

Information Visualization PERCEPTION and COLOR



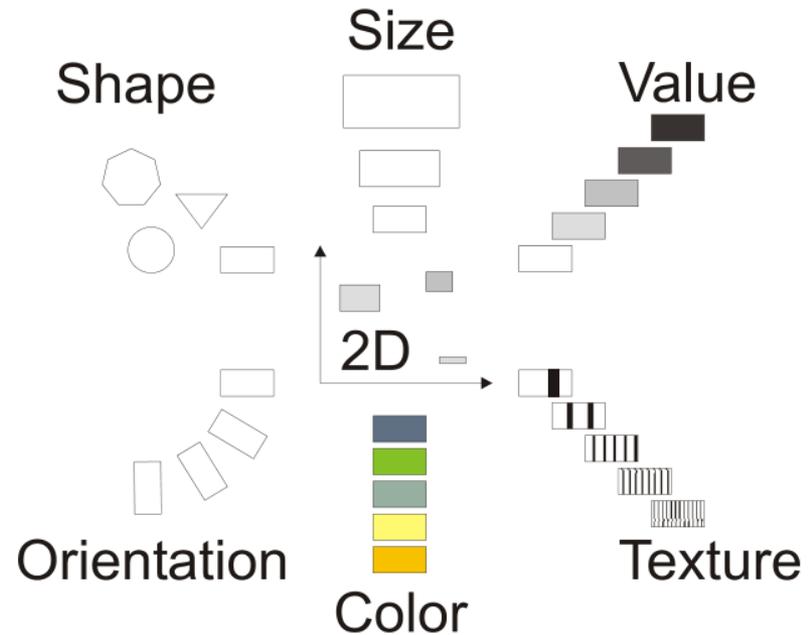
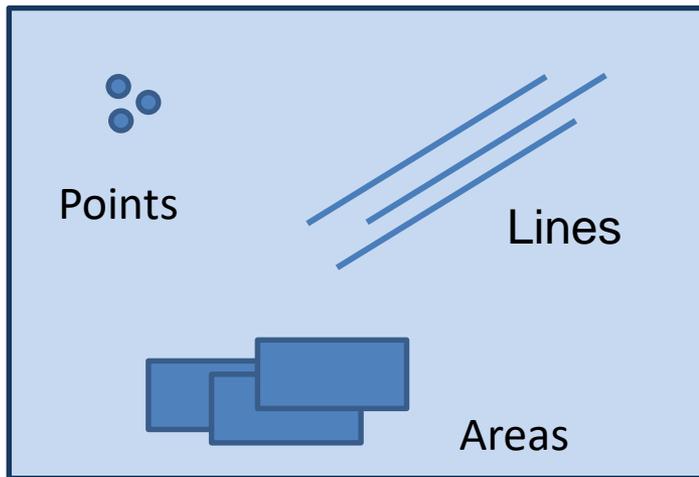
Petra Isenberg

tobias.isenberg@inria.fr

Recap

In Lecture 1 you learned about the basic components of visualization:

- marks and visual variables



and others

Summary

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

Today you will

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

WHAT IS COLOR?

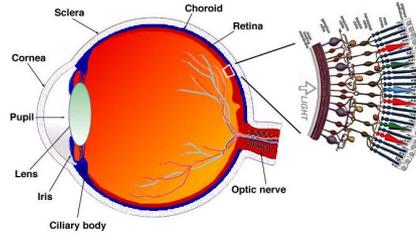
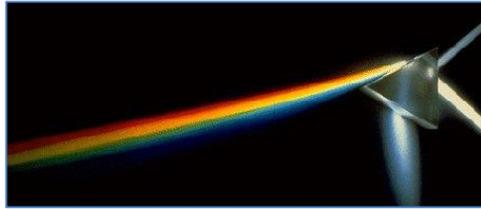
Let's do an experiment ...



What is Color?

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

What is Color?



“Yellow”

Physical
World

Lights, surfaces,
objects

Visual
System

Eye, optic
nerve, visual
cortex

Mental
Models

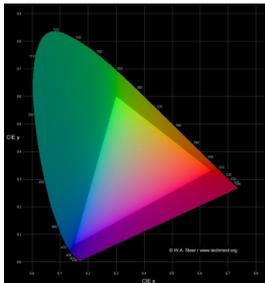
Red, green, brown

Bright, light, dark,
vivid, colorful, dull

Color
Models

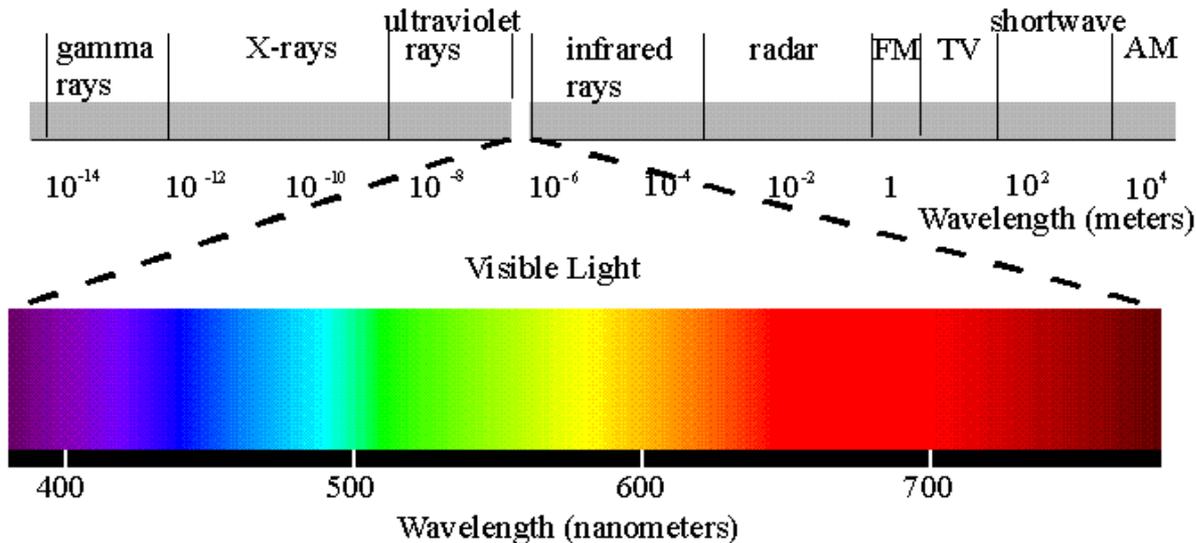
RGB, CMYK,
CIE XYZ, CIE Lab
HSV/HSB, ...

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



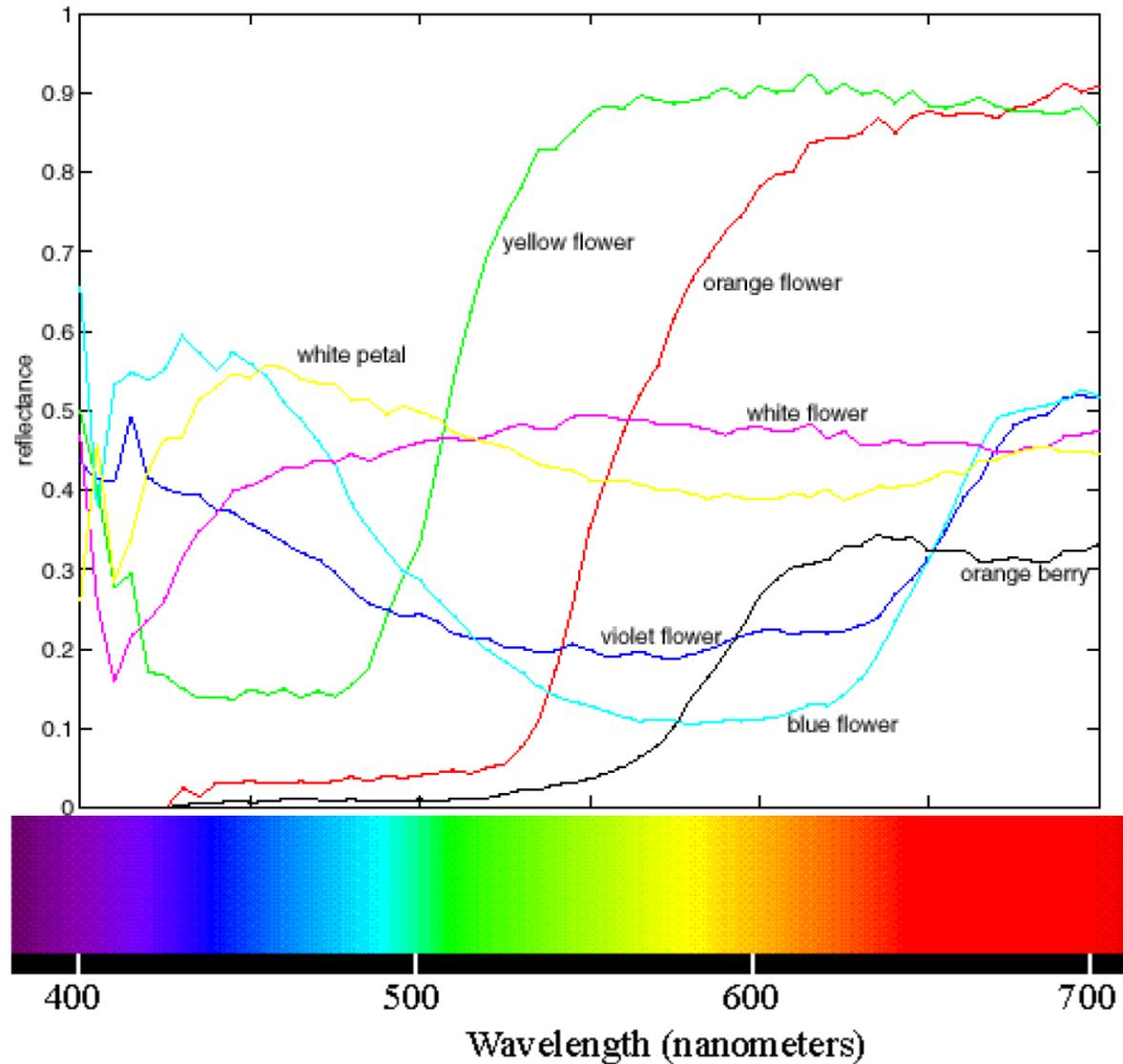
Physical World

Light is radiation in a range of wavelengths:
370–730nm

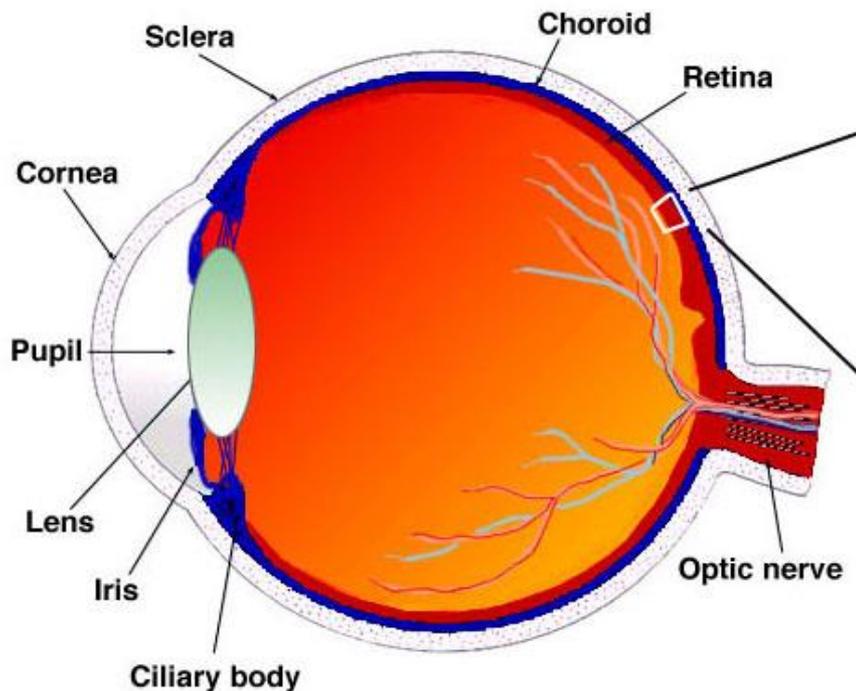


Light of a single wavelength is *monochromatic*

Most colors are not monochromatic



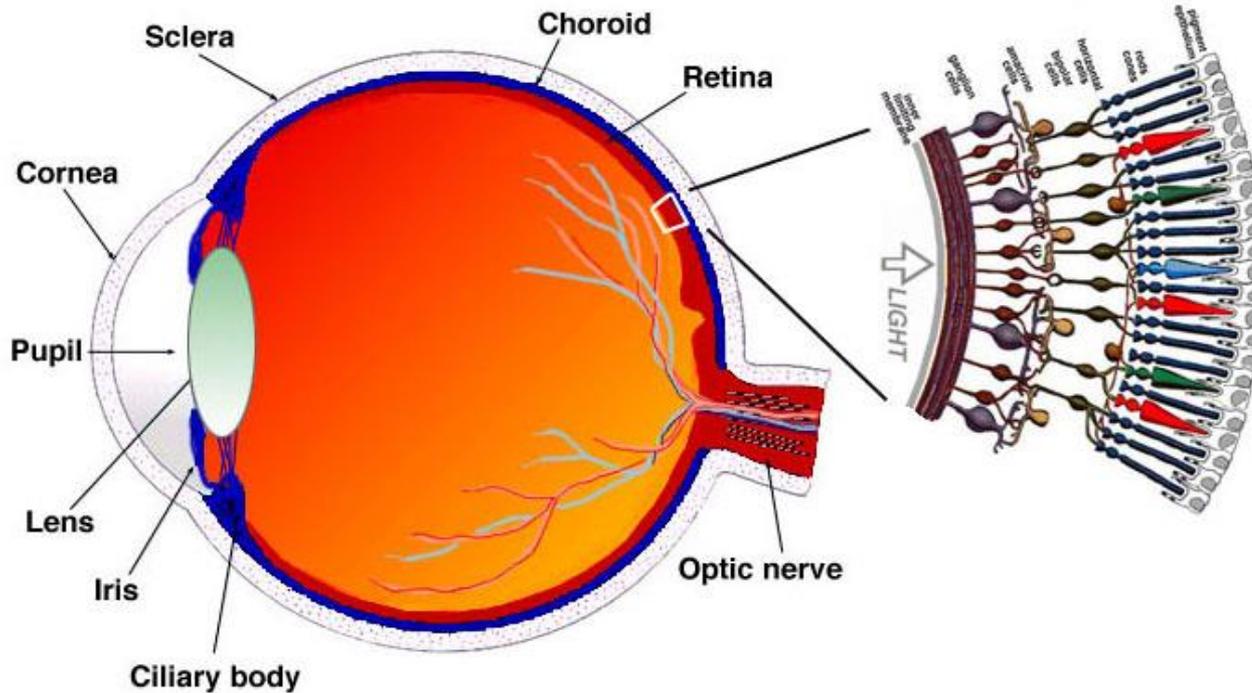
Physical World → Visual System



You **do not** see the spectrum of light

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

Physical World → Visual System



Rods

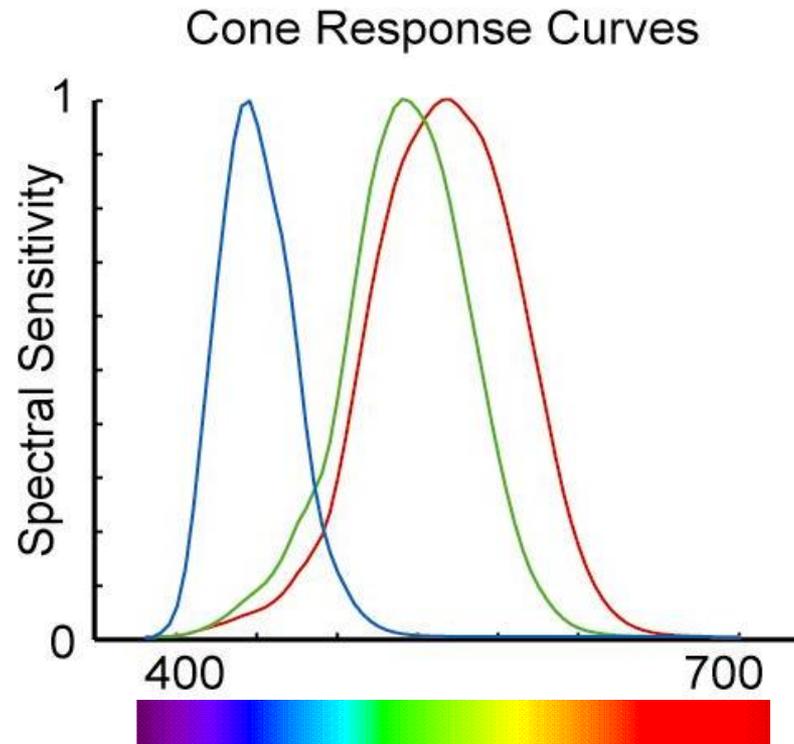
No color (sort of)
All over the retina
More sensitive

Cones

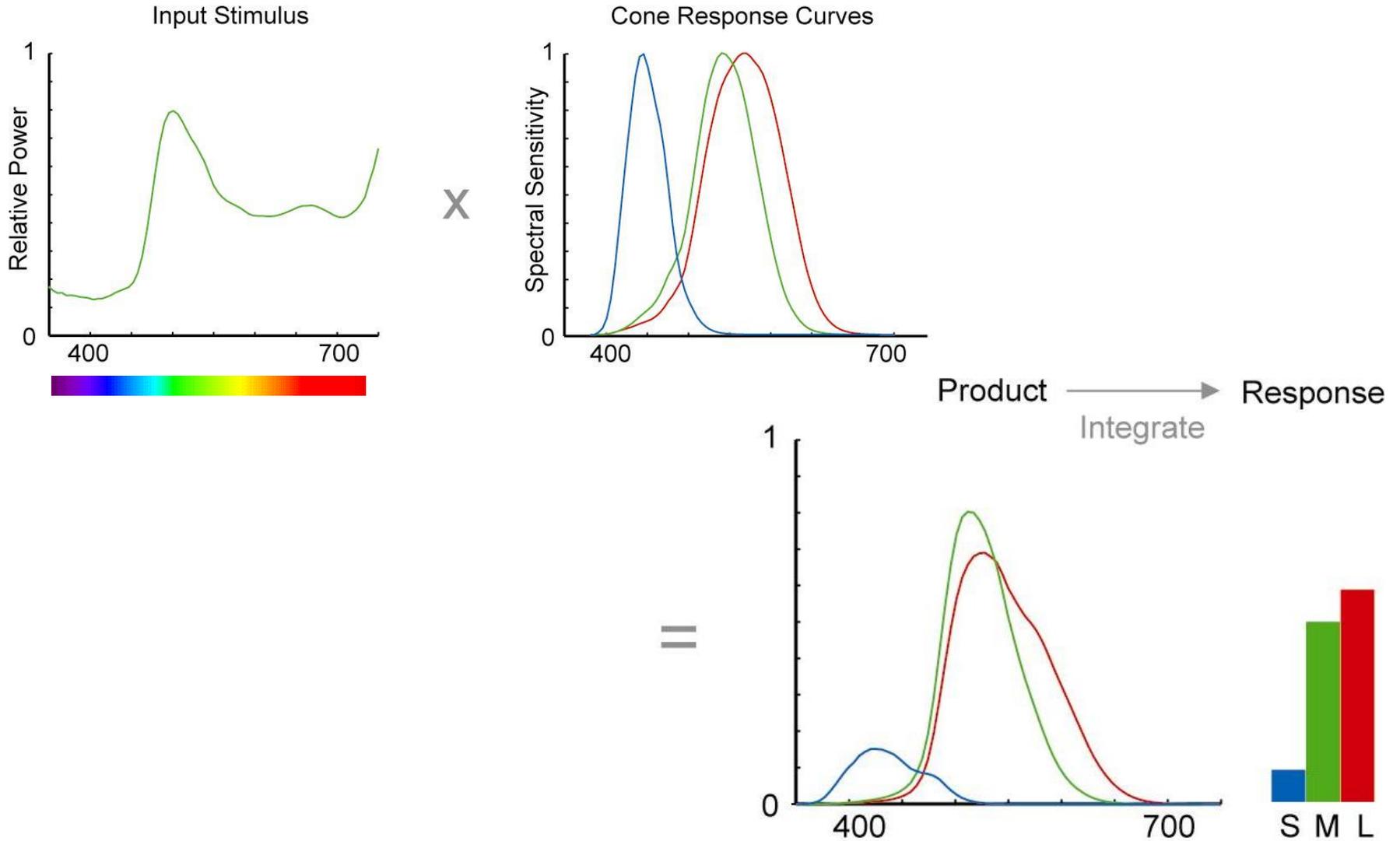
Three different kinds
of “color receptors”
Mostly in the center
Less Sensitive

Cone response

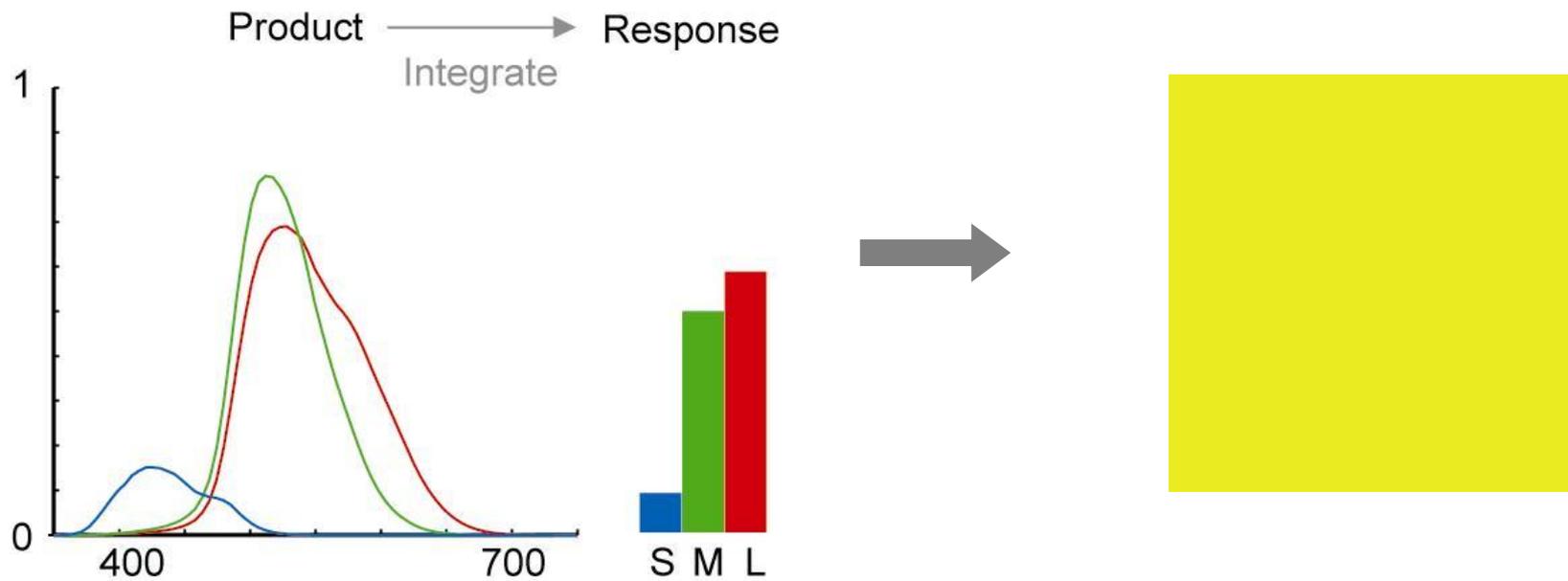
LMS (Long, Middle, Short) cones
Sensitive to different wavelengths



Cone response

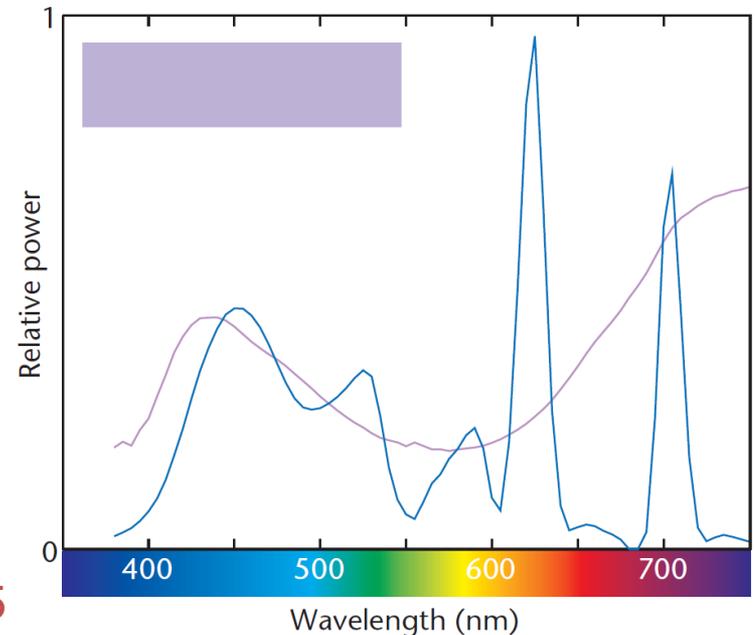


Visual System → Color Models



Two Principles of Color Perception

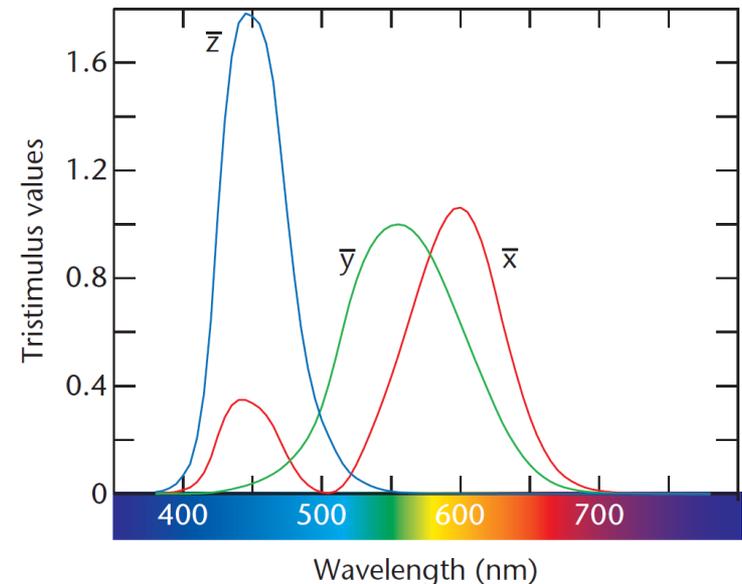
- **trichromacy:**
representation of all spectral distributions possible with **three values** without information loss (w.r.t. the visual system)
→ essential for CS!
- **metamerism:**
different spectra exist that produce the same trichromatic response



Stone 2005

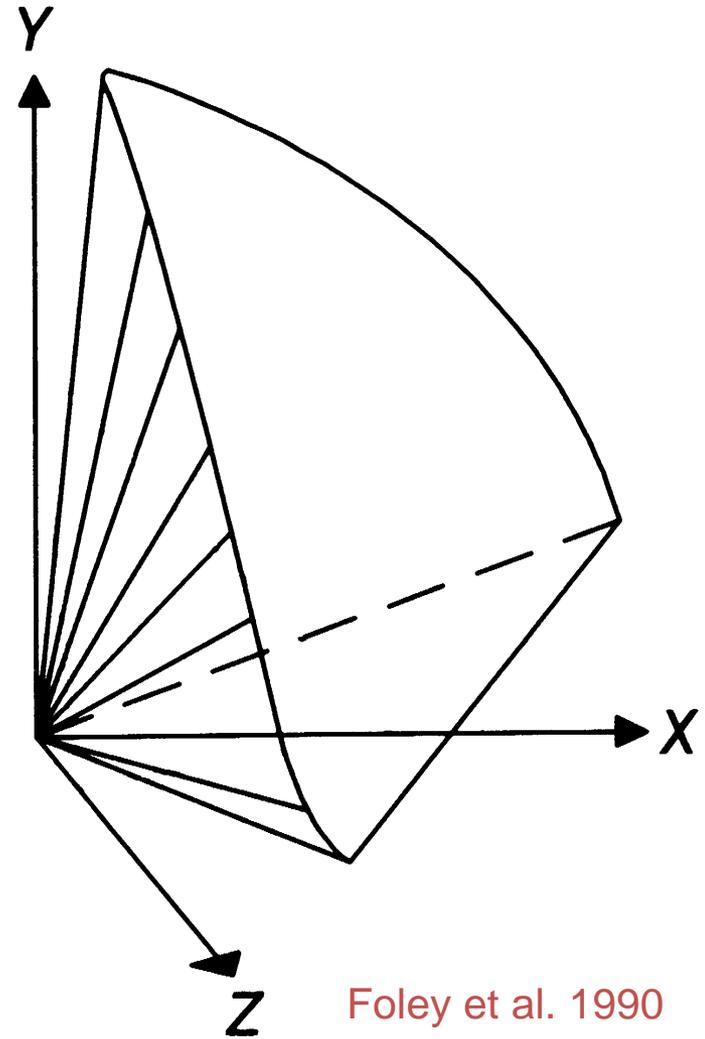
XYZ Color Model

- definition of three primary colors: X, Y, Z
 - color-matching functions (the numerical description of the chromatic response of the *observer*)
 - here non-negative
 - Y follows the standard human response to luminance, i.e., the Y value represents perceived brightness
 - can represent all perceivable colors
- mathematically derived from color matching experiments



