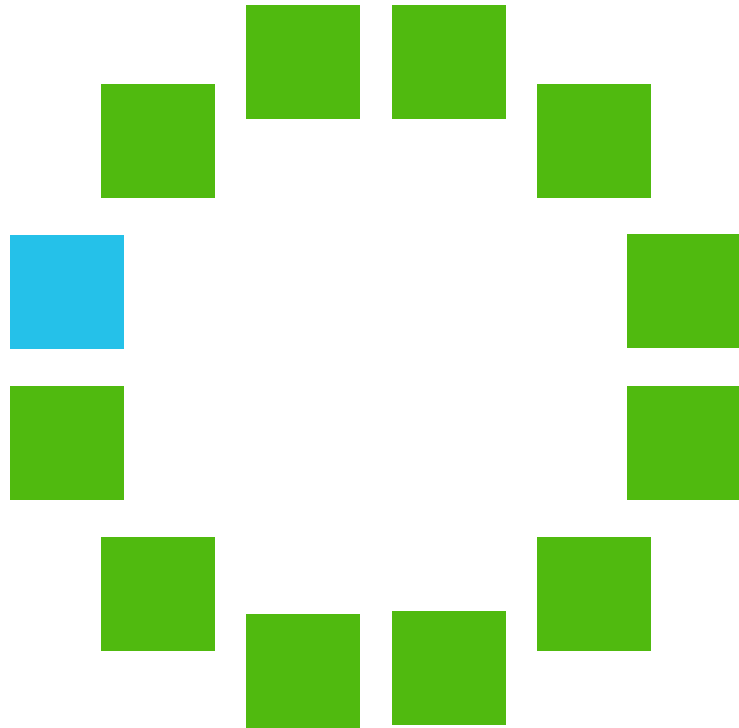
But language-color interaction

- 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



But language-color interaction

- experiment: how long to find a differing color?

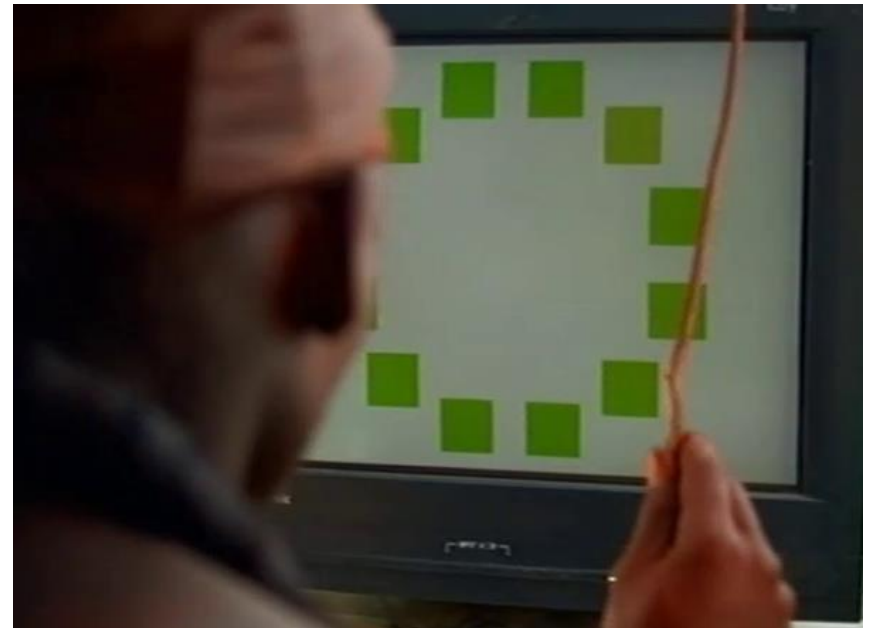
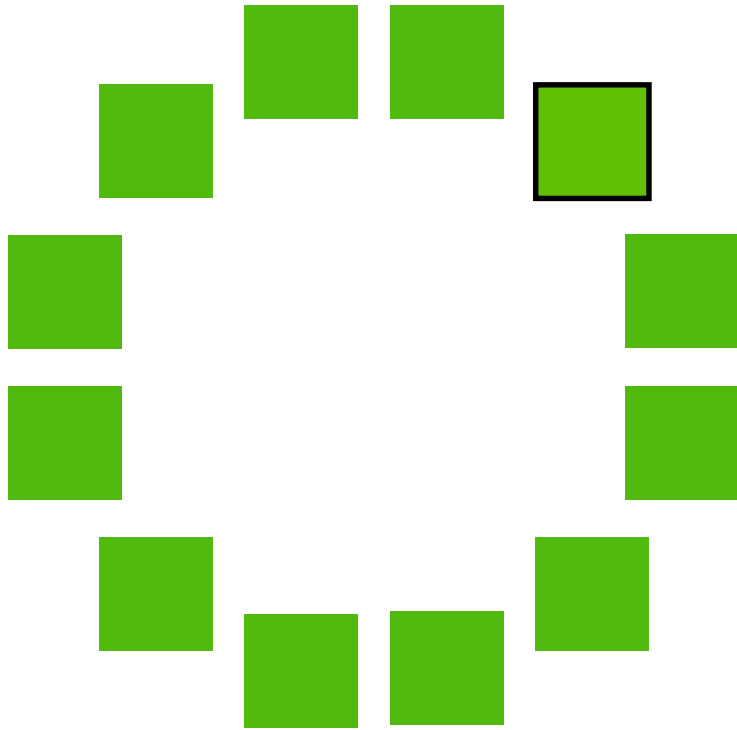


© BBC

difficult to impossible for Himba people

But language-color interaction

- experiment: how long to find a differing color?

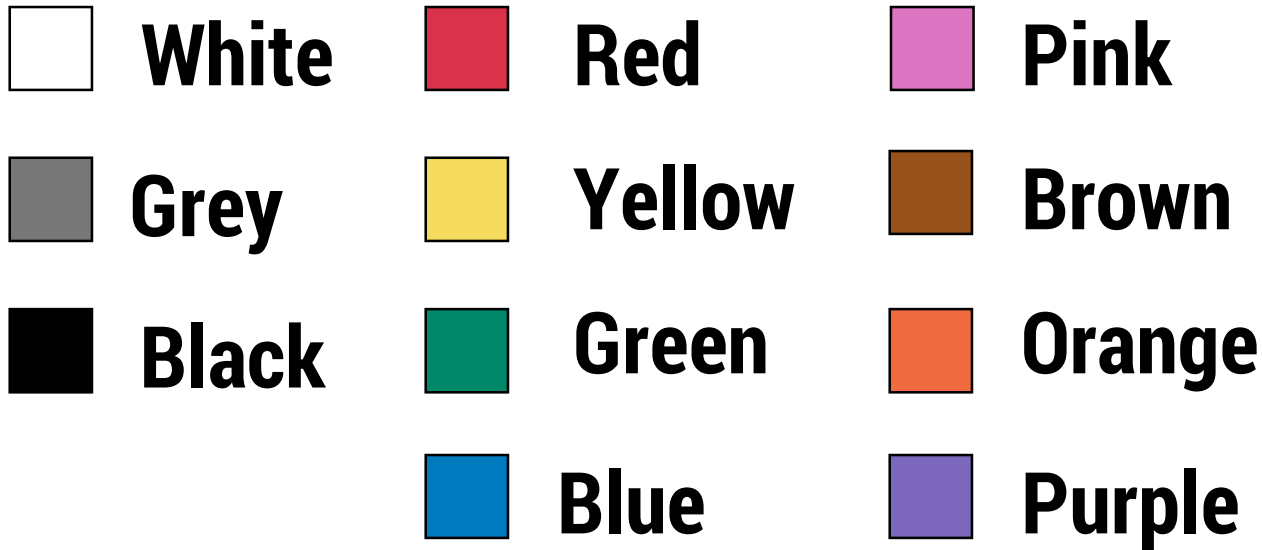


© BBC

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

Universal (?) Basic Color Terms

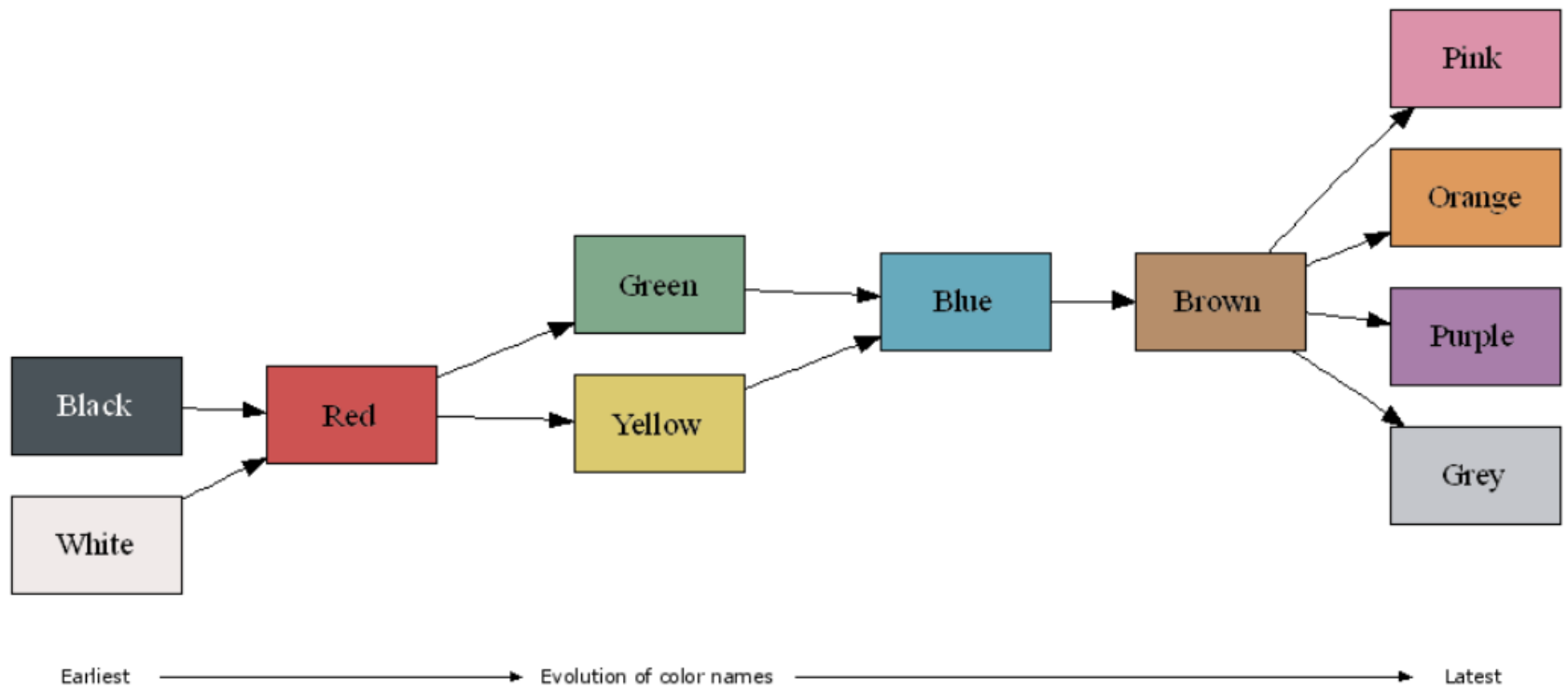
Basic color terms recur across languages



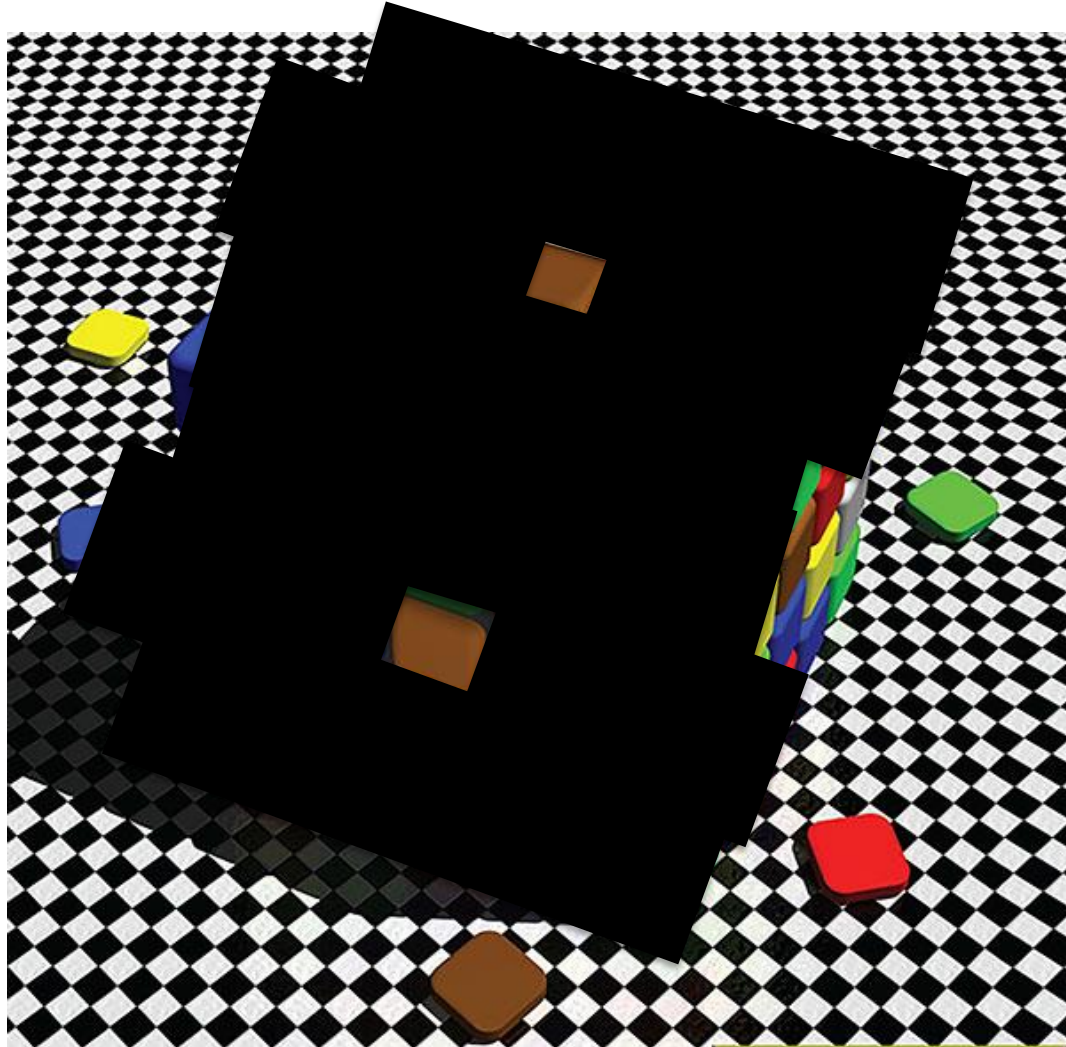
Interesting factoid: Cartographers found out that they need 4 unique hues to unambiguously distinguish all areas on an arbitrarily complex map

Evolution of Basic Color Terms

Proposed universal evolution of color names across languages.



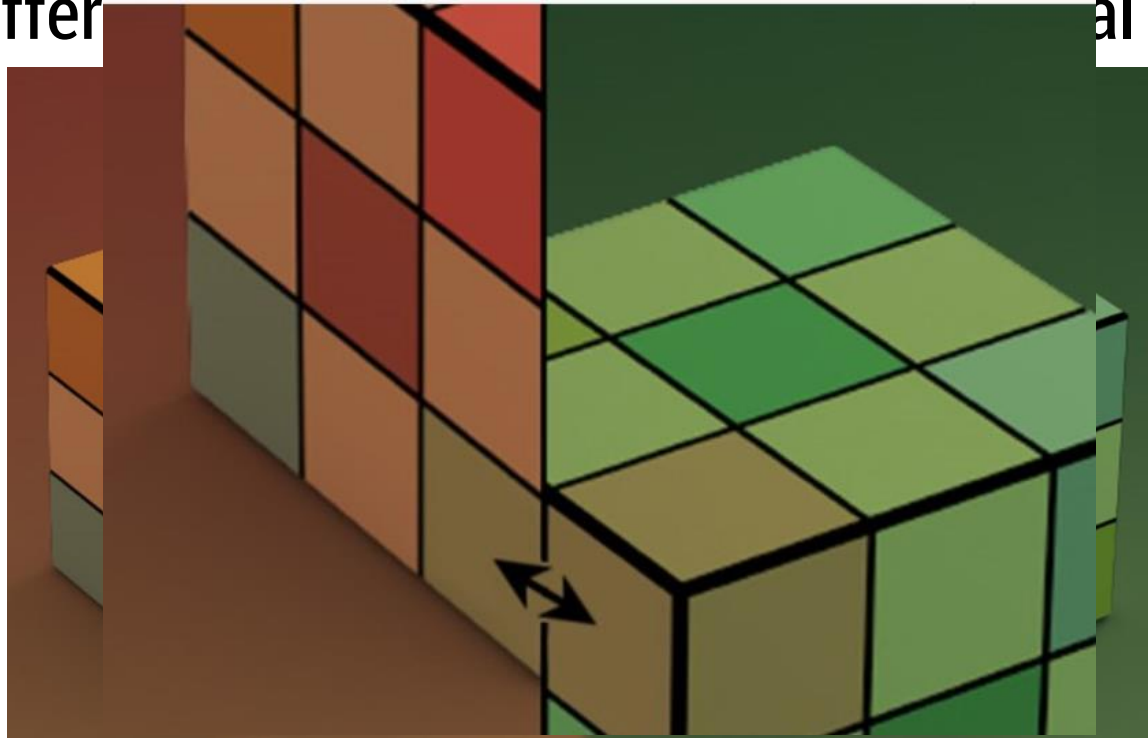
Some other color usage problems



This one is called COLOR CONTRAST: the same spectral input can appear as a different color

Color Constancy

- Background color and lighting have a big effect on how we see color
- Two different backgrounds can make identical



CONCLUSION

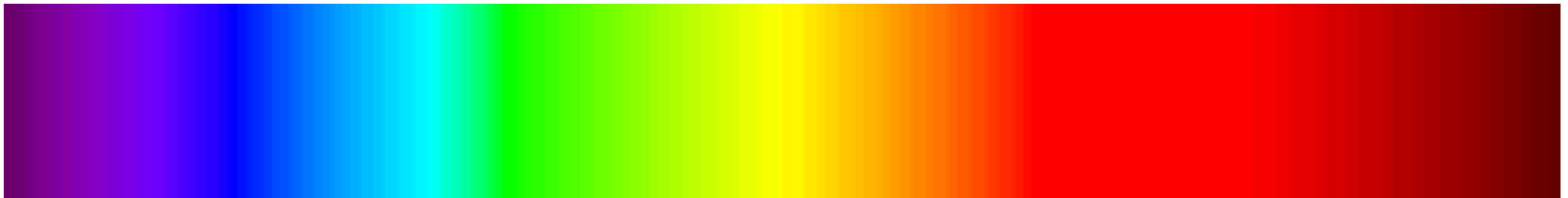
- Color vision (just like brightness) does not correspond to physical measurements
- Be mindful in how you apply color in your computer-generated scenes!

COLOR FOR VISUALIZATION

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



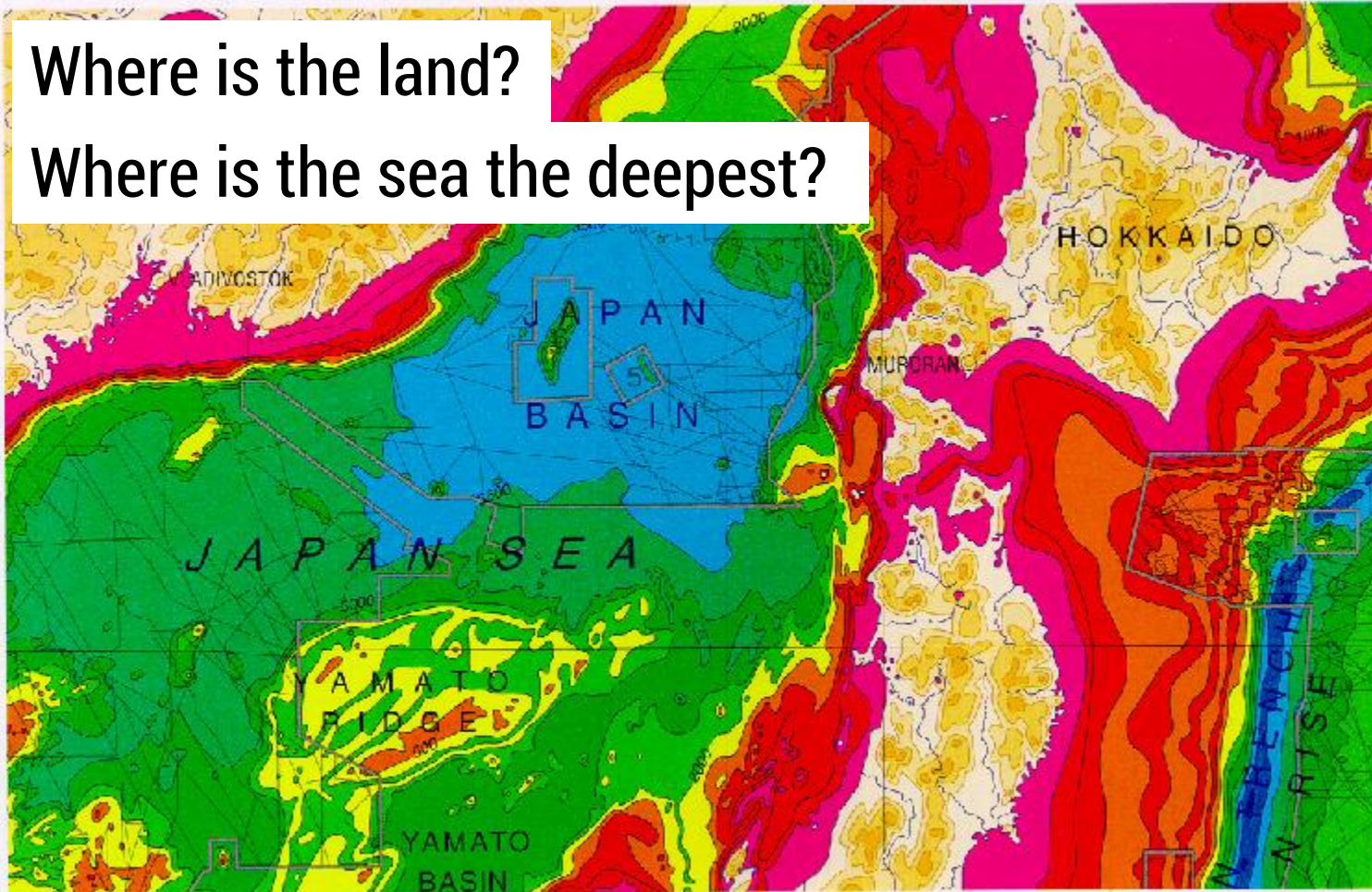
And it's (usually) a huge mistake!

