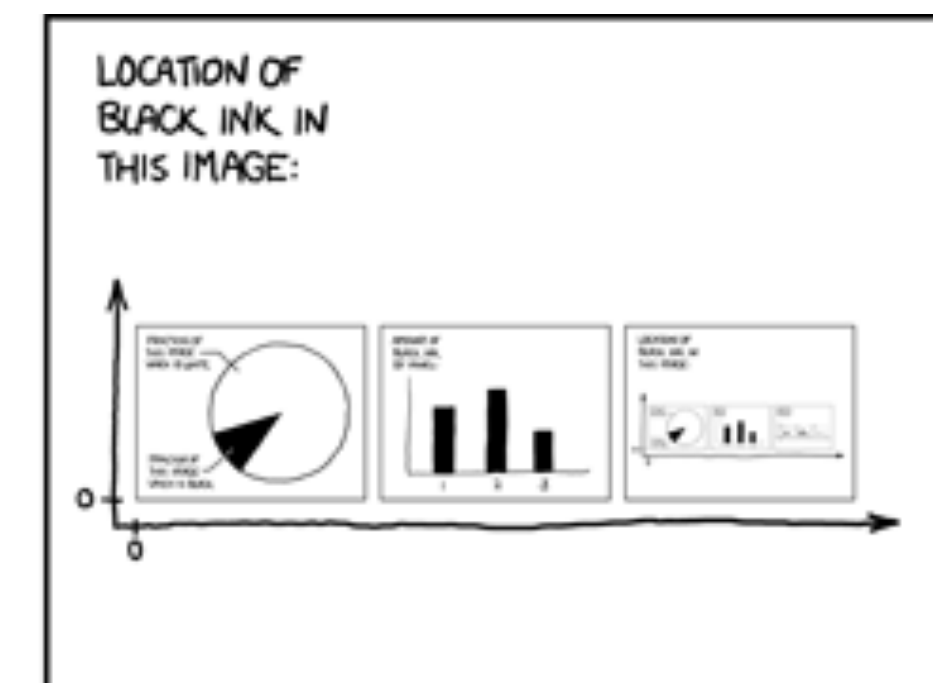
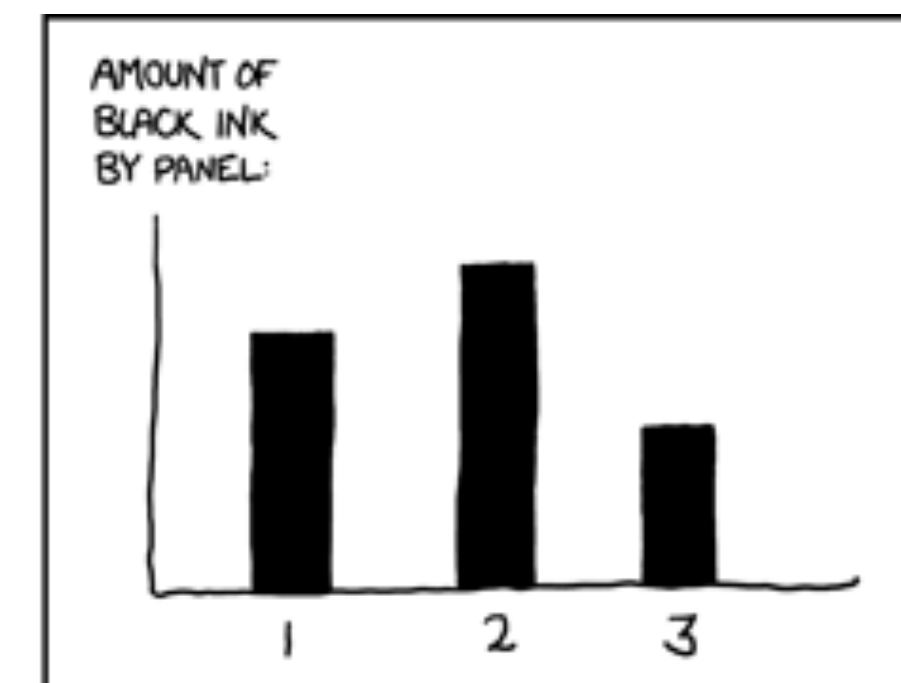
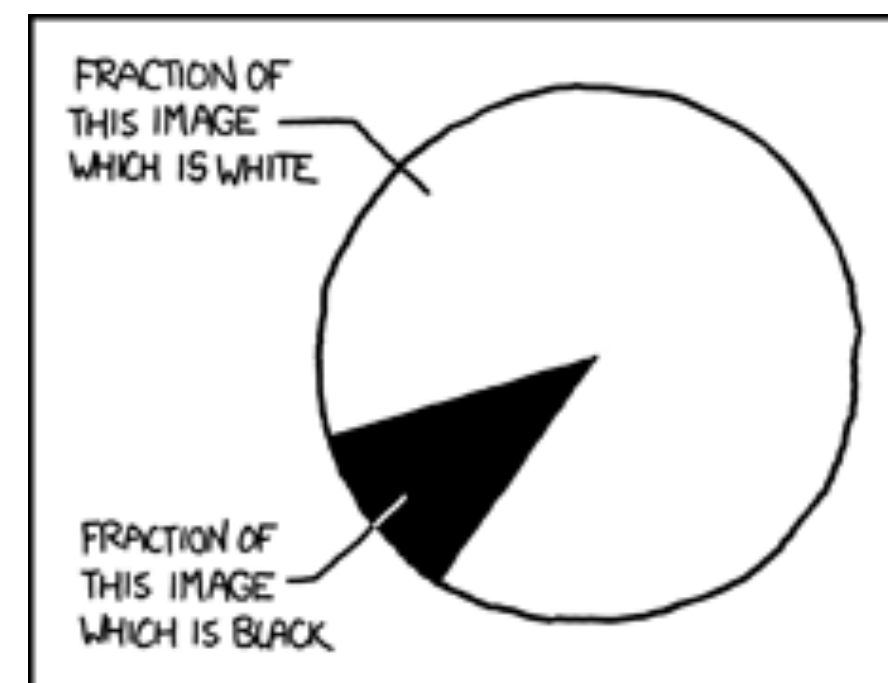


# CS-5630 / CS-6630 Visualization for Data Science

## The Visualization Alphabet: Marks and Channels

Alexander Lex  
[alex@sci.utah.edu](mailto:alex@sci.utah.edu)



How can I visually represent two numbers, e.g.,  
**4 and 8**

# Marks & Channels

**Marks:** represent **items** or **links**

**Channels:** change **appearance** based on **attribute**

**Channel = Visual Variable**

# Marks for Items

Basic geometric elements

➞ Points



0D

➞ Lines



1D

➞ Areas

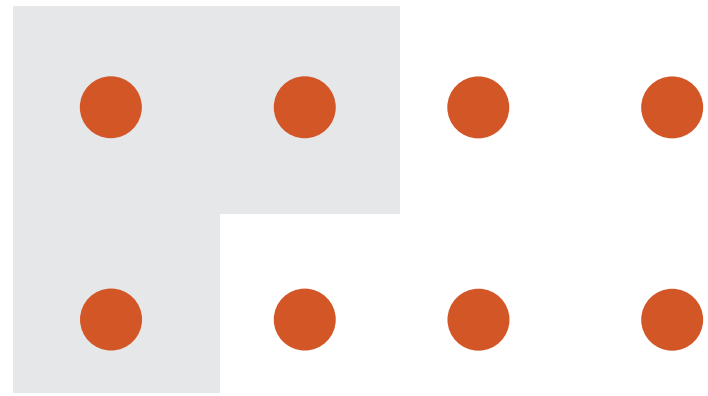


2D

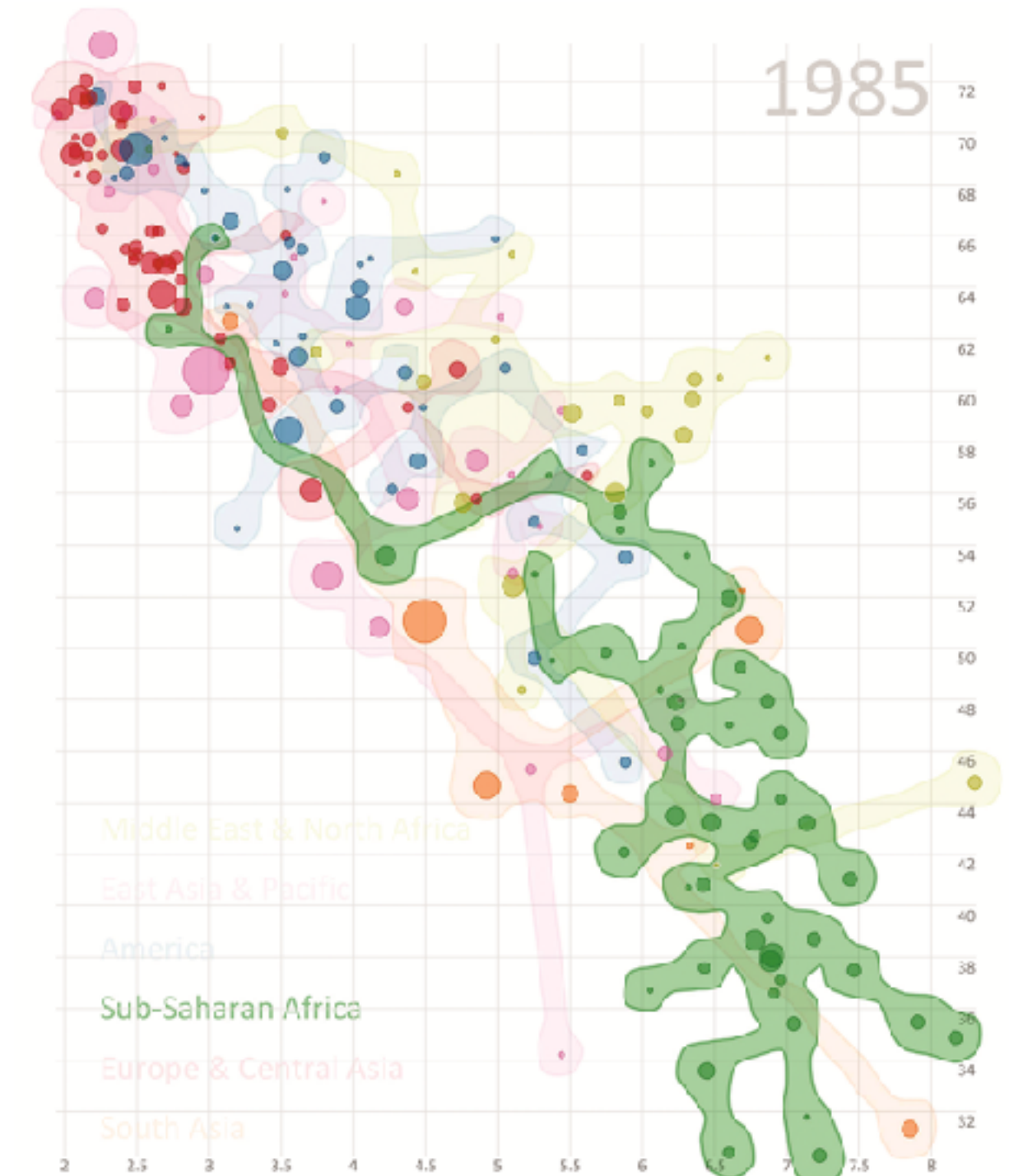
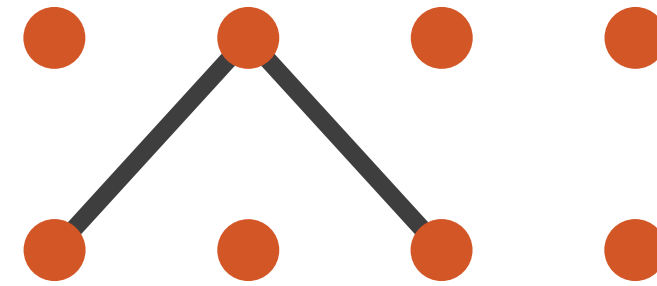
3D mark: Volume, but rarely used

# Marks for Links

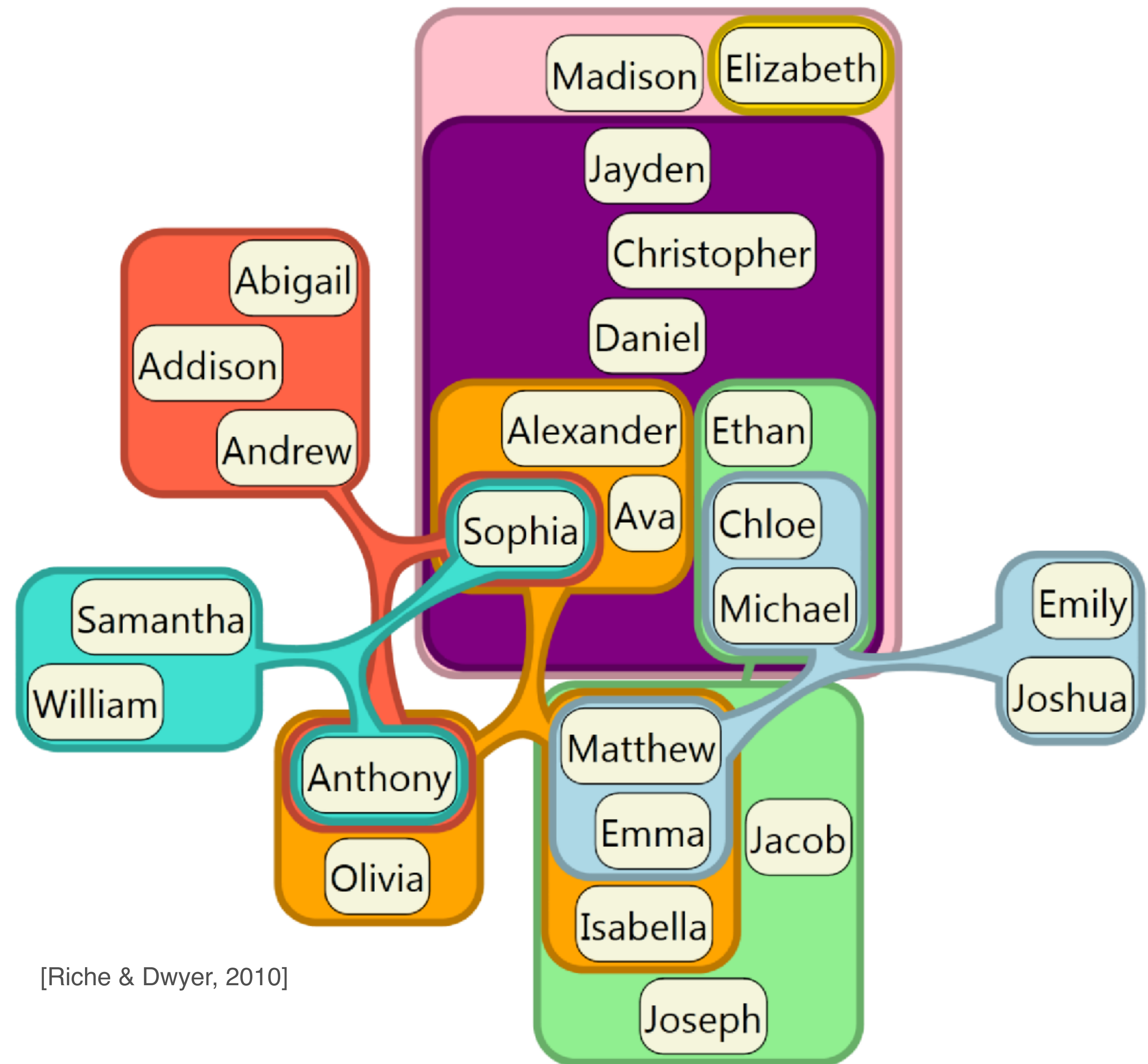
## ➔ Containment



## ➔ Connection



# Containment can be nested



[Riche & Dwyer, 2010]



# Channels (aka Visual Variables)

Control appearance  
proportional to or  
based on attributes

→ Position

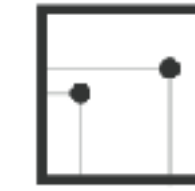
→ Horizontal



→ Vertical



→ Both



→ Color



→ Shape



→ Tilt



→ Size

→ Length



→ Area



→ Volume



# Jacques Bertin

French cartographer  
[1918-2010]

Semiology of Graphics [1967]

