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

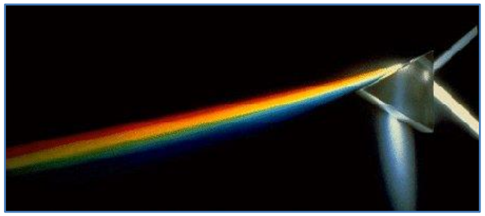
Color helps us to:

- Identify things
- Classify things

Through

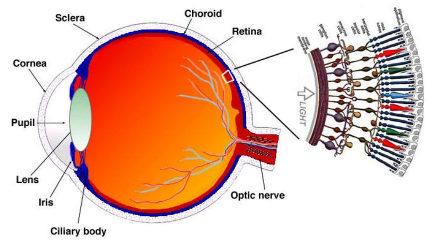
- Grouping
- Background segregation

How do we describe color?



Physical World

Lights, surfaces, objects



Visual System

Eye, optic nerve, visual cortex

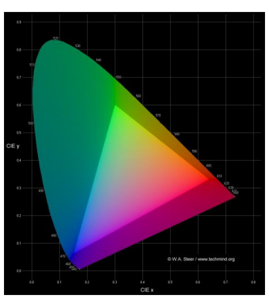
"Yellow"

Mental Models

Red, green, brown

Bright, light, dark, vivid, colorful, dull

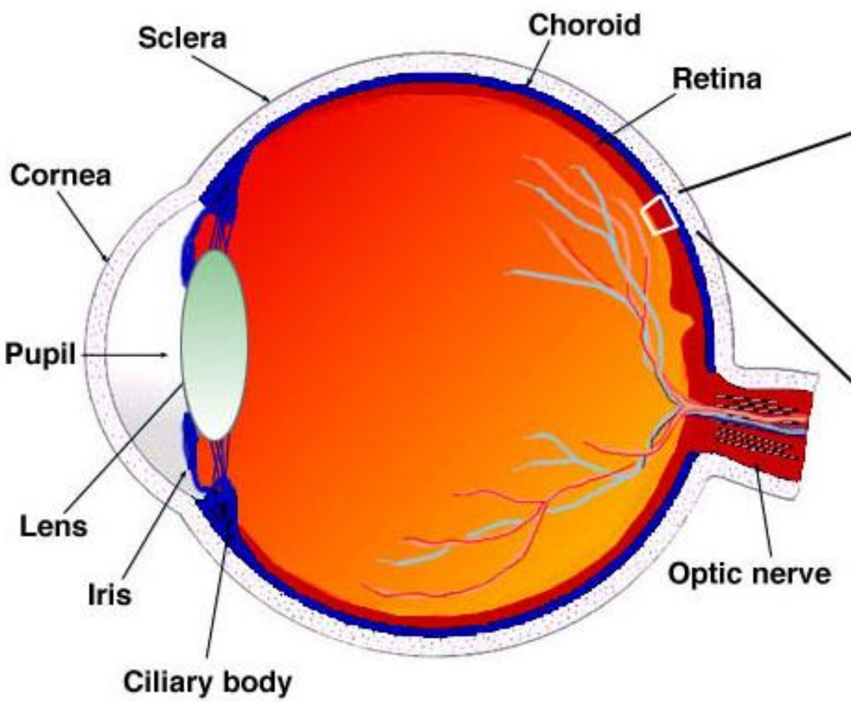
Warm, cool, bold, blah, attractive, ugly, pleasant, jarring



Color Models

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

Physical World→**Visual System**

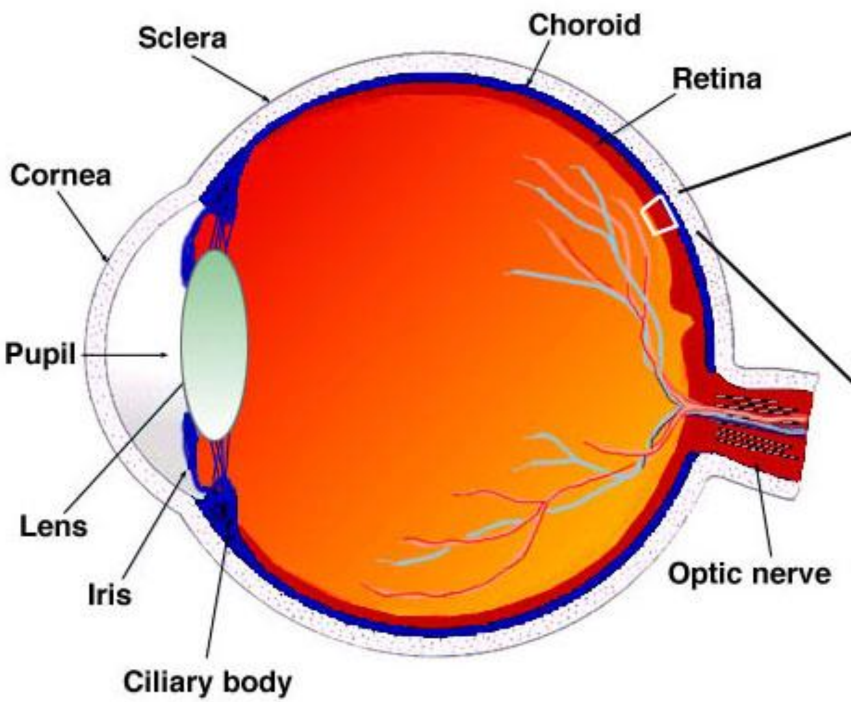


Retina is stimulated by three factors:

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

Simple Anatomy of the Retina, Helga Kolb

Physical World→**Visual System**



You **do not** see individual photons or light waves

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

Simple Anatomy of the Retina, Helga Kolb

Example: Lightness vs. Luminance

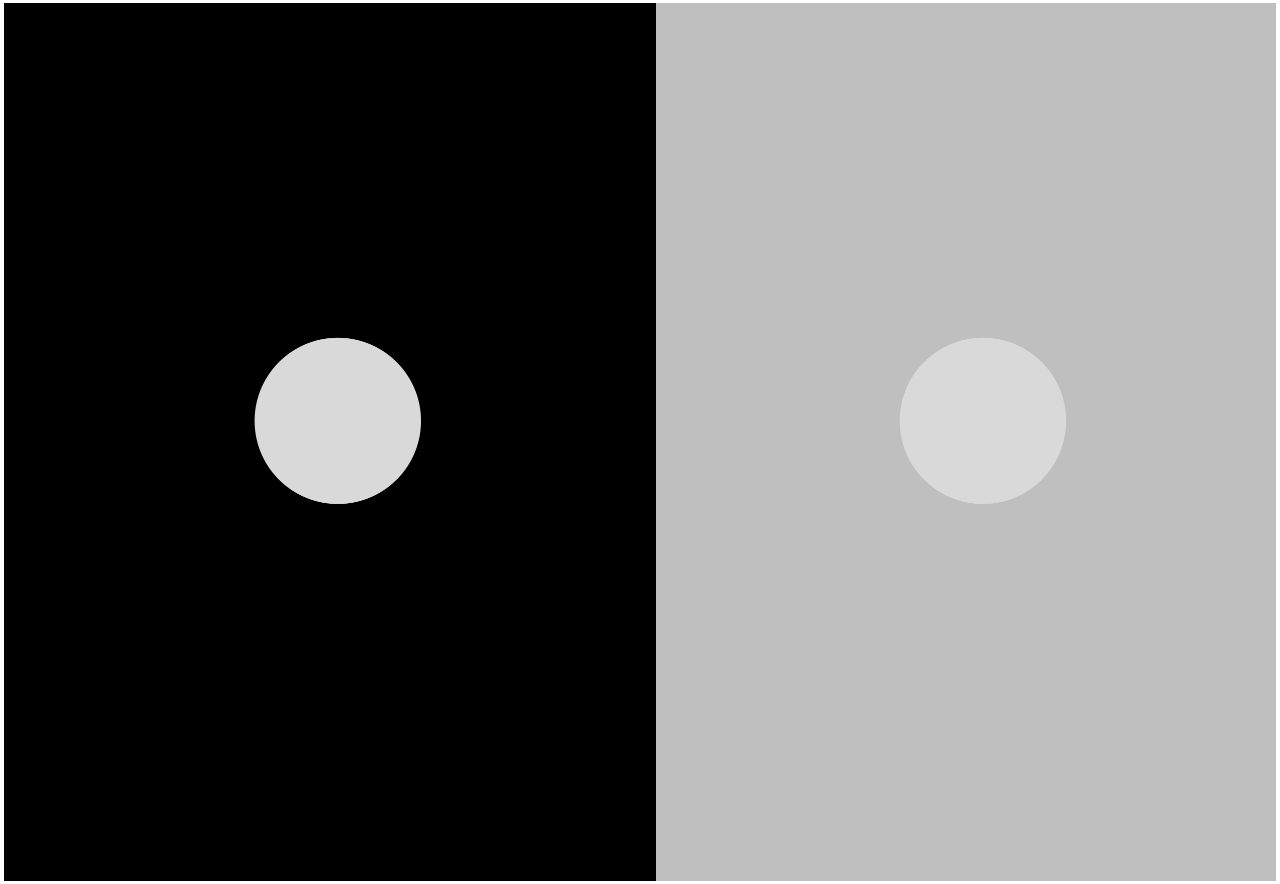
- LUMINANCE: an objective measurement of light intensity per unit area (e.g. cd/m2; physical)

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

Lightness experiment

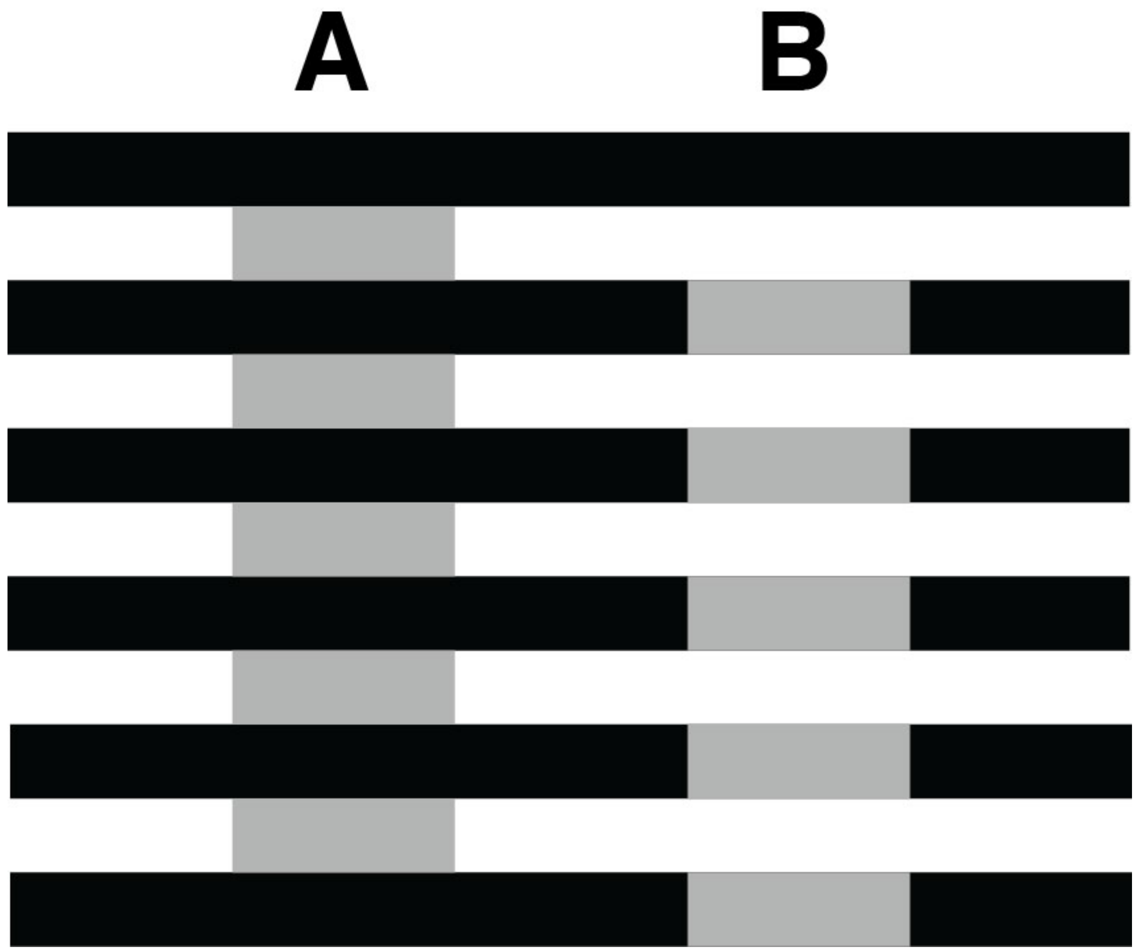
The two circles are physically the same

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?

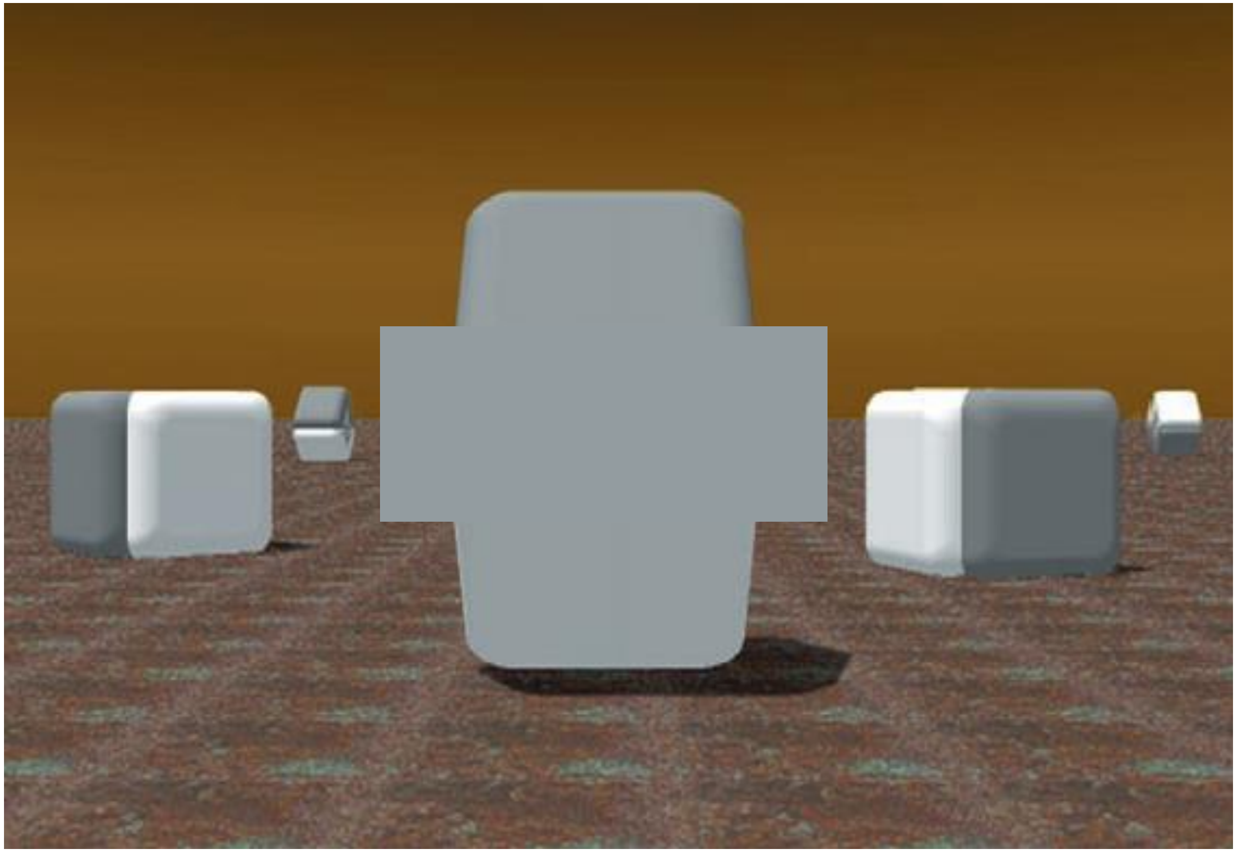
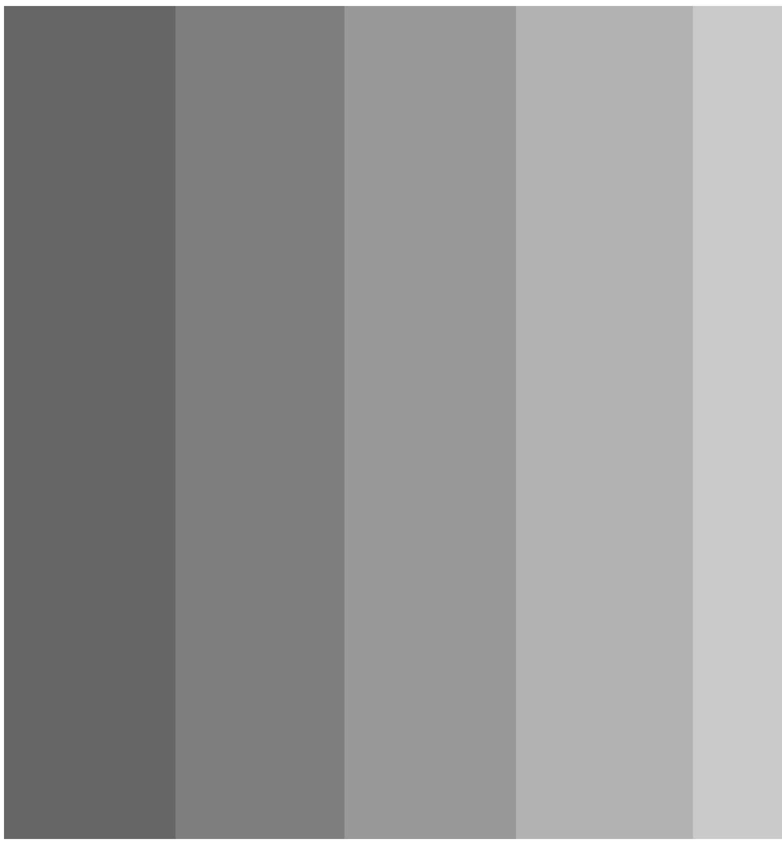
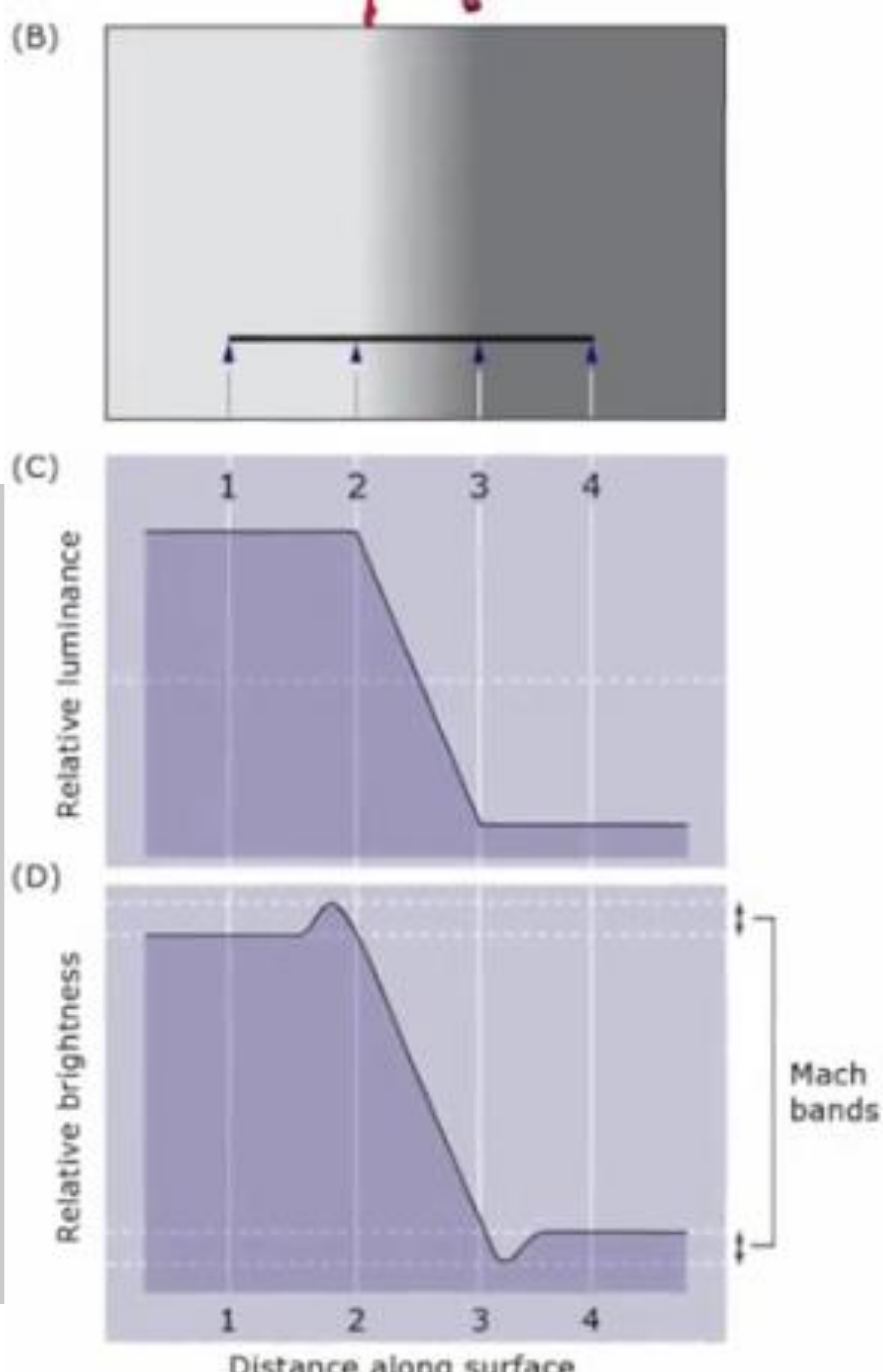


Image source: The Journal of Neuroscience, October 1, 1999, 19(19):8542–8551 An Empirical Explanation of the Cornsweet Effect.

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?

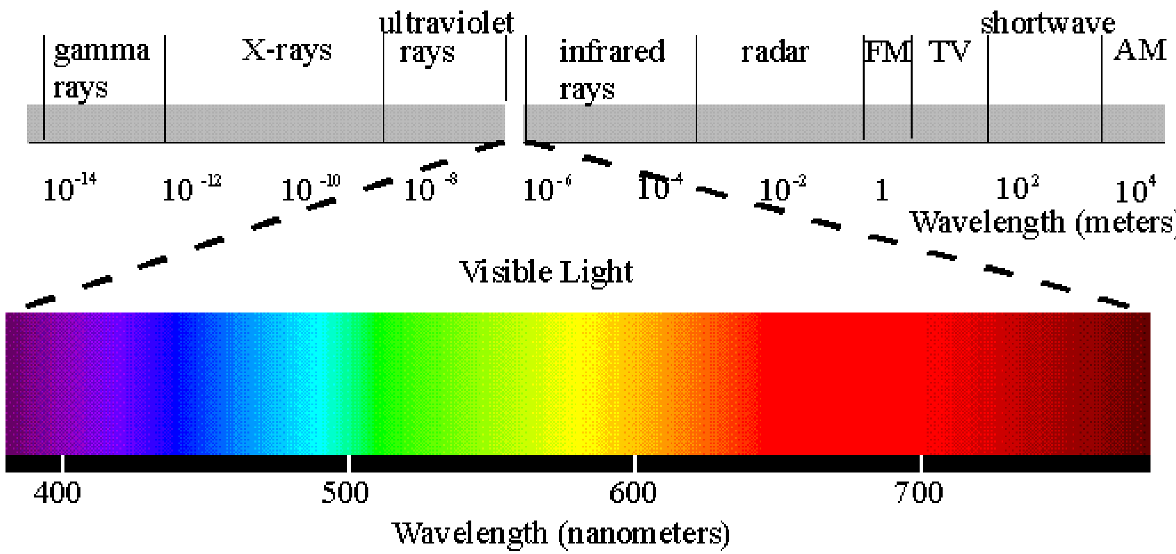
Some definitions

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

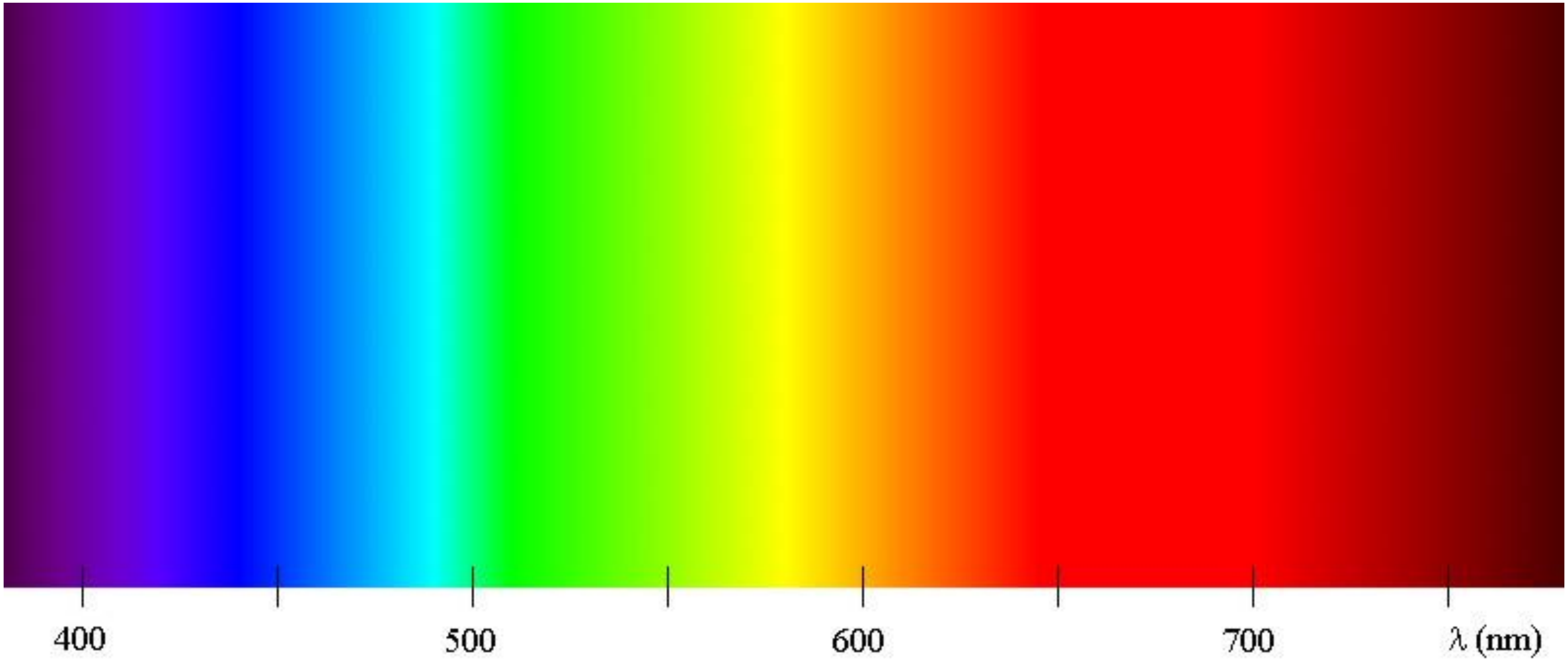
Physical World – The Nature of Light

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

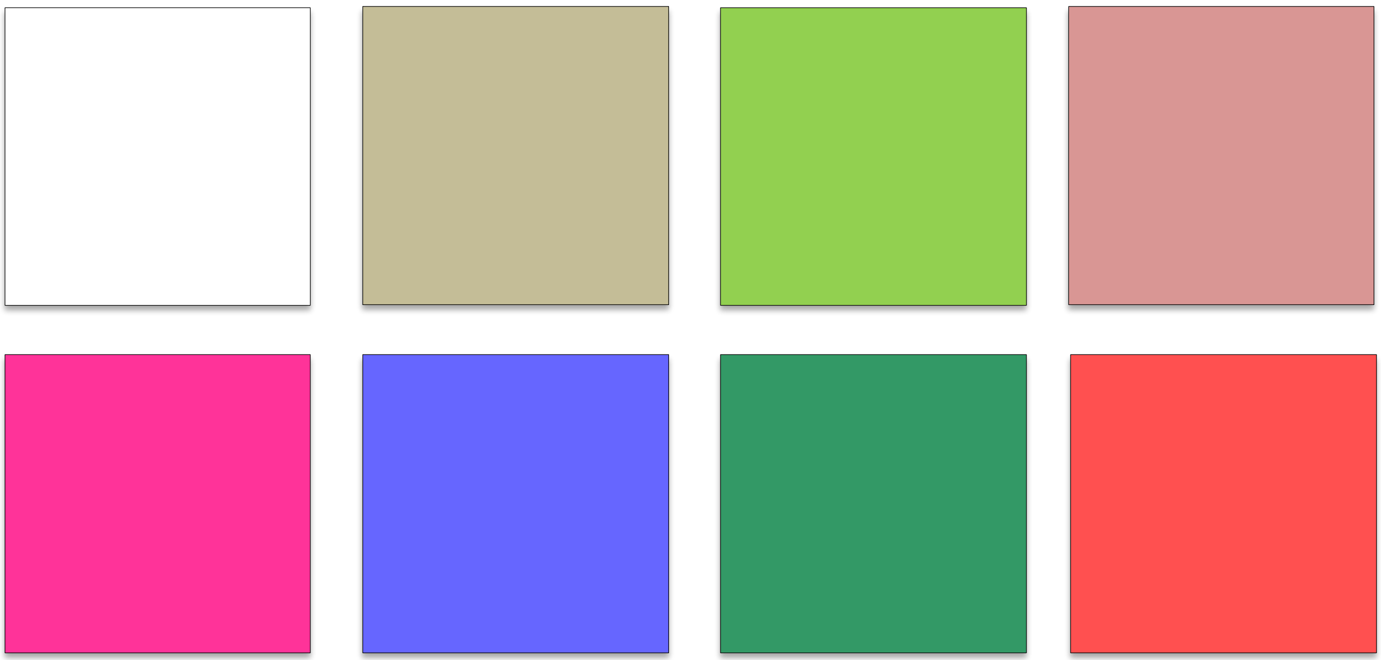


Light of a single wavelength is *monochromatic*

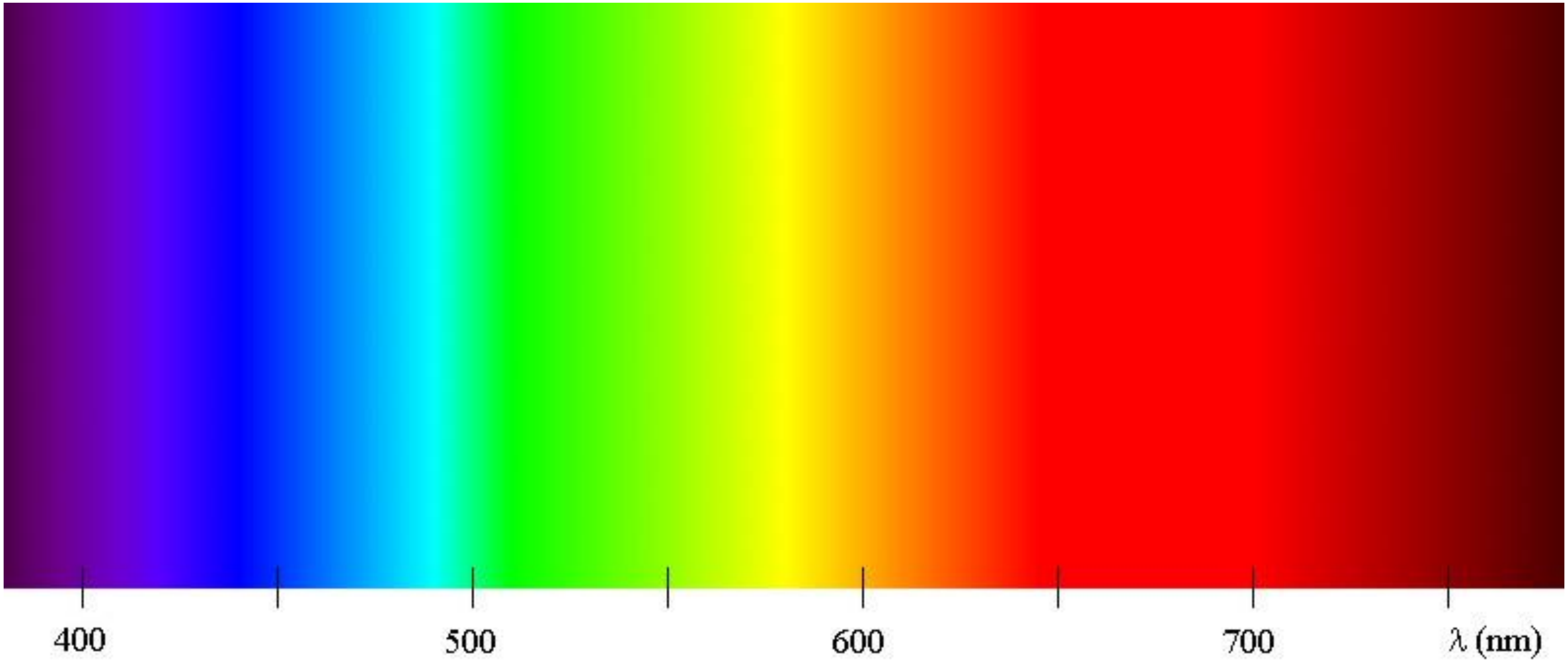
What do you notice?



http://www.science4all.org/article/colors/



Monochromatic colors

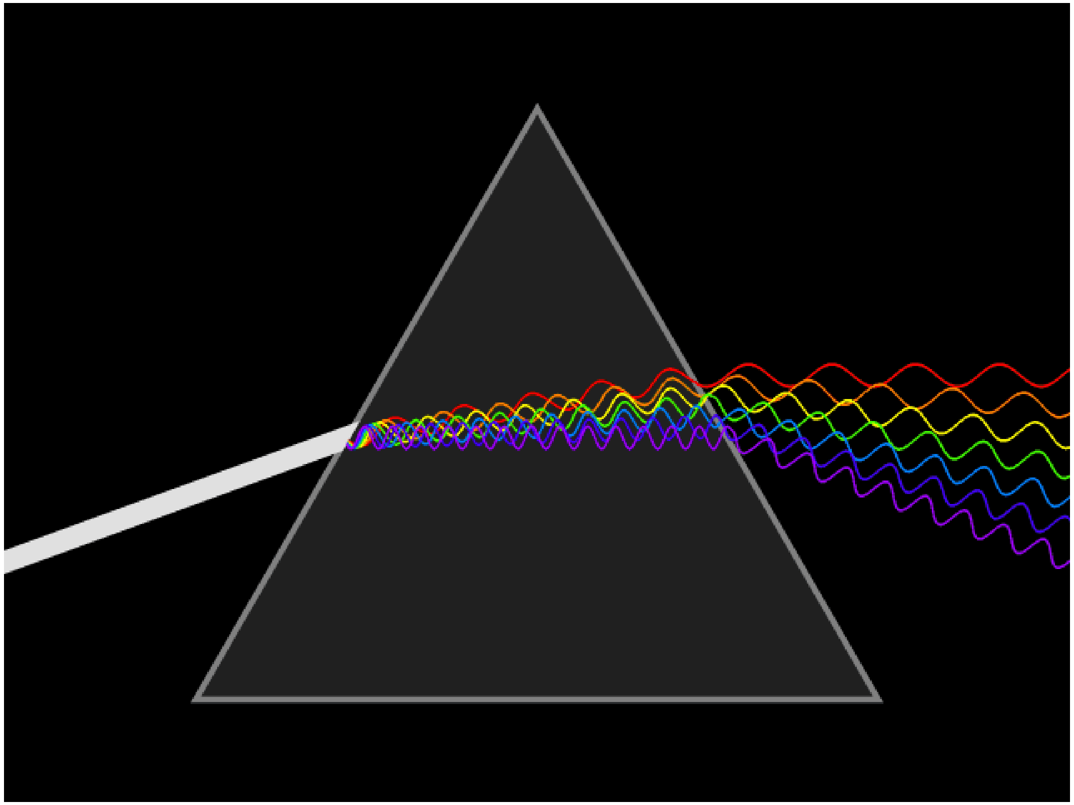


Can be obtained with one or more rays of light with a single wavelength

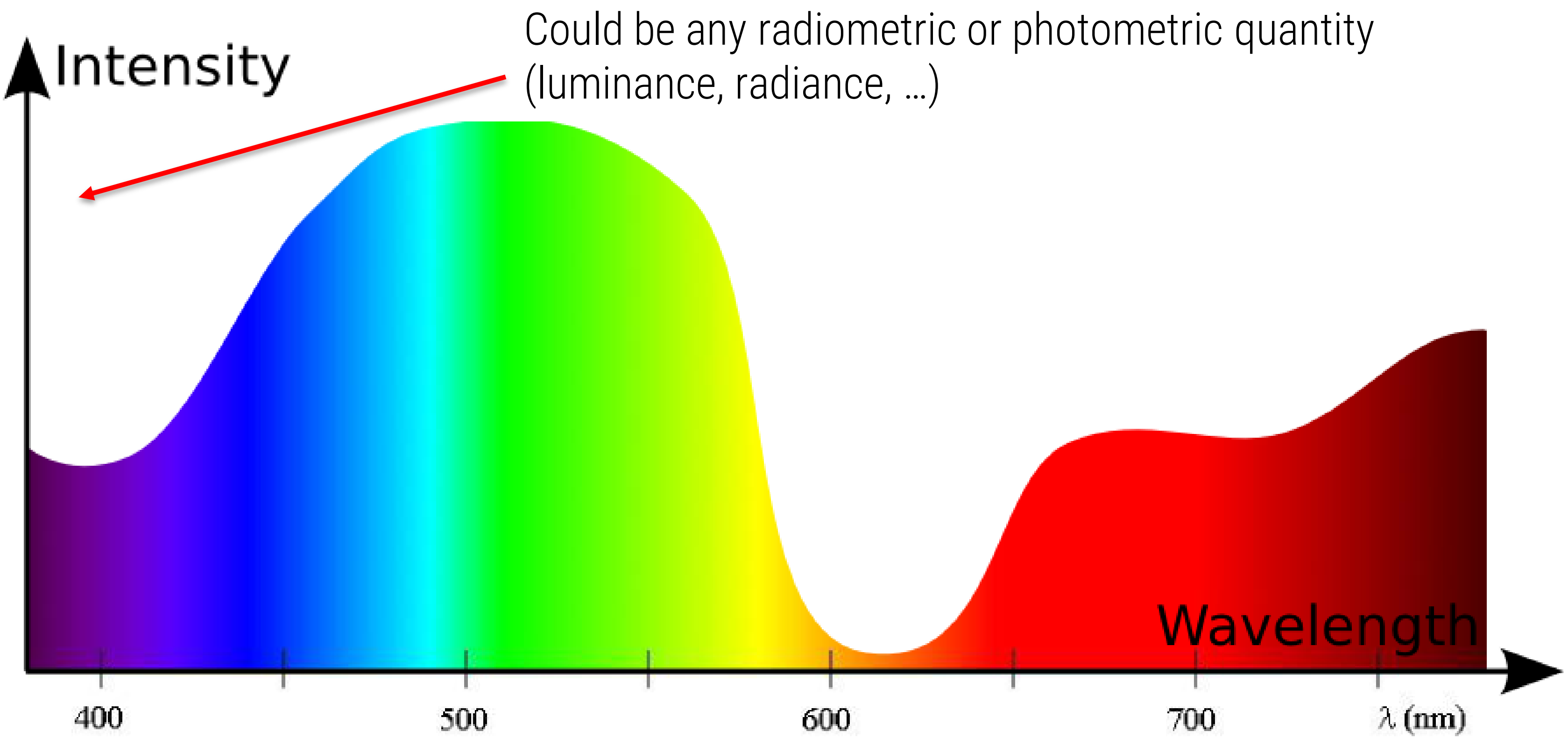
http://www.science4all.org/article/colors/

BUT…

Light rays are typically composed of multiple wavelengths



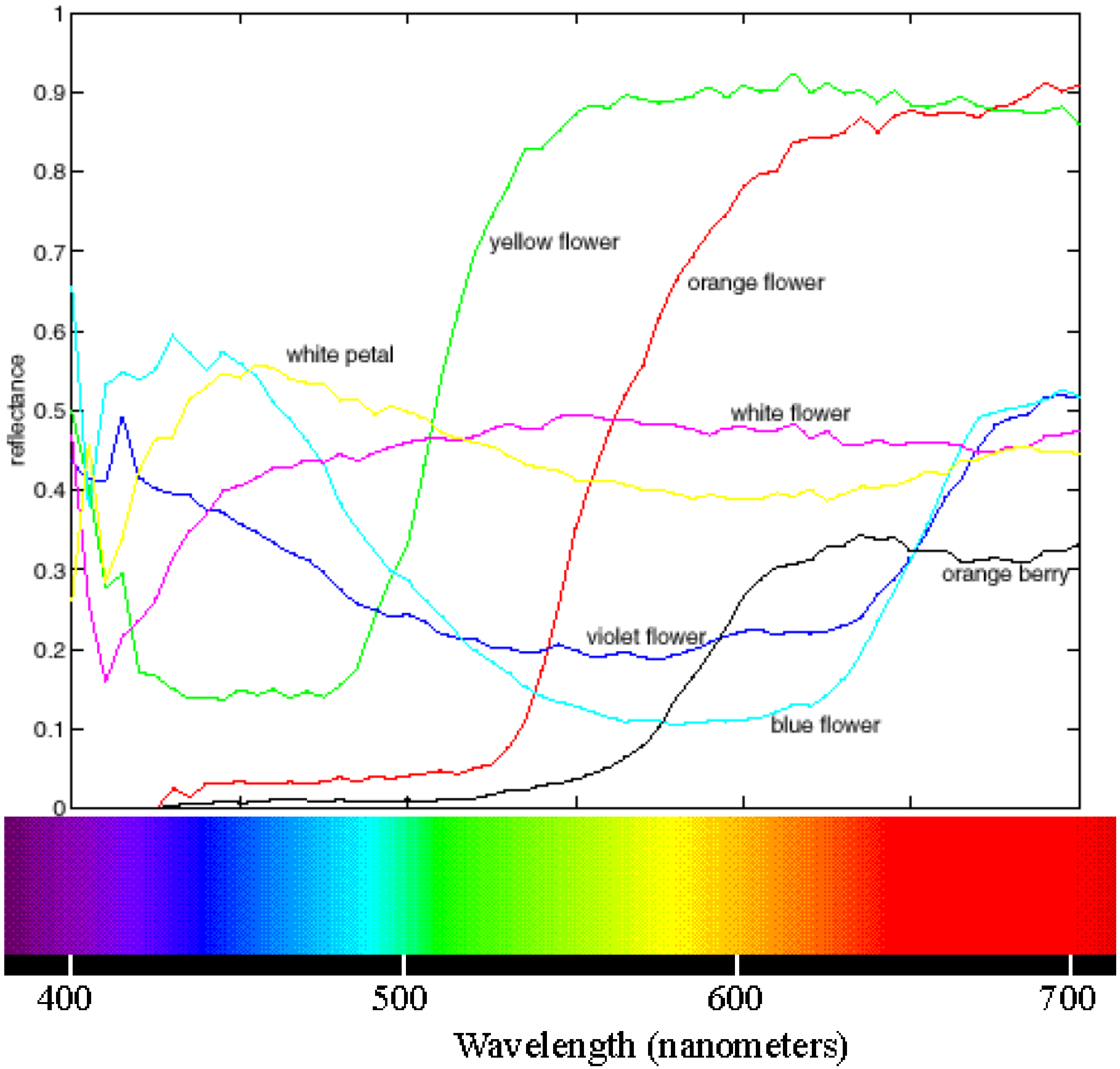
How do we describe a beam of light?