General Bathymetric Chart of the Ocean

Every color mark signals:
longitude, latitude, sea/land, depth/altitude

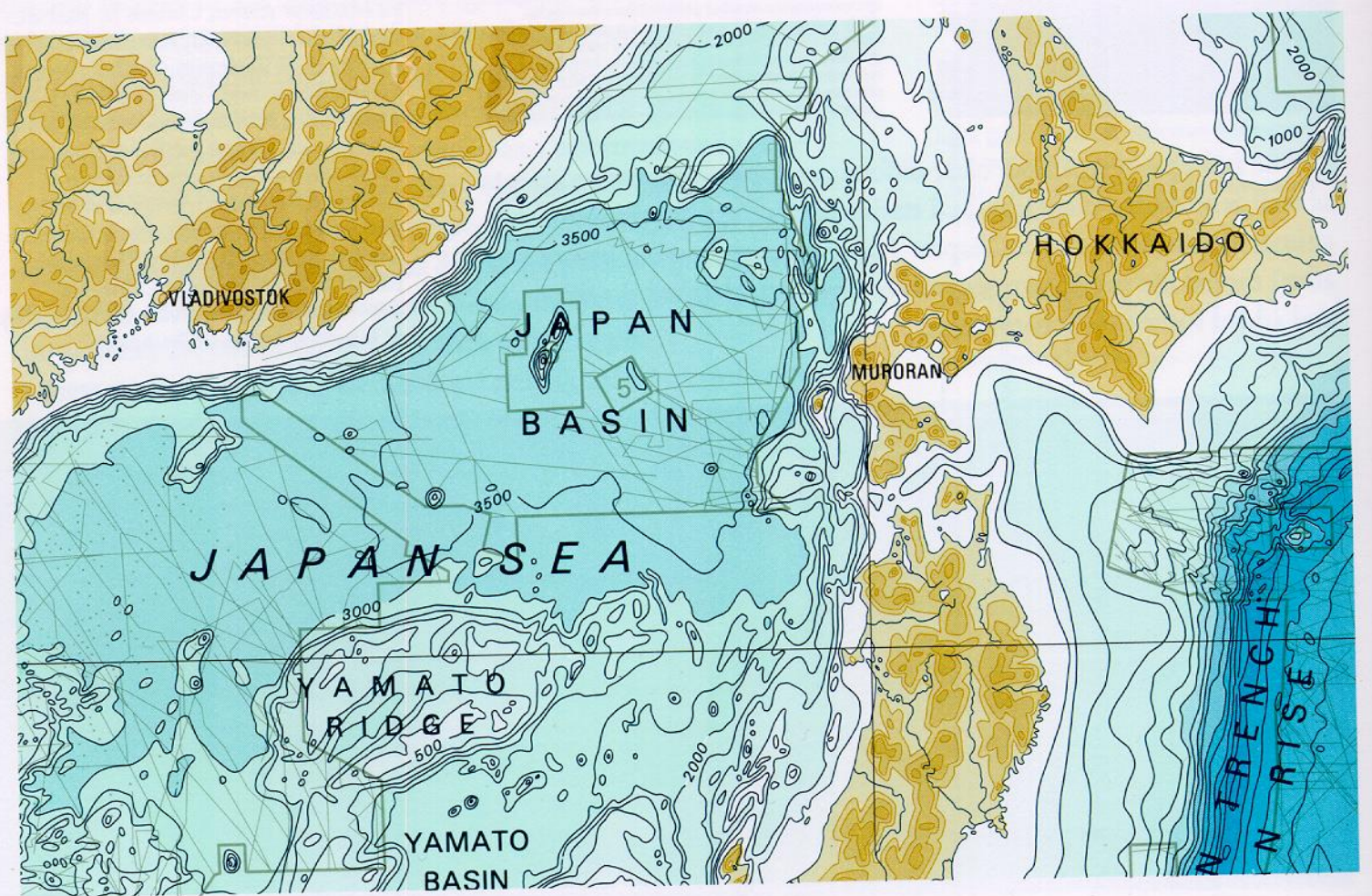
Where is the land?

Where is the sea the deepest?

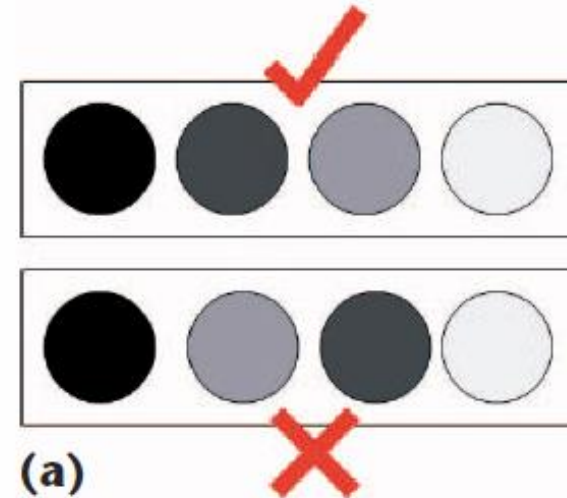
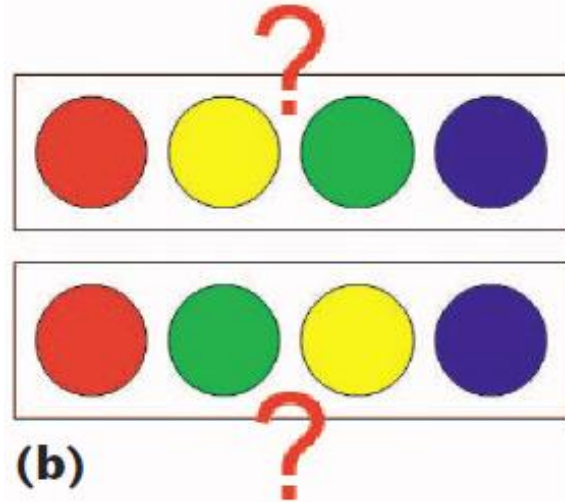


General Bathymetric Chart of the Ocean

Now describe what kind of color scale was possibly used here



Perceptual Ordering



Rainbow Color Scale

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

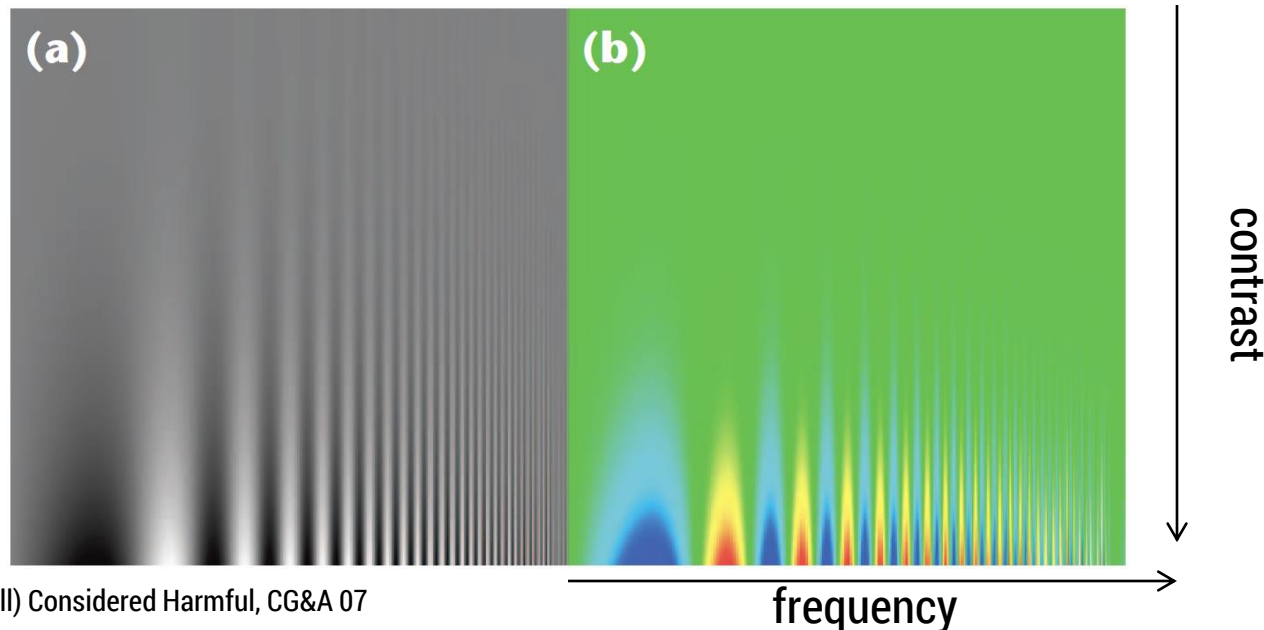
Gray Scale

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

Color Scale Luminance

Rainbow Color Scale

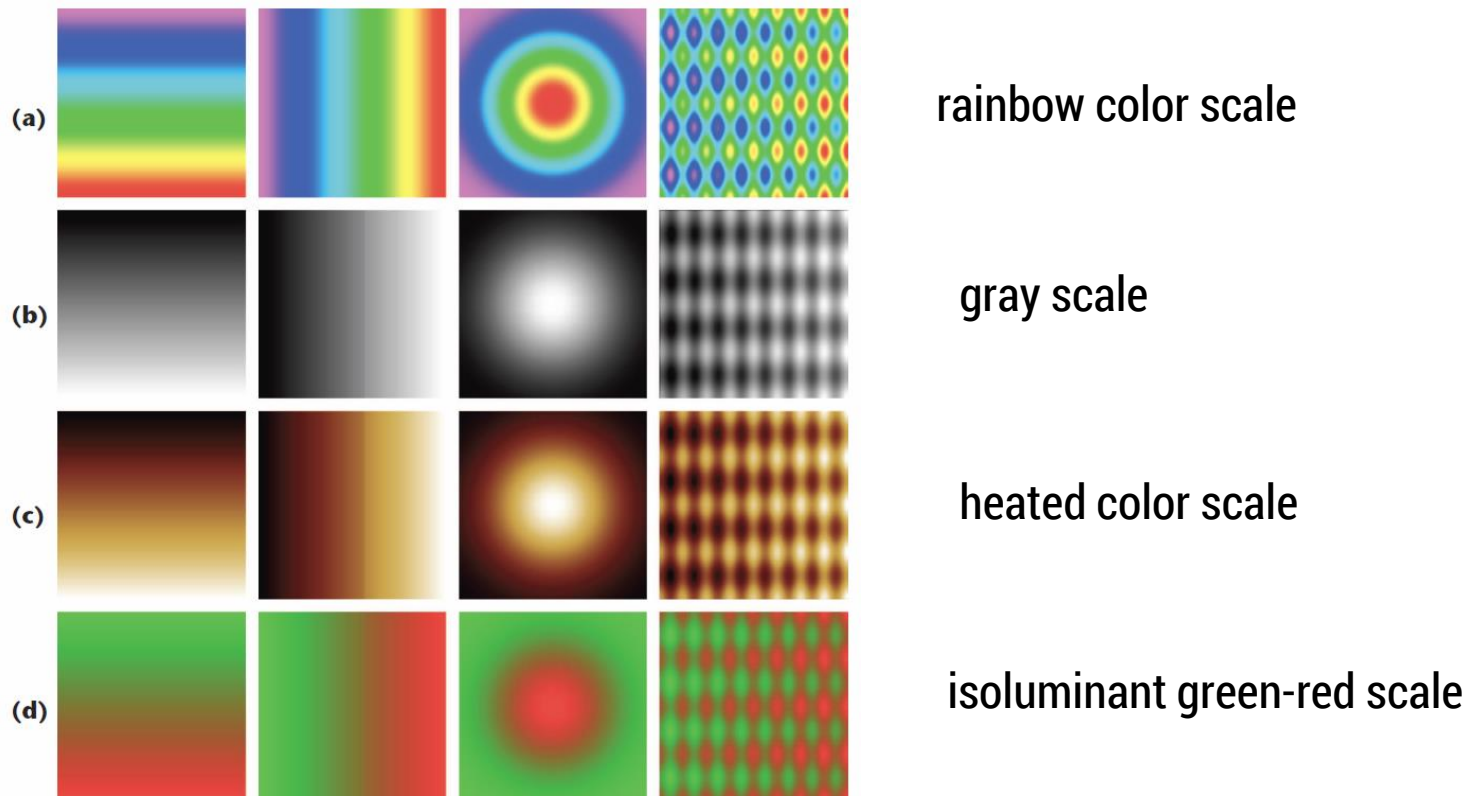
- The visual system perceives high spatial frequencies through changes in luminance
- Is isoluminant (for large portions), changes only appear at color boundaries
- Obscures small details in the data



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



HOW TO PICK 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

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

Fruits	Brands
 Apple	 Apple
 Banana	 AT&T
 Blueberry	 Home Depot
 Cherry	 Kodak
 Grape	 Starbucks

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

Beware of bad interactions

CONTRAST

You can make this work if you consider value

CONTRAST

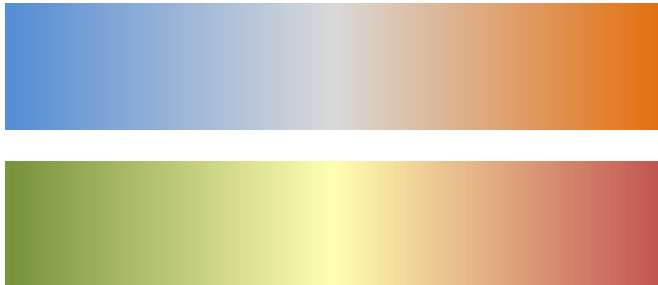
Using Color for Scales

(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

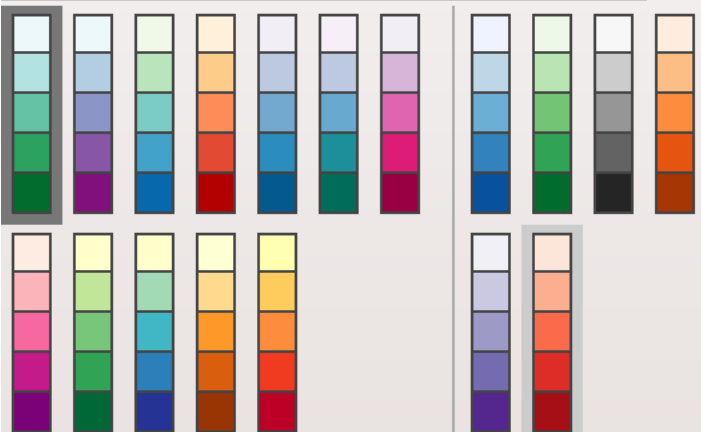
number of data classes on your map

3 | ▼ [learn more >](#)

the nature of your data

sequential | ▼ [learn more >](#)

pick a color scheme: BuGn



multihue

single hue

(optional) only show schemes that are:

colorblind safe print friendly

photocopy-able [learn more >](#)

Highly recommended!

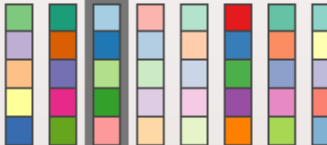
Designed originally for maps
but will also work well for other
types of visualizations

<http://colorbrewer2.org/>

number of data classes on your map
 5 [learn more >](#)

the nature of your data
 qualitative [learn more >](#)

pick a color scheme: Paired



(optional) only show schemes that are:

colorblind safe print friendly
 photocopy-able [learn more >](#)

pick a color system

166, 206, 227 RGB CMYK HEX
 31, 120, 180
 178, 223, 138
 51, 160, 44
 251, 154, 153

adjust map context

roads borders
 cities

select a background

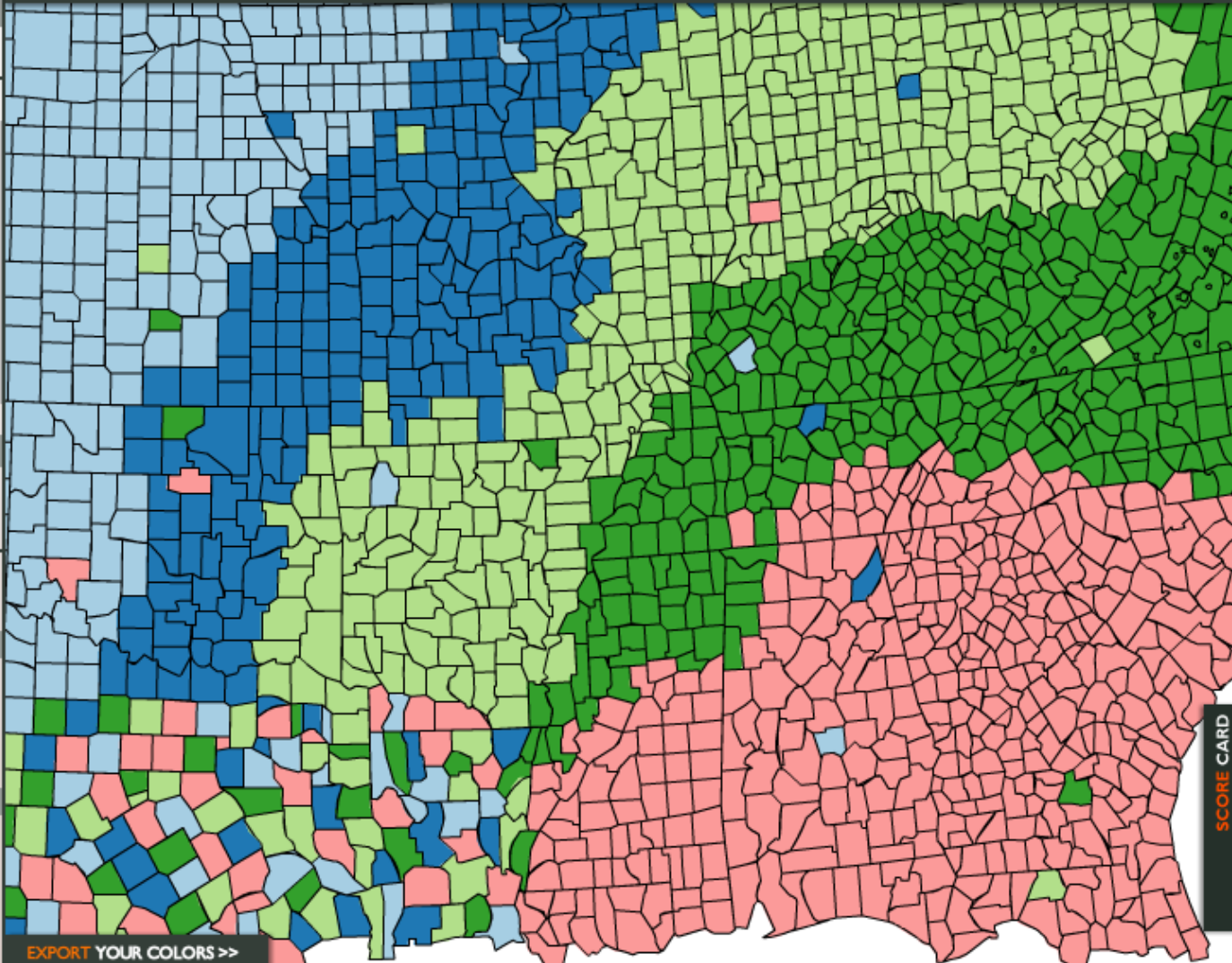
solid color terrain

color transparency

[EXPORT YOUR COLORS >>](#)

COLORBREWER 2.0
 color advice for cartography

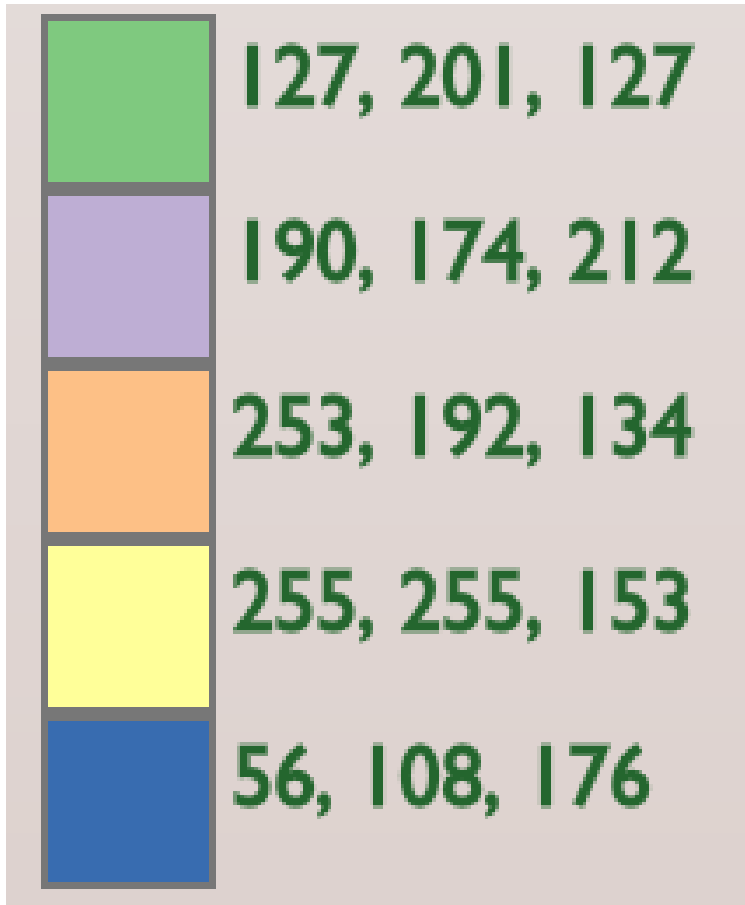
how to use | updates | credits



SCORE CARD

<http://colorbrewer2.org/>

ColorBrewer

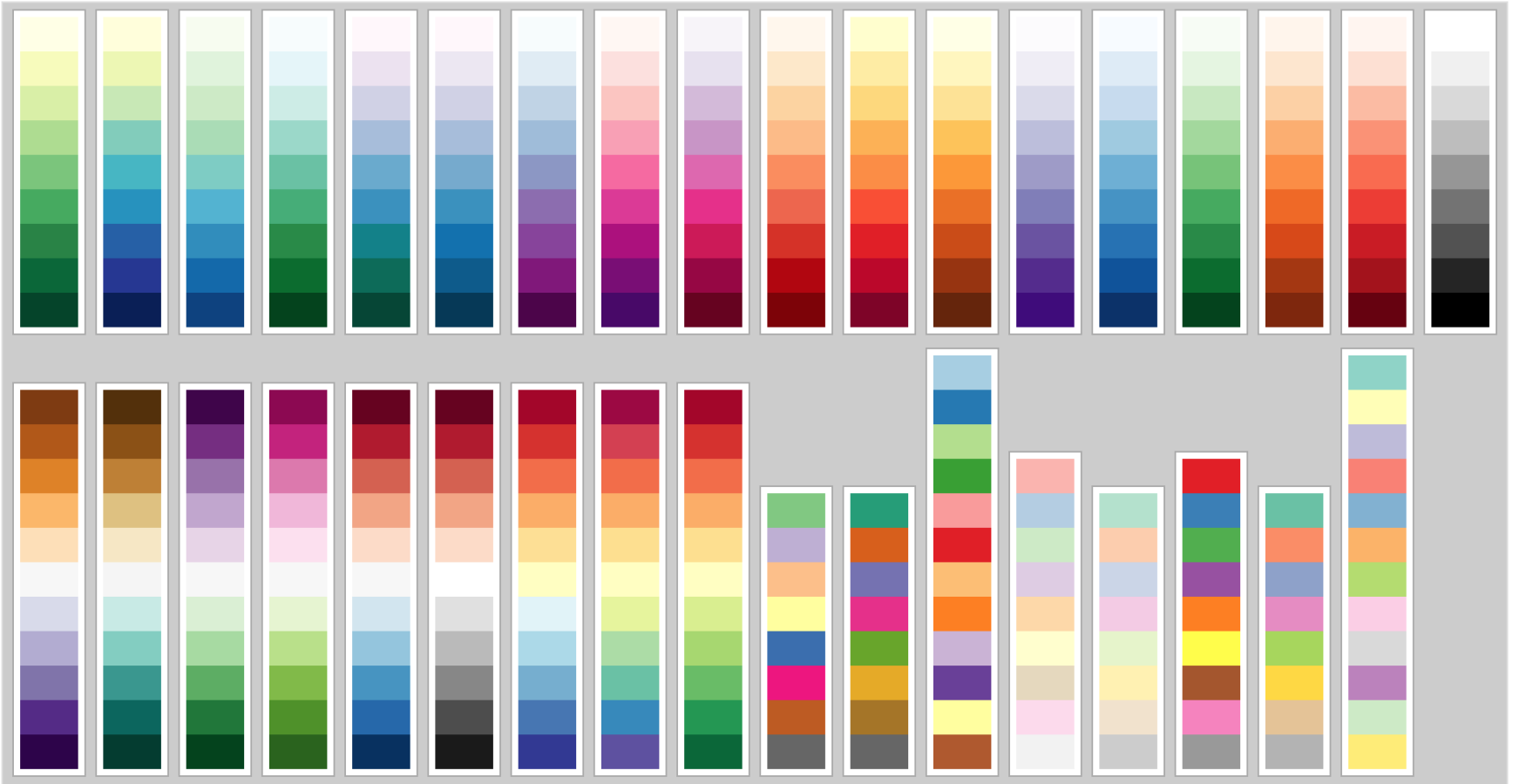


(RGB)