Theoretical principles for visual  
encodings



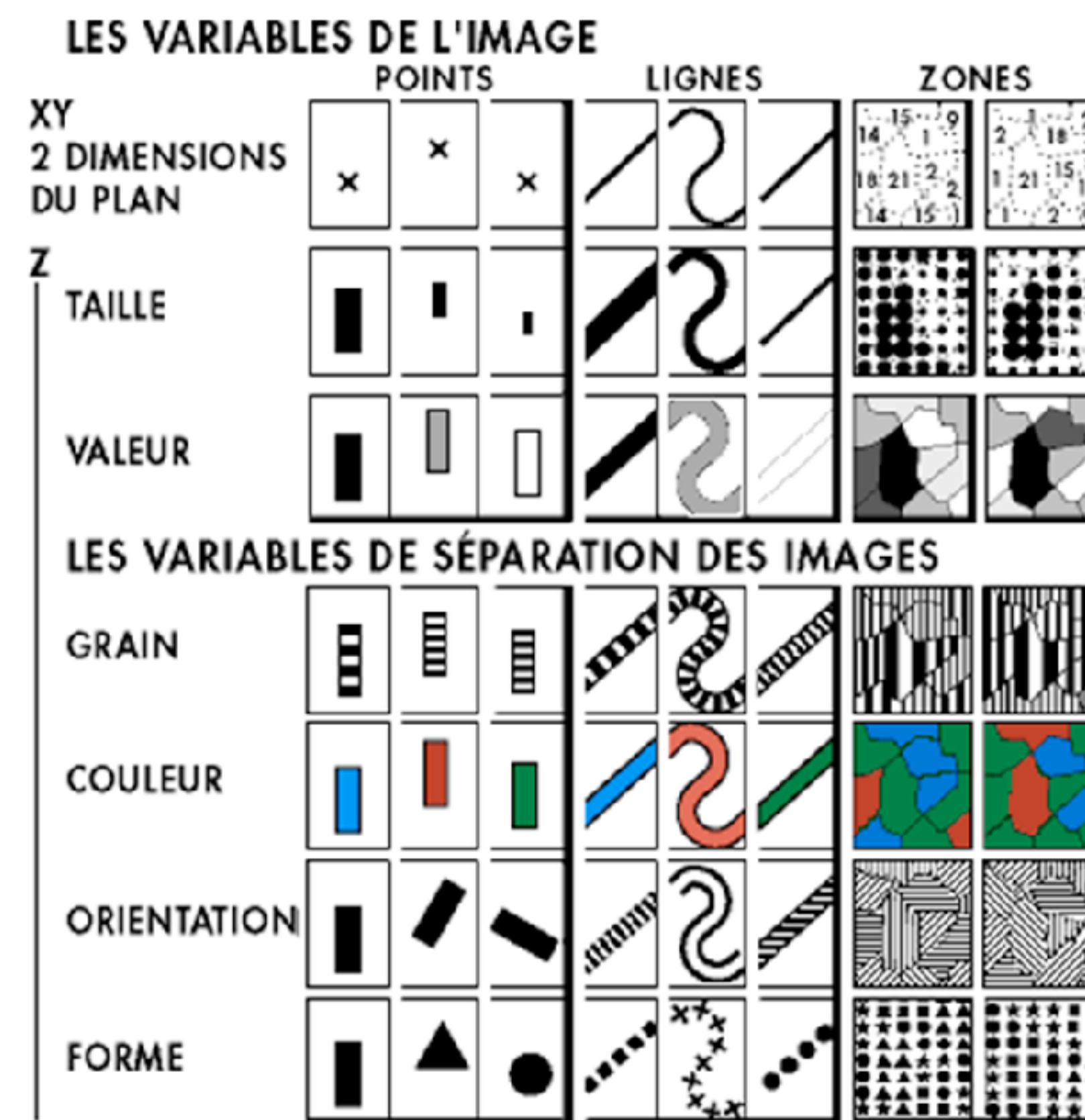


# Bertin's Visual Variables

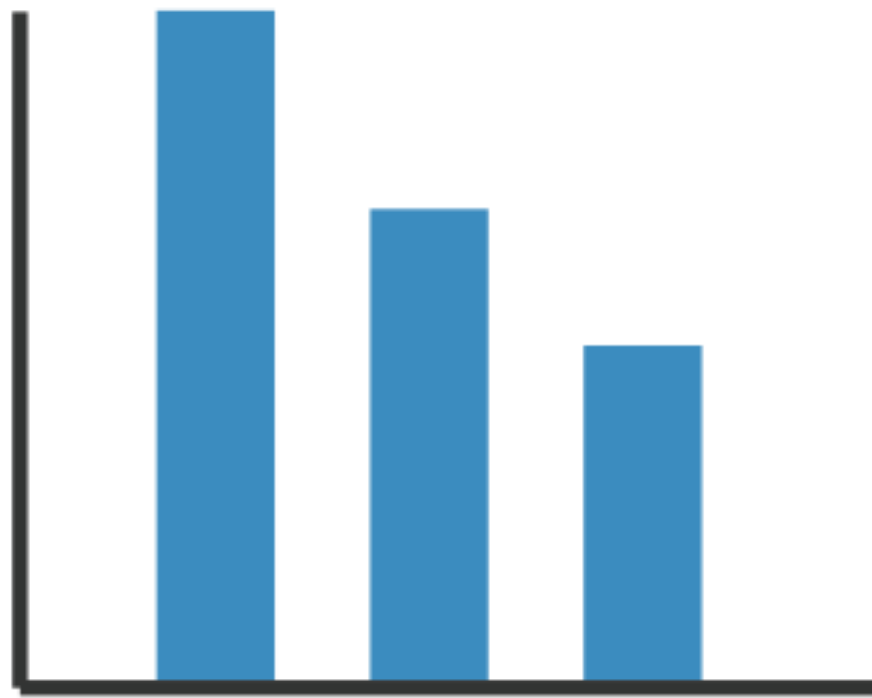
Marks:      Points      Lines      Areas

Position  
Size  
(Grey)Value

Texture  
Color  
Orientation  
Shape



# Using Marks and Channels



Mark: Line

Channel: Length/Position

1 quantitative attribute

1 categorical attribute



Mark: Point

Channel: Position

2 quantitative attr.



Adding Hue

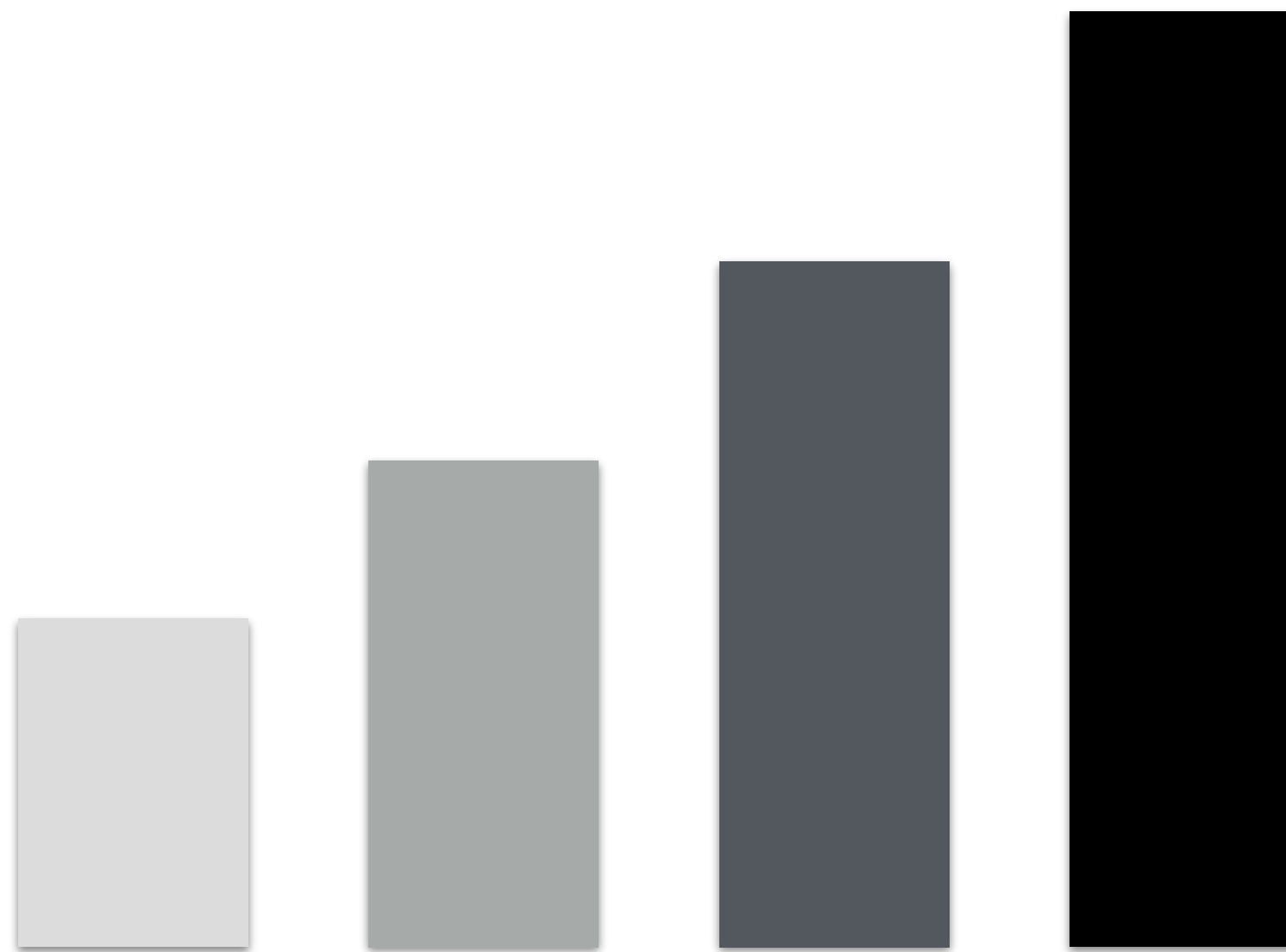
+1 categorical attr.



Adding Size

+1 quantitative attr.

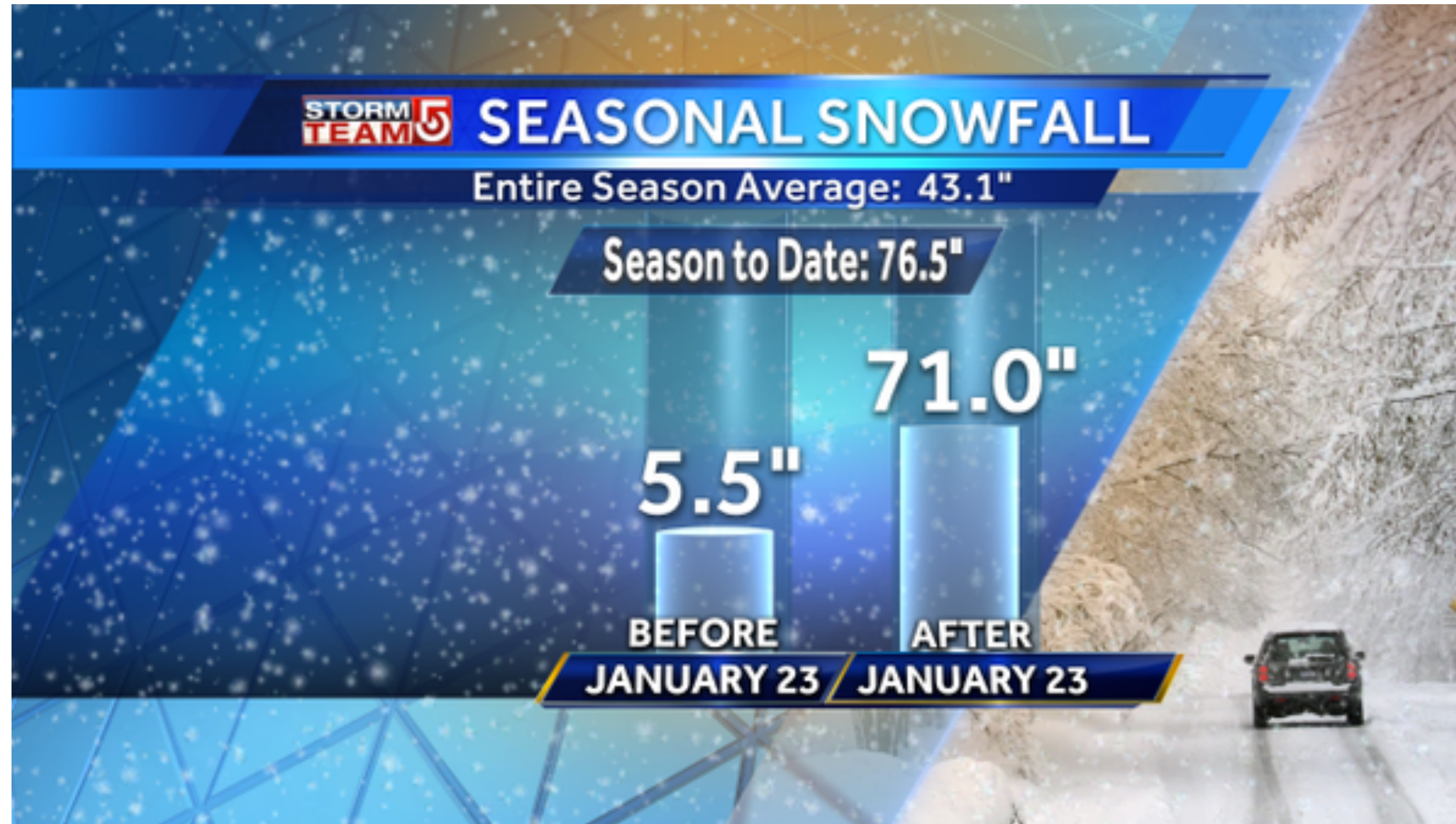
# Redundant encoding



Length, Position and Value



# Good bar chart?



Rule: Use channel proportional to data!

# Types of Channels

## Magnitude Channels

How much? Which Rank?

Position

Length

Saturation ...

**Ordinal & Quantitative Data**

## Identity Channels

What?

Shape

Color (hue)

Spatial region ...

**Categorical Data**

Channels: Expressiveness Types and Effectiveness Ranks

➔ **Magnitude Channels: Ordered** Attributes



➔ **Identity Channels: Categorical** Attributes

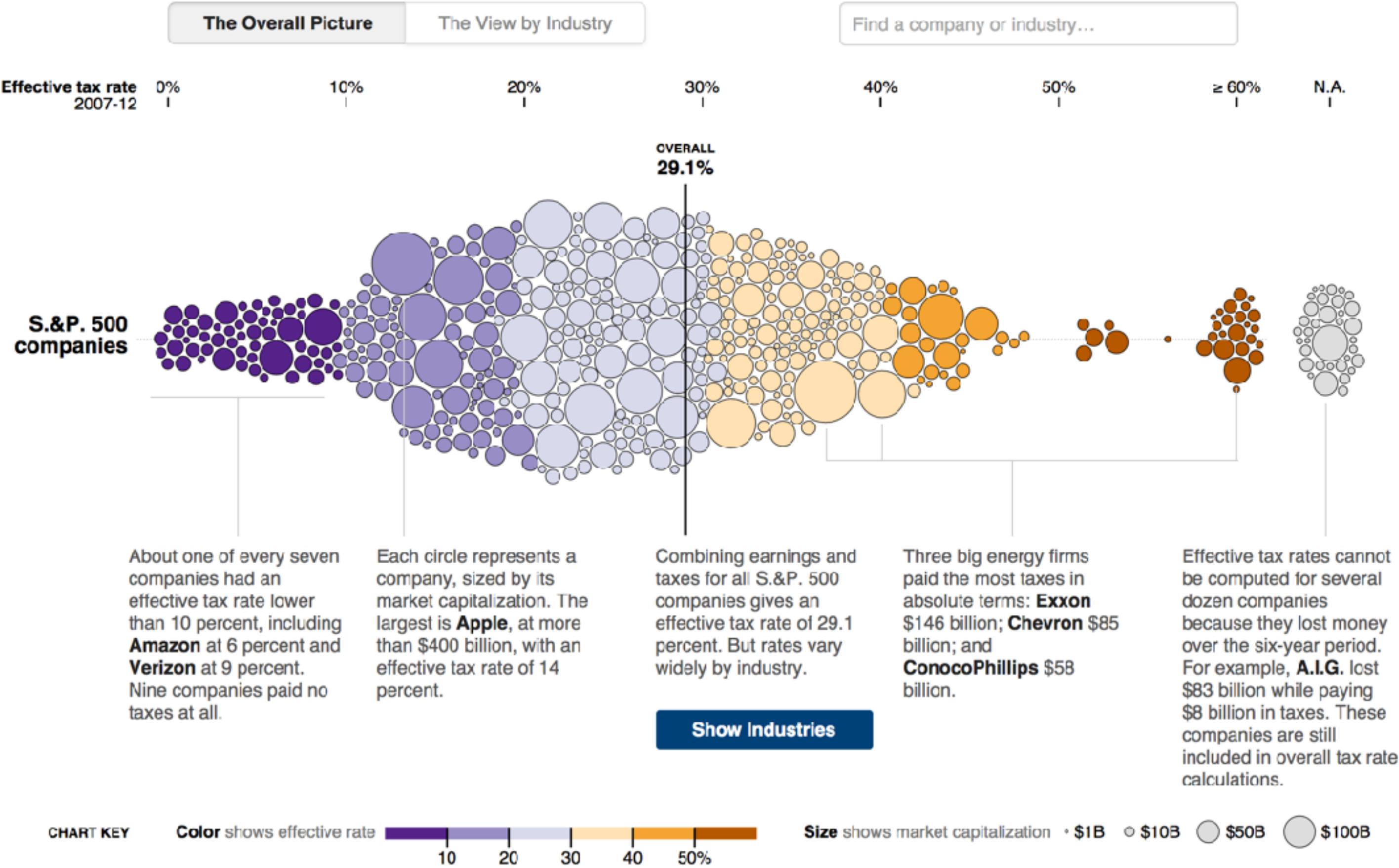




# What visual variables are used?

## Across U.S. Companies, Tax Rates Vary Greatly

Last week, in a Congressional hearing, Apple got grilled for its low-tax strategy. But not every business can copy that approach. Here is a look at what S.&P. 500 companies paid in corporate income taxes — federal, state, local and foreign — from 2007 to 2012, according to S&P Capital IQ. [Related Article »](#)



# Characteristics of Channels

## Selective

Is a mark distinct from other marks?

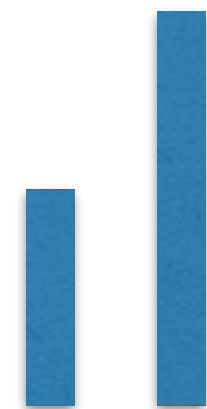
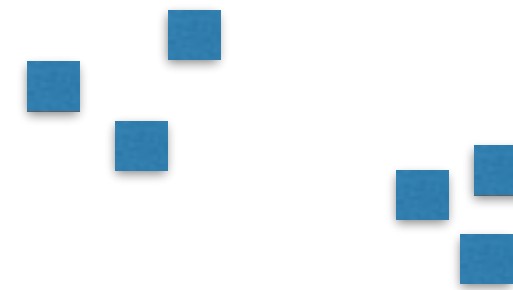
Can we make out the difference between two marks?

## Associative

Does it support grouping?

## Quantitative (Magnitude vs Identity Channels)

Can we quantify the difference between two marks?