XYZ CIE Color Space

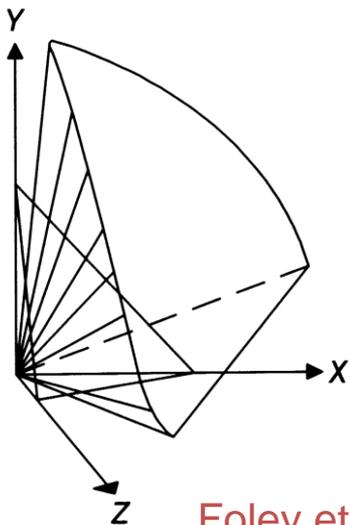
- plotting XYZ space in 3D
- all colors that are perceivable by humans form a deformed cone
- X , Y , and Z -axes are outside this cone



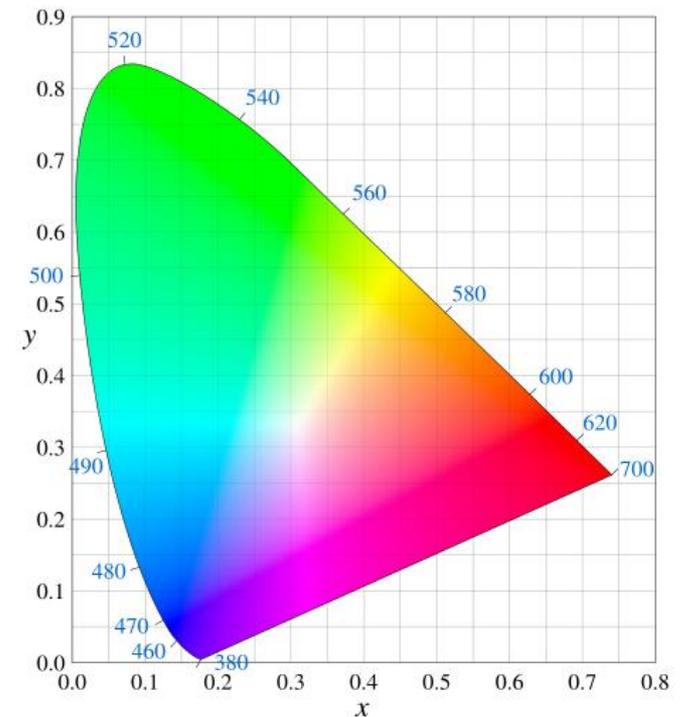
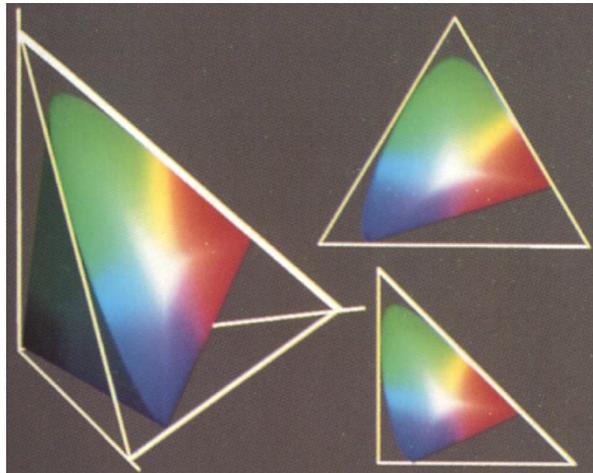
Foley et al. 1990

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

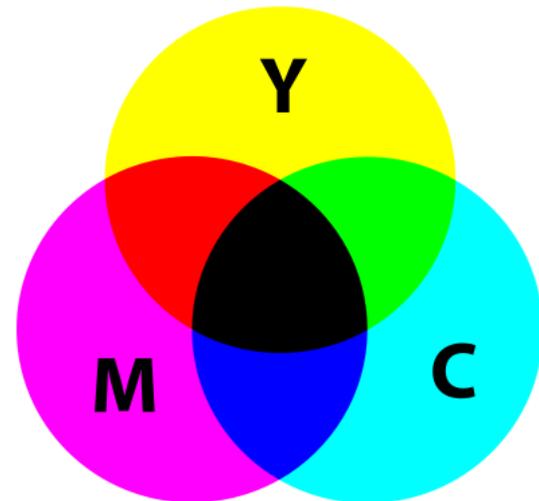
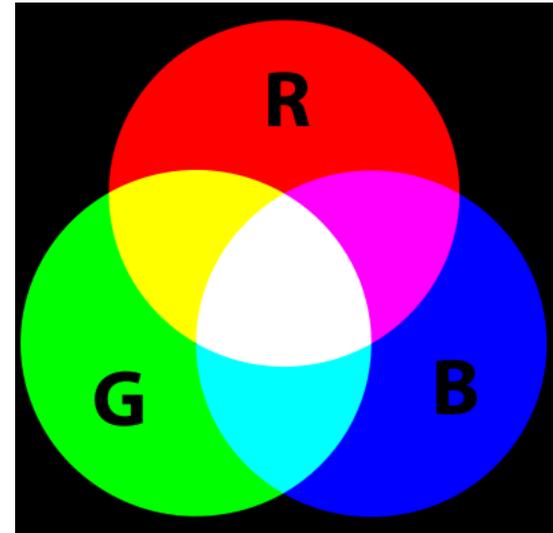


Foley et al. 1990



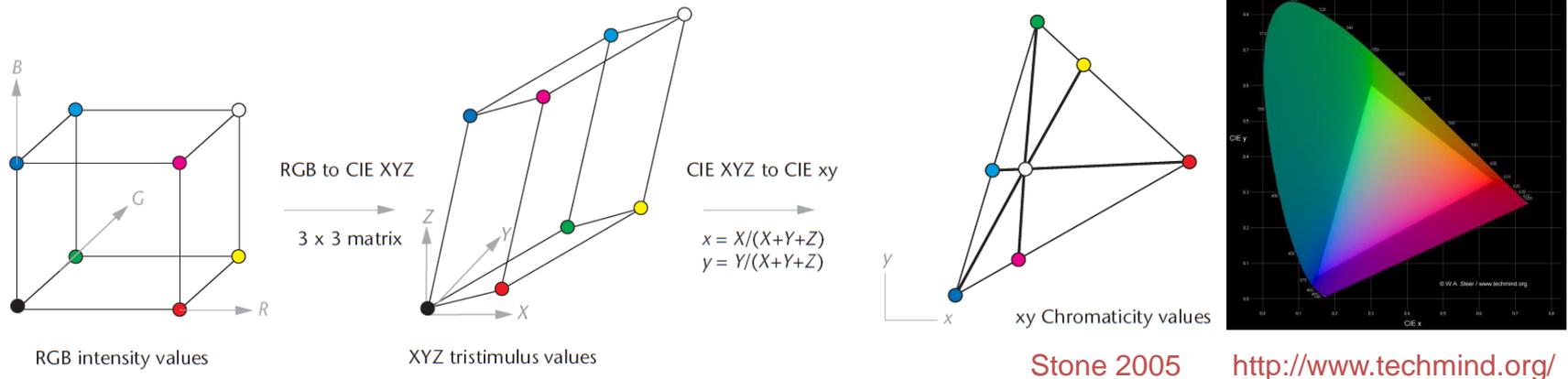
Other Color Models: RGB & CMYK

- (physical) color mixing depends on color production process
 - light emission: additive mixing (CRTs etc.): **RGB model**
 - light absorption: subtractive mixing (printing process): **CMY(K) model**

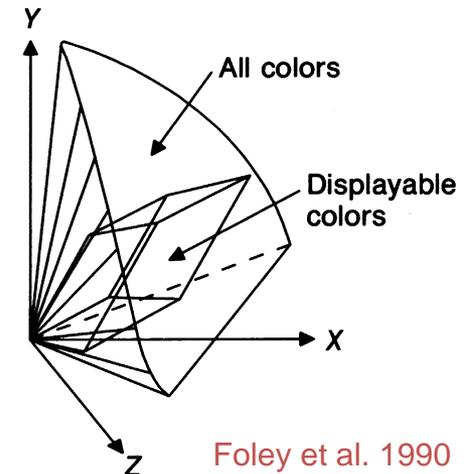


RGB and XYZ

- RGB to XYZ conversion

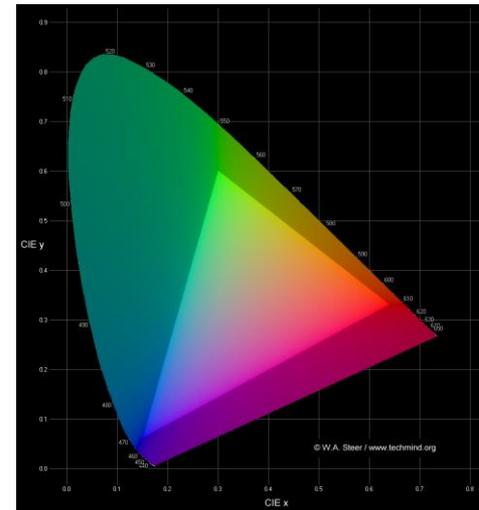


- RGB space: distorted cube
- black: origin of XYZ and projection center
- RGB projected to triangle



Can RGB Represent All Visible Colors?

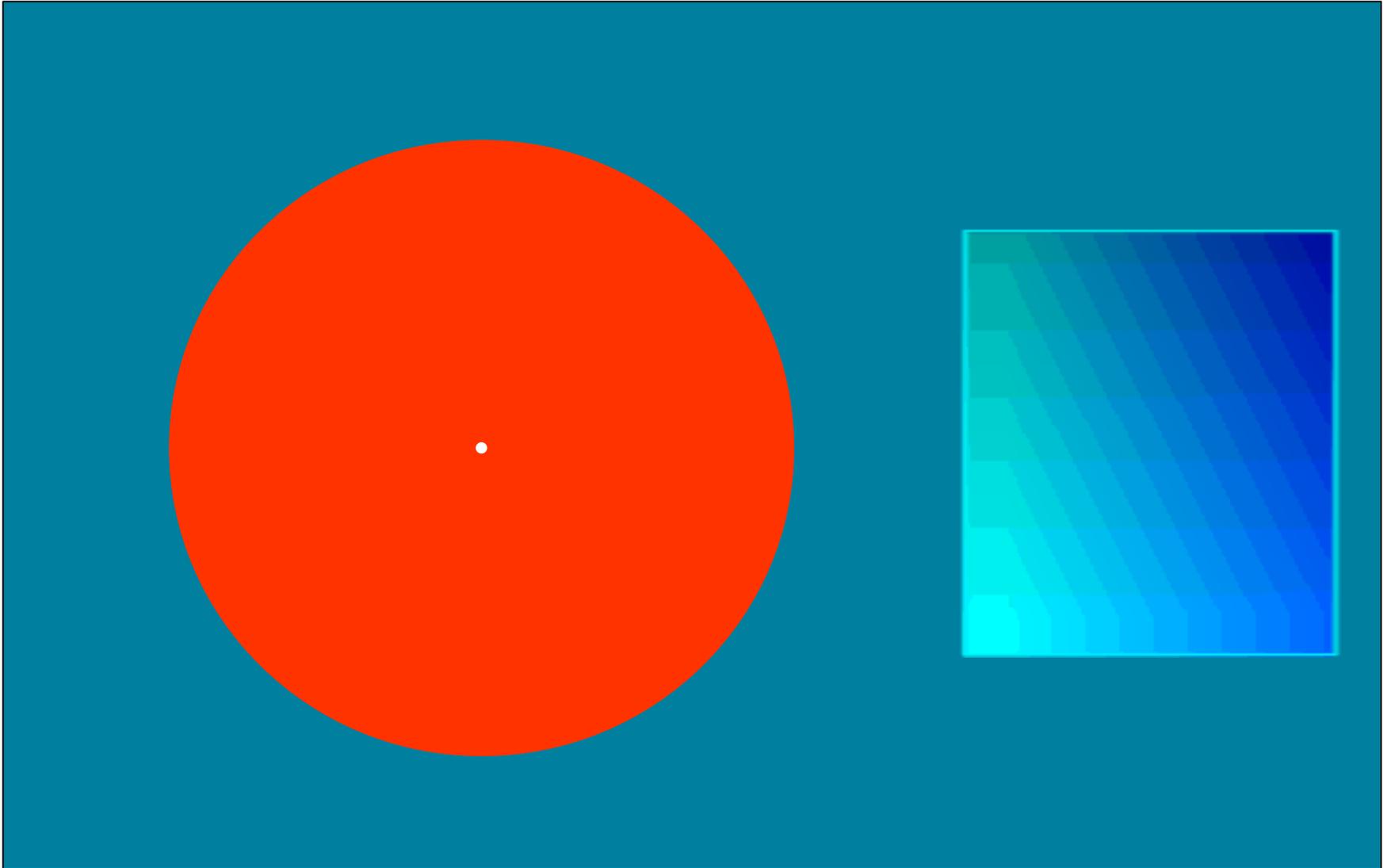
- no, because all colors form horseshoe shape in CIE chromaticity diagram and RGB gamut is triangular



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

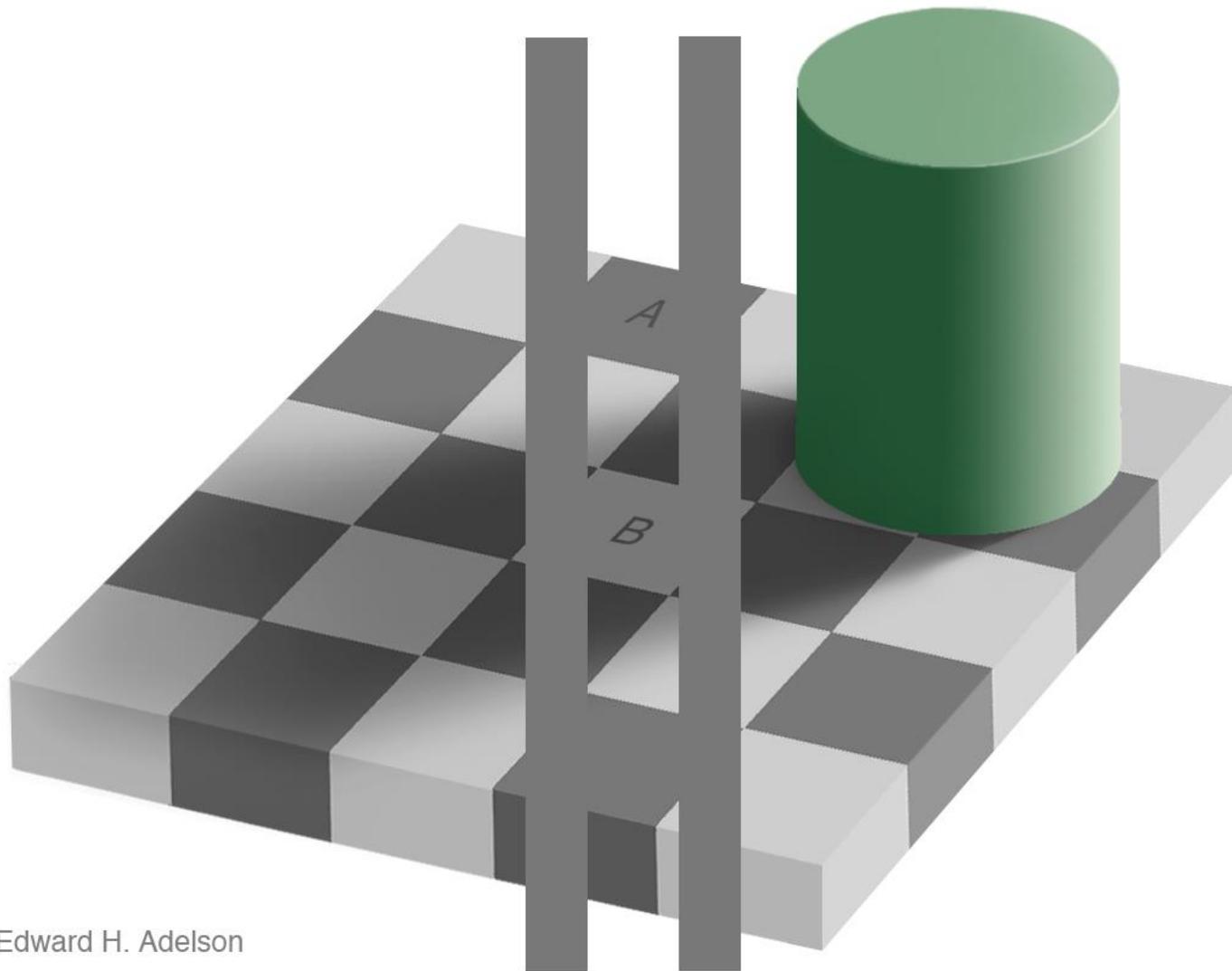
- But my shiny new 30" UHD OLED is state-of-the-art, it can surely show all colors!"
- → Let's see a color that it cannot show ...

Let's see REAL cyan ...