(Hex)

Every ColorBrewer Scale



For CSS and JavaScript (by Mike Bostock)

<http://bl.ocks.org/mbostock/5577023>

7% of the viewers may not see anything if you use red-green,

ONE WARNING ABOUT

RED-GREEN

Color Vision Deficiency



normal color vision

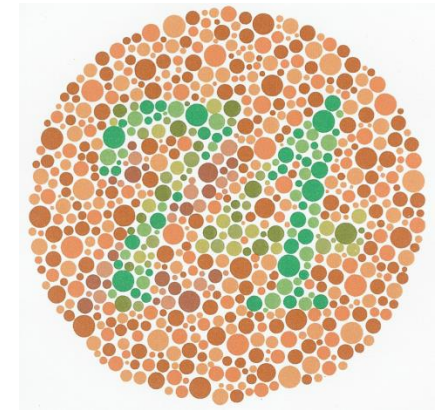
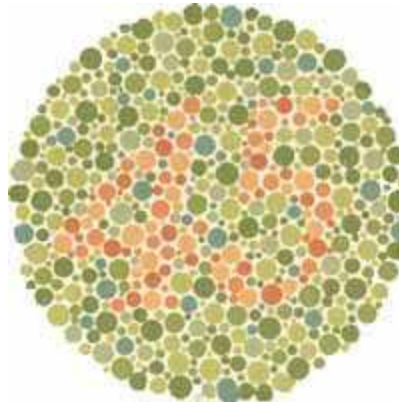
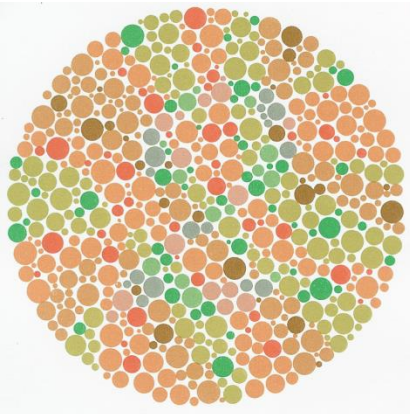
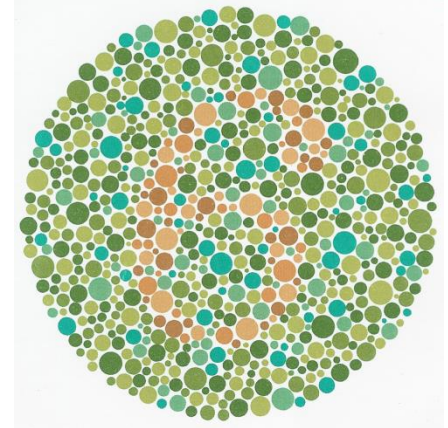
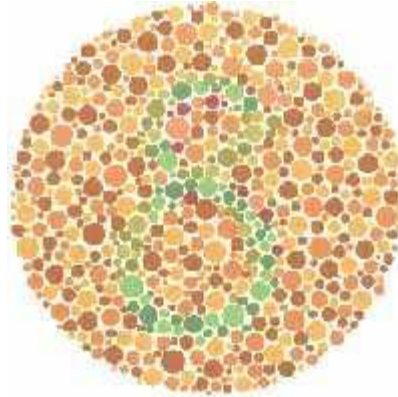
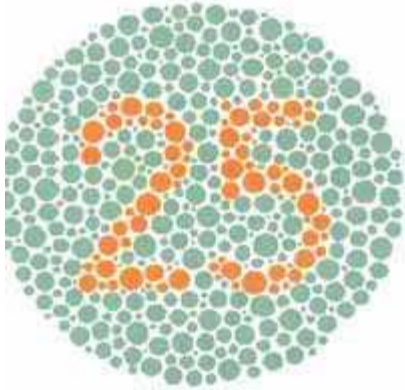


simulation of color contrast
for deuteranopic color vision
(green receptors absent)

approx. 7% of male population color-deficient

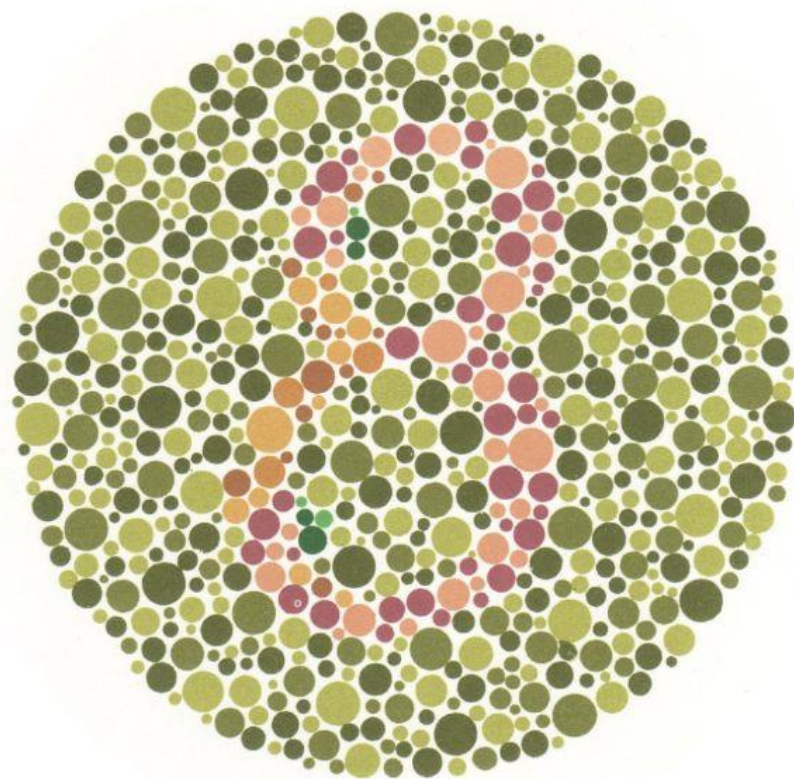
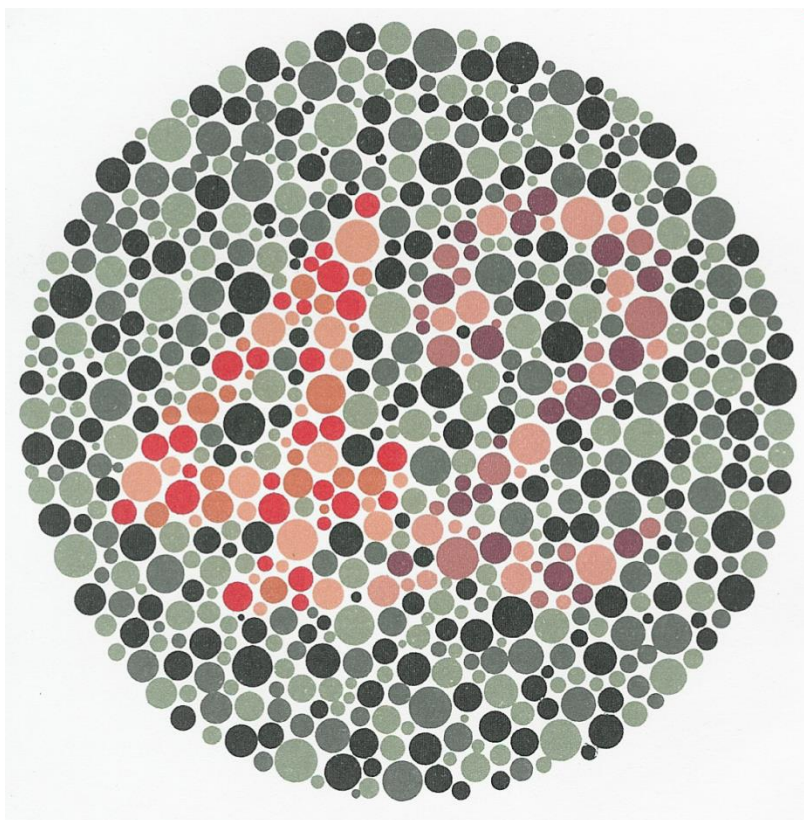
mostly red-green color deficiency (deuteranopia or protanopia) – but other forms exist as well

Color Deficiency Test (Ishihara Test)

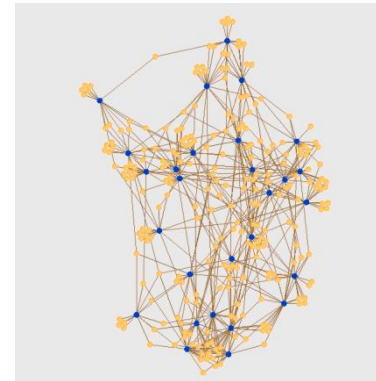
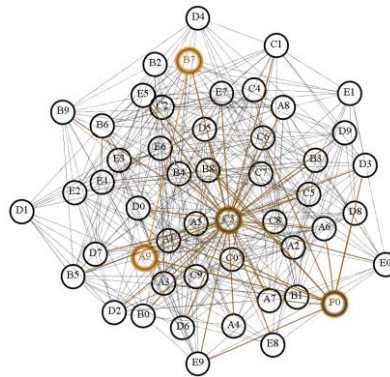
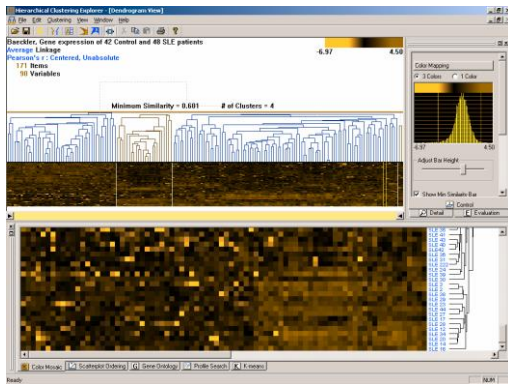
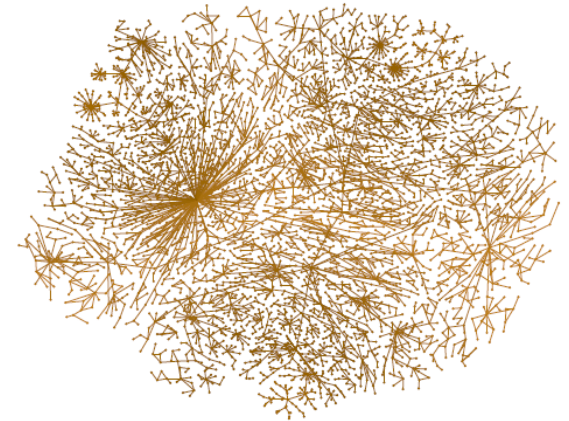
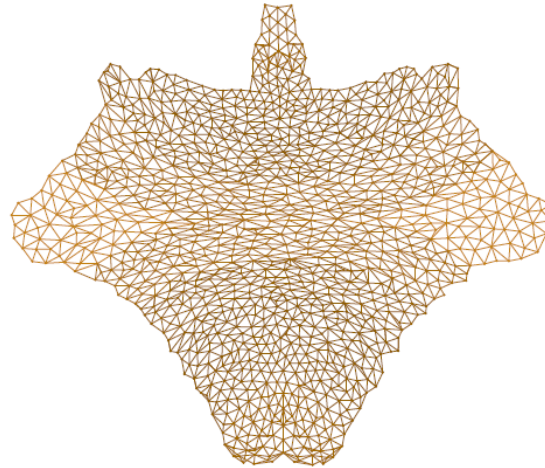
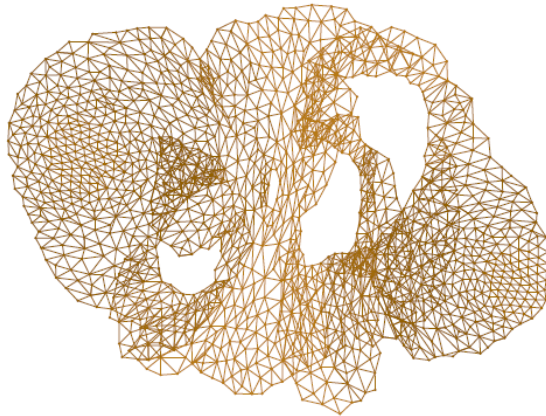


This likely won't work correctly here given the uncalibrated projector

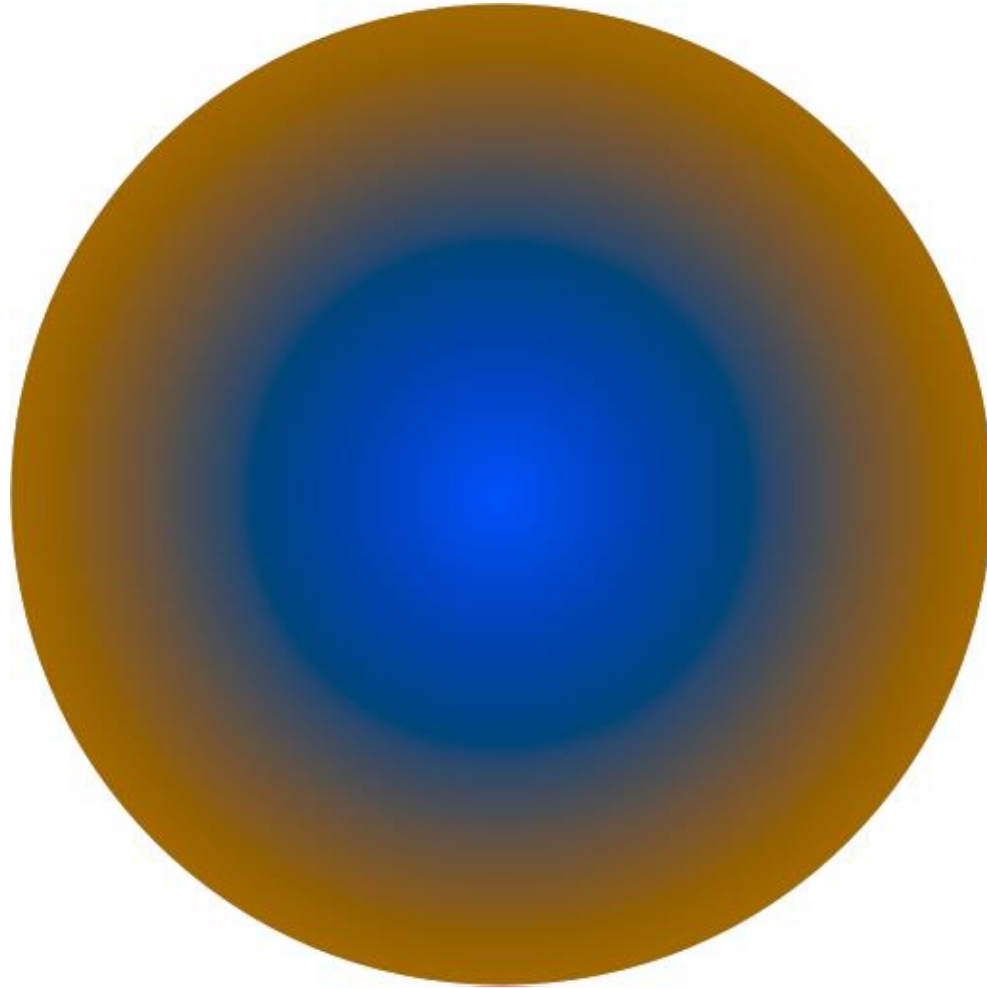
Color Deficiency Test



Examples from VIS/InfoVis 2004

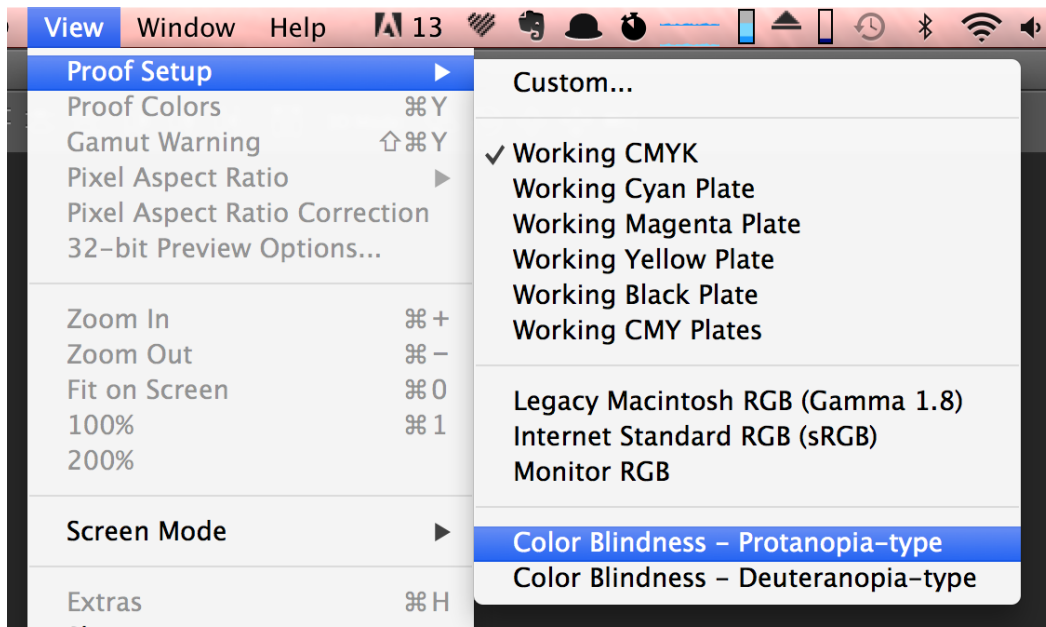


Better: Red-Blue Contrast



Check Your Visualizations!

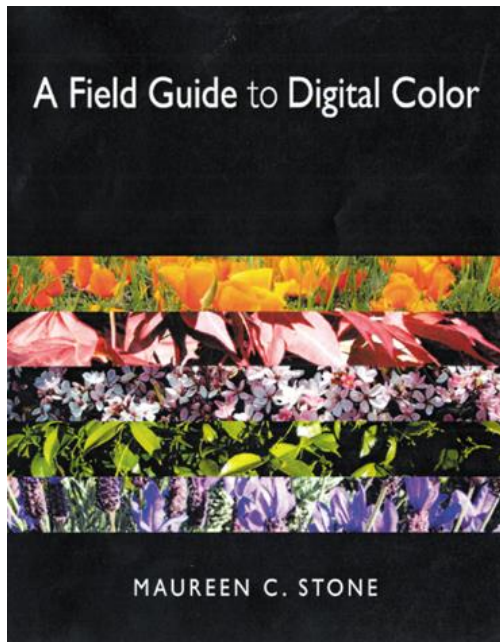
When possible, avoid red-green color contrasts for visualization purposes.



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>

(Fun) Color Resources!

Wired “The Crayola-fication of the World”

by Aatish Bhatia

<http://www.wired.com/wiredscience/2012/06/the-crayola-fication-of-the-world-how-we-gave-colors-names-and-it-messed-with-our-brains-part-i/>

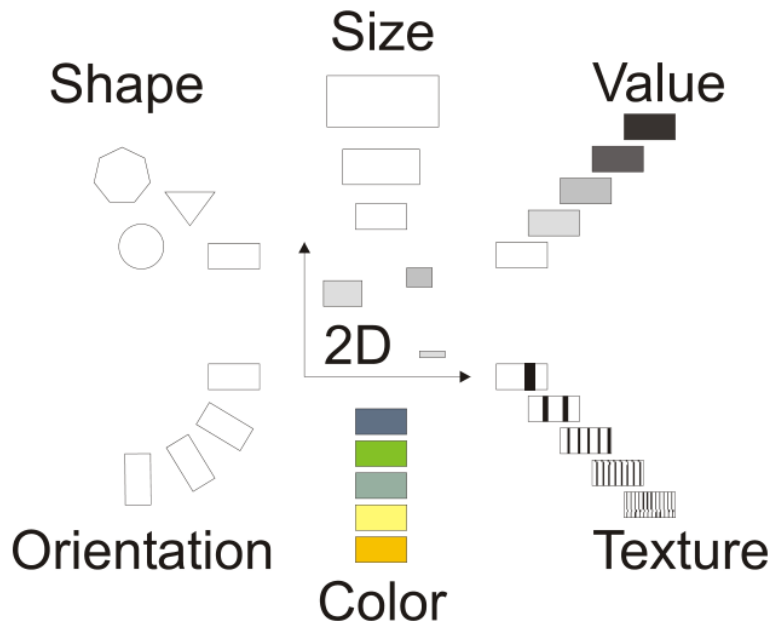
The screenshot shows a web browser displaying the article "The Crayola-fication of the world: How we gave colors names, and it messed with our brains (part 1)" by Aatish Bhatia on the Wired website. The article is part of the "Empirical Zeal" series. The main content area features a quote from Herman Melville: "Who in the rainbow can draw the line where the violet tint ends and the orange tint begins? Distinctly we see the difference of the colors, but where exactly does the one first blendingly enter into the other? So with sanity and insanity." Below the quote is a large image of a color spectrum with vertical bars of various colors. The article is dated 06.06.12 at 4:06 PM. The right sidebar includes an "About Aatish Bhatia" section, a "Wired Science Blogs" list, and a "MOST RECENT STORIES" section.

RadioLab “Colors” WNYC Podcast

<http://www.radiolab.org/story/211119-colors/>

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)

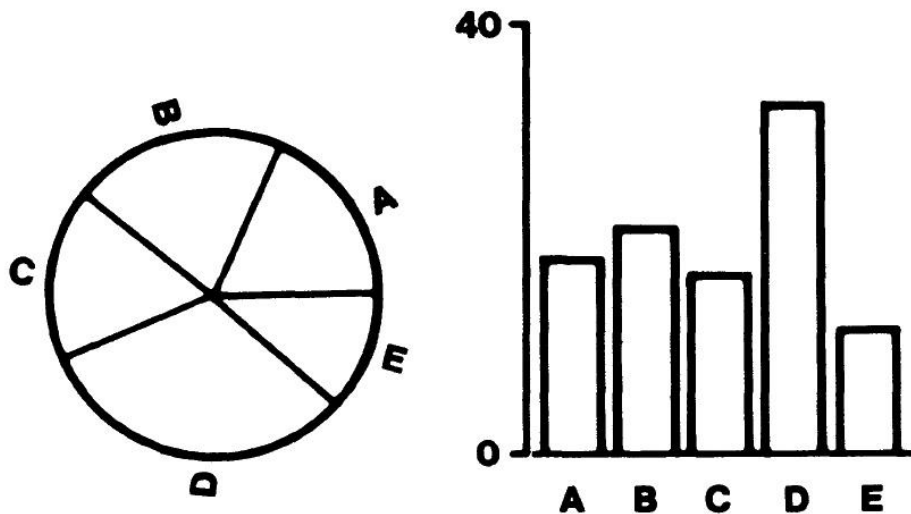


Figure 3. Graphs from position-angle experiment.