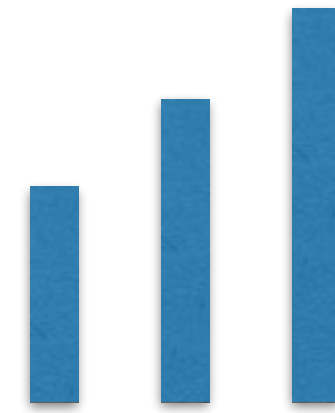
# Characteristics of Channels

Order (Magnitude vs Identity)

Can we see a change in order?

Length

How many unique marks can we make?



# Position

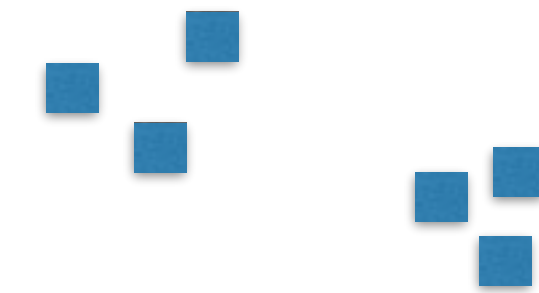
Strongest visual variable

Suitable for all data types

Problems:

Sometimes not available  
(spatial data)

Cluttering



Selective: yes

Associative: yes

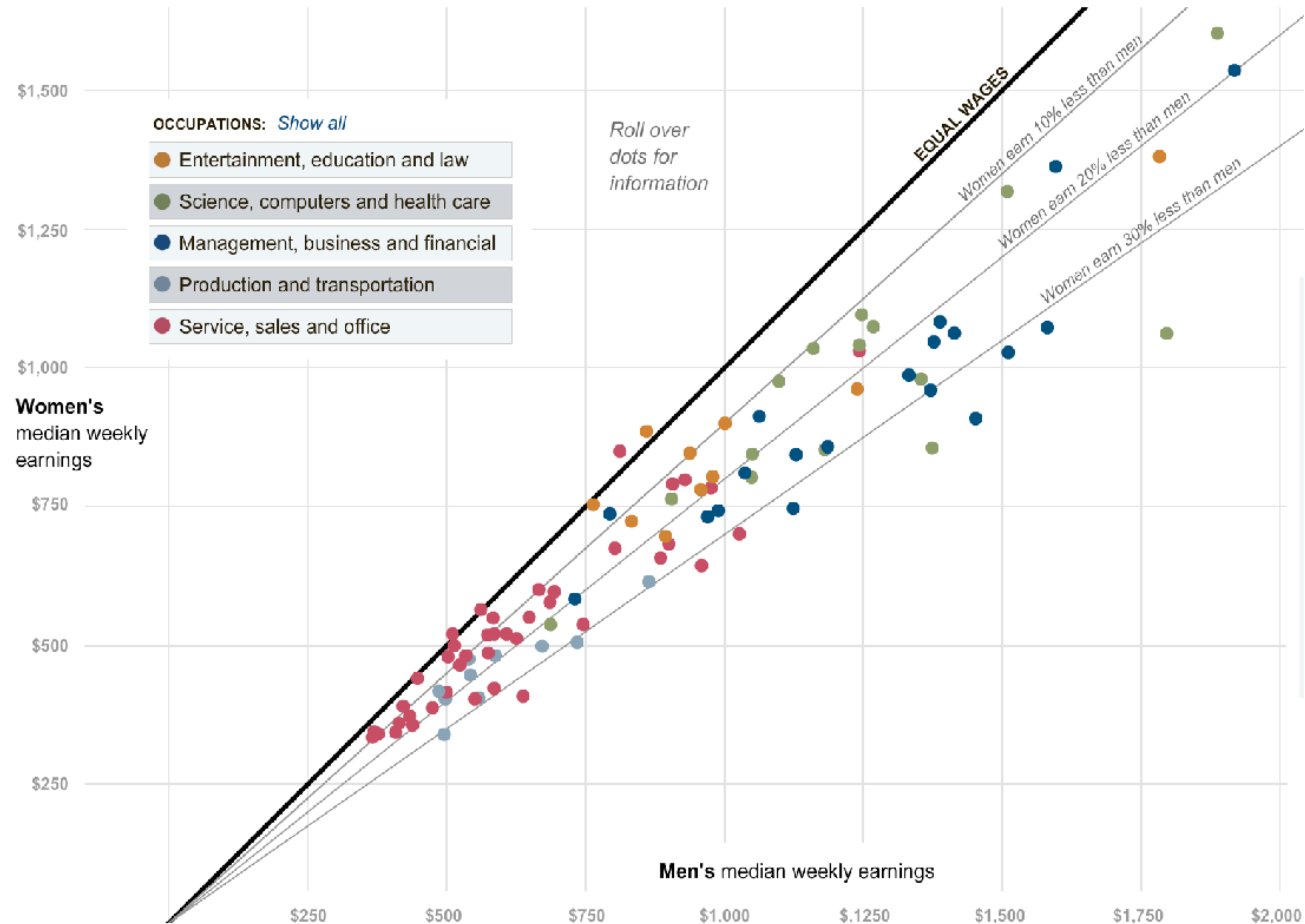
Quantitative: yes

Order: yes

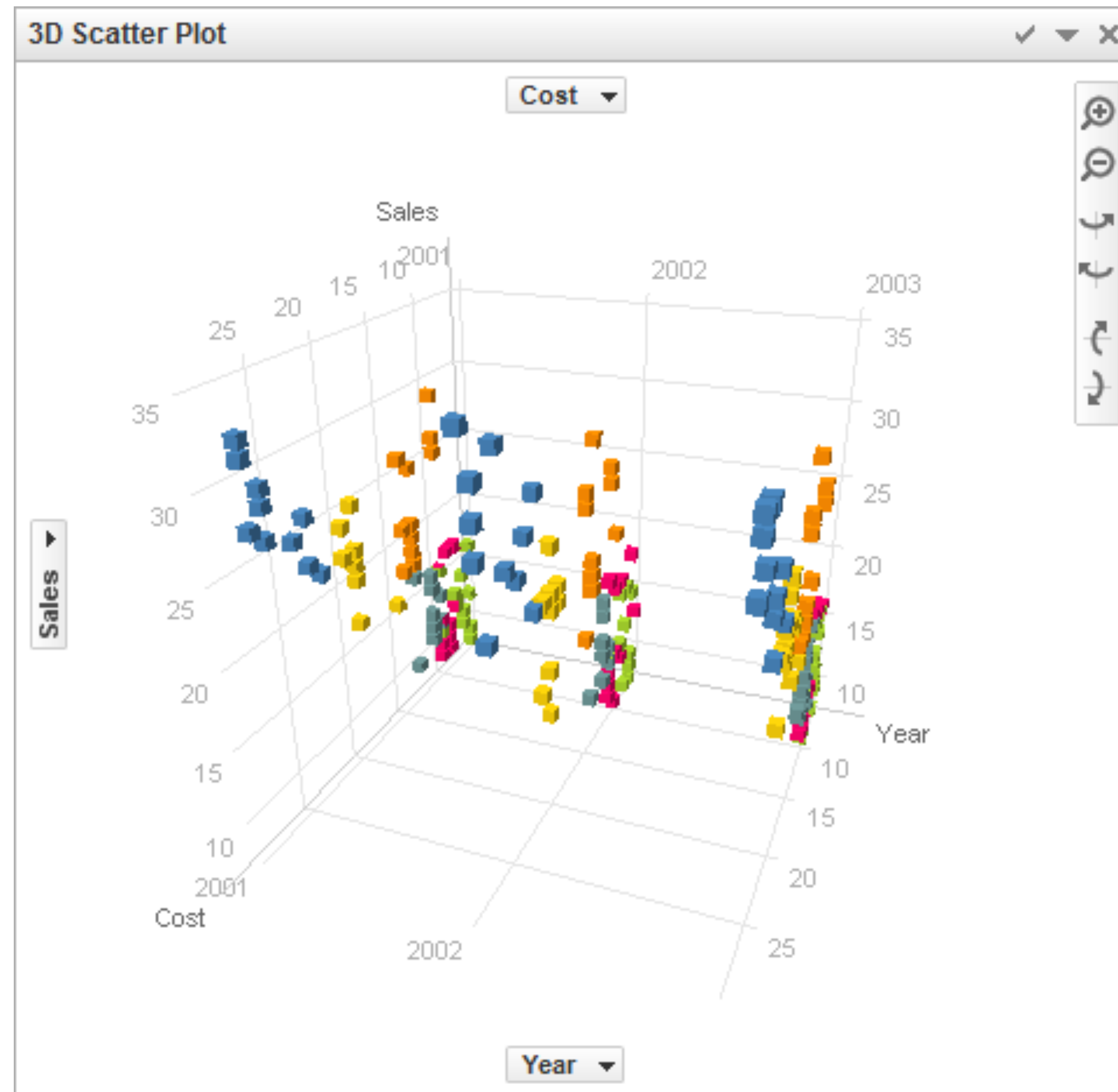
Length: fairly big



# Example: Scatterplot



# Position in 3D?



[Spotfire]



# Length & Size

Good for 1D, OK for 2D, Bad for 3D

Easy to see whether one is bigger

Aligned bars use position redundantly

For 1D length:

Selective: yes

Associative: yes

Quantitative: yes

Order: yes

Length: high



# Example 2D Size: Bubbles

## Four Ways to Slice Obama's 2013 Budget Proposal

Explore every nook and cranny of President Obama's federal budget proposal.

All Spending

Types of Spending

Changes

Department Totals

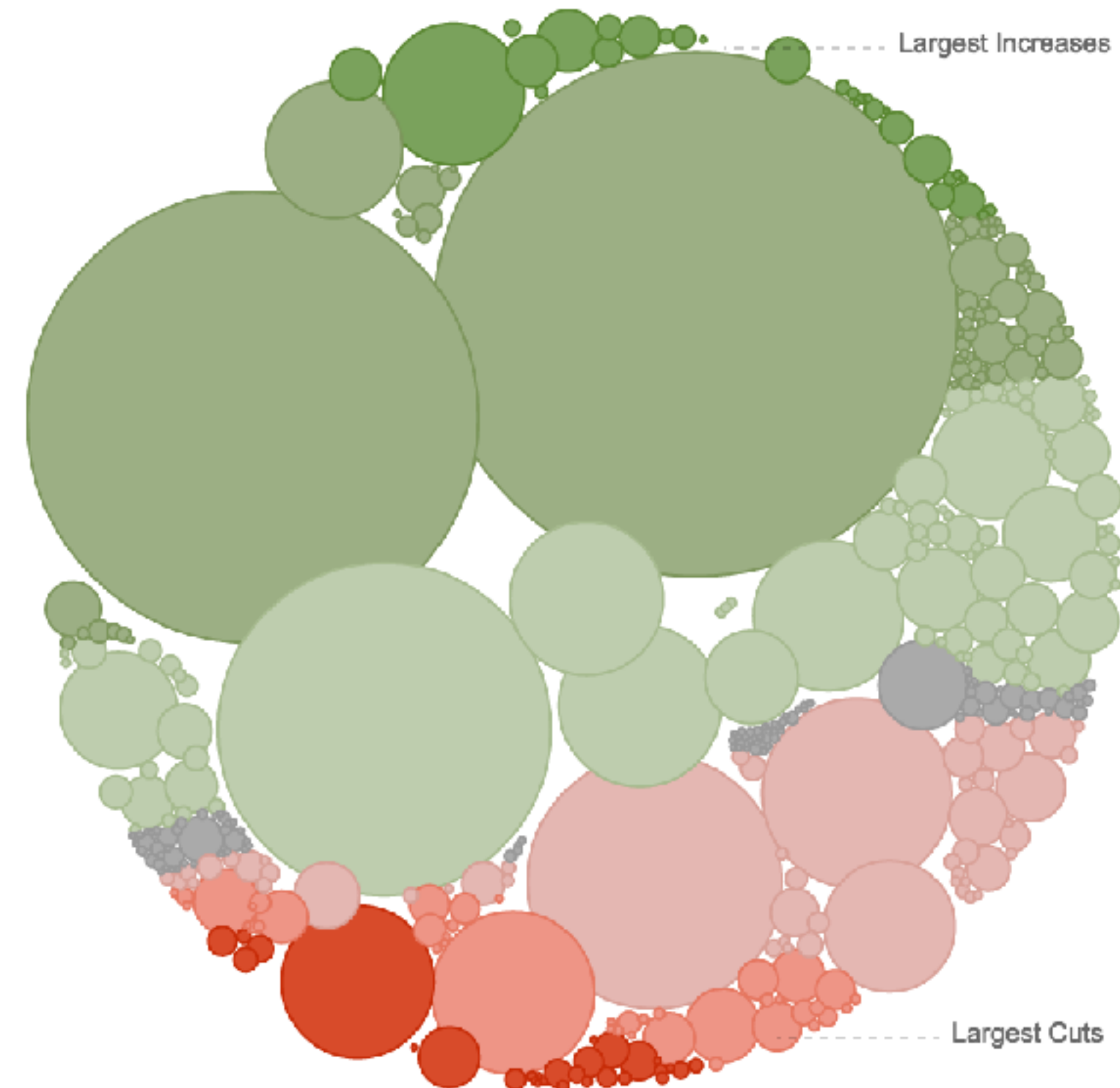
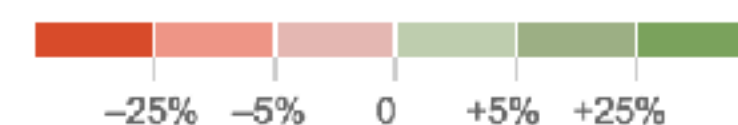
### How \$3.7 Trillion Is Spent

Mr. Obama's budget proposal includes \$3.7 trillion in spending in 2013, and forecasts a \$901 billion deficit.

Circles are sized according to the proposed spending.



Color shows amount of cut or increase from 2012.



# Value/Luminance/Saturation

OK for quantitative data when length & size are used.

Not very many shades recognizable

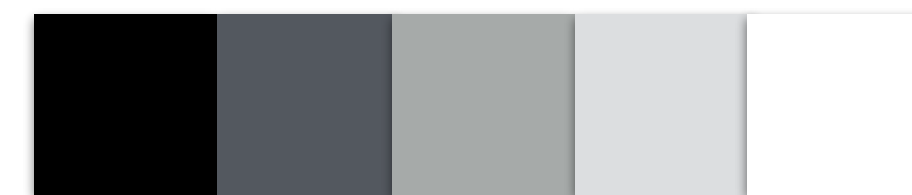
Selective: yes

Associative: yes

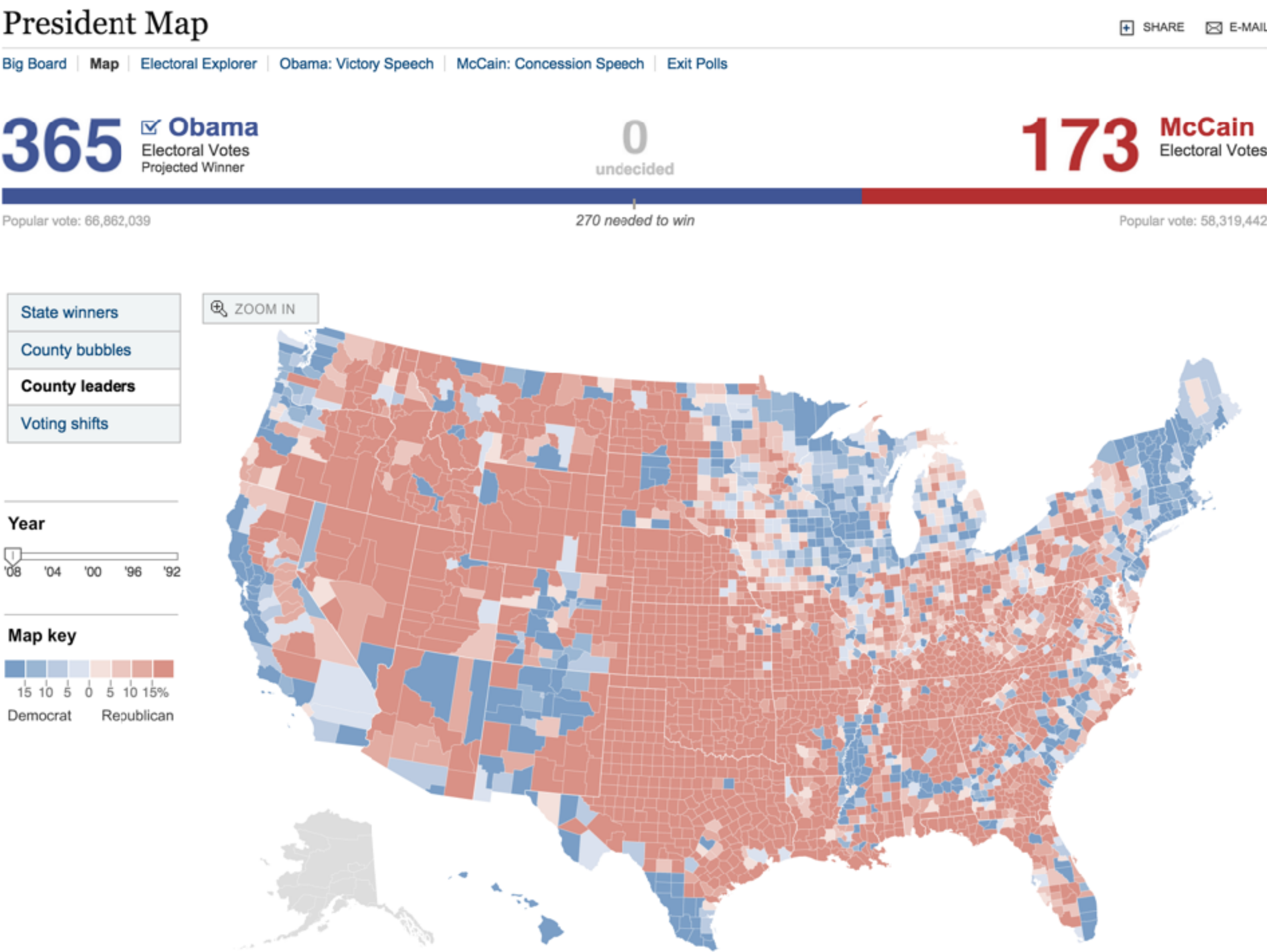
Quantitative: somewhat (with problems)

Order: yes

Length: limited

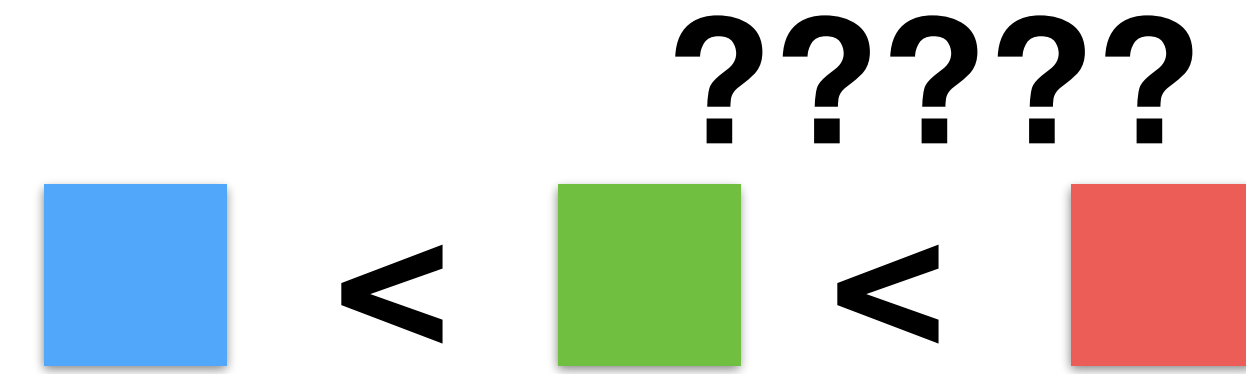


# Example: Diverging Value-Scale





# Color



Good for qualitative data (identity channel)

Limited number of classes/length (~7-10!)