WEIRD STUFF HAPPENS

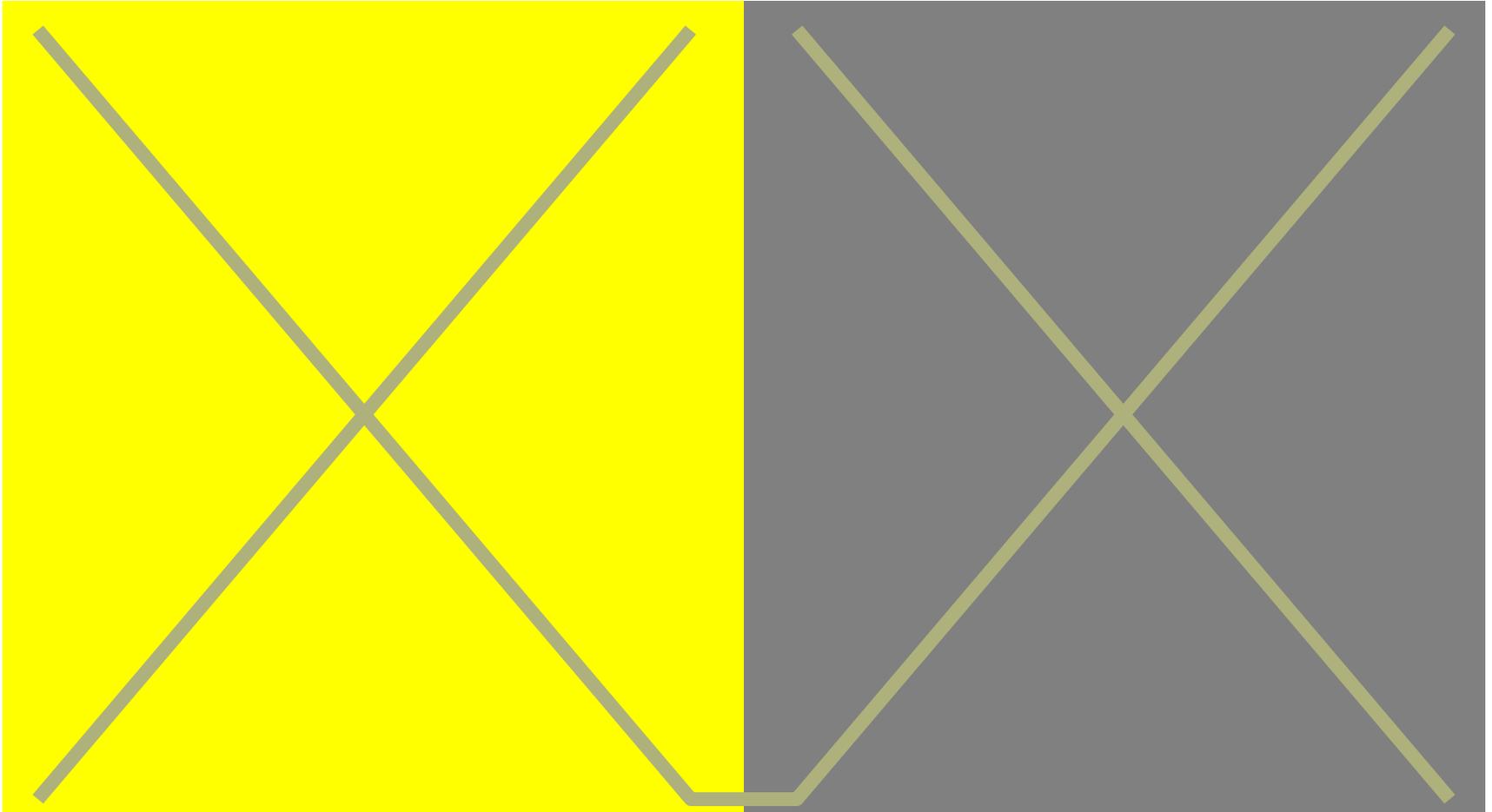
Visual System → Color Perception



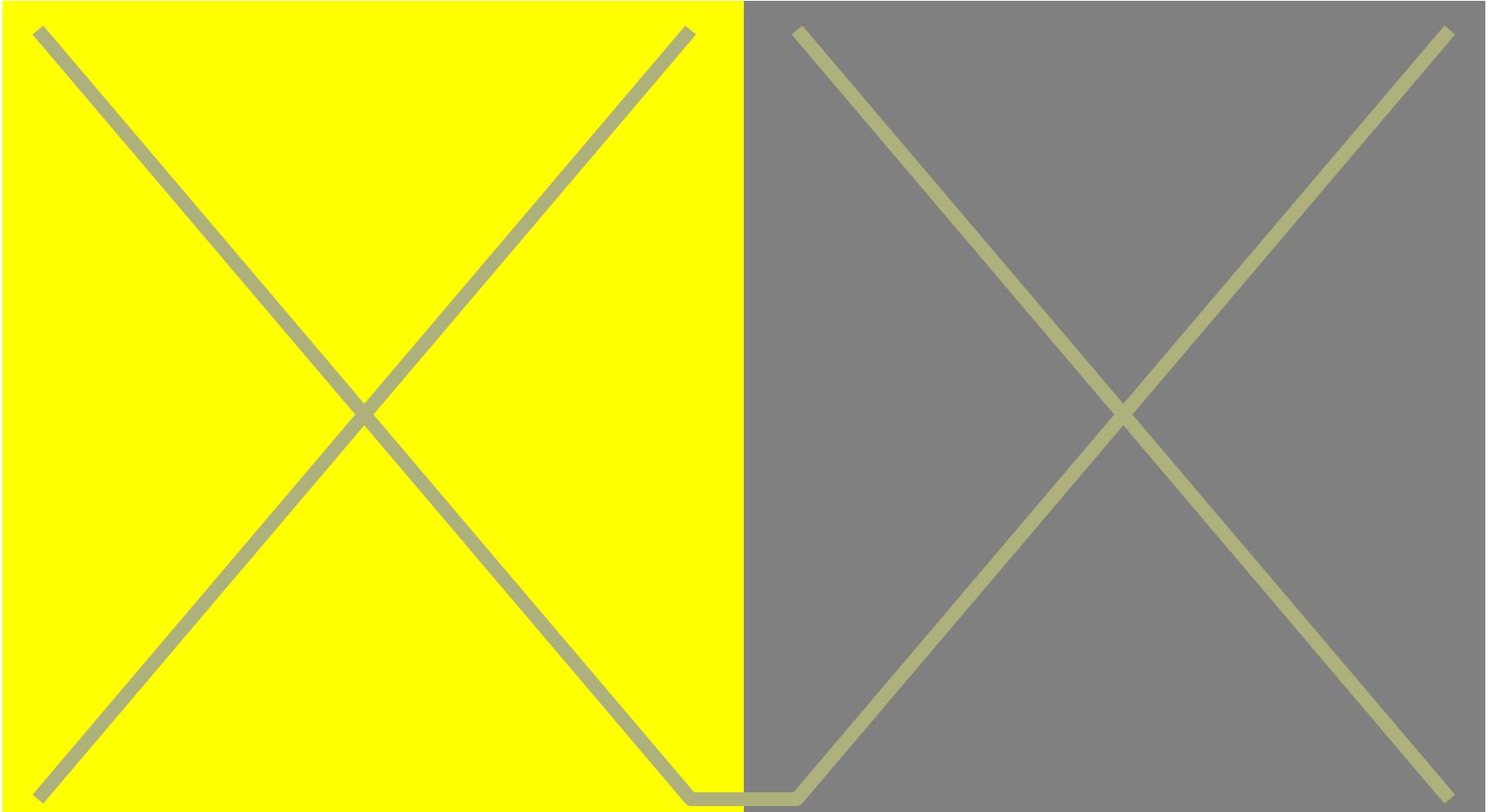
Edward H. Adelson

Slide adapted from Stone & Zellweger

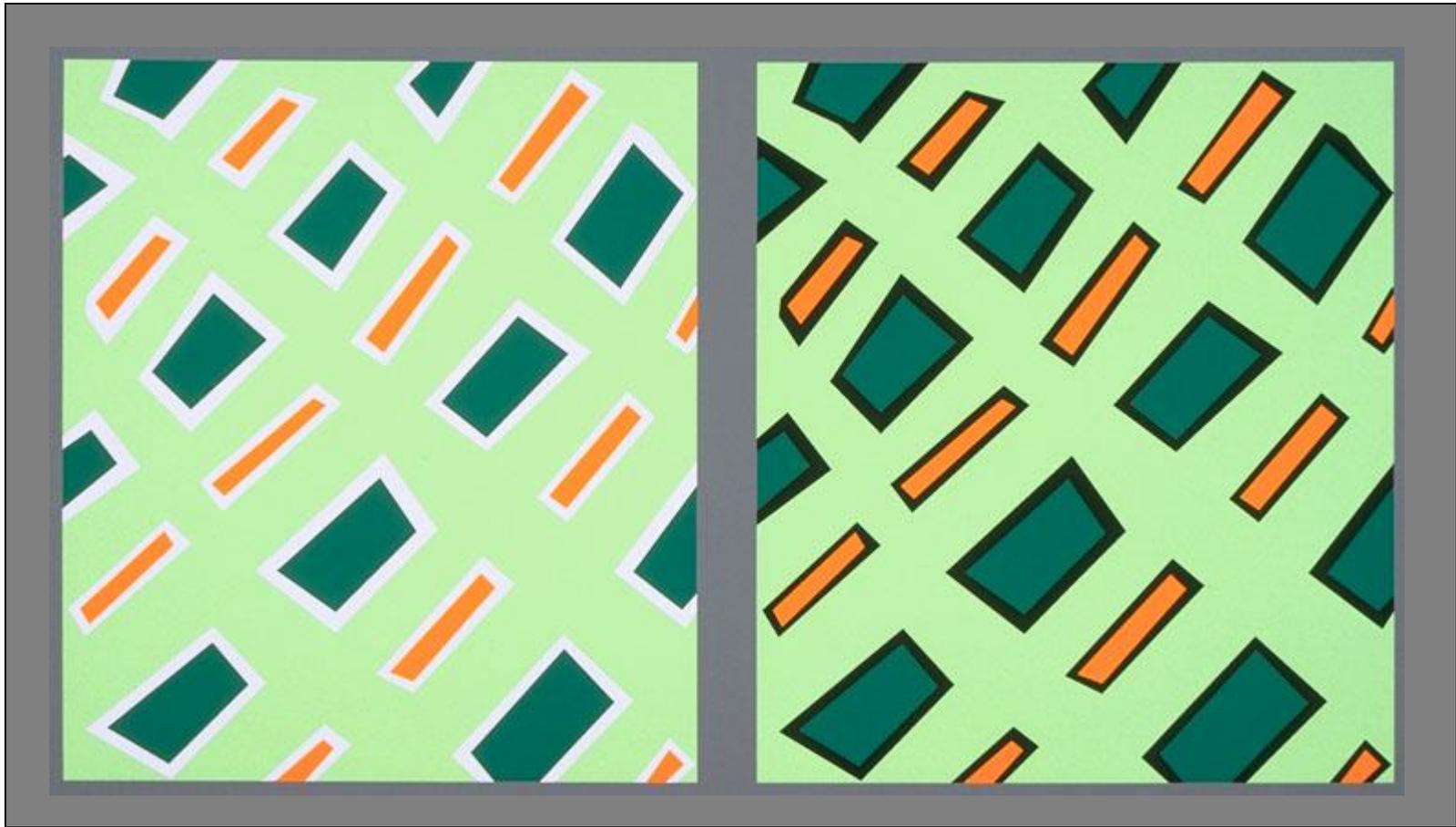
Visual System → Color Perception



Simultaneous Contrast

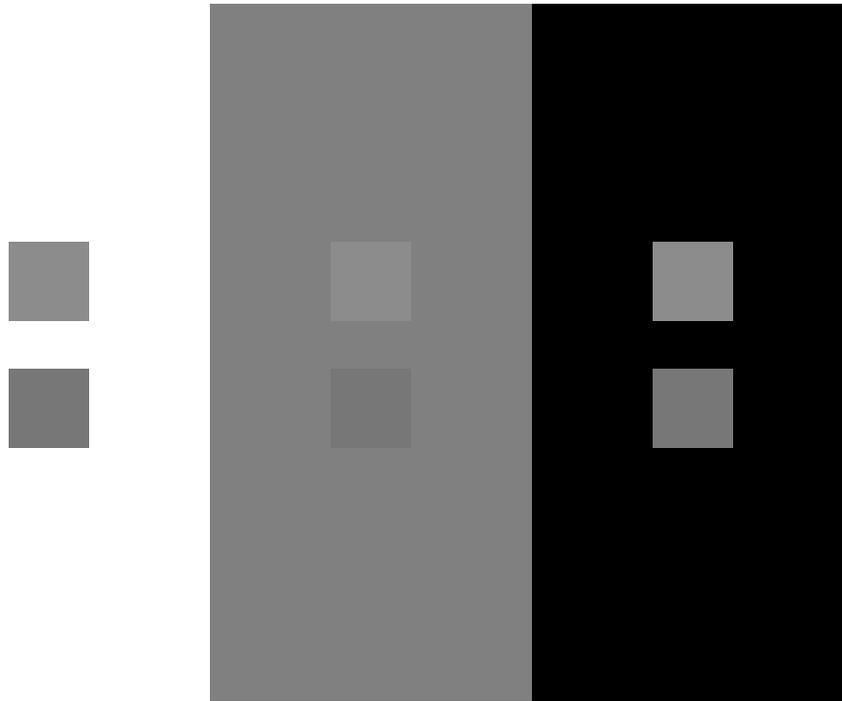


Bezold Effect



Crispensing

Perceived difference depends on background

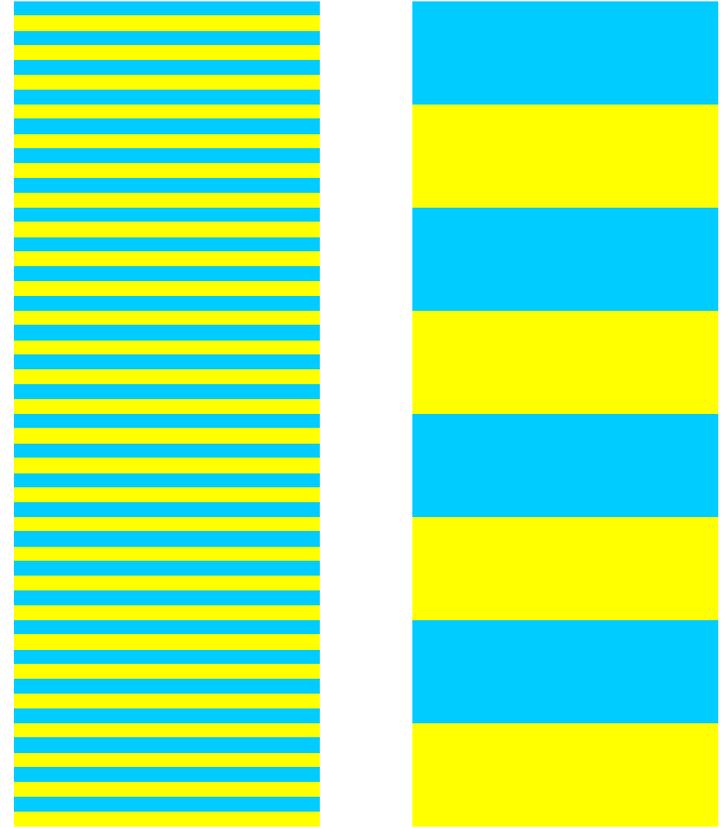


Spreading

Spatial frequency

- The paint chip problem
- Small text, lines, glyphs
- Image colors

Adjacent colors blend



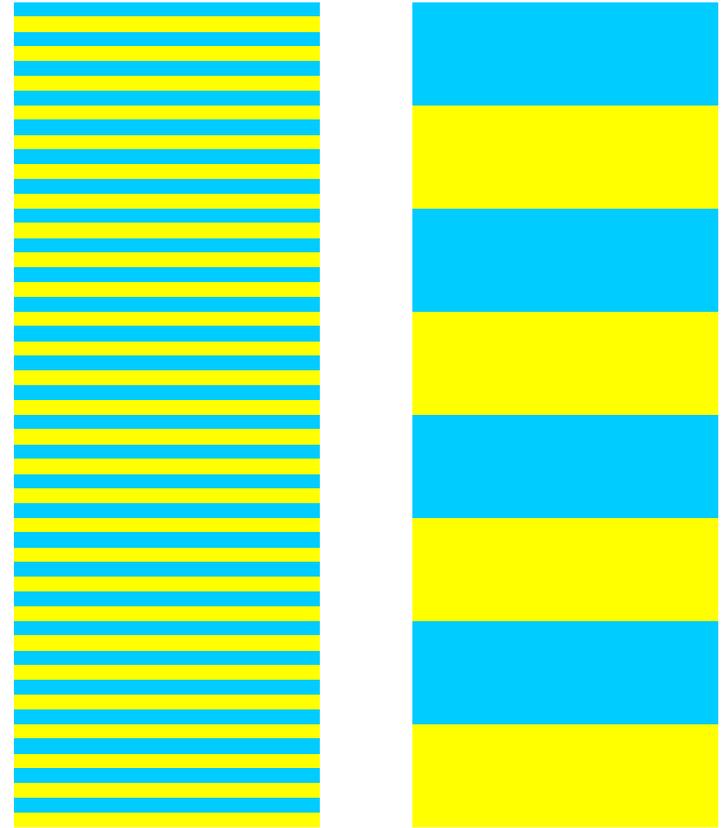
Redrawn from *Foundations of Vision*
© Brian Wandell, Stanford University

Spreading

Spatial frequency

- The paint chip problem
- Small text, lines, glyphs
- Image colors

Adjacent colors blend



Redrawn from *Foundations of Vision*
© Brian Wandell, Stanford University

Color Perception → Color Naming



What “Yellow” is this?

Color Perception → Color Naming



What color is this?

Color Perception → Color Naming

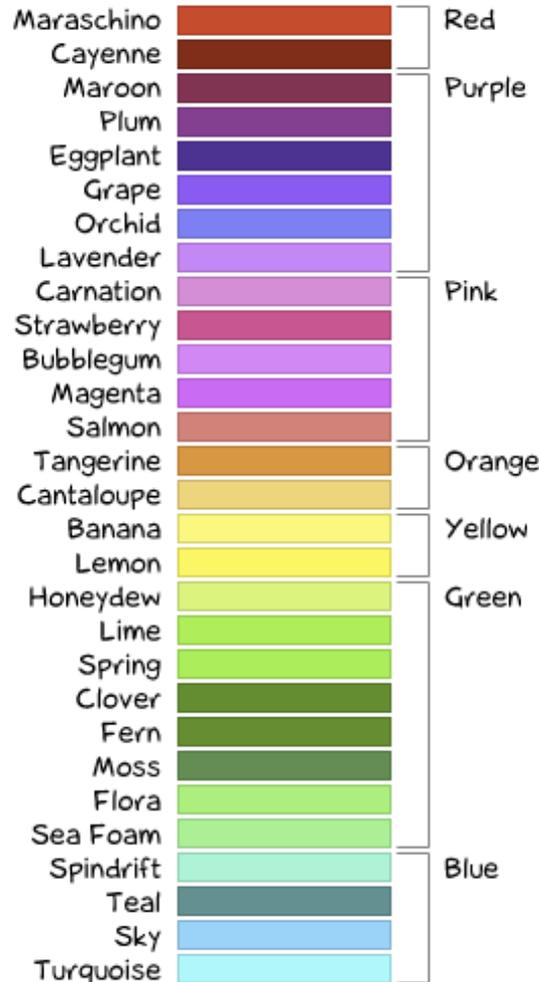


What “Teal?” is this?

“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

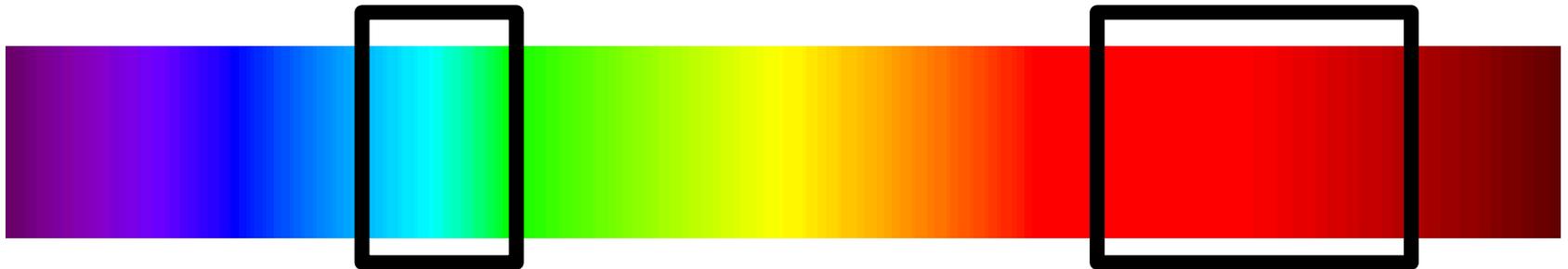
Actual color names
if you're a girl ...

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

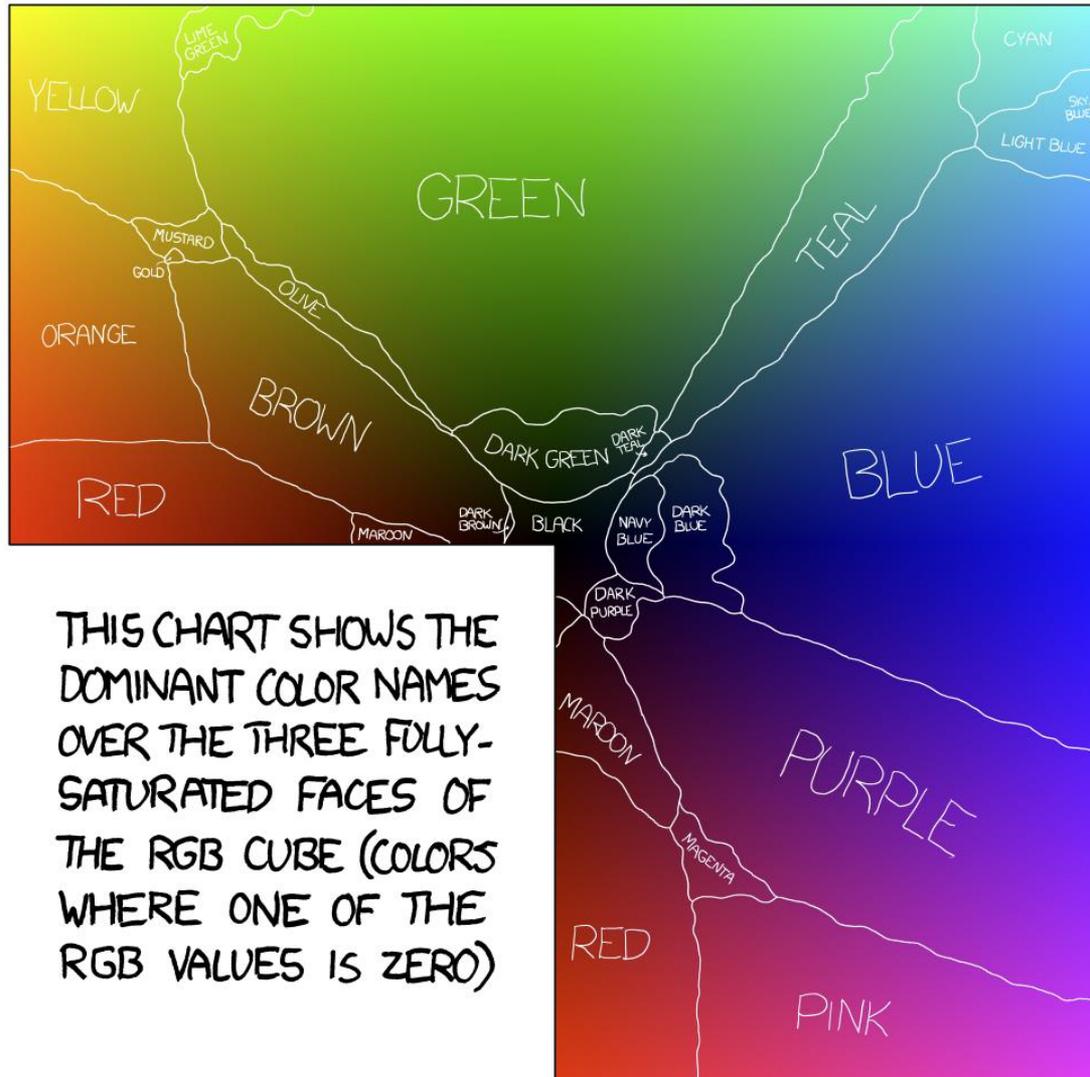


Color Naming

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

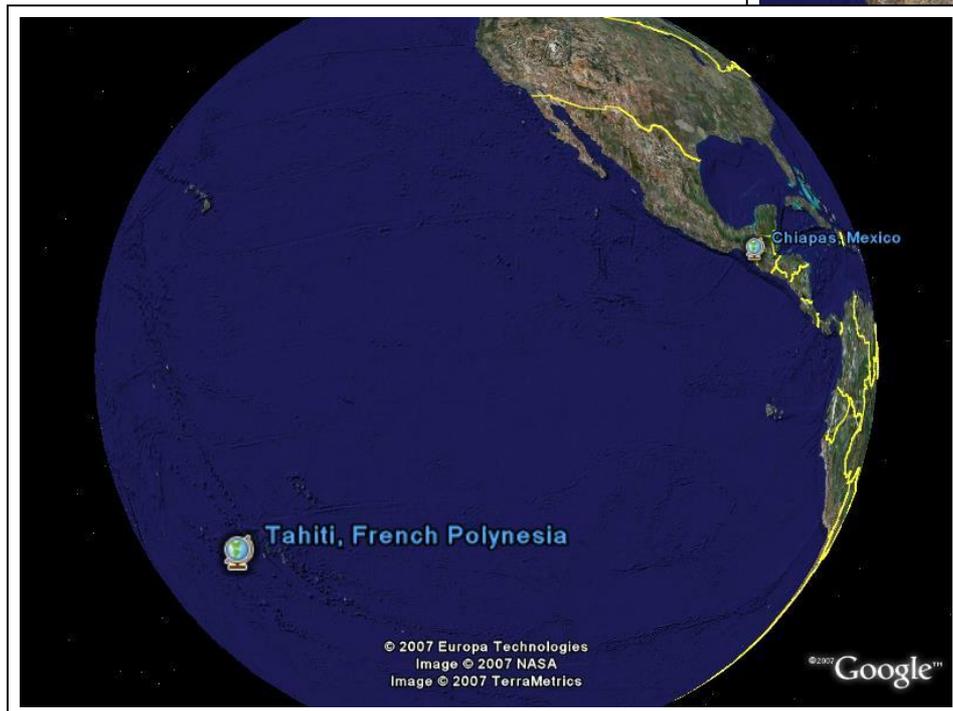


Are there natural boundaries?



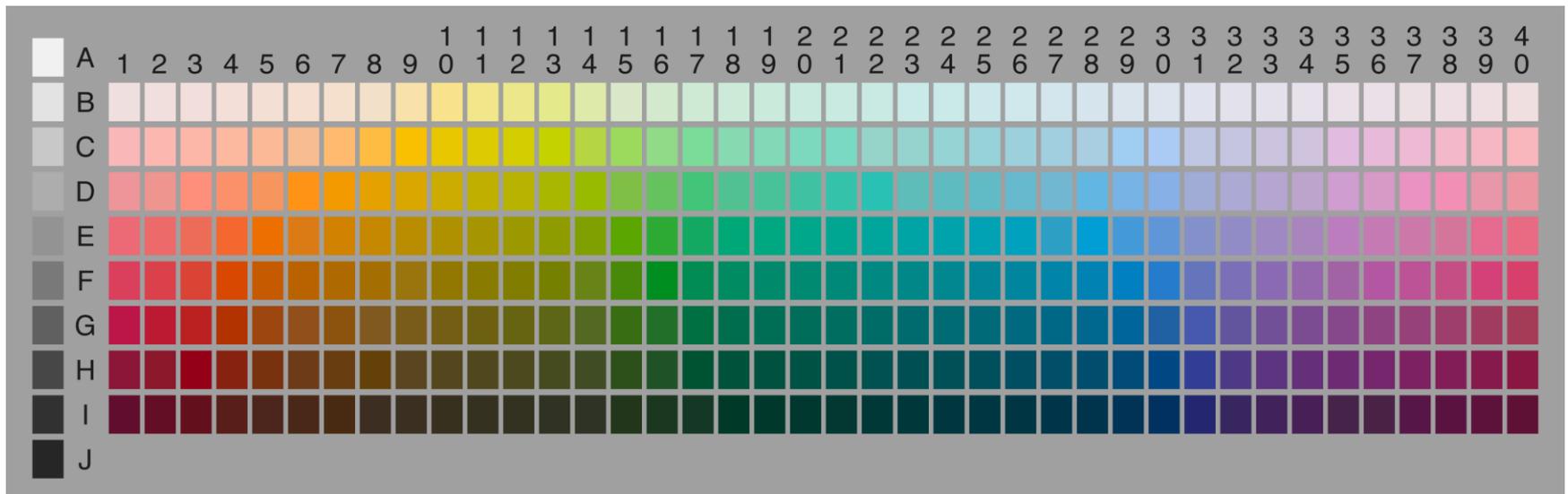
Basic Color Terms

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

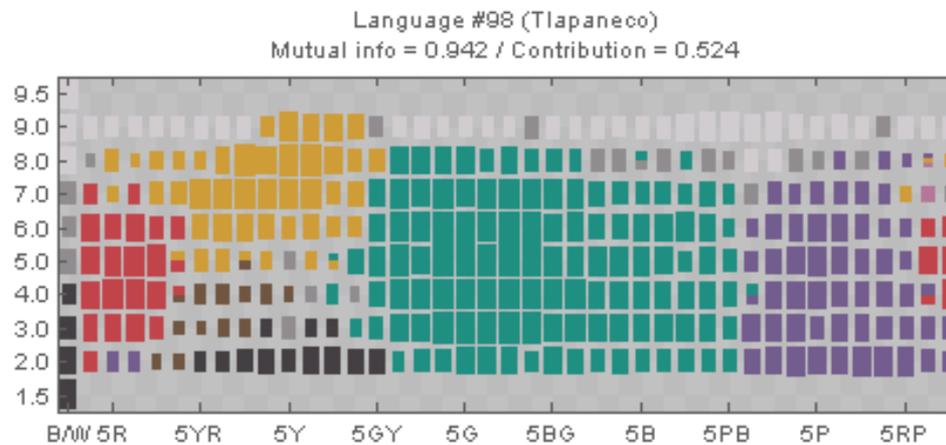
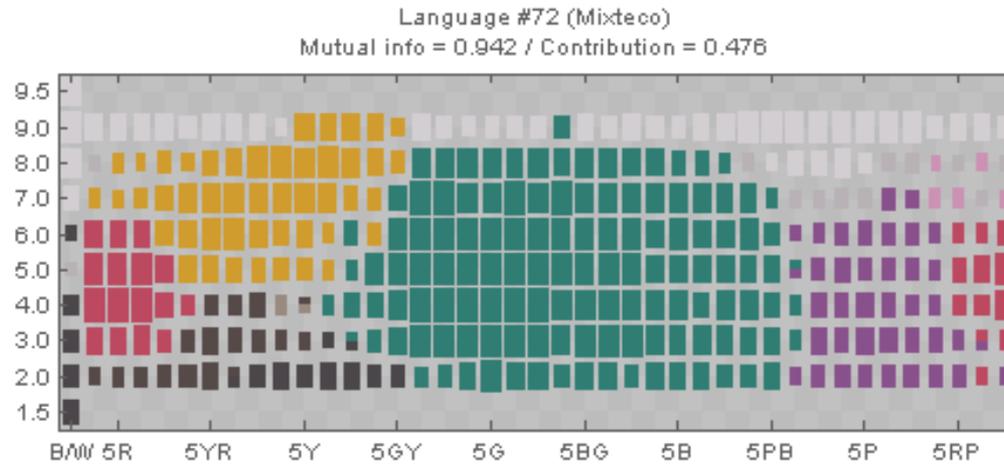


World Color Survey

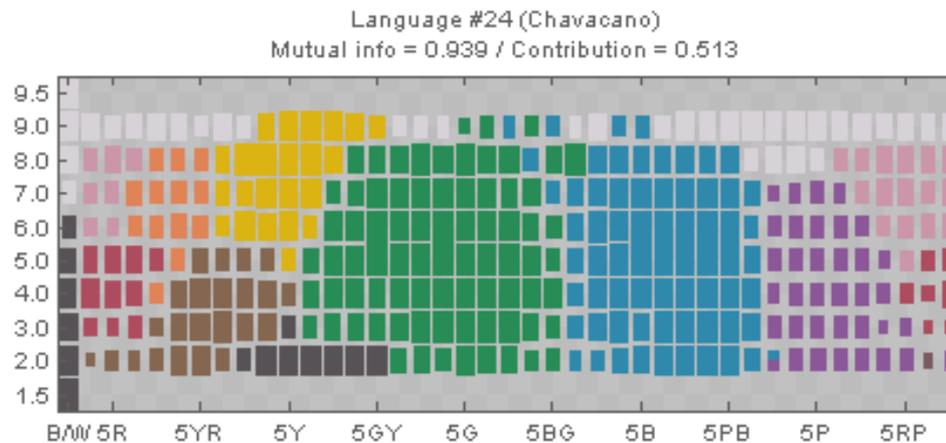
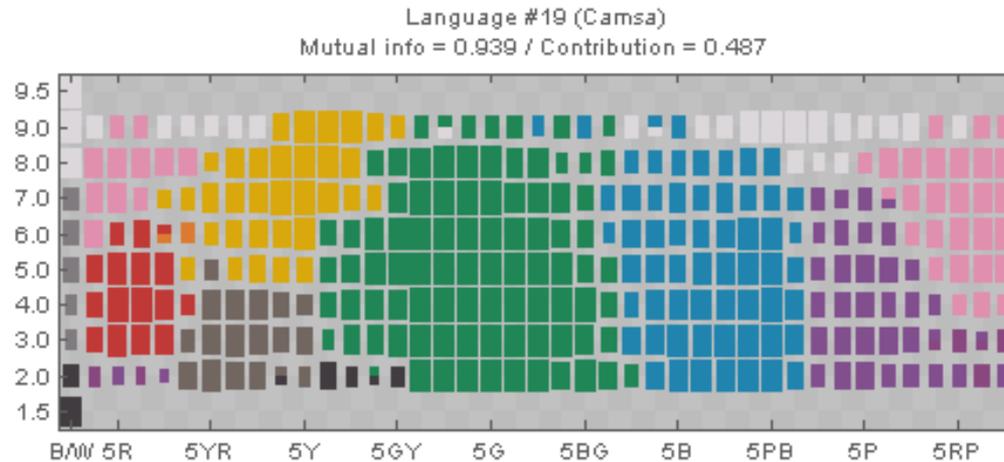
Surveyed 2616 speakers of 110 languages using 330 different color chips



Results from WCS (Mexico)



Results from WCS (South Pacific)



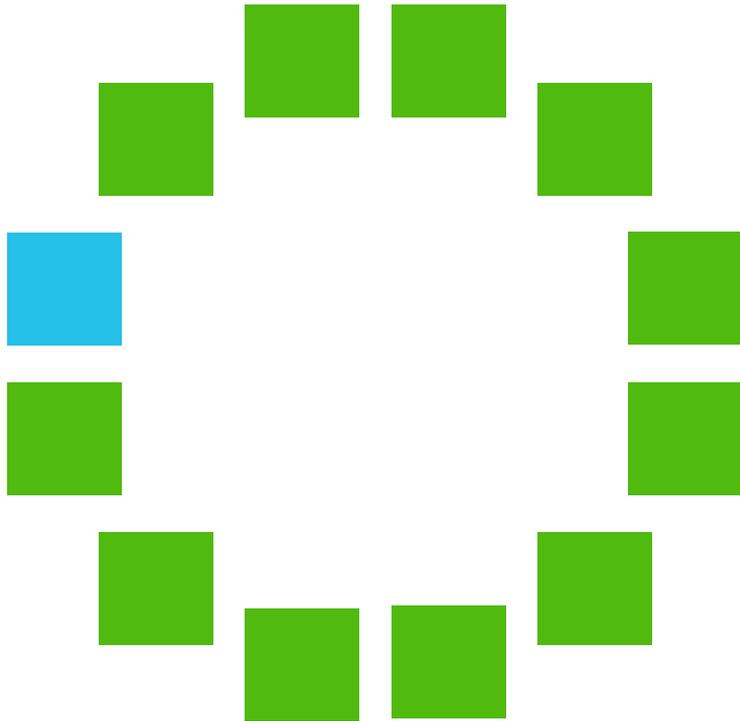
But language-color interaction

- 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?

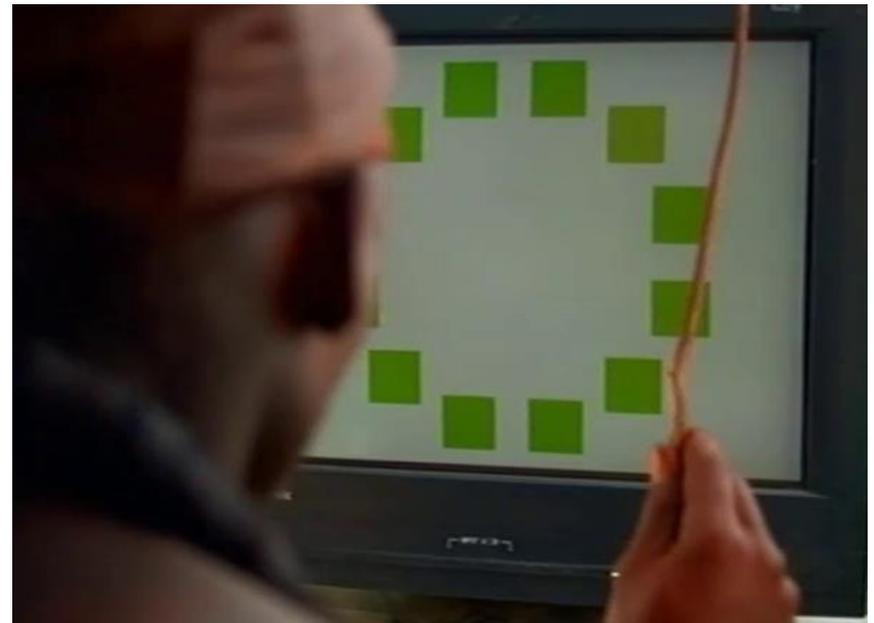
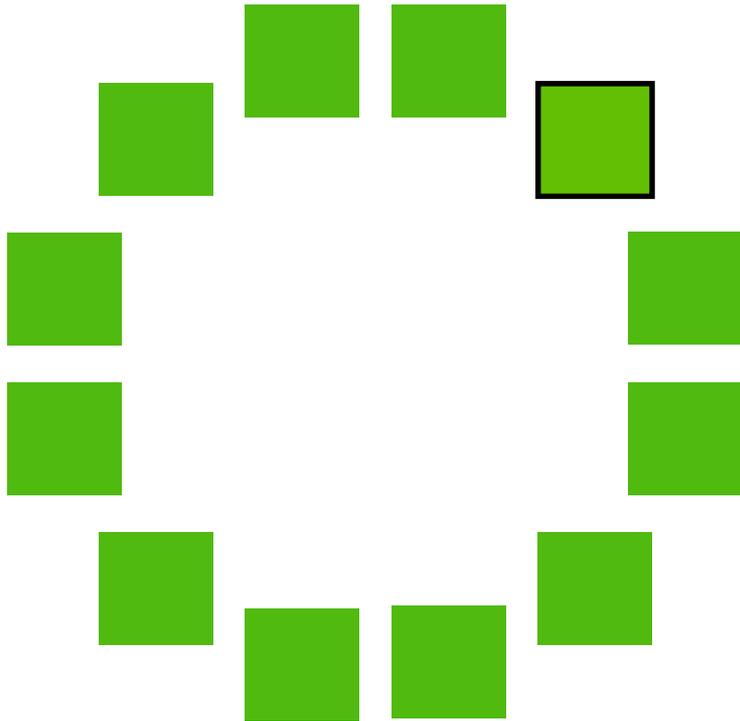


© BBC

difficult to impossible for Himba people

But language-color interaction

- experiment: how long to find a differing color?