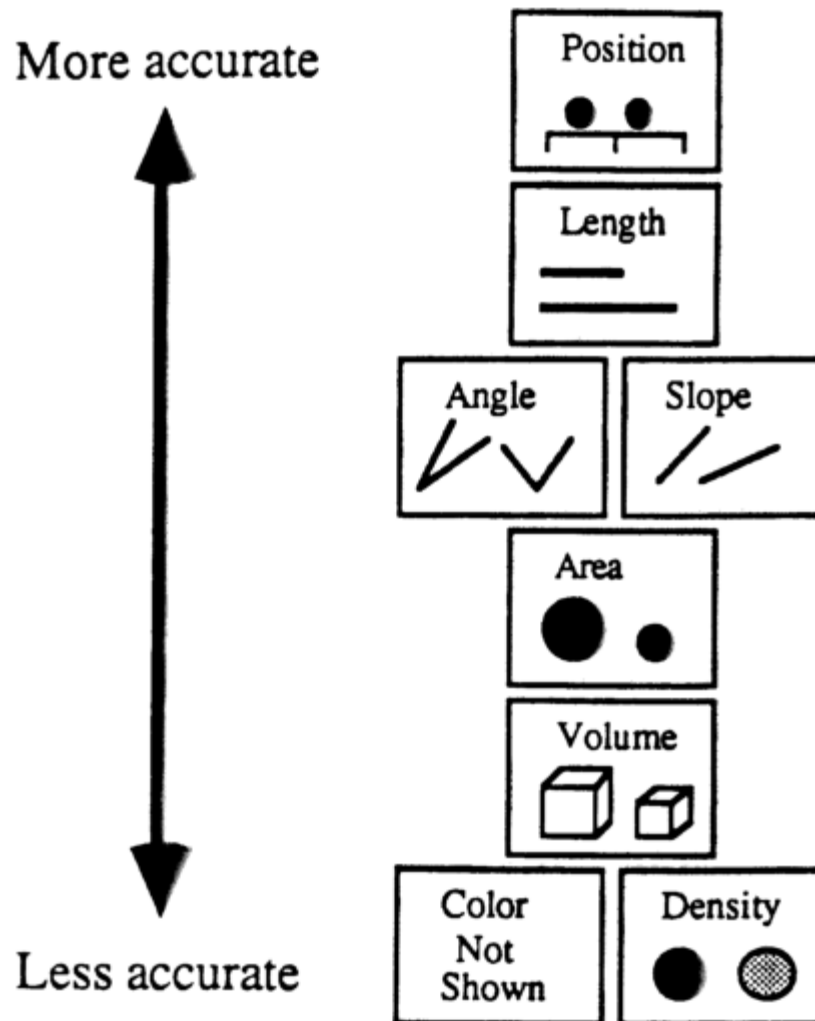
Performed **controlled experiments** to determine how effectively people could judge **changes in visual features**

Focus on **quantitative information**

Variables used: angle, area (size), color hue, color saturation, density (value), length, position, slope, volume

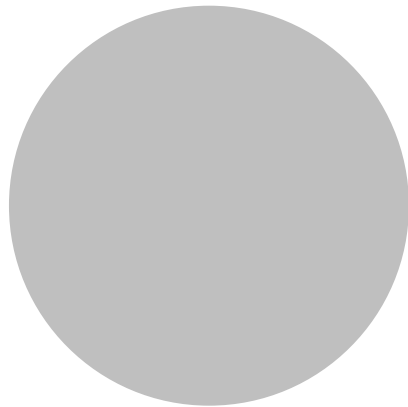
Elementary Graphical Perception Tasks

William S. Cleveland (1980s)

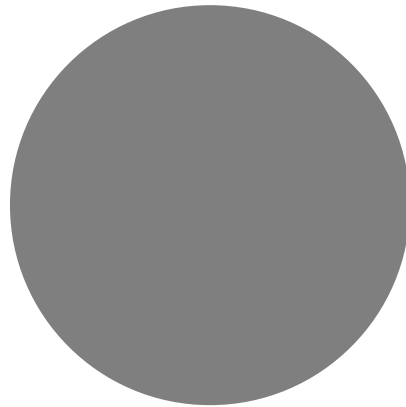


Color Value

What percentage in value is the right from the left?



100%

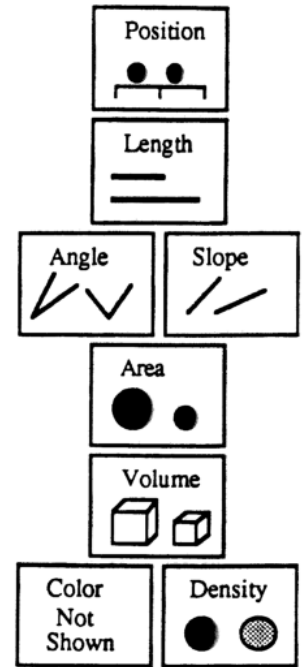


66%

More accurate

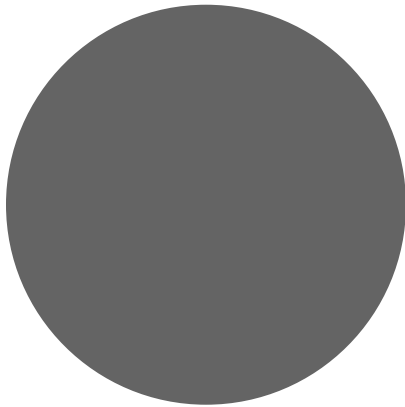


Less accurate

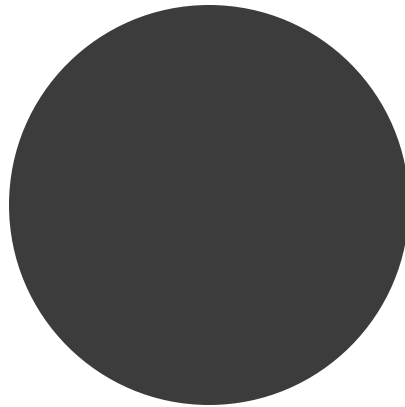


Color Value

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



100%

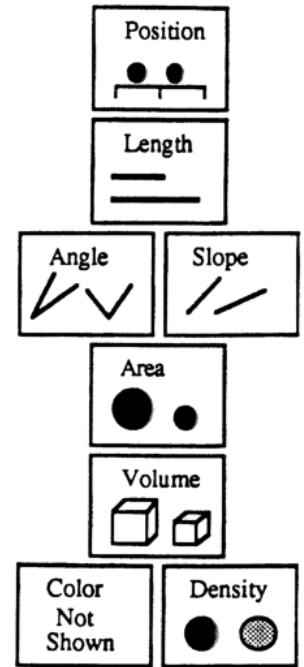


60%

More accurate

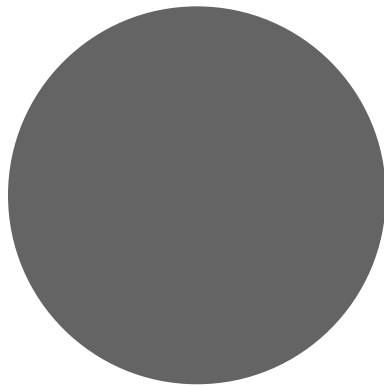


Less accurate

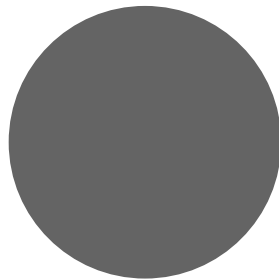


Area

What percentage in size is the right from the left?



100%

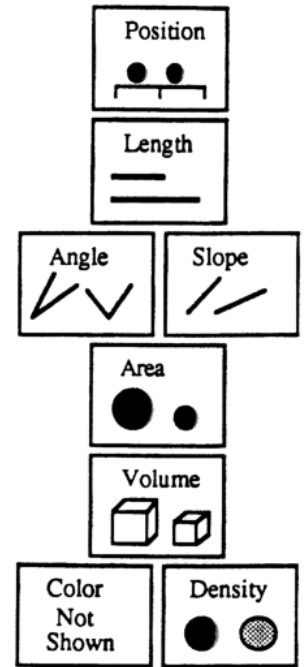


52%

More accurate

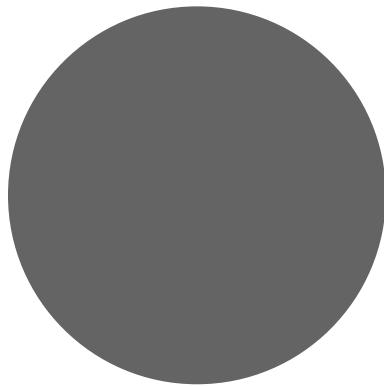


Less accurate

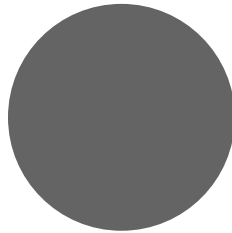


Area

What percentage in size is the right from the left?



100%

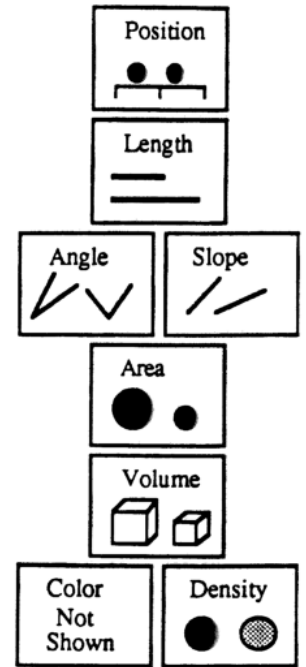


36%

More accurate

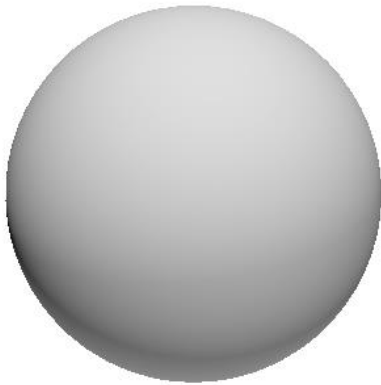


Less accurate

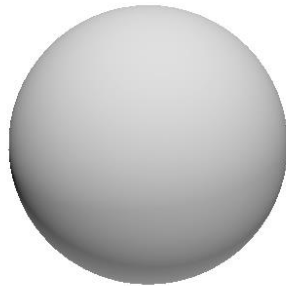


Volume

What percentage in size is the right from the left?



100%

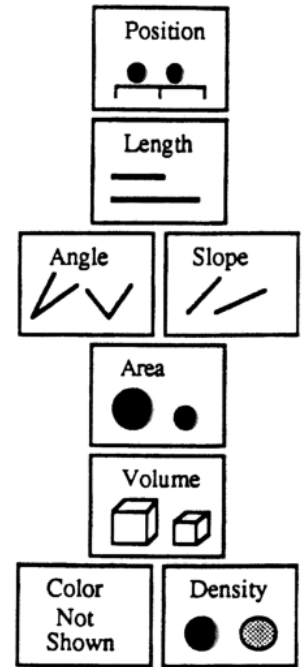


40%

More accurate



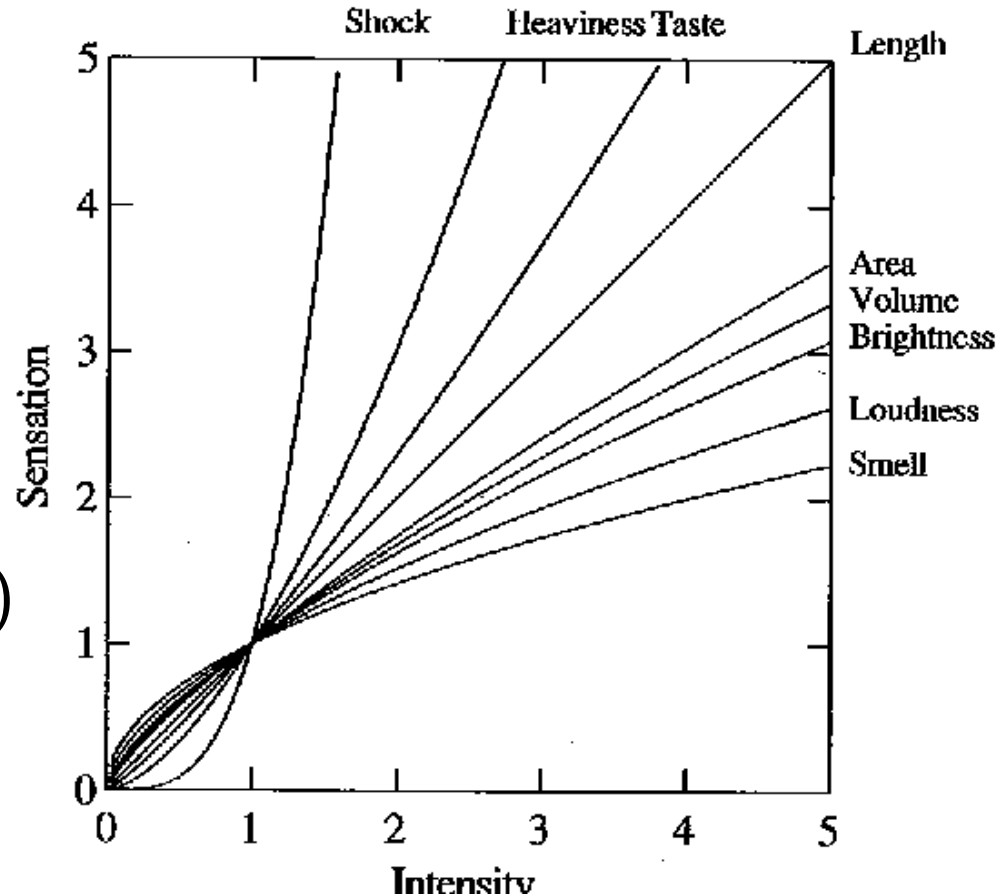
Less accurate



Why are people so bad at this?

Relationship between stimulus and perception **isn't always linear!**

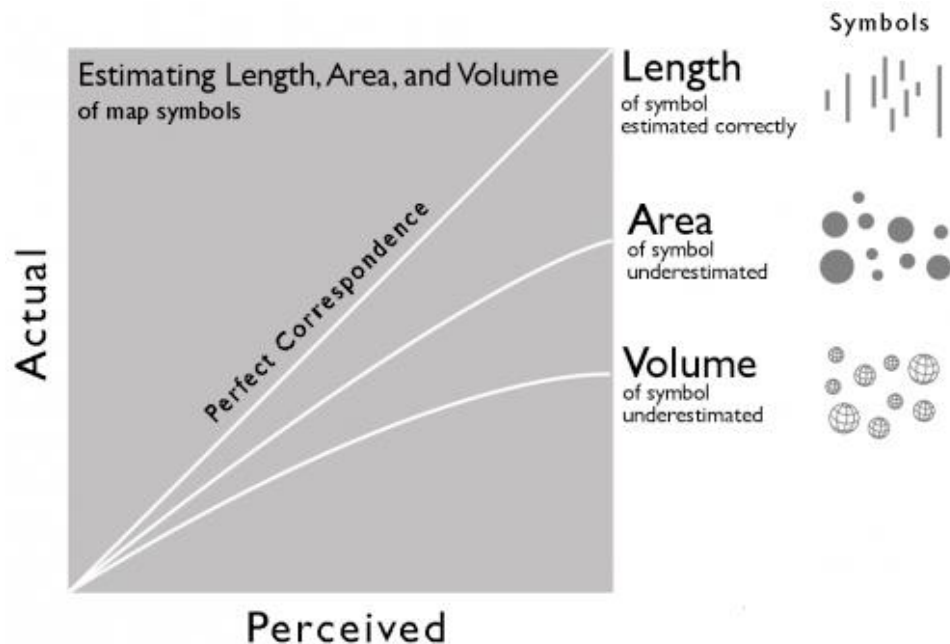
Stevens' power law describes a relationship between a physical stimulus (S) and its **perceived** intensity or strength (P)



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!

POPULATION MAP

of

OHIO

1920

GUY-HAROLD SMITH

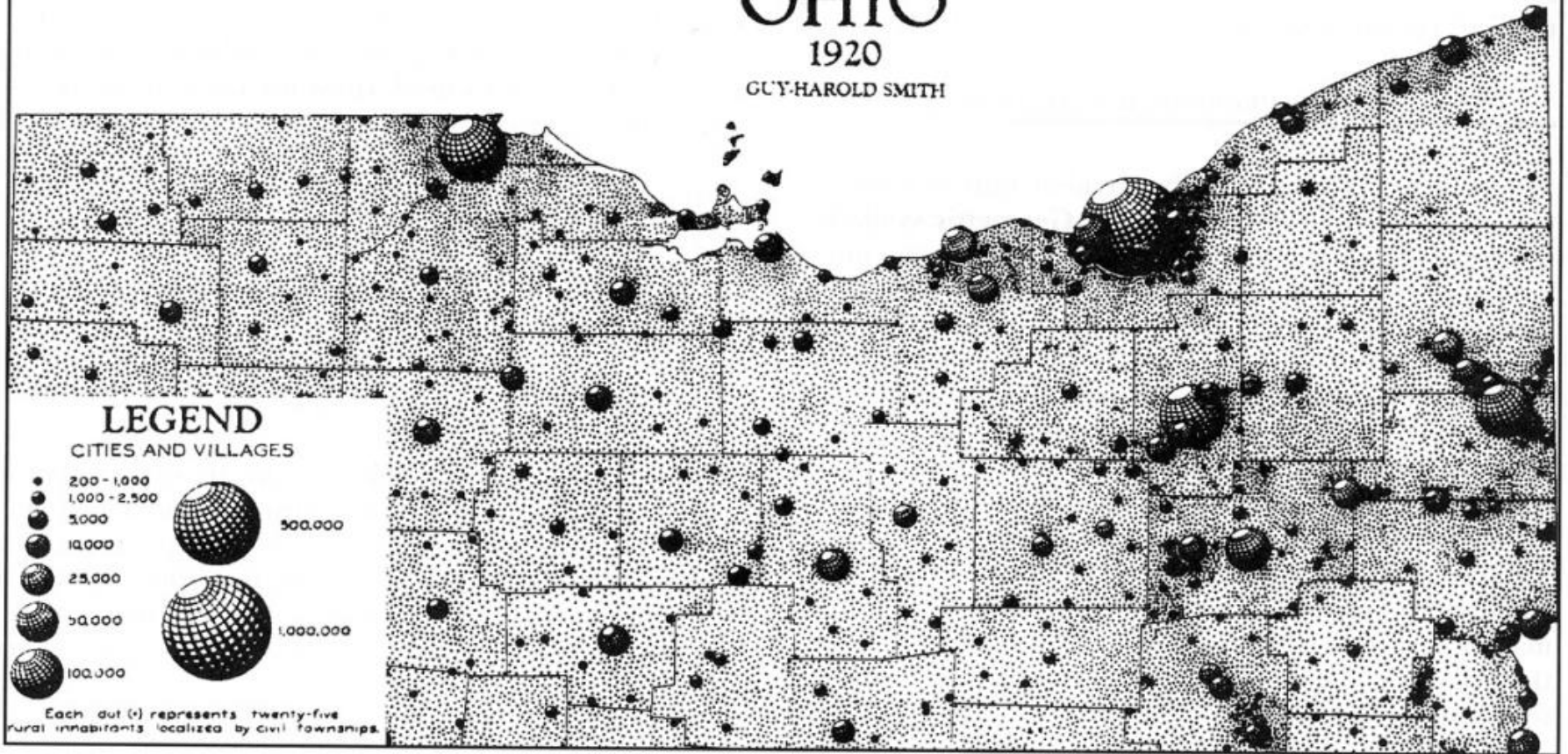
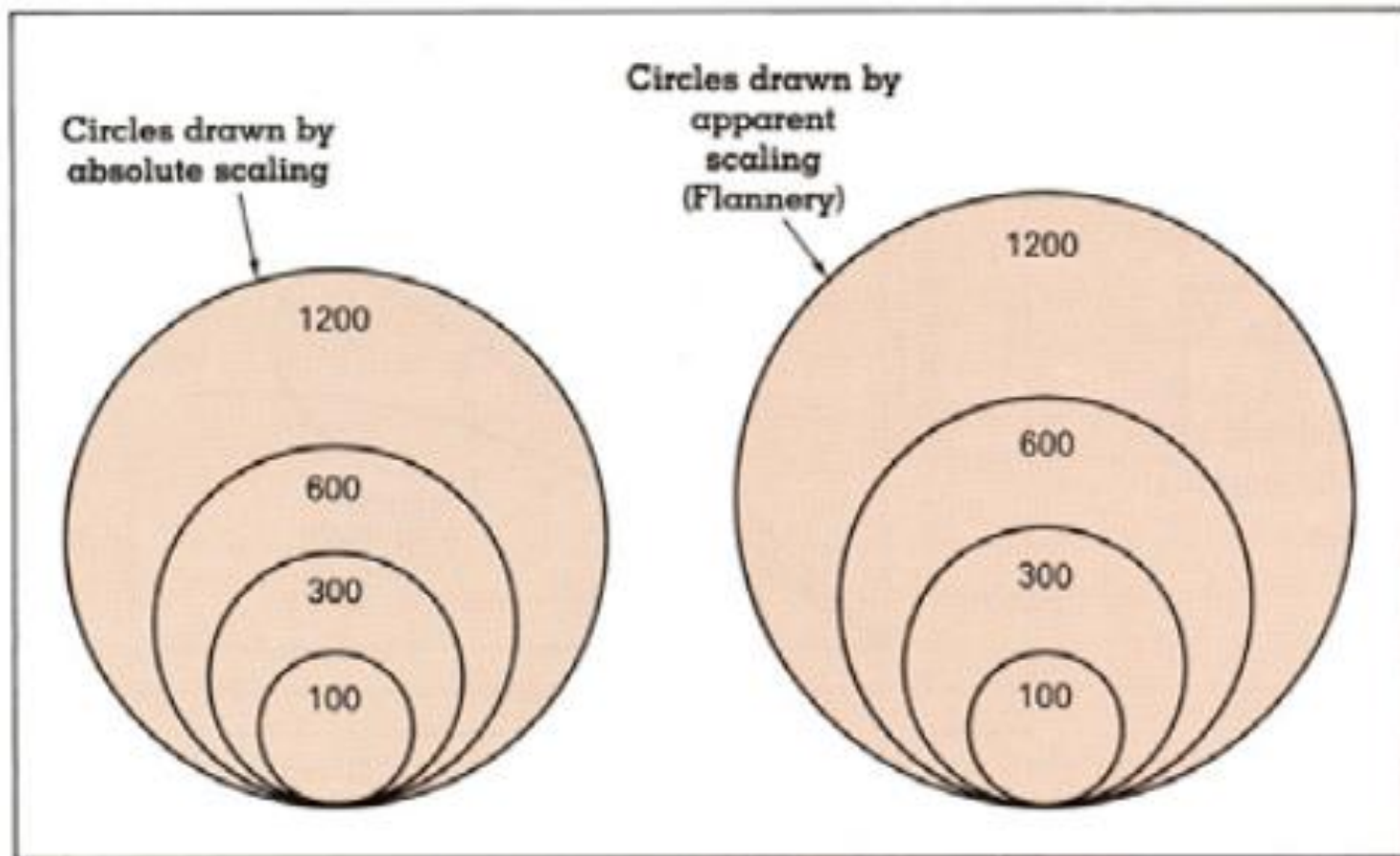


FIGURE 7.4. An eye-catching map created using three-dimensional geometric symbols. (After Smith, 1928. First published in *The Geographical Review*, 18(3), plate 4. Reprinted with permission of the American Geographical Society.)

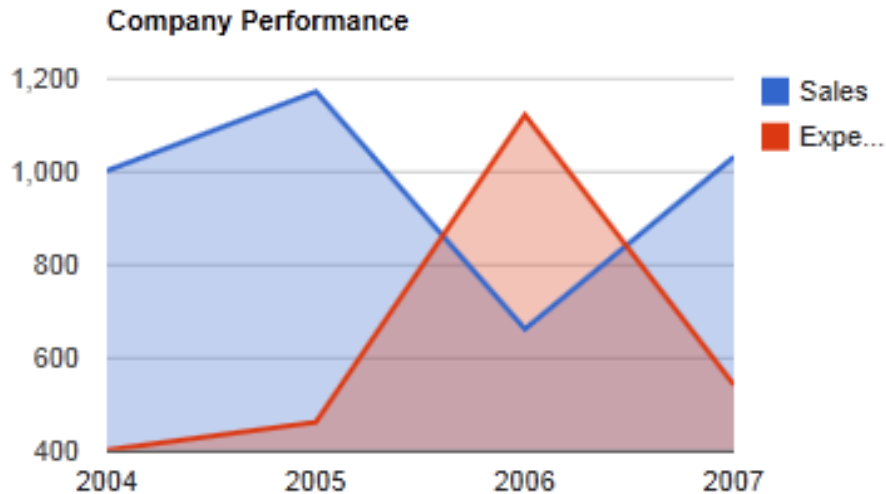


[Cartography: Thematic Map Design, Figure 8.6, p. 170, Dent, 96]

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

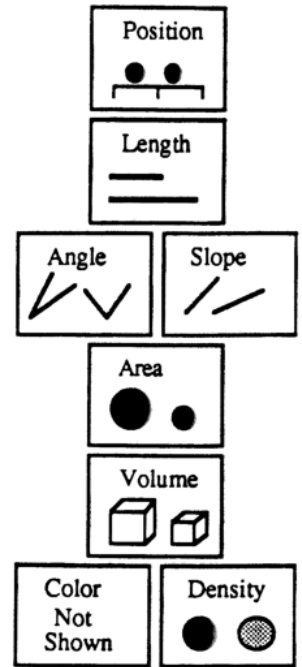
Area

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



More accurate

Less accurate



no idea – this is very difficult

Length

What percentage in length is the right from the left?