Does not work for quantitative data!

Lots of pitfalls! Be careful!

My rule:

minimize color use for encoding data

use for brushing

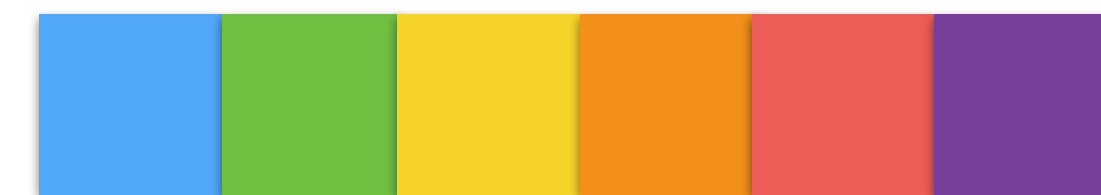
Selective: yes

Associative: yes

Quantitative: no

Order: no

Length: limited





# Color: Bad Example

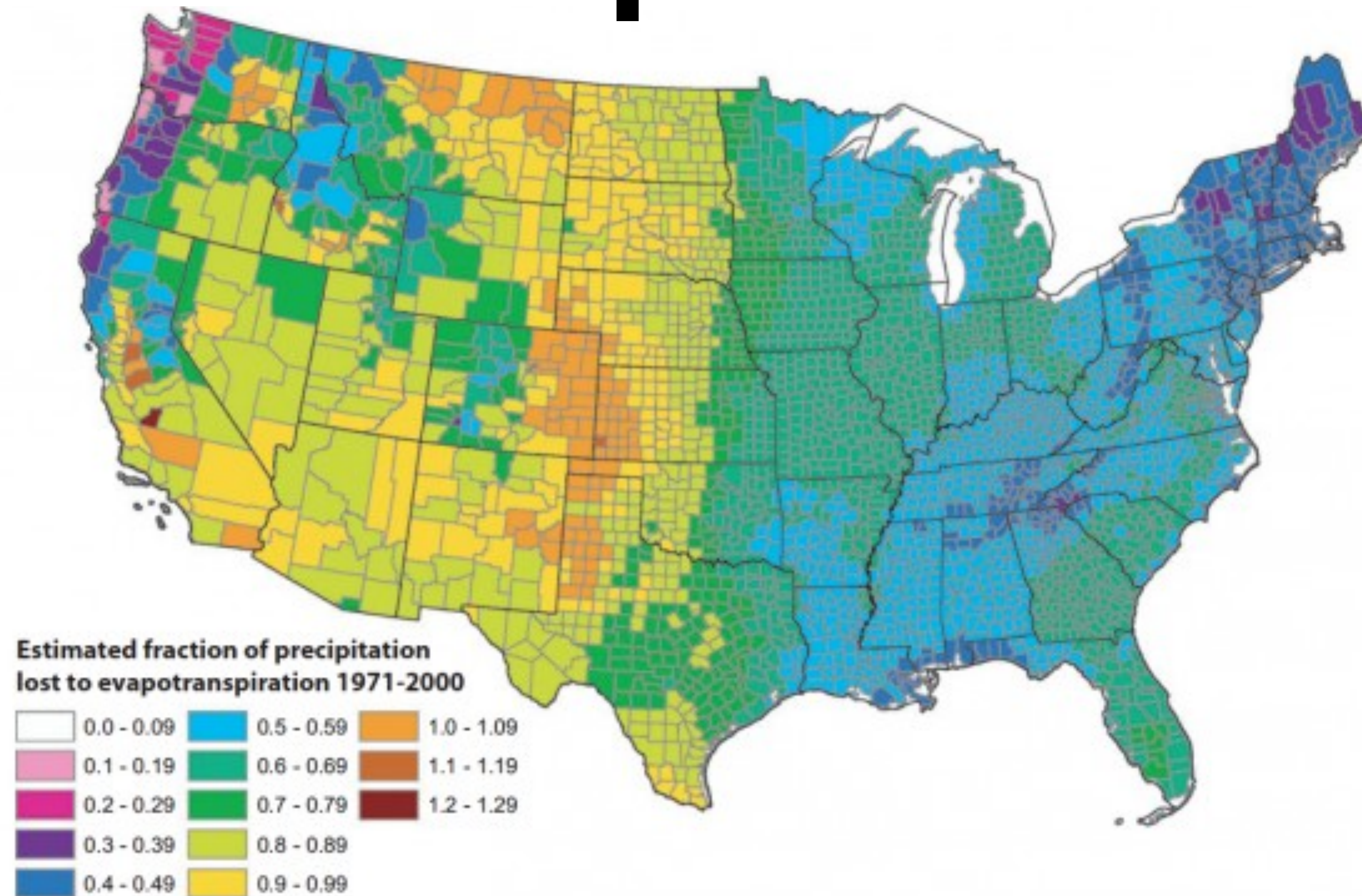


FIGURE 13. Estimated Mean Annual Ratio of Actual Evapotranspiration (ET) to Precipitation ( $P$ ) for the Conterminous U.S. for the Period 1971-2000. Estimates are based on the regression equation in Table 1 that includes land cover. Calculations of  $ET/P$  were made first at the 800-m resolution of the PRISM climate data. The mean values for the counties (shown) were then calculated by averaging the 800-m values within each county. Areas with fractions  $>1$  are agricultural counties that either import surface water or mine deep groundwater.

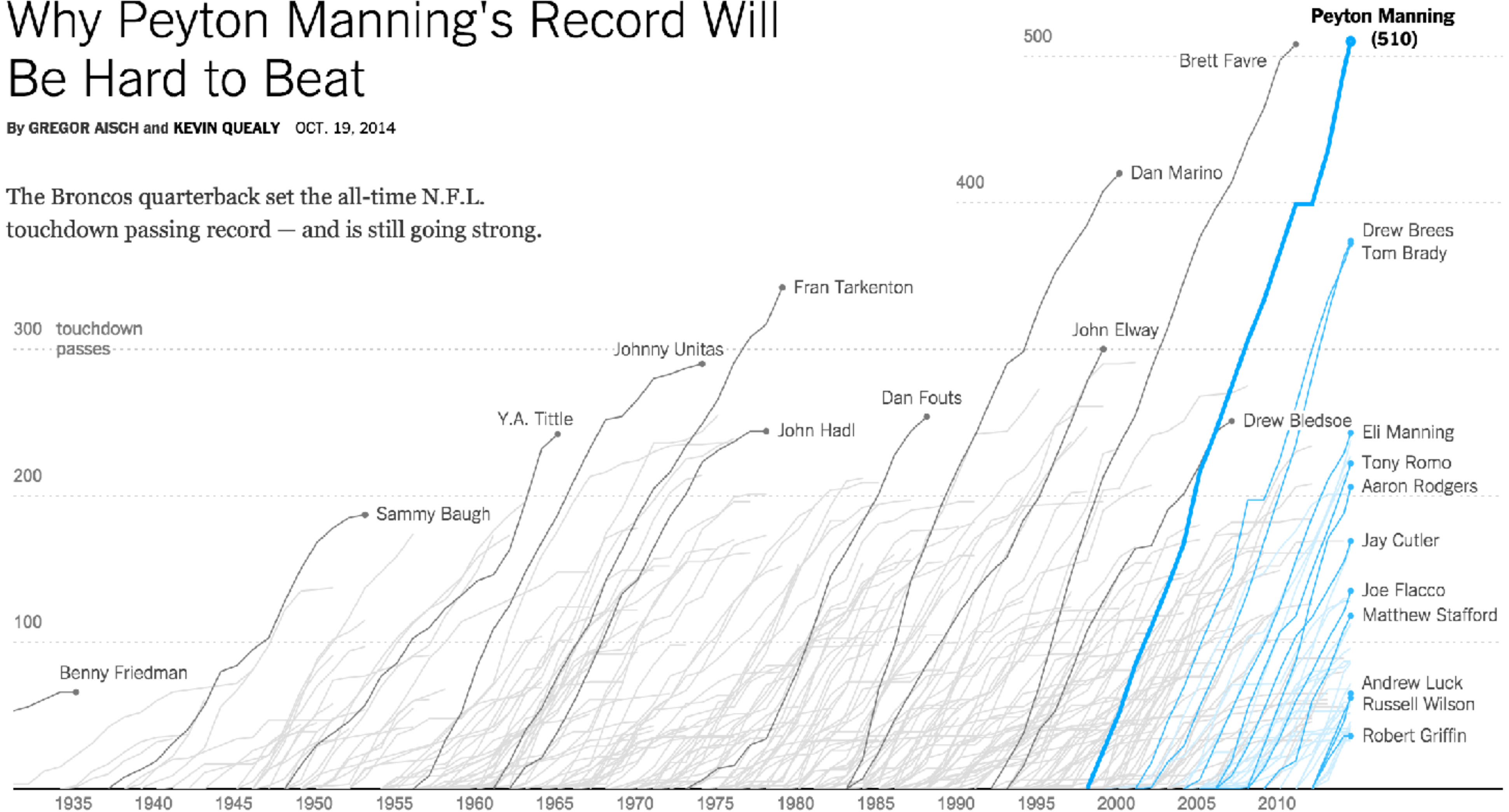


# Color: Good Example

## Why Peyton Manning's Record Will Be Hard to Beat

By GREGOR AISCH and KEVIN QUEALY OCT. 19, 2014

The Broncos quarterback set the all-time N.F.L. touchdown passing record — and is still going strong.



# Shape

Great to recognize many classes.

No grouping, ordering.

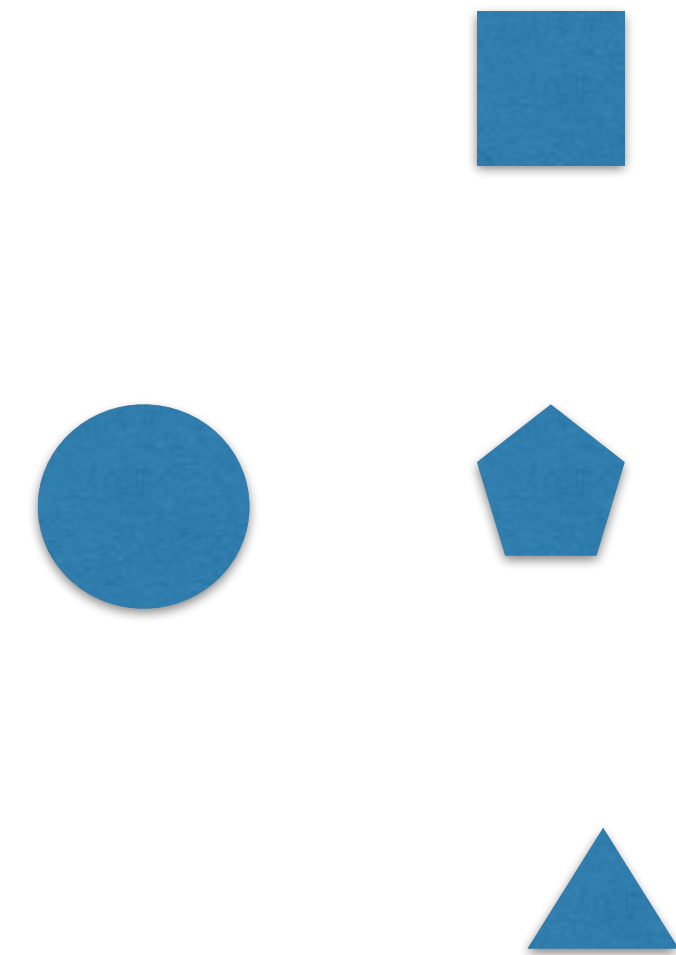
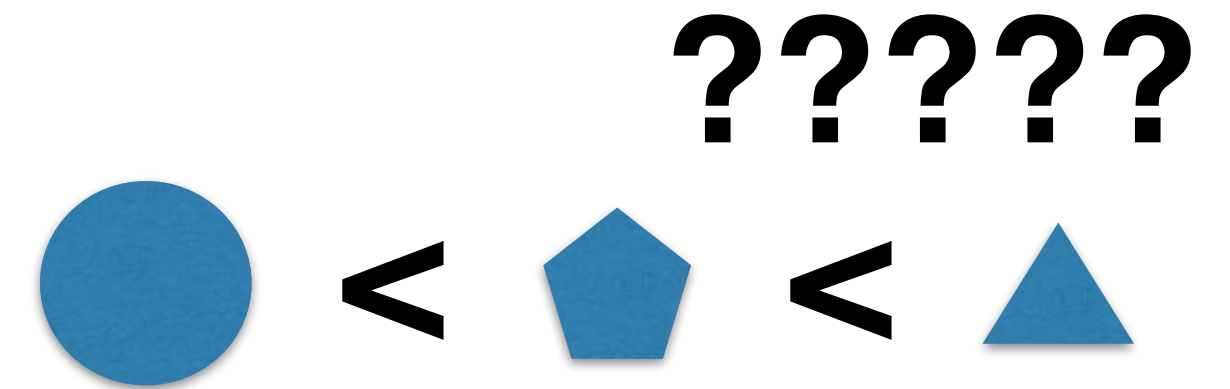
Selective: yes

Associative: limited

Quantitative: no
































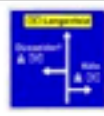










































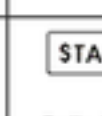















































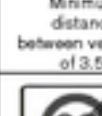

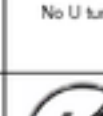







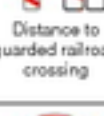



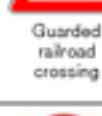
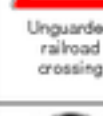

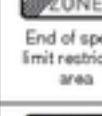

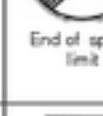
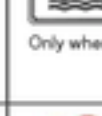

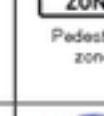
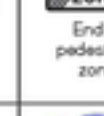