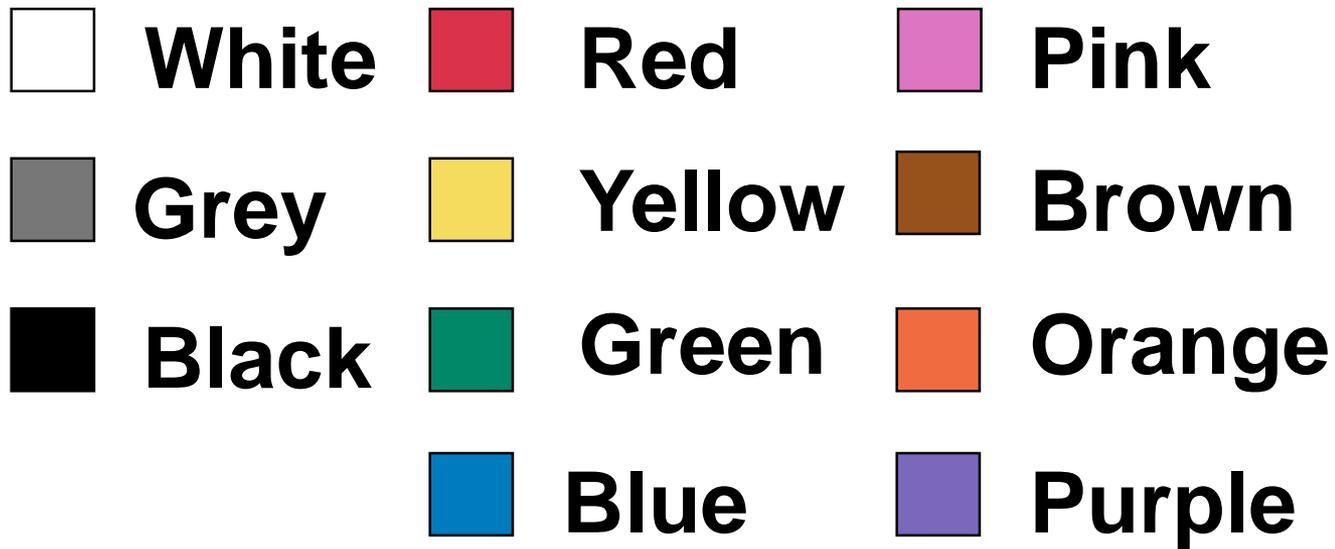


© BBC

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

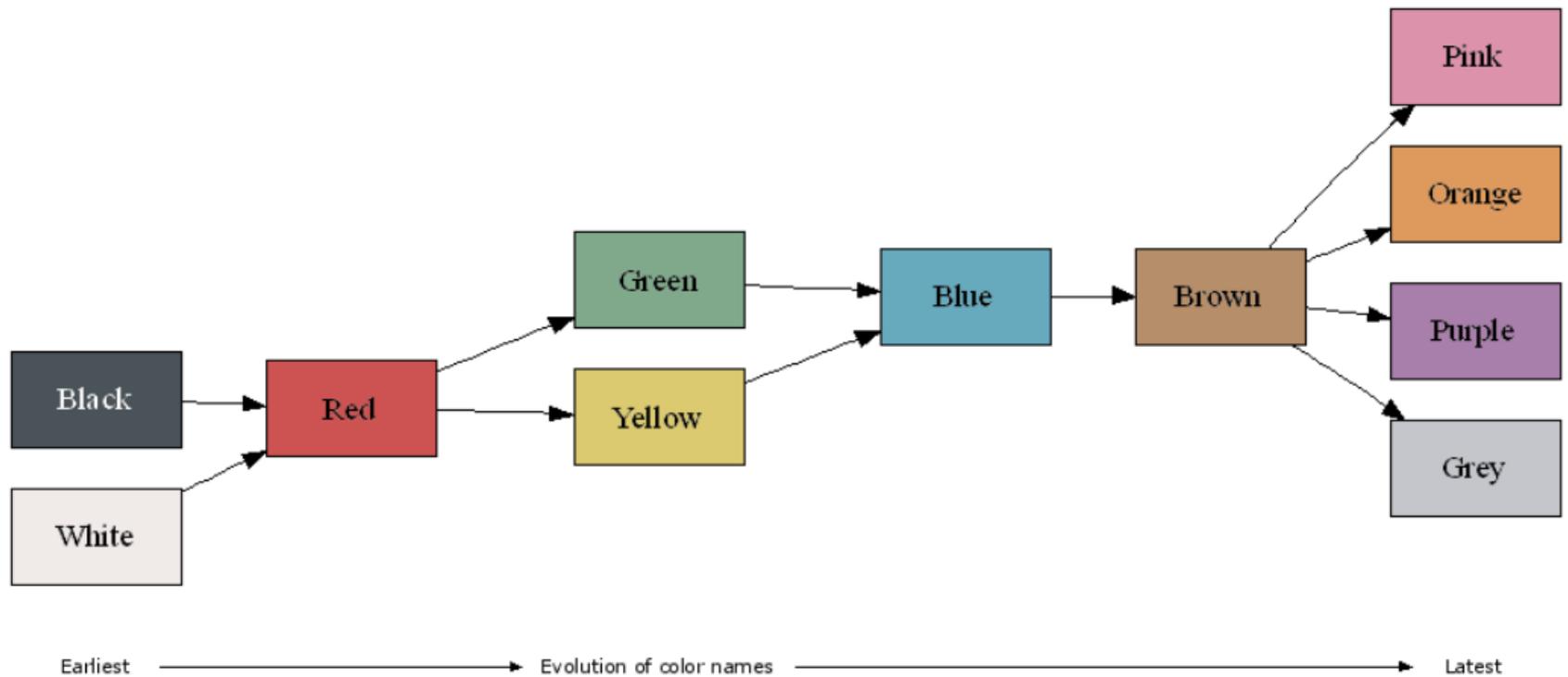
Universal (?) Basic Color Terms

Basic color terms recur across languages



Evolution of Basic Color Terms

Proposed universal evolution of color names across languages.

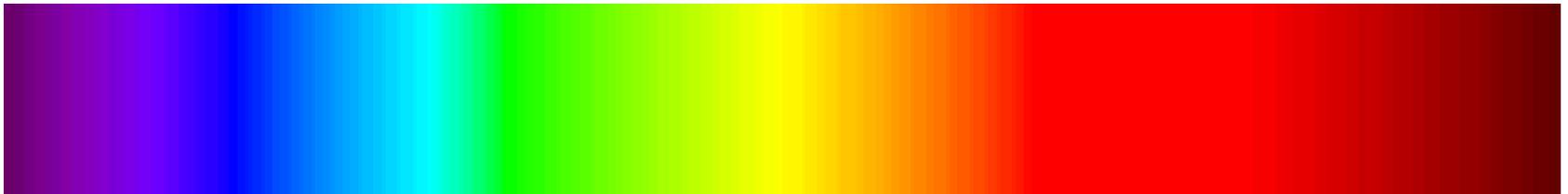


COLOR FOR VISUALIZATION

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



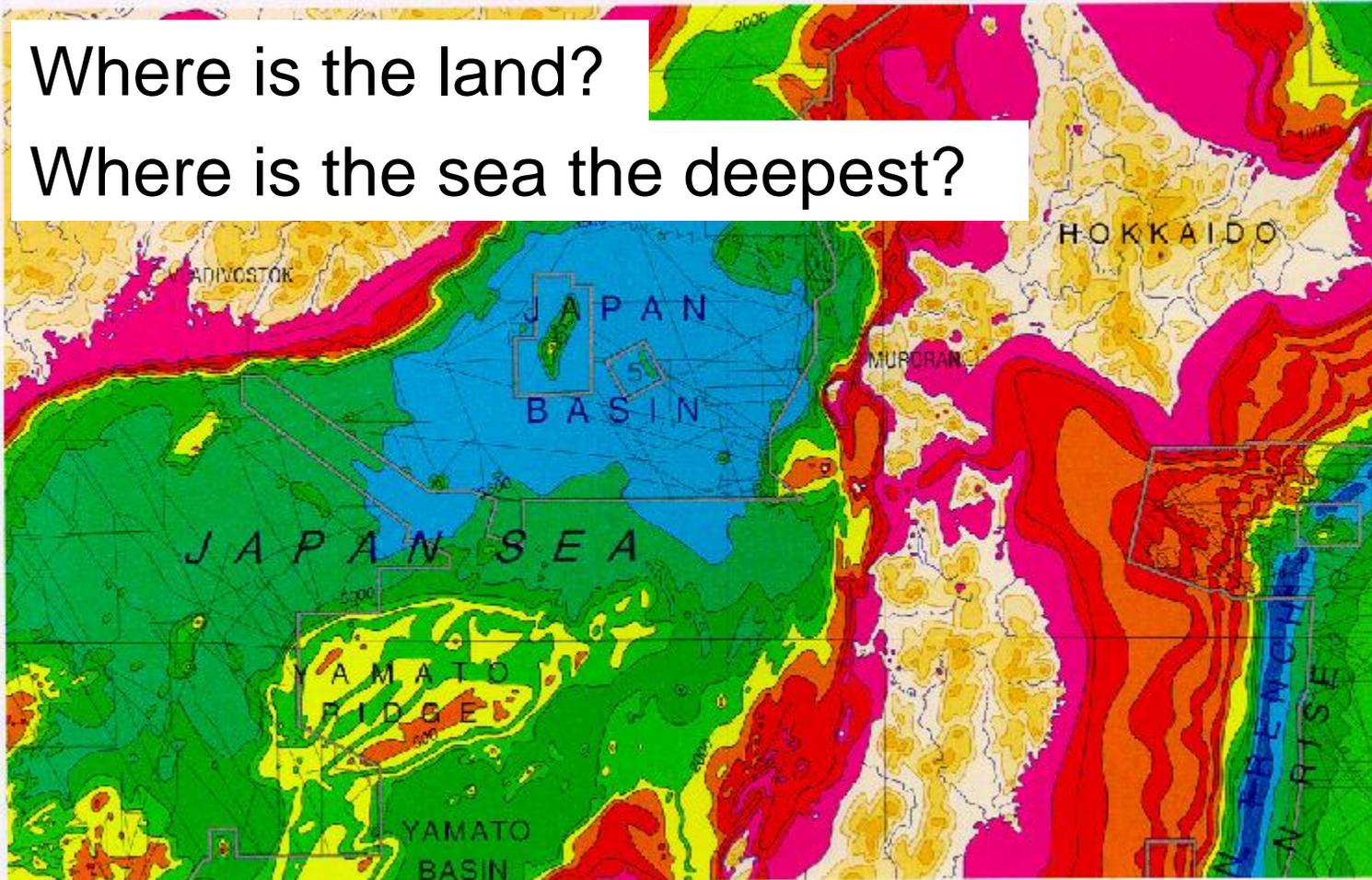
And it's (usually) a huge mistake!

General Bathymetric Chart of the Ocean

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

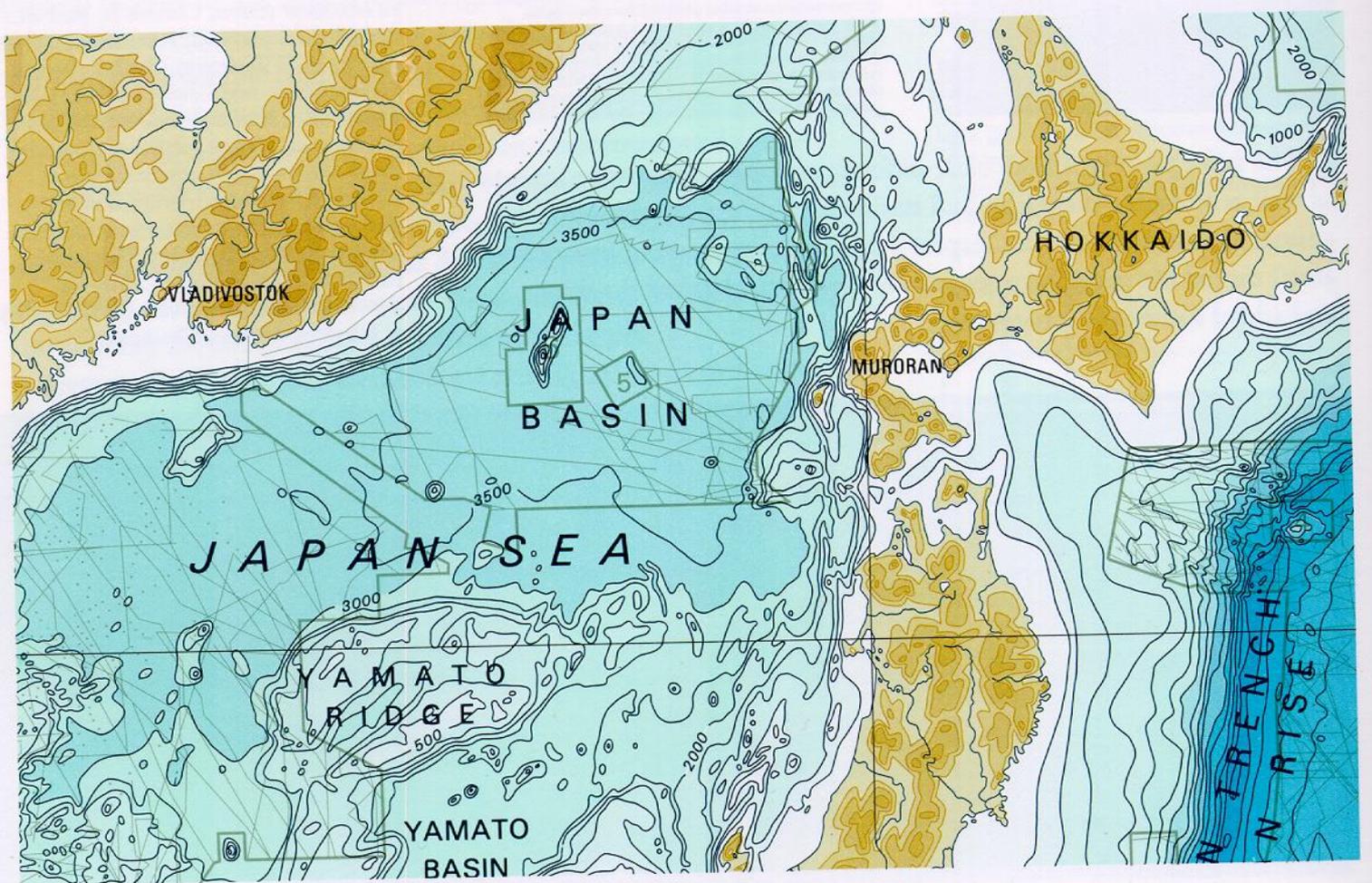
Where is the land?

Where is the sea the deepest?

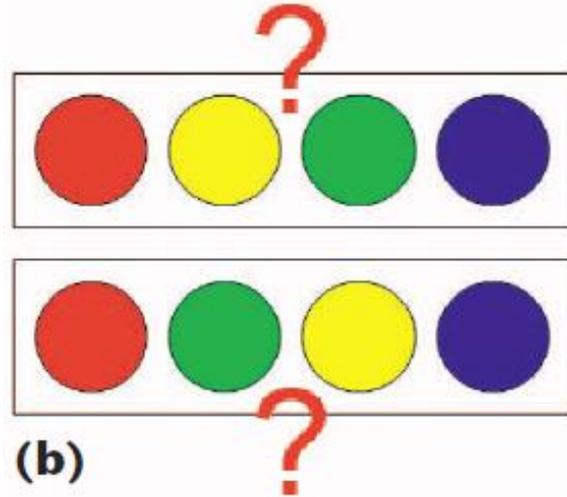


General Bathymetric Chart of the Ocean

Now describe what kind of color scale was possibly used here

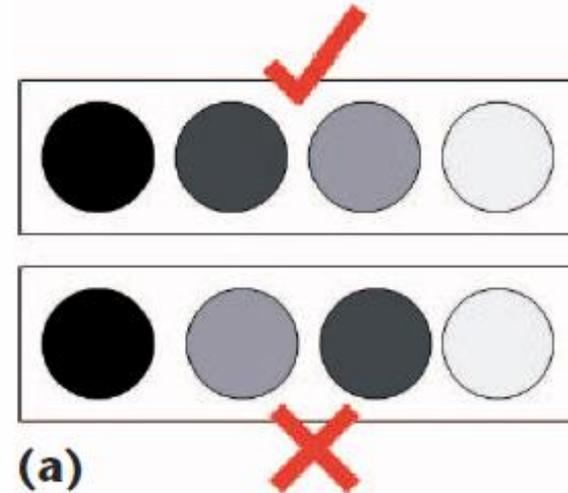


Perceptual Ordering



Rainbow Color Scale

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



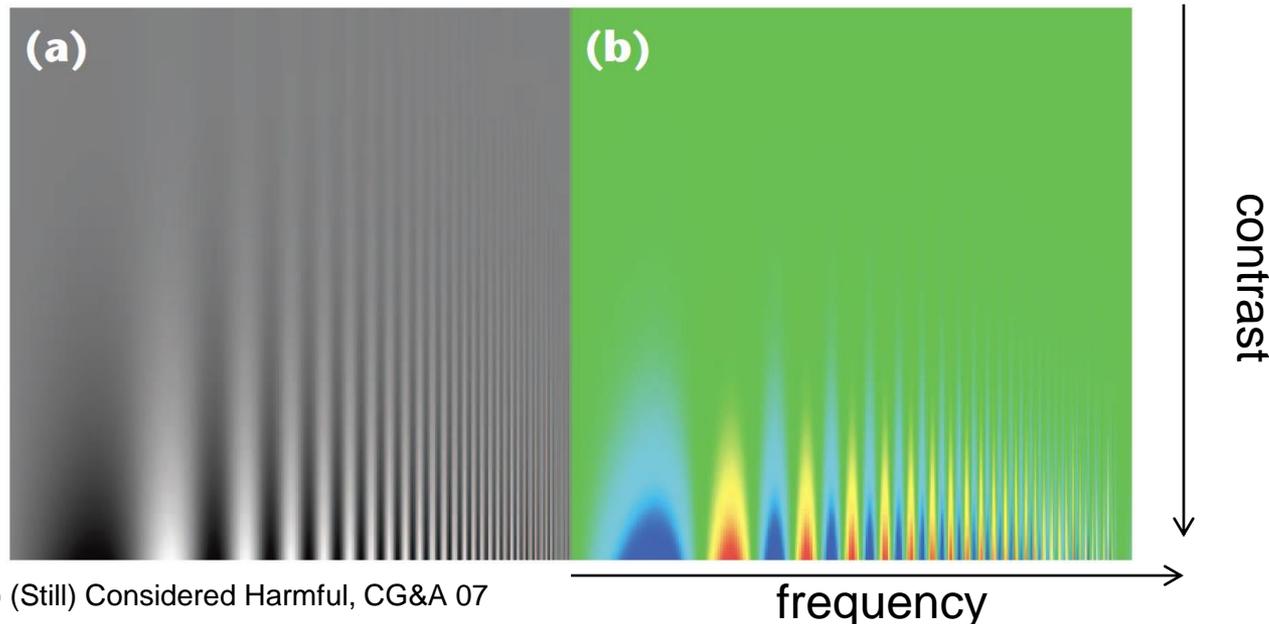
Gray Scale

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

Color Scale Luminance

Rainbow Color Scale

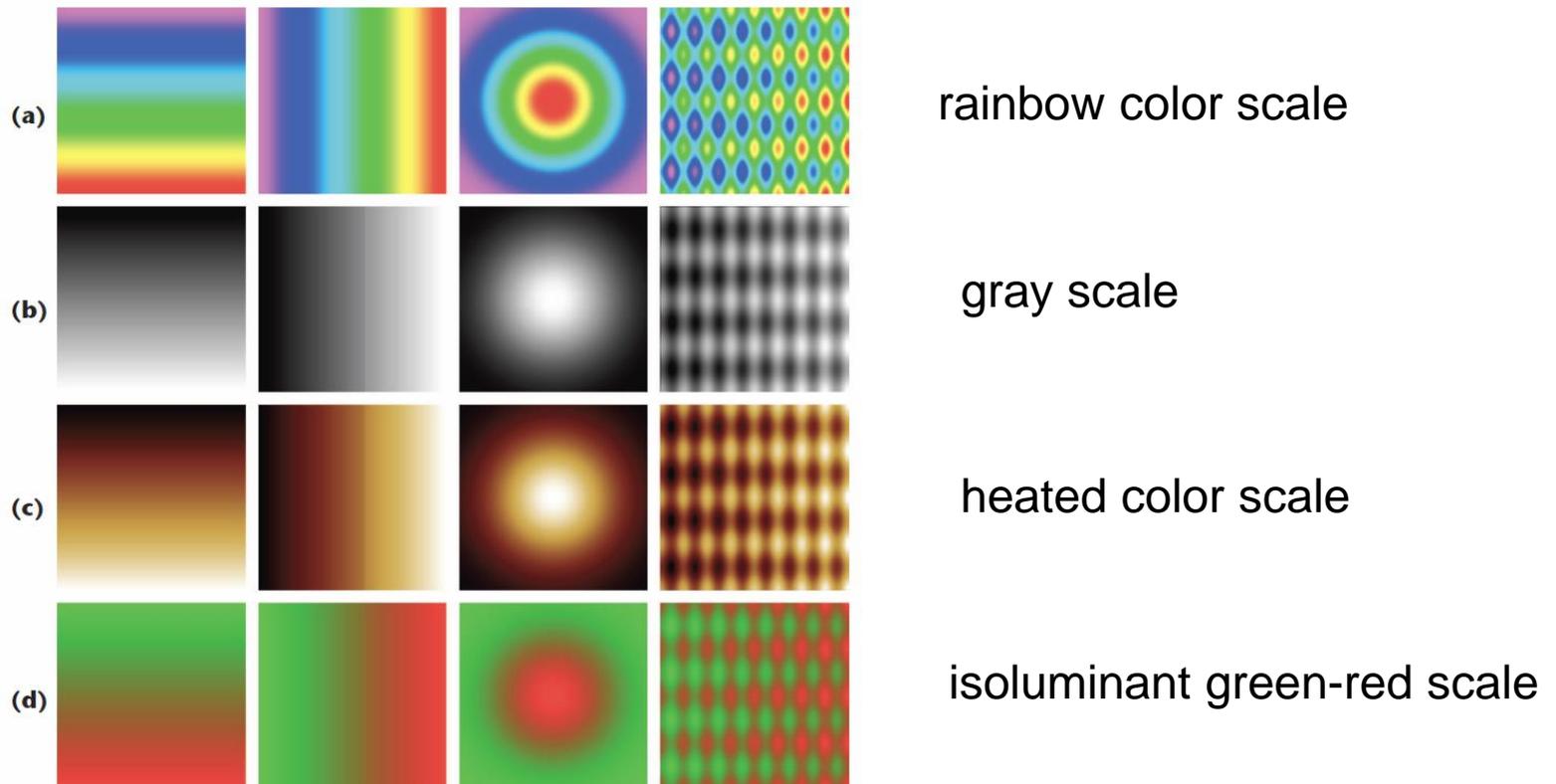
- The visual system perceives high spatial frequencies through changes in luminance
- Is isoluminant (for large portions), changes only appear at color boundaries
- Obscures small details in the data



Color Scale Transitions

Rainbow color scale

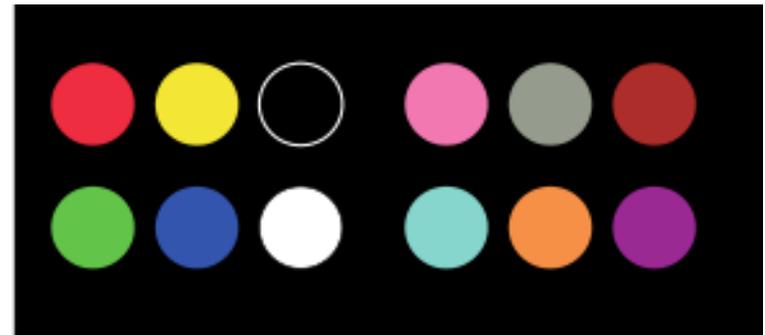
- appears separated into bands of almost constant hue
- sharp transitions between hues are perceived as sharp transitions in the data



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



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 (red/blue etc.)

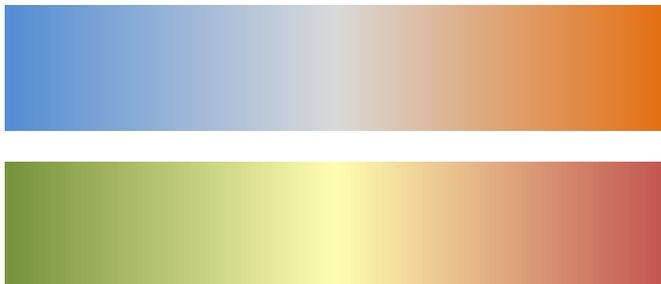
Using Color for Scales

(For ordinal or quantitative data)

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



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



ColorBrewer

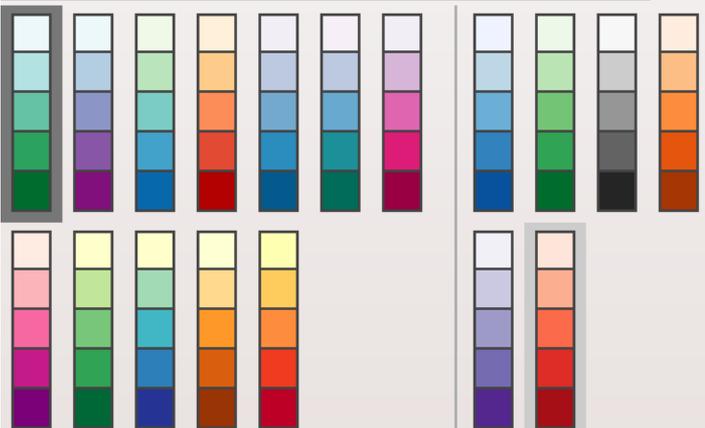
number of data classes on your map

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

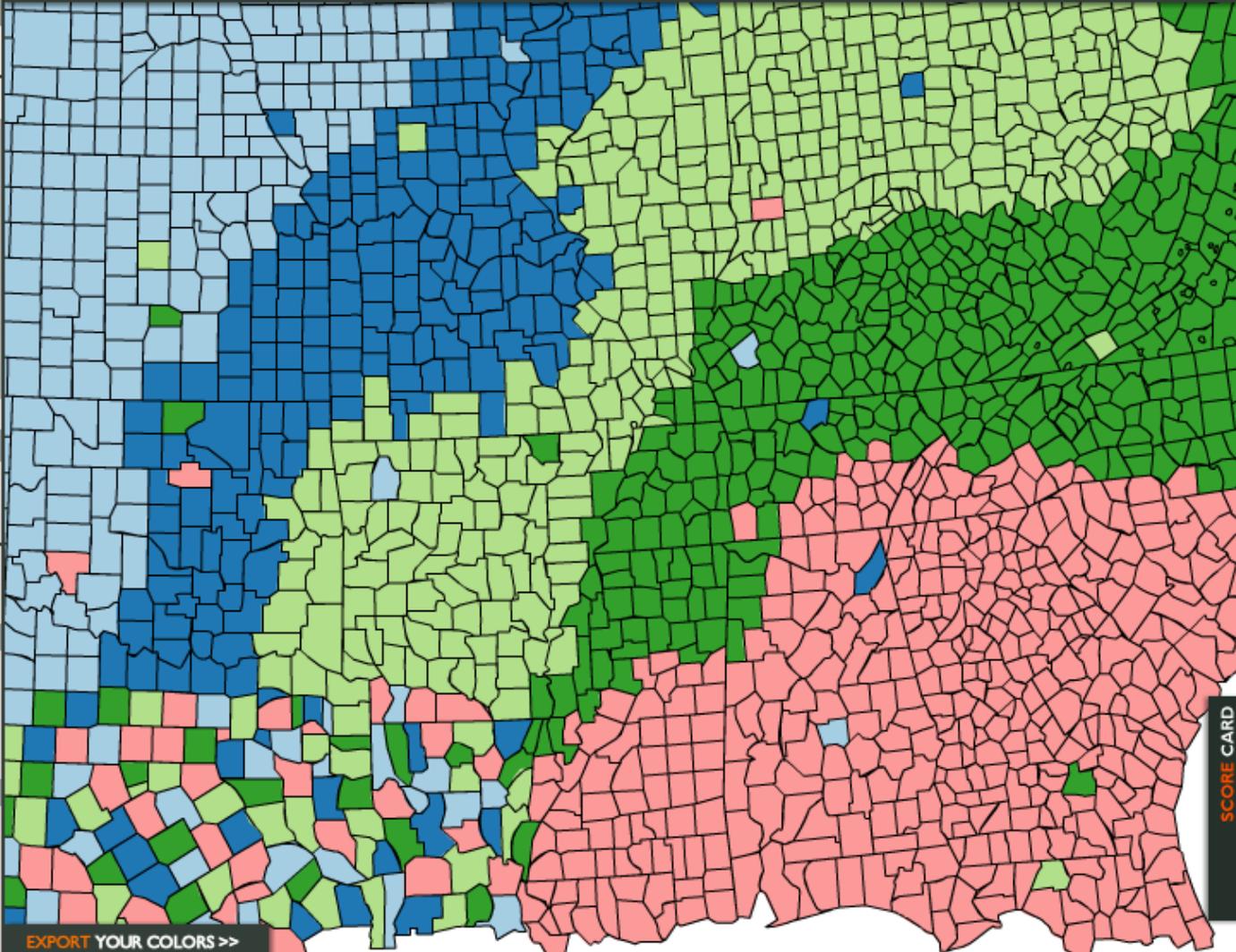
solid color terrain

color transparency

[EXPORT YOUR COLORS >>](#)