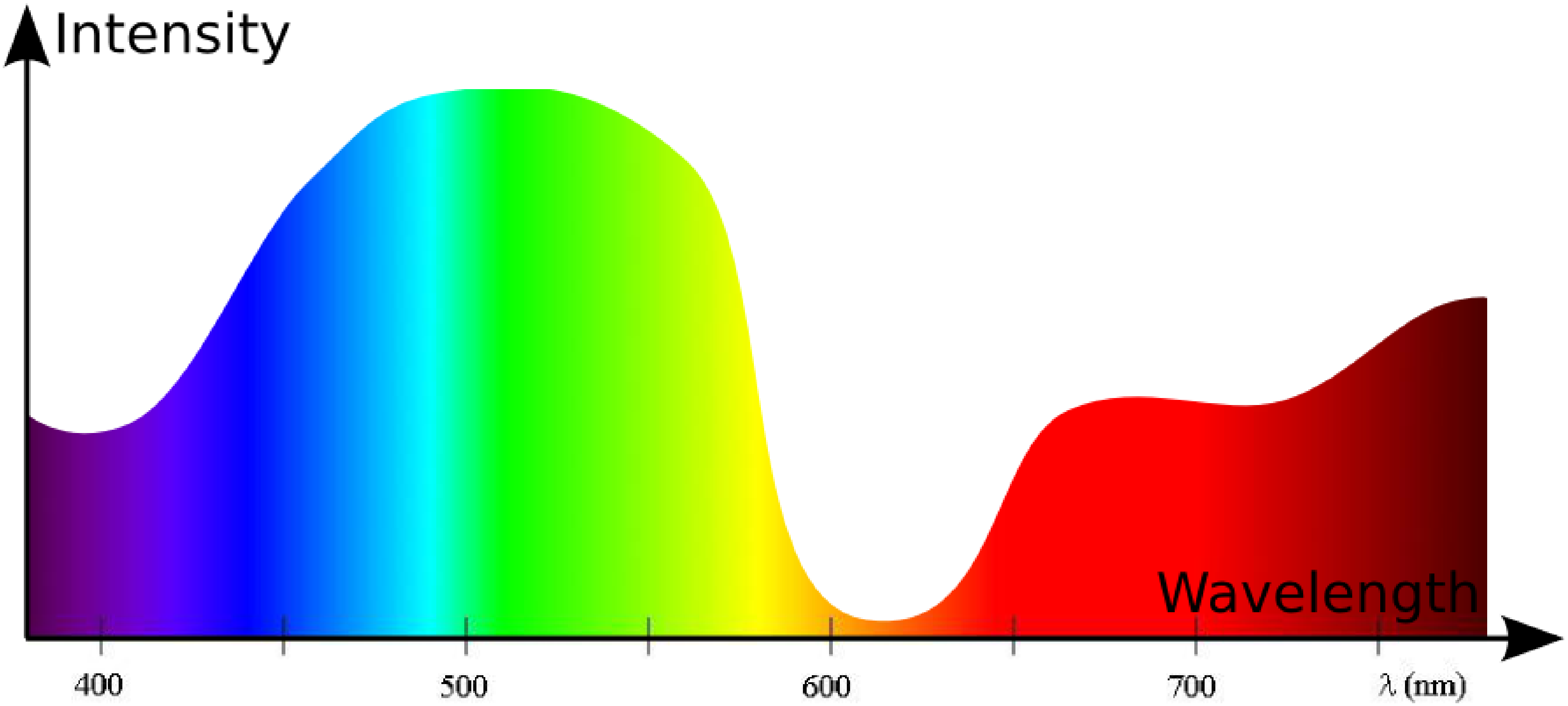
spectral power distribution (SPD)

http://www.science4all.org/article/colors/

Non-monochromatic color spectra



How do we know which color this would be?



http://www.science4all.org/article/colors/

Physically speaking

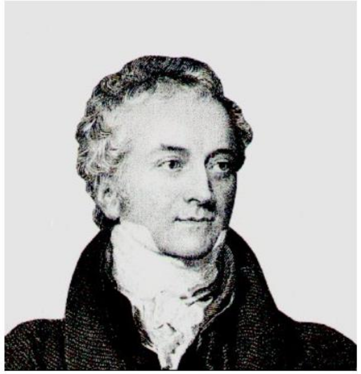
If you want to see different wavelengths at different energies across the spectrum

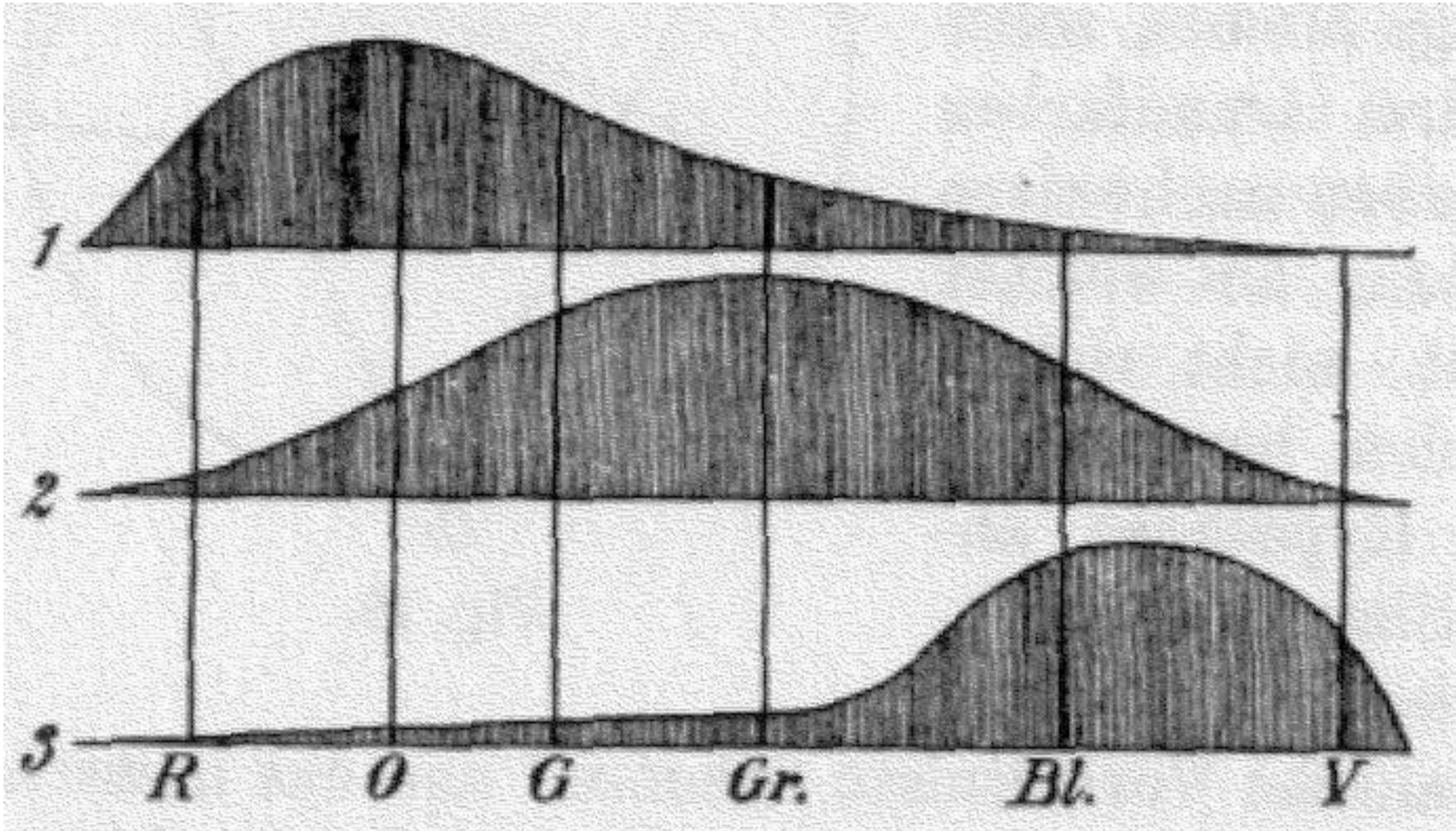
→ you need to have multiple photo receptors that can be compared

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.



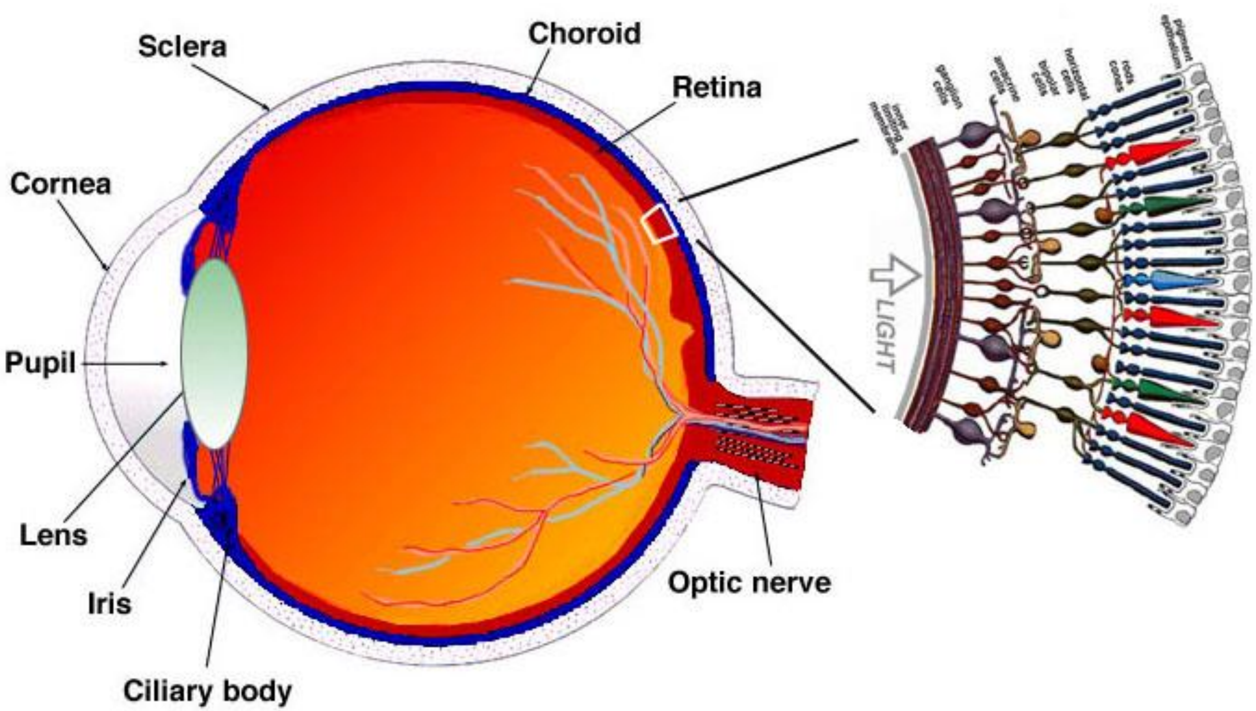


https://en.wikipedia.org/wiki/Young%E2%80%93Helmholtz_theory#/media/File:YoungHelm.jpg

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”

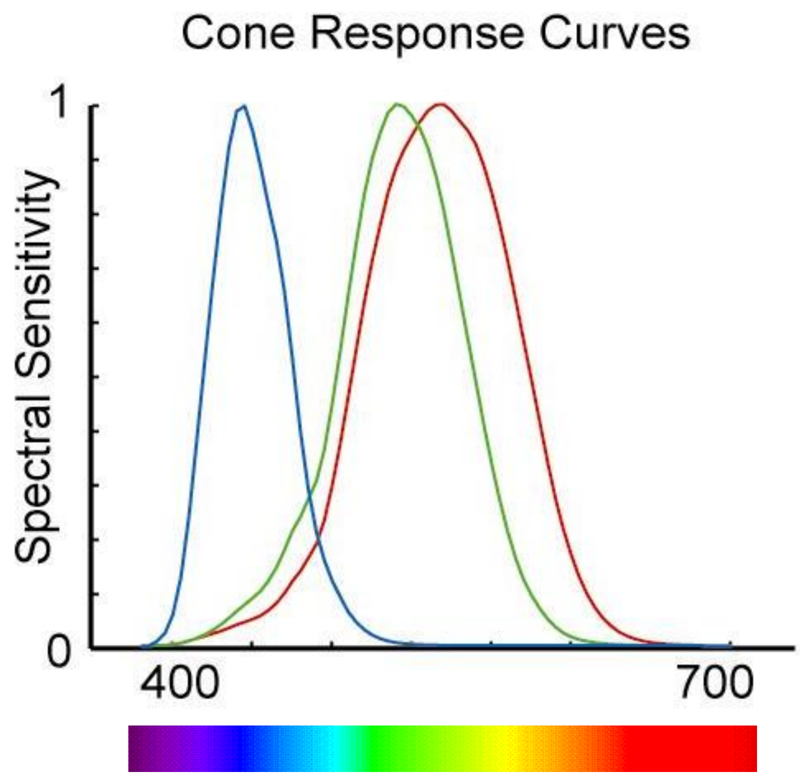
Mostly in the center

Less Sensitive

Simple Anatomy of the Retina, Helga Kolb

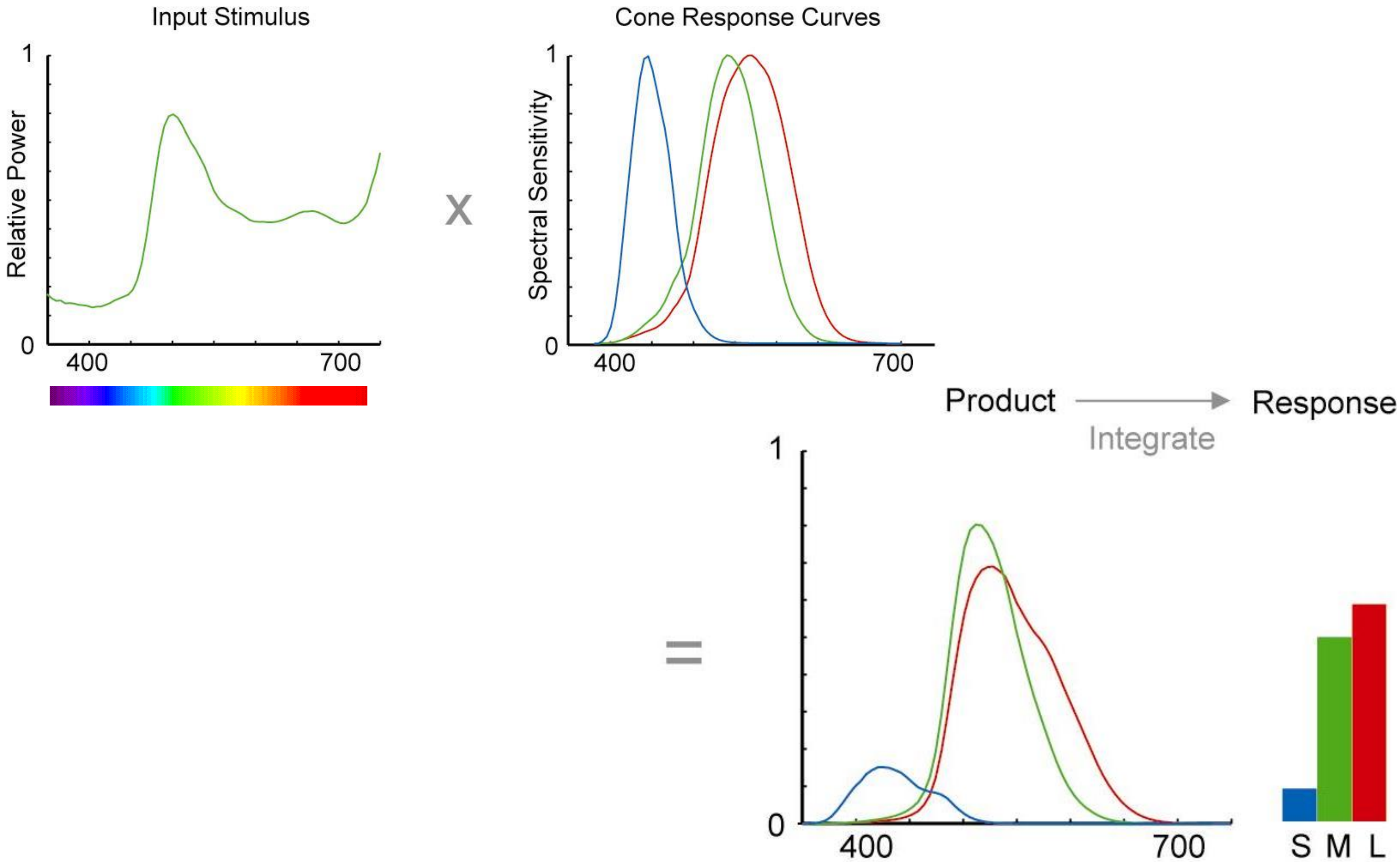
Cone response

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



A Field Guide to Digital Color, Maureen Stone

Cone response



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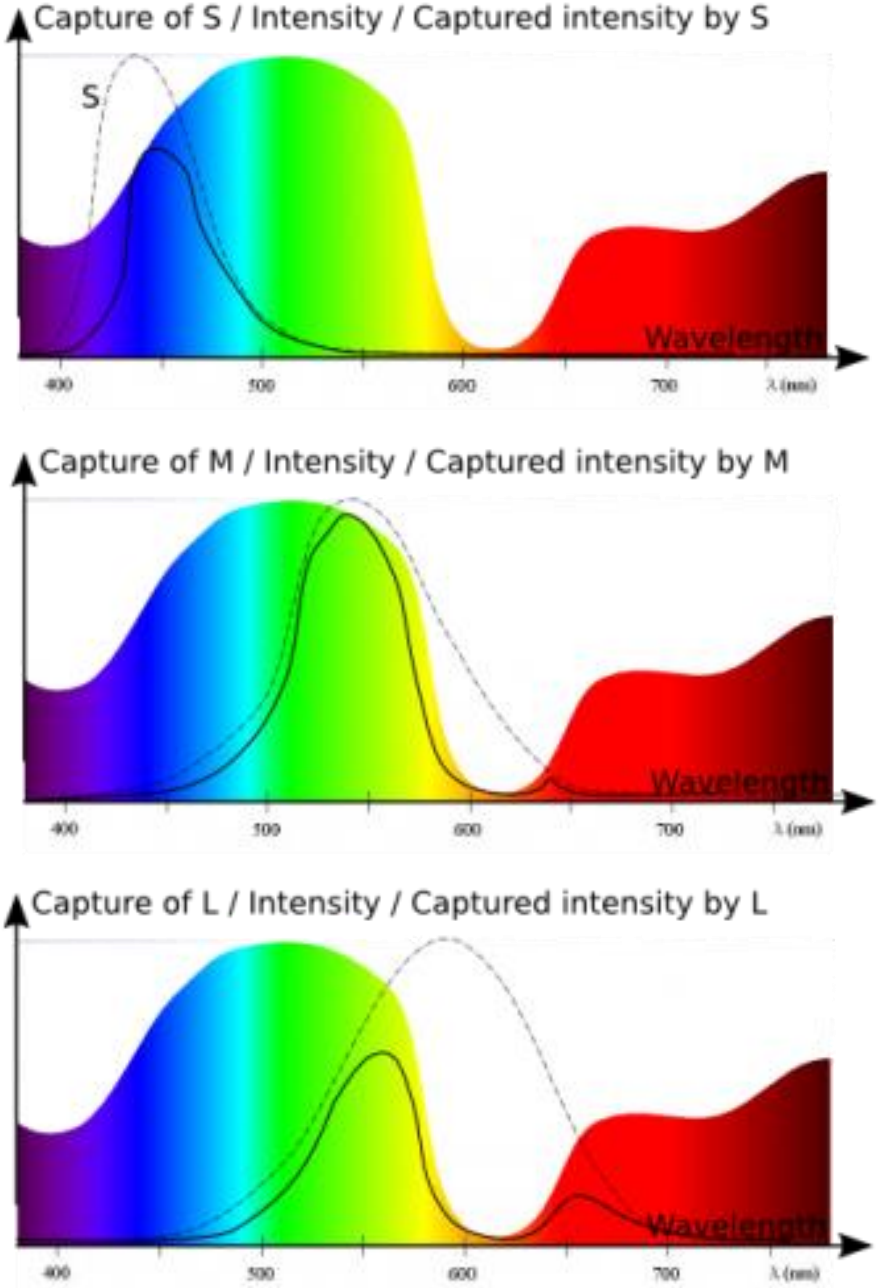
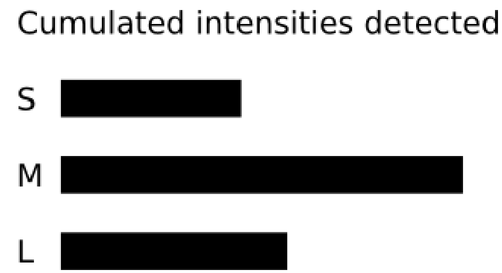
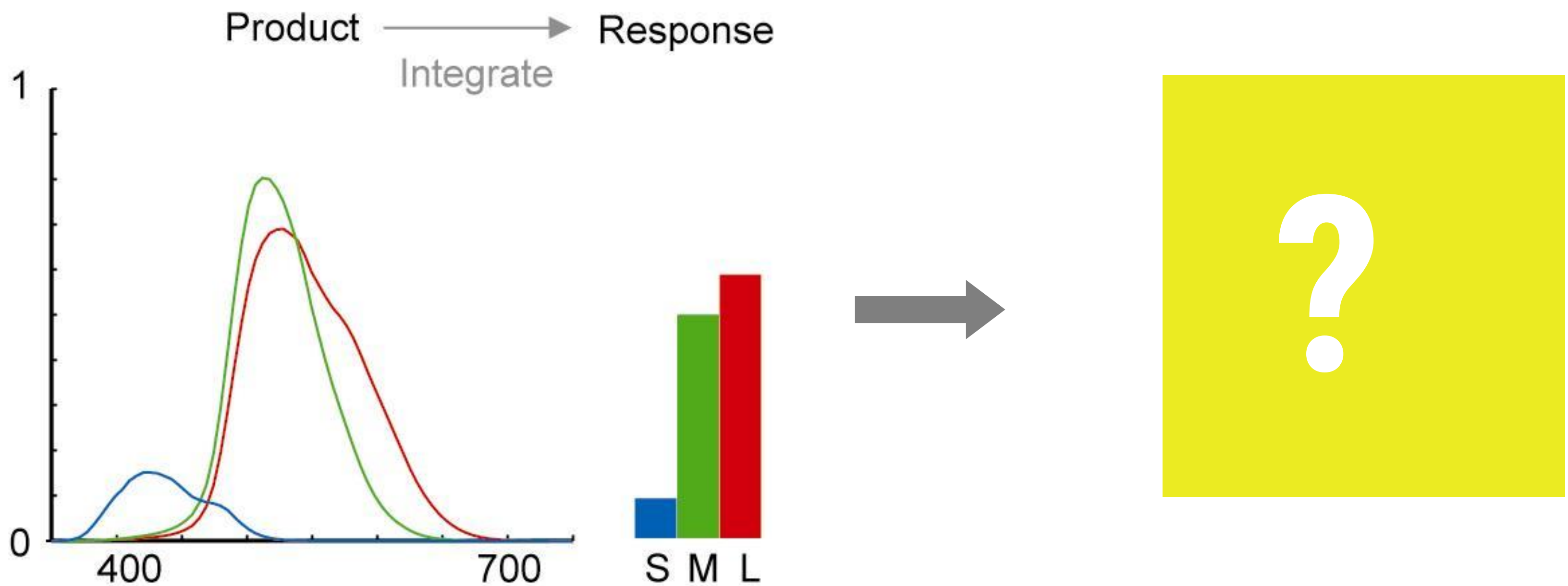




SML decomposition

http://www.science4all.org/article/colors/

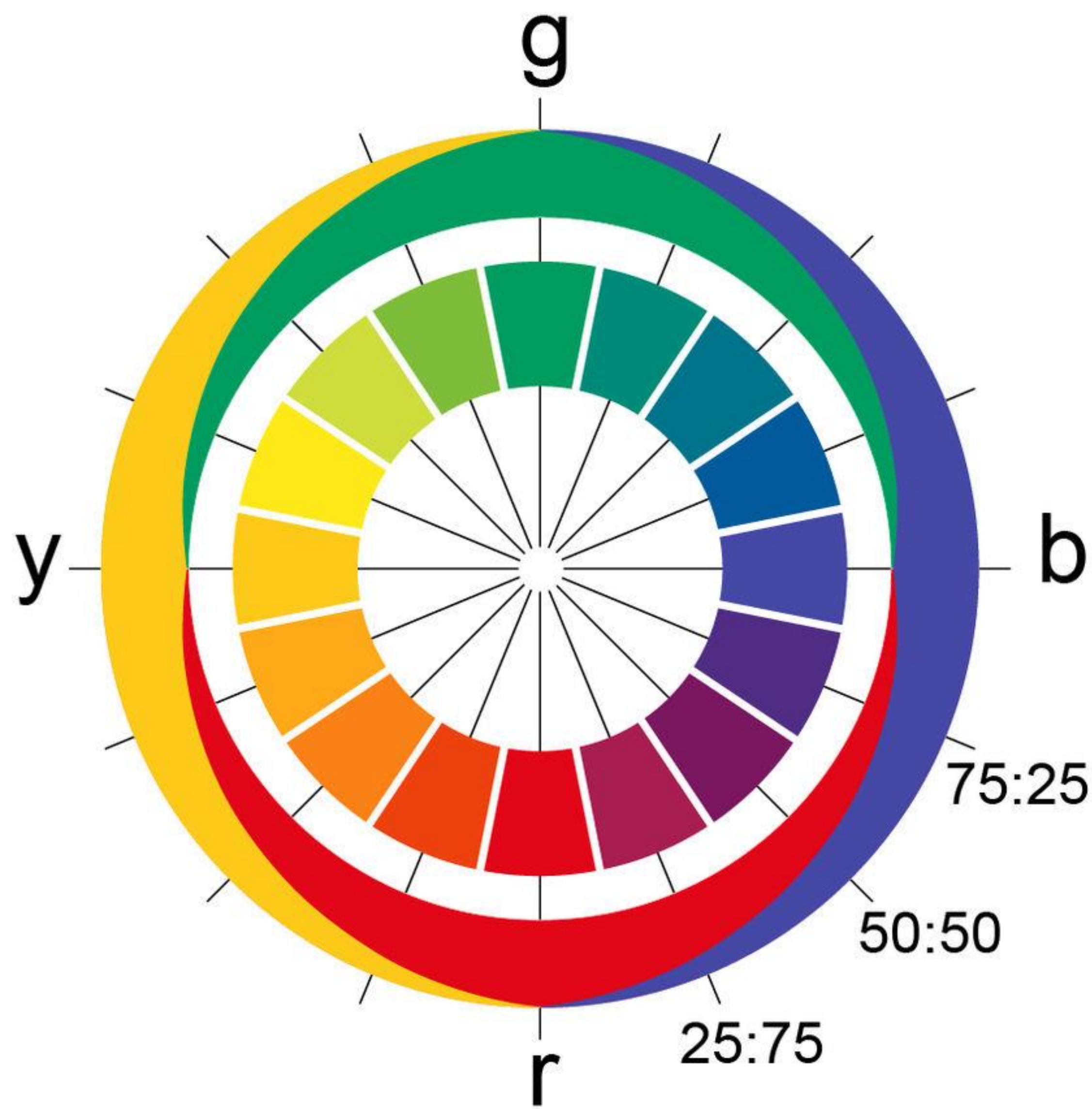
Visual System → **Color Models**



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

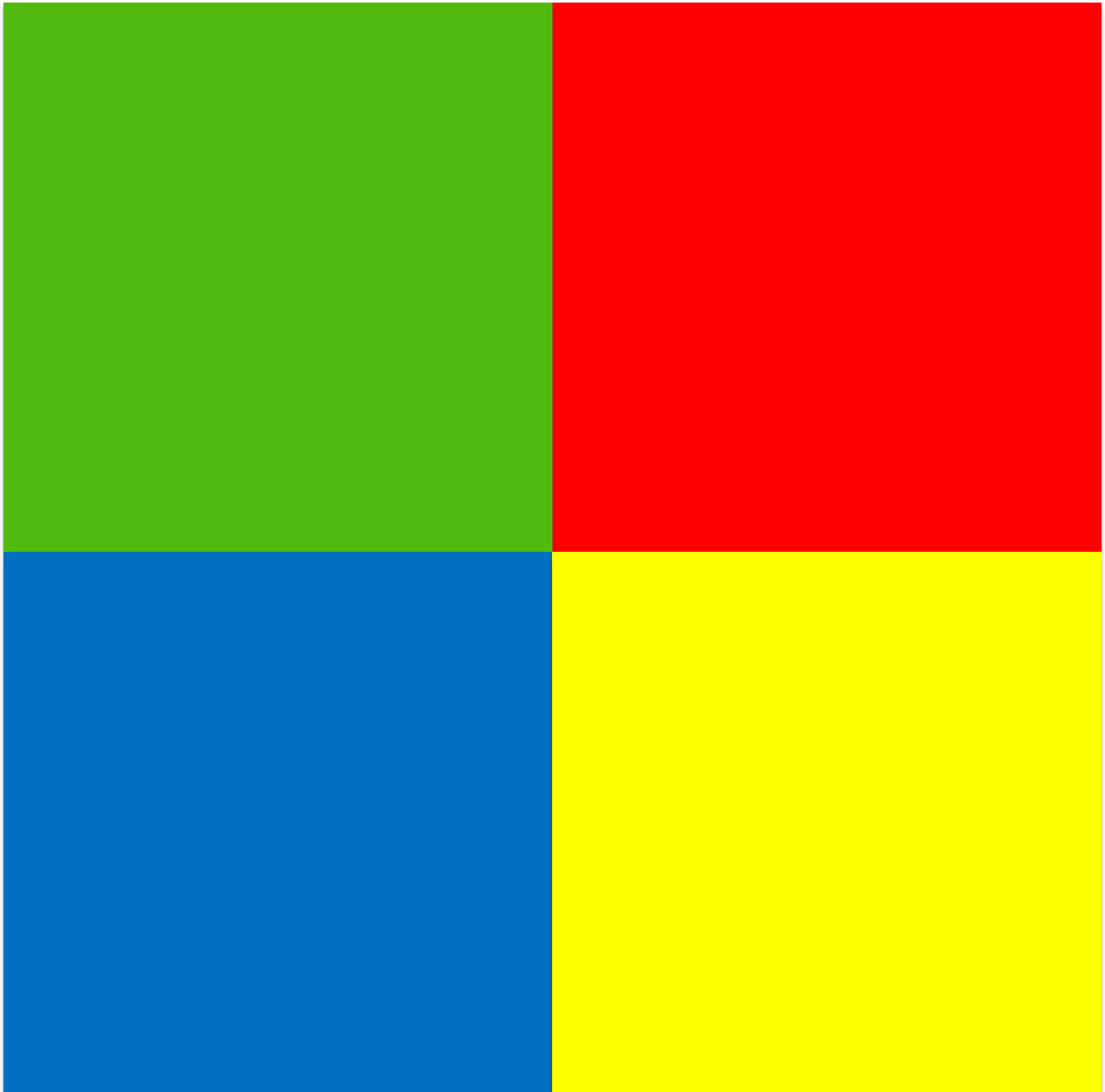
HOW IS THE CAPTURED COLOR INFORMATION PROCESSED?