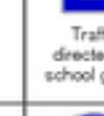










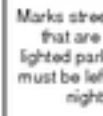







Order: no

Length: vast







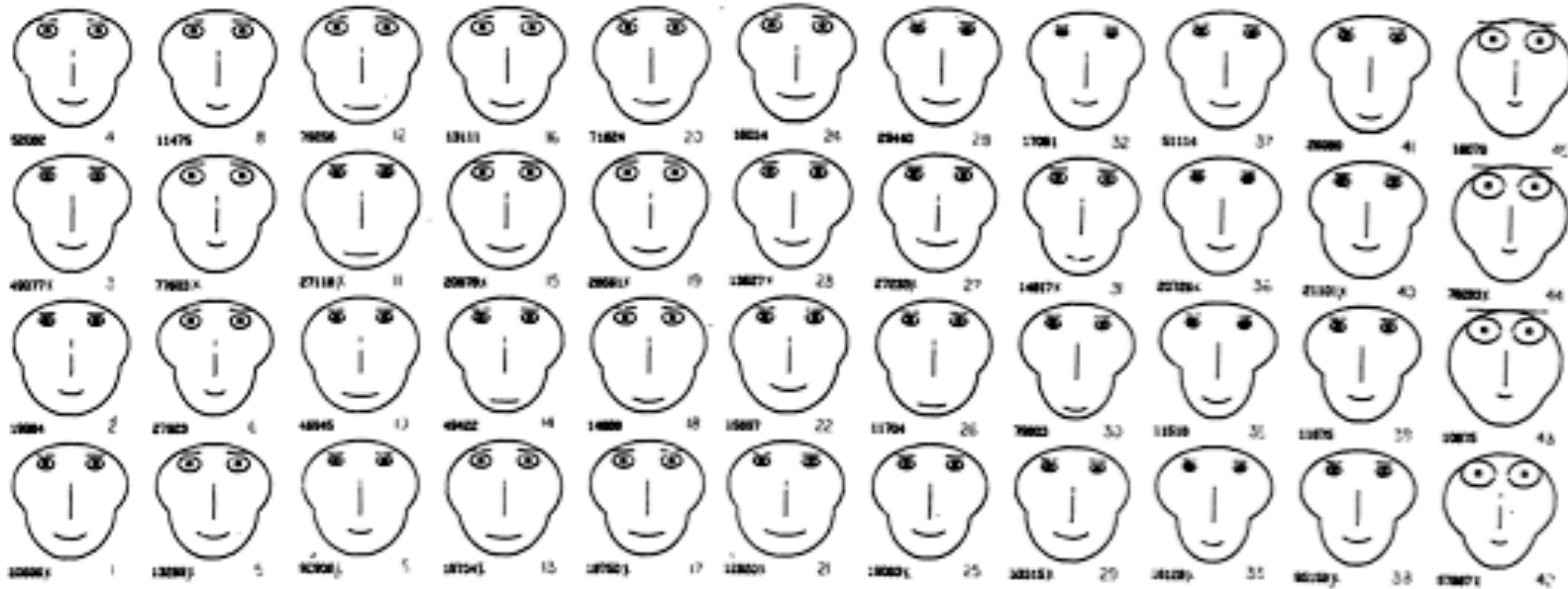
 Autobahn	 Autobahn ends	 Motor vehicles only	 End of motor vehicles only	 Autobahn exit	 Direction to autobahn	 Distance to next change of traffic	 Auto repairs	 Gas station also with lead free fuel	 Autobahn snack machines	 Autobahn restaurant	 Autobahn hotel	 Danger	 Crossroads	 Oncoming traffic	 Falling stones	 Danger streetcar
 Tents and trailers camping area	 Radio station traffic information number	 First aid station	 Telephone	 Police	 Recommended speed	 Parking on curb permitted	 Parking area	 Parking disc clock	 Park and ride area	 Autobahn detour	 Detour route sign	 24 hour service off of the autobahn	<b>FOR SAFETY YOU MUST KNOW German traffic signs</b> <small>UNIVERS POSTER 190.34.12, Jan. 2011 Copyright UNIVERS POSTER 190.34, No. 95</small> <a href="http://my.hausarbeit.com/">http://my.hausarbeit.com/</a>			
 Autobahn direction sign	 Direction to autobahn	 Change of traffic lanes	 Direction sign	 Bypass routing	 Detour	 Direction of travel	 Directional sign	 European highway	 Federal highway number	 Built-up area (front)	 Built-up area (reverse) revision	 Single curve	 Double curve	 Road narrows	 Road narrows	 No motorcycles
 End of city limits	 Direction of travel for bicycles	 Point of interest	 Name place	 Supplemental sign	 Orange traffic arrow Recommended direction of travel in situ	 Soft shoulder	 Secondary route	 Right of way changed	 Gravel	 Road damage	 Quay or river bank	 Low flying aircraft	 Pedestrian crosswalk ahead	 Pedestrian crosswalk	 No vehicles carrying dangerous goods	 No bicycles
 Residents only	 Speed and distance sign	 Solid white line	 Broken white line	 Passing only from broken line side	 Off limits markings	 Arrow on pavement	 Directional arrows	 Pedestrian crosswalk	 No parking	 Traffic jam ahead	 Traffic jam area ahead	 Bicycle crossing	 Dangerous downgrade	 Dangerous upgrade	 Rough road	 No bicycles
 Slippery road	 Loose gravel	 Children	 Construction site	 Drawbridge ahead	 Wild animal crossing	 Domestic animal crossing	 Side wind	 Smog Motor vehicle traffic prohibited	 Signal lights ahead	 Stop	 Yield right of way	 Mandatory direction of travel	 Mandatory direction of travel	 Mandatory direction of travel	 Mandatory direction of travel	 Tourist office or information
 Maximum height allowed	 Maximum width allowed	 Maximum weight allowed	 No vehicles carrying more than 3000 liters of pollutants	 Vehicles above a specific axle weight prohibited	 Motor vehicles prohibited	 Tractors and trucks with an authorized loaded weight of more than 3.5 tons prohibited	 Minimum distance between vehicles of 3.5t	 Maximum length allowed	 No U turns	 Prohibited for all vehicles	 Entry prohibited	 Mandatory direction of travel	 Mandatory direction of travel	 Beginning of a pedestrian priority area	 End of pedestrian priority area	 Traffic circle
 Distance to guarded railroad crossing	 Distance to unguarded railroad crossing	 Railroad crossing	 Railroad crossing	 Guarded railroad crossing	 Unguarded railroad crossing	 Speed zone	 End of speed limit restricted area	 Speed limit	 End of speed limit	 Only when wet	 Right on red green arrow sign	 Pedestrian zone	 End of pedestrian zone	 Children playing	 Traffic directed by school guard	 Bus lane
 Restricted no stopping	 No stopping	 No passing	 End of no passing zone	 No passing for trucks in excess of 3.5 tons authorized weight	 End of no passing zone	 Limited parking place clock card in windshield	 End of limited parking zone	 End of restriction	 Marks streetlights that are not lighted parklights must be left on at night	 Customs control	 Oncoming traffic has right of way	 Snow chains mandatory	 Horse riders only	 Pedestrians only	 Bicycles only	 Information panel at frontier crossings
 Priority road	 Priority road	 End of Priority road	 Right of way	 Priority road ahead	 Bridge carrying capacity for NATO vehicles	 One way street in direction of arrow	 Dead end	 One-way traffic	 Oncoming traffic must wait	 Compulsory minimum speed limit	 End of compulsory minimum zone	 Separated bicycle and pedestrian pavements restricted speed area	 Jointly used pavements for pedestrians and bicycles	 Taxi parking only	 Water protection area	 Exit number





# Chernoff Faces

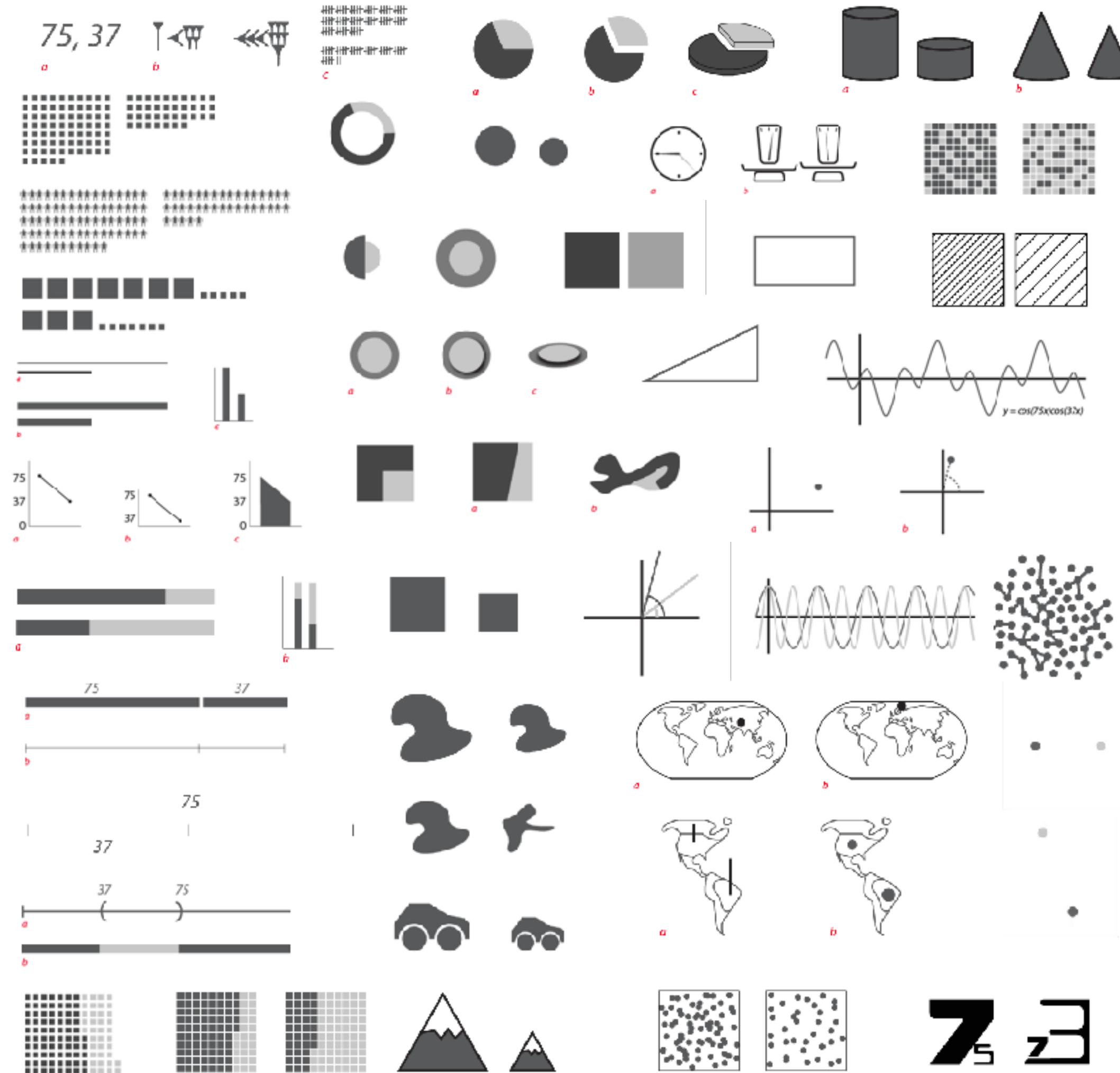
Idea: use facial parameters to map quantitative data



Does it work?  
Not really!

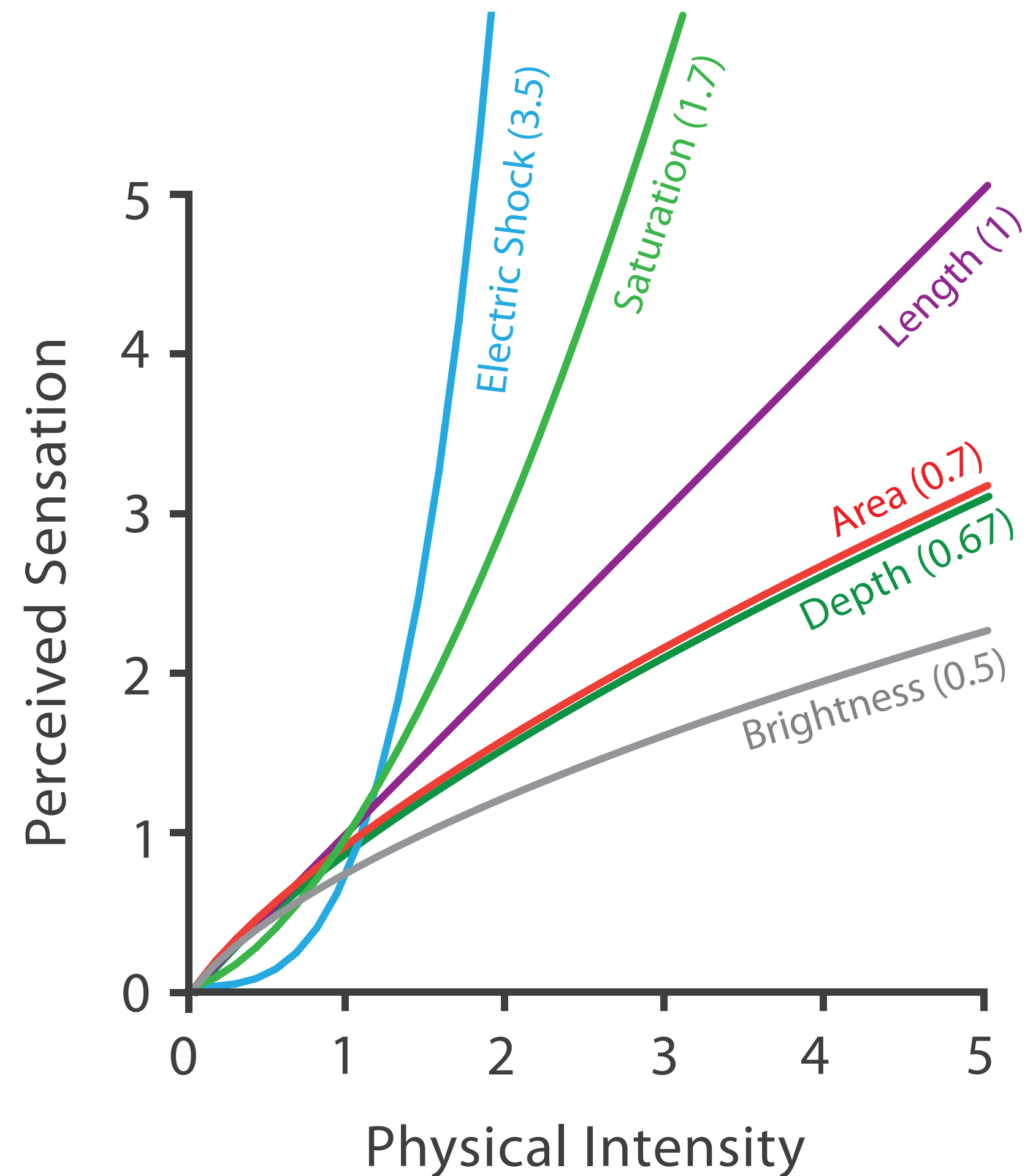
Critique: <https://eagereyes.org/criticism/chernoff-faces>

# More Channels



# Why are quantitative channels different?

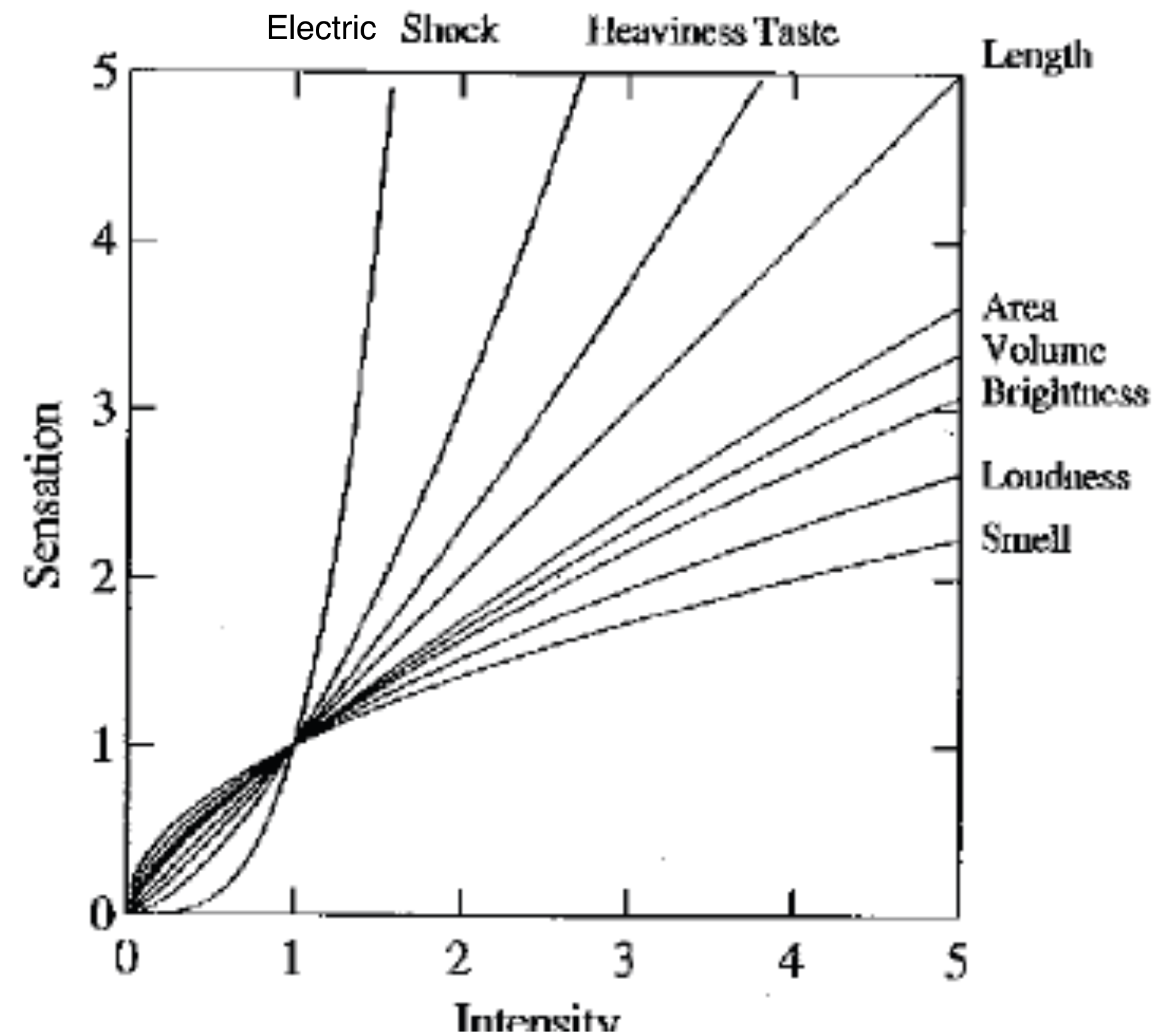
Steven's Psychophysical Power Law:  $S = I^N$



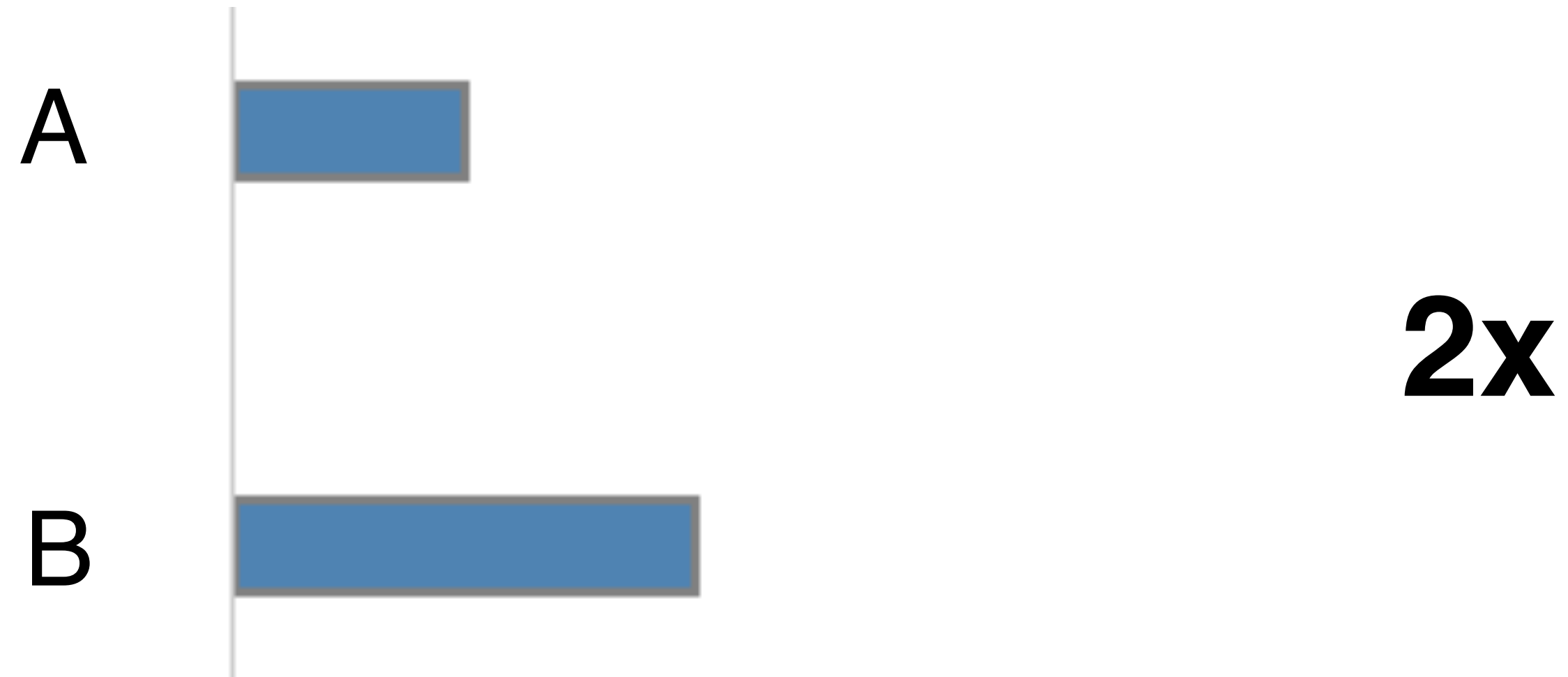
$S$  = sensation  
 $I$  = intensity



# Steven's Power Law, 1961



# How much longer?



# How much longer?




# How much steeper?

A

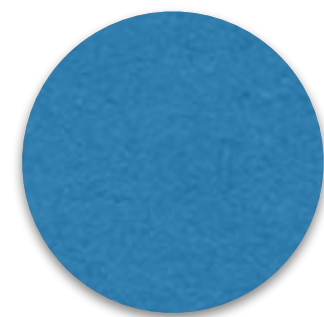
A steep line segment labeled A, starting from a point on the horizontal axis and extending upwards at a steep angle.