COLORBREWER 2.0
 color advice for cartography

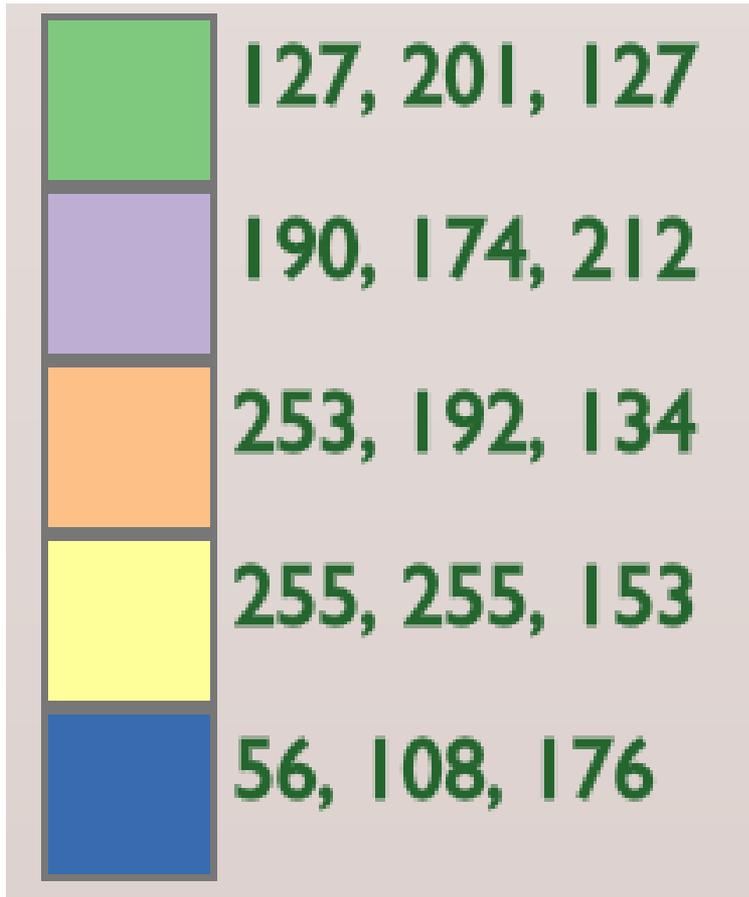
how to use | updates | credits



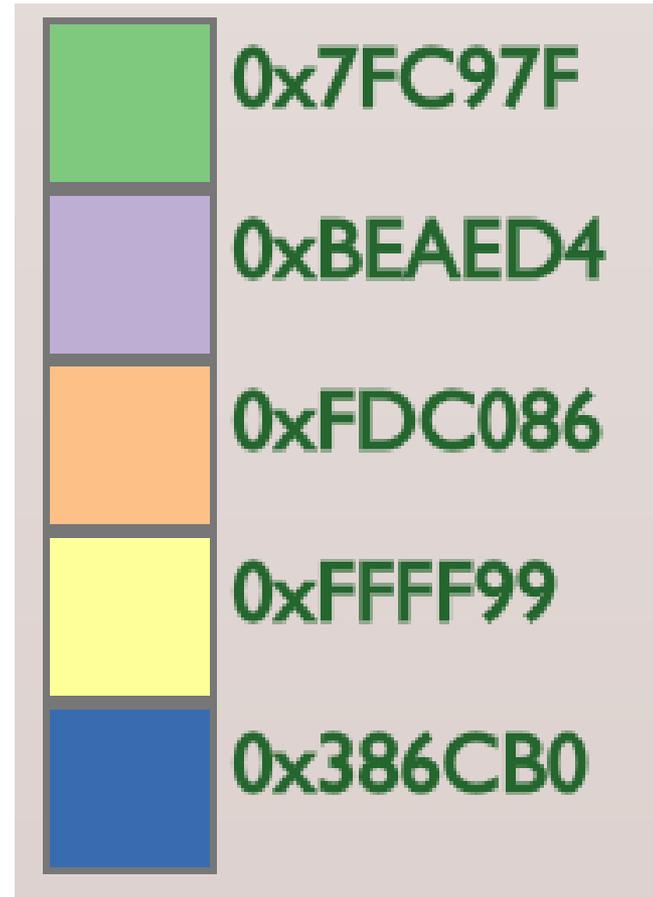
SCORE CARD

<http://colorbrewer2.org/>

ColorBrewer

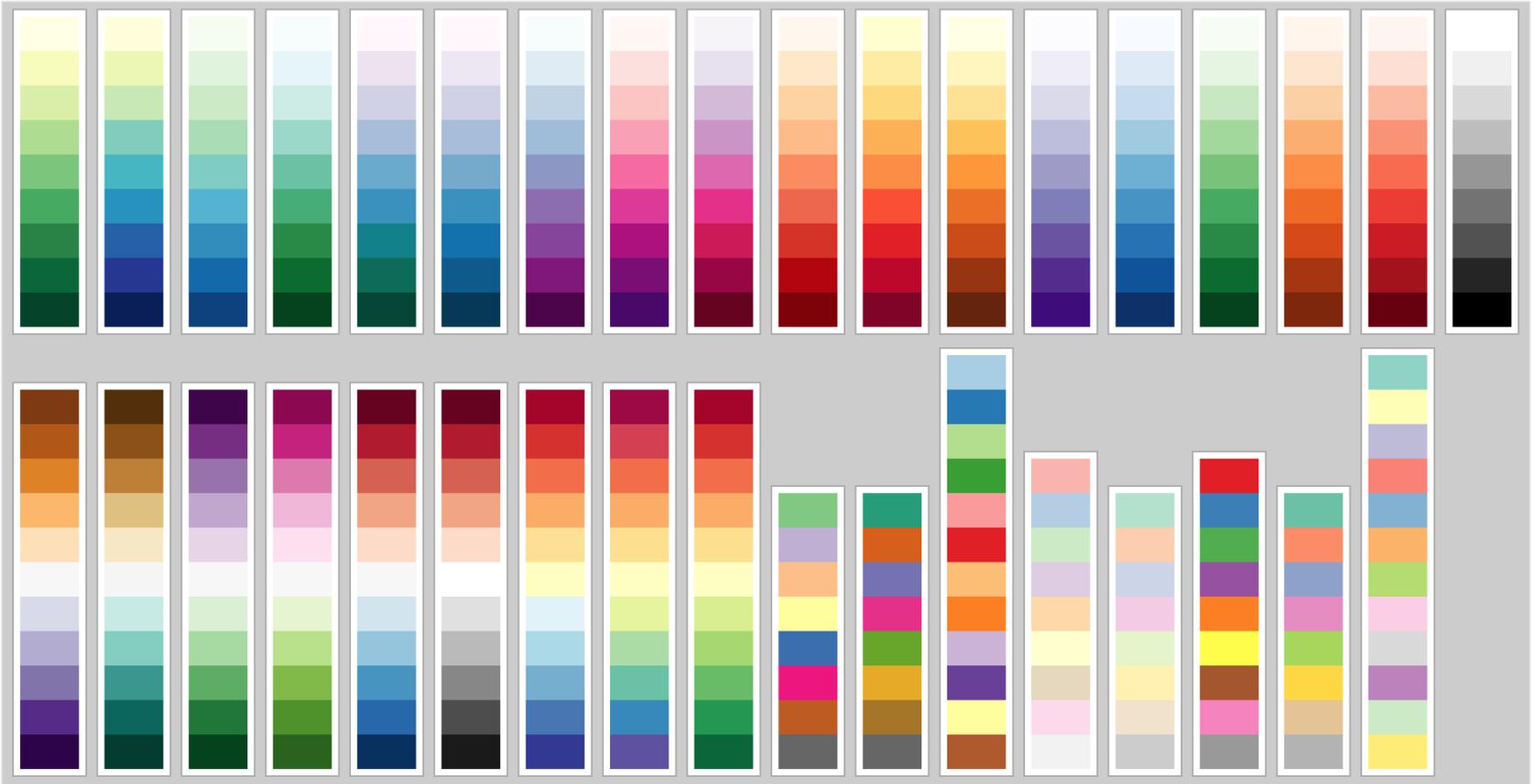


(RGB



(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,

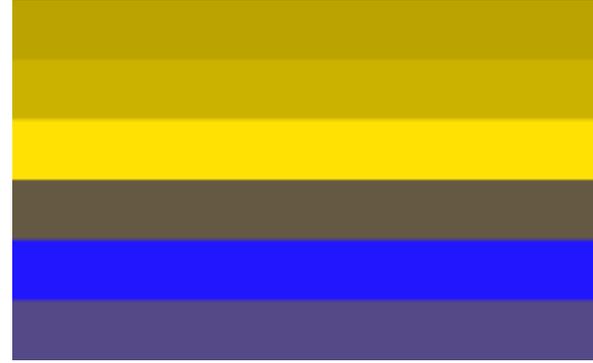
ONE WARNING ABOUT

RED-GREEN

Color Vision Deficiency



normal color vision

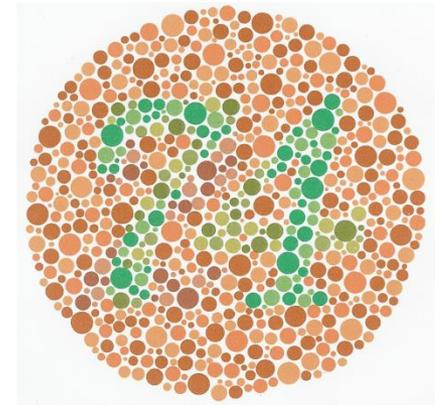
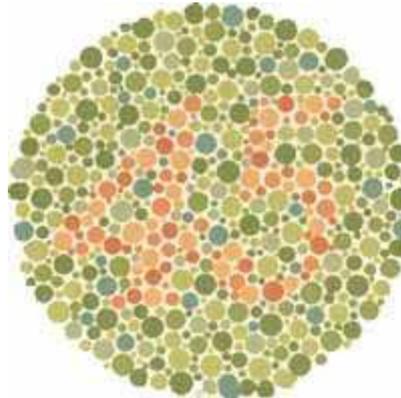
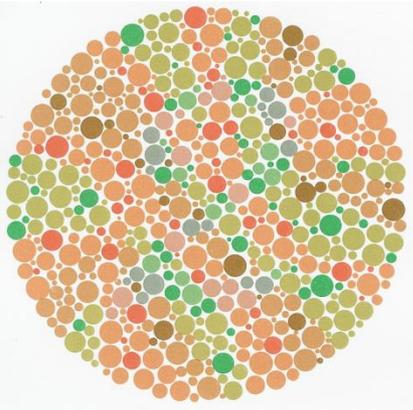
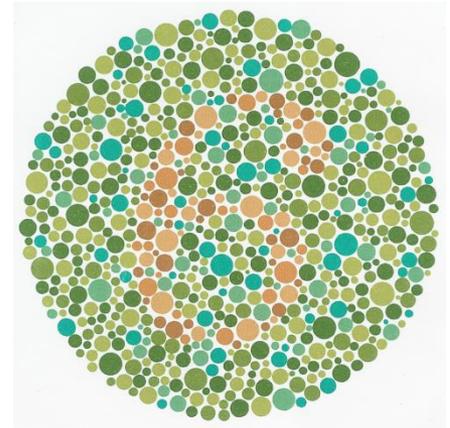
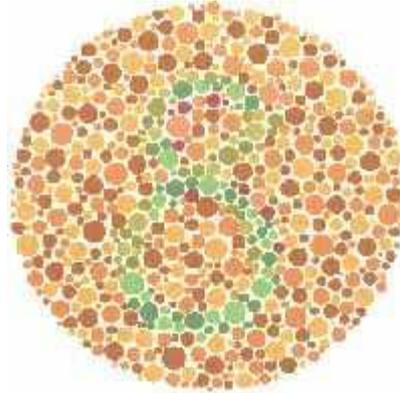
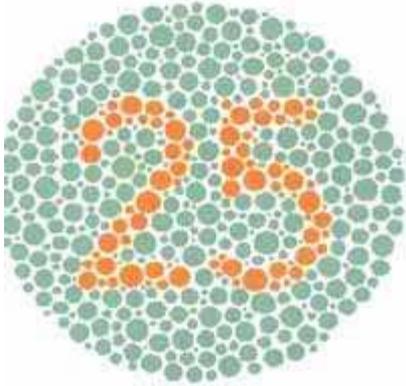


simulation of color contrast
for deuteranopic color vision
(green receptors absent)

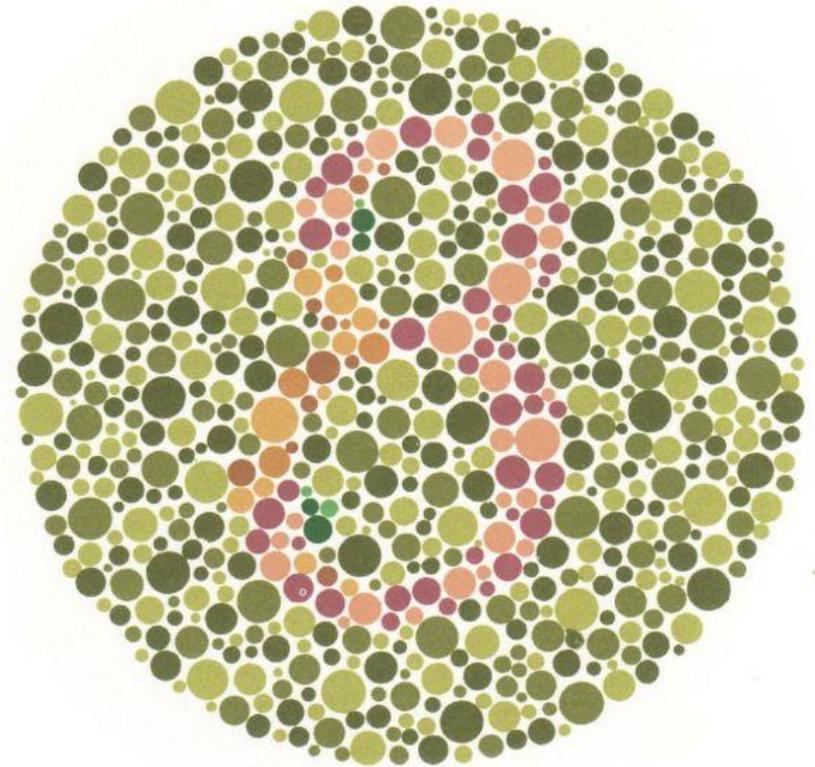
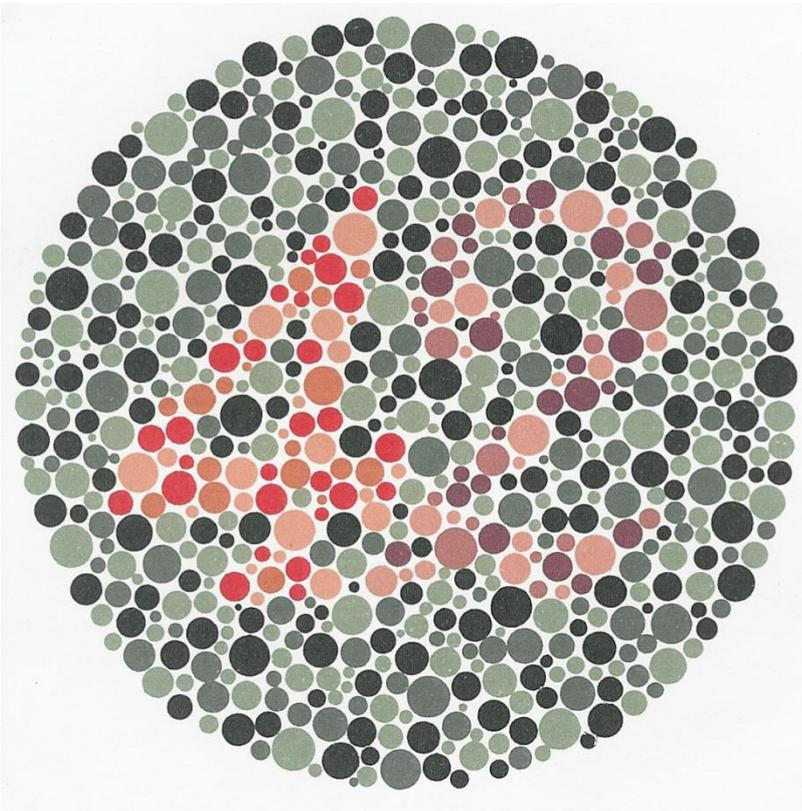
approx. 7% of male population color-deficient

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

Color Deficiency Test (Ishihara Test)



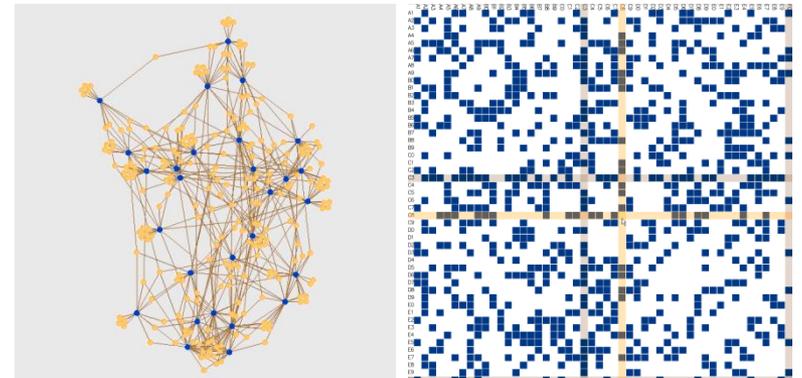
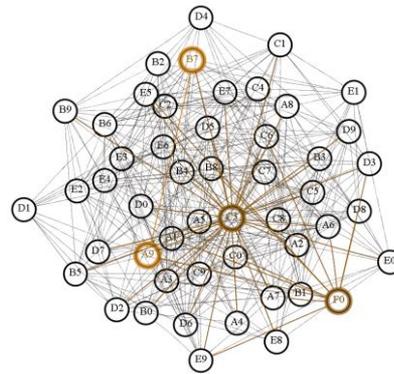
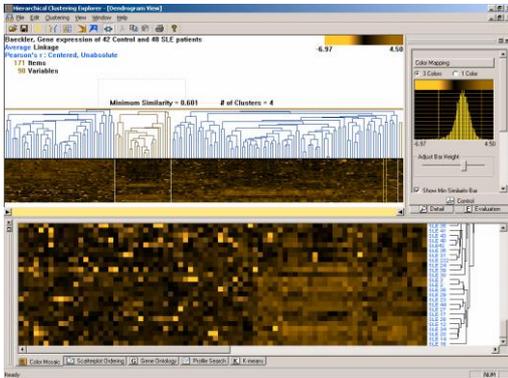
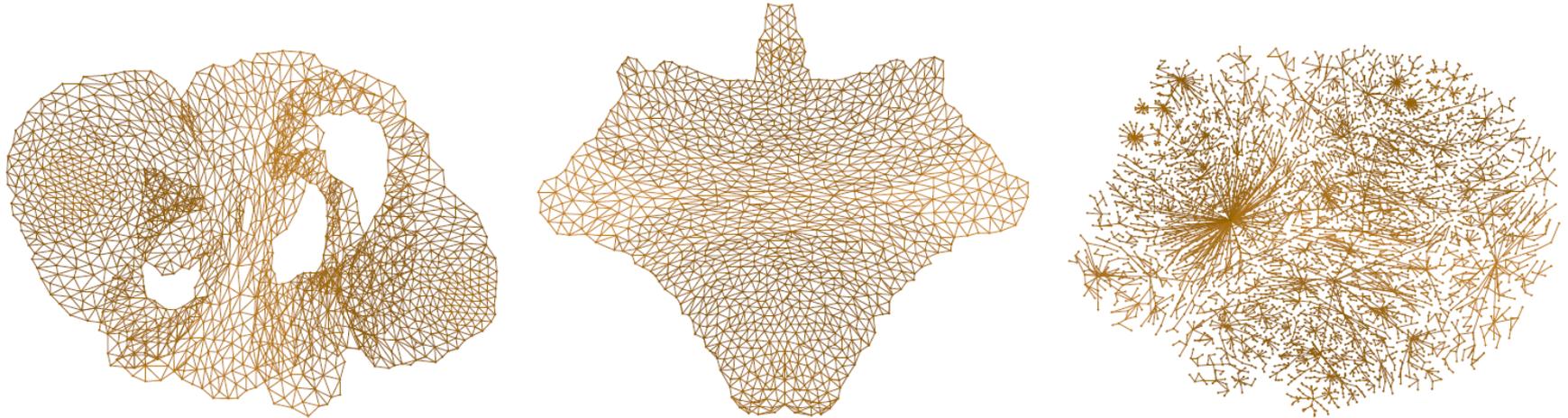
Color Deficiency Test



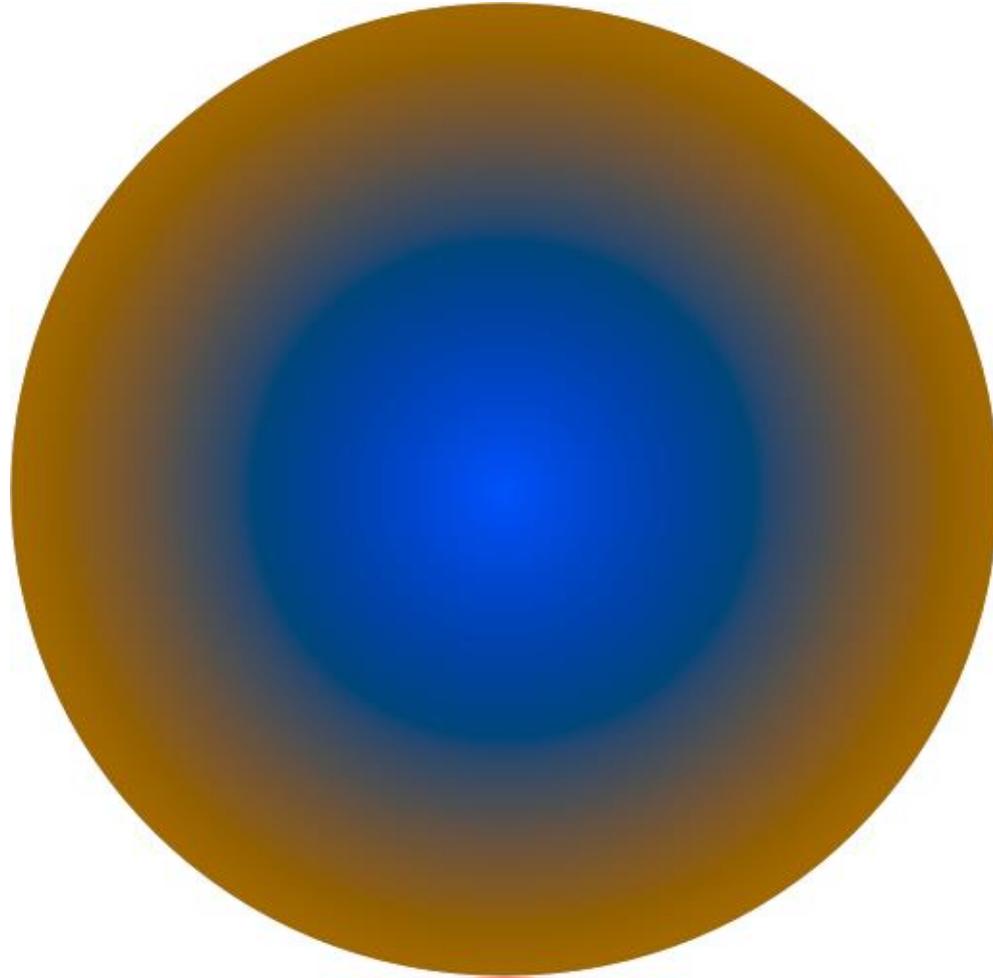
Color Deficiency



Examples from VIS/InfoVis 2004

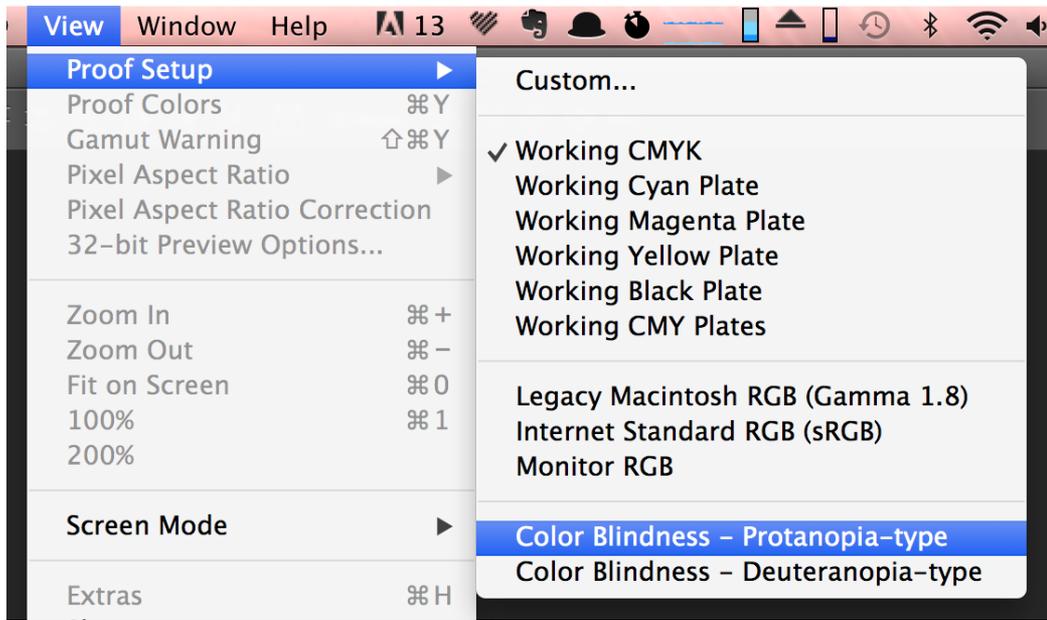


Better: Red-Blue Contrast



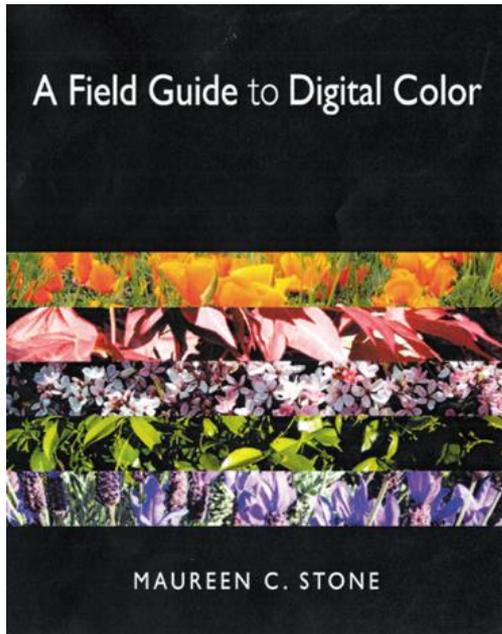
Check Your Visualizations!

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>

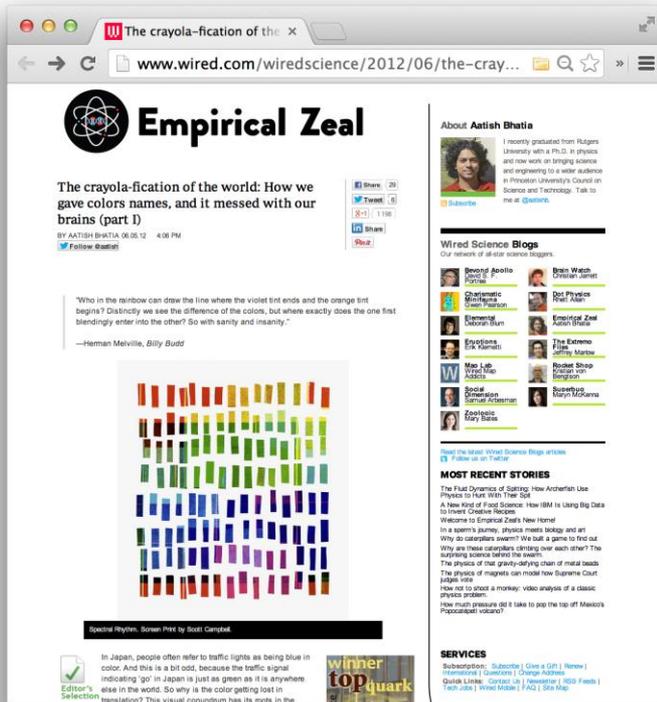
<http://kuler.adobe.com>

(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/>



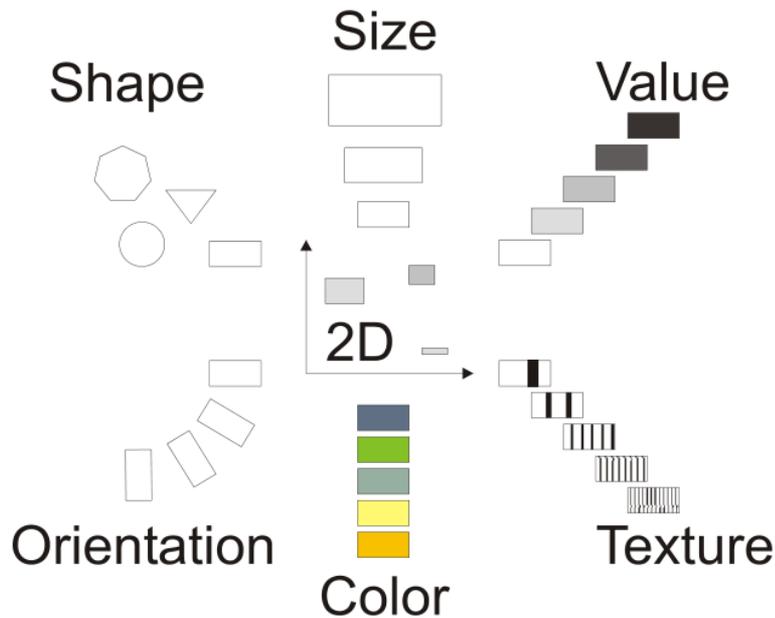
RadioLab “Colors”

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)

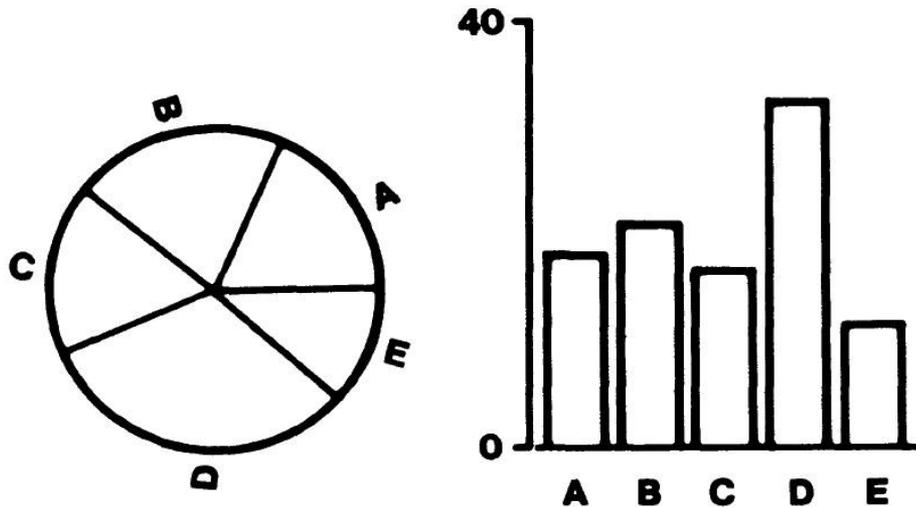


Figure 3. Graphs from position-angle experiment.