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

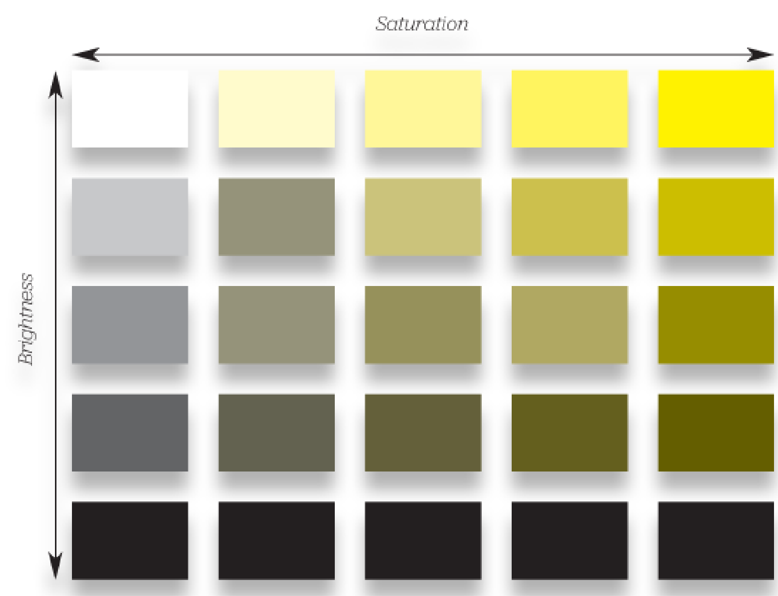
- Now we know do with cells whose center of the receptive field is sensitive to green and the surround to red = color opponent cells (also exists for blue and yellow)

- (too much detail for our purposes)

HOW TO DESCRIBE COLOR PERCEPTION

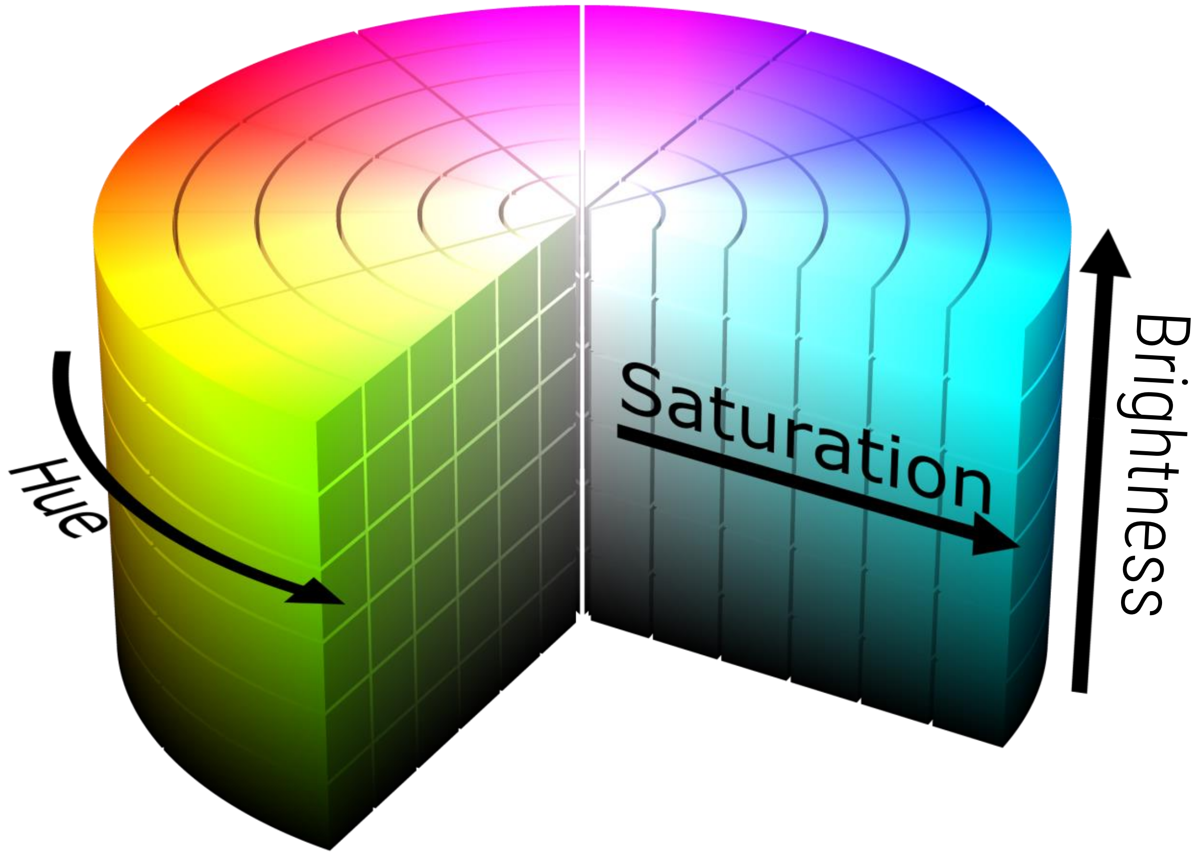
Color Terms

- 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



https://designingfortheweb.co.uk/images/compare.png

Color Spaces



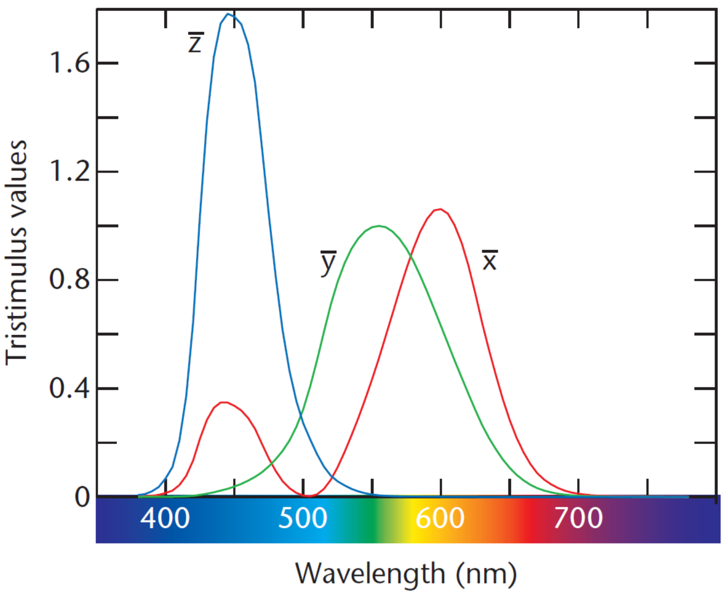
XYZ Color Model

- 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

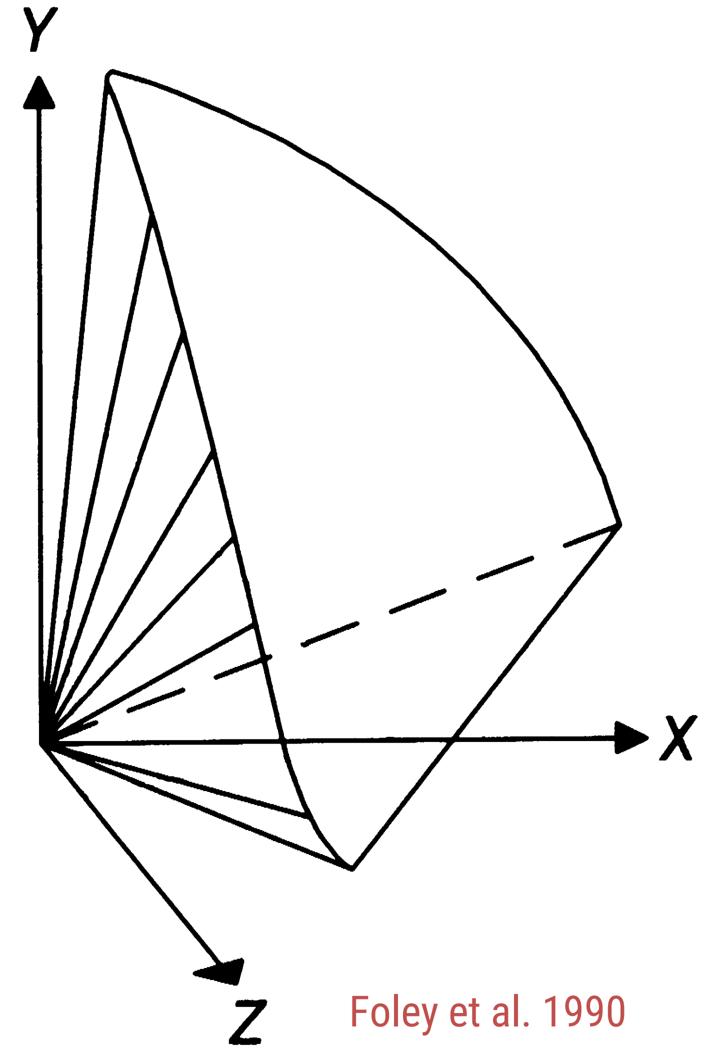
- color-matching functions (the numerical description of the chromatic response of the *observer)*
  - here non-negative
- Y follows the standard human response to luminance, i.e., the Y value represents perceived brightness
- can represent all perceivable colors



Stone 2005

XYZ CIE Color Space

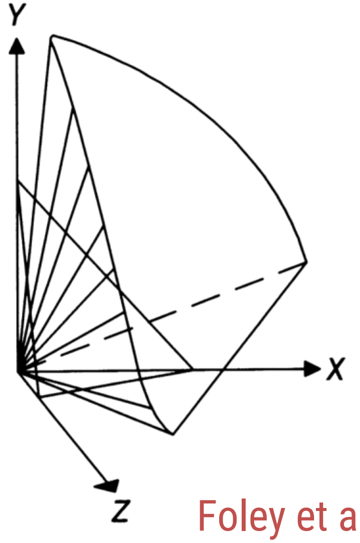
- plotting XYZ space in 3D
- all colors that are perceivable by humans form a deformed cone
- *X*, *Y*, and *Z*-axes are outside this cone

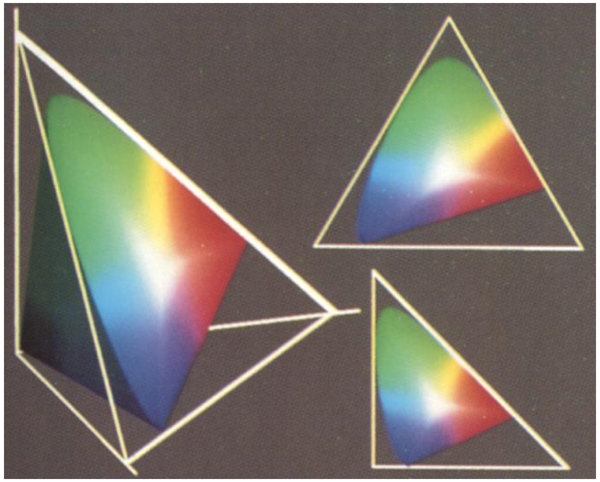


Foley et al. 1990

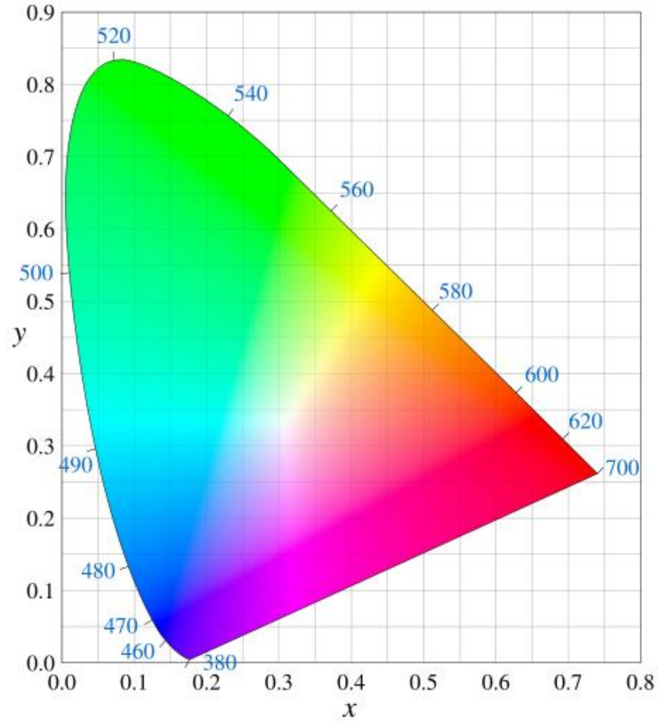
CIE Chromaticity Diagram

- 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



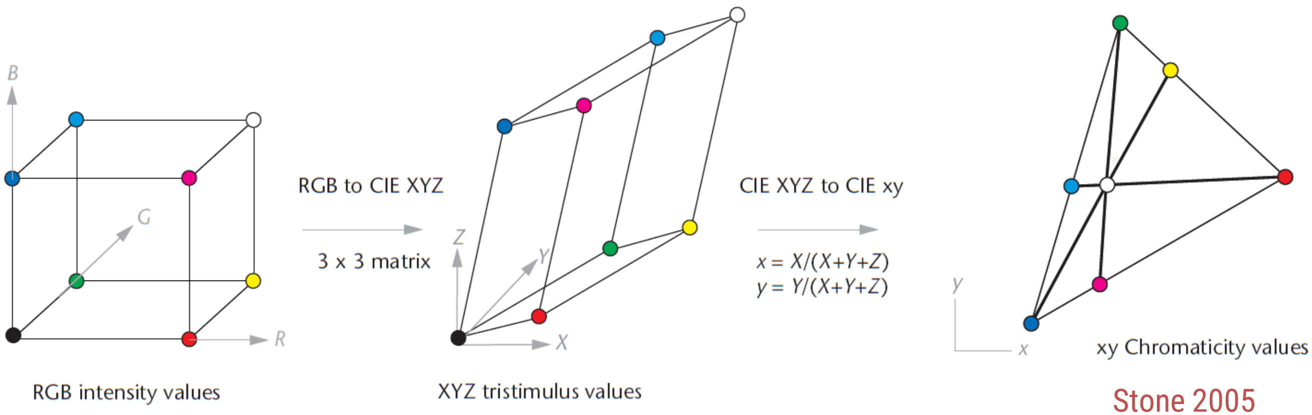


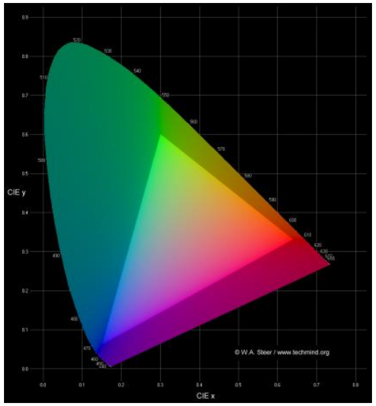
Foley et al. 1990



RGB and XYZ

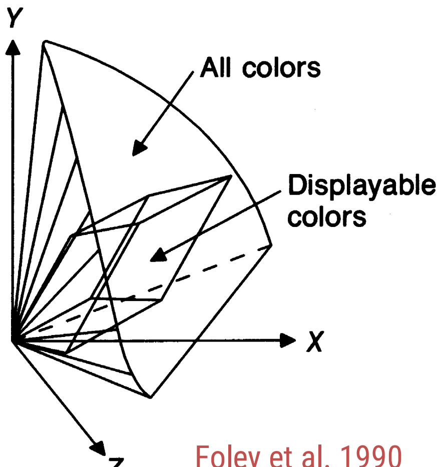
- RGB to XYZ conversion





Stone 2005 http://www.techmind.org/

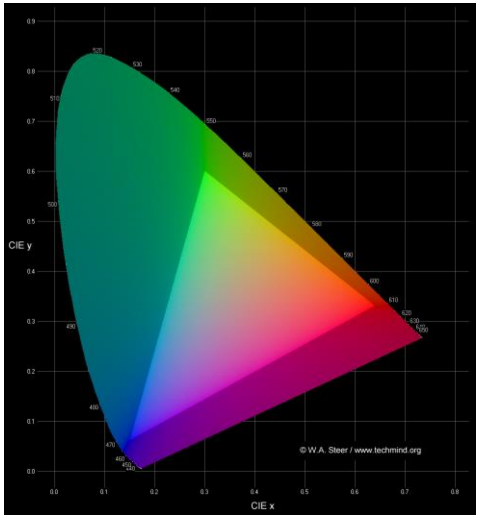
- RGB space: distorted cube
- black: origin of XYZ and projection center
- RGB projected to triangle



Foley et al. 1990

Can RGB Represent All Visible Colors?

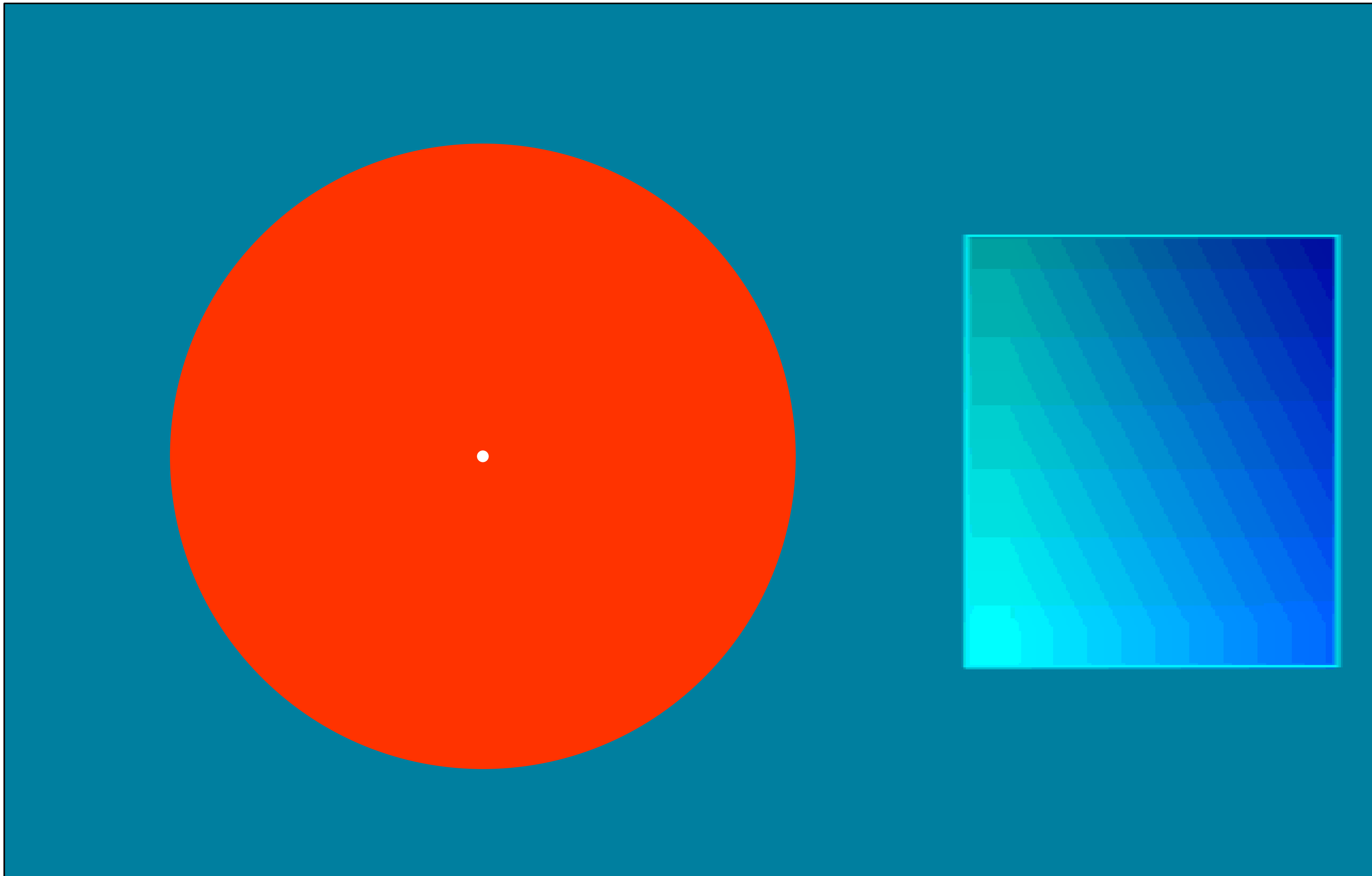
- no, because all colors form horseshoe shape in CIE chromaticity diagram and RGB gamut is triangular



http://www.techmind.org/

- But my shiny new 30” UHD OLED is state-of-the-art, it can surely show all colors!”
- $\rightarrow$ 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”

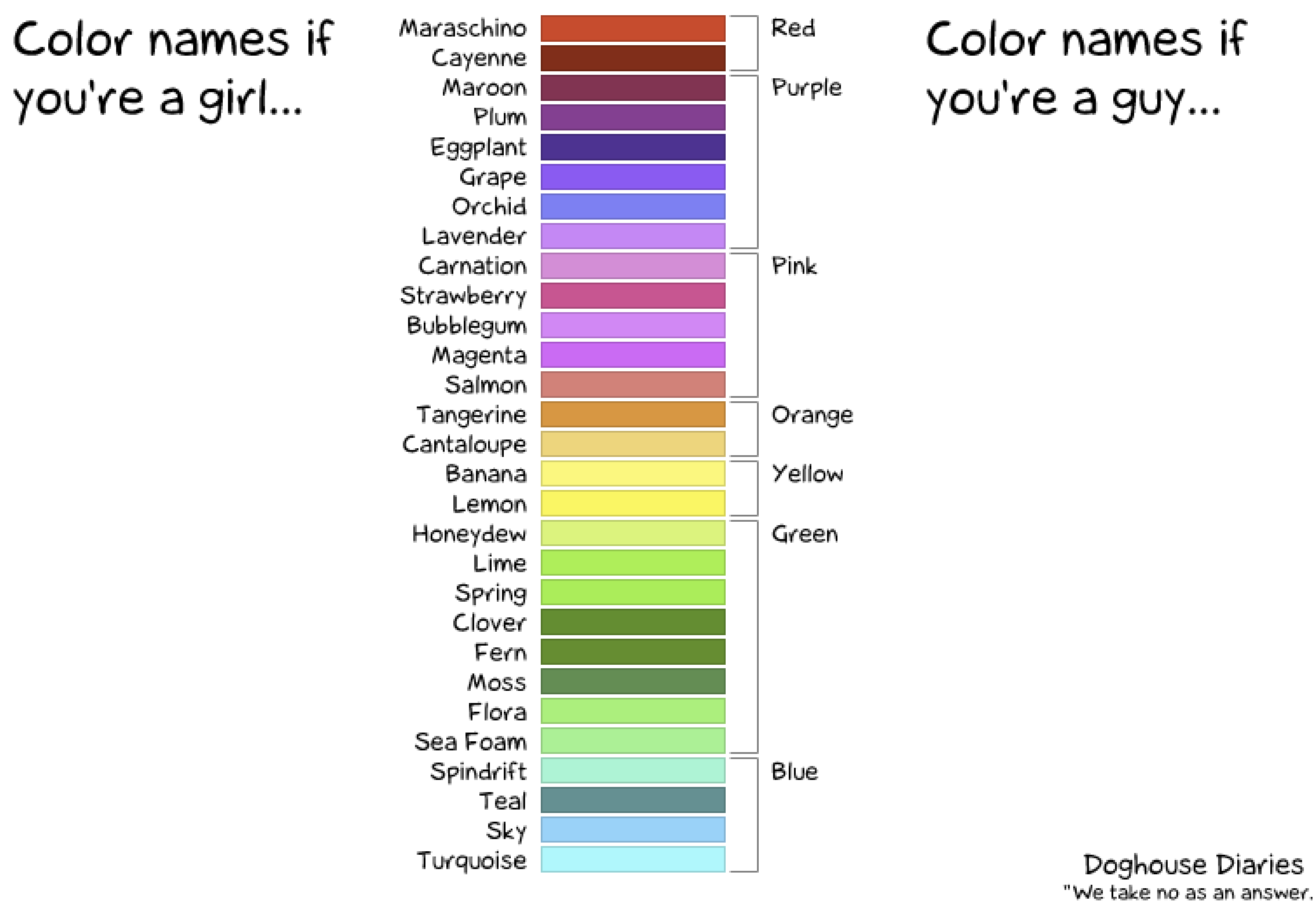
Color Perception → **Color Naming**

What color is this?

“Teal ?”

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

Color according to gender?



Color according to XKCD

A crowdsourced color-labeling game

~5 million colors

~222,500 user sessions

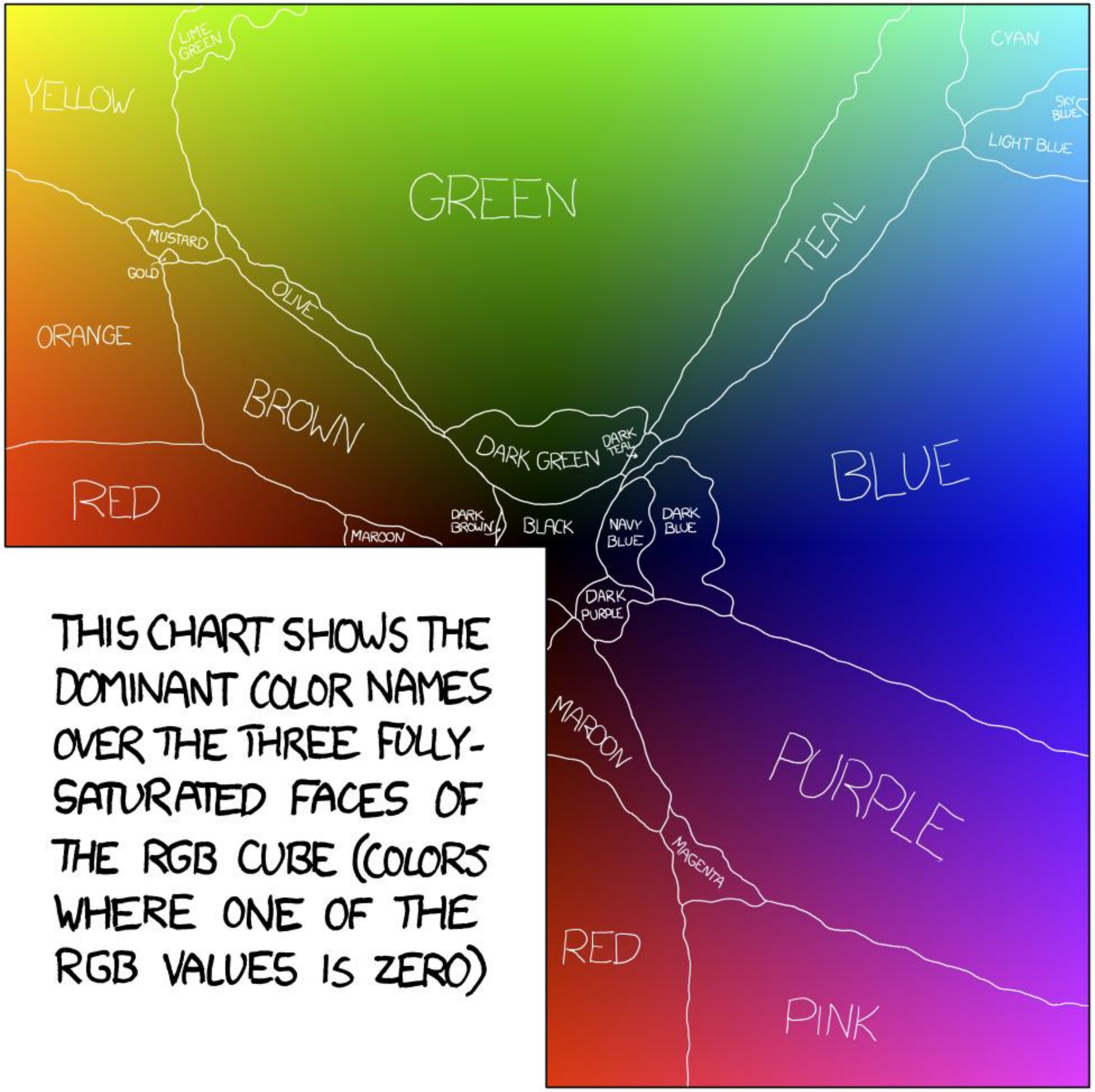
http://blog.xkcd.com/2010/05/03/color-survey-results/

Color according to XKCD

Color Naming

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

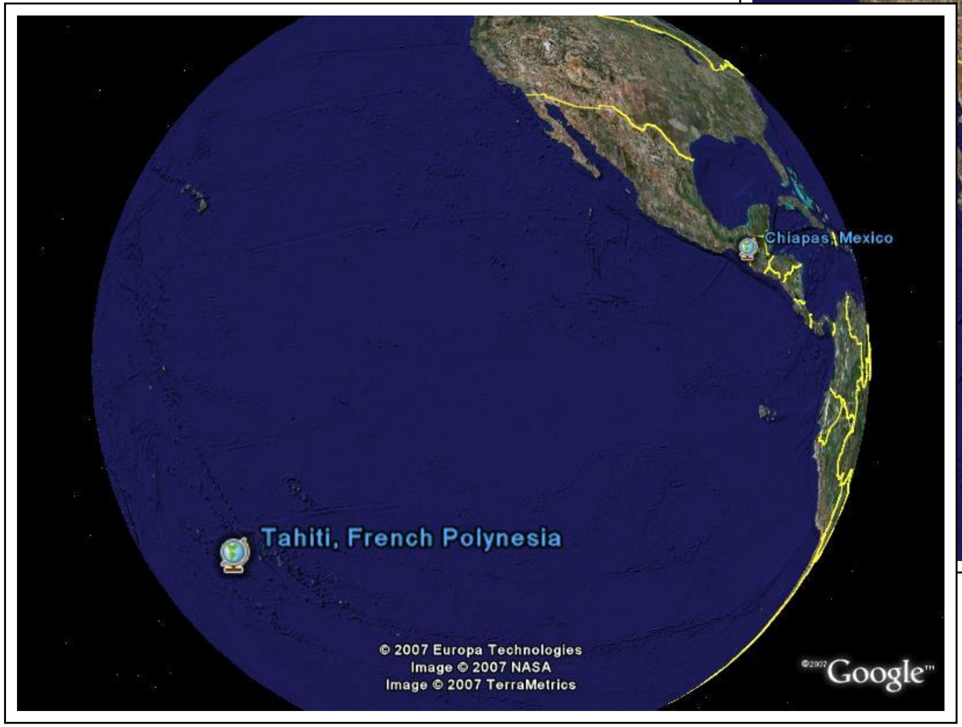
Are there natural boundaries?



xkcd

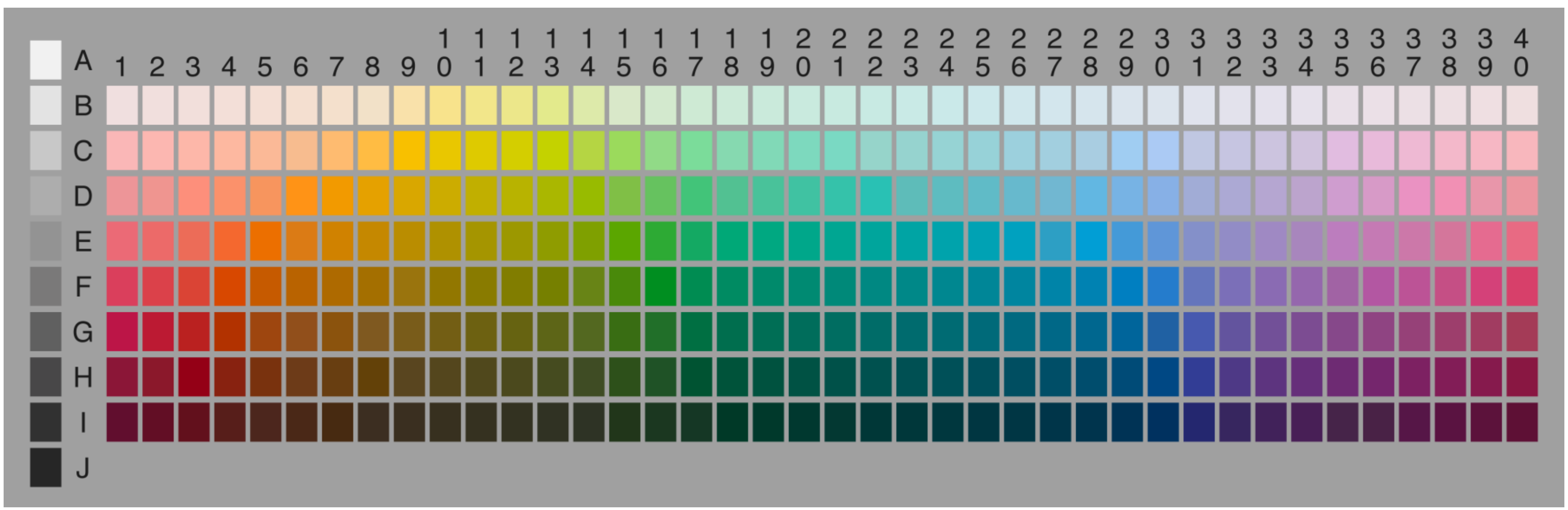
Basic Color Terms

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



World Color Survey

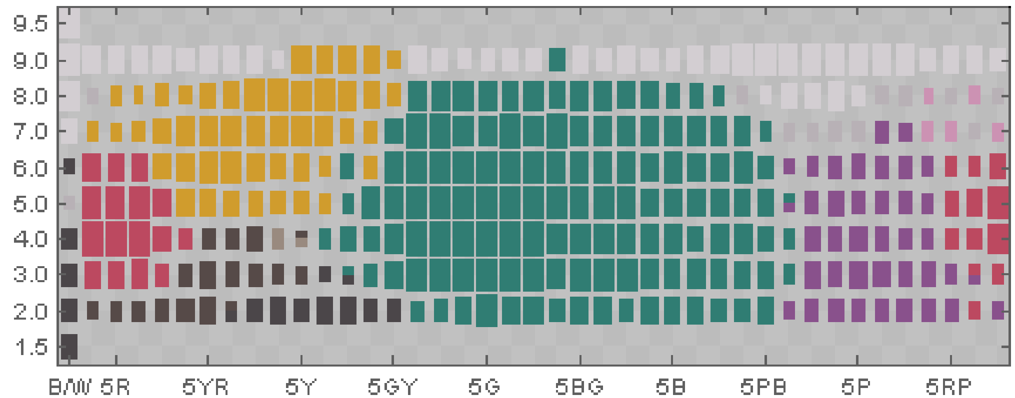
Surveyed 2616 speakers of 110 languages using 330 different color chips



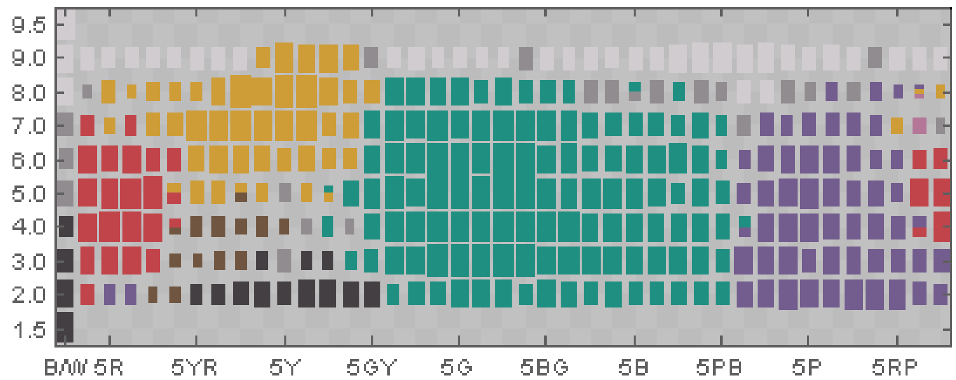
see also: http://wals.info/feature/132A?tg_format=map#2/32.5/153.5

Results from WCS (Mexico)

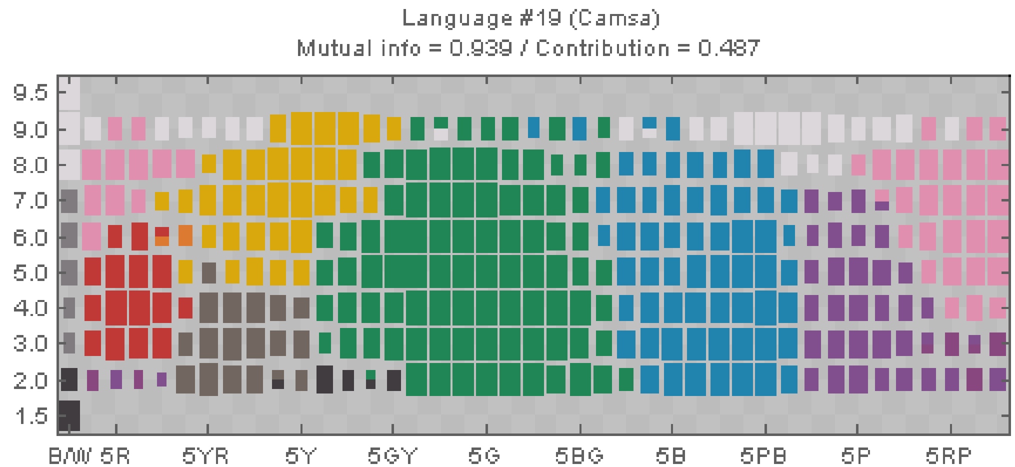
Language #72 (Mixteco)
Mutual info = 0.942 / Contribution = 0.476

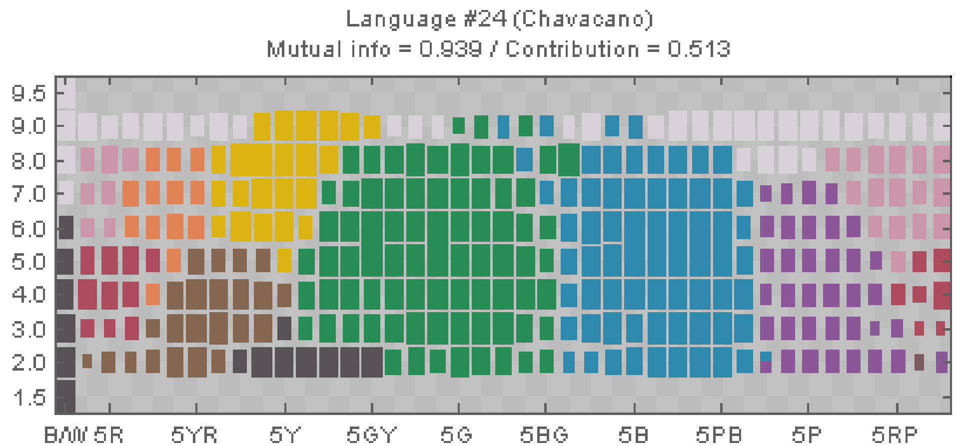


Language #98 (Tlapaneco)
Mutual info = 0.942 / Contribution = 0.524



Results from WCS (South Pacific)



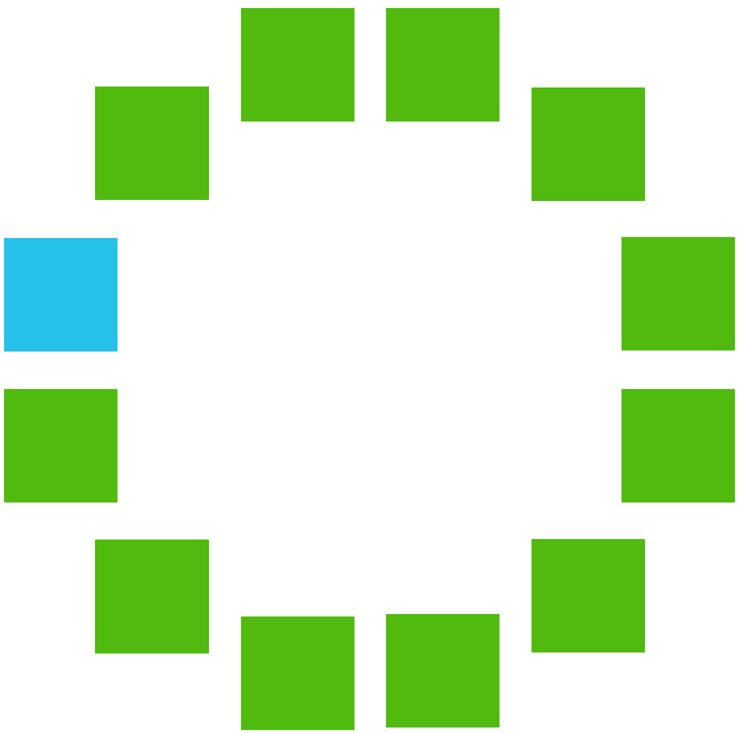


But language-color interaction

- 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?