100%

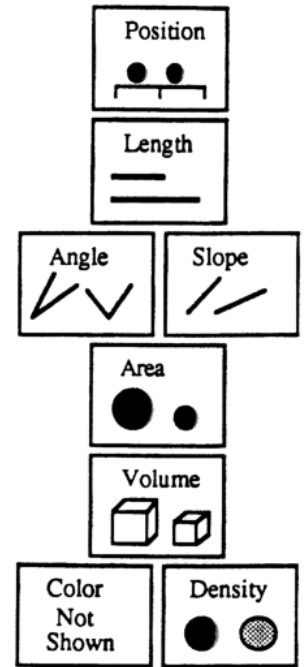


75%

More accurate



Less accurate



Length / Position

What percentage in length is the right from the left?

100%

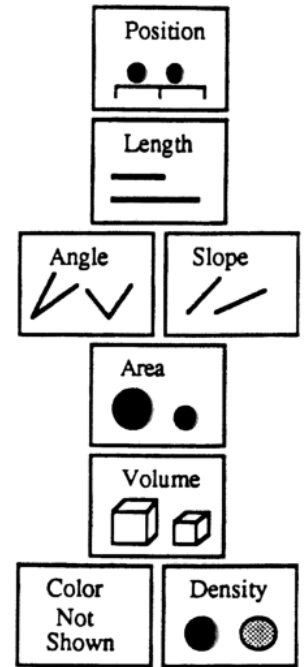


25%

More accurate



Less accurate

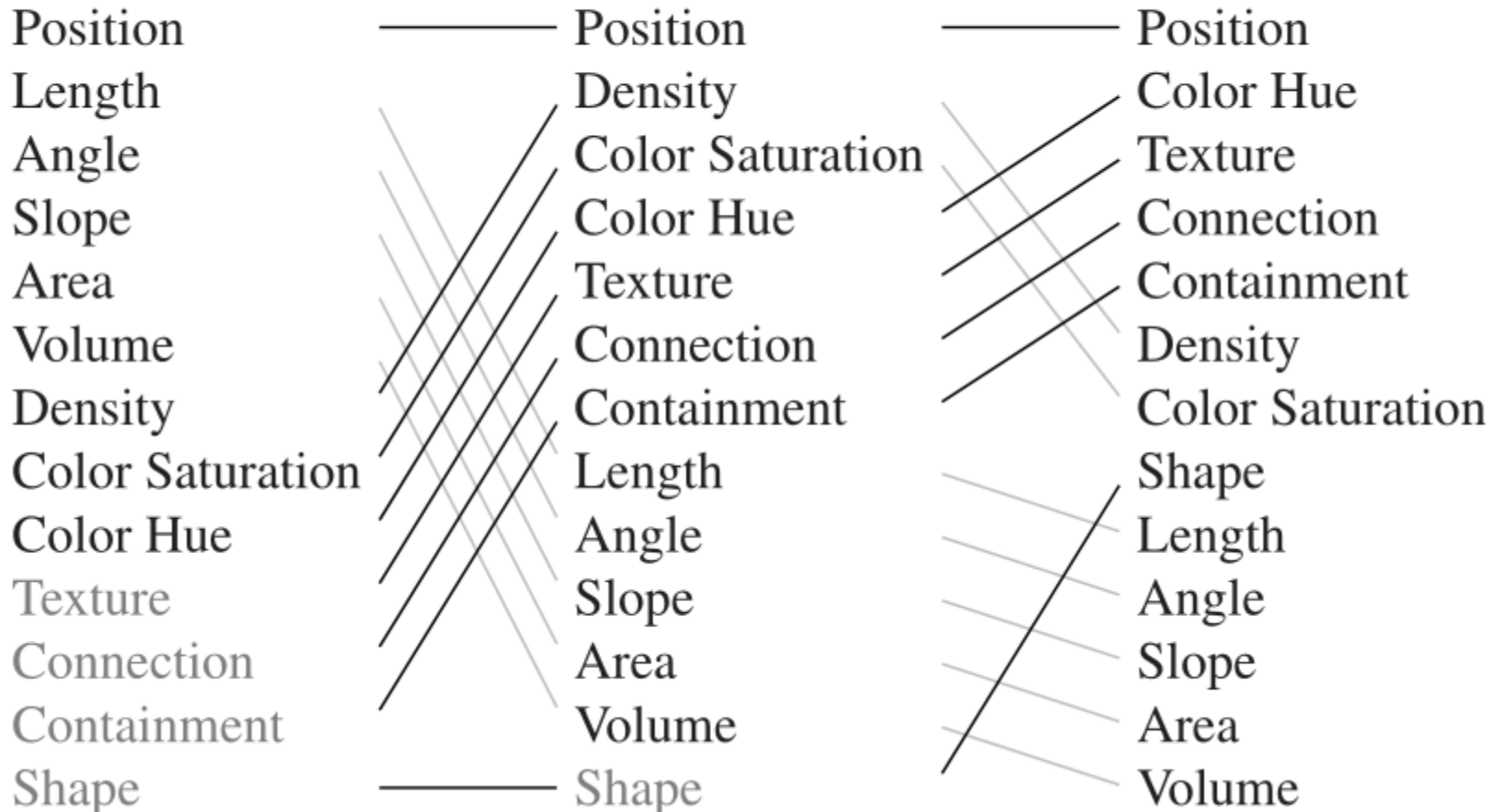


Effectiveness of Data Encodings (Conjecture)

Quantitative

Ordinal

Nominal



➔ **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

Effectiveness

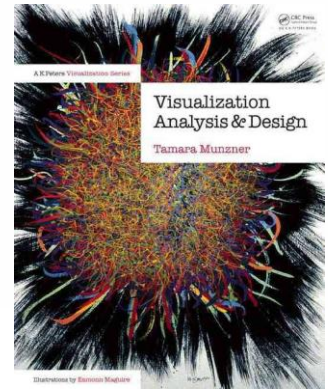
➔ **Identity Channels: Categorical Attributes**

Spatial region 

Color hue 

Motion 

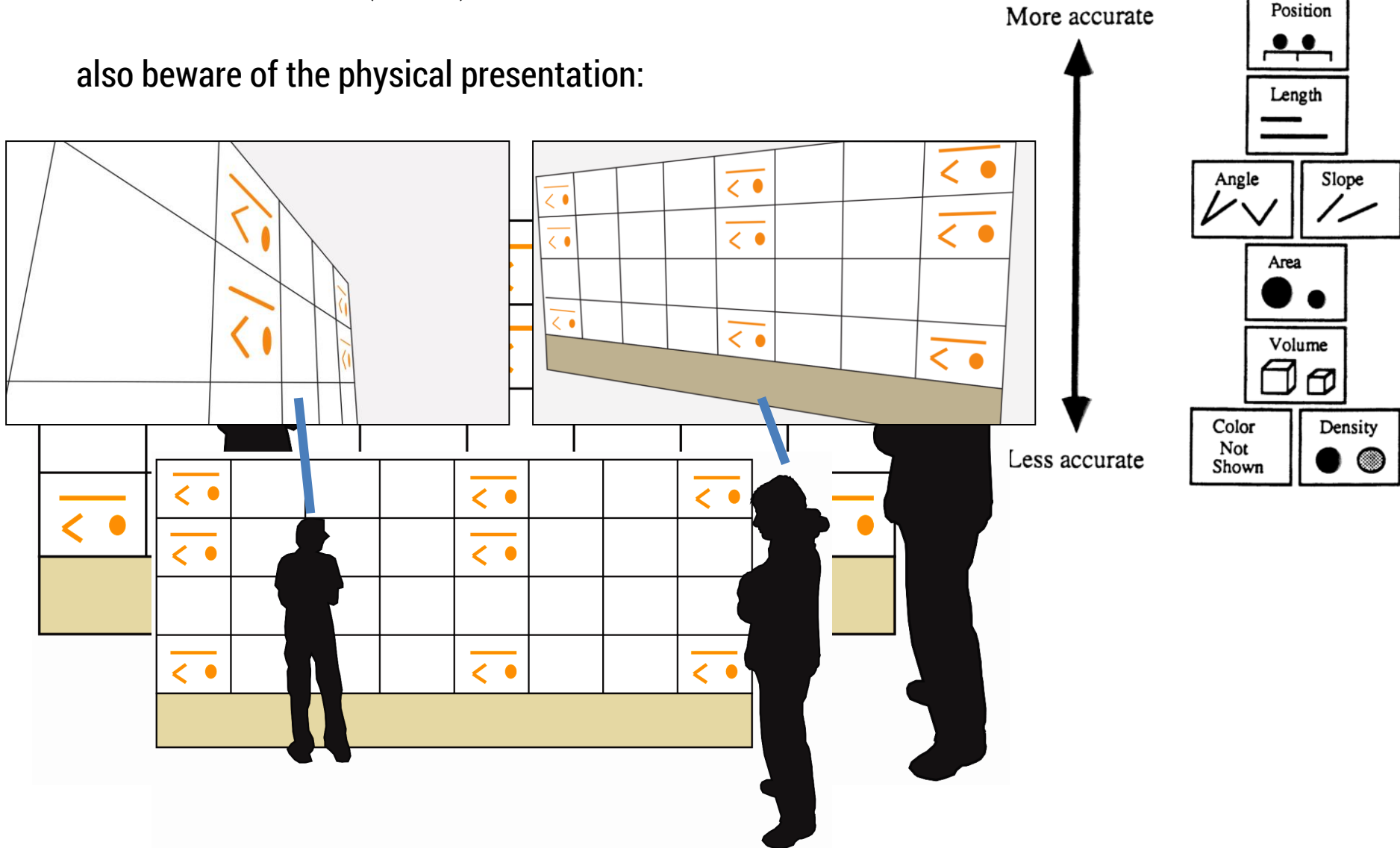
Shape 



Elementary Graphical Perception Tasks

William S. Cleveland (1980s)

also beware of the physical presentation:



PREATTENTIVE PROCESSING

How many 3's do you see?

1281768756138976546984506985604982826762
9809858458224509856458945098450980943585
9091030209905959595772564675050678904567
8845789809821677654876364908560912949686

How about now?

12817687561**3**8976546984506985604982826762
980985845822450985645894509845098094**3**585
90910**3**0209905959595772564675050678904567
8845789809821677654876**3**64908560912949686

Preattentive Processing

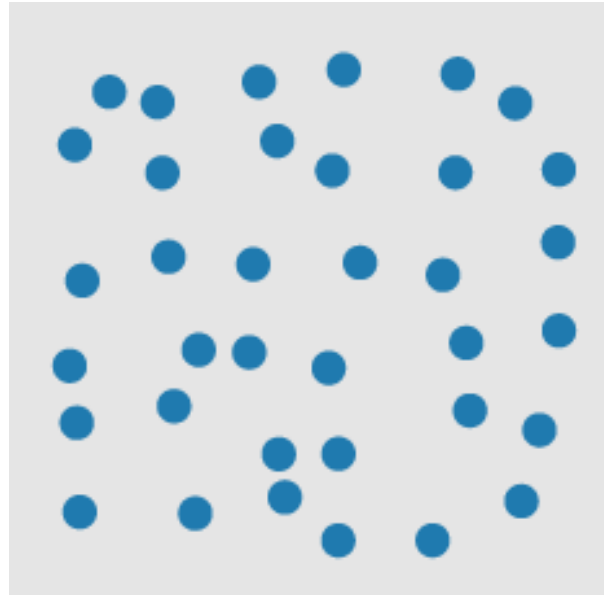
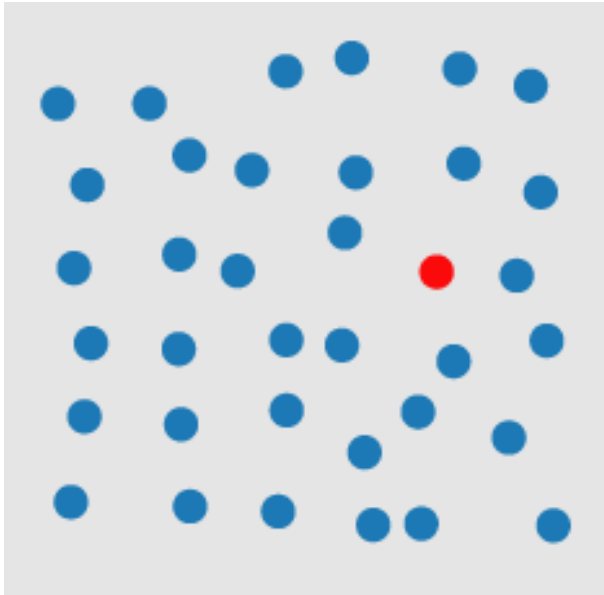
- Some stimuli can be perceived **without** the need for focused attention
- Generally within **200-250 ms**
- Seems to be done **in parallel** by the low-level vision system

Visual encoding has a **big** impact on this!

Visual encodings influence **preattentive** processing

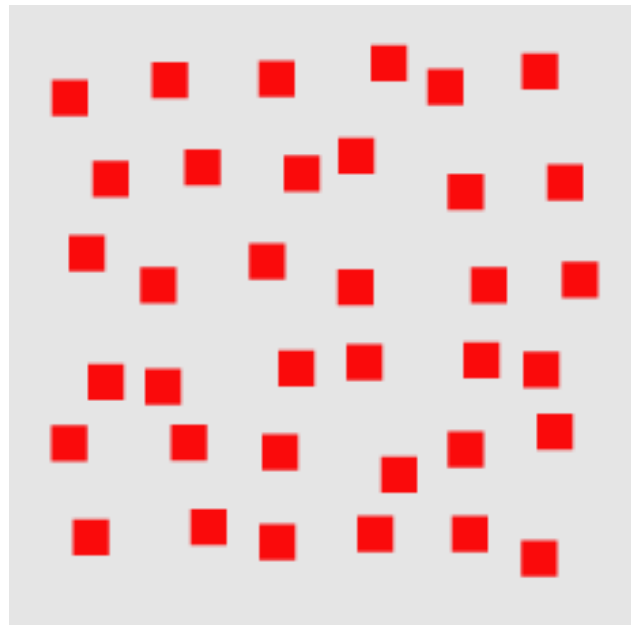
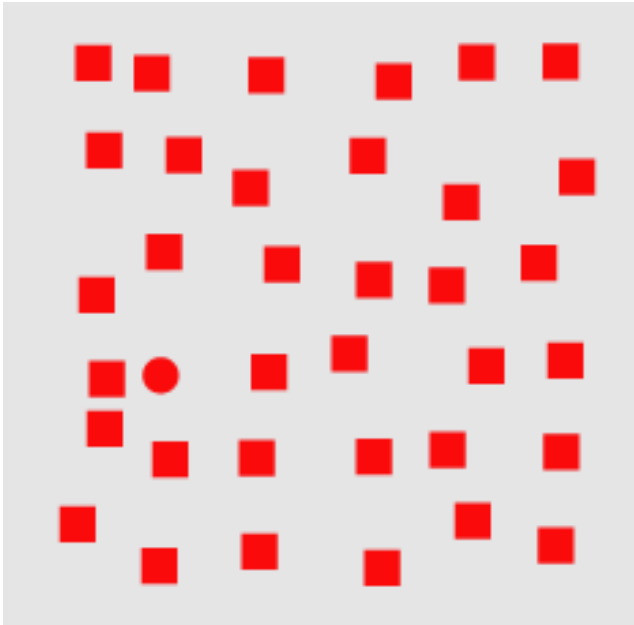
**DETERMINE IF A RED CIRCLE
IS PRESENT**

Hue



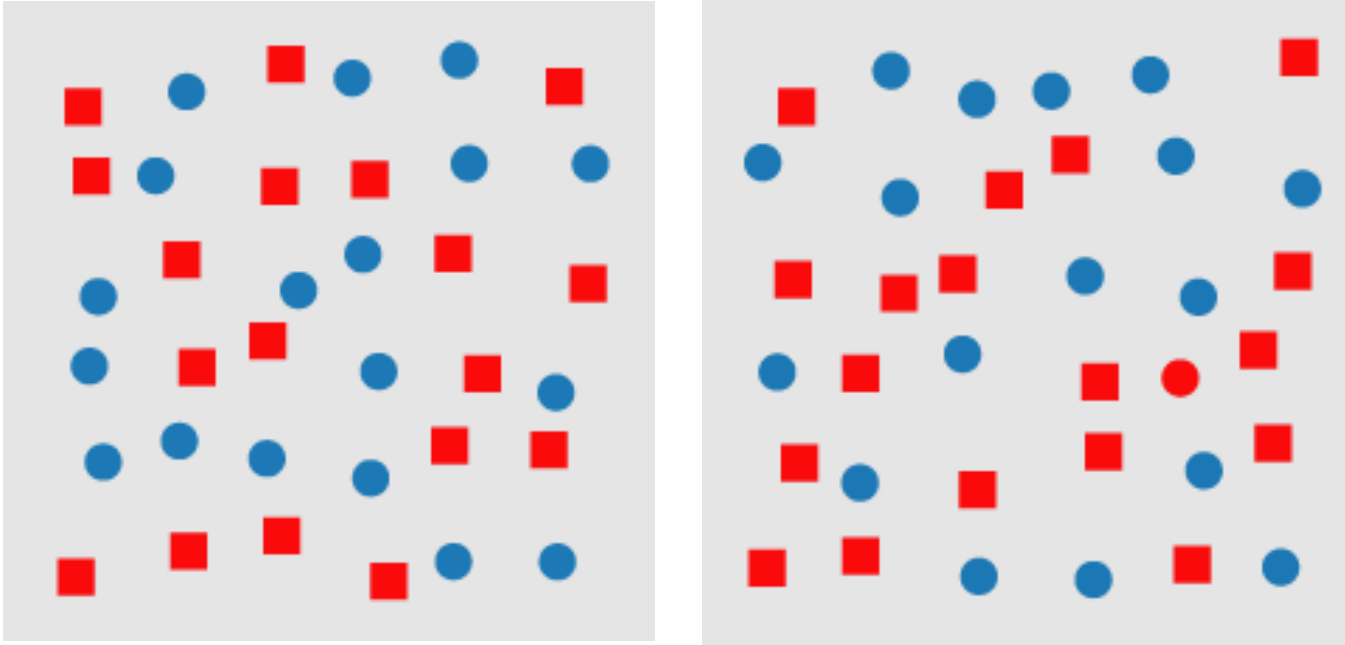
Yes, can be done preattentively

Shape



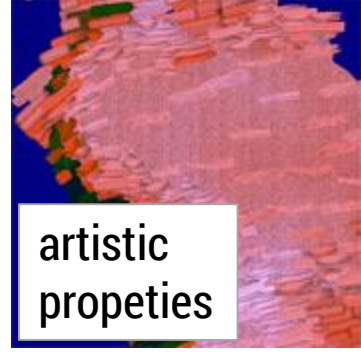
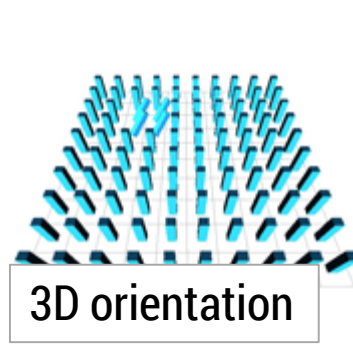
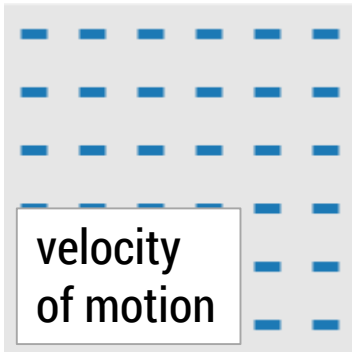
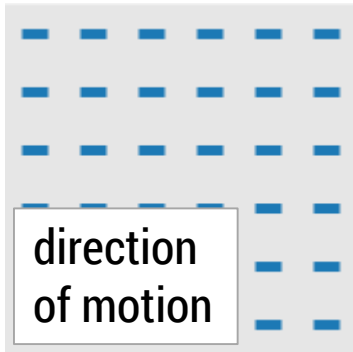
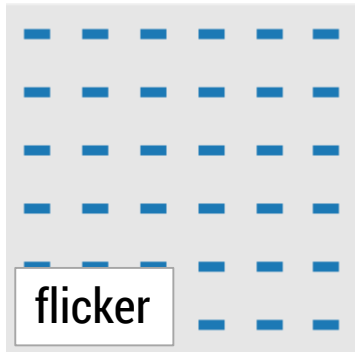
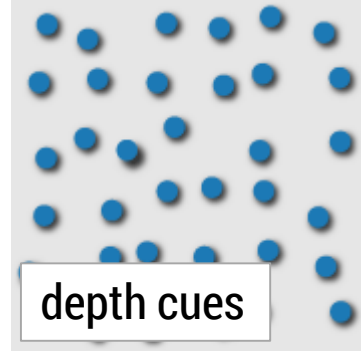
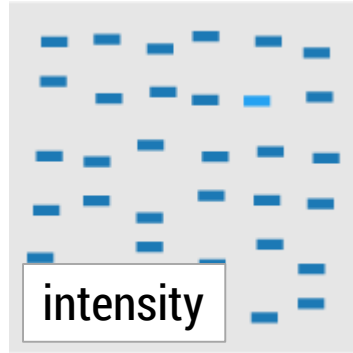
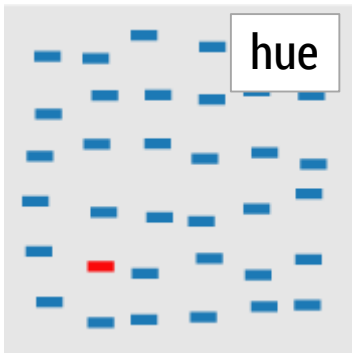
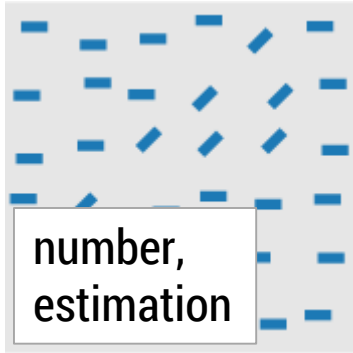
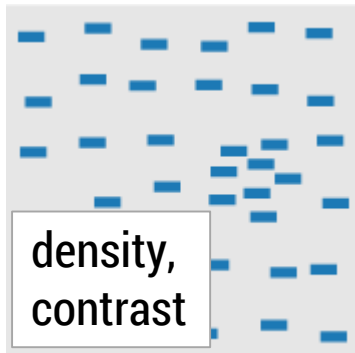
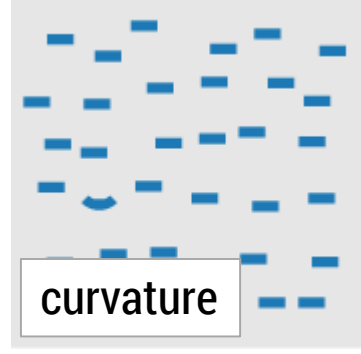
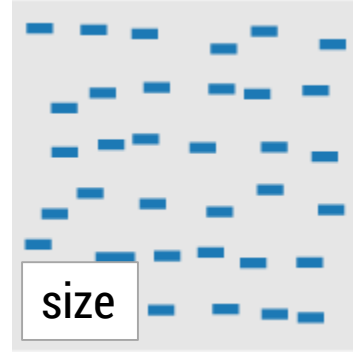
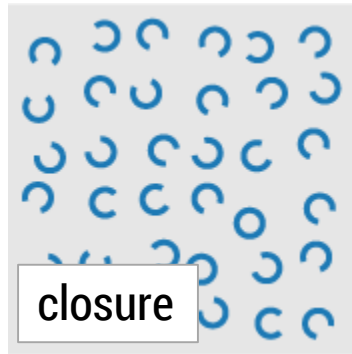
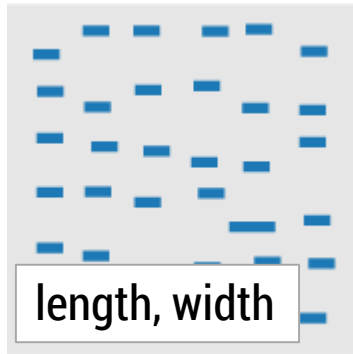
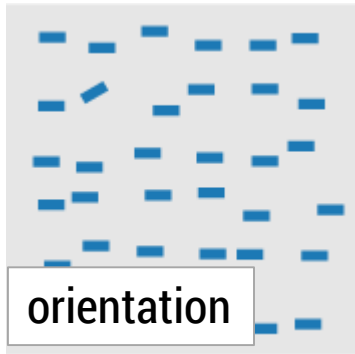
Yes, can be done preattentively