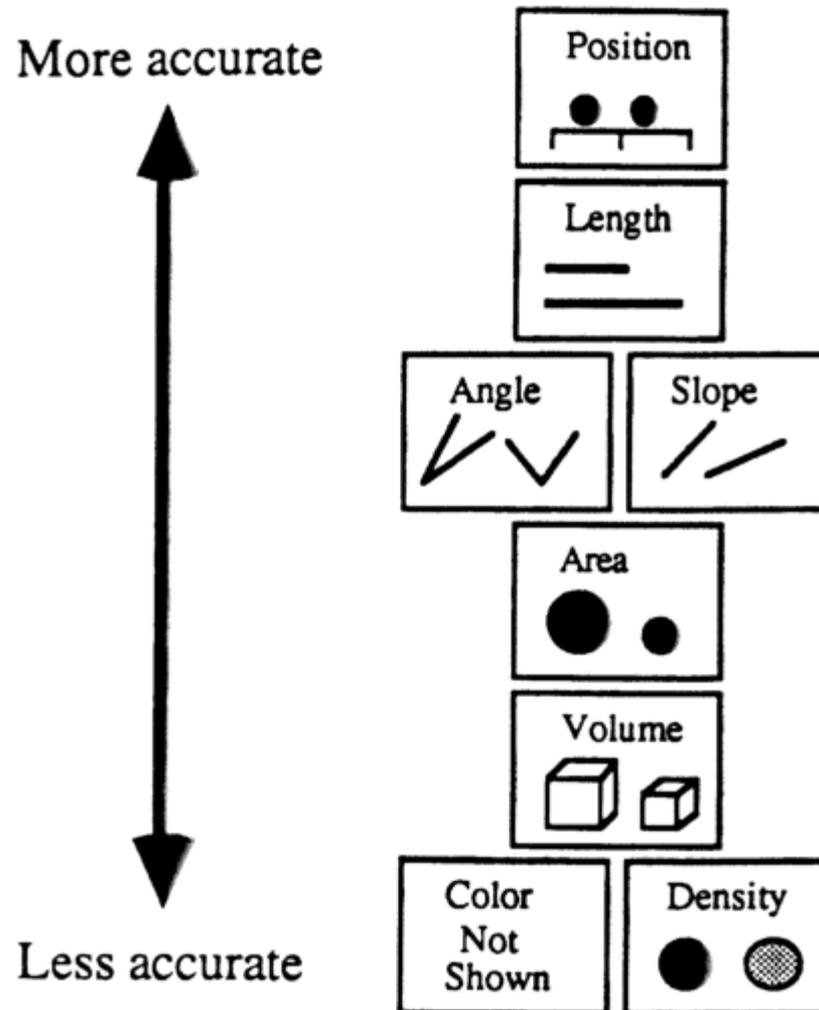
Performed **controlled experiments** to determine how effectively people could judge **changes in visual features**

Focus on **quantitative information**

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

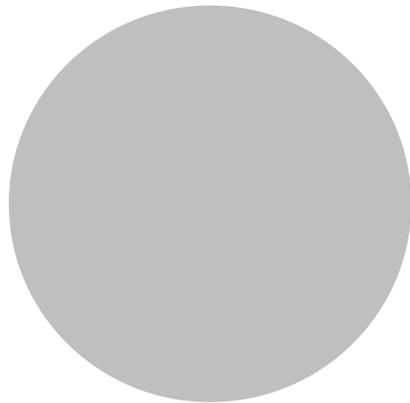
Elementary Graphical Perception Tasks

William S. Cleveland (1980s)

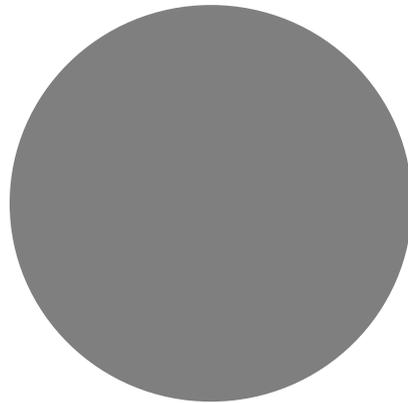


Color Value

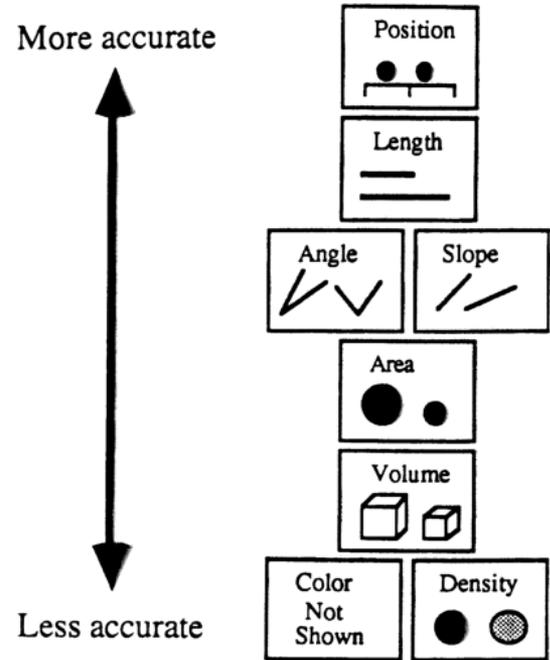
- What percentage in value is the right from the left?



100%

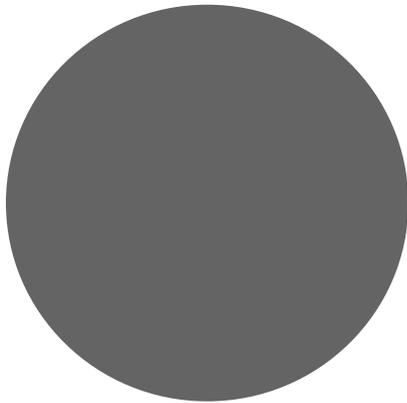


66%

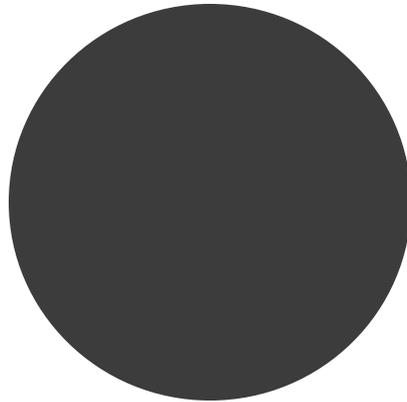


Color Value

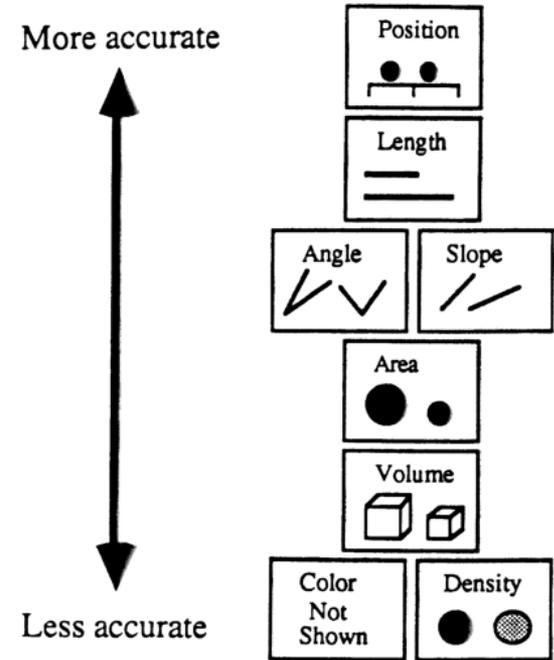
- What percentage in value is the right from the left?



100%

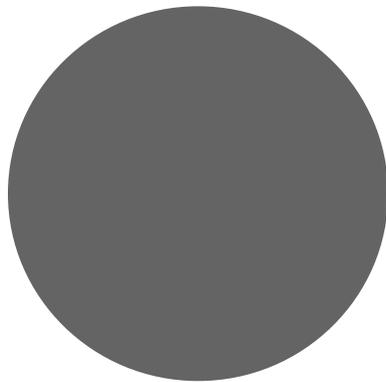


60%

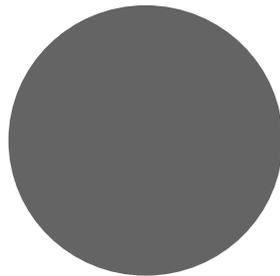


Area

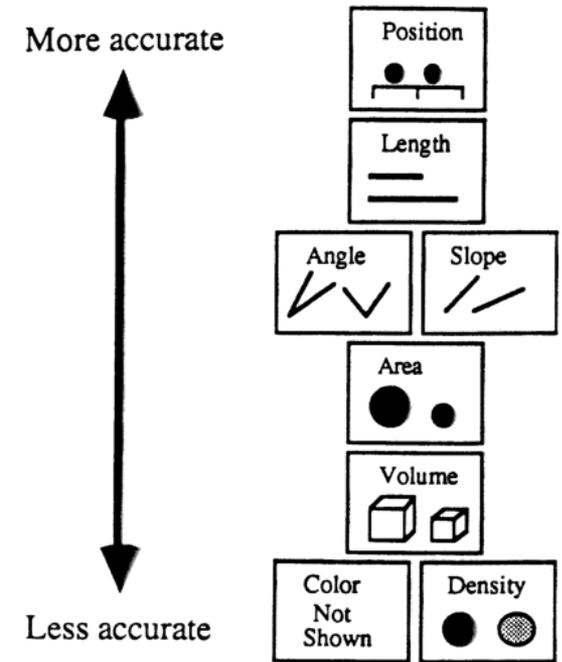
- What percentage in size is the right from the left?



100%

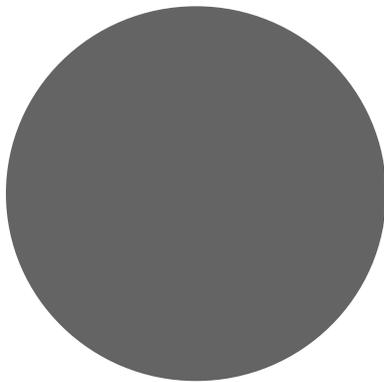


52%

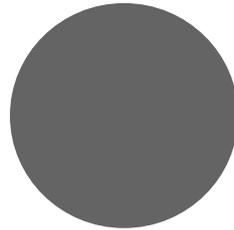


Area

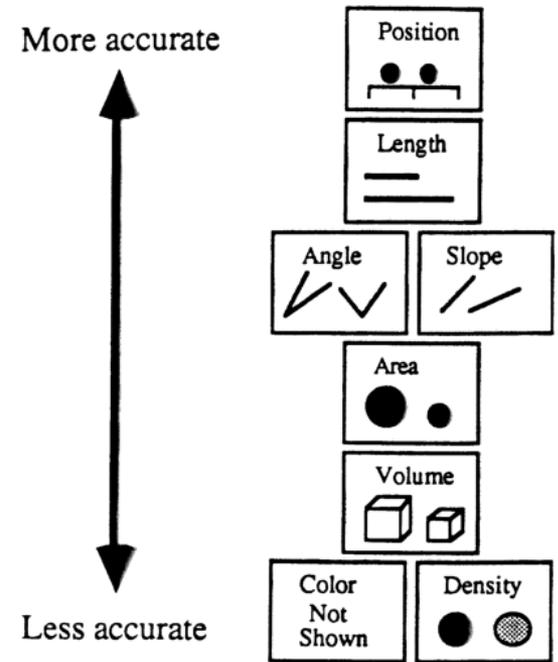
- What percentage in size is the right from the left?



100%

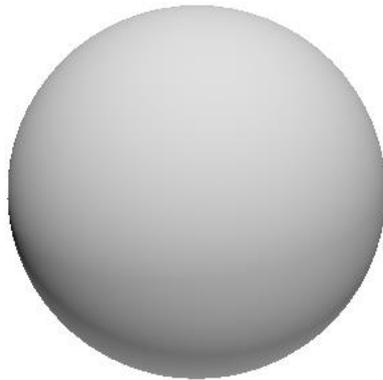


36%

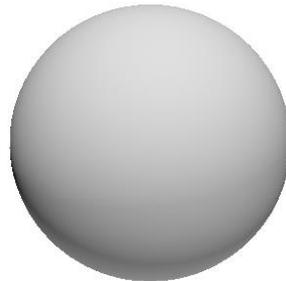


Volume

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



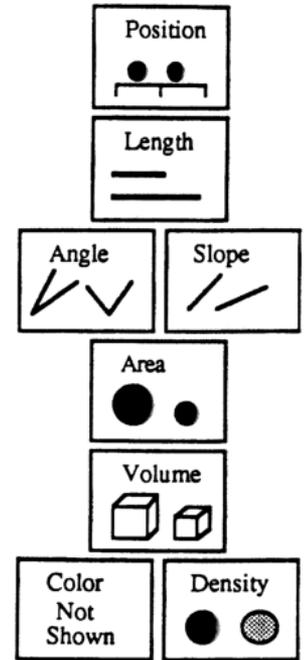
100%



40%

More accurate

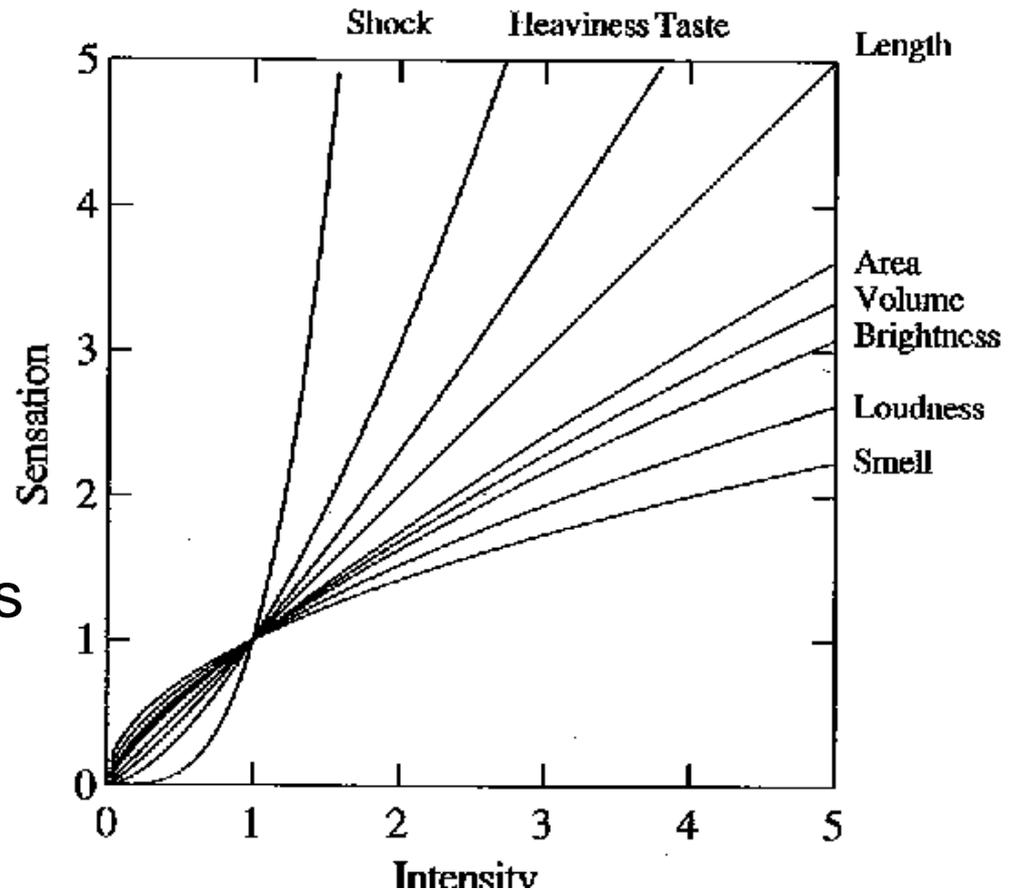
Less accurate



Why are people so bad at this?

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

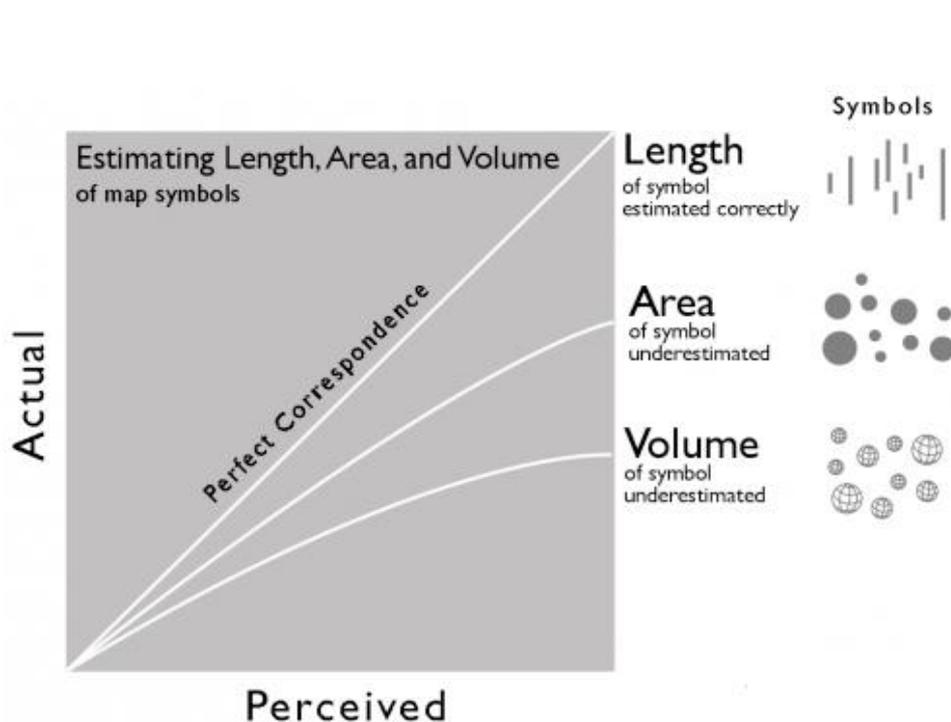
Stevens' power law describes a relationship between a physical stimulus (S) and its **perceived** intensity or strength (P)



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

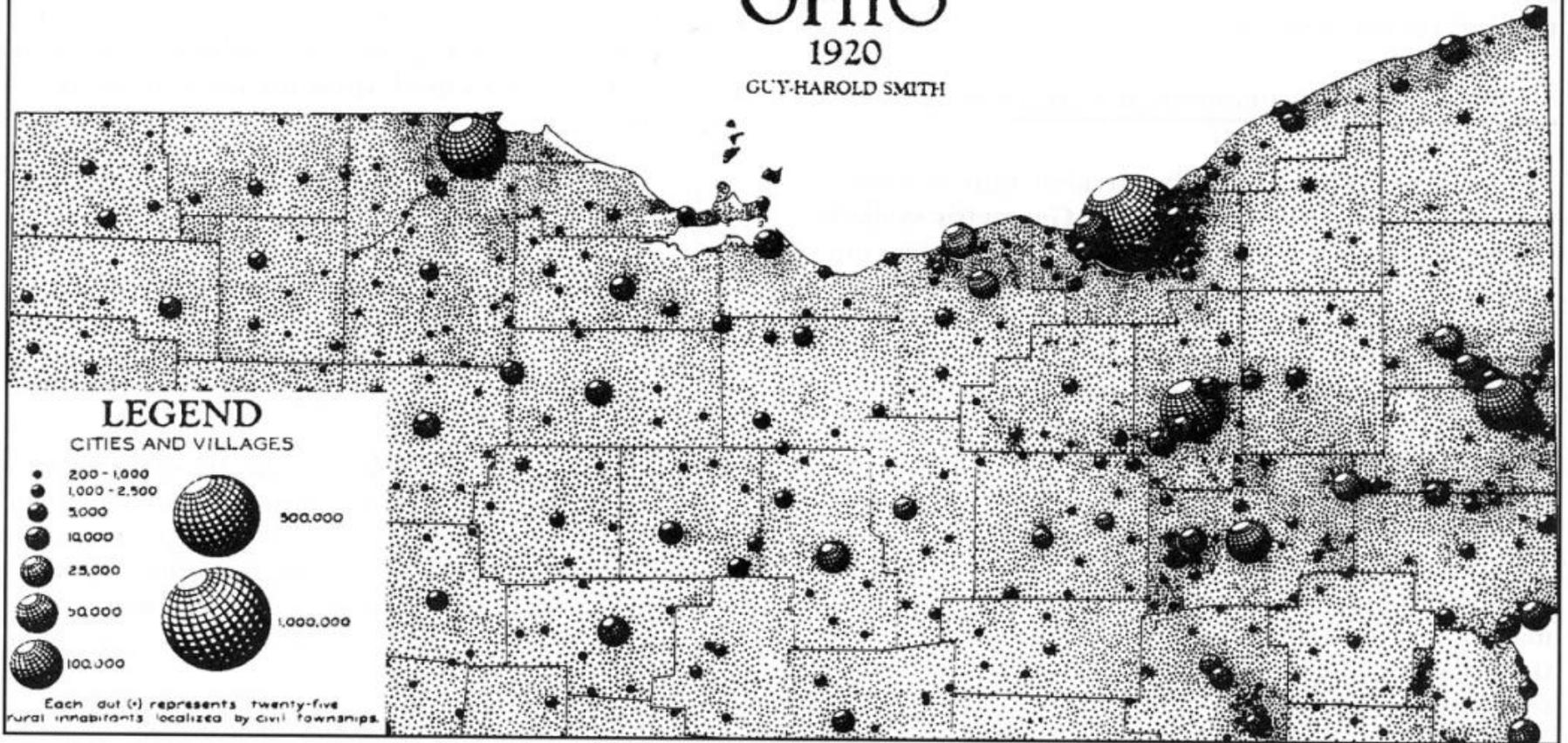
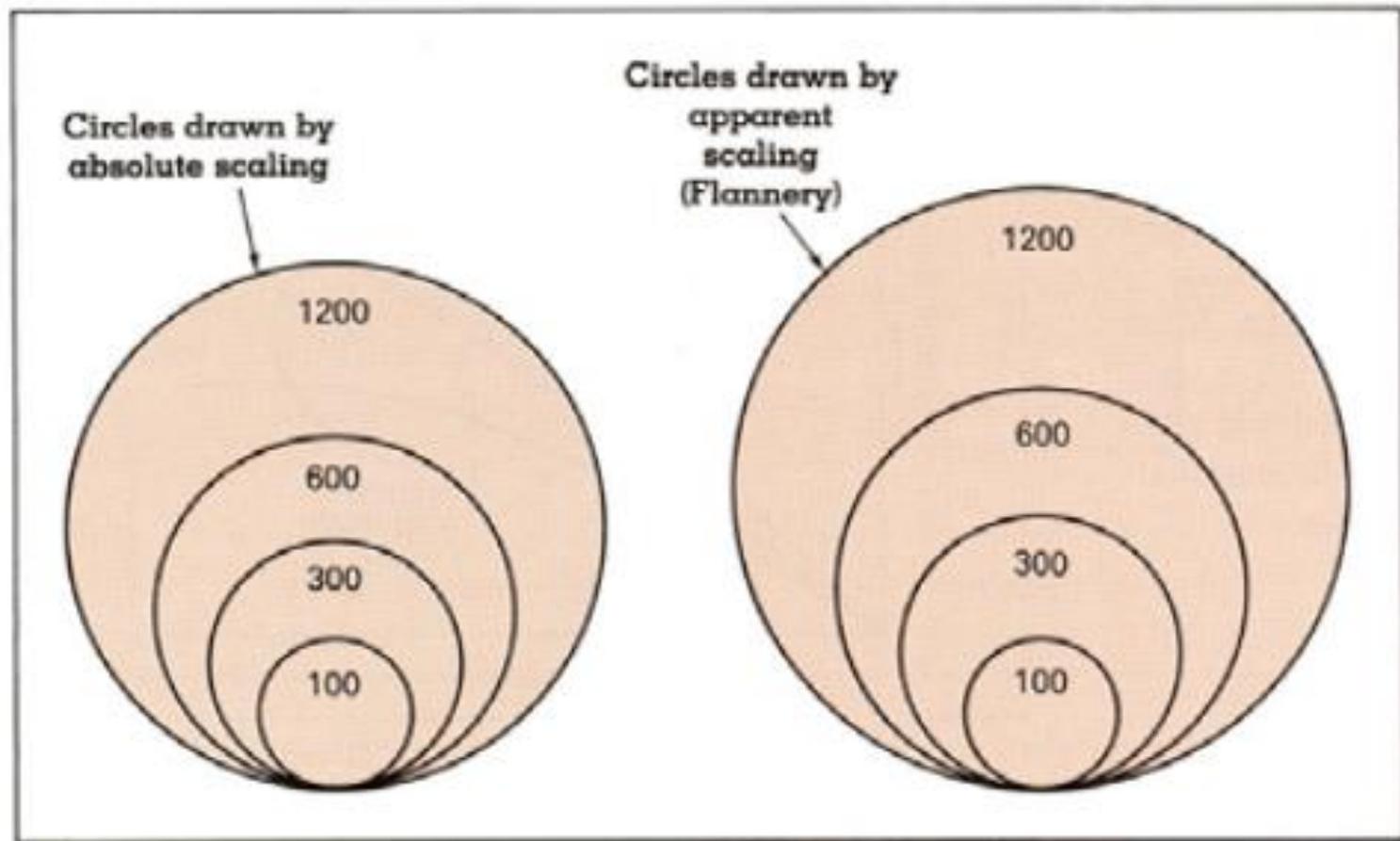


FIGURE 7.4. An eye-catching map created using three-dimensional geometric symbols. (After Smith, 1928. First published in *The Geographical Review*, 18(3), plate 4. Reprinted with permission of the American Geographical Society.)

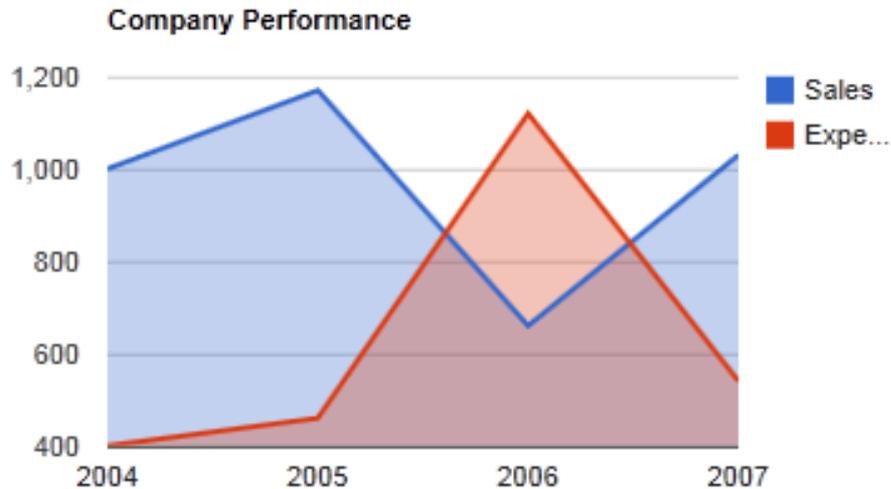


[Cartography: Thematic Map Design, Figure 8.6, p. 170, Dent, 96]

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

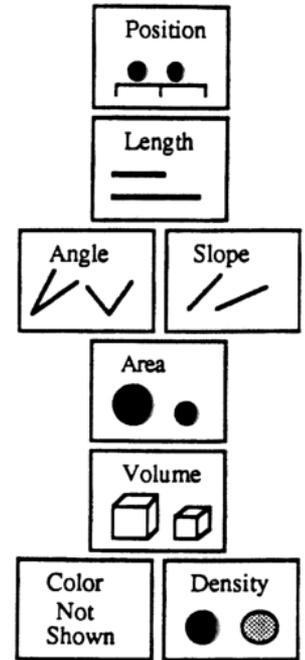
Area

- 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?