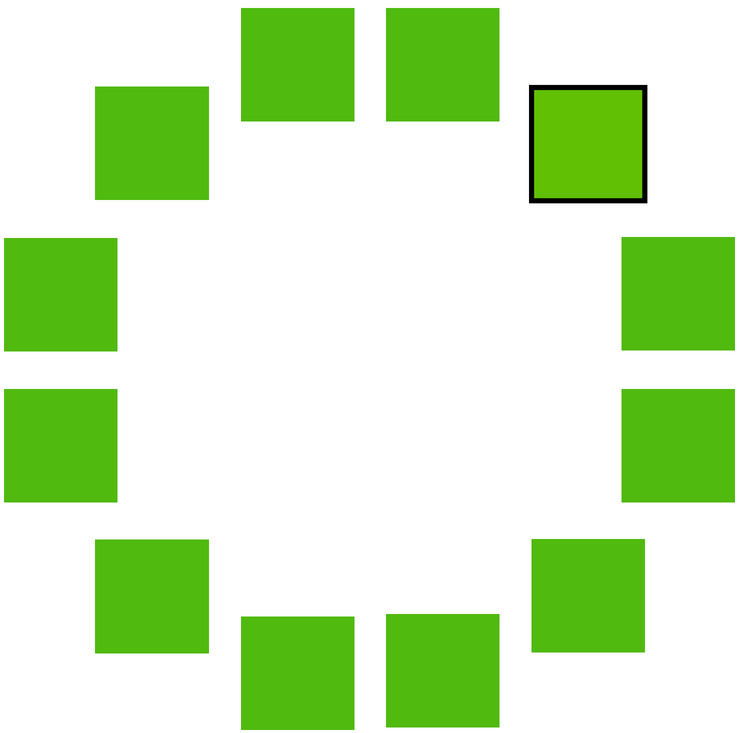


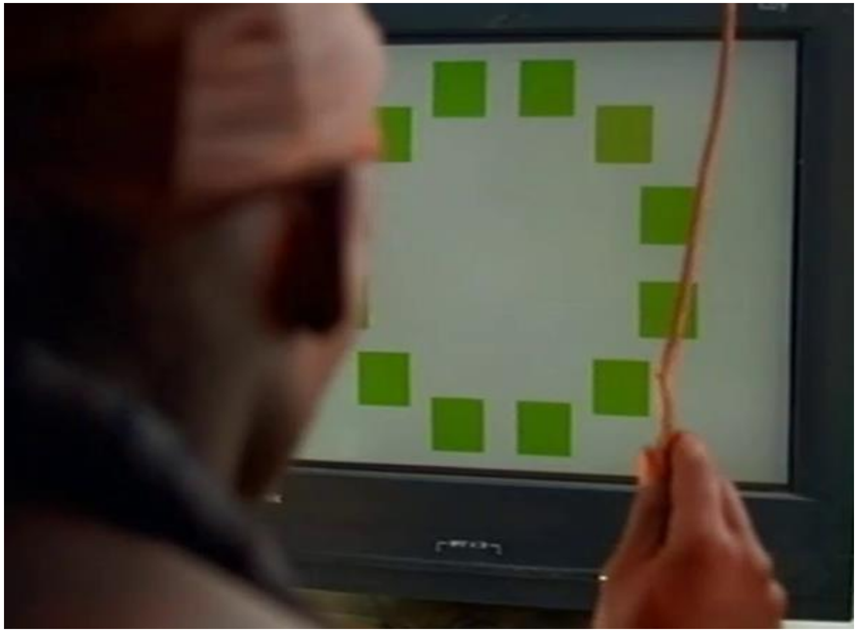
© BBC

difficult to impossible for Himba people

But language-color interaction

- experiment: how long to find a differing color?





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

Universal (?) Basic Color Terms

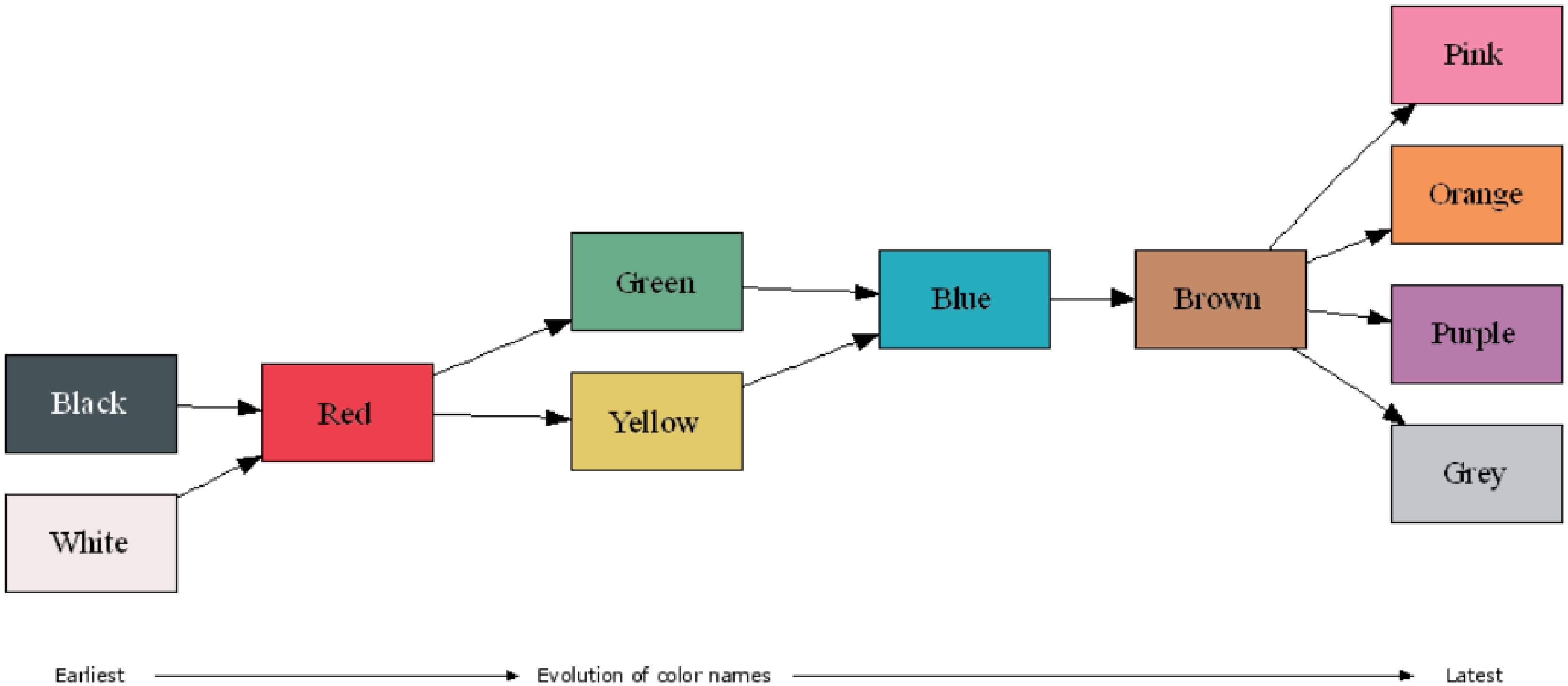
Basic color terms recur across languages

White	**Red**	**Pink**
Grey	**Yellow**	**Brown**
Black	**Green**	**Orange**
	Blue	**Purple**

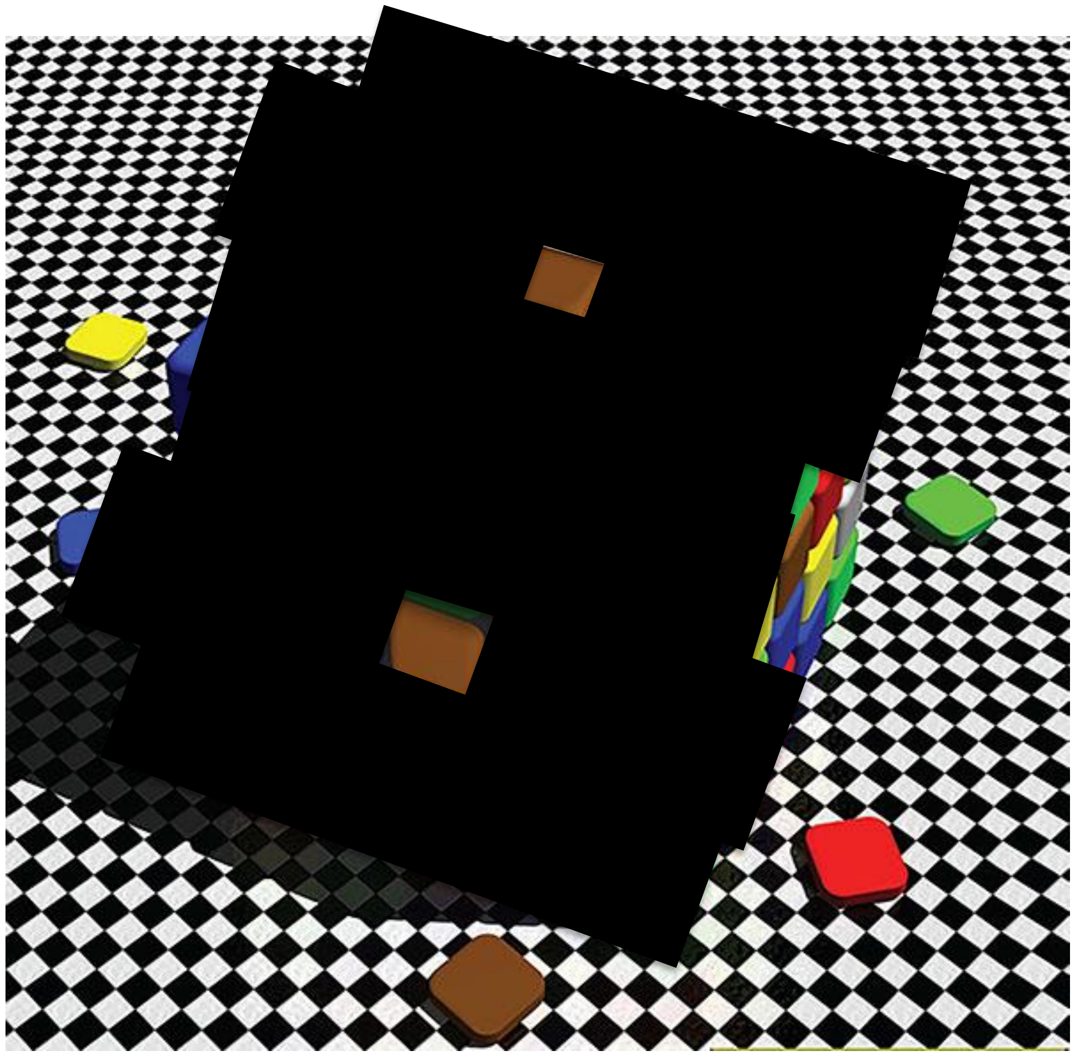
Interesting factoid: Cartographers found out that they need 4 unique hues to unambiguously distinguish all areas on an arbitrarily complex map

Evolution of Basic Color Terms

Proposed universal evolution of color names across languages.



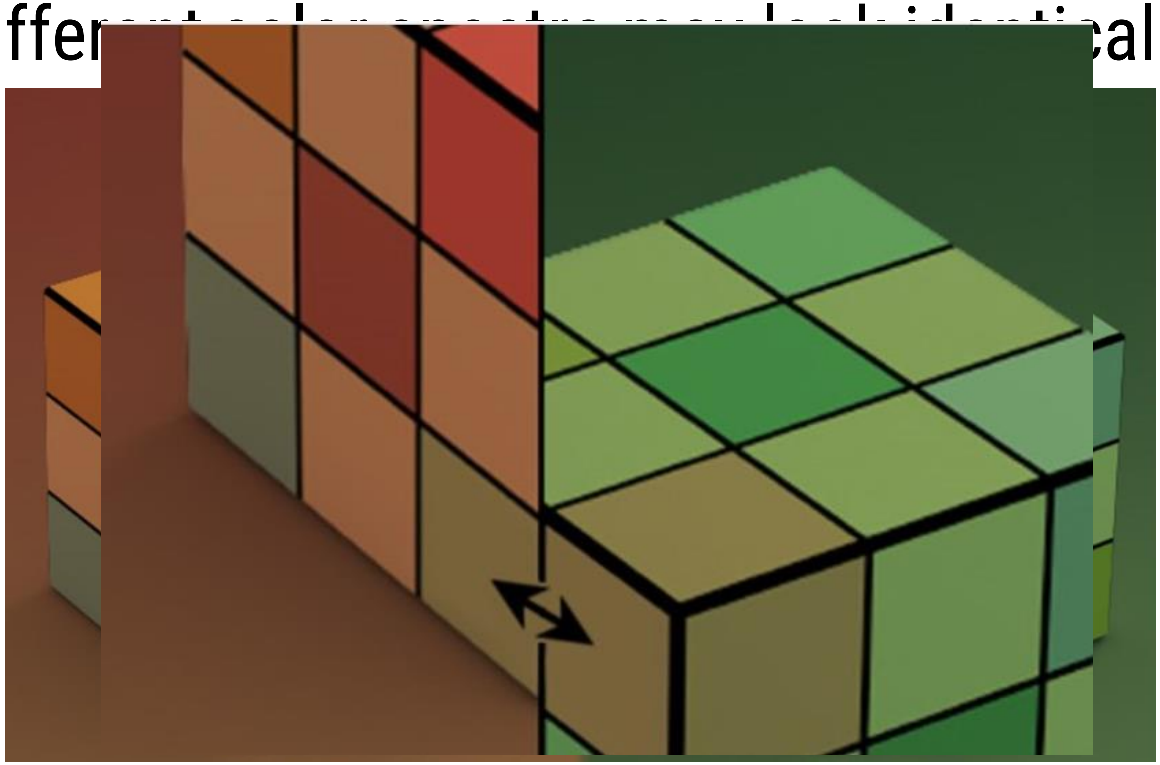
Some other color usage problems



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 differ… cal



@nationalgeographic.com

CONCLUSION

- Color vision (just like brightness) does not correspond to physical measurements

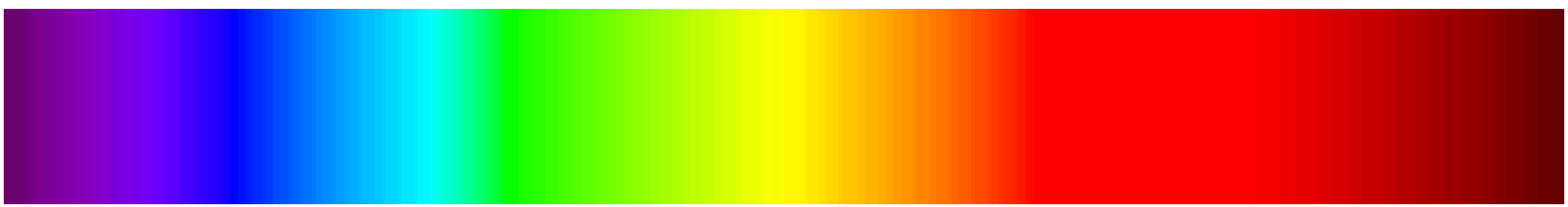
- Be mindful in how you apply color in your computer-generated scenes!

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



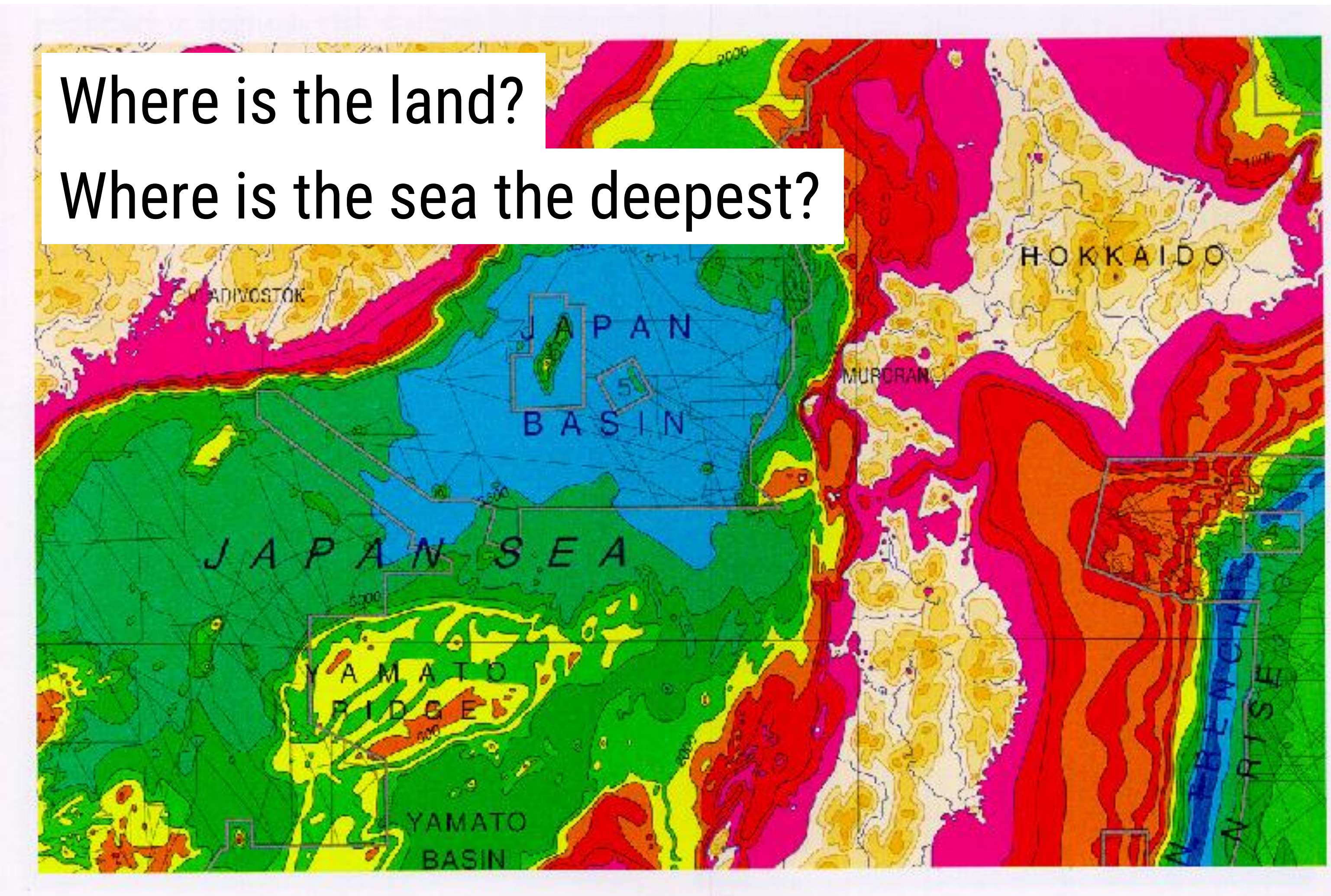
And it's (usually) a huge mistake!

General Bathymetric Chart of the Ocean

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

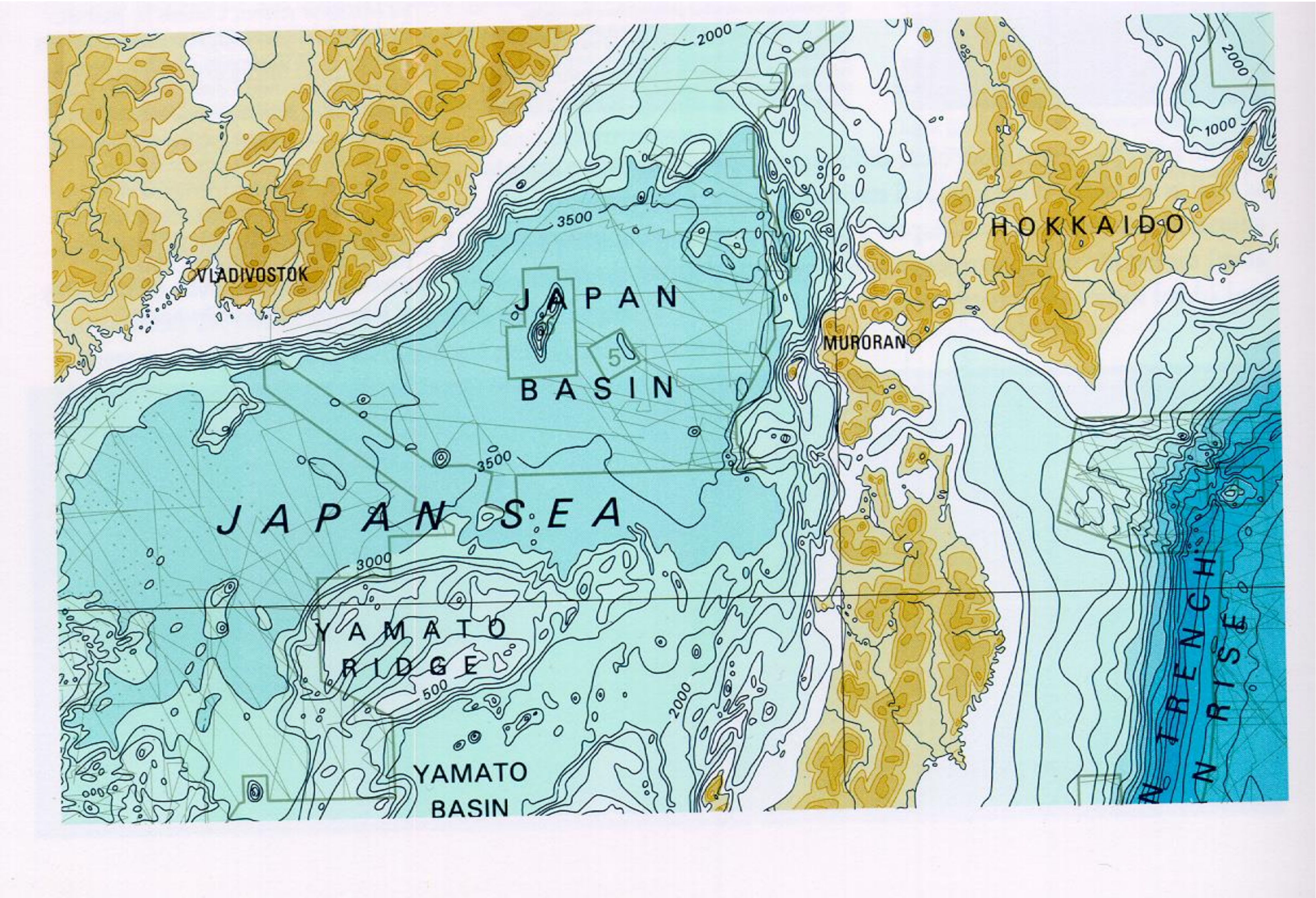
Where is the land?

Where is the sea the deepest?

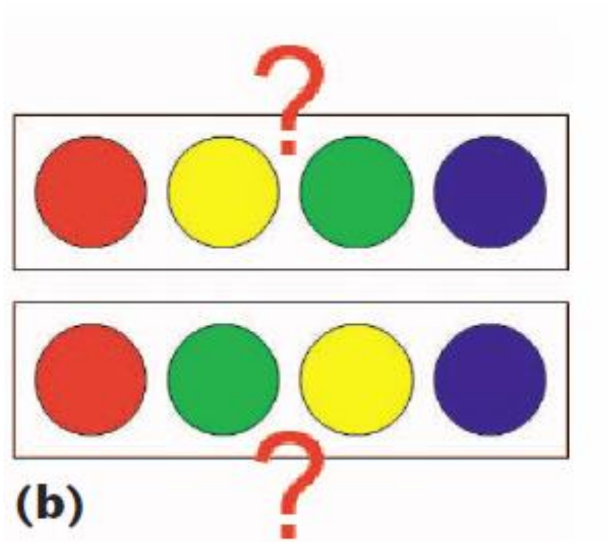


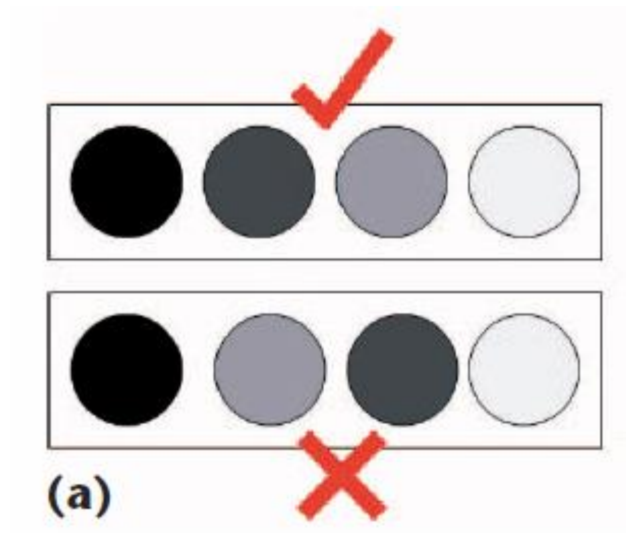
General Bathymetric Chart of the Ocean

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

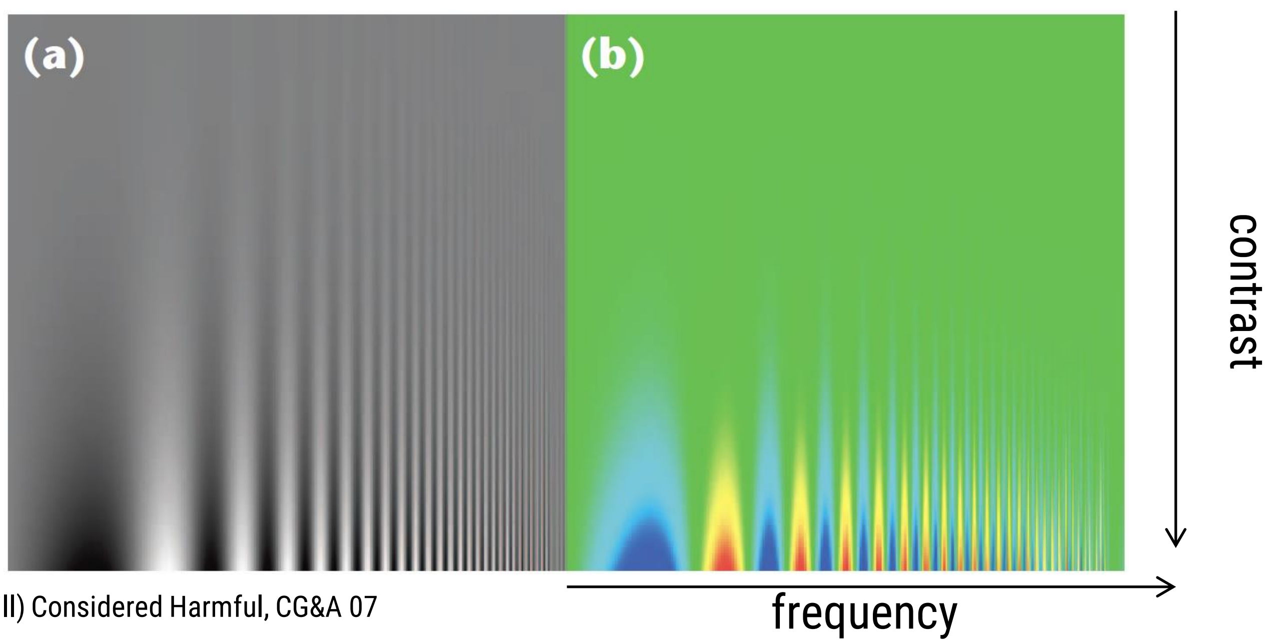
- Increases luminance (value) from dark to light
- Is perceptually ordered

From: Rainbow Color Map (Still) Considered Harmful, CG&A 07

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

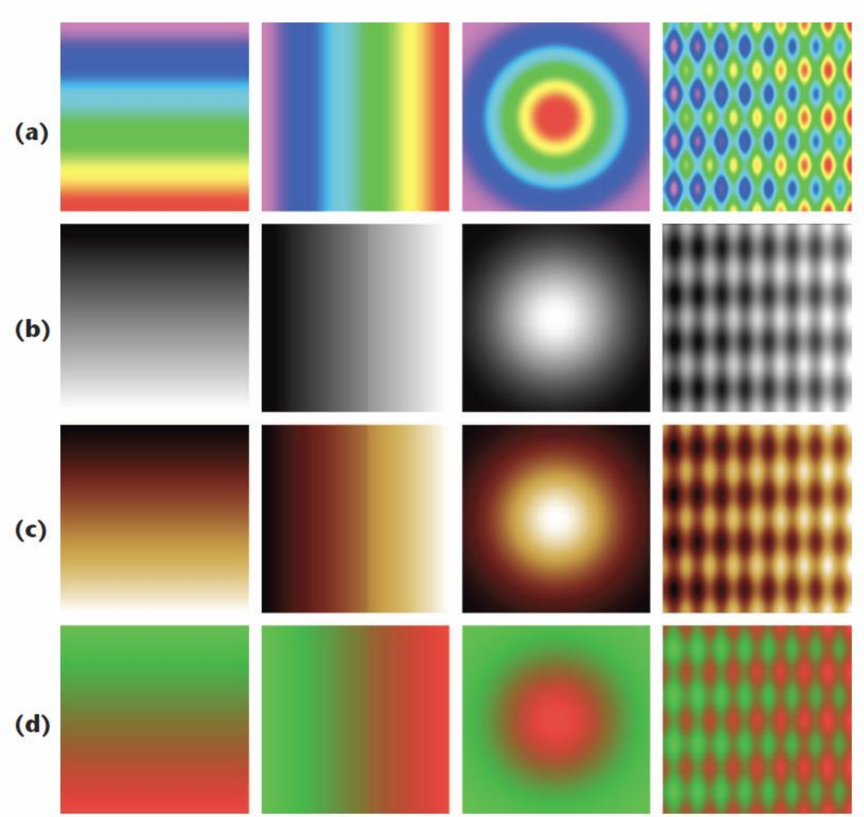


From: Rainbow Color Map (Still) Considered Harmful, CG&A 07

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

From: Rainbow Color Map (Still) Considered Harmful, CG&A 07

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

From Ware, Information Visualization

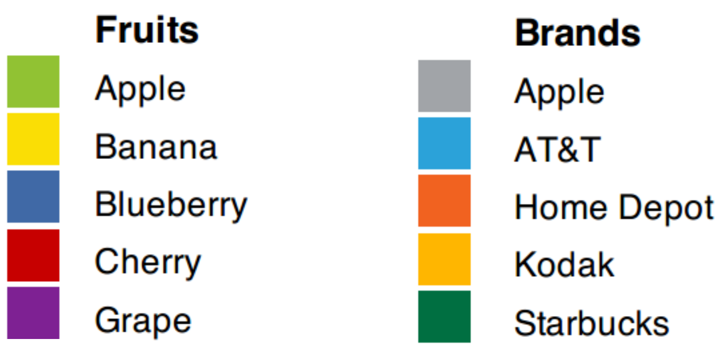
Using Color to Label

(For groups, categories, highlights, etc.)

Colors should be distinctive and named

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

Use cultural conventions & appreciate symbolism



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

Beware of bad interactions

MAGDEBURG

Die Stadt mit Zugkraft

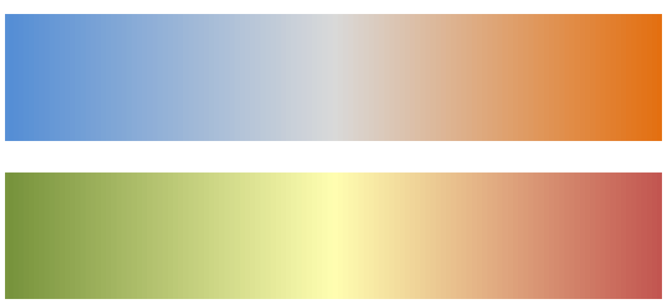
Using Color for Scales

(For ordinal or quantitative data)

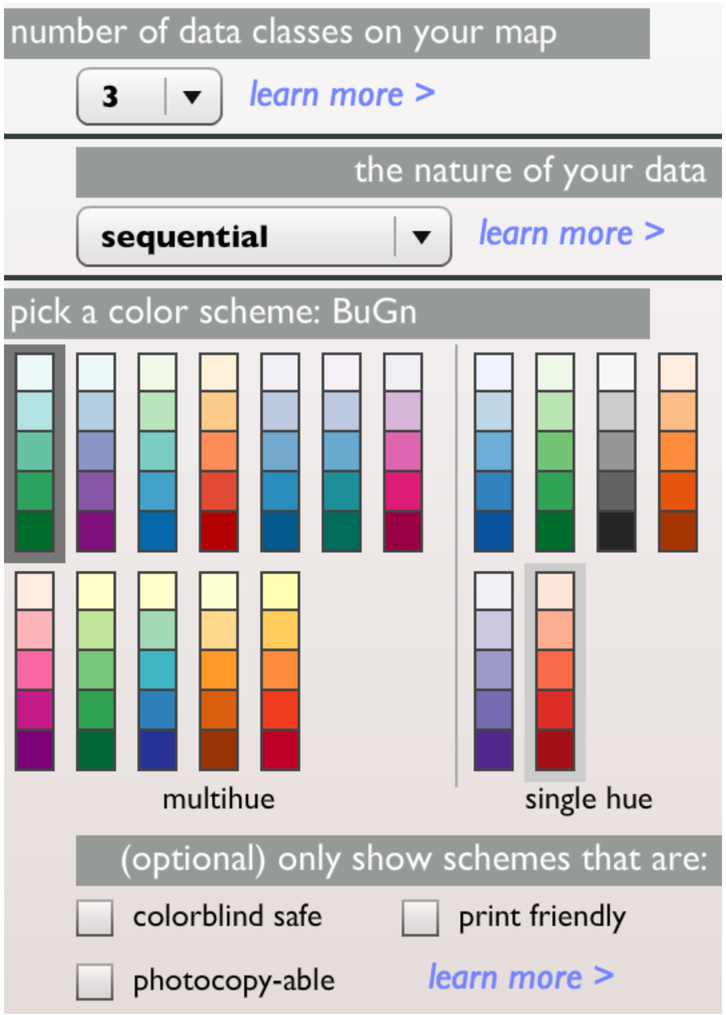
Use a scale that varies **lightness** in addition to color

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



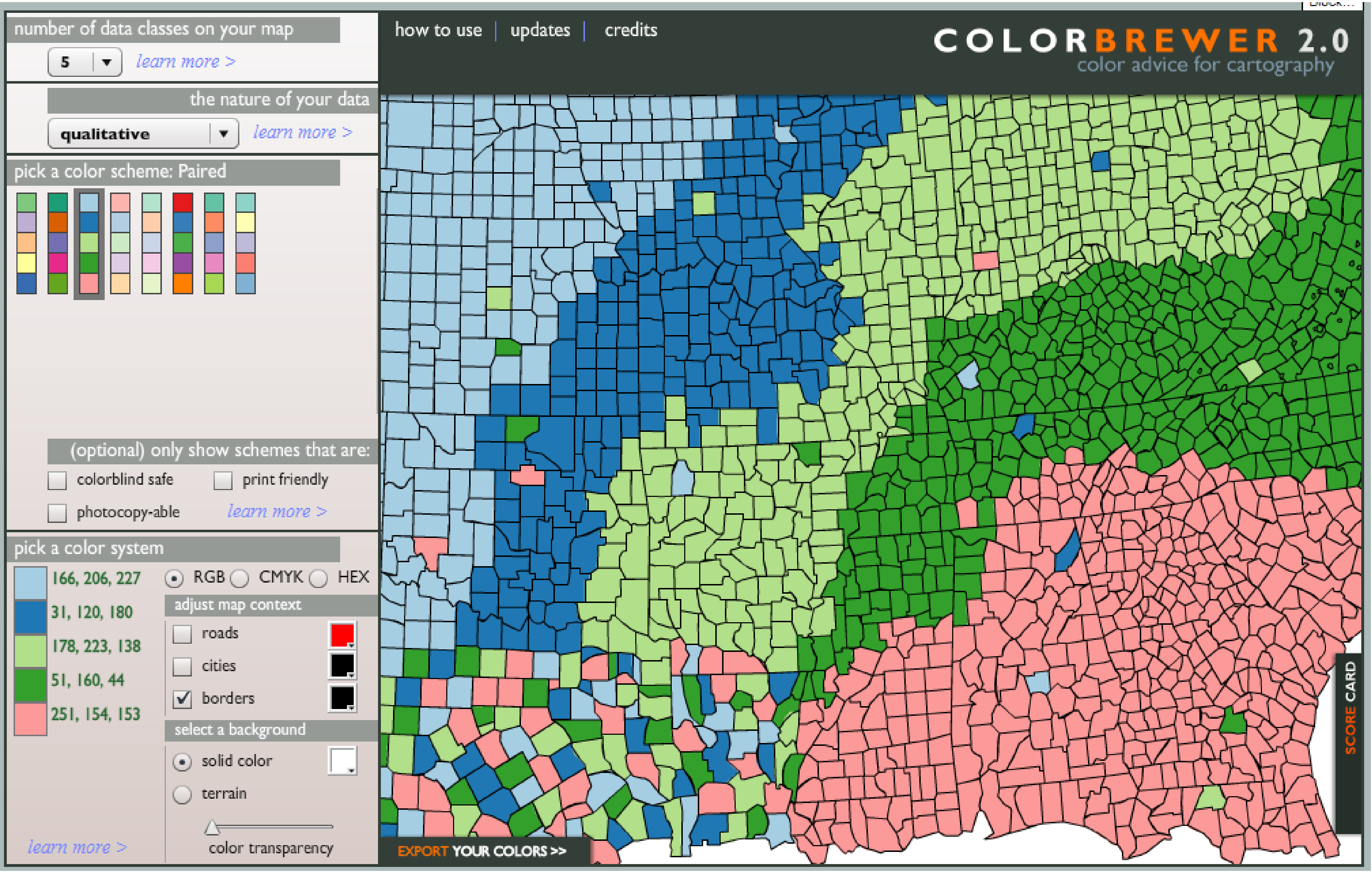
ColorBrewer



Highly recommended!

