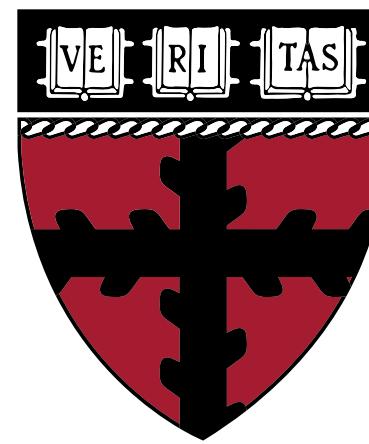


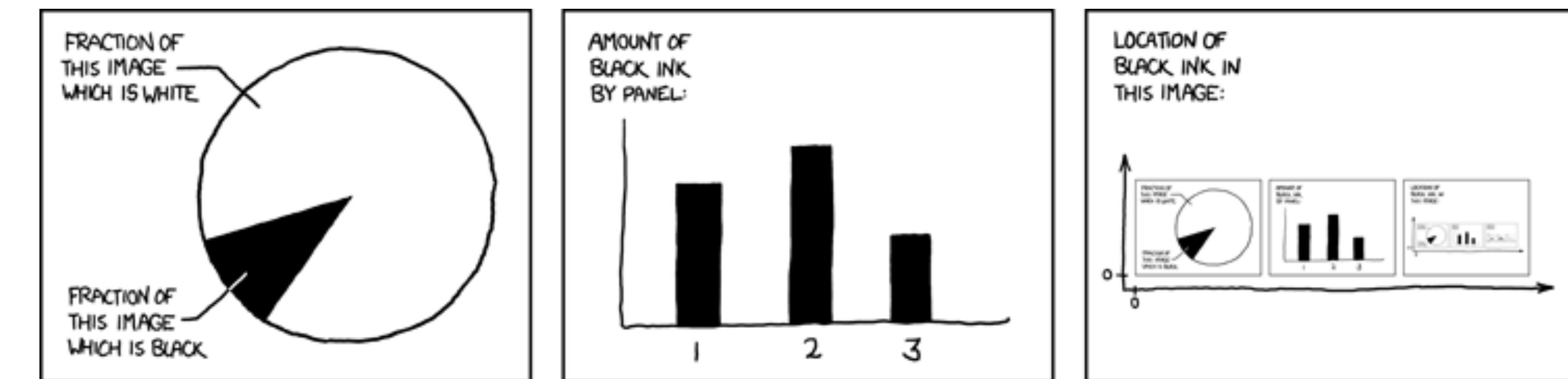
CS171 Visualization

Alexander Lex
alex@seas.harvard.edu

The Visualization Alphabet: Marks and Channels



HARVARD
School of Engineering
and Applied Sciences



[xkcd]

This Week

Thursday: Task Abstraction, Validation

Homework 1 due on Friday!

Any more problems with private GitHub repositories?

Later today: Introduction to HW 2

Reading: D3, Chapter 12; VAD, Chapters 3&4

Next Week

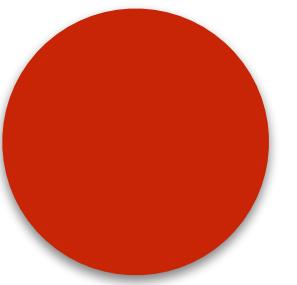
Lecture 7: Homework 2 Design Studio

Lecture 8: Interaction

Guest Lecture