Hue and Shape

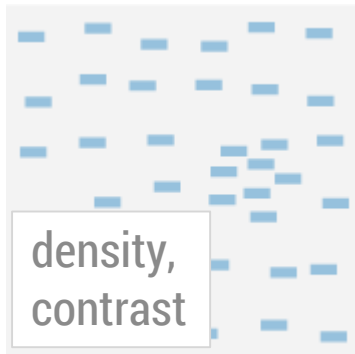
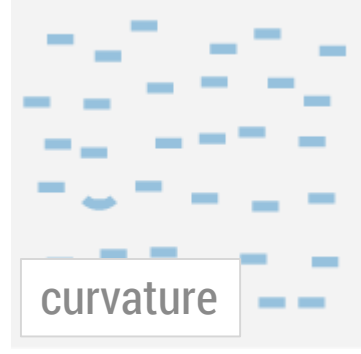
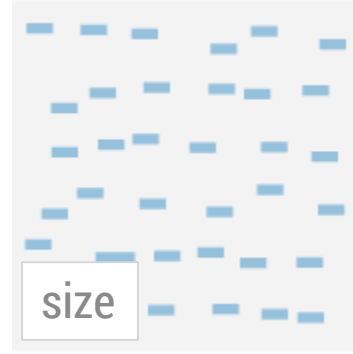
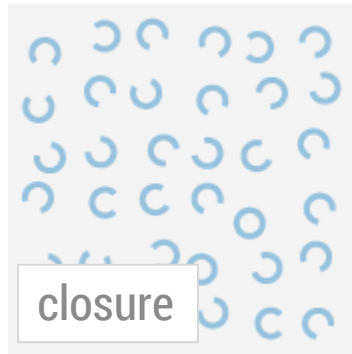
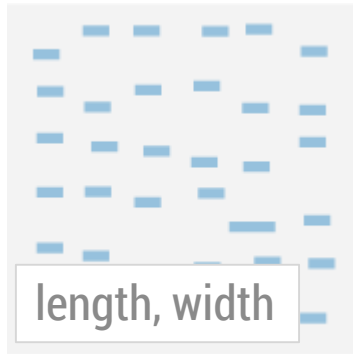
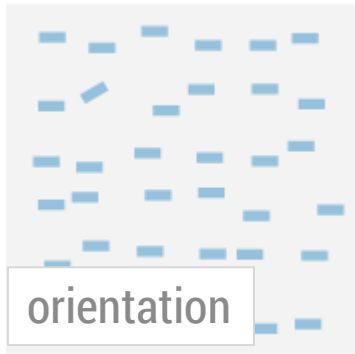


Cannot be done preattentively due to the **conjunction** of shape and hue
→ need to search

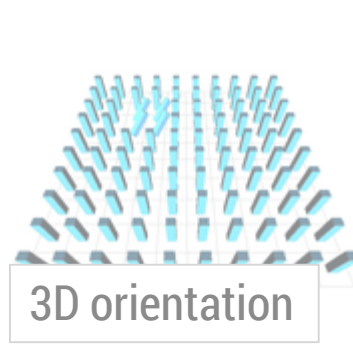
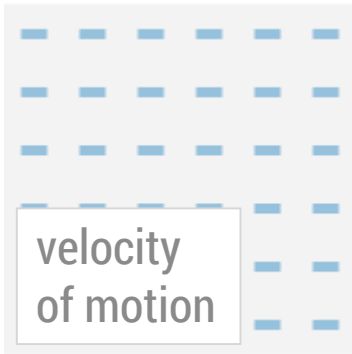
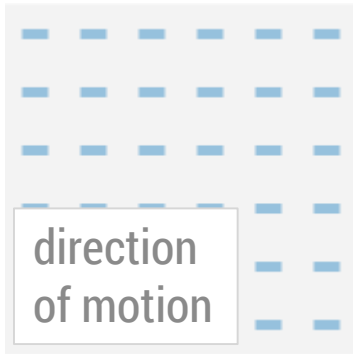
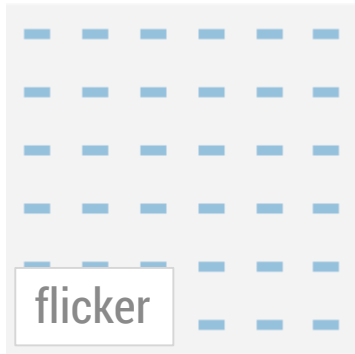
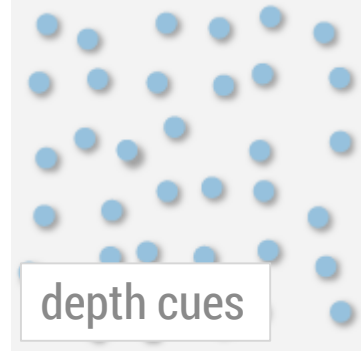
Preattentive visual features (some)



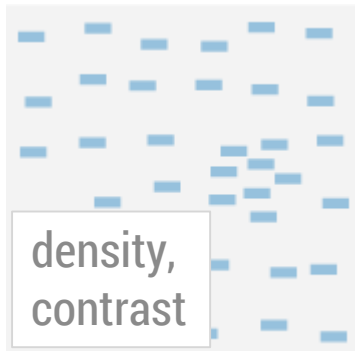
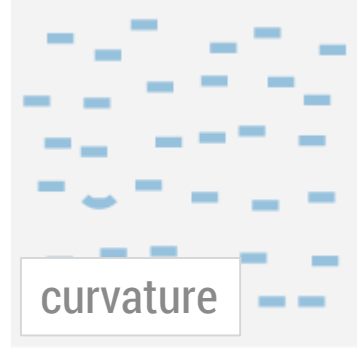
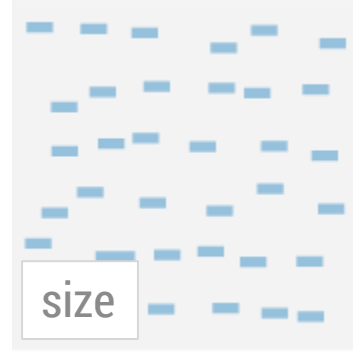
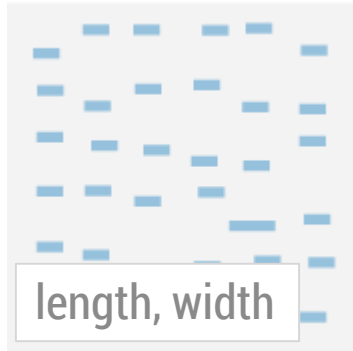
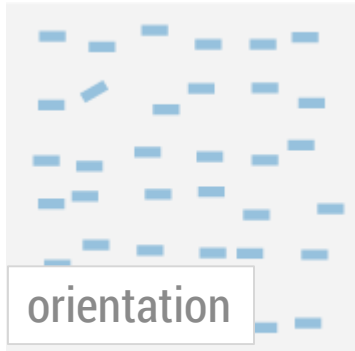
Preattentive visual features (some)



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

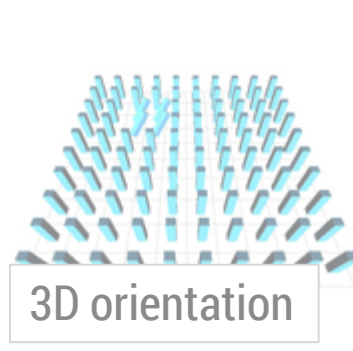
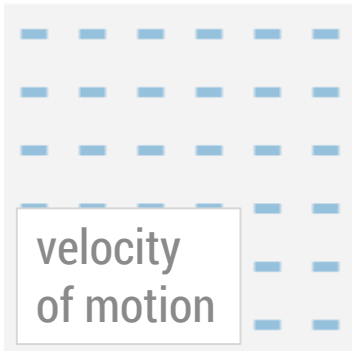
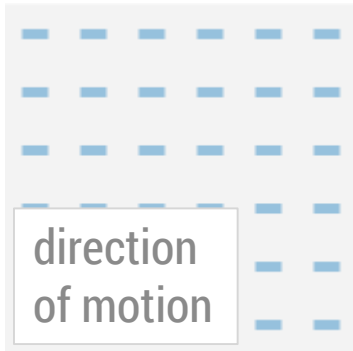
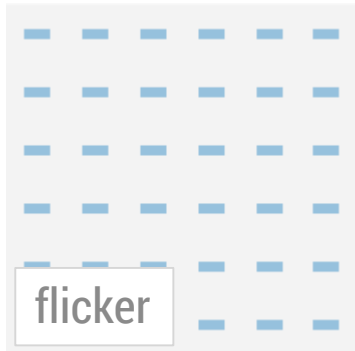
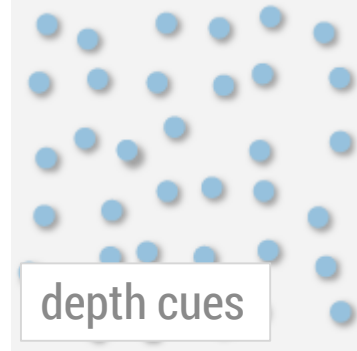


Preattentive visual features (some)



Avoid conjunctions that inhibit preattentive recognition.

(Most conjunctions are require search.)



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

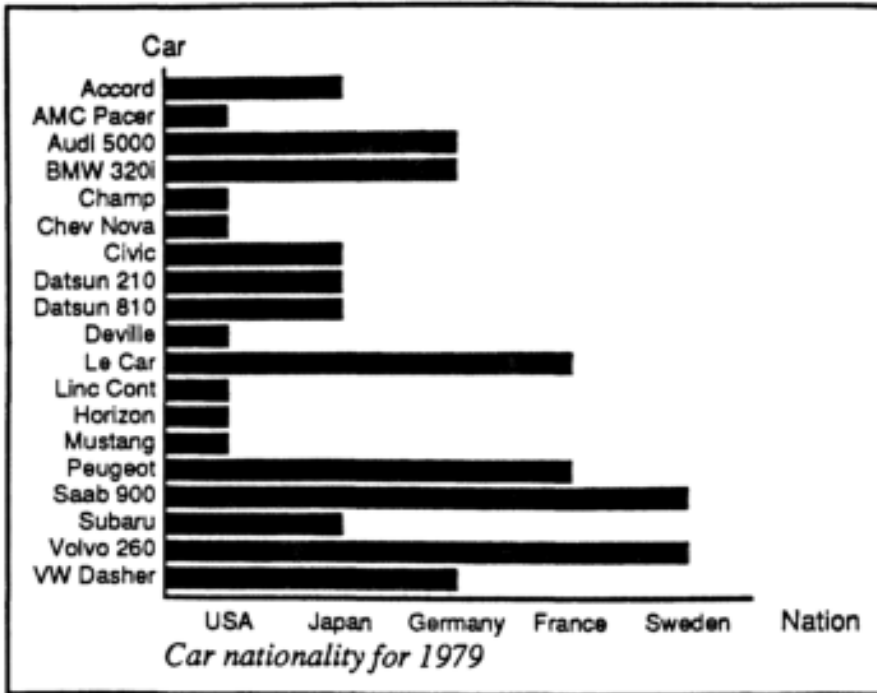
What kind of data are we looking at?

Nations: Nominal

Cars: Nominal

(Nation,Car): Nominal

Let's evaluate...



Quantitative

Position
Length
Angle
Slope
Area
Volume
Density
Color Saturation
Color Hue
Texture
Connection
Containment
Shape

Ordinal

Position
Density
Color Saturation
Color Hue
Texture
Connection
Containment
Length
Angle
Slope
Area
Volume
Shape

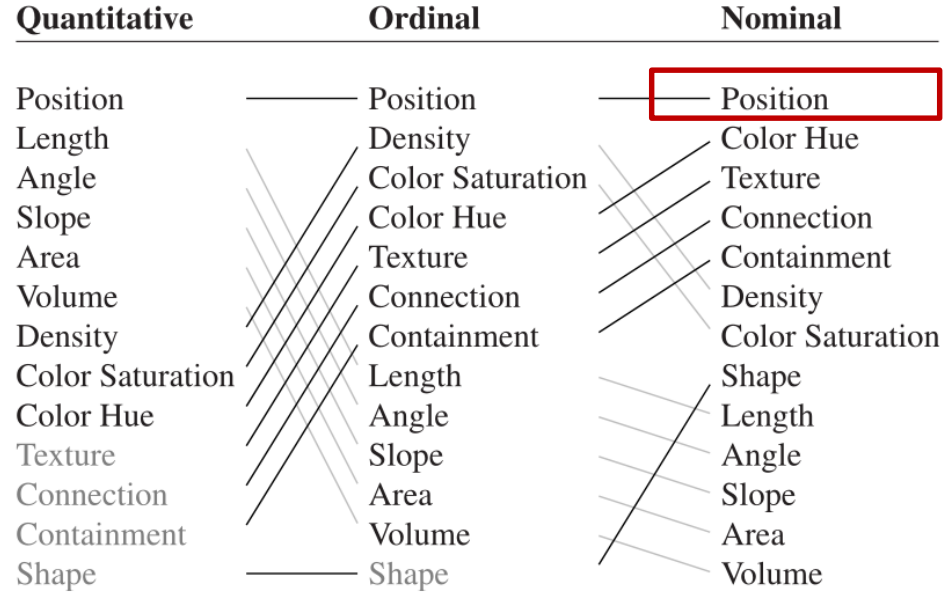
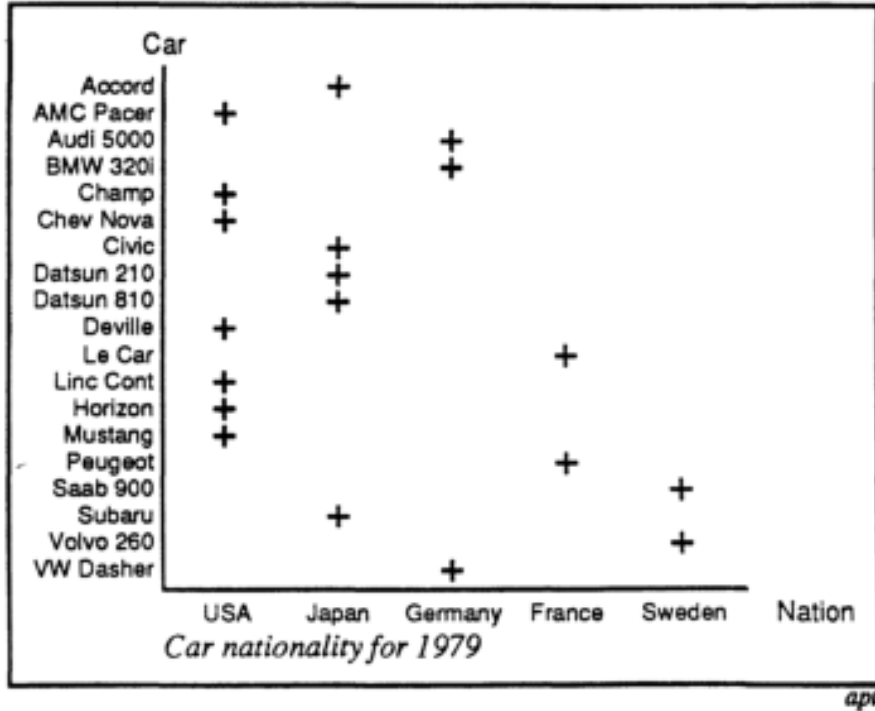
Nominal

Position
Color Hue
Texture
Connection
Containment
Density
Color Saturation
Shape
Length
Angle
Slope
Area
Volume

Problem:

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

Let's evaluate...



Better!

Let's evaluate...

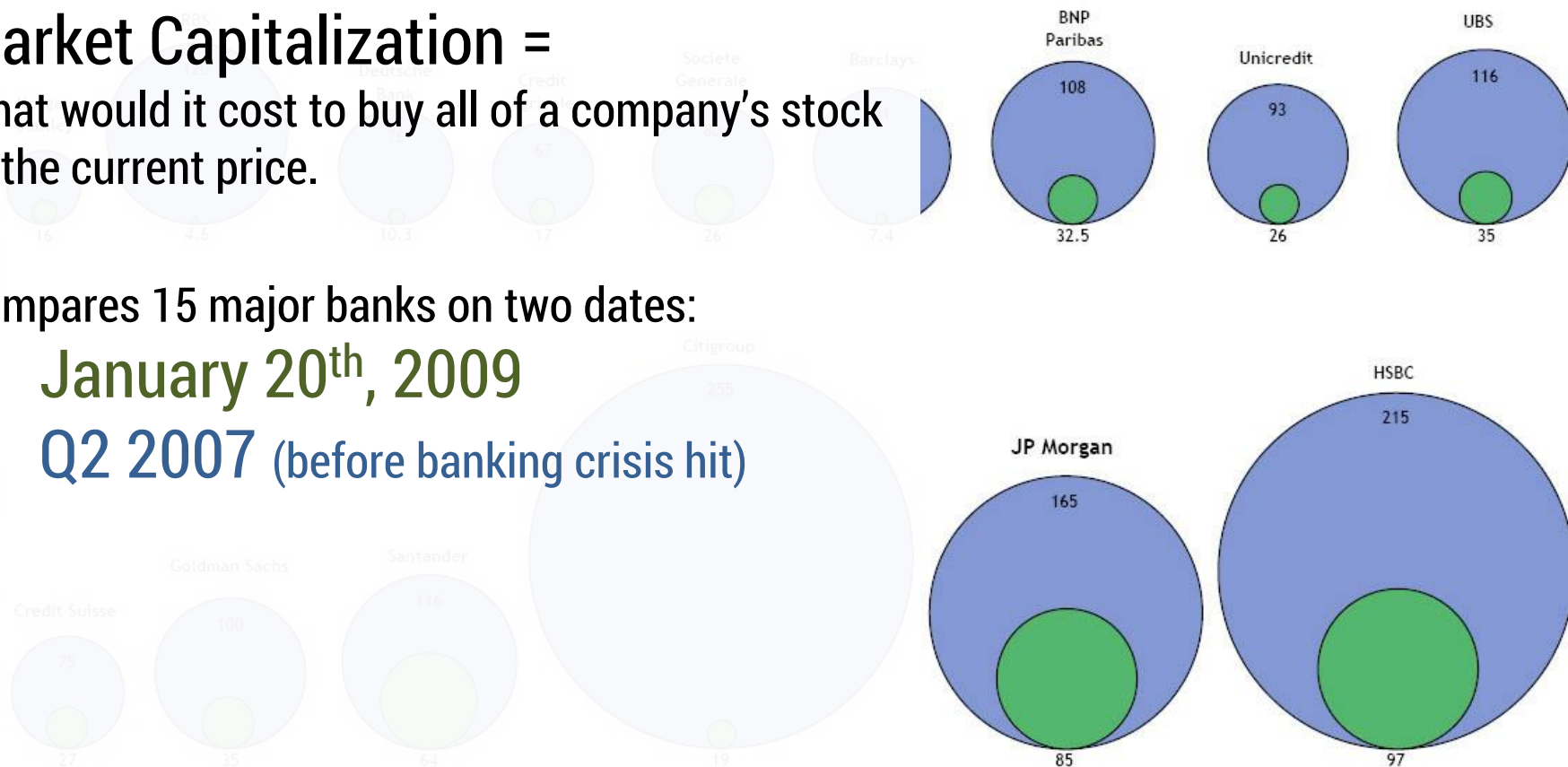
Banks: Market Cap

- Market Value as of January 20th 2009, \$Bn
- Market Value as of Q2 2007, \$Bn

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:

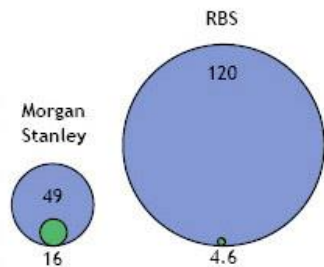
- **January 20th, 2009**
- **Q2 2007** (before banking crisis hit)



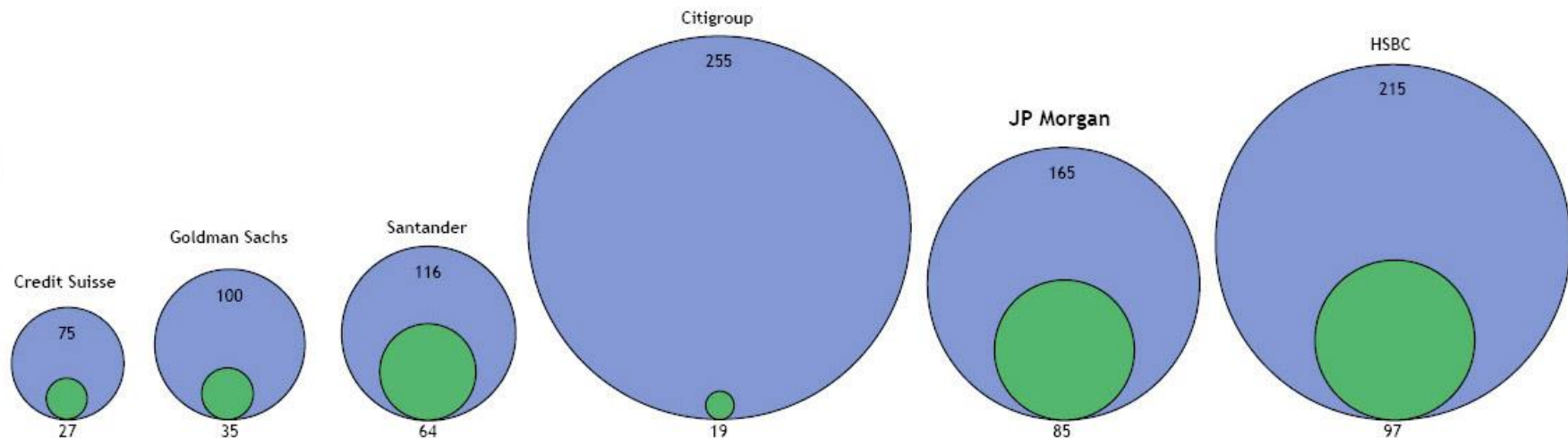
Problems here?

Banks: Market Cap

- Market Value as of January 20th 2009, \$Bn
- Market Value as of Q2 2007, \$Bn



We are not good at comparing areas.
(And the areas here are actually misleading!)