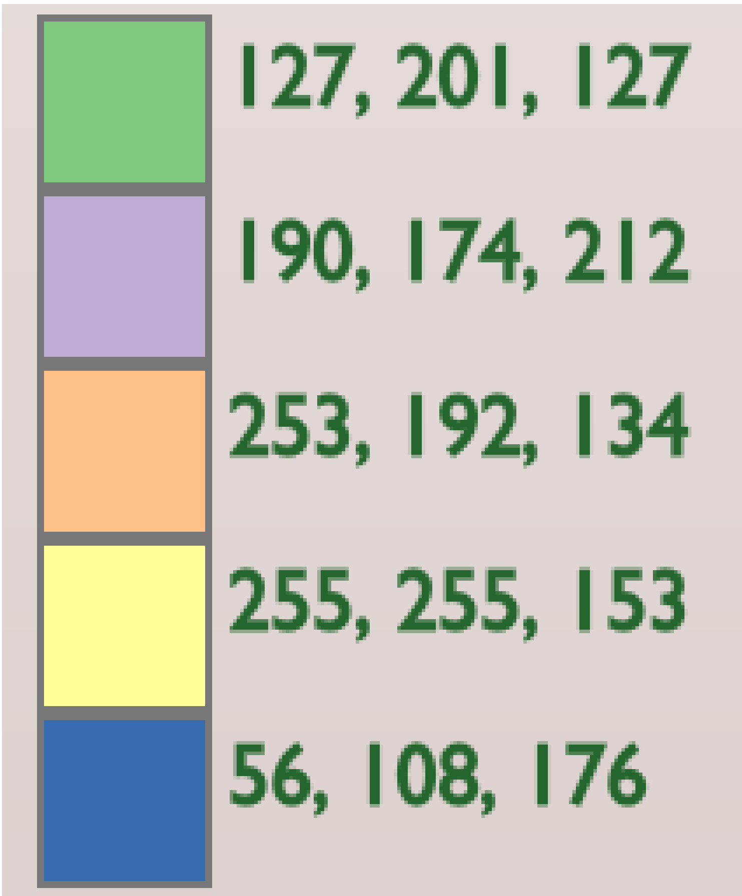
Designed originally for maps but will also work well for other types of visualizations

http://colorbrewer2.org/



http://colorbrewer2.org/

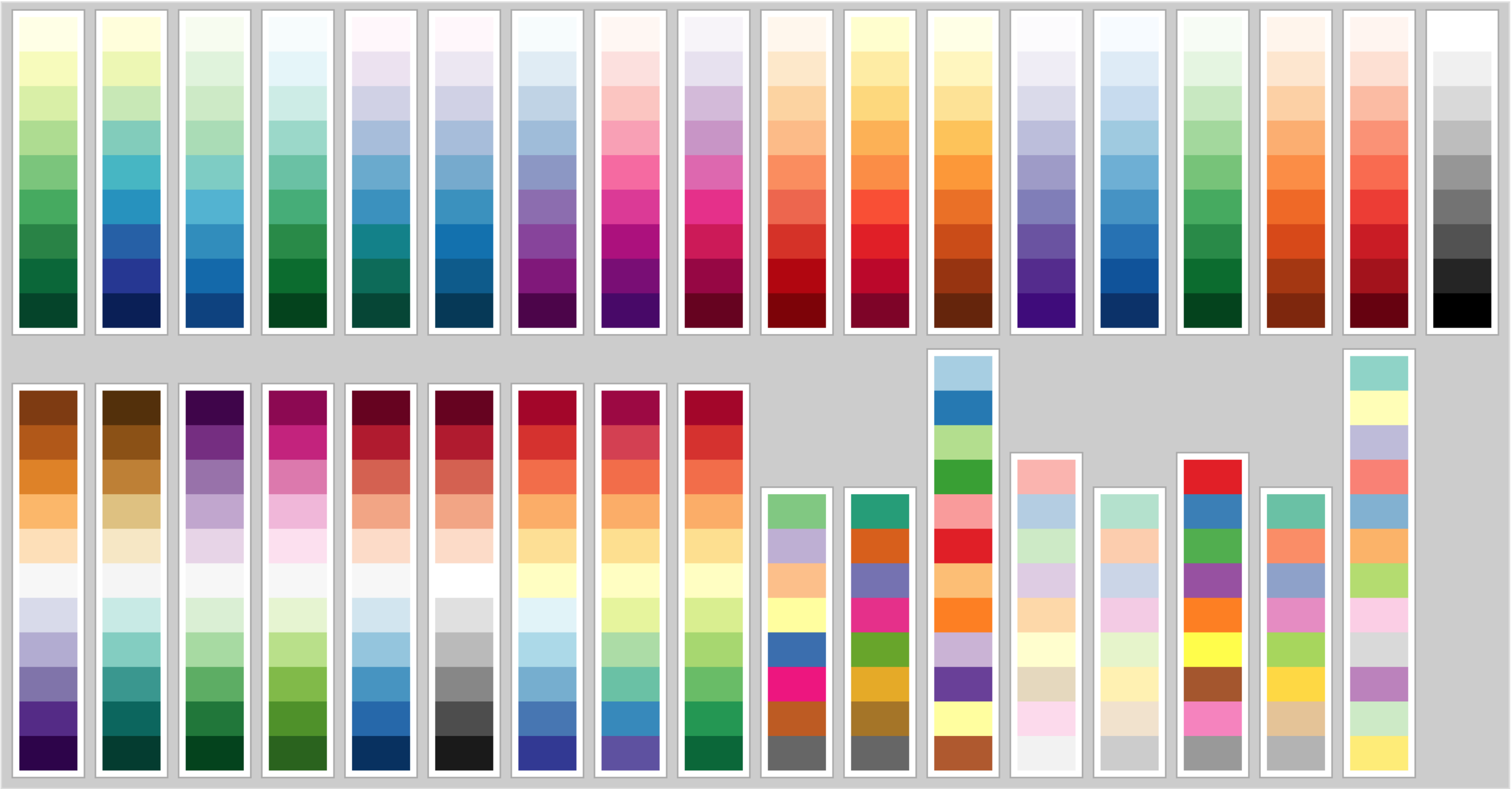
ColorBrewer



(RGB)

(Hex)

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

The following slides on the topic are adapted from Tobias Isenberg's

Color Vision Deficiency

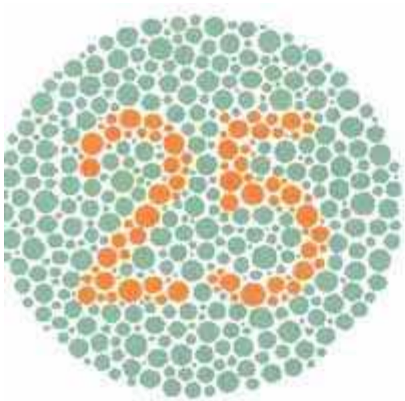
vormal color vision

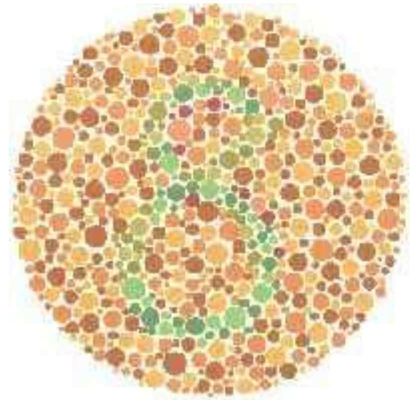
simulation of color contrast
for deuteranopic color vision
(green receptors absent)

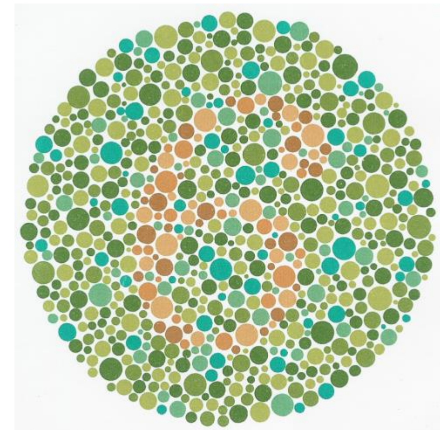
approx. 7% of male population color-deficient

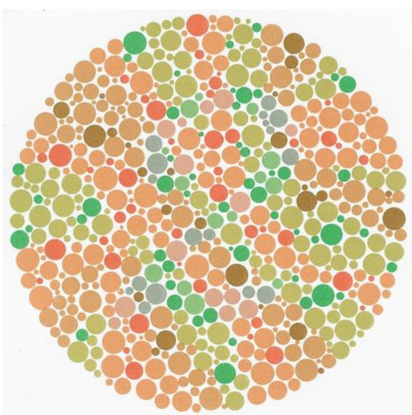
mostly red-green color deficiency (deuteranopia or protanopia) – but other forms exist as well

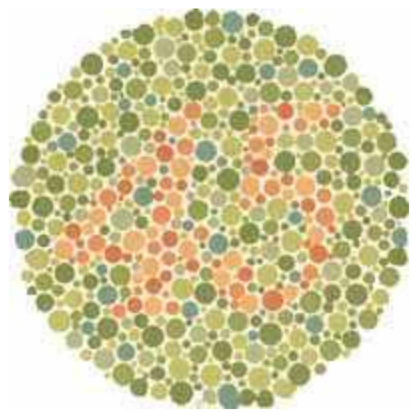
Color Deficiency Test (Ishihara Test)

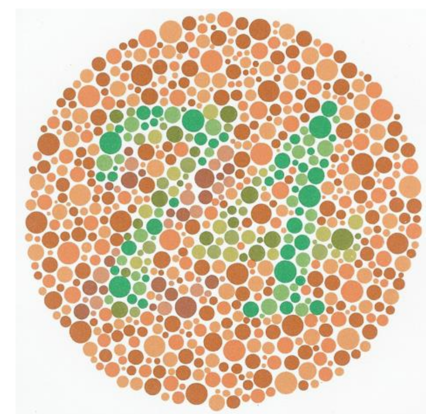




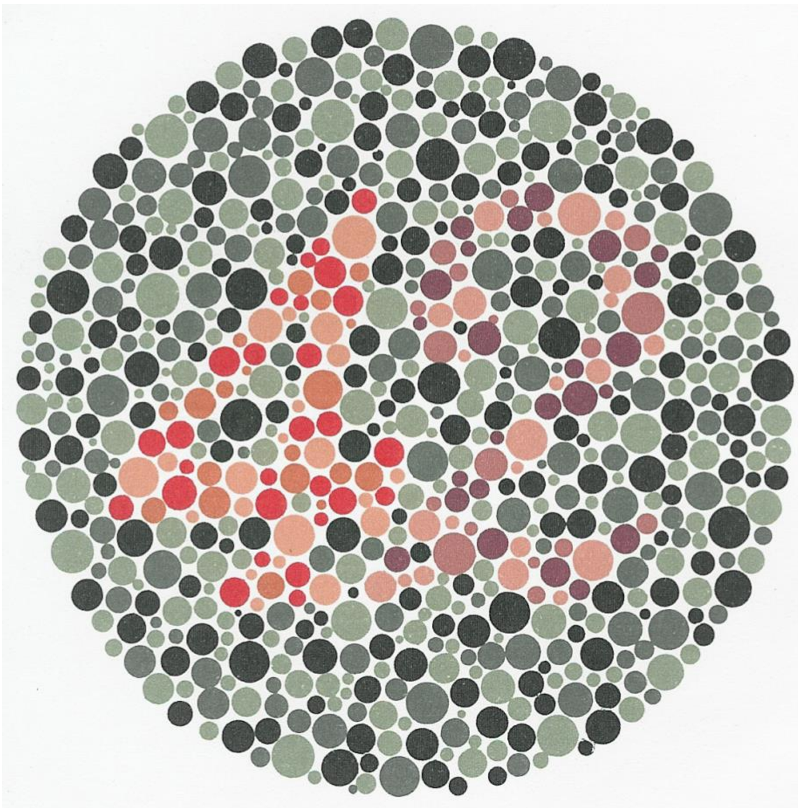


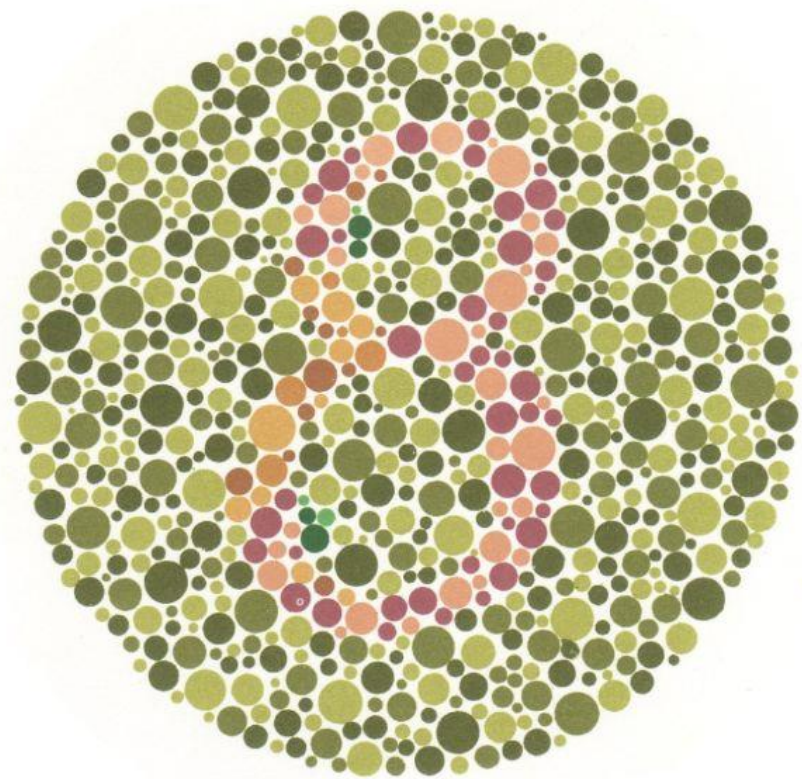




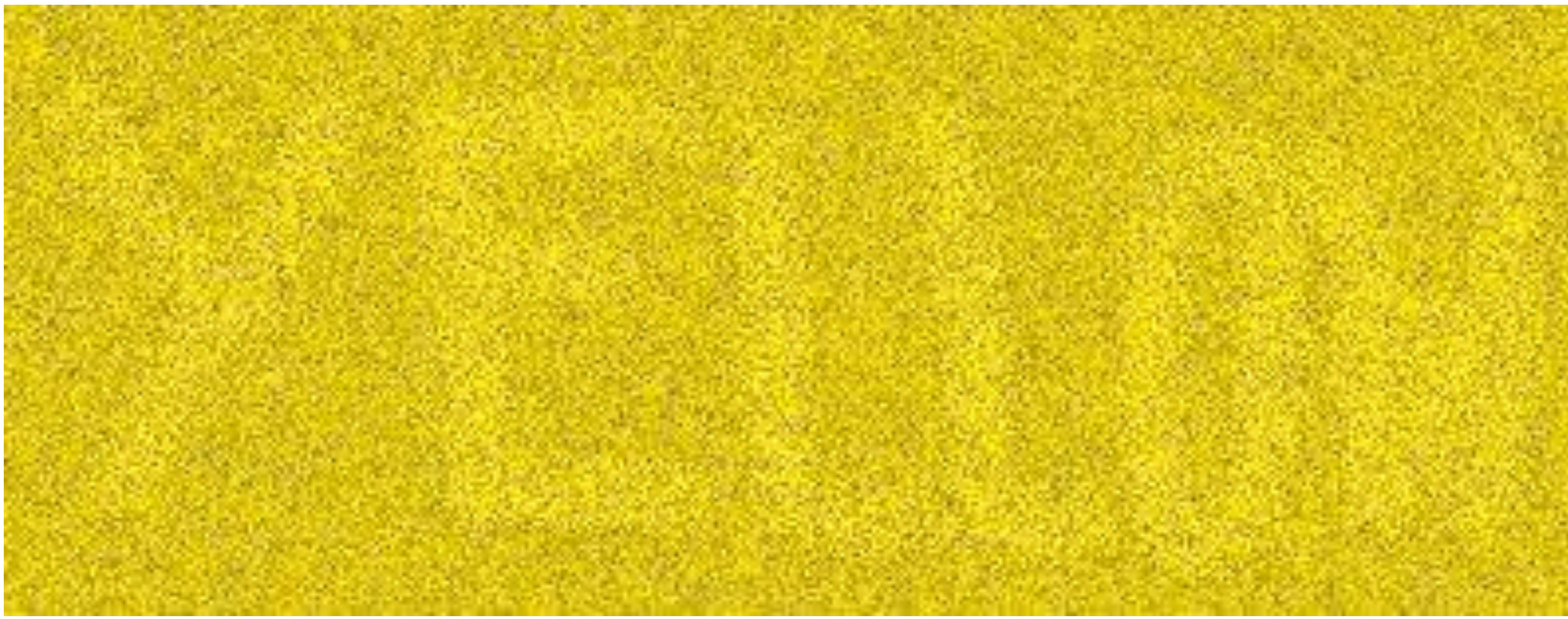


Color Deficiency Test

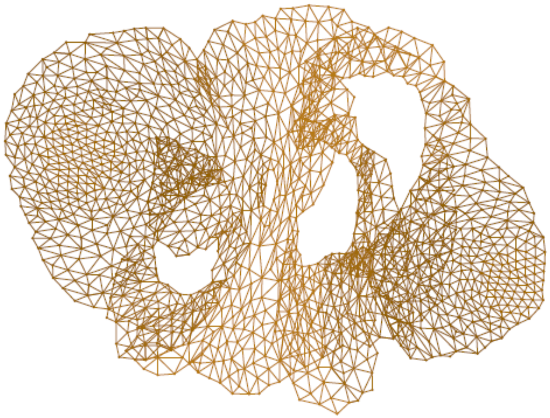


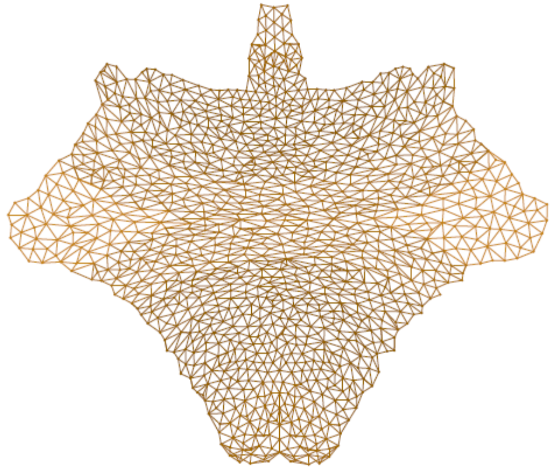


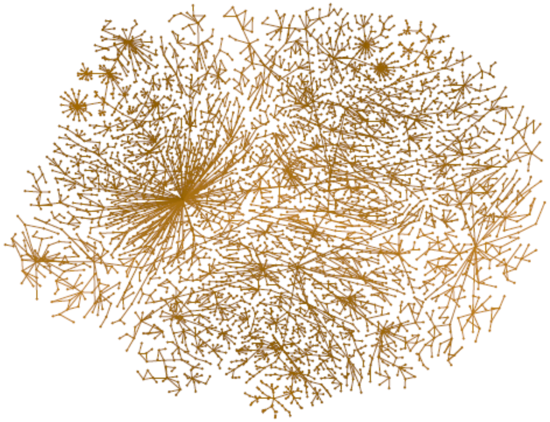
Color Deficiency

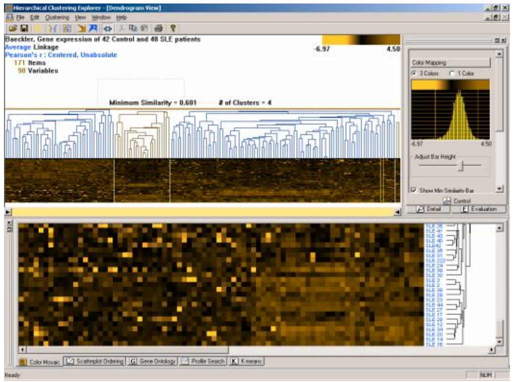


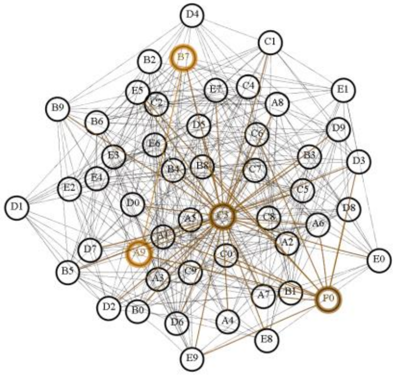
Examples from VIS/InfoVis 2004

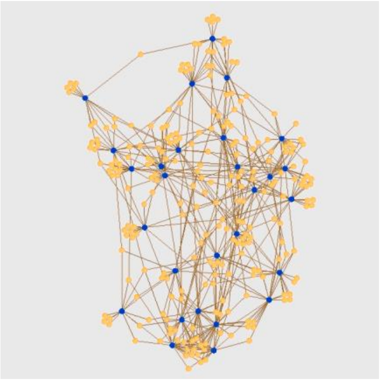




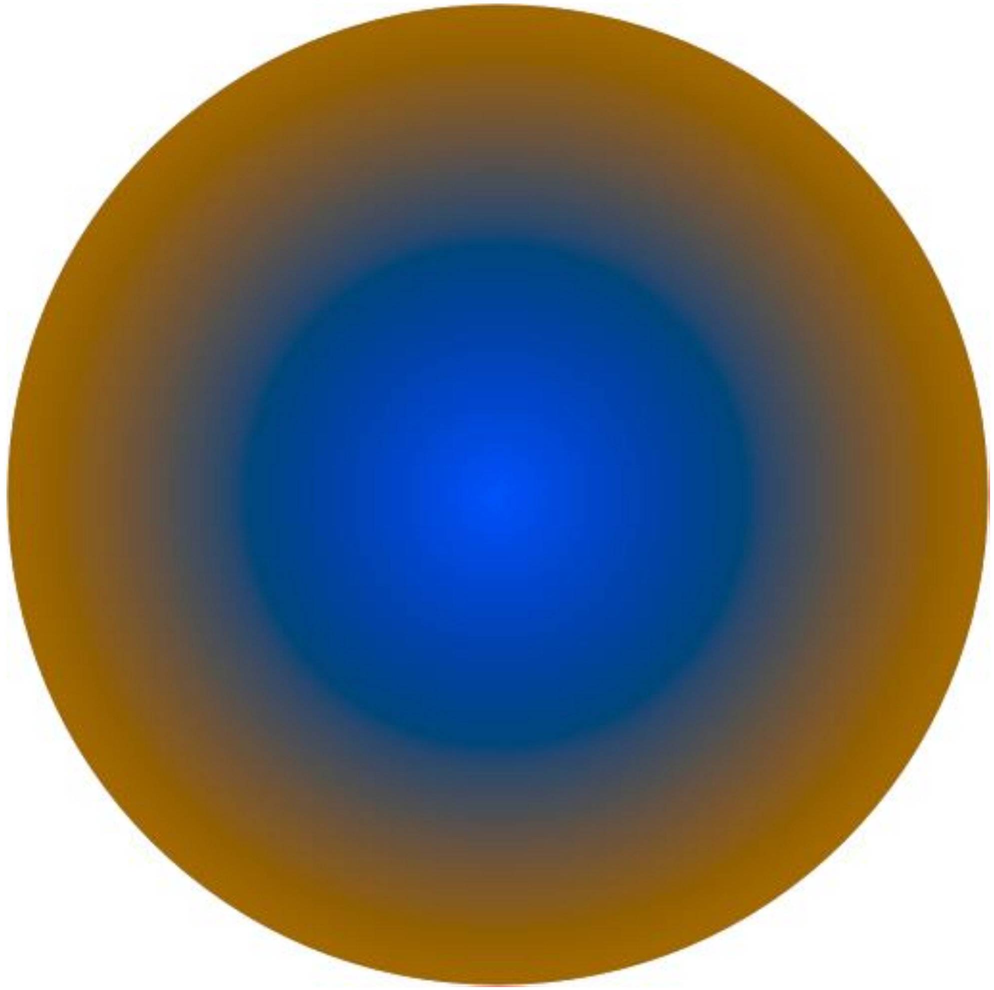






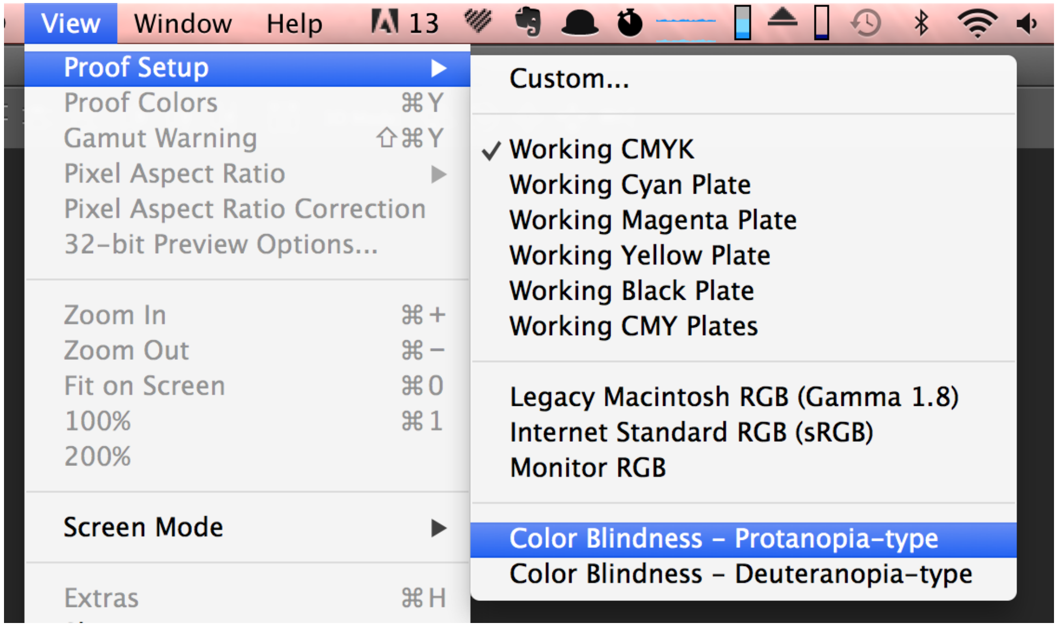


Better: Red-Blue Contrast



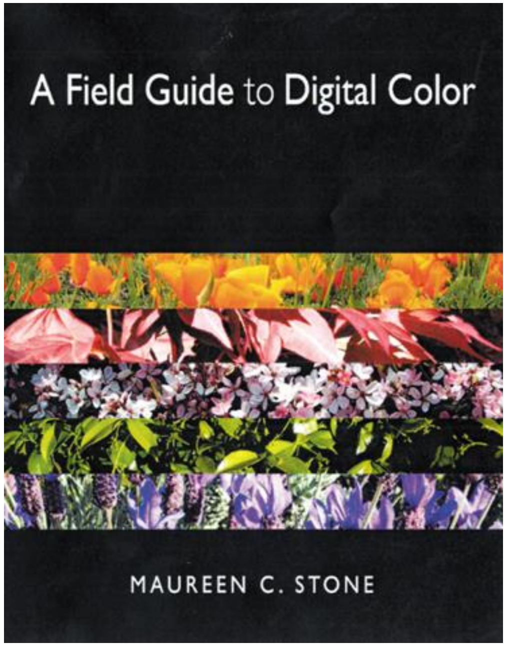
Check Your Visualizations!

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

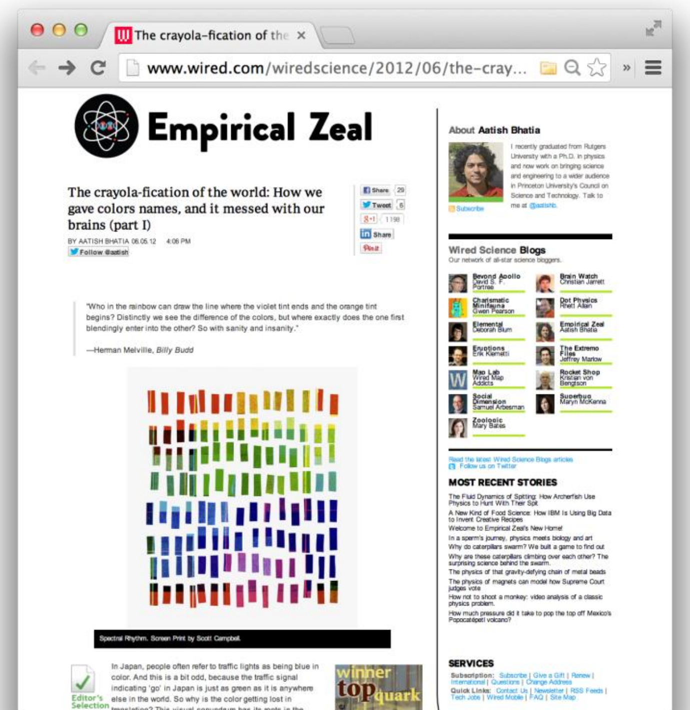
Cindy Brewer's *ColorBrewer*
http://colorbrewer2.org
For CSS and JavaScript
http://bl.ocks.org/mbostock/5577023

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/



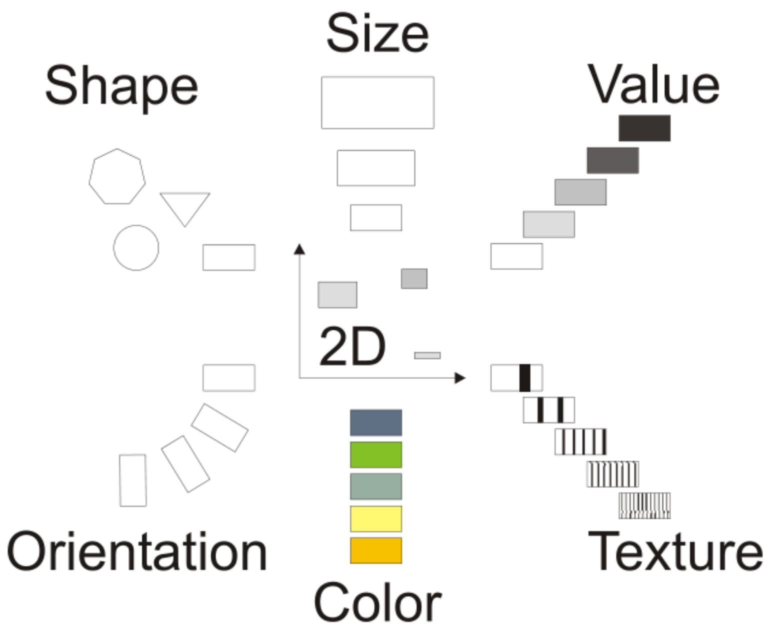
RadioLab "Colors"

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)

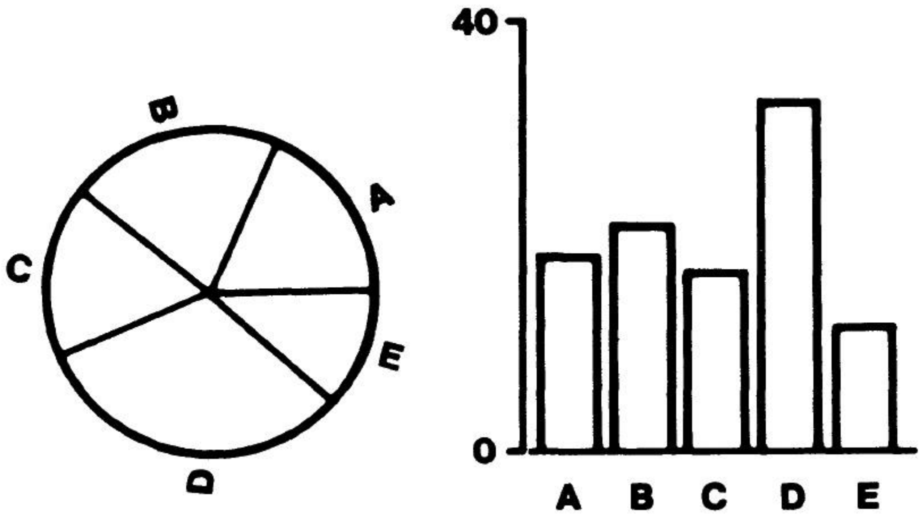


Figure 3. Graphs from position–angle experiment.

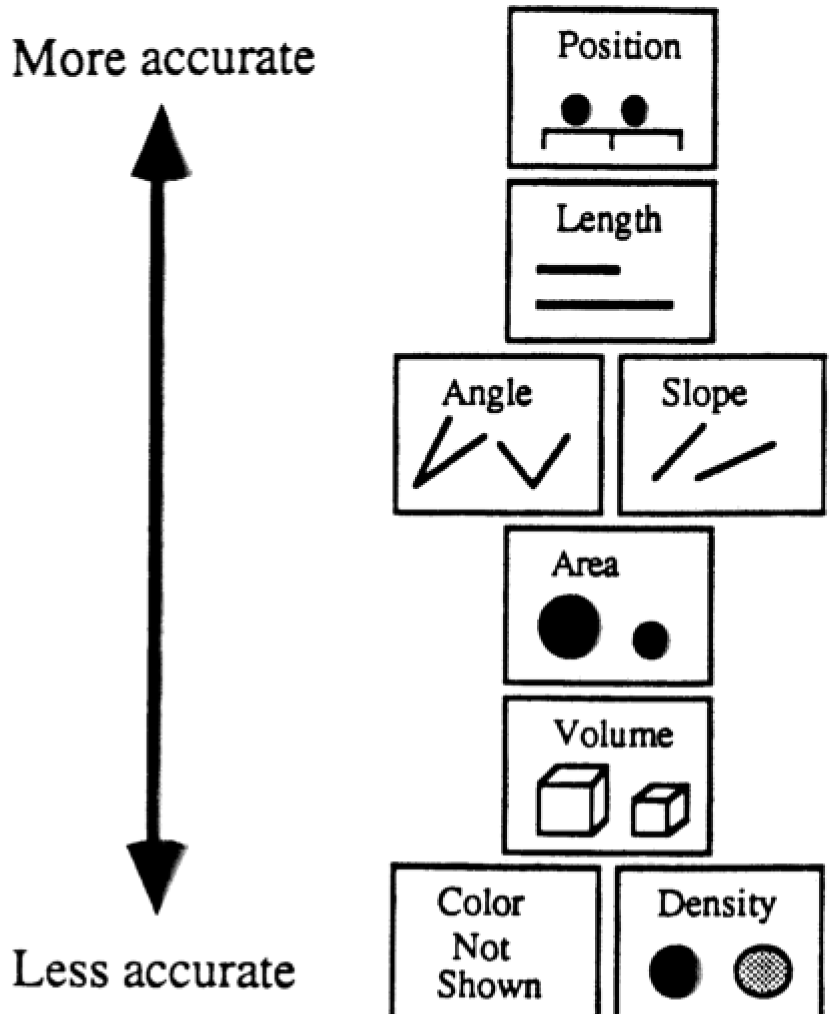
Performed **controlled experiments** to determine how effectively people could judge **changes in visual features**

Focus on **quantitative information**

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

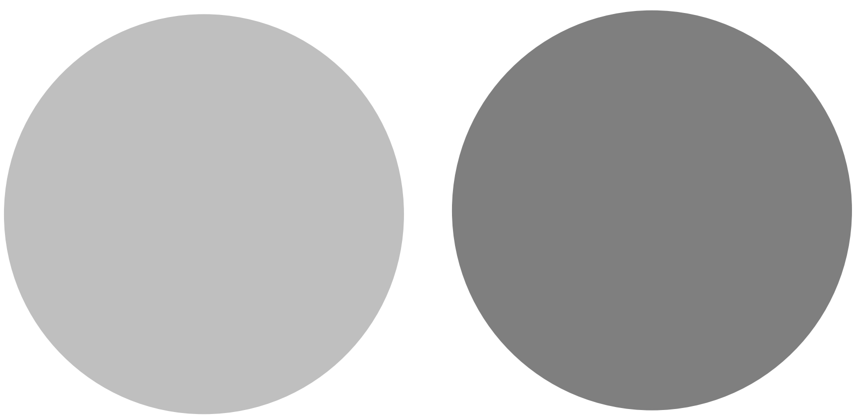
Elementary Graphical Perception Tasks

William S. Cleveland (1980s)

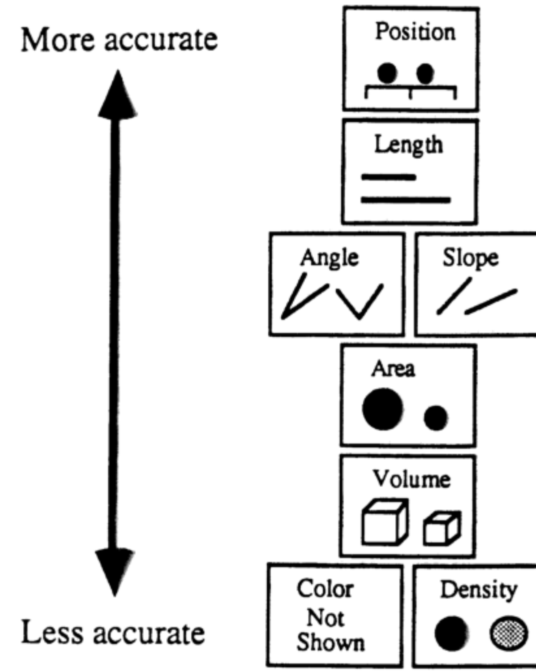


Color Value

What percentage in
value is the right from the left?