B

A shallow line segment labeled B, starting from a point on the horizontal axis and extending upwards at a shallow angle.

**$\sim 4x$**

# How much larger?



A

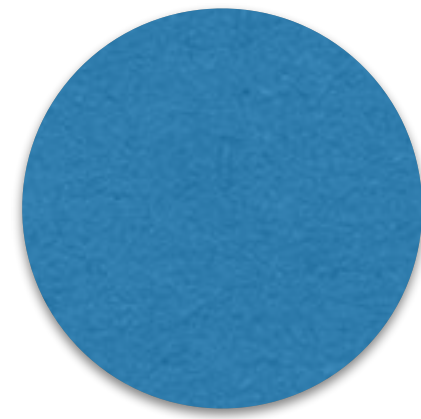


B

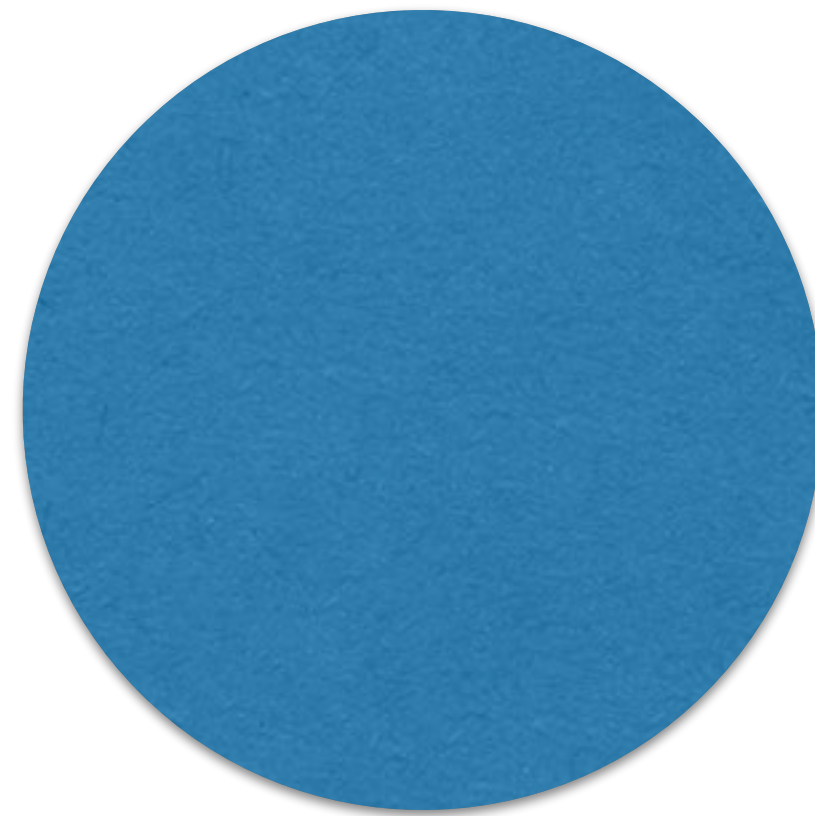
**5x**



# How much larger?



A



B

**2x  
diameter**

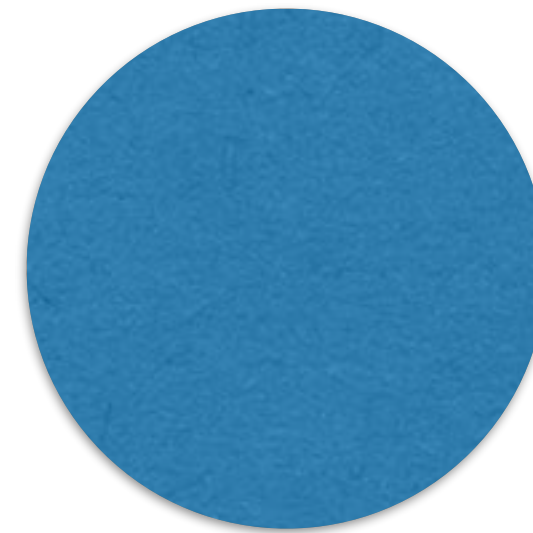
**4x area**

area is proportional to  
diameter squared

# How much larger (area)?



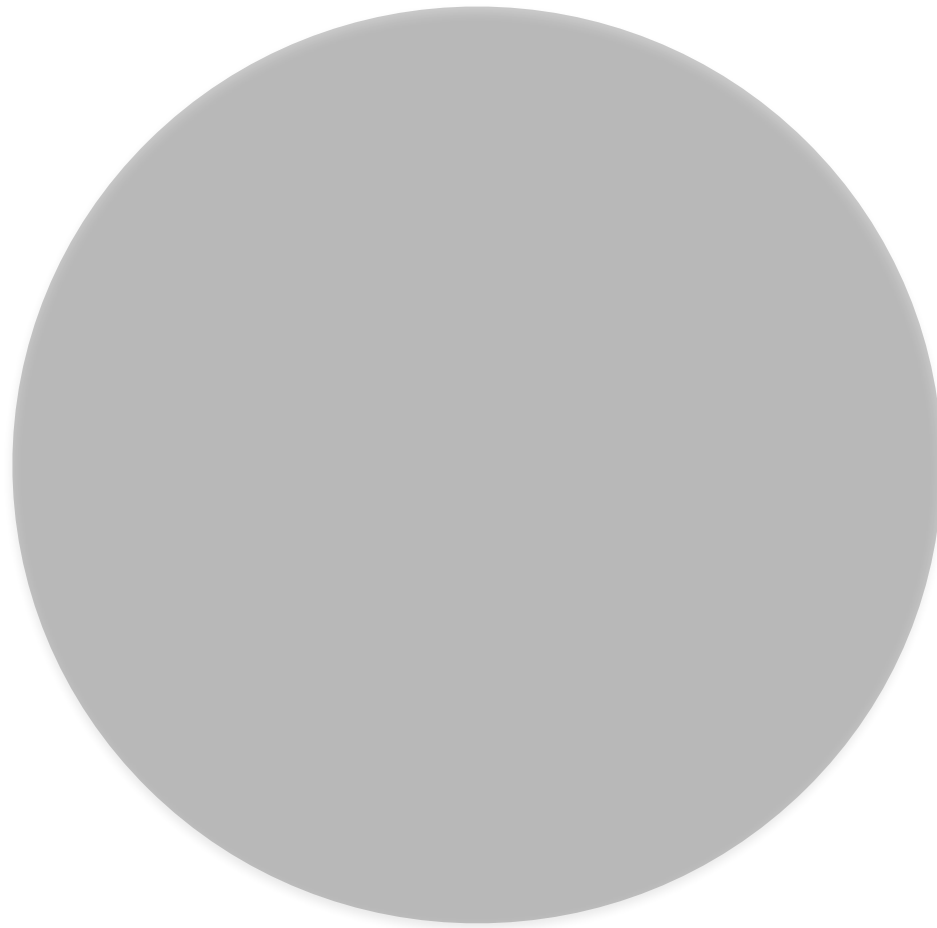
A



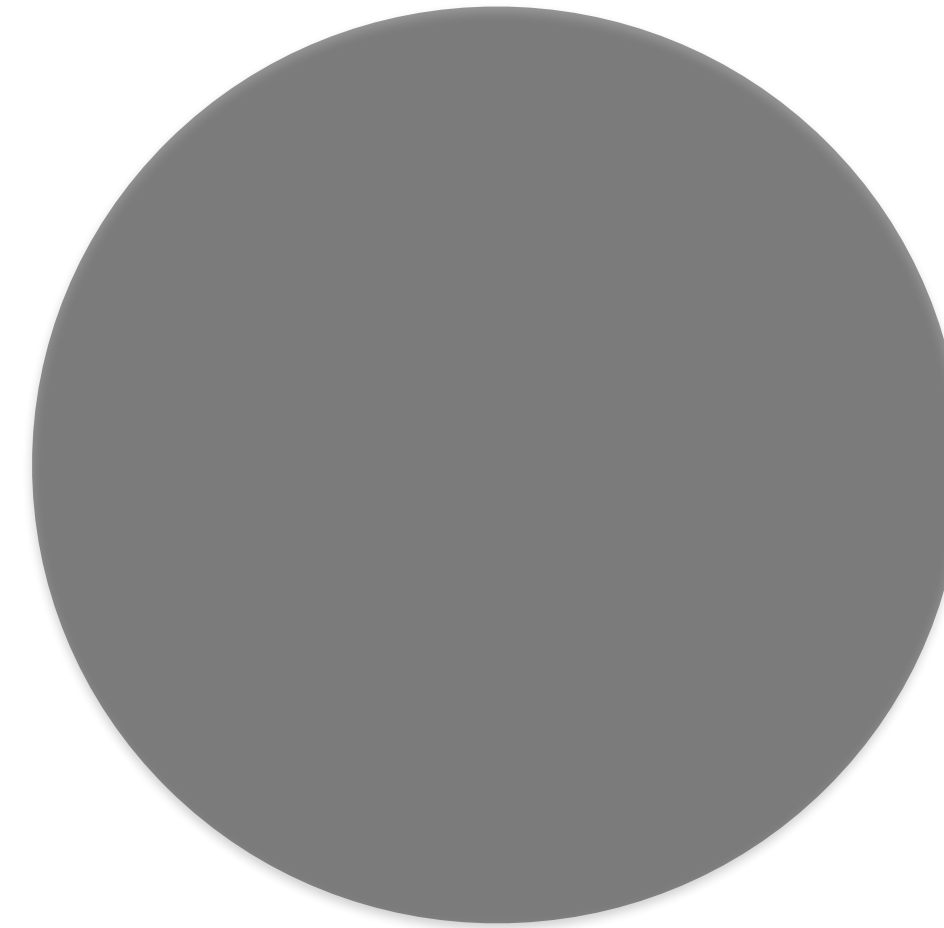
B

**3x**

# How much darker?



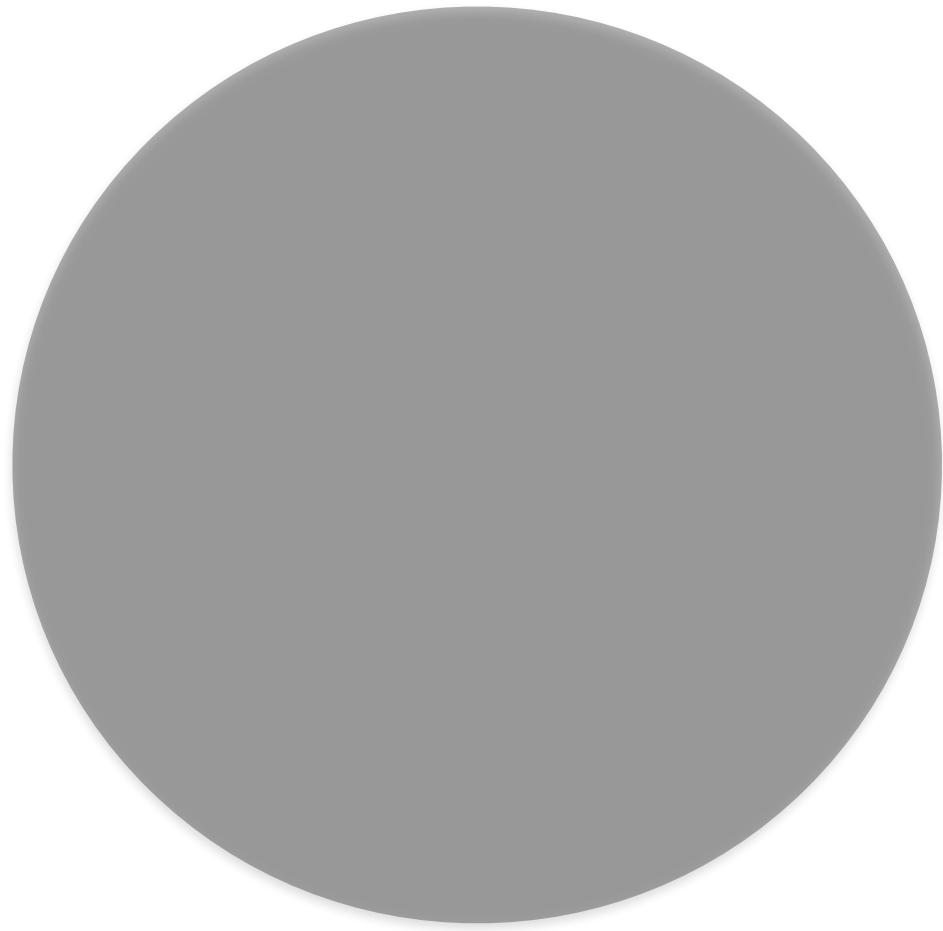
A



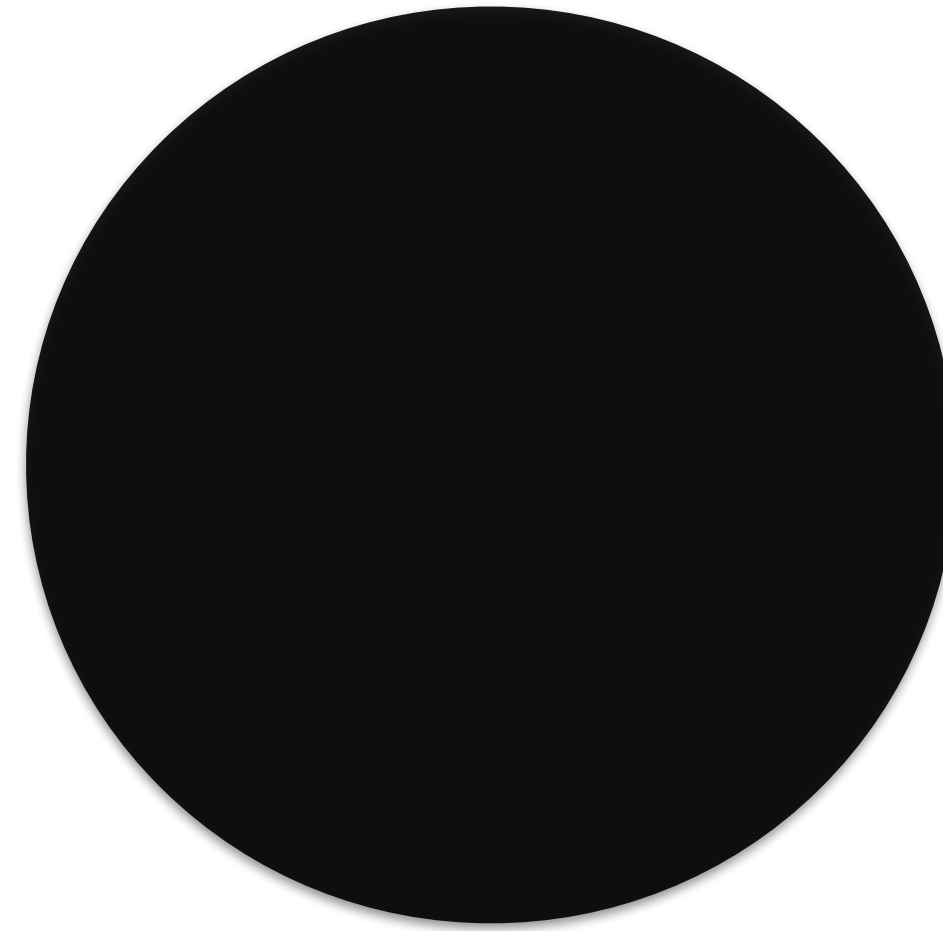
B

**2x**

# How much darker?



A



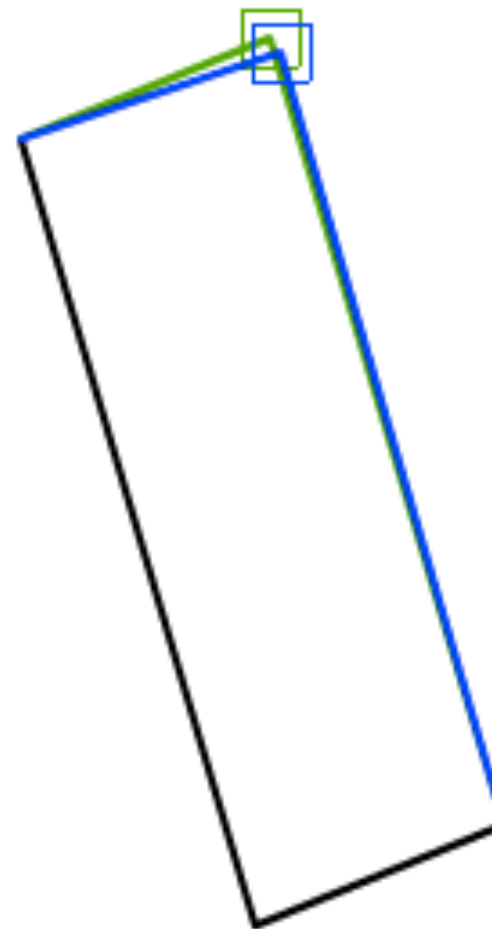
B

**3x**

# Position, Length & Angle

## The eyeballing game

Adjust to make a parallelogram



Accurate to 5.0 units

Next

### Your inaccuracy by category:

Parallelogram	5.0	----	----
Midpoint	----	----	----
Bisect angle	----	----	----
Triangle center	----	----	----
Circle center	----	----	----
Right angle	----	----	----
Convergence	----	----	----