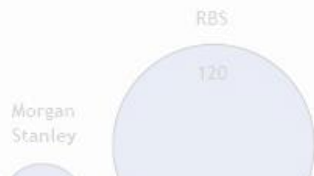


J.P.Morgan

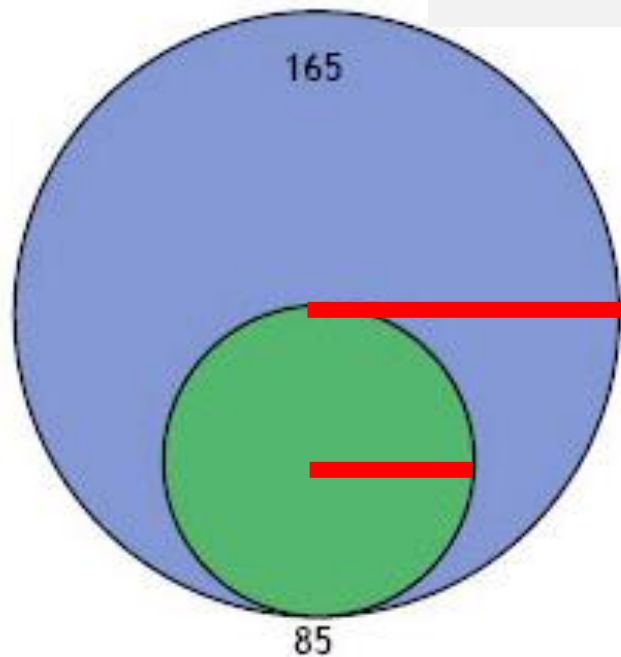
Problems here?

Banks: Market Cap

- Market Value as of January 20th 2009, \$Bn
- Market Value as of Q2 2007, \$Bn



JP Morgan

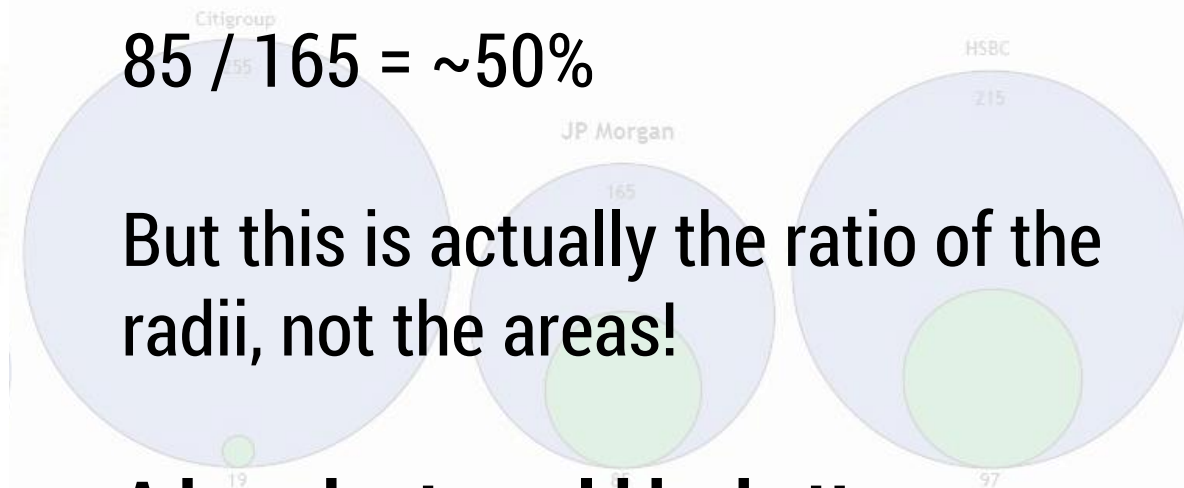


We are not good at comparing areas.
(And the areas here are actually misleading!)

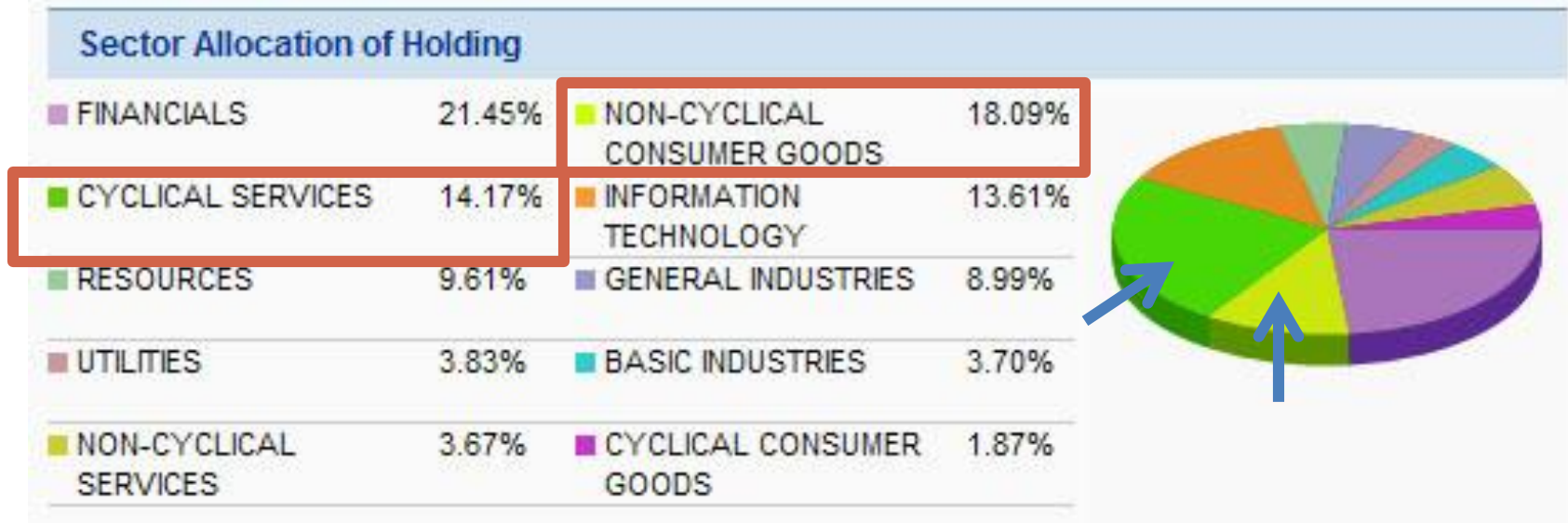
$$85 / 165 = \sim 50\%$$

But this is actually the ratio of the radii, not the areas!

A bar chart would be better.

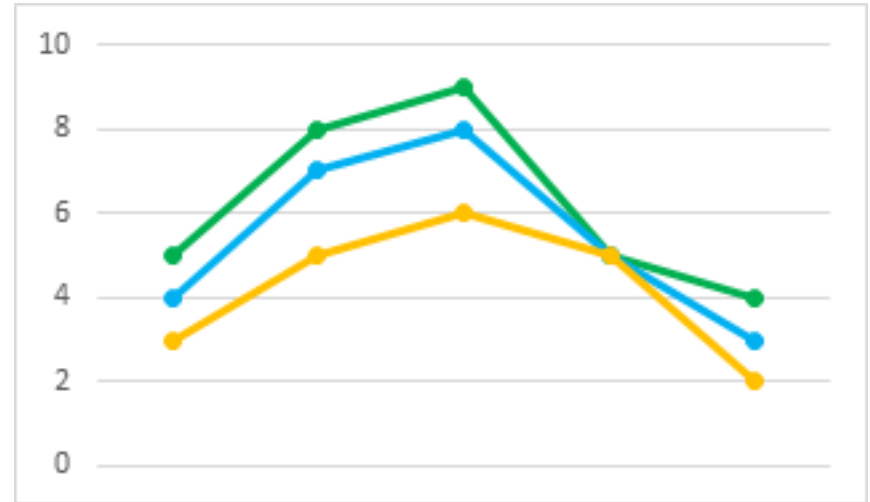
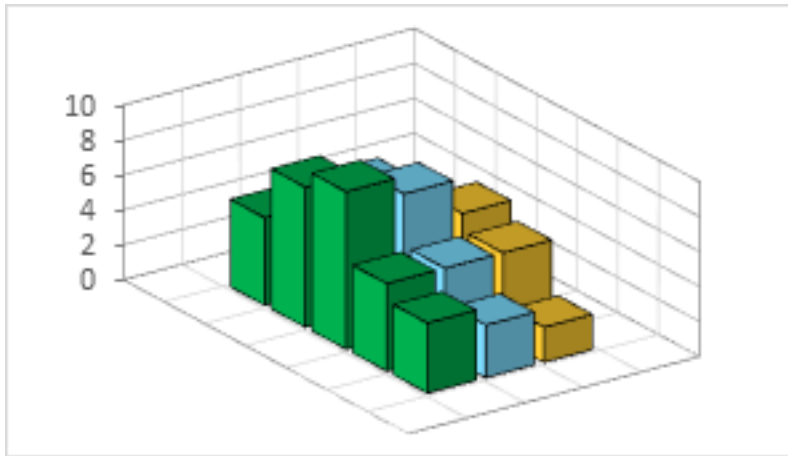


Problem here?

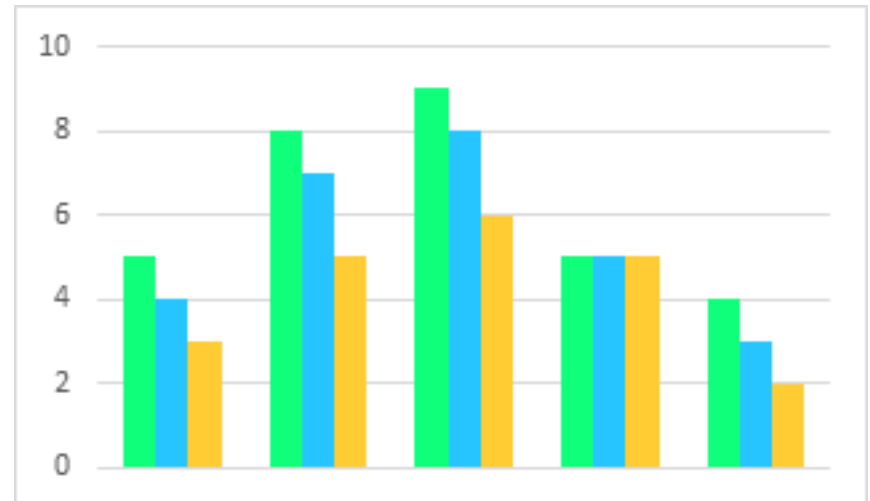


- There is likely a **bug or error** in the data
- Pie slices are difficult to compare by **area** or by **angle**
- **Similar colors** are difficult to distinguish
- **Perspective distortion** adds to the problem

Similarly...3D bar charts are not recommended



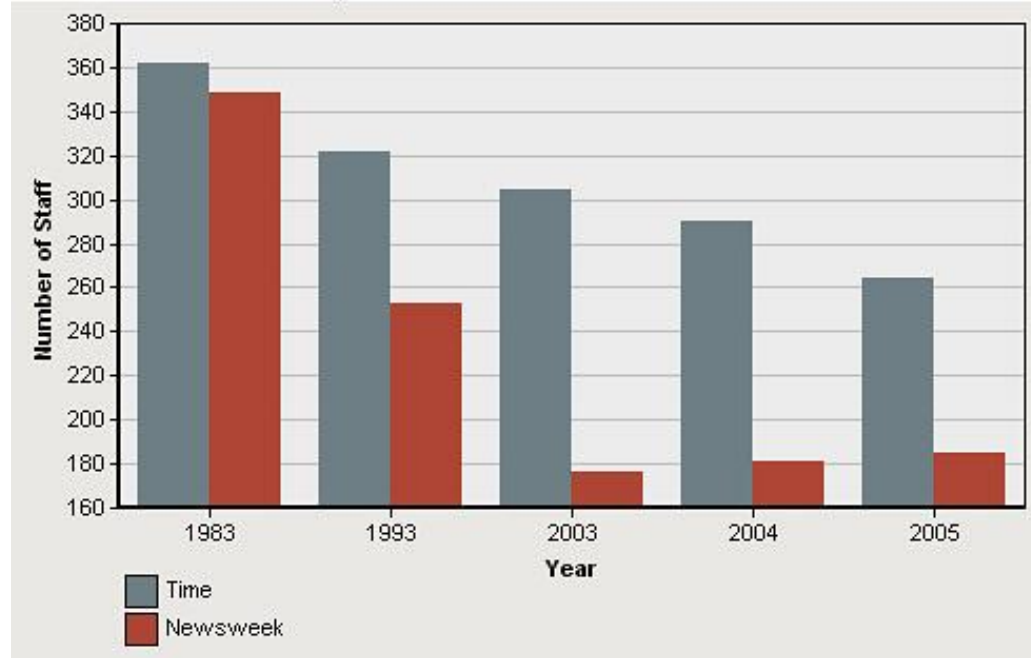
These are **much easier** to read & compare!



Problem here?

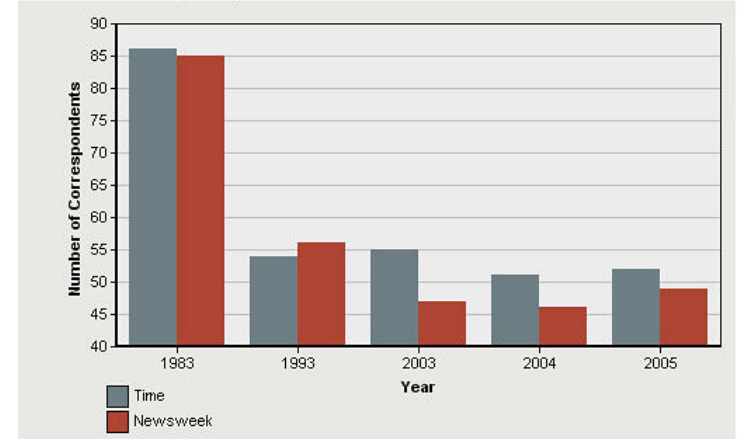
NEWS MAGAZINE STAFF SIZE OVER TIME

Time and Newsweek select years 1983 - 2005



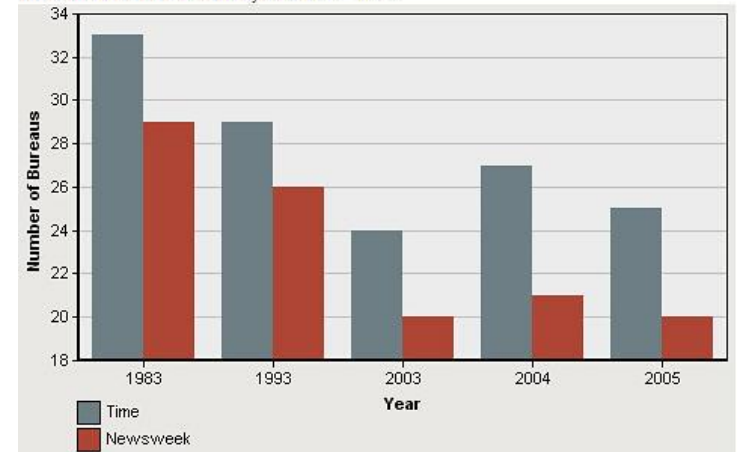
NUMBER OF CORRESPONDENTS IN BUREAUS OVER TIME

Time and Newsweek, select years 1983 - 2005

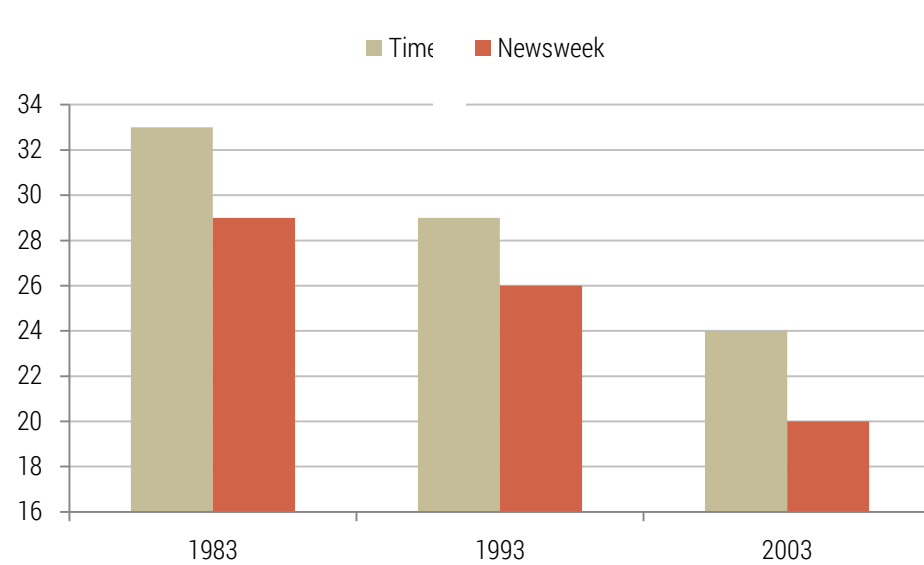


NEWS MAGAZINE BUREAUS OVER TIME

Time and Newsweek select years 1983 - 2005

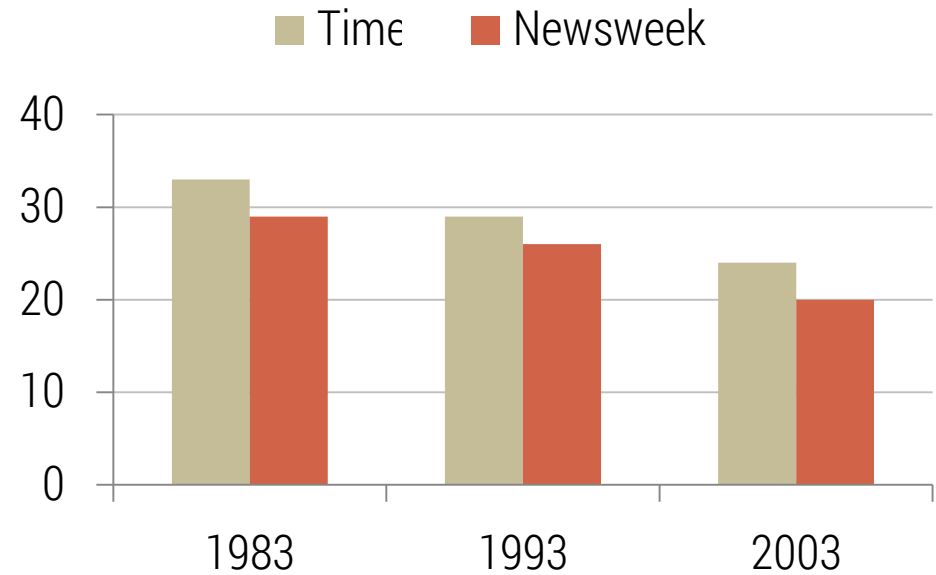


Length Comparison



At first glance:

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



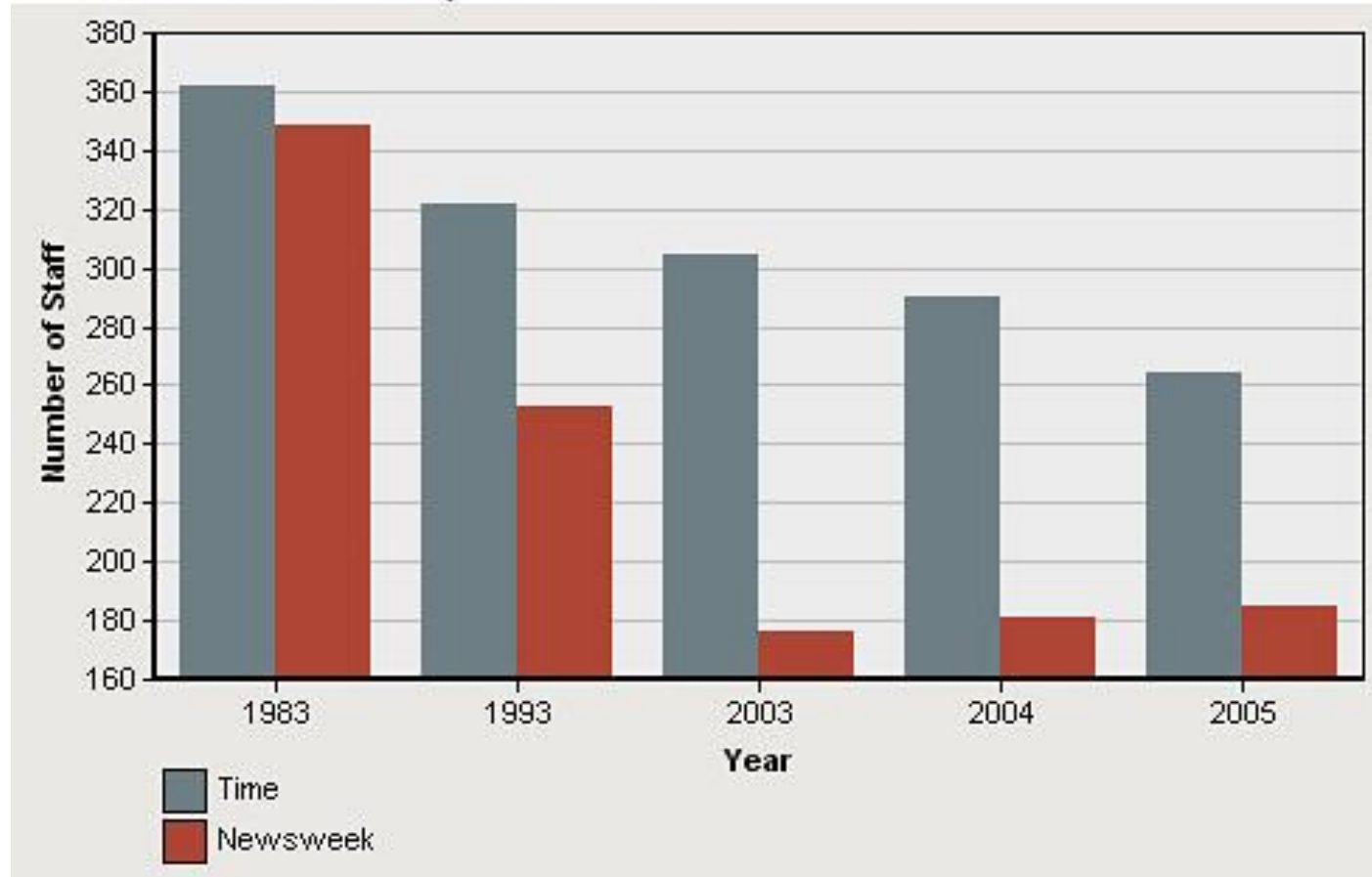
If we add a proper baseline at 0:

- 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

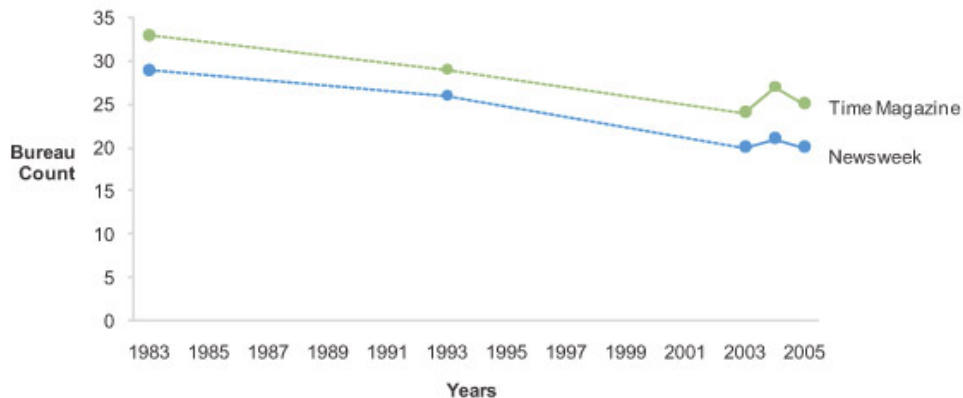
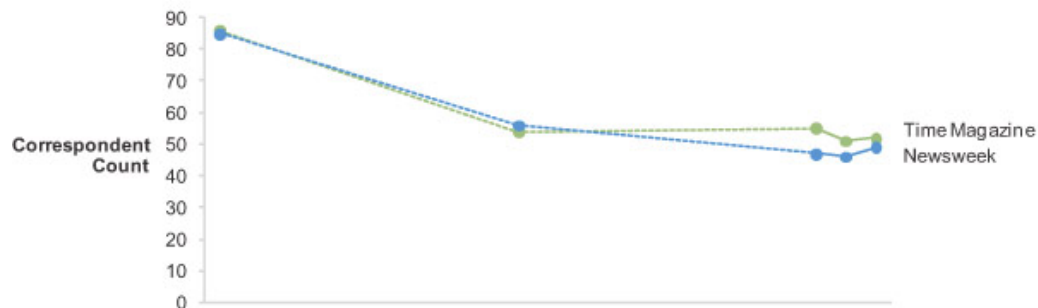
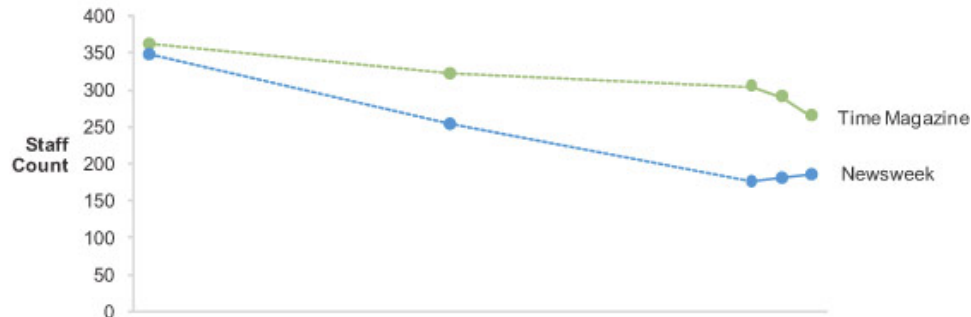


10 years each

1 year each

Redesign (by Stephen Few)

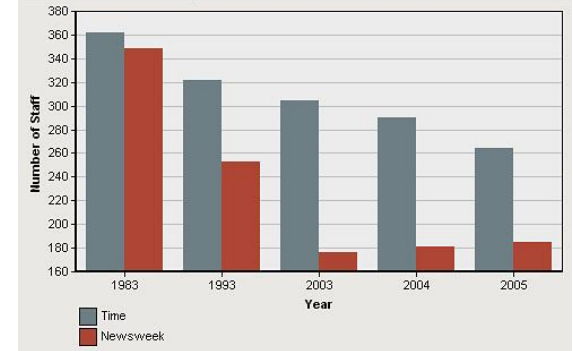
Time Magazine's vs. Newsweek Magazine's Size Over Time



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.