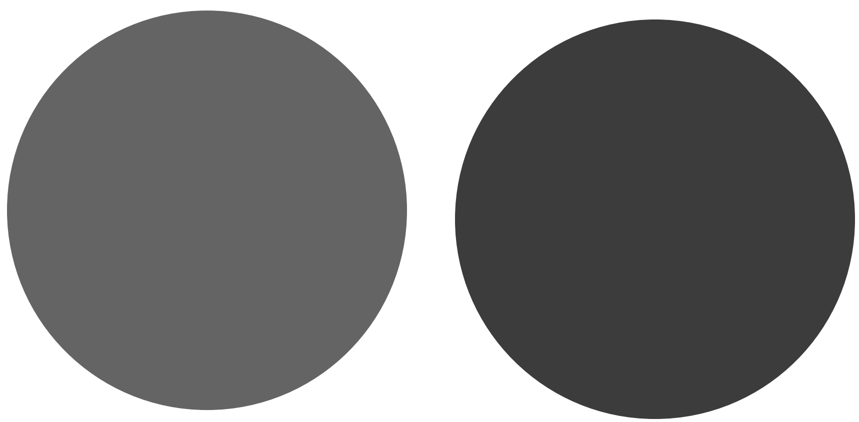


100% 66%

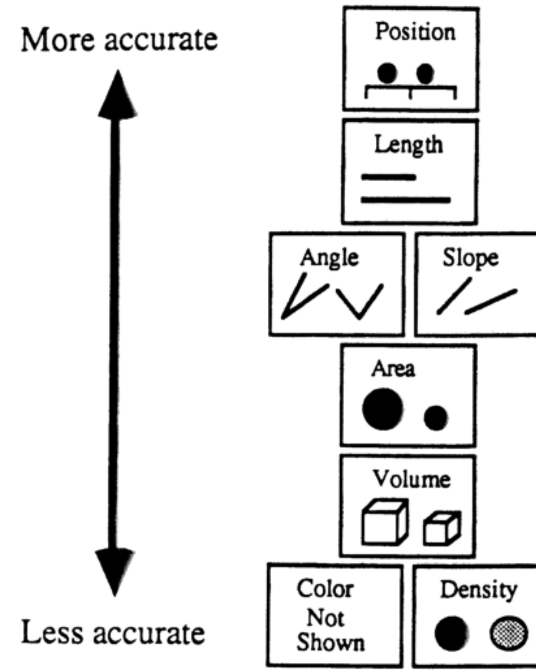


Color Value

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

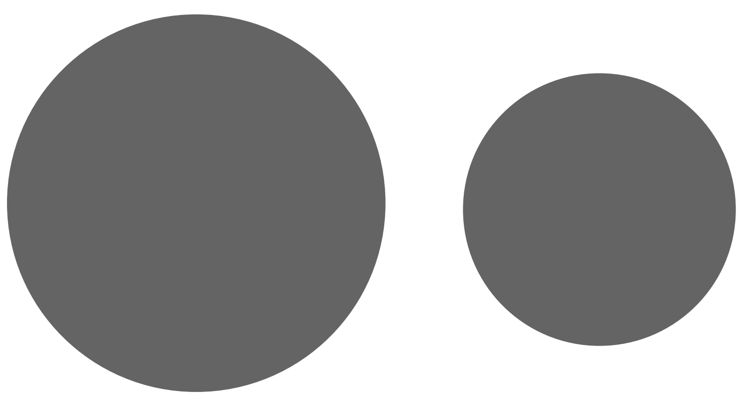


100% 60%



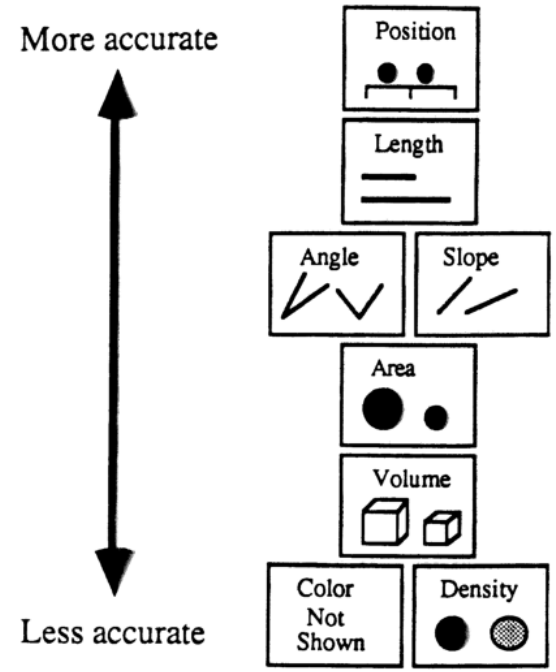
Area

What percentage in
size is the right from the left?



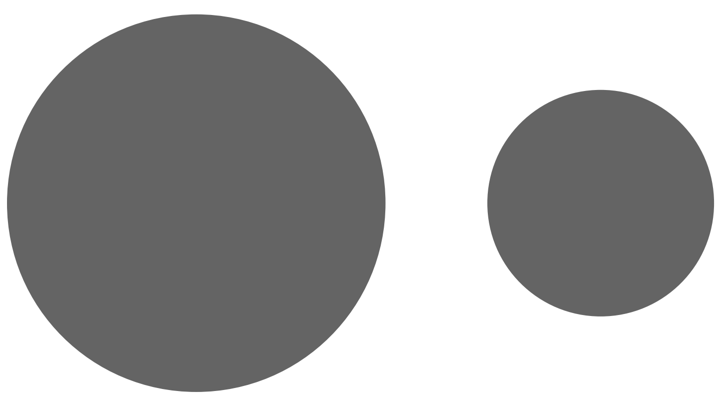
100%

52%

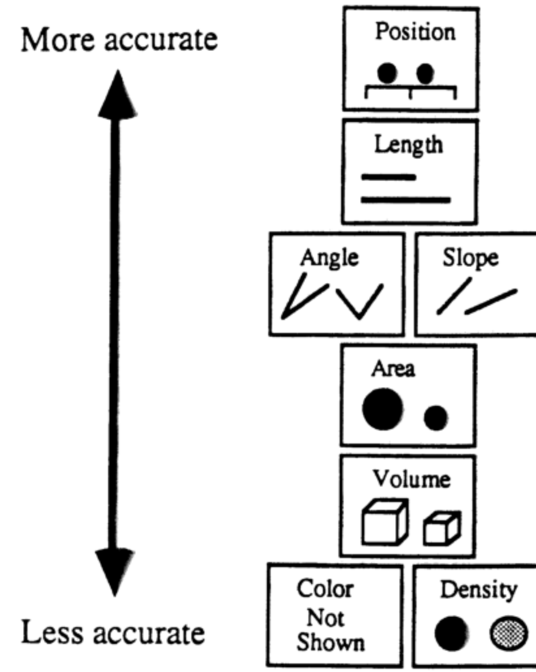


Area

What percentage in
size is the right from the left?

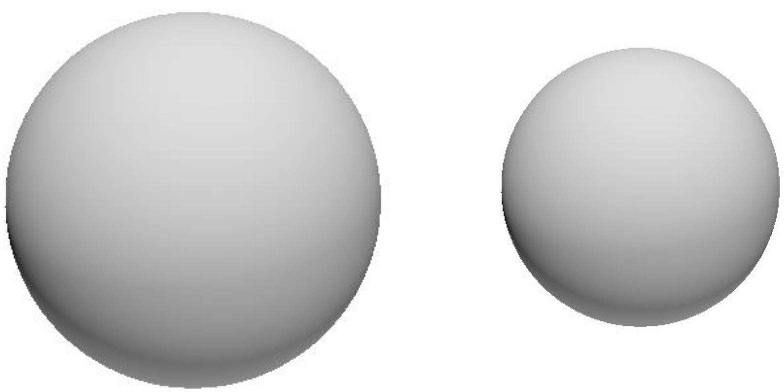


100% 36%

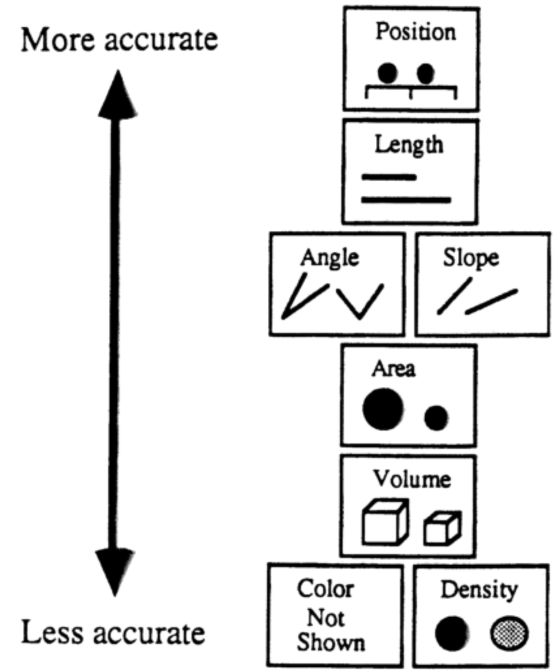


Volume

What percentage in
size is the right from the left?



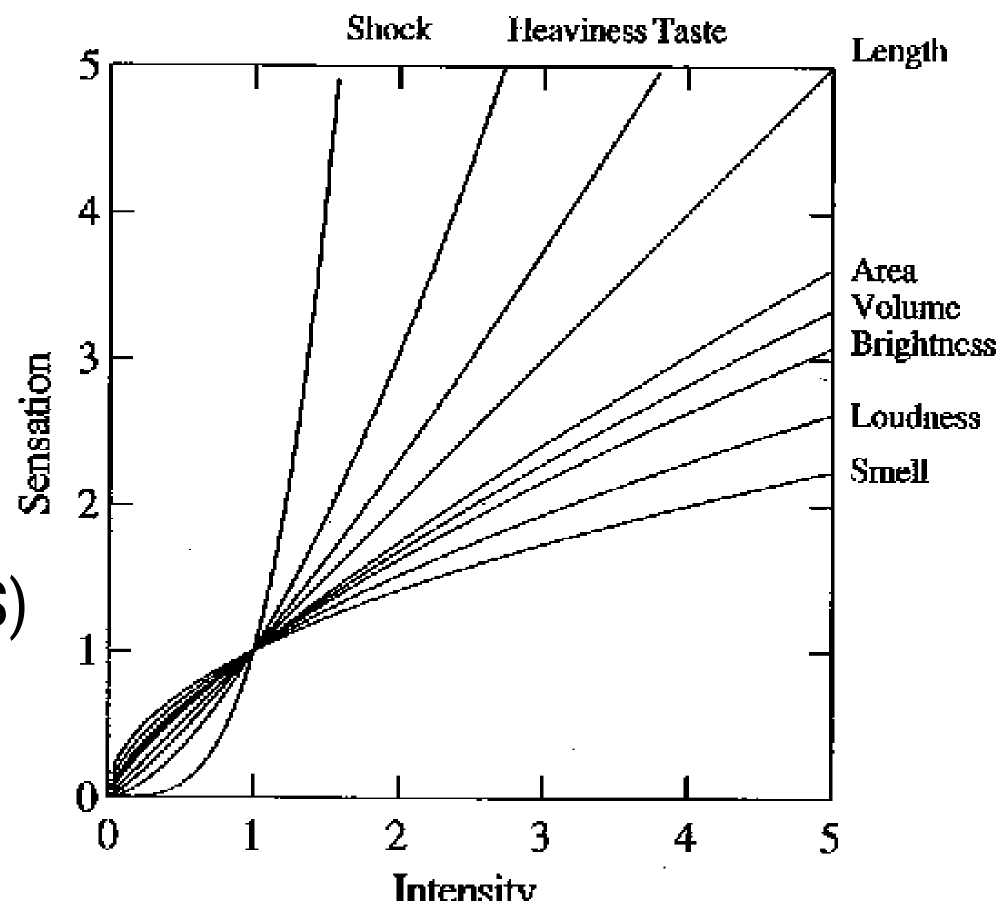
100% 40%



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)

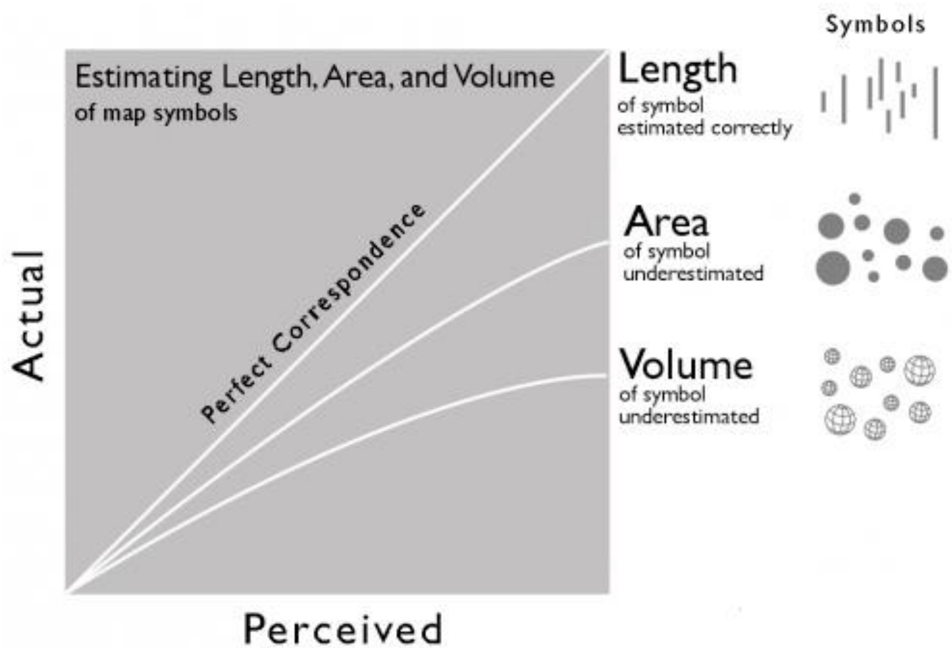


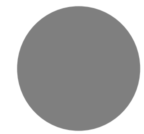
[Graph from Wilkinson 99, based on Stevens 61]

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/

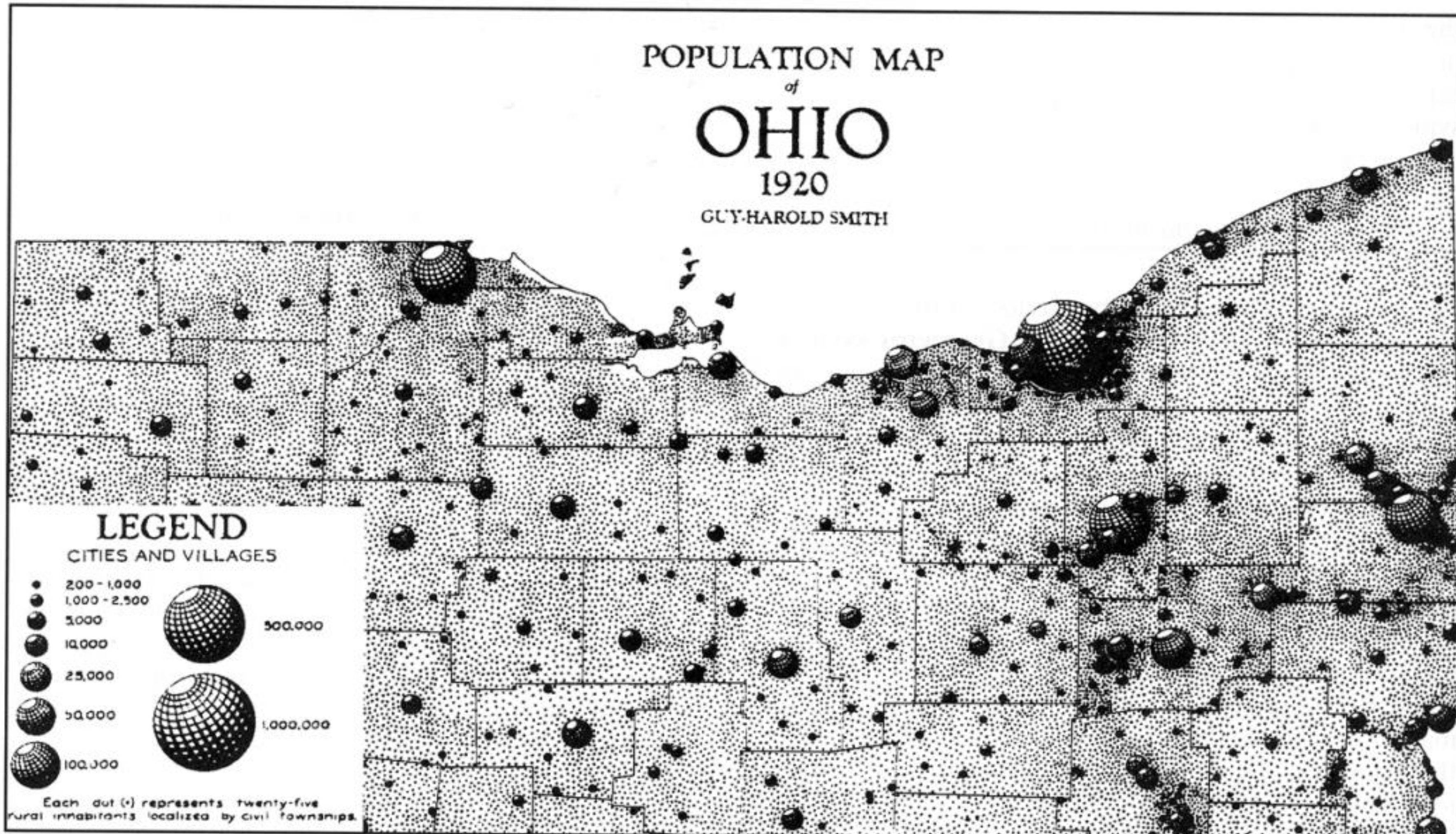
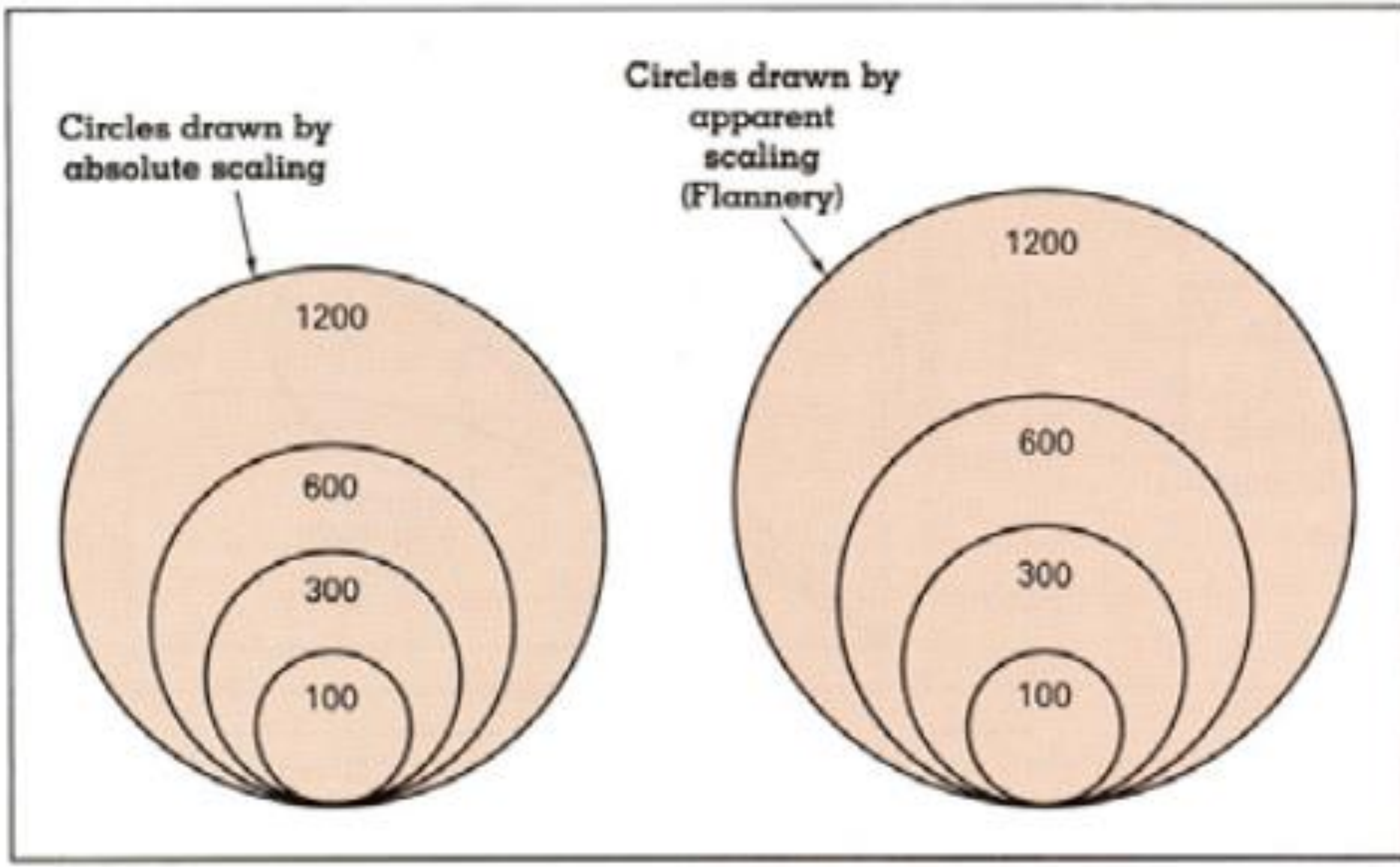


FIGURE 7.4. An eye-catching map created using three-dimensional geometric symbols. (After Smith, 1928. First published in *The Geographical Review,* 18(3), plate 4. Reprinted with permission of the American Geographical Society.)

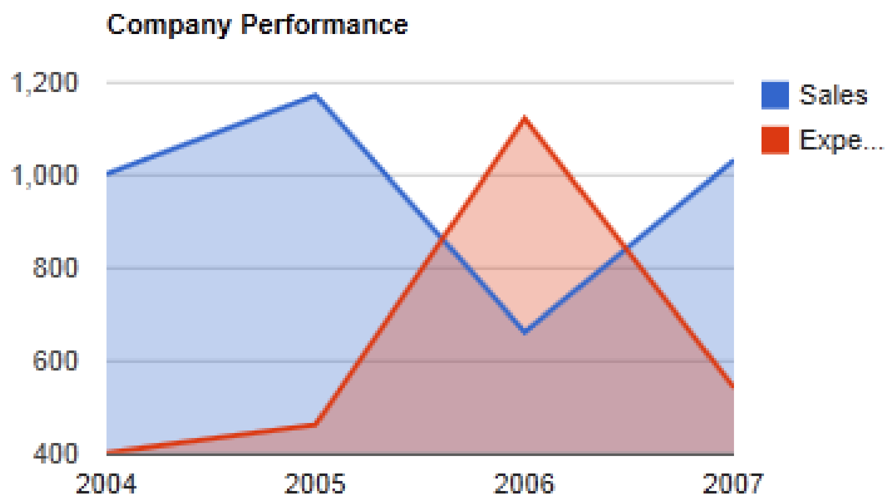


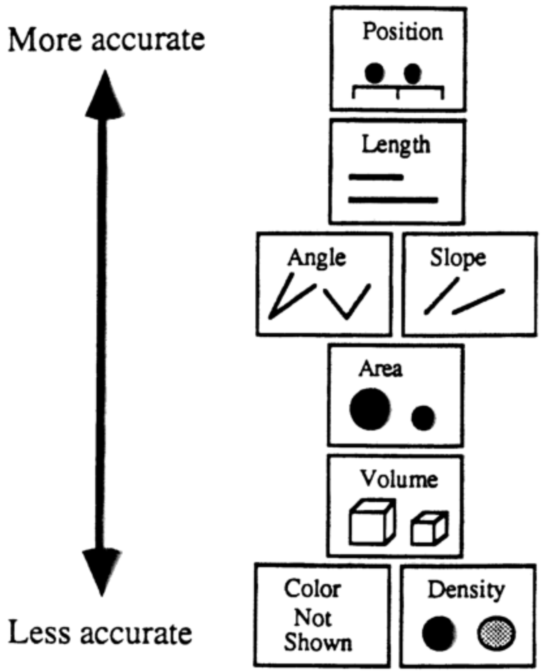
[Cartography: Thematic Map Design, Figure 8.6, p. 170, Dent, 96]

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

Area

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





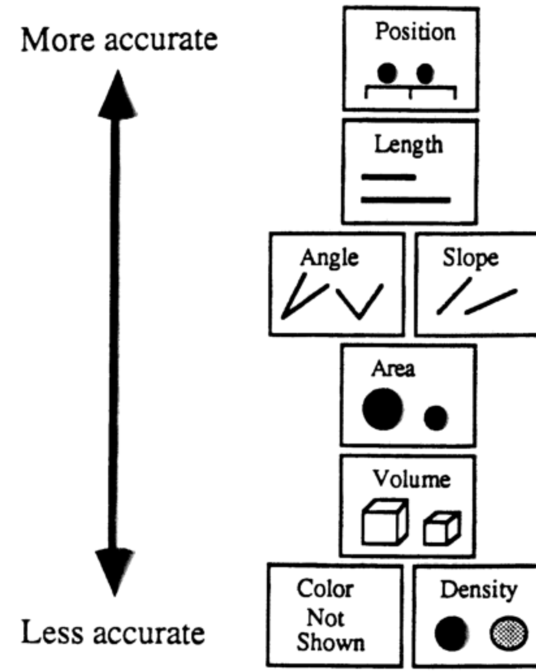
no idea – **this is very difficult**

Length

What percentage in
length is the right from the left?

100%

75%

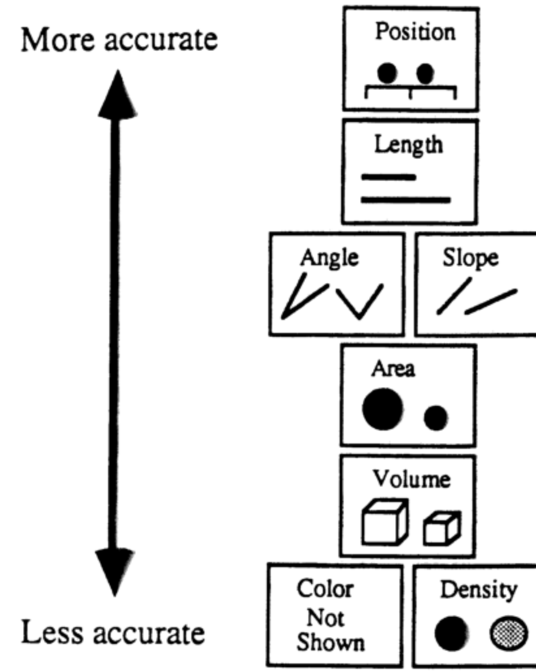


Length / Position

What percentage in
length is the right from the left?

100%

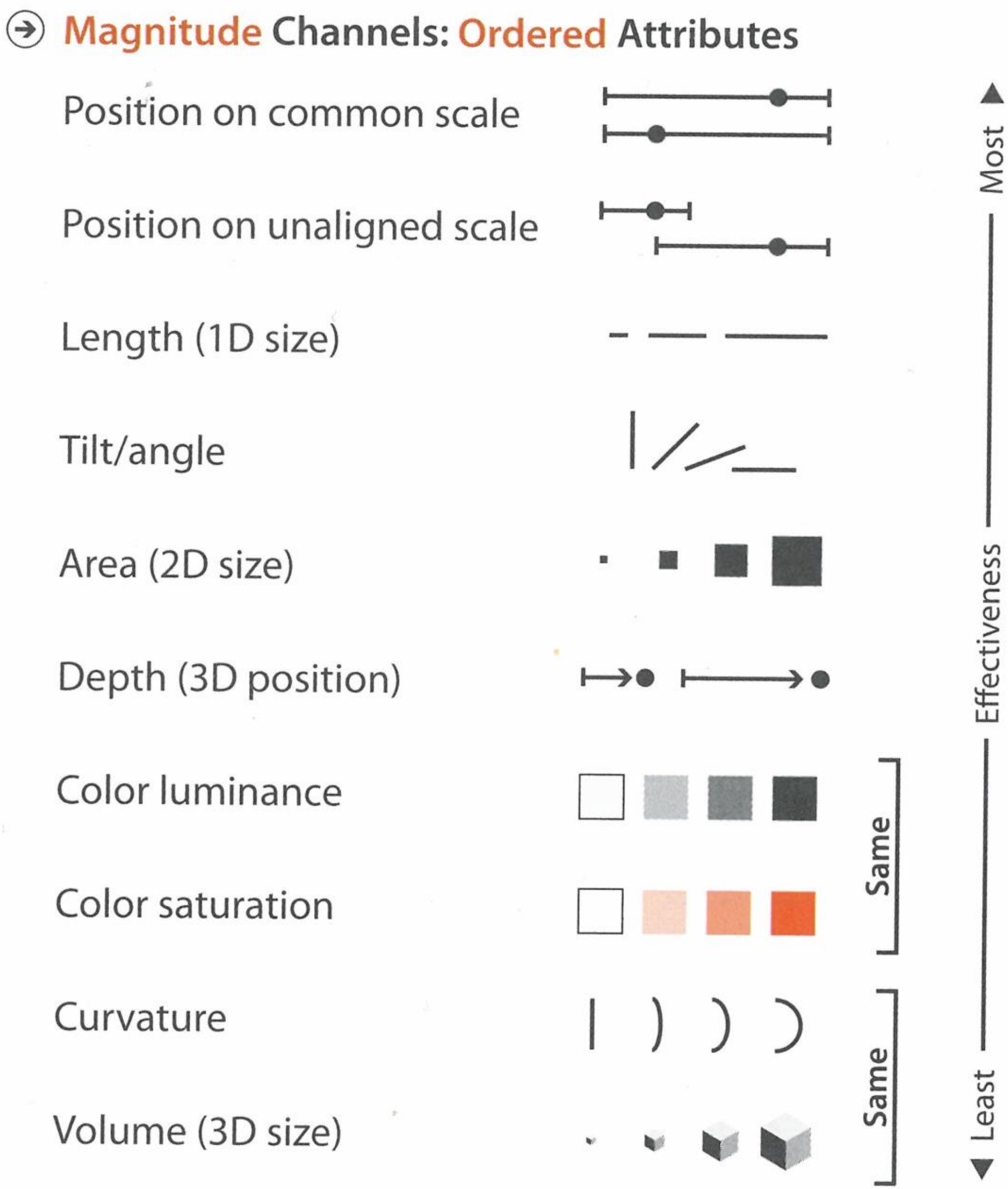
25%

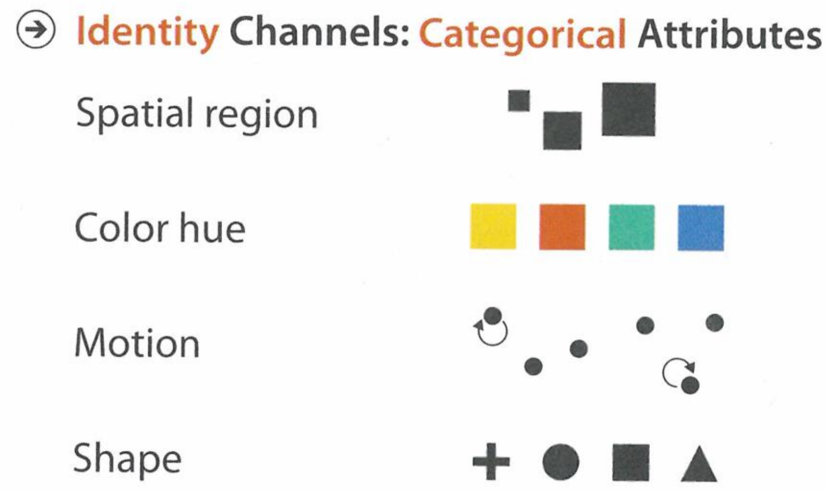


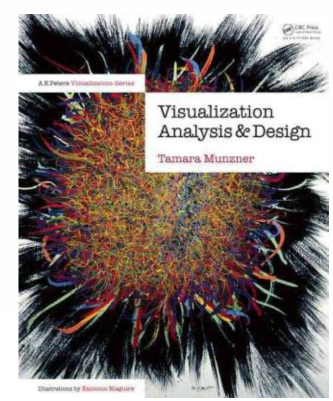
Effectiveness of Data Encodings (Conjecture)

Quantitative	**Ordinal**	**Nominal**
Position	Position	Position
Length	Density	Color Hue
Angle	Color Saturation	Texture
Slope	Color Hue	Connection
Area	Texture	Containment
Volume	Connection	Density
Density	Containment	Color Saturation
Color Saturation	Length	Shape
Color Hue	Angle	Length
Texture	Slope	Angle
Connection	Area	Slope
Containment	Volume	Area
Shape	Shape	Volume

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

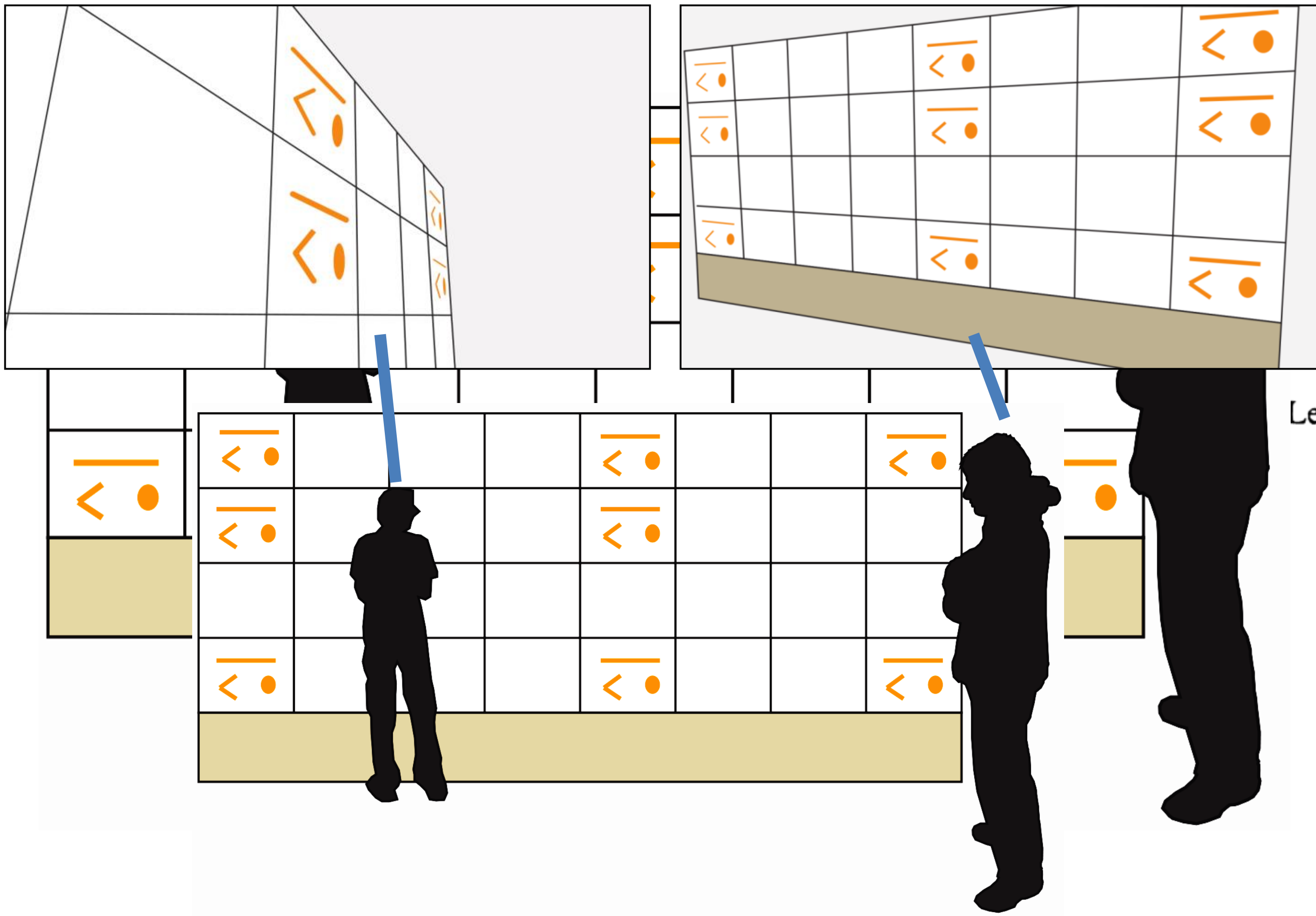

Identity Channels: Categorical Attributes
Spatial region
Color hue
Motion
Shape

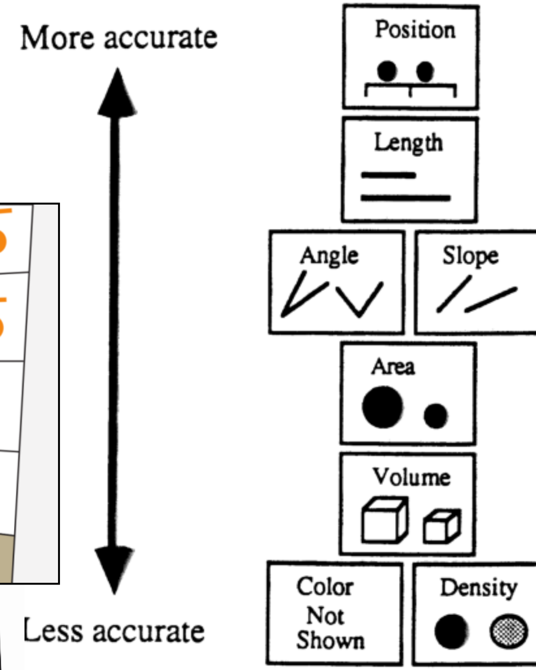

Visualization
Analysis & Design
Tamara Munzner

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

From: Ware, Information Visualization using Vision to Think

How about now?