**Average error:** 5.00 (lower is better)

**Time taken:** 3.3

### Best of last 500 score and time: [\(more\)](#)

1.32 250 s Harabubakken sparkakar kl  
1.36 81 s ± rides saddle horn  
1.39 110 s have both-can f myself±  
1.46 93 s ± is one kinky dude  
1.50 95 s no NT...sample my taco? ±  
1.55 114 s  
1.57 113 s  
1.65 85 s ± "come on funny feeling"  
1.70 71 s JSA  
1.75 89 s JSA

**Best on this computer score and time:**



# Other Factors Affecting Accuracy

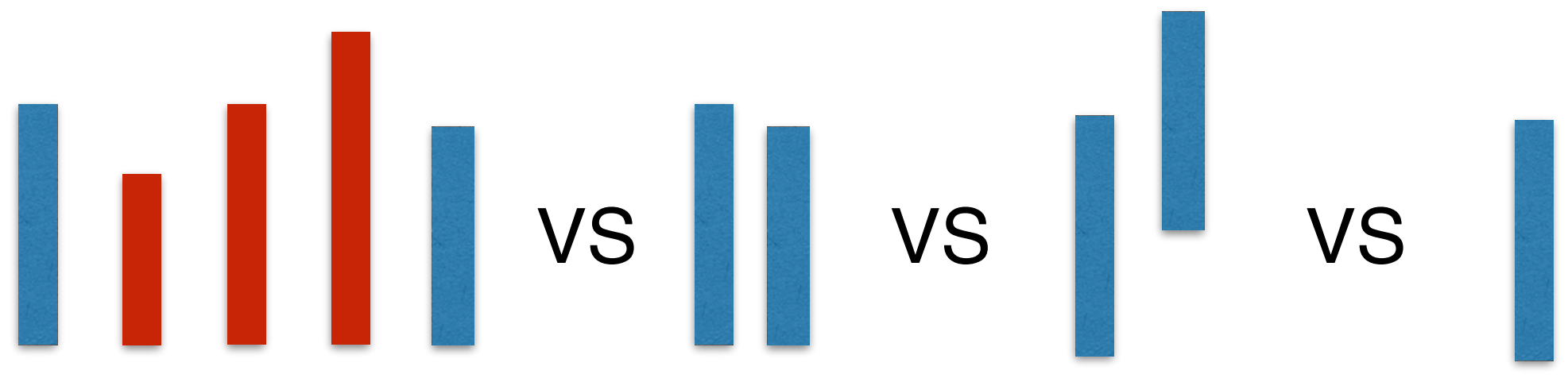
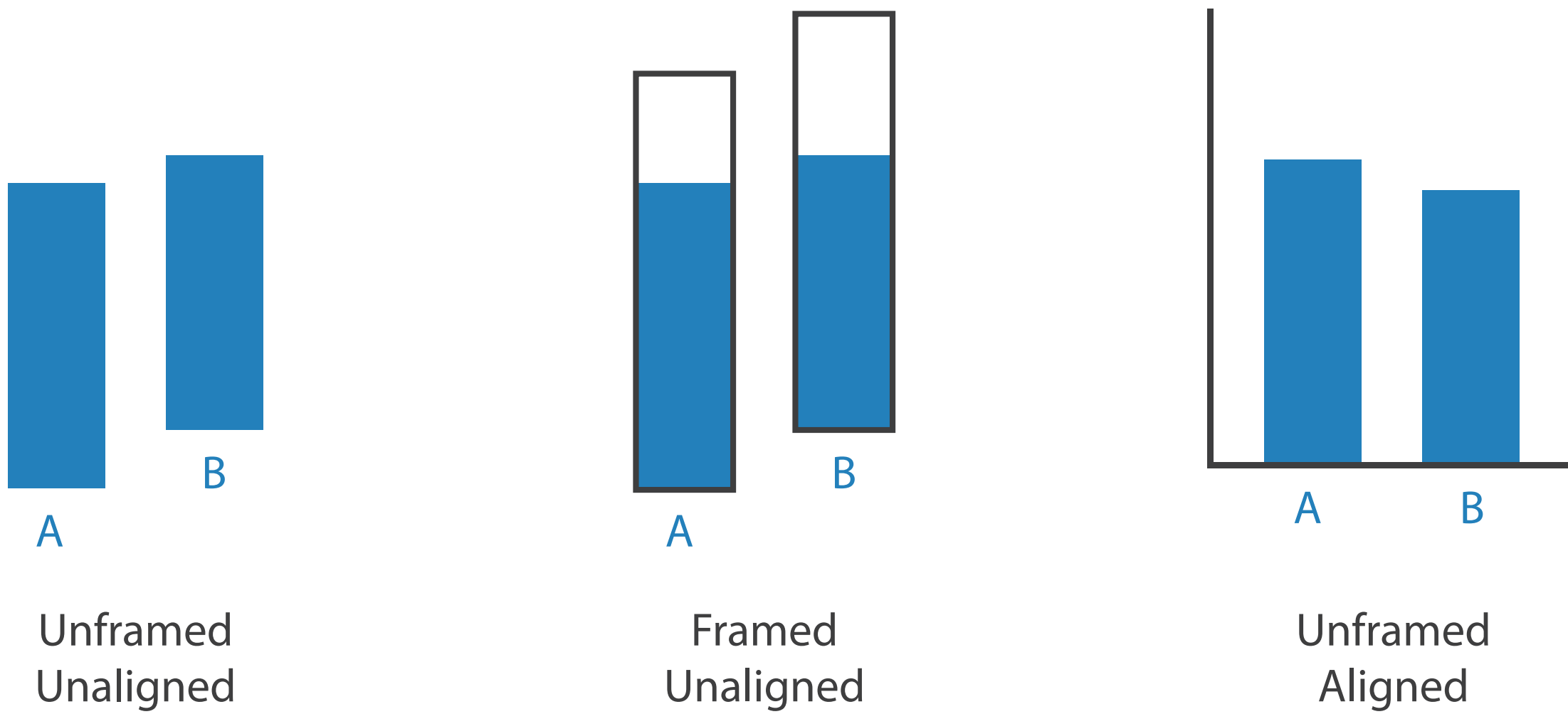
Alignment

Distractors

Distance

Common scale

...



# Cleveland / McGill, 1984

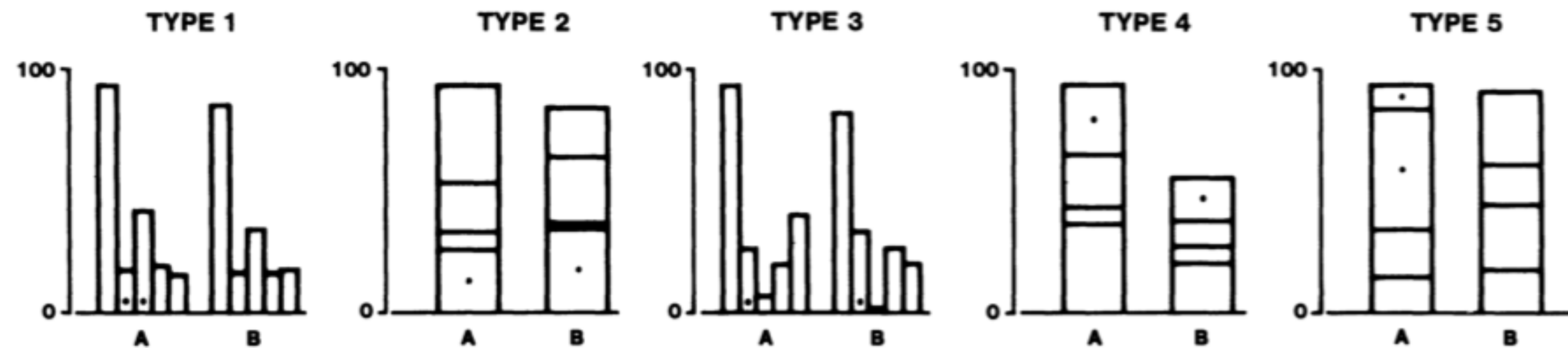


Figure 4. Graphs from position-length experiment.

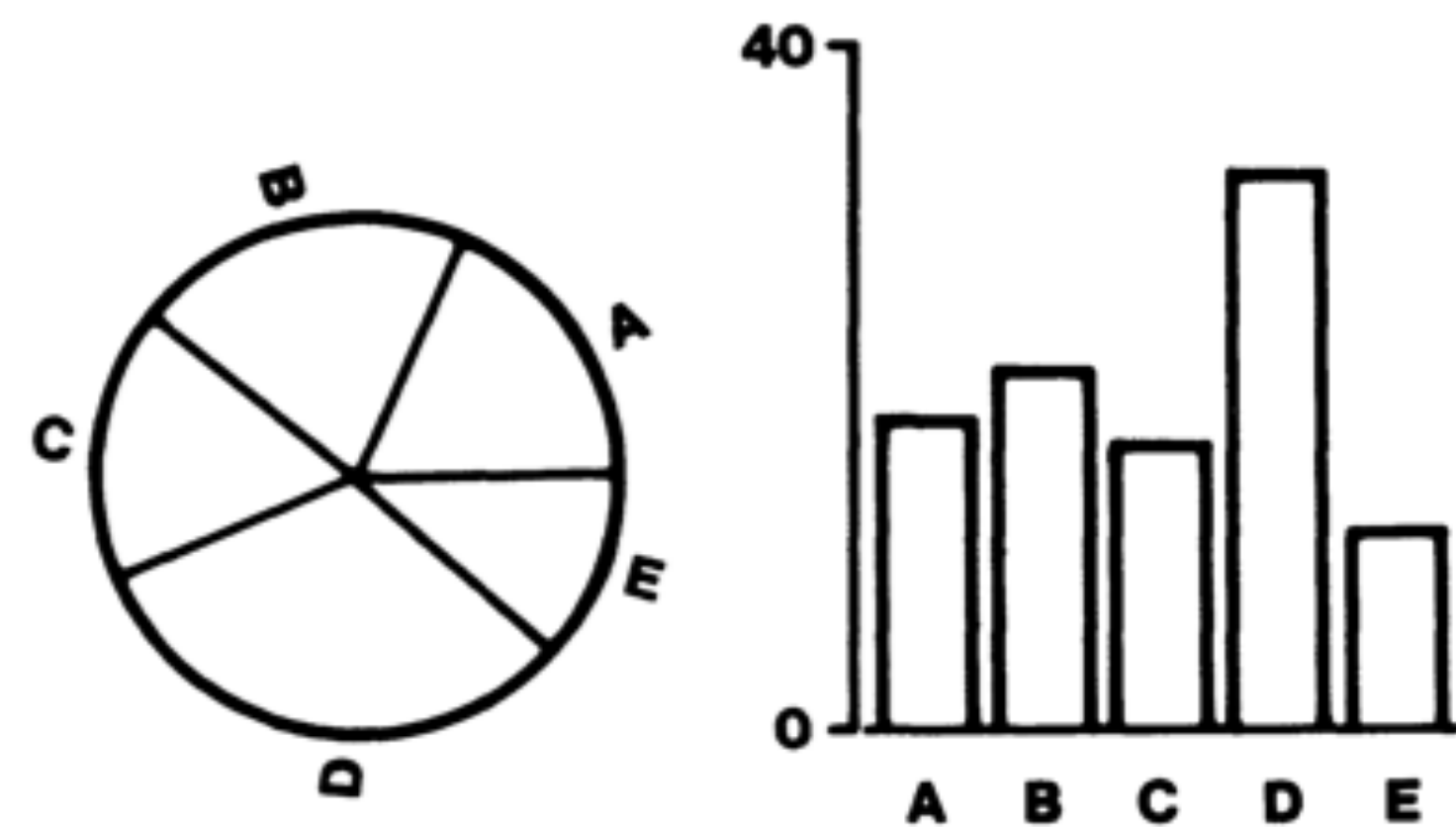
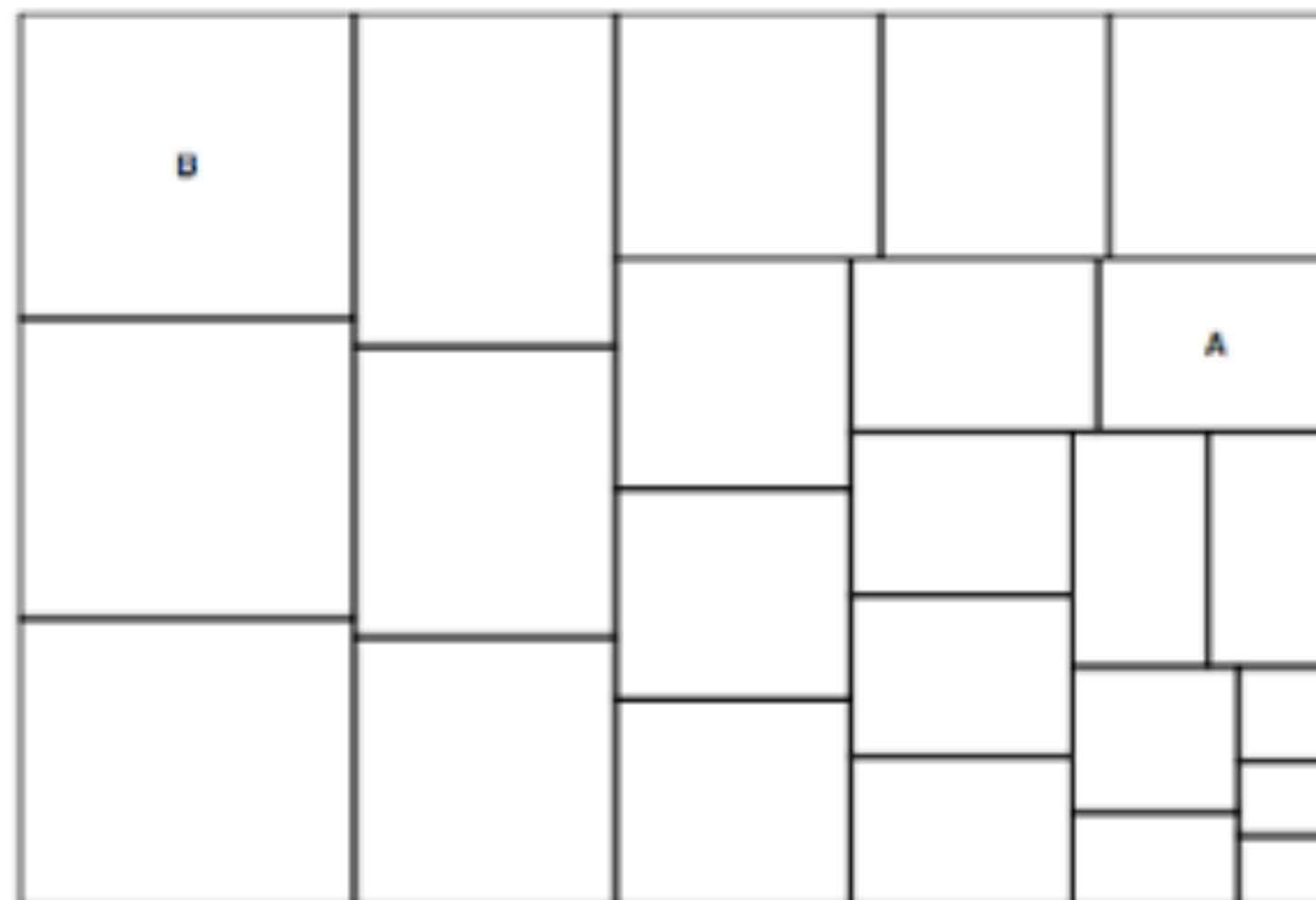
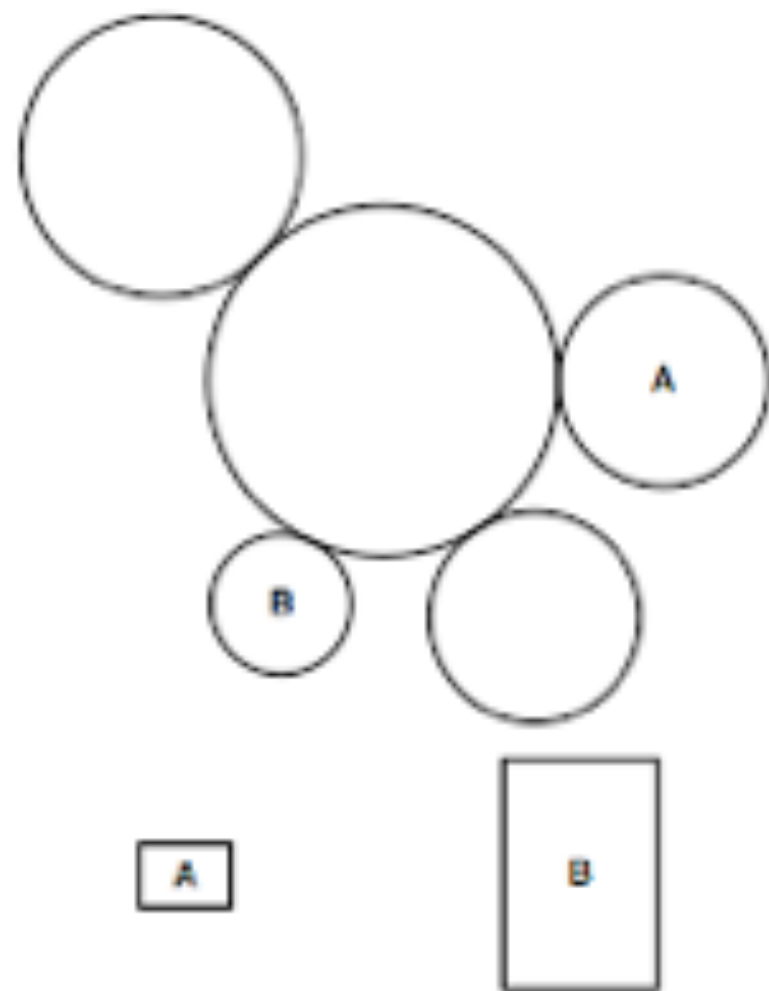
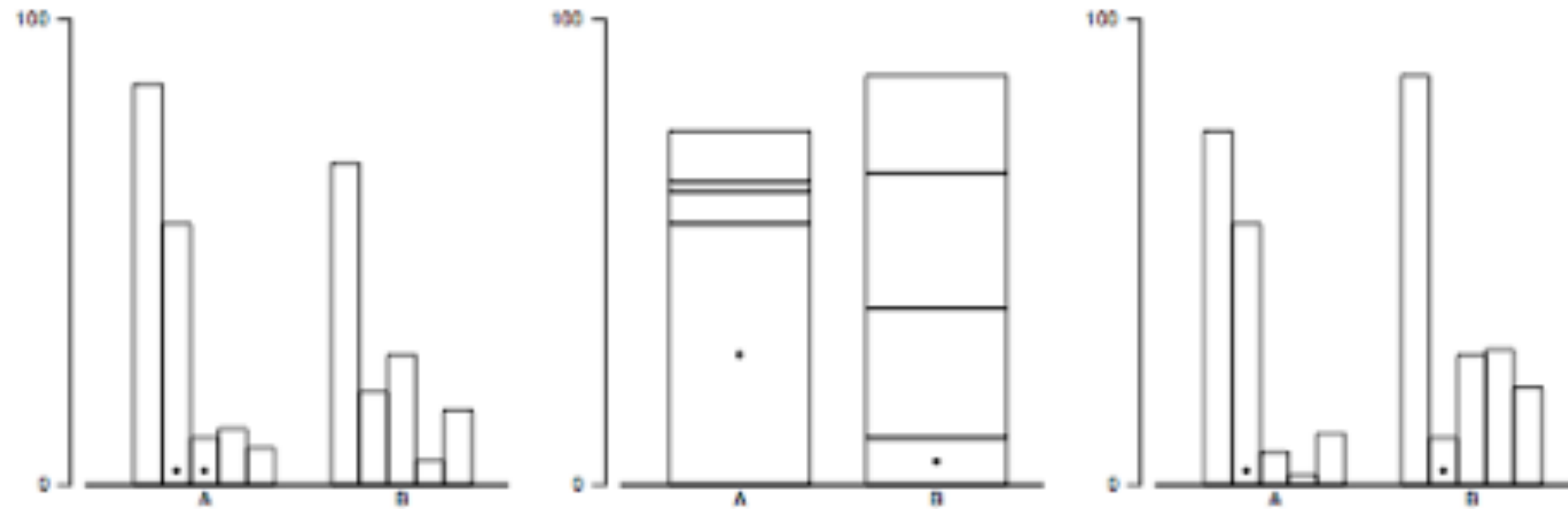