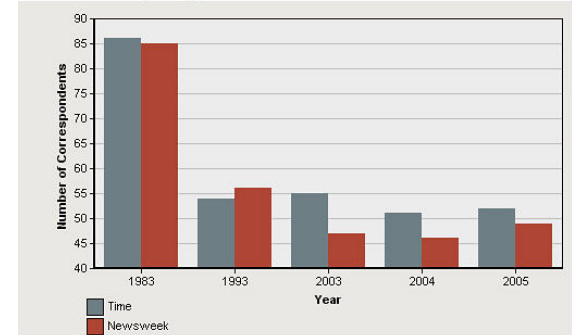
NEWS MAGAZINE STAFF SIZE OVER TIME

Time and Newsweek select years 1983 - 2005



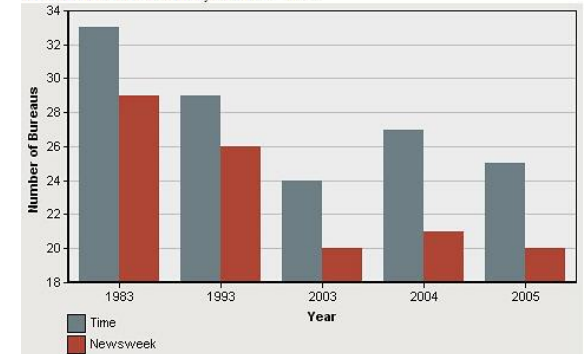
NUMBER OF CORRESPONDENTS IN BUREAUS OVER TIME

Time and Newsweek, select years 1983 - 2005

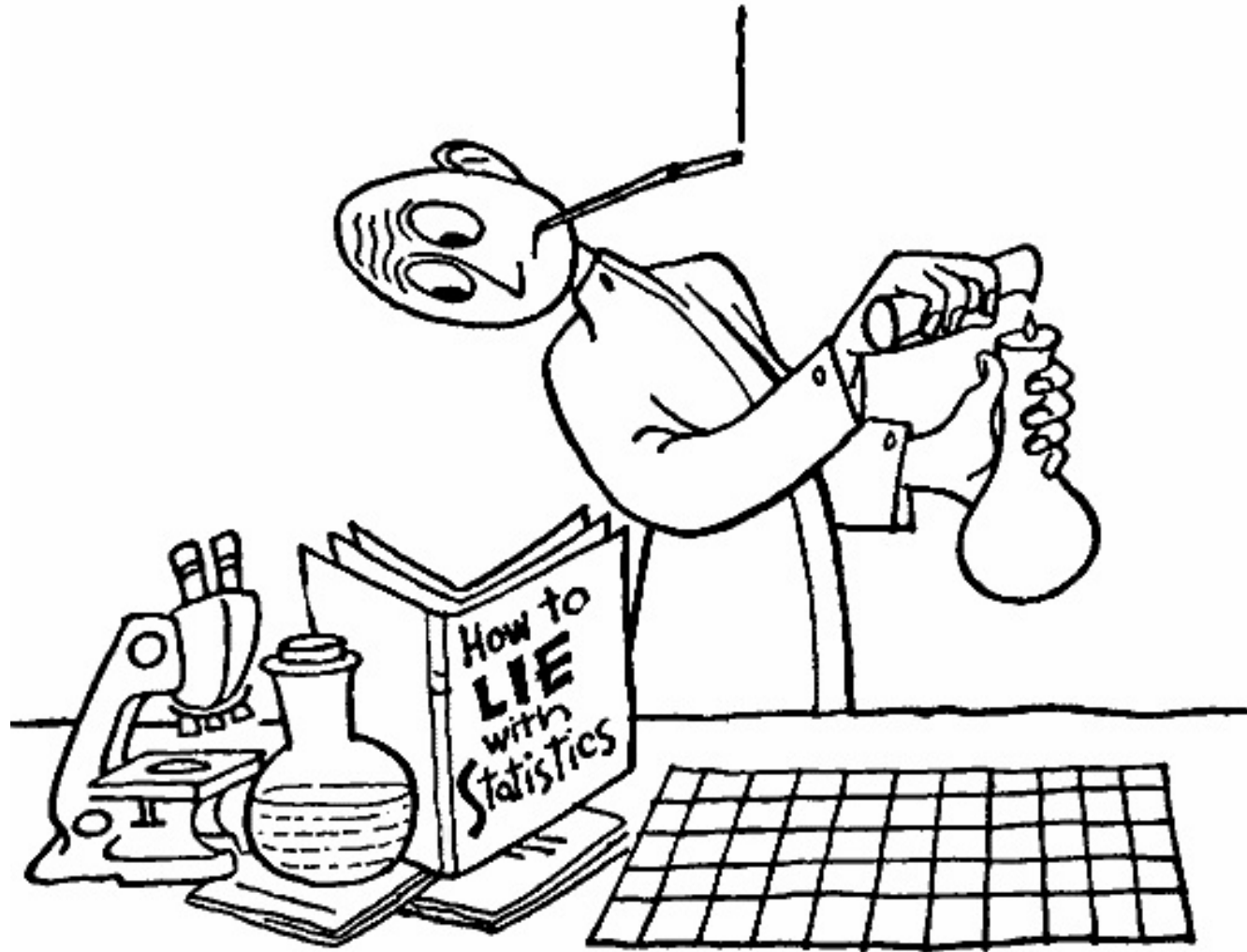


NEWS MAGAZINE BUREAUS OVER TIME

Time and Newsweek select years 1983 - 2005



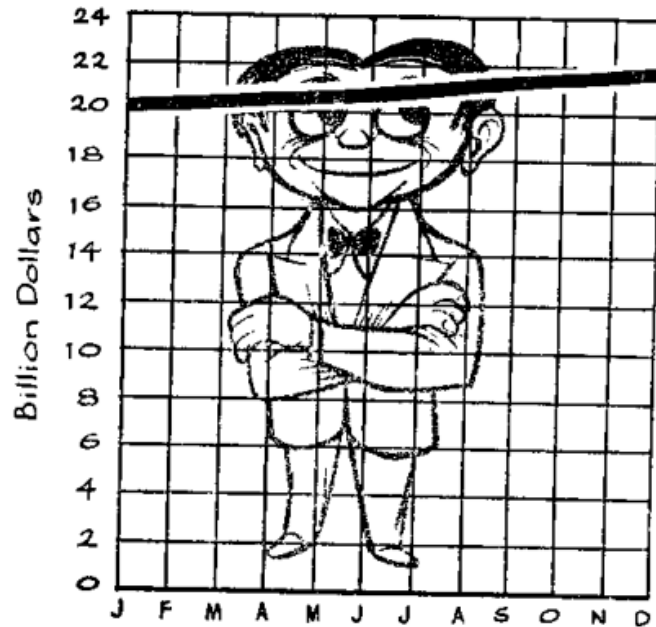
A few more (classic) guidelines!



Good reference: *How to Lie with Statistics*, by Darrell Huff (1954)

Chart Rules

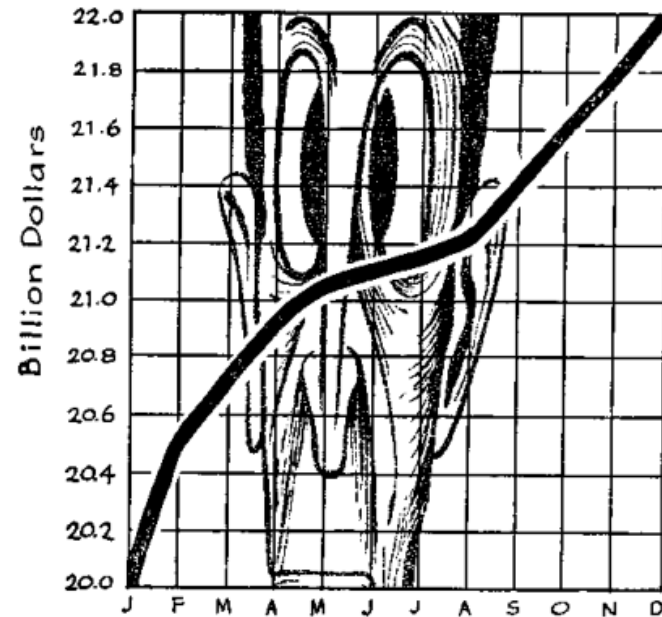
- Provide a proper baseline



A 10% increase. Good!



Already looks more impressive



Wow!

Chart Rules

- Provide a **proper baseline & label your axes**

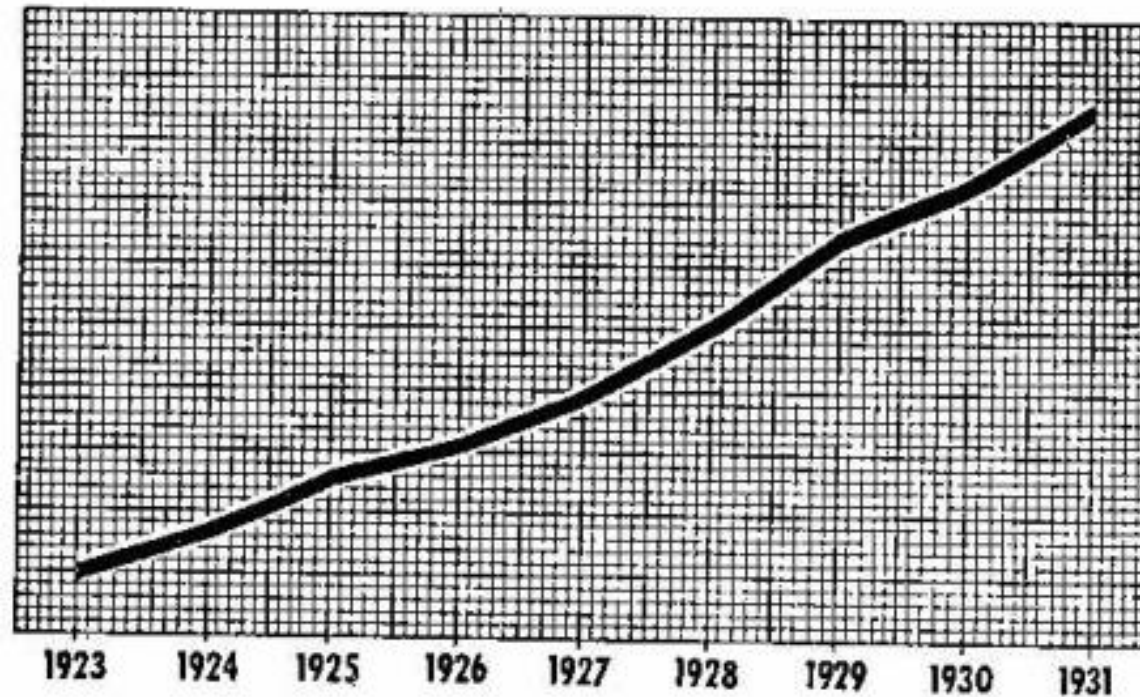
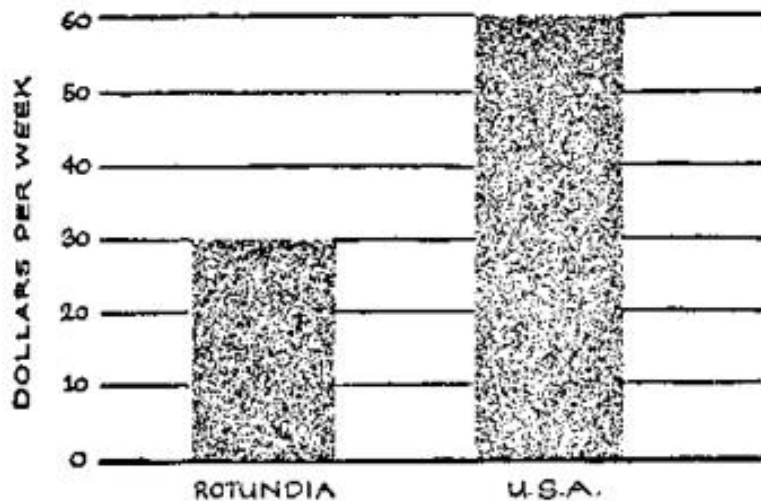


Chart Rules

- Provide a **proper baseline & label your axes**
- Avoid **eye-candy**



Actual data



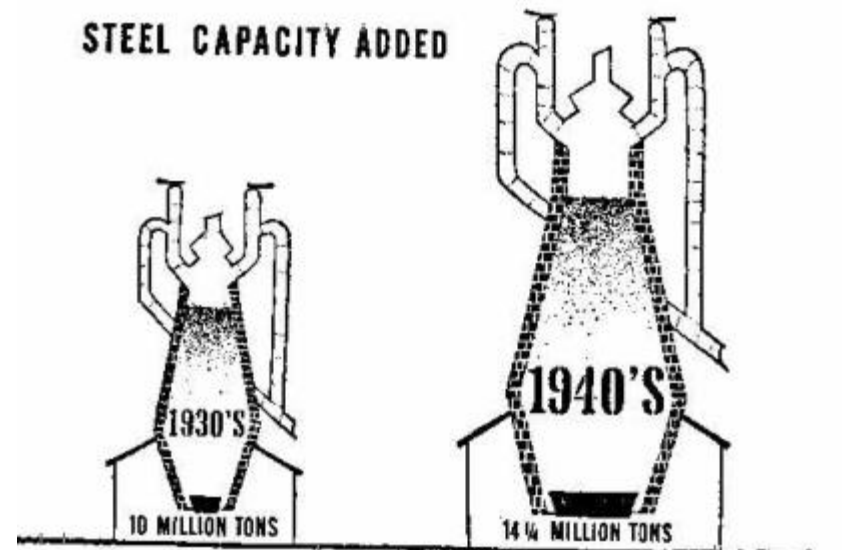
The same data with eye-candy & no numbers ... but at least it tells the same general story.



Impressive, but a lie!

Chart Rules

- Provide a **proper baseline & label your axes**
- Avoid **eye-candy**
- Avoid **area comparisons** whenever possible



Adapted by courtesy of STEELWAYS.

Chart Rules

- Provide a **proper baseline & label your axes**
- Avoid **eye-candy**
- Avoid **area comparisons** whenever possible
- Provide **legends**

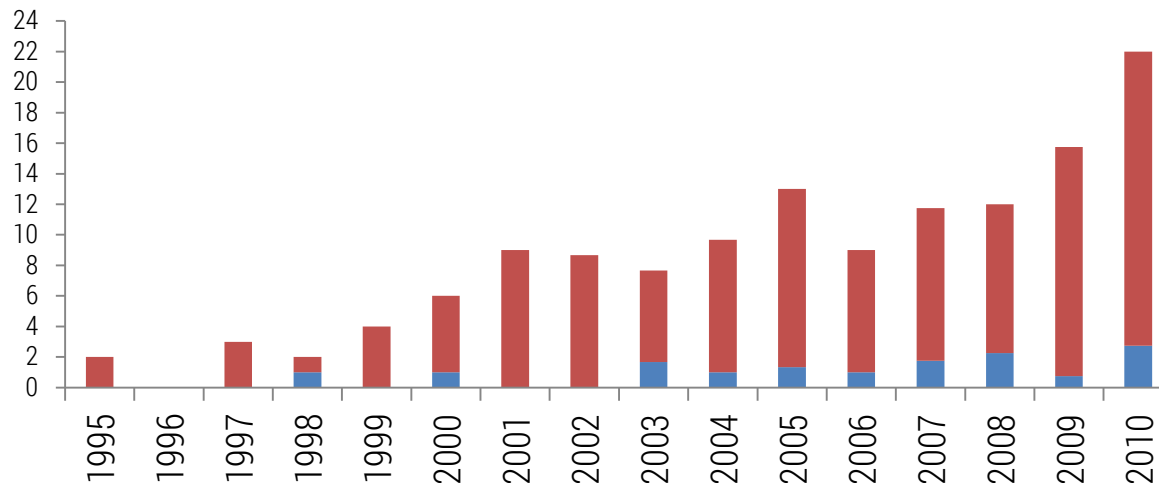
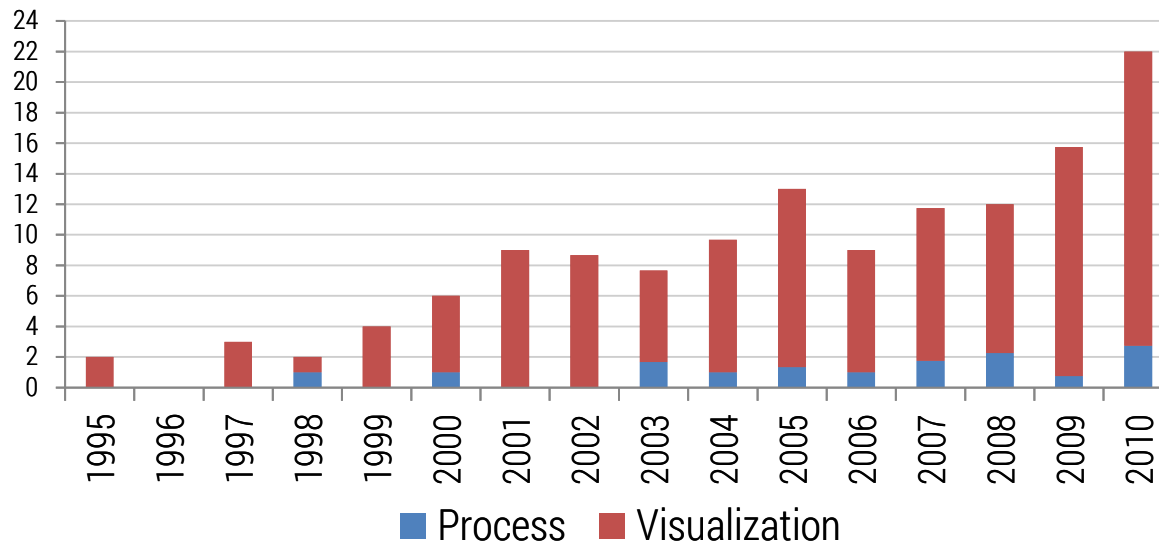
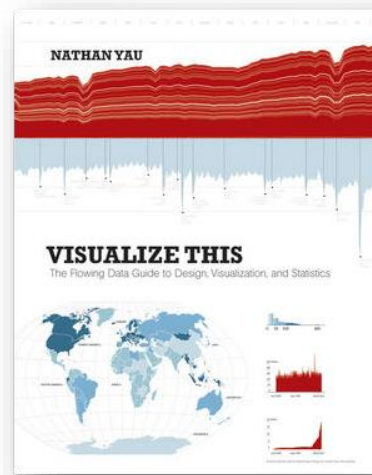
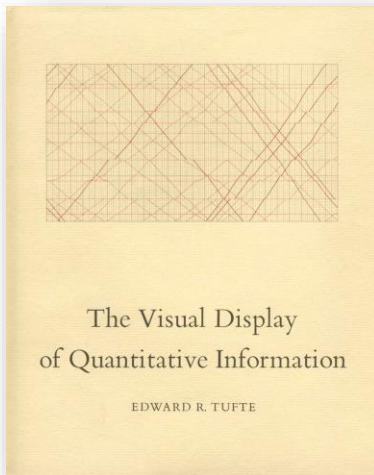
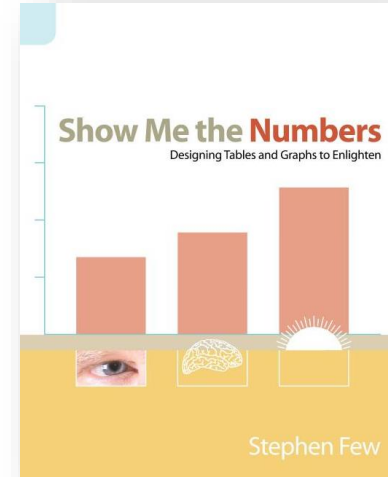
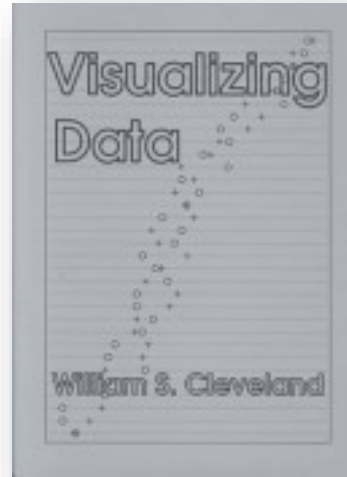
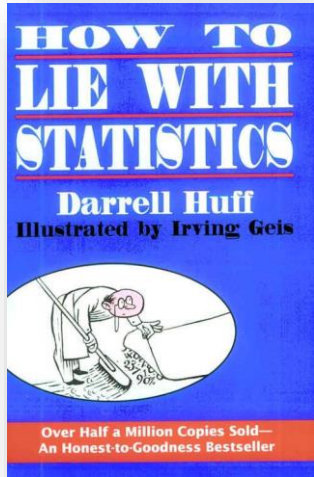


Chart Rules

- Provide a **proper baseline & label your axes**
- Avoid **eye-candy**
- Avoid **area comparisons** whenever possible
- Provide **legends**
- **Grids help** – but make them subtle
(about 20% opacity – no black lines)



Many more useful guidelines!



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**

Müller-Lyer Sinusoidal Waves

New variant by Gianni A. Sarcone

Though the **blue** and **red** segments seem to oscillate, they are always the **same length!** **Nothing moves except the arrows** at the endpoints of each color segment...