1281768756138976546984506985604982826762
9809858458224509856458945098450980943585
9091030209905959595772564675050678904567
8845789809821677654876364908560912949686

From: Ware, Information Visualization using Vision to Think

Preattentive Processing

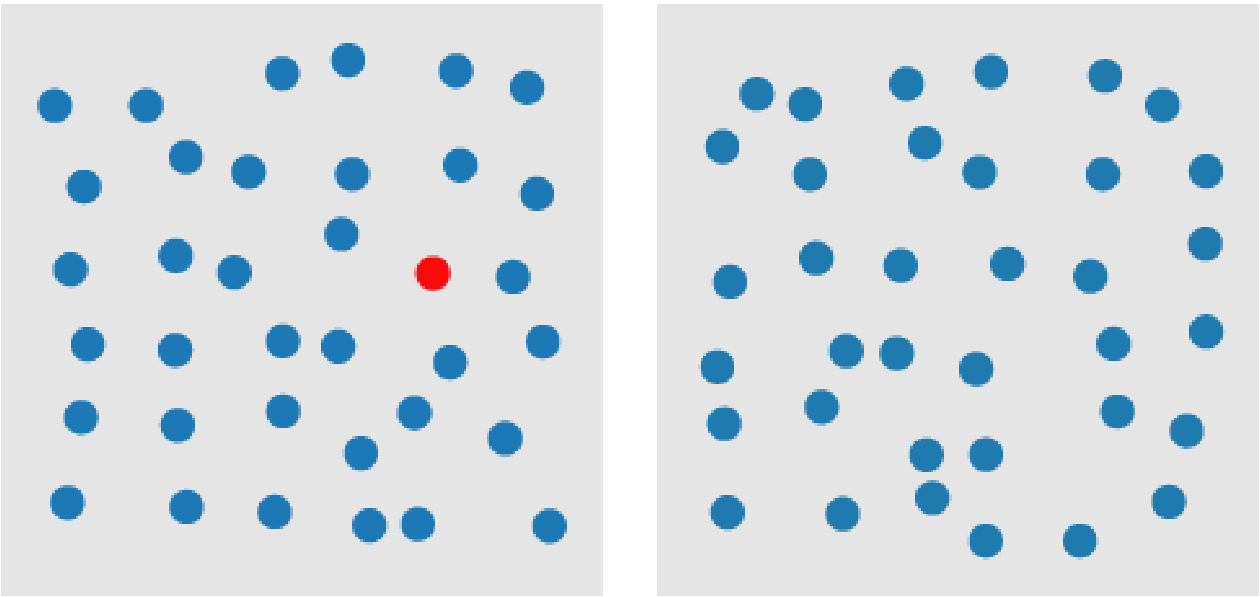
- Some stimuli can be perceived **without** the need for focused attention
- Generally within **200-250 ms**
- Seems to be done **in parallel** by the low-level vision system

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

Visual encodings influence **preattentive** processing

DETERMINE IF A RED CIRCLE IS PRESENT

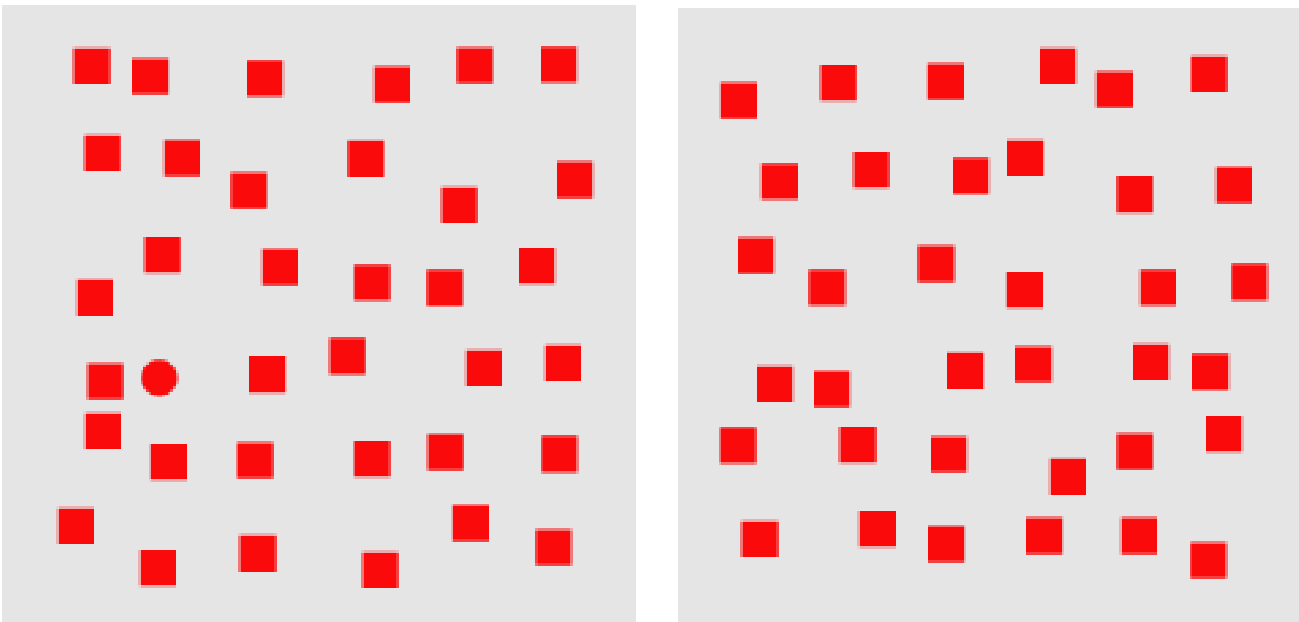
Hue



Yes, can be done preattentively

From: Healey, Perception in Visualization

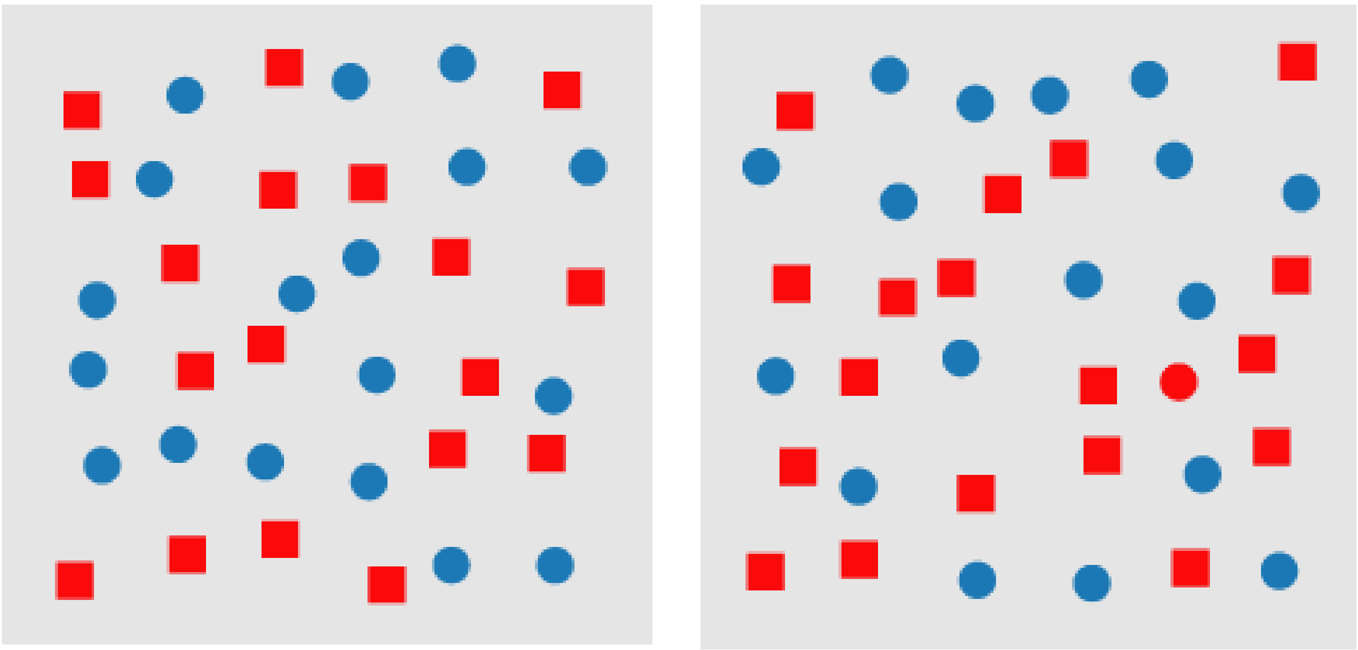
Shape



Yes, can be done preattentively

From: Healey, Perception in Visualization

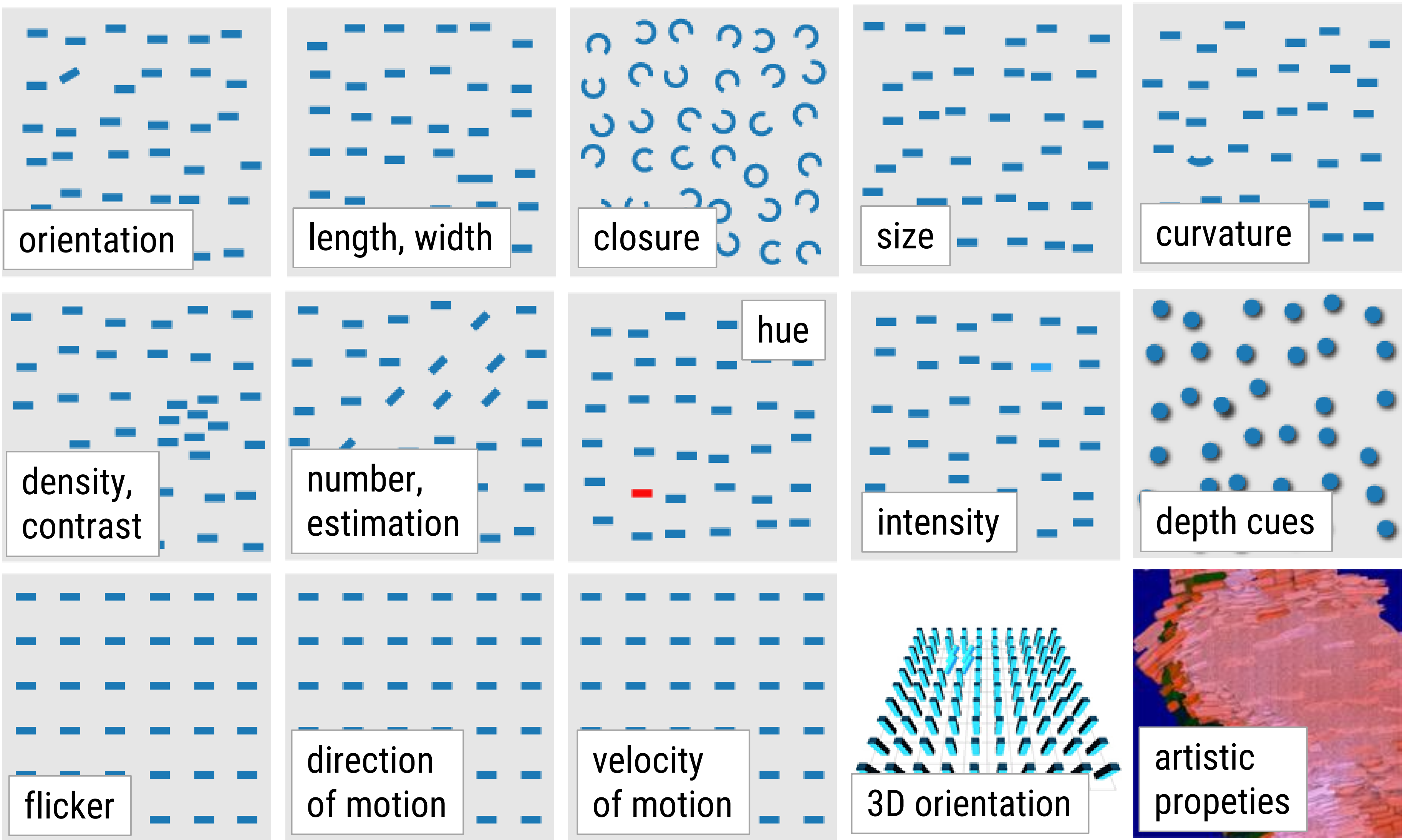
Hue and Shape



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

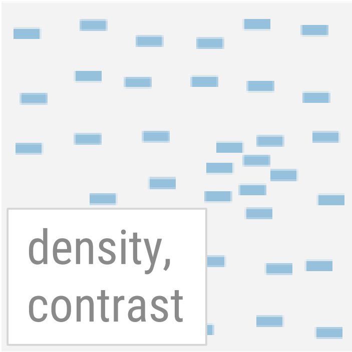
From: Healey, Perception in Visualization

Preattentive visual features (some)

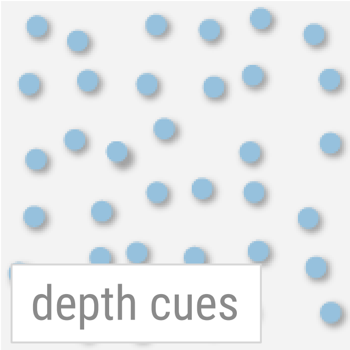


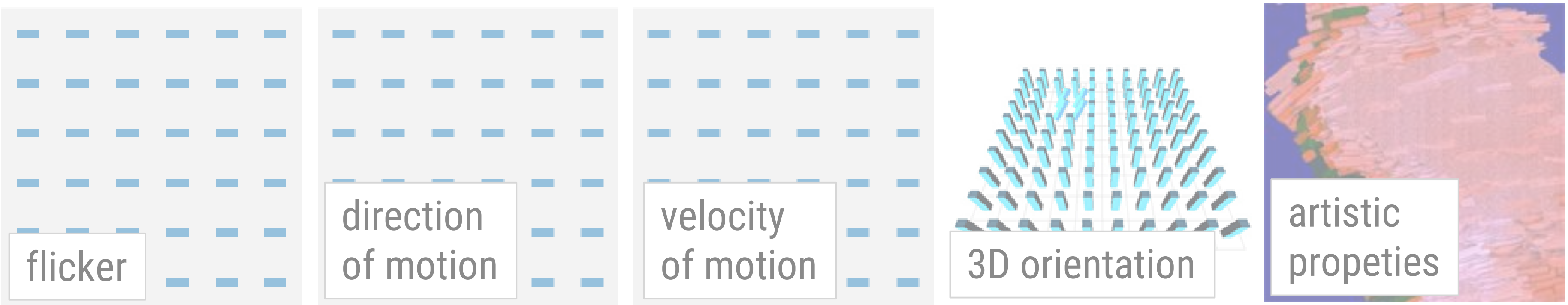
From: Healey, Perception in Visualization

Preattentive visual features (some)



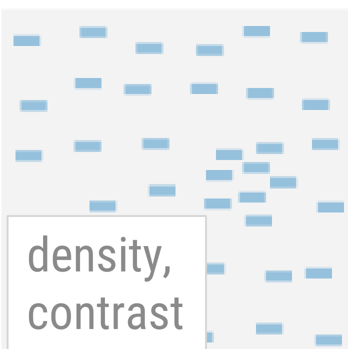
When designing visualizations, try to **use pre-attentive** features to support the **most important tasks**.





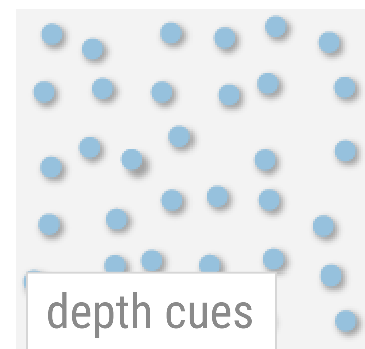
From: Healey, Perception in Visualization

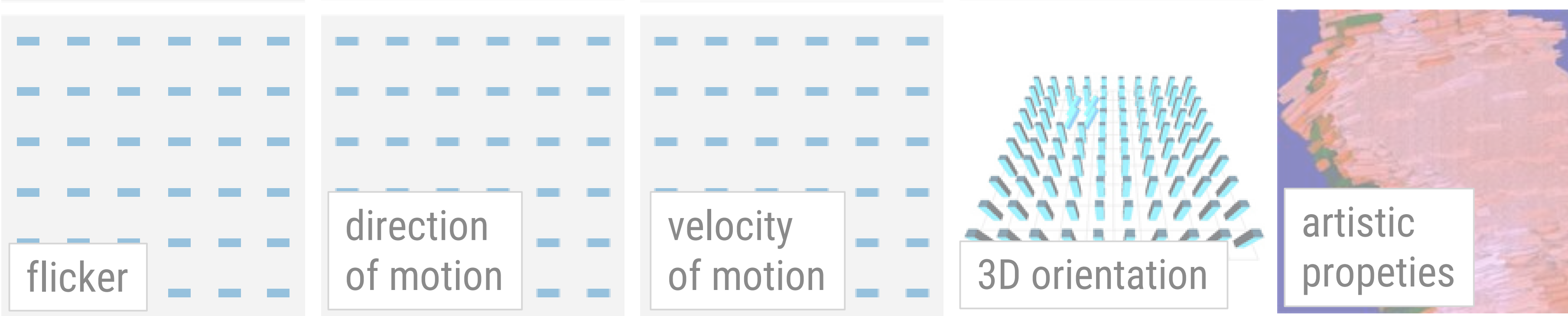
Preattentive visual features (some)



Avoid conjunctions that inhibit preattentive recognition.

(**Most conjunctions** are require search.)





From: Healey, Perception in Visualization

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

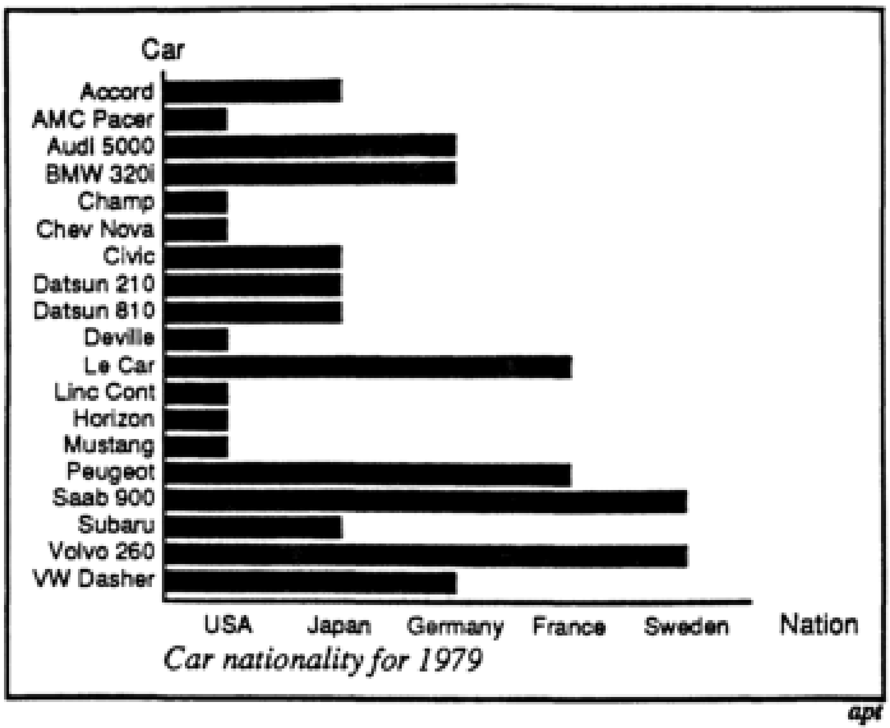
What kind of data are we looking at?

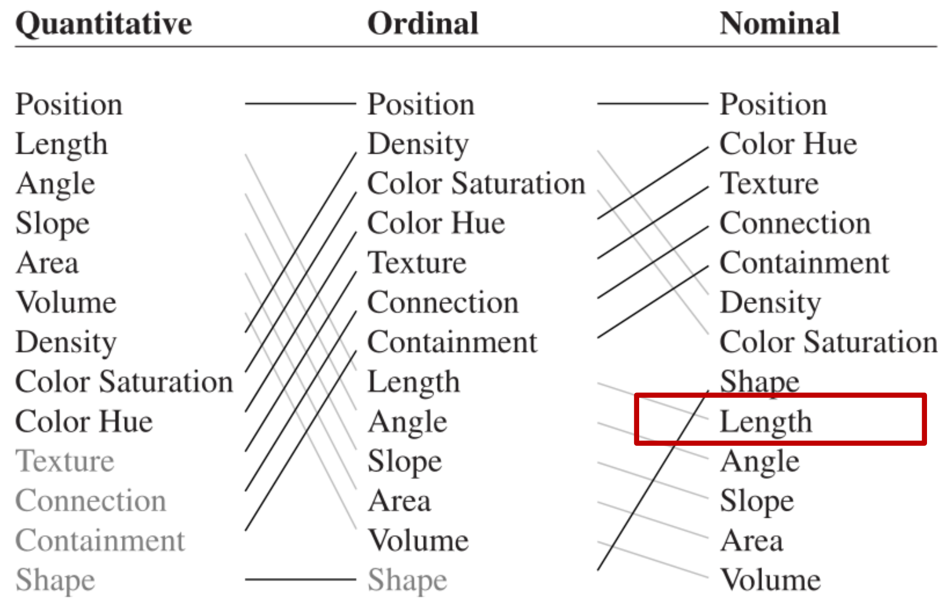
Nations: **Nominal**

Cars: **Nominal**

(Nation,Car): **Nominal**

Let’s evaluate…

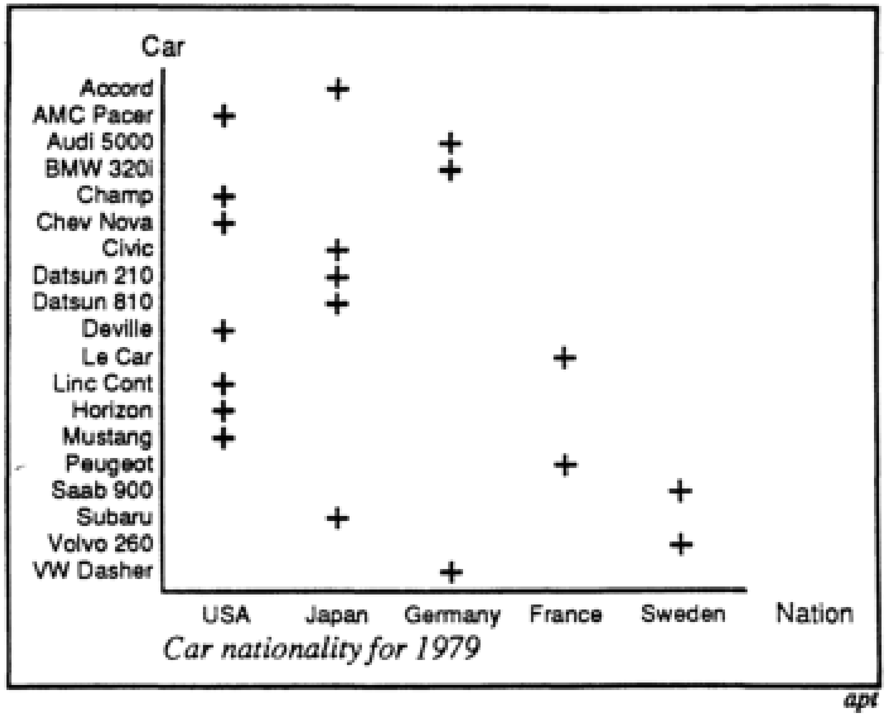


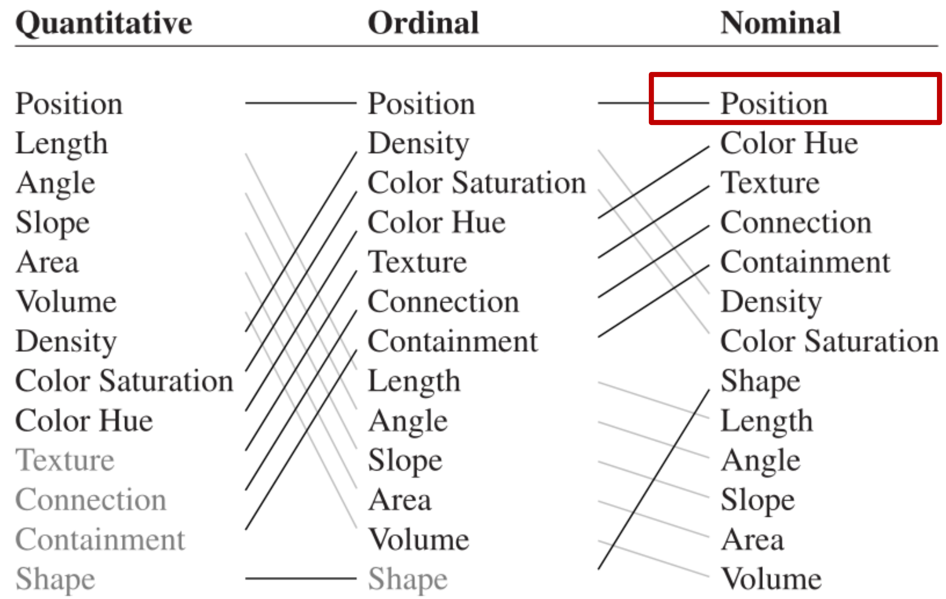


Problem:

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

Let's evaluate…





Better!

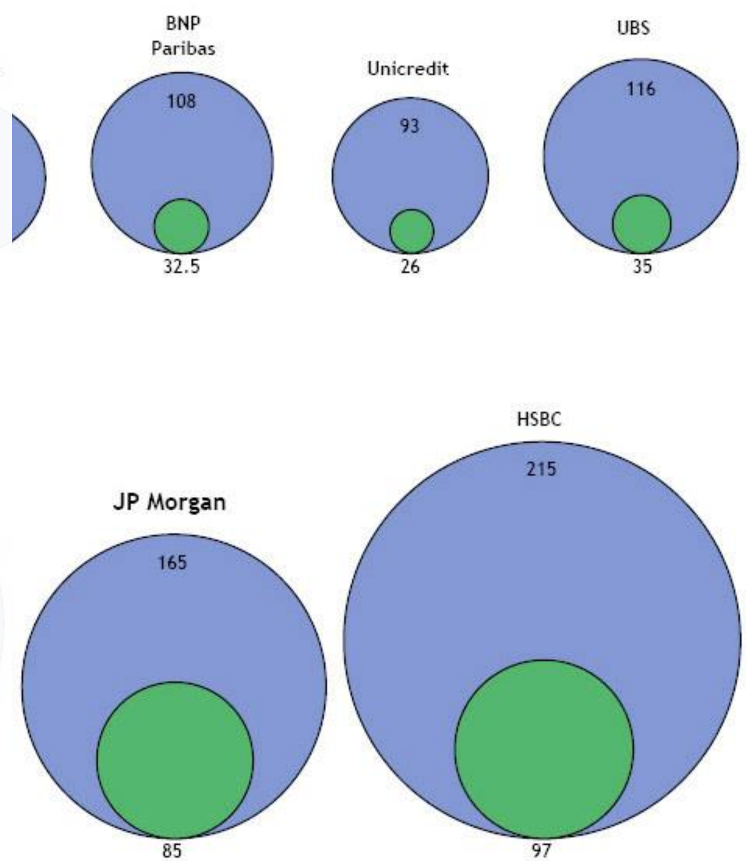
Let's evaluate…

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:

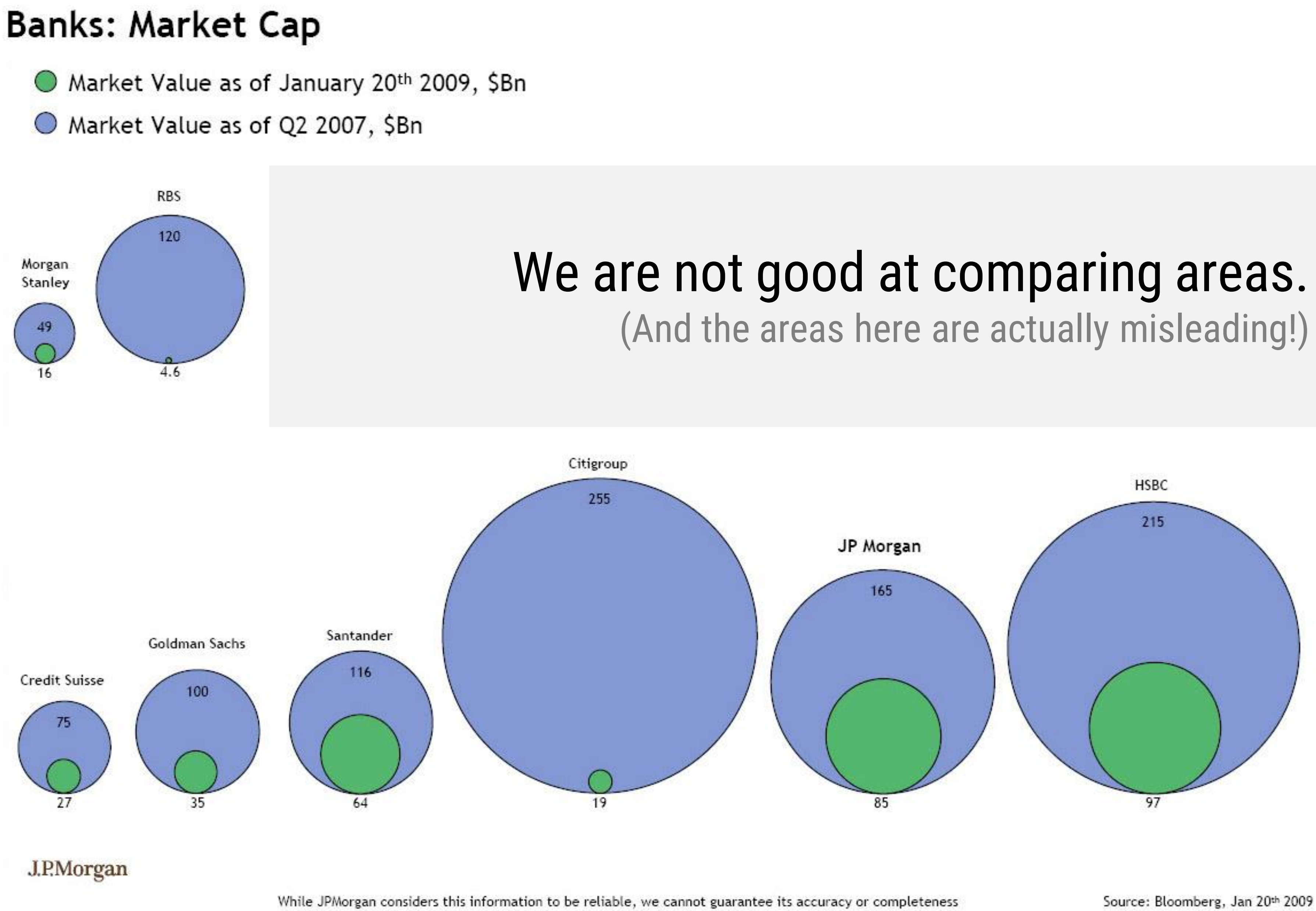
- January 20th, 2009
- Q2 2007 (before banking crisis hit)

J.P.Morgan

While JPMorgan considers this information to be reliable, we cannot guarantee its accuracy or completeness

Source: Bloomberg, Jan 20th 2009

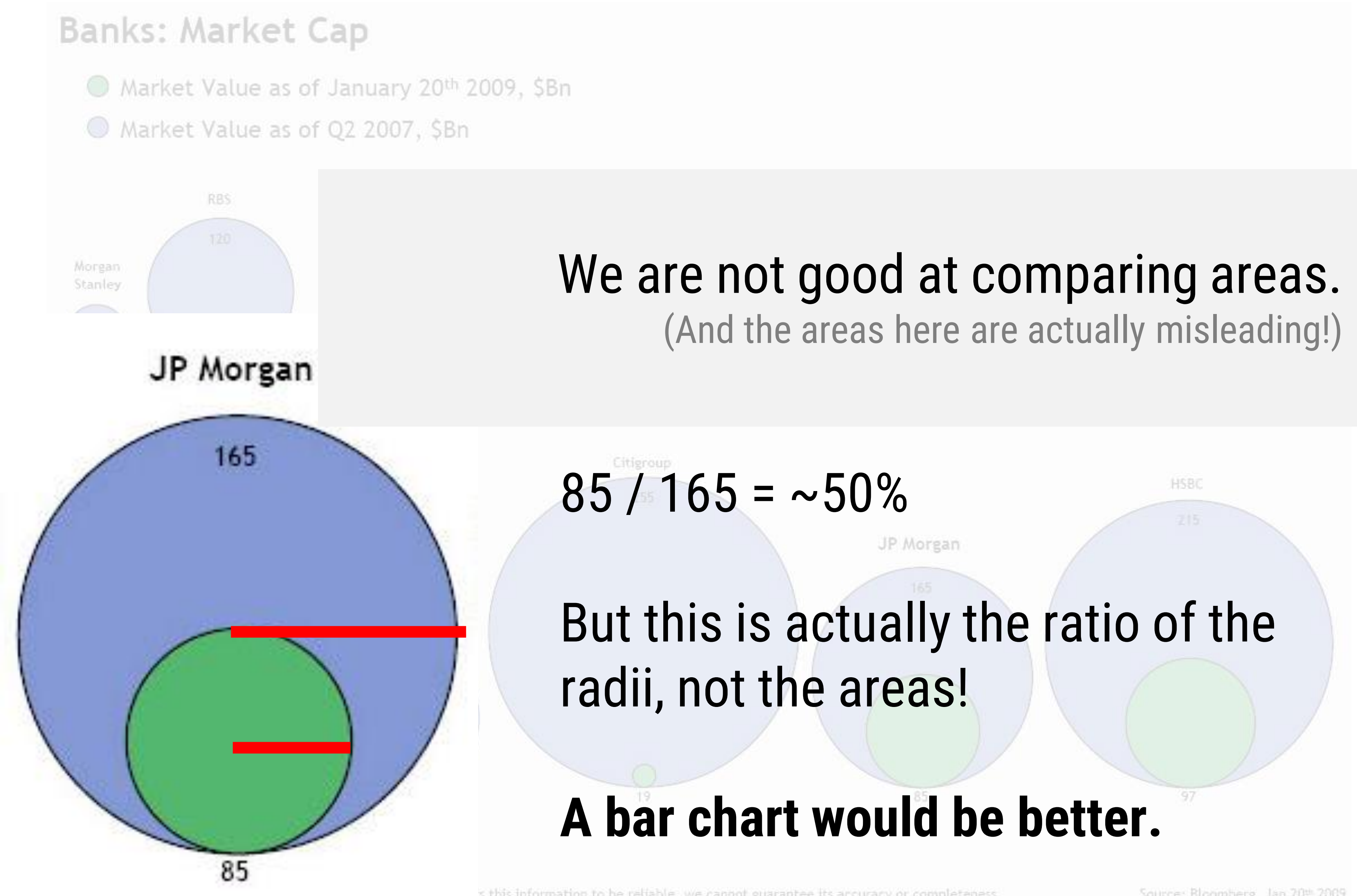
Problems here?



We are not good at comparing areas.

(And the areas here are actually misleading!)

Problems here?



We are not good at comparing areas.

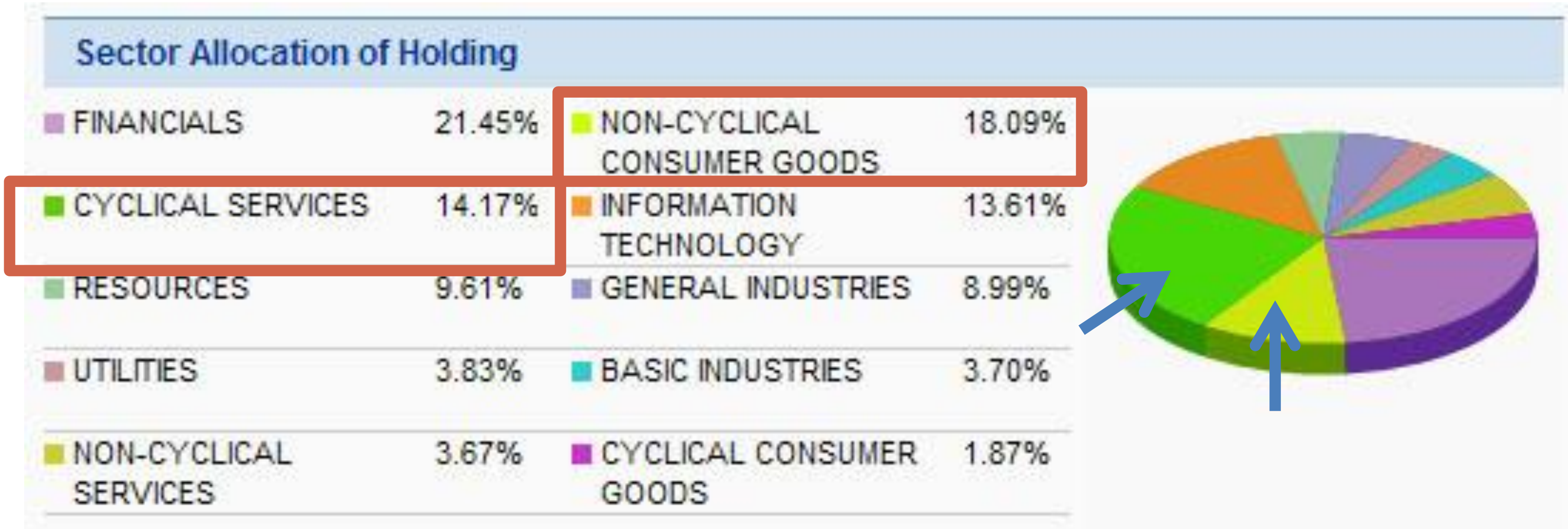
(And the areas here are actually misleading!)

85 / 165 = ~50%

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

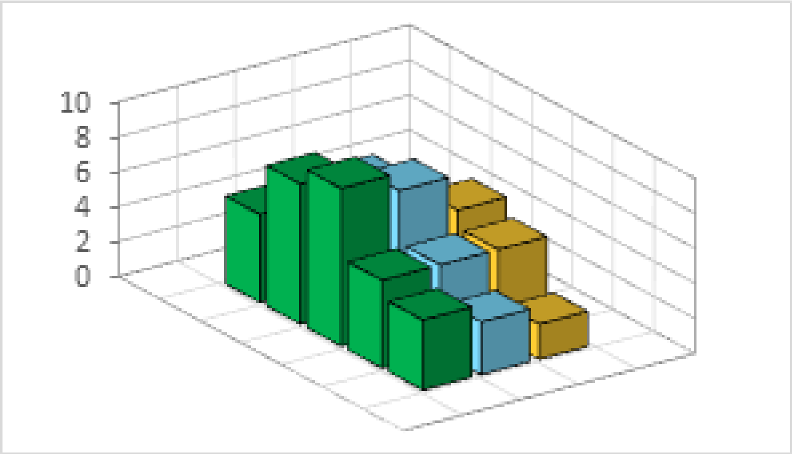
A bar chart would be better.