Figure 3. Graphs from position-angle experiment.

# Heer & Bostock, 2010



CHI 2010: Visualization

April 10–15, 2010, Atlanta, GA, USA

## Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design

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### ABSTRACT

Understanding perception is critical to effective visualization design. With its low cost and scalability, crowdsourcing presents an attractive option for evaluating the large design space of visualizations; however, it first requires validation. In this paper, we assess the viability of Amazon’s Mechanical Turk as a platform for graphical perception experiments. We replicate previous studies of spatial encoding and luminance contrast and compare our results. We also conduct new experiments on rectangular area perception (as in treemaps or cartograms) and on chart size and gridline spacing. Our results demonstrate that crowdsourced perception experiments are viable and contribute new insights for visualization design. Lastly, we report cost and performance data from our experiments and distill recommendations for the design of crowdsourced studies.

**ACM Classification:** H5.2 [Information interfaces and presentation]: User Interfaces—Evaluation/Methodology

**General Terms:** Experimentation, Human Factors.

**Keywords:** Information visualization, graphical perception, user study, evaluation, Mechanical Turk, crowdsourcing.

### INTRODUCTION

“Crowdsourcing” is a relatively new phenomenon in which web workers complete one or more small tasks, often for micro-payments on the order of \$0.01 to \$0.10 per task.

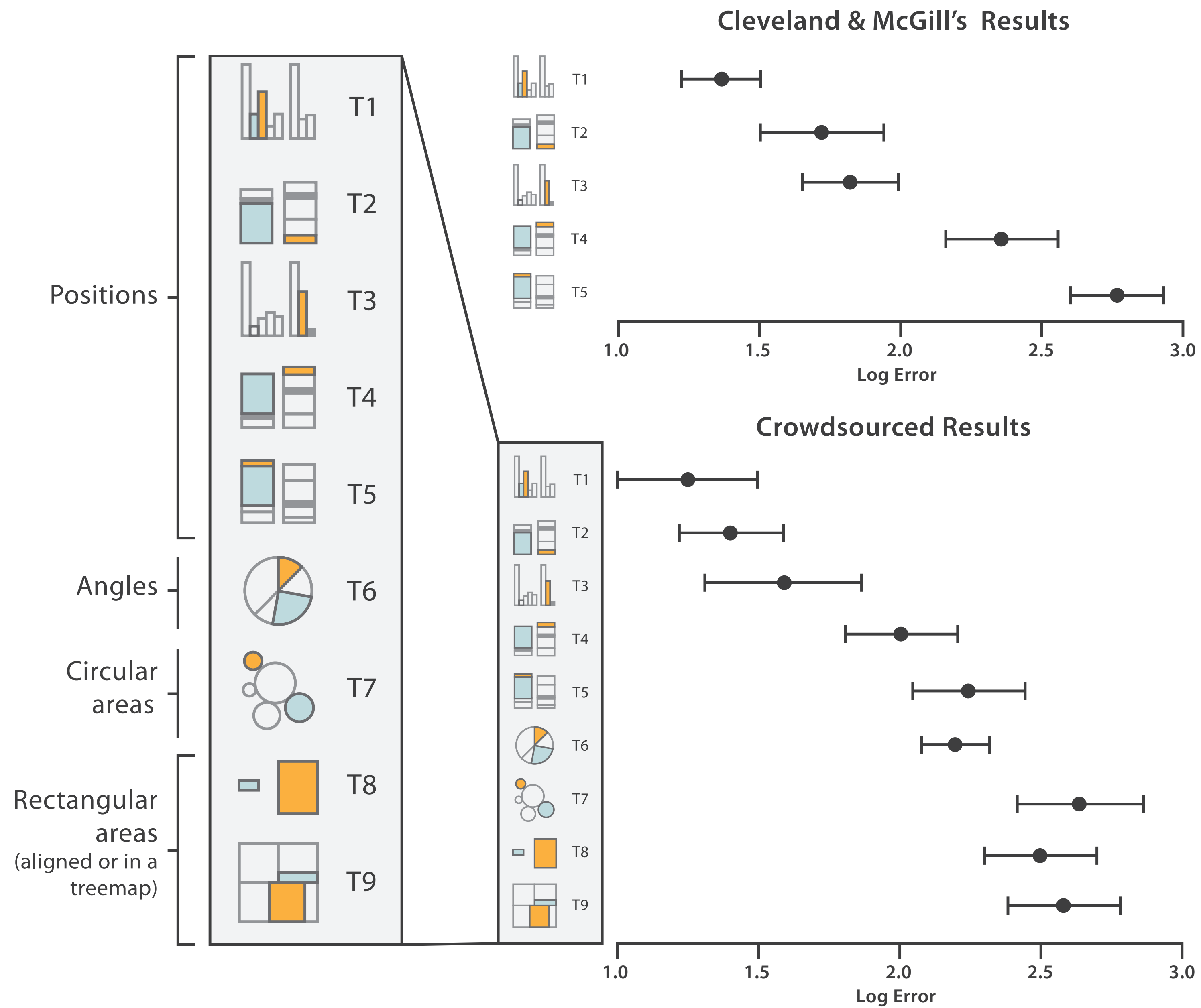
for ecological validity. Crowdsourced experiments may also substantially reduce both the cost and time to result.

Unfortunately, crowdsourcing introduces new concerns to be addressed before it is credible. Some concerns, such as ecological validity, subject motivation and expertise, apply to any study and have been previously investigated [13, 14, 23]; others, such as display configuration and viewing environment, are specific to visual perception. Crowdsourced perception experiments lack control over many experimental conditions, including display type and size, lighting, and subjects’ viewing distance and angle. This loss of control inevitably limits the scope of experiments that reliably can be run. However, there likely remains a substantial subclass of perception experiments for which crowdsourcing can provide reliable empirical data to inform visualization design.

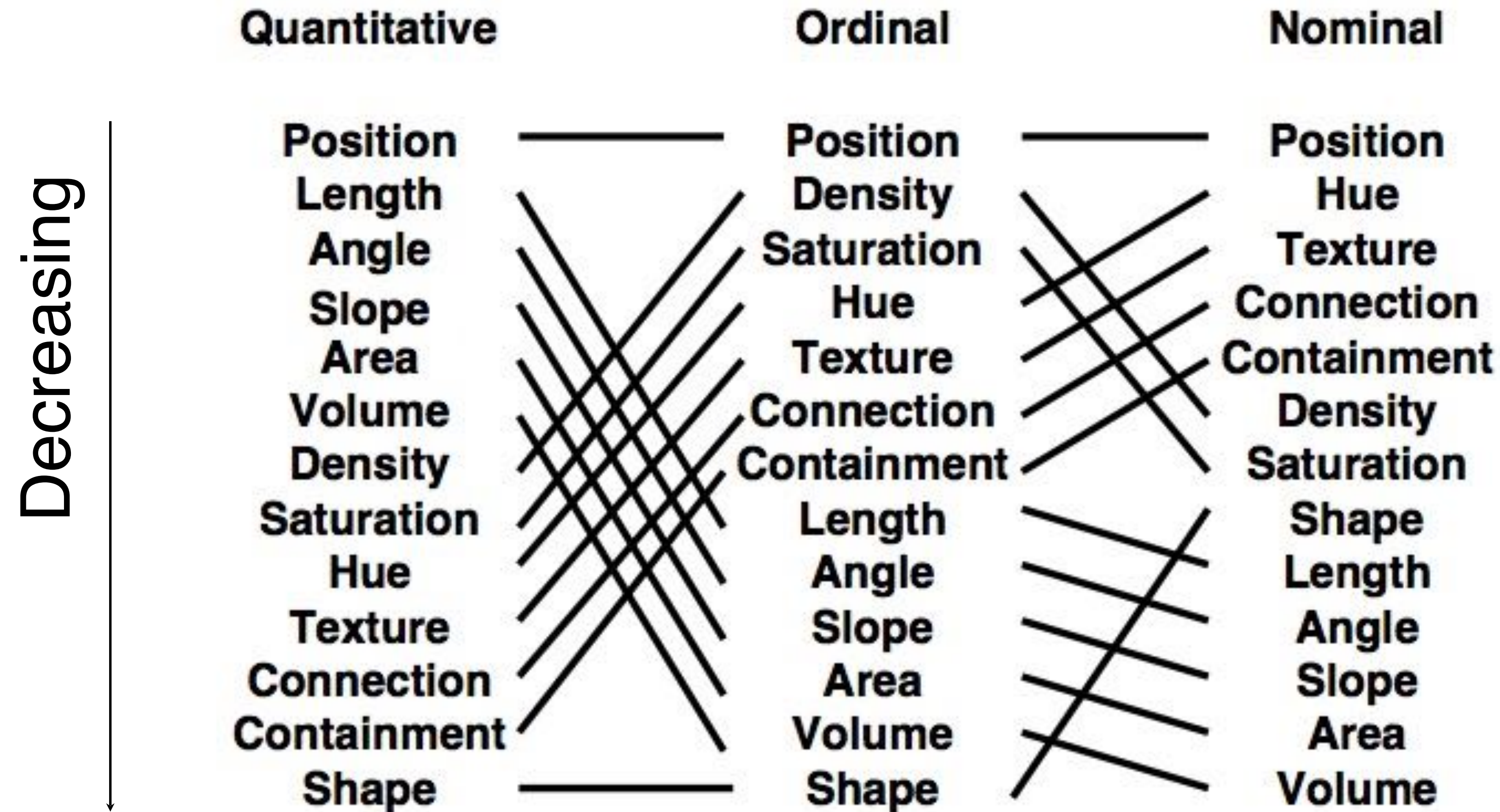
In this work, we investigate if crowdsourced experiments insensitive to environmental context are an adequate tool for graphical perception research. We assess the feasibility of using Amazon’s Mechanical Turk to evaluate visualizations and then use these methods to gain new insights into visualization design. We make three primary contributions:

- We replicate prior laboratory studies on spatial data encodings and luminance contrast using crowdsourcing techniques. Our new results match previous work, are consistent with theoretical predictions [21], and suggest that





# Jock Mackinlay, 1986



Channels: Expressiveness Types and Effectiveness Ranks

➔ **Magnitude Channels: Ordered** Attributes



➔ **Identity Channels: Categorical** Attributes

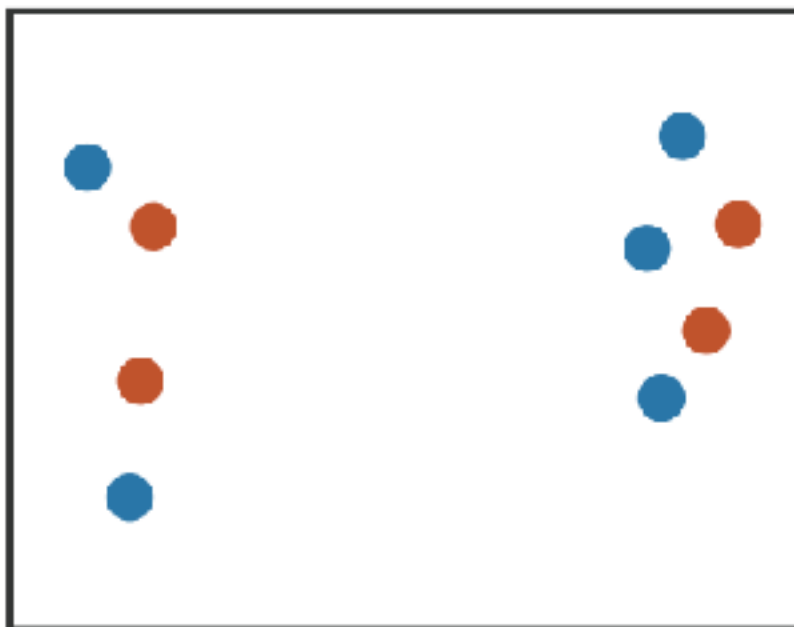




# Separability of Attributes

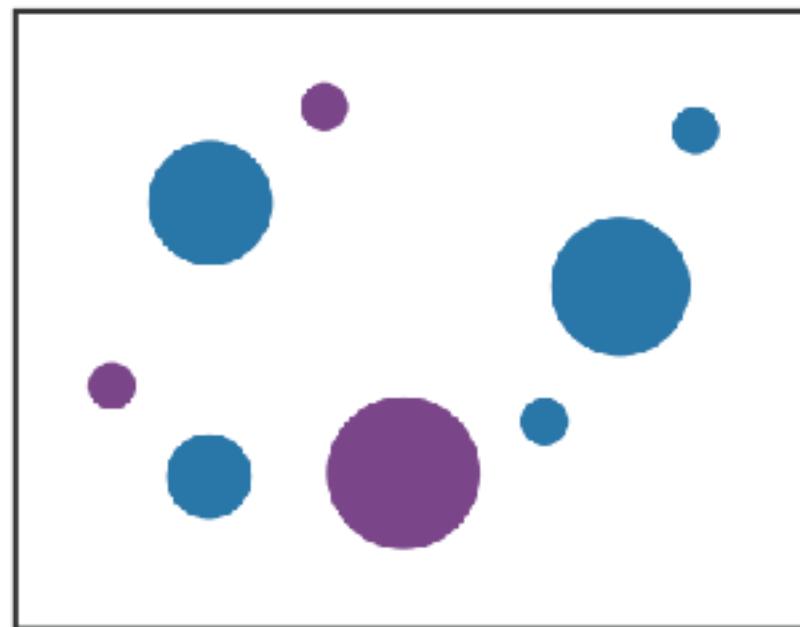
Can we combine multiple visual variables?

Position  
+ Hue (Color)



Fully separable

Size  
+ Hue (Color)



Some interference

Width  
+ Height



Some/significant  
interference

Red  
+ Green



Major interference