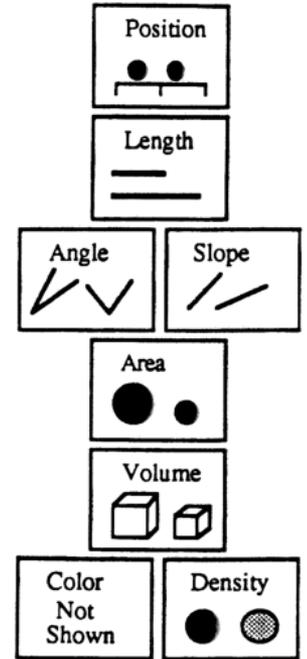
100%



75%

More accurate

Less accurate



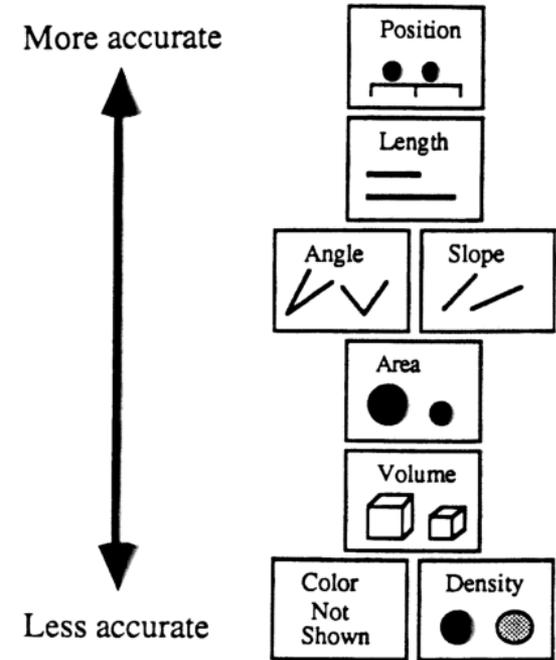
Length / Position

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

100%



25%

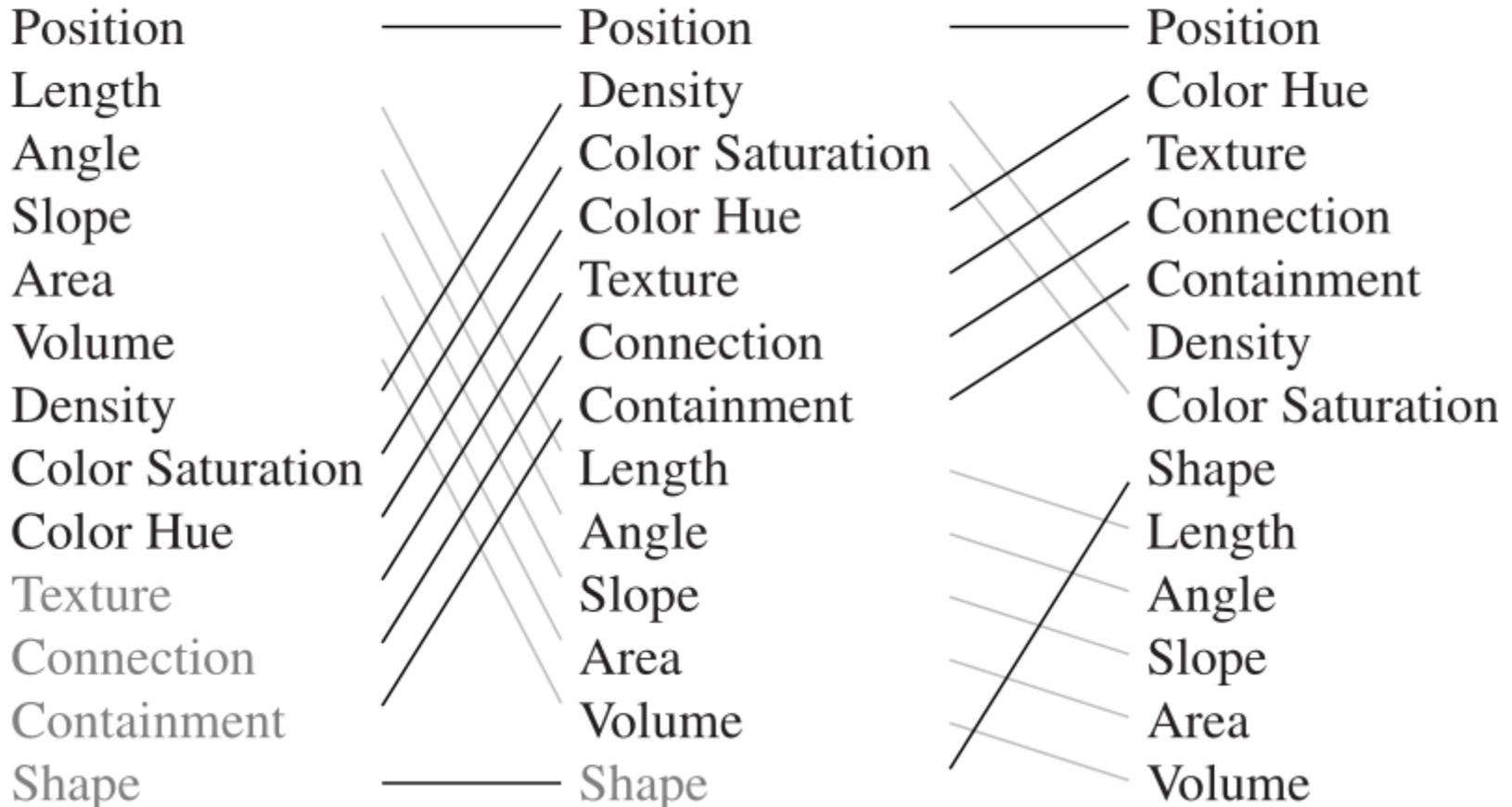


Effectiveness of Data Encodings (Conjecture)

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

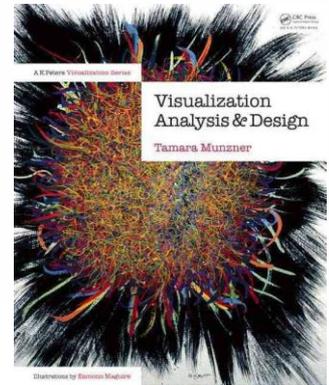
➔ **Identity Channels: Categorical Attributes**

Spatial region 

Color hue 

Motion 

Shape 



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

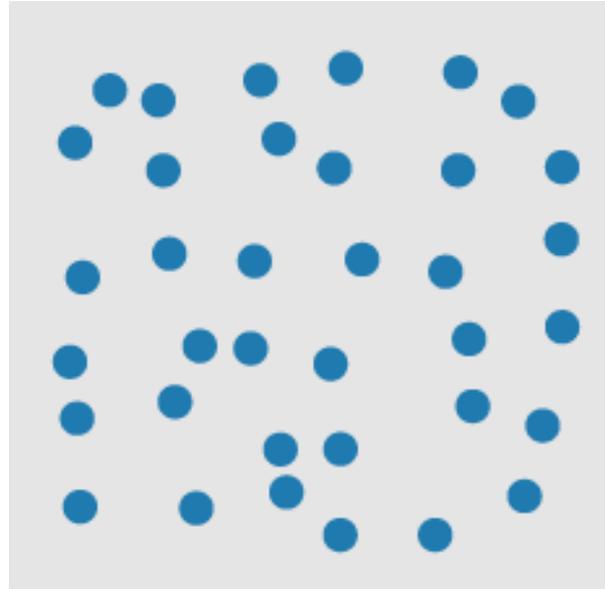
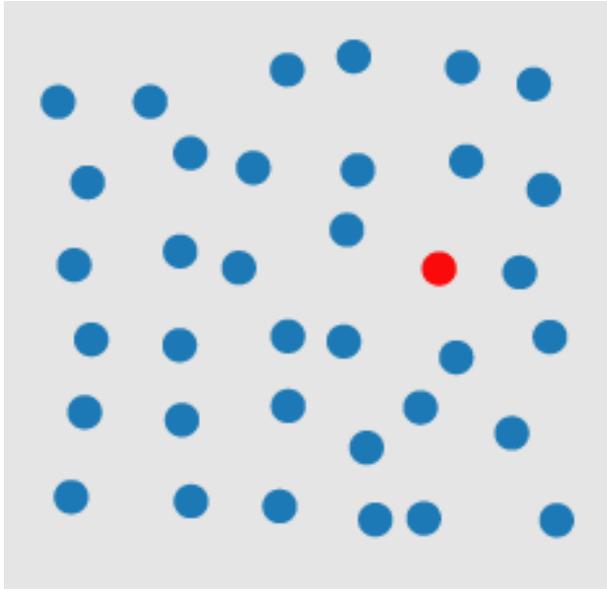
- Some stimuli can be perceived **without** the need for focused attention
- Generally within **200-250 ms**
- Seems to be done **in parallel** by the low-level vision system

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

Visual encodings influence **preattentive** processing

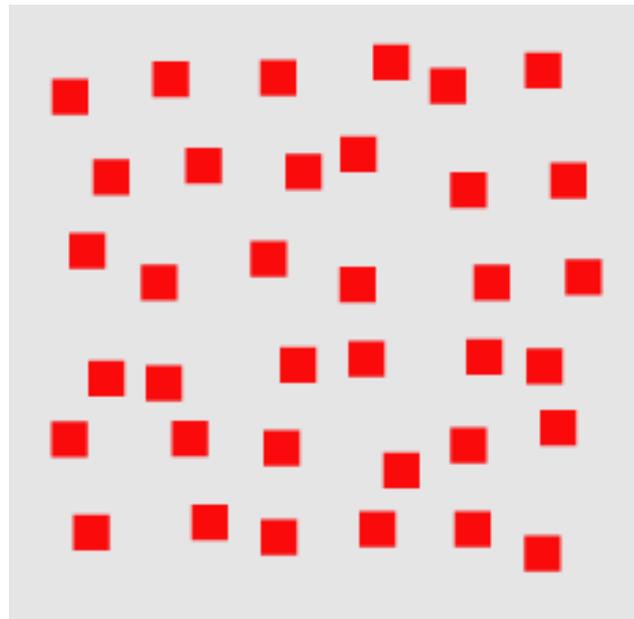
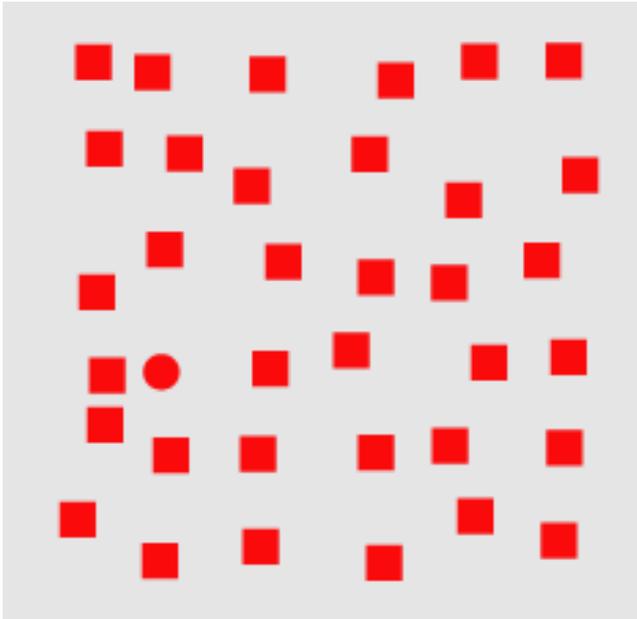
**DETERMINE IF A RED CIRCLE
IS PRESENT**

Hue



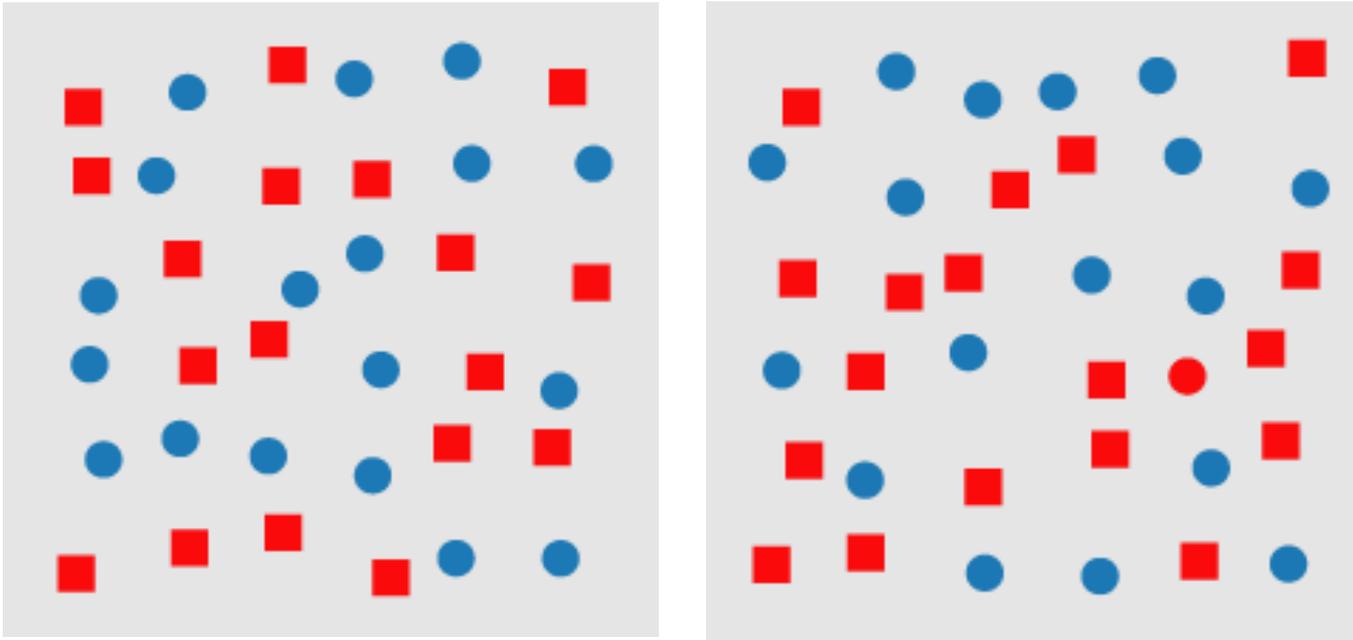
Yes, can be done preattentively

Shape



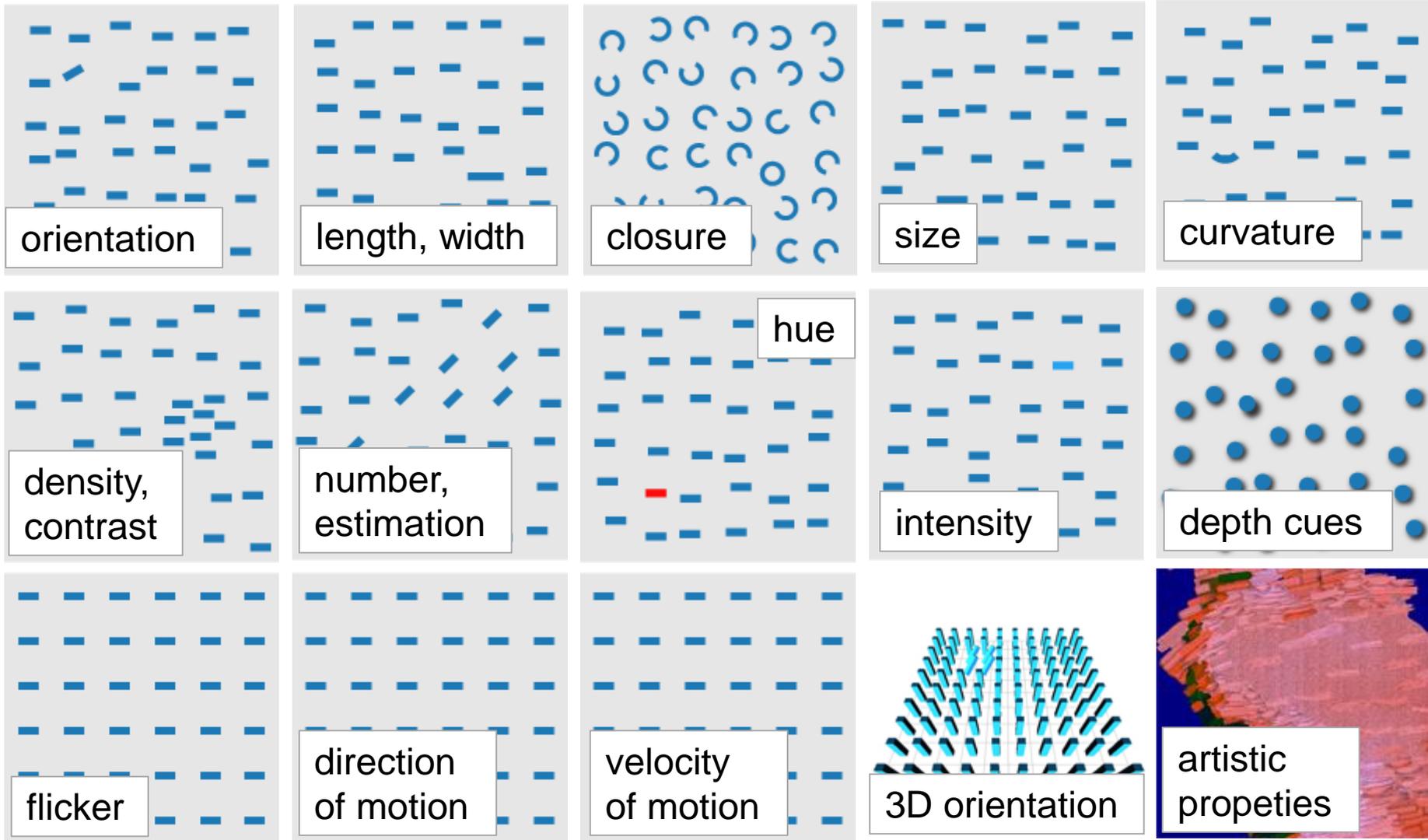
Yes, can be done preattentively

Hue and Shape

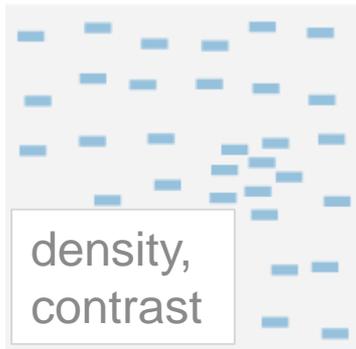
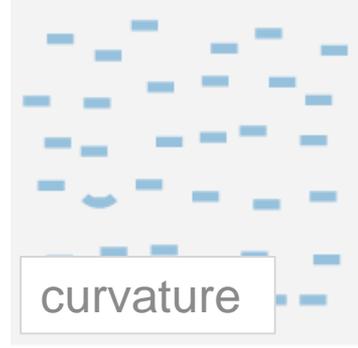
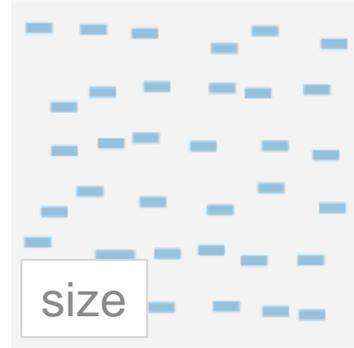
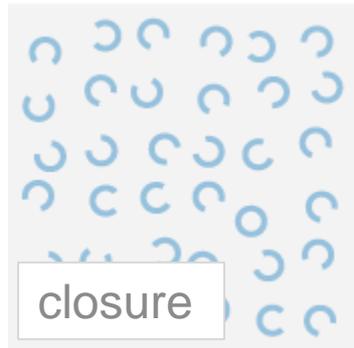
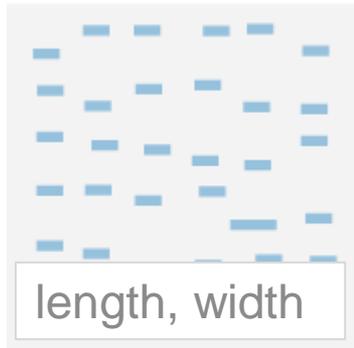


Cannot be done preattentively due to the **conjunction** of shape and hue
→ need to search

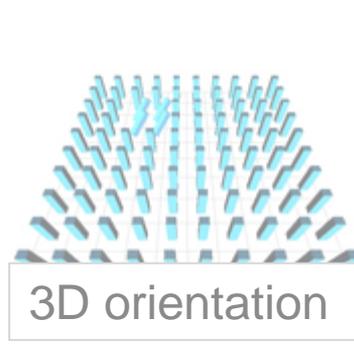
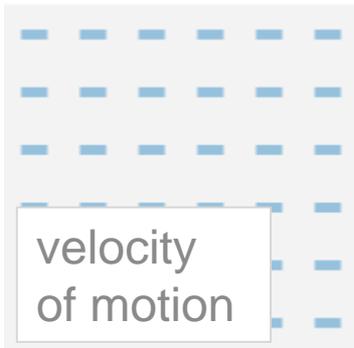
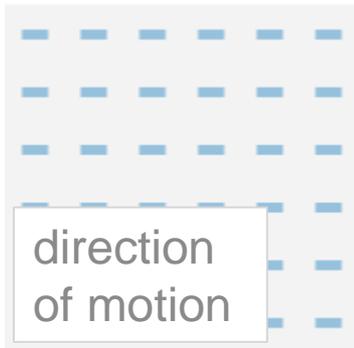
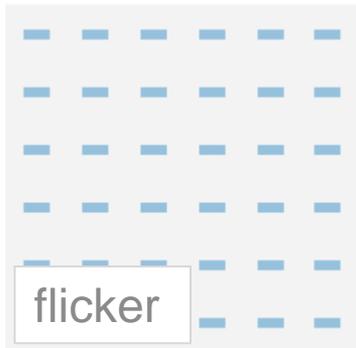
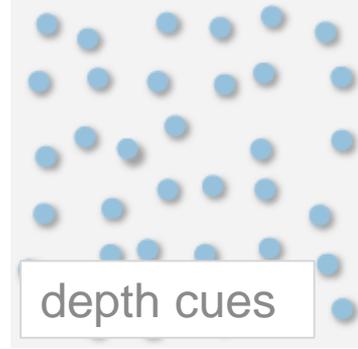
Preattentive visual features (some)



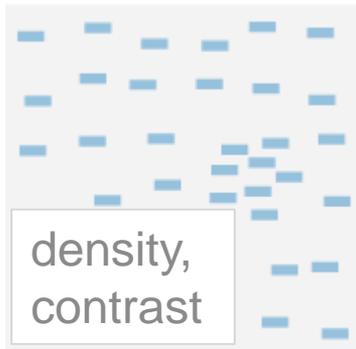
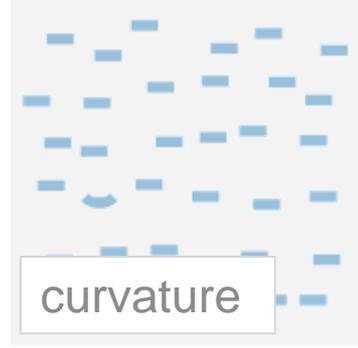
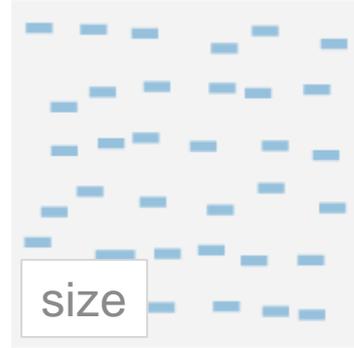
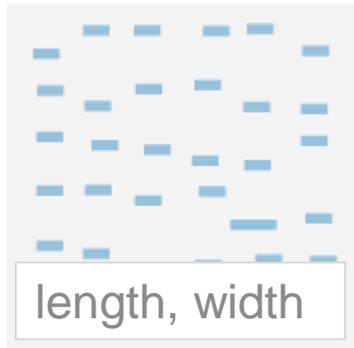
Preattentive visual features (some)



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

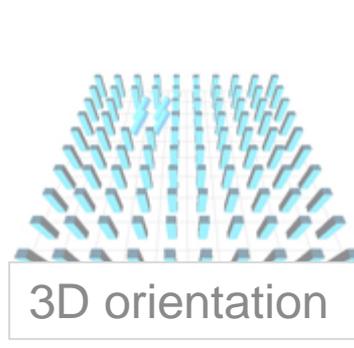
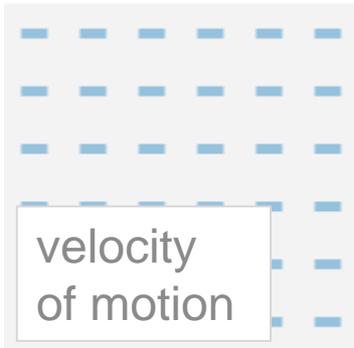
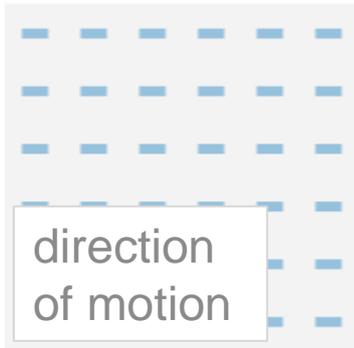
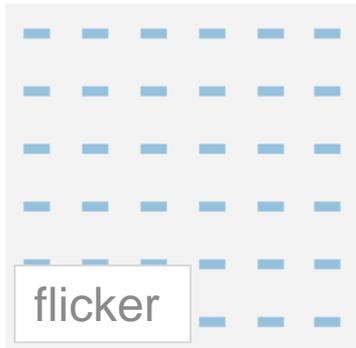
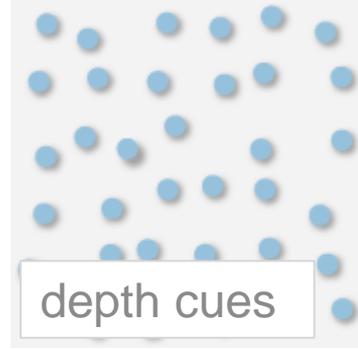


Preattentive visual features (some)



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

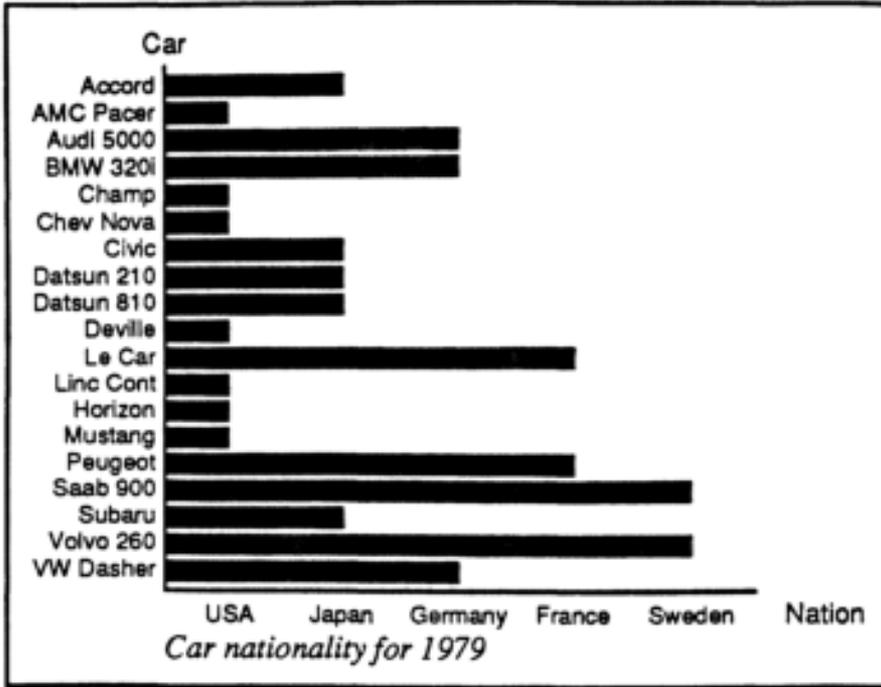
What kind of data are we looking at?