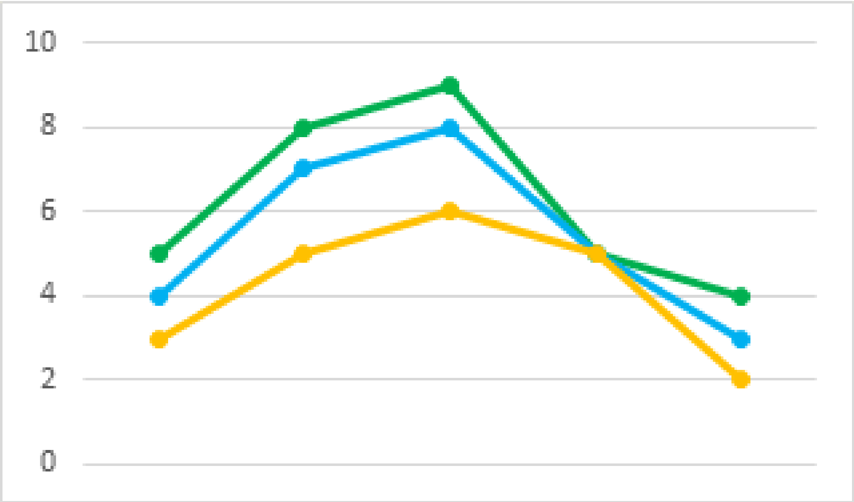
Problem here?



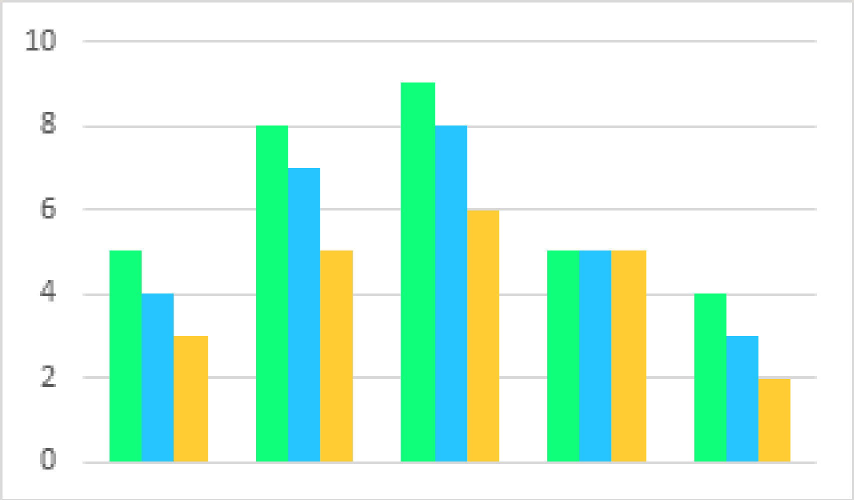
- There is likely a **bug or error** in the data
- Pie slices are difficult to compare by **area** or by **angle**
- **Similar colors** are difficult to distinguish
- **Perspective distortion** adds to the problem

Similarly…3D bar charts are not recommended



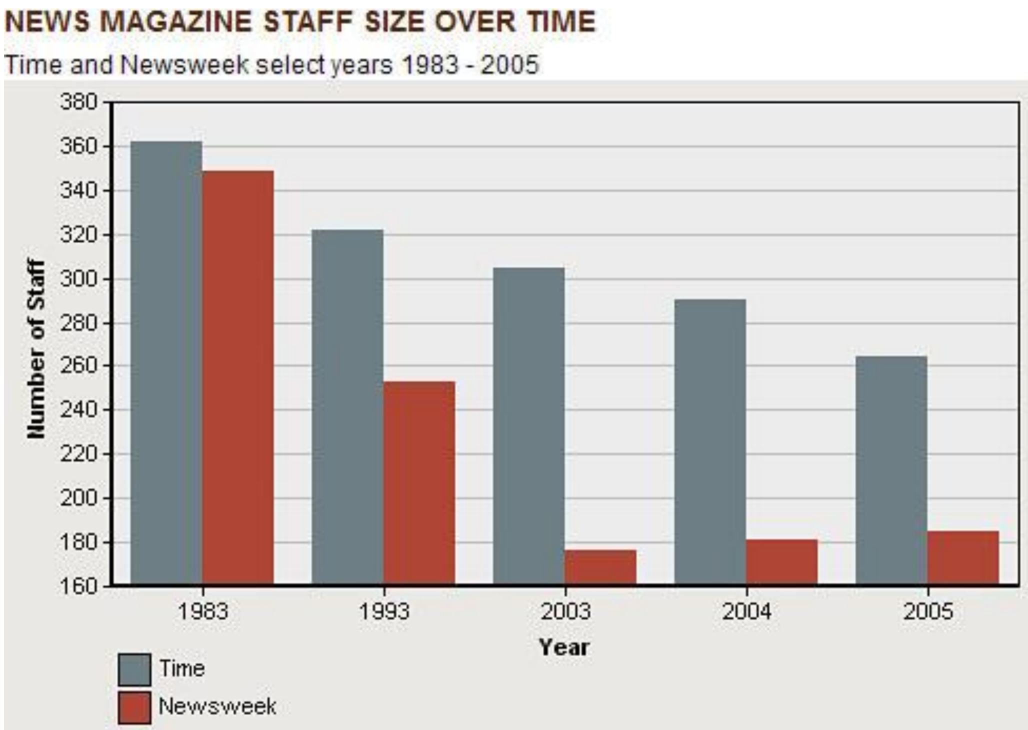


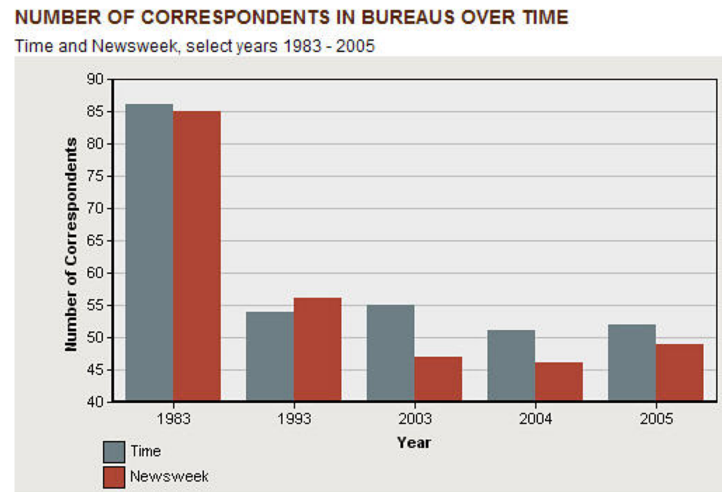
These are **much easier** to read & compare!

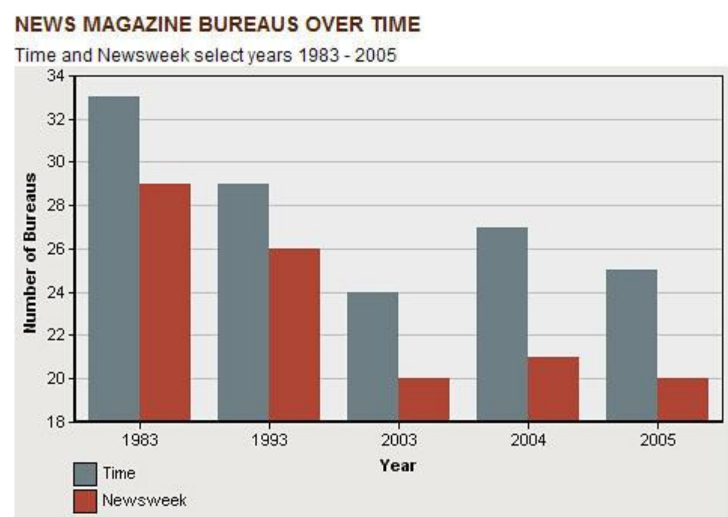


John Peltier http://peltiertech.com/WordPress/3d-bar-chart-alternatives/

Problem here?

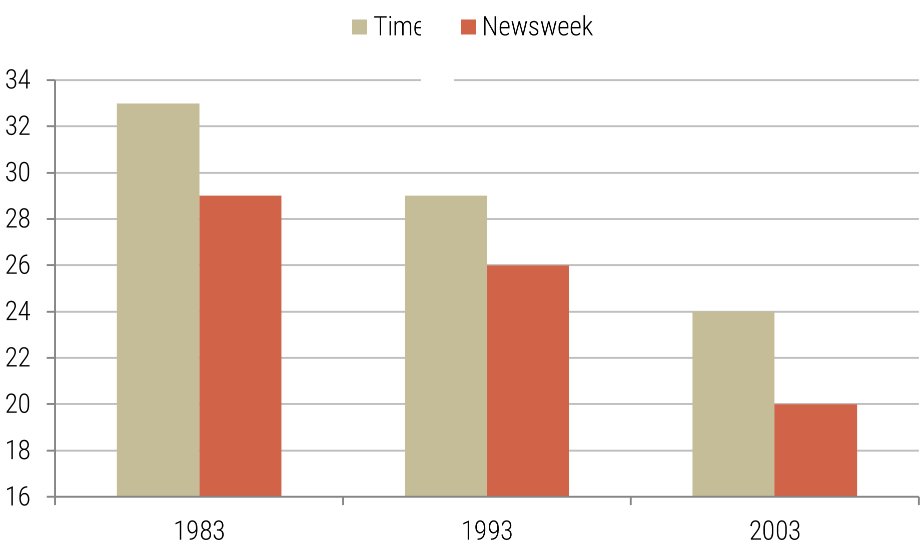


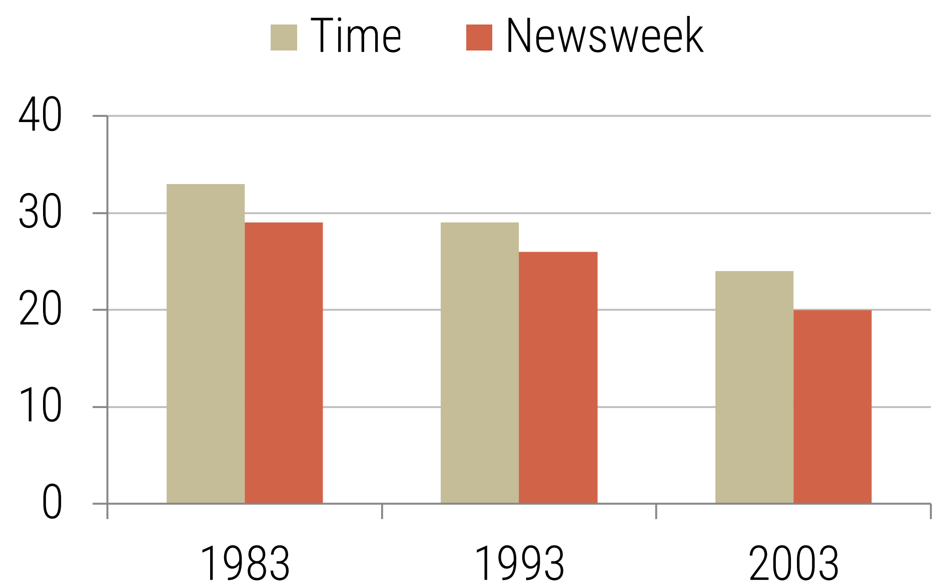




Journalism.org (via Stephen Few)

Length Comparison





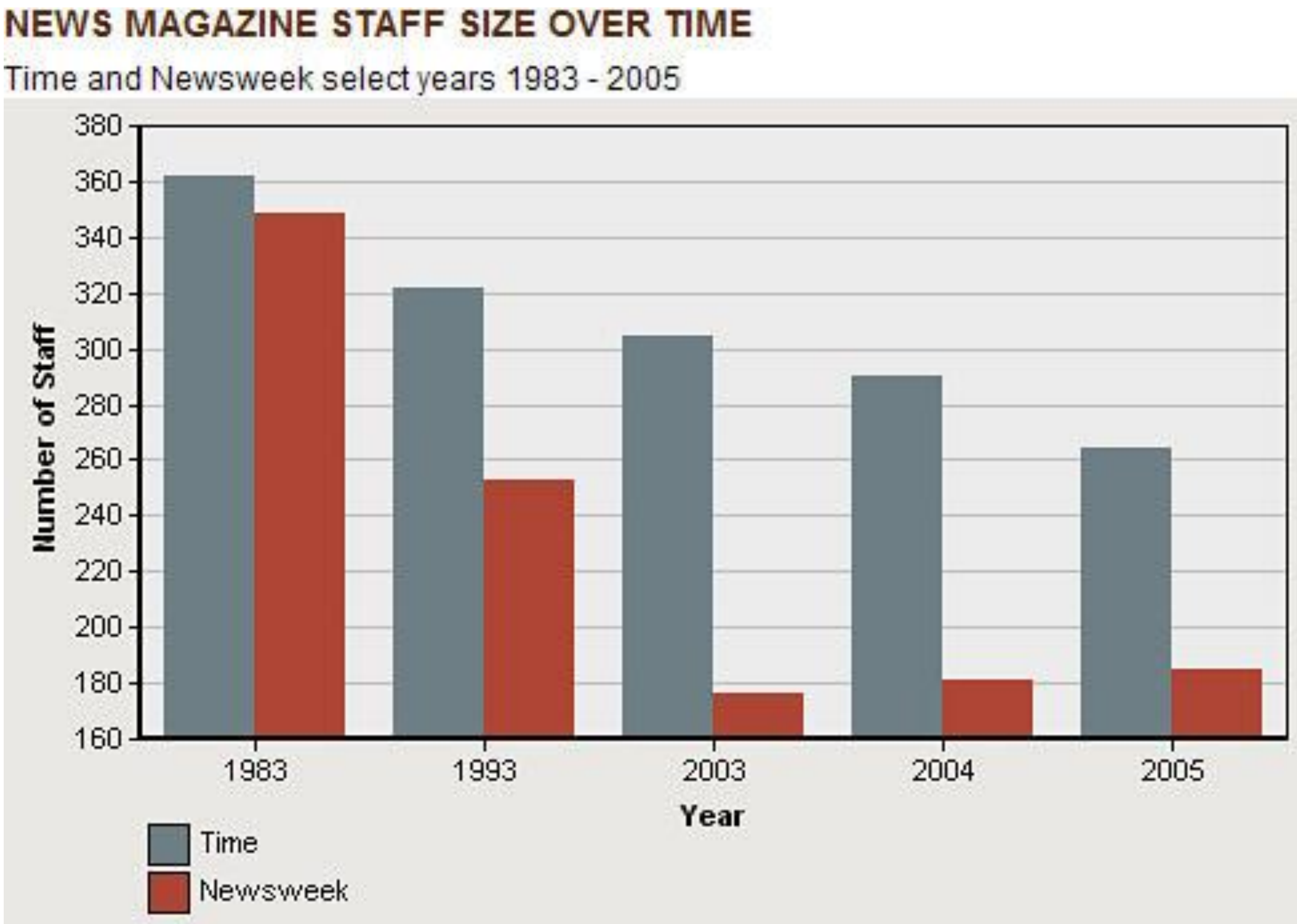
At first glance:

- 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

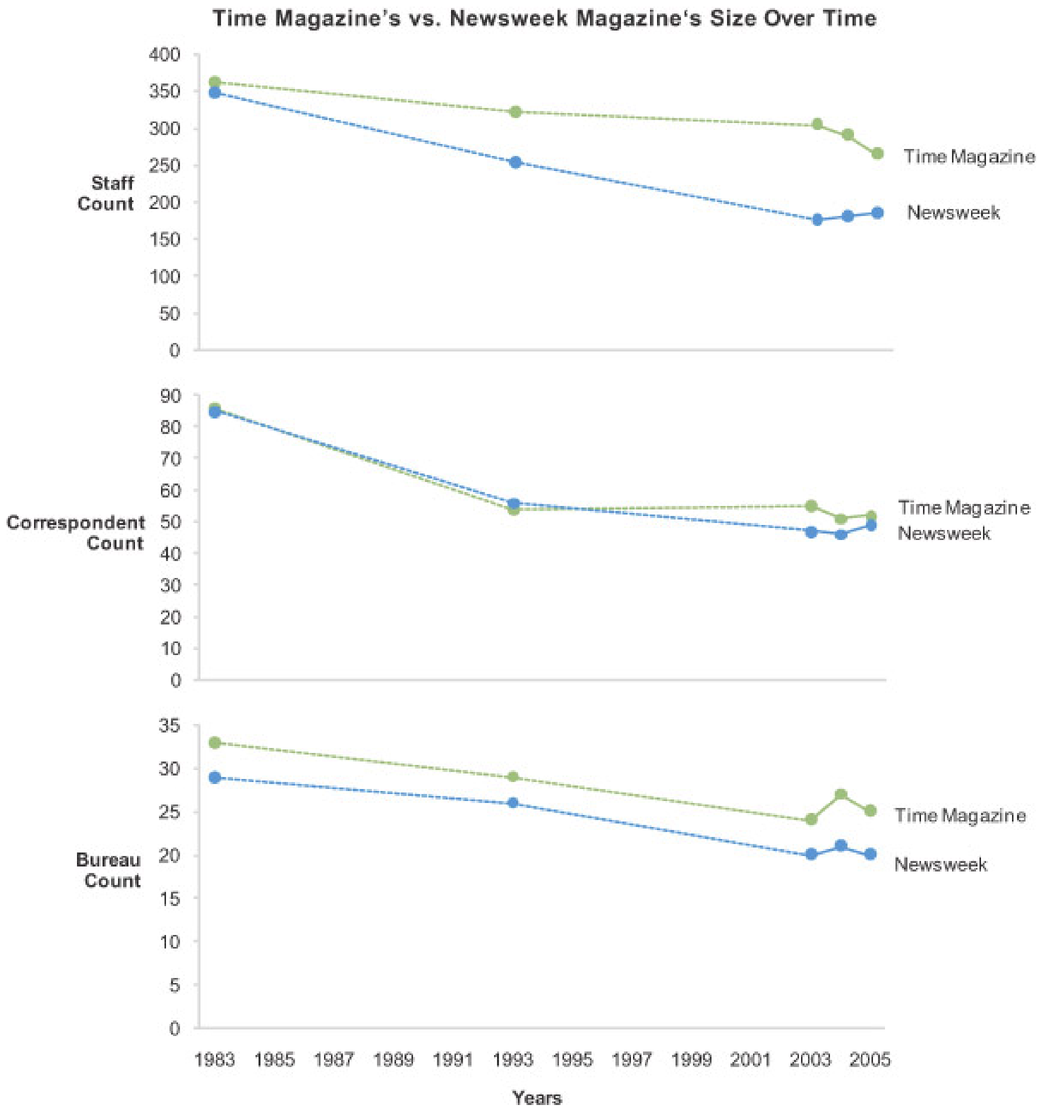
Moreover…



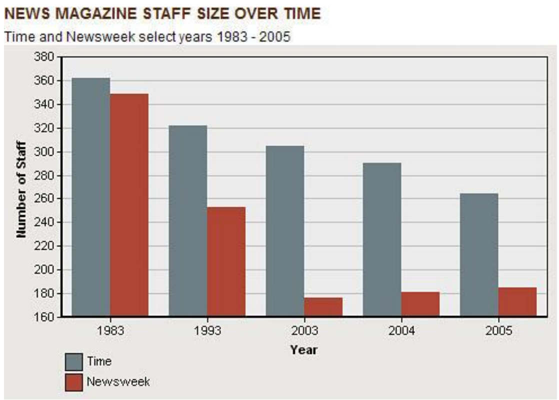
10 years each

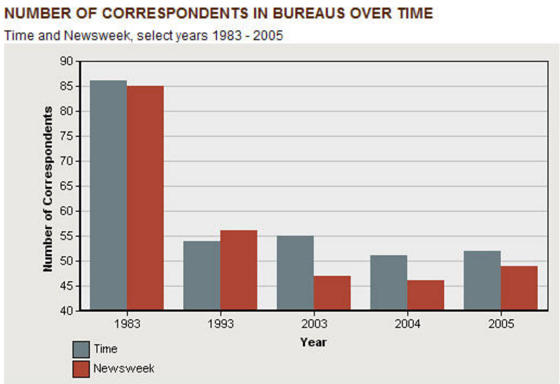
1 year each

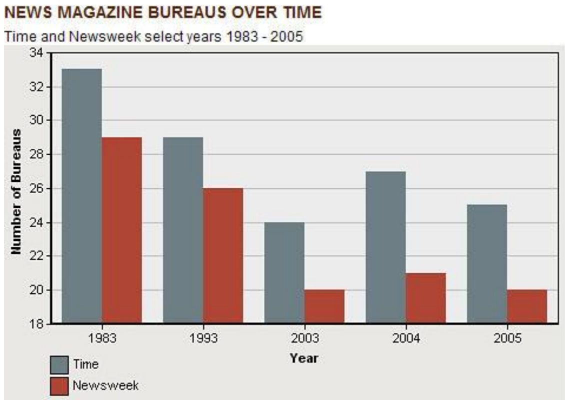
Redesign (by Stephen Few)



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.





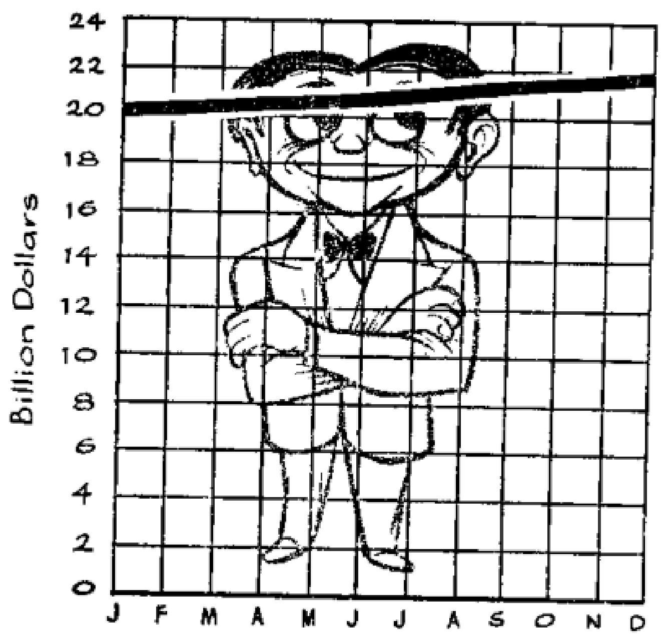


A few more (classic) guidelines!

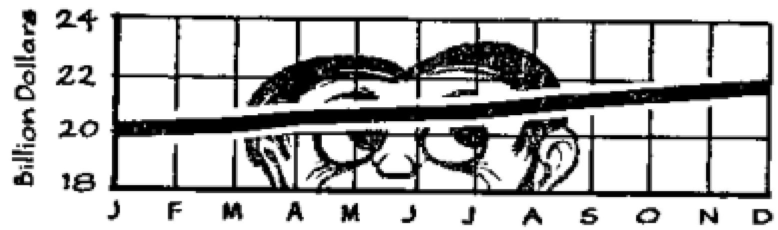
Good reference: *How to Lie with Statistics*, by Darrell Huff (1954)

Chart Rules

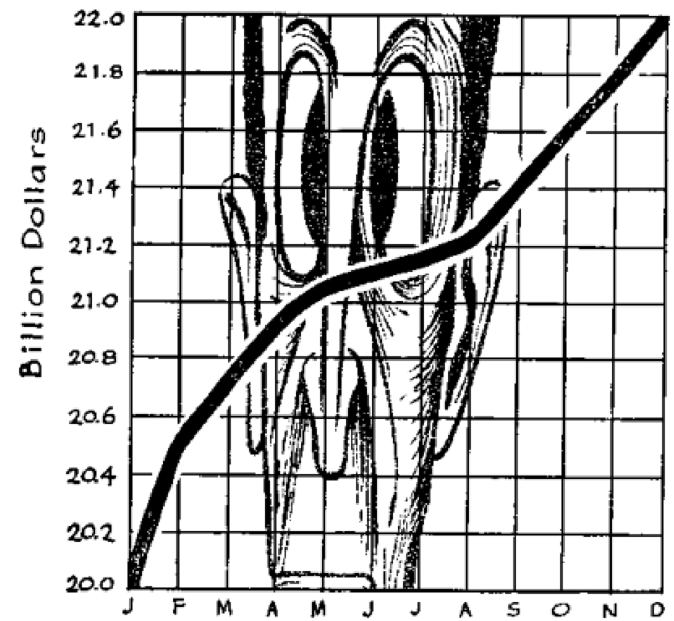
- Provide a proper baseline



A 10% increase. Good!



Already looks more impressive



Wow!

Chart Rules

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

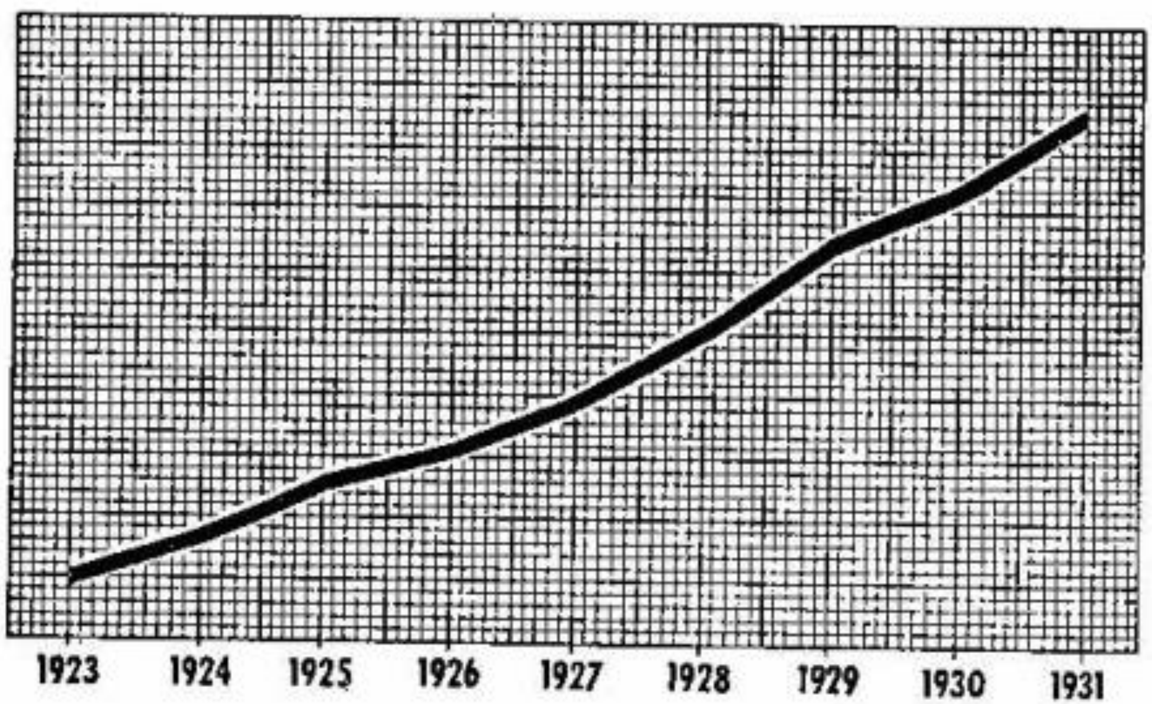
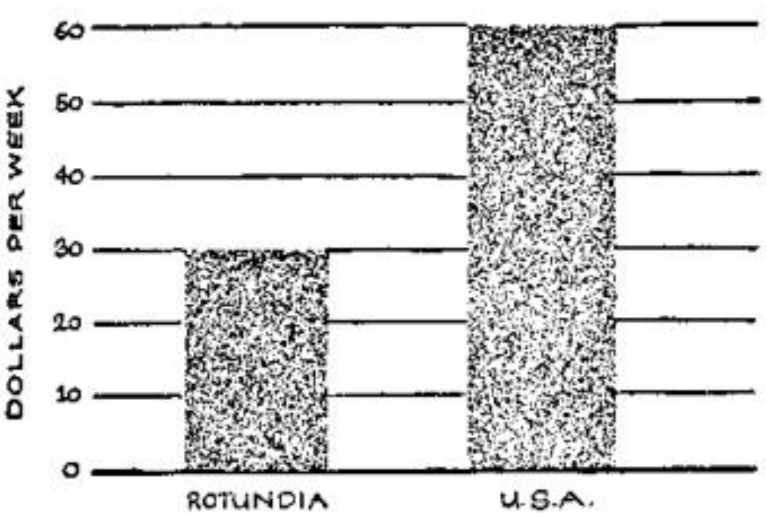
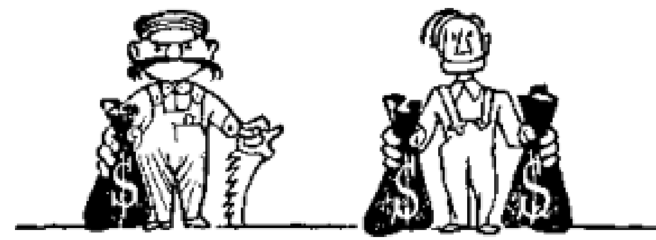


Chart Rules

- 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

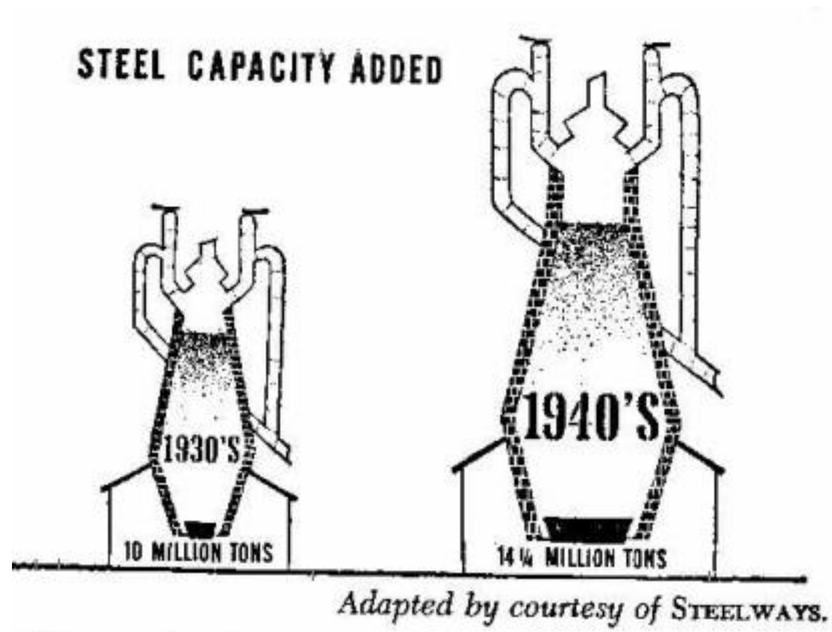


Chart Rules

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

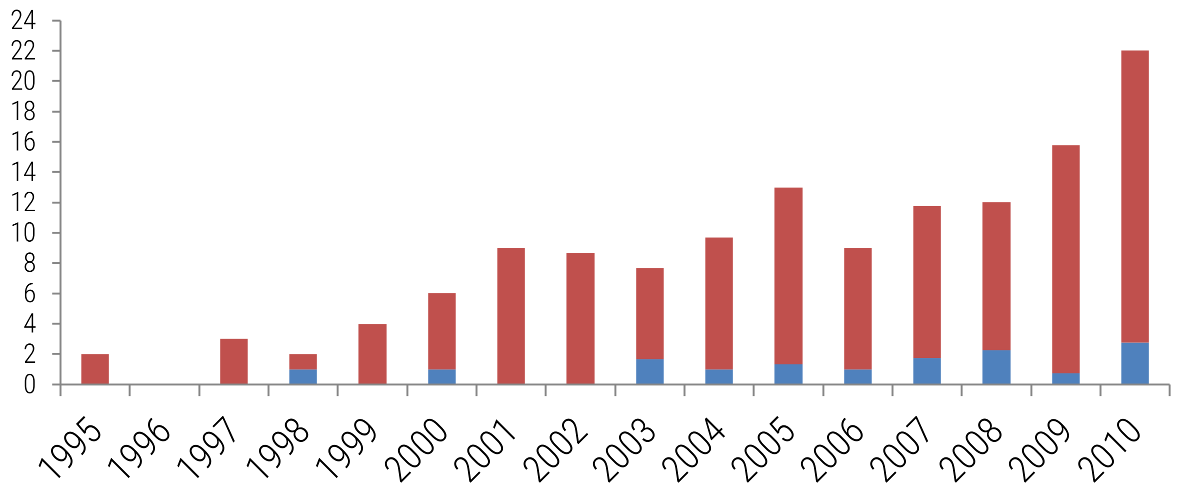
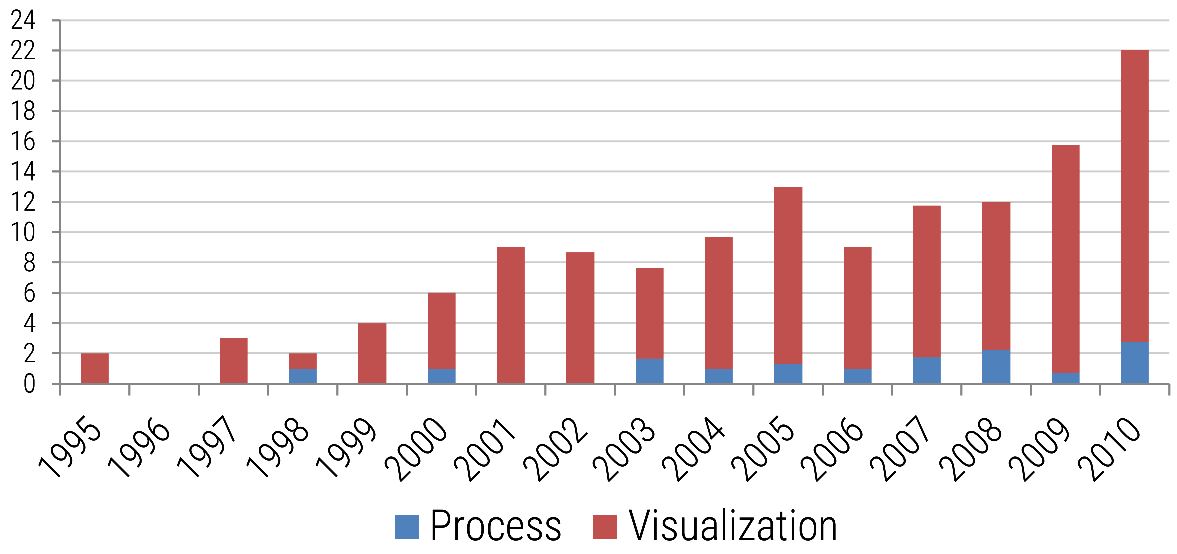
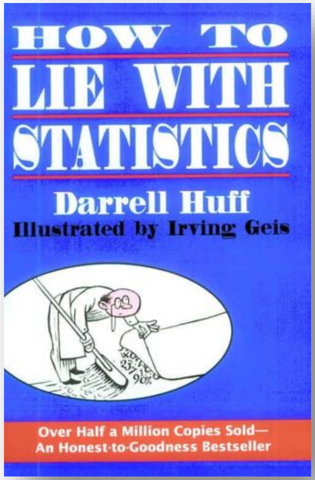


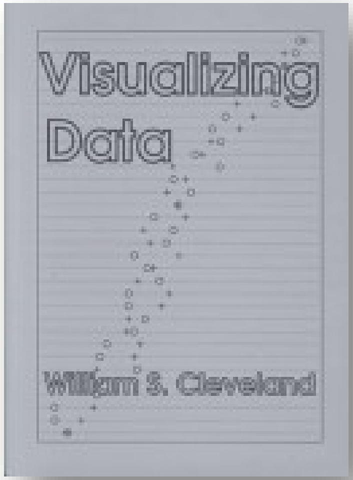
Chart Rules

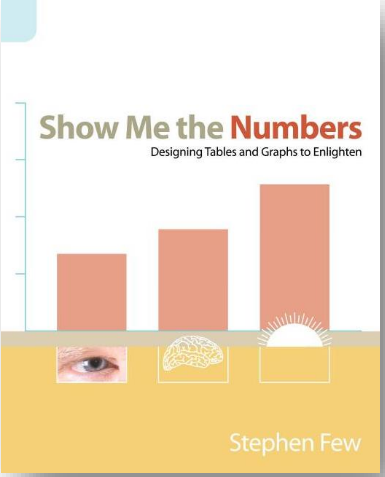
- Provide a **proper baseline** & **label your axes**
- Avoid **eye-candy**
- Avoid **area comparisons** whenever possible
- Provide **legends**
- **Grids help** – but make them subtle
  (about 20% opacity – **no black lines**)

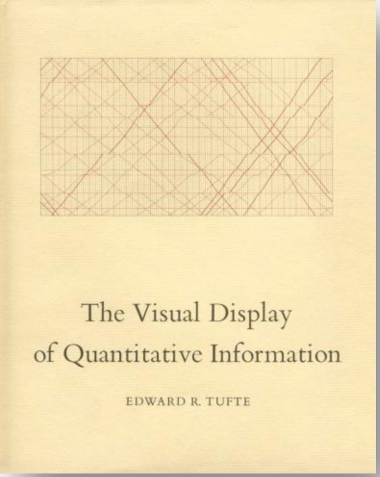


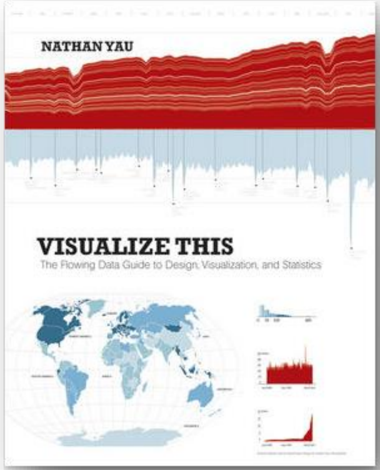
Many more useful guidelines!











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...