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

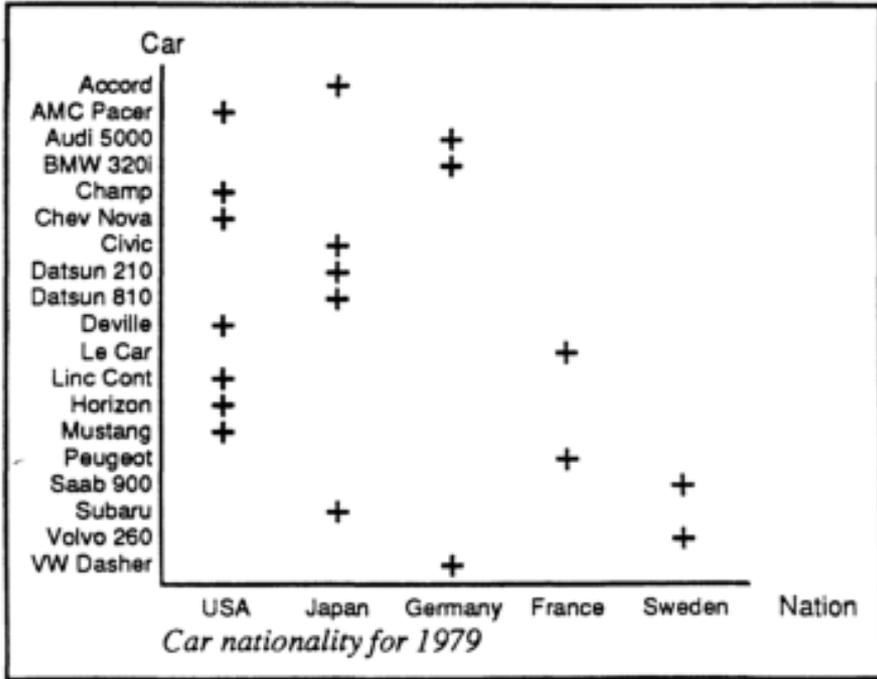
Nominal

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

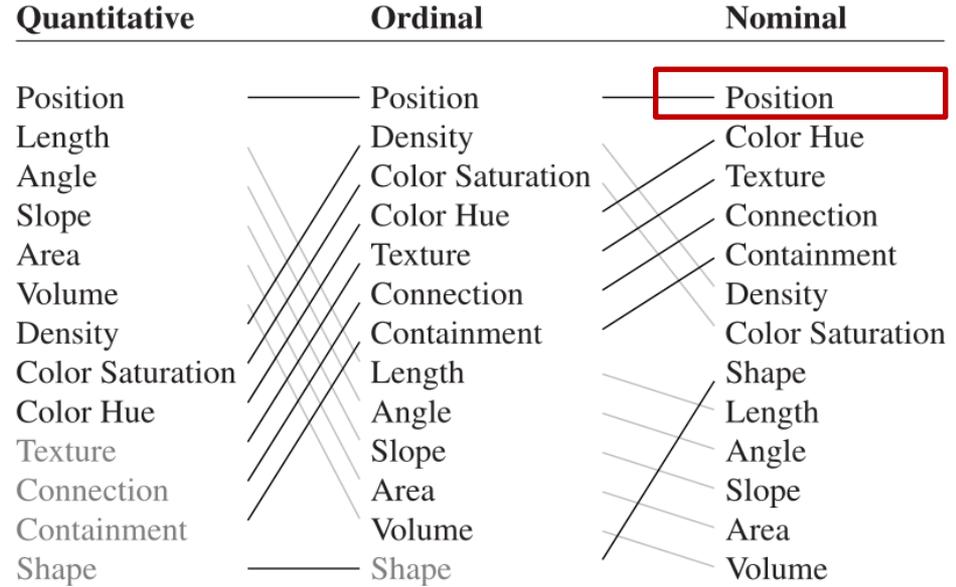
Problem:

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

Let's evaluate...



apt



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:

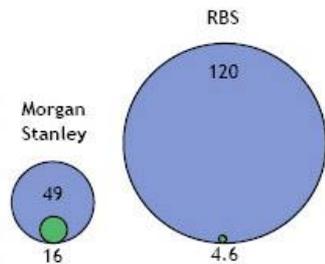
- **January 20th, 2009**
- **Q2 2007** (before banking crisis hit)



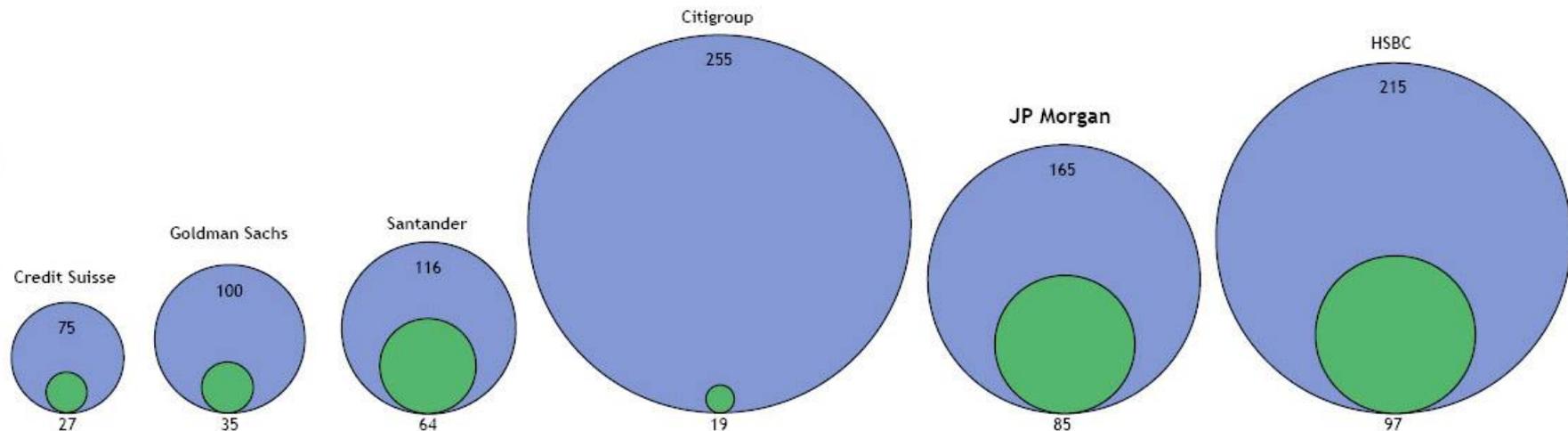
Problems here?

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!)

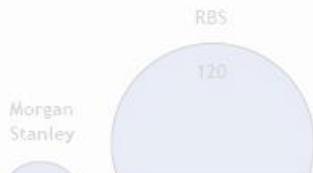


J.P.Morgan

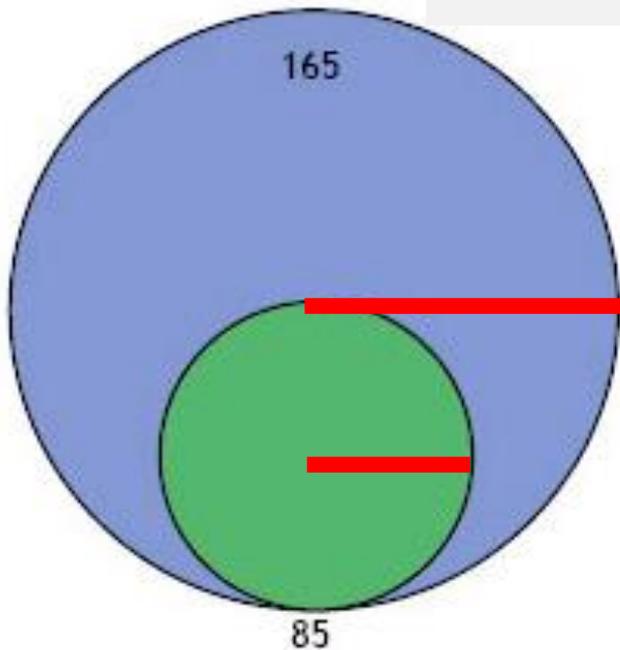
Problems here?

Banks: Market Cap

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



JP Morgan

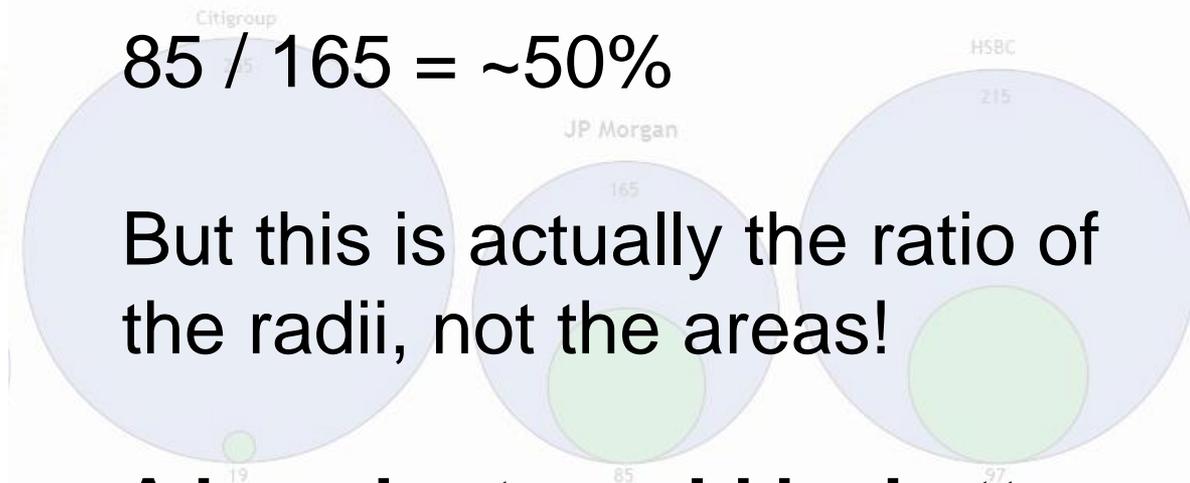


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(And the areas here are actually misleading!)

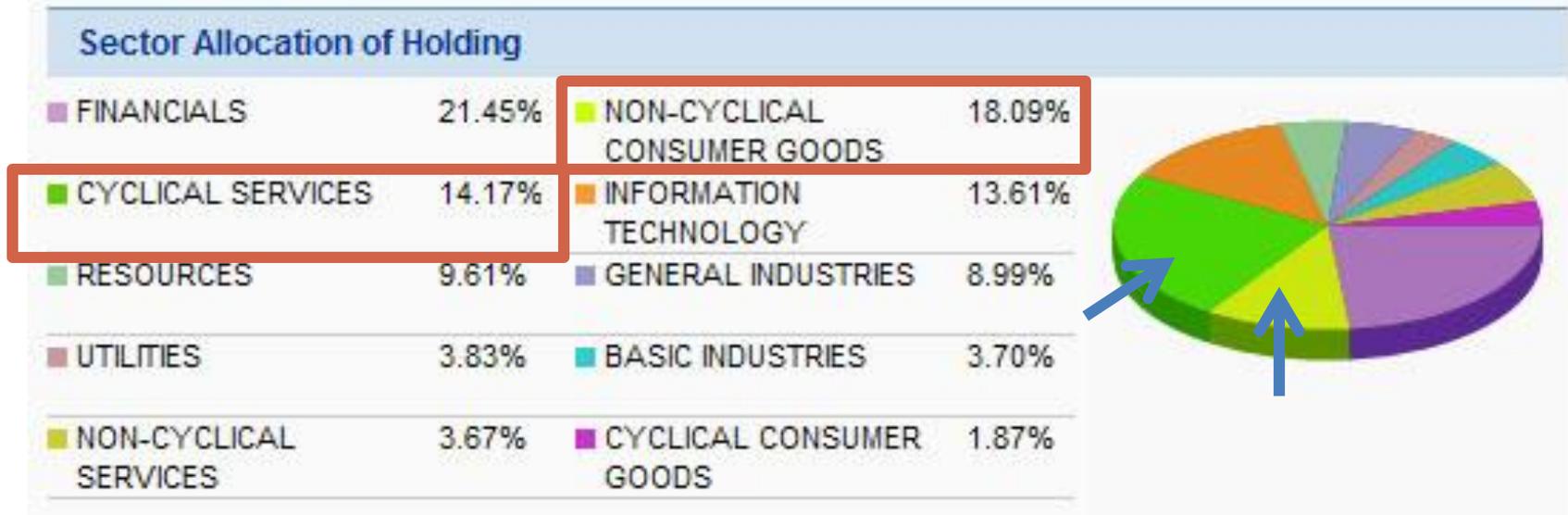
$$85 / 165 = \sim 50\%$$

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

A bar chart would be better.

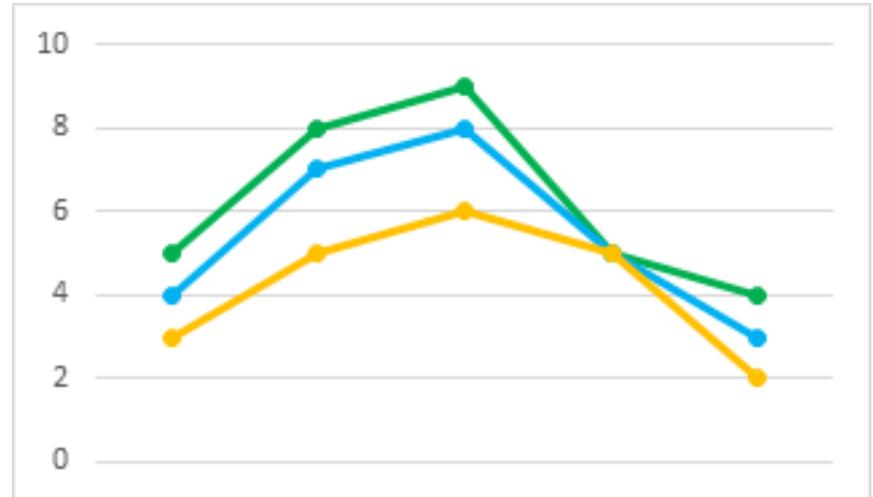
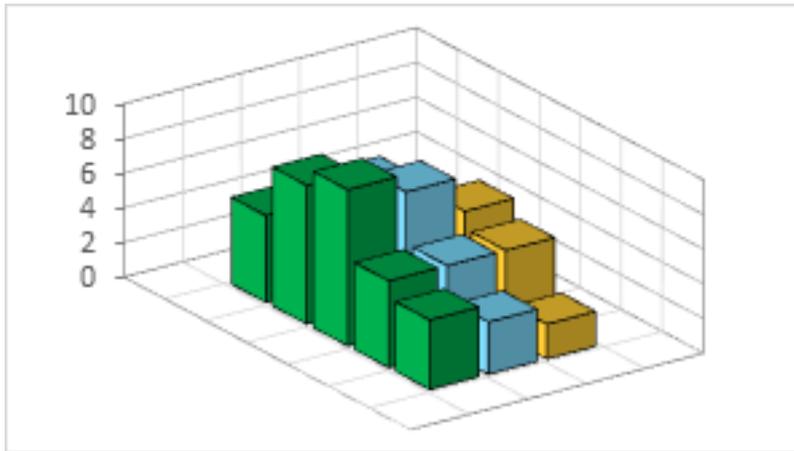


Problem here?

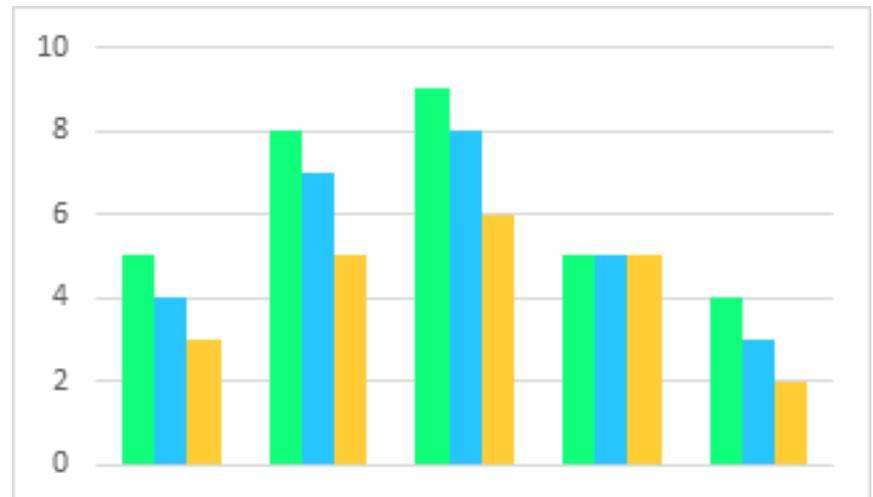


- There is likely a **bug or error** in the data
- Pie slices are difficult to compare by **area** or by **angle**
- **Similar colors** are difficult to distinguish
- **Perspective distortion** adds to the problem

Similarly...3D bar charts are not recommended



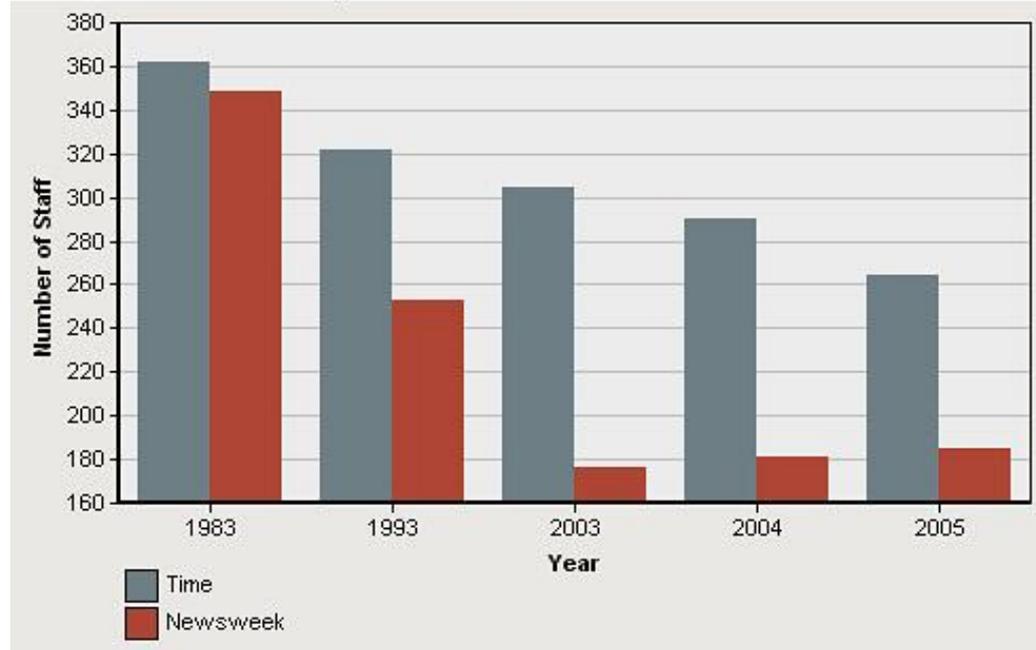
These are **much easier** to read & compare!



Problem here?

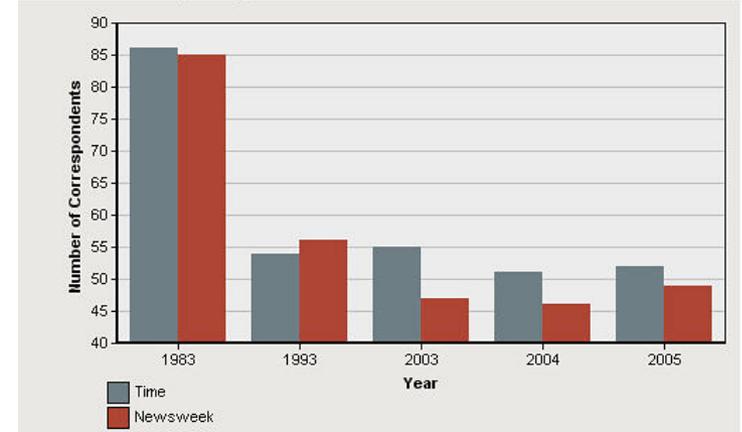
NEWS MAGAZINE STAFF SIZE OVER TIME

Time and Newsweek select years 1983 - 2005



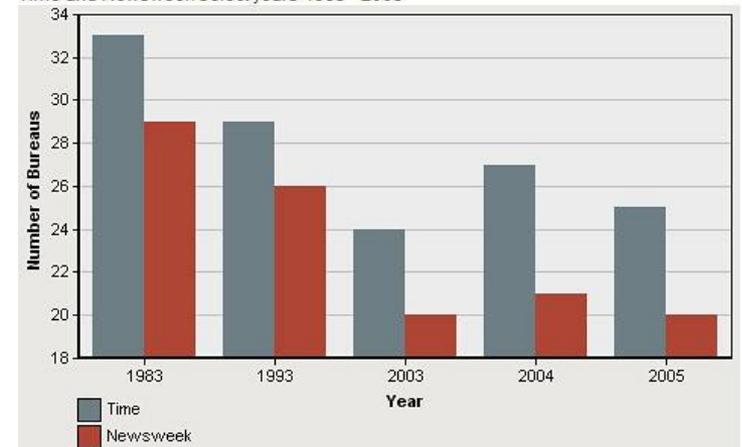
NUMBER OF CORRESPONDENTS IN BUREAUS OVER TIME

Time and Newsweek, select years 1983 - 2005

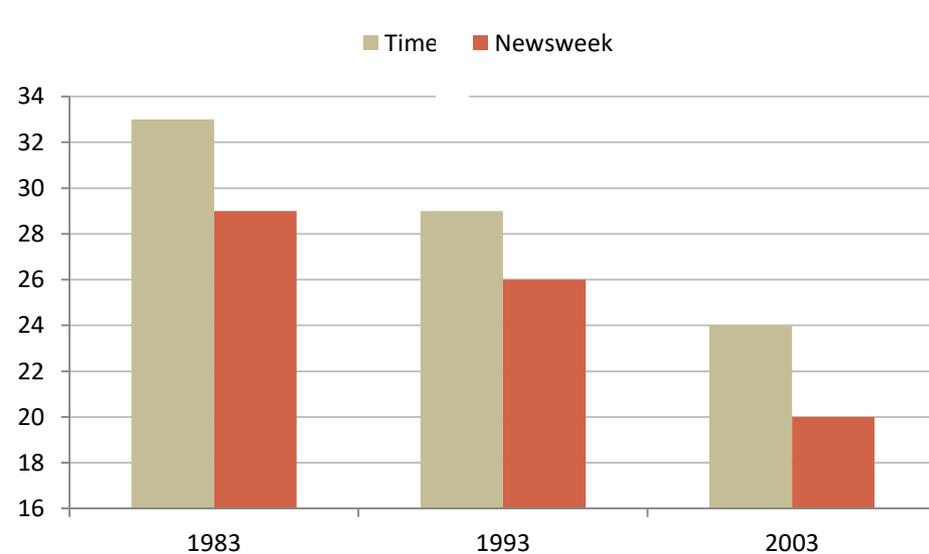


NEWS MAGAZINE BUREAUS OVER TIME

Time and Newsweek select years 1983 - 2005

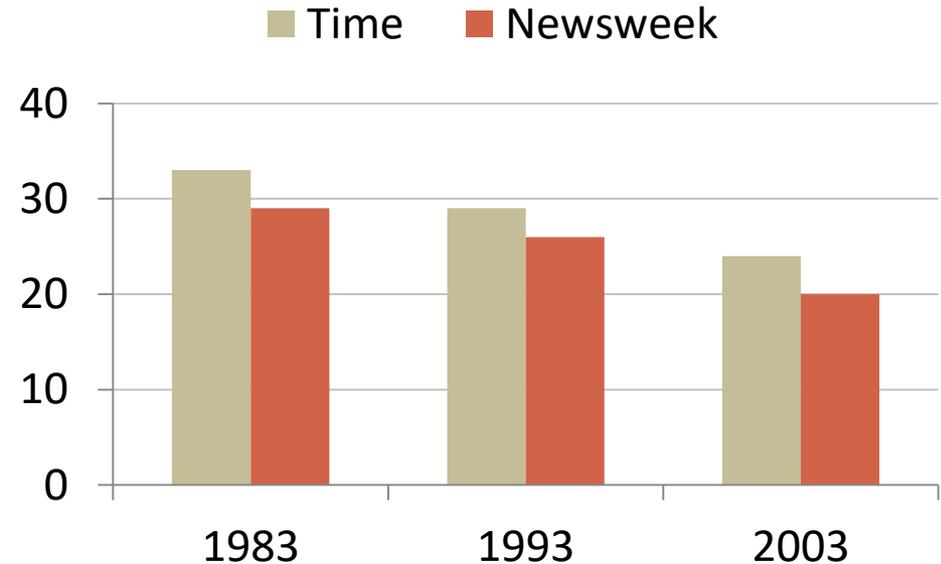


Length Comparison



At first glance:

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



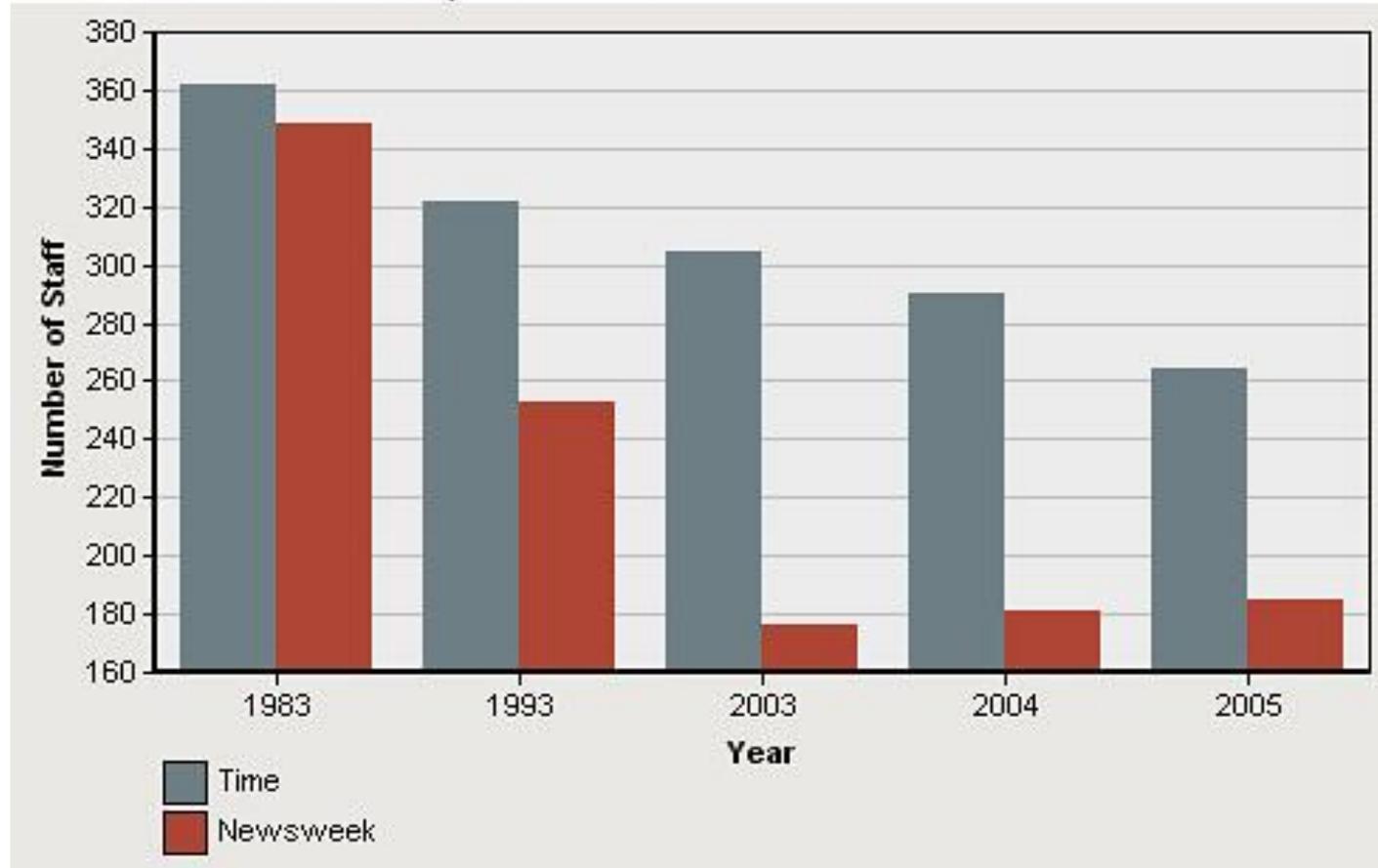
If we add a proper baseline at 0:

- 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

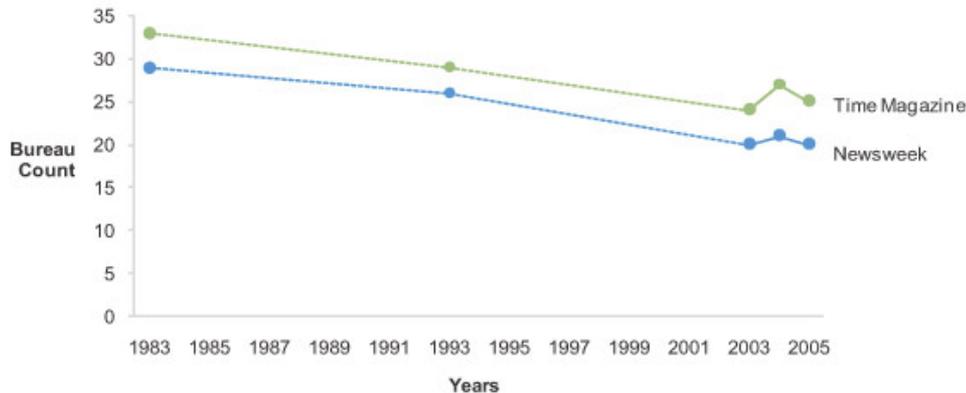


10 years each

1 year each

Redesign (by Stephen Few)

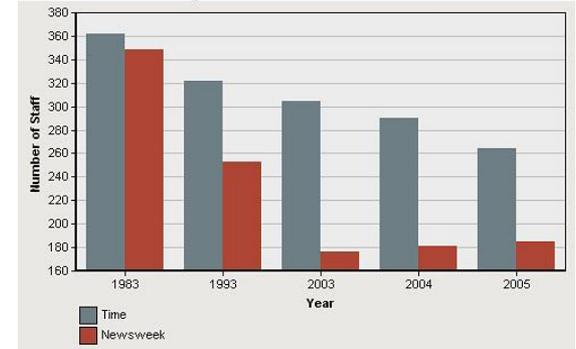
Time Magazine's vs. Newsweek Magazine's Size Over Time



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.

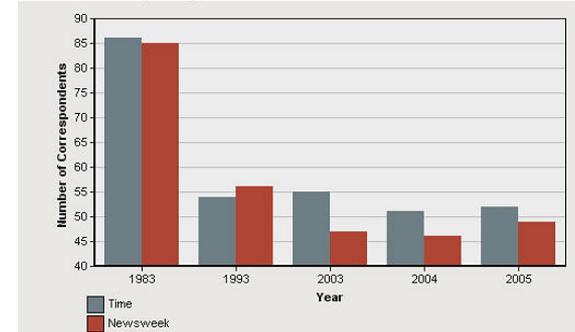
NEWS MAGAZINE STAFF SIZE OVER TIME

Time and Newsweek select years 1983 - 2005



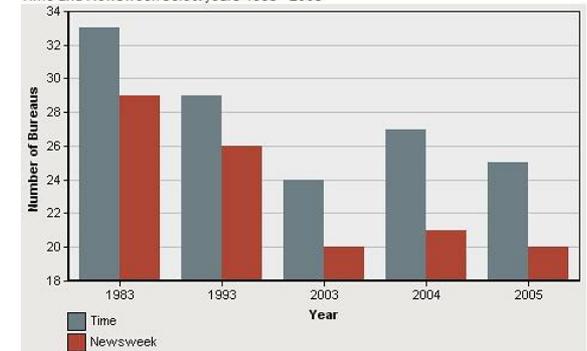
NUMBER OF CORRESPONDENTS IN BUREAUS OVER TIME

Time and Newsweek, select years 1983 - 2005



NEWS MAGAZINE BUREAUS OVER TIME

Time and Newsweek select years 1983 - 2005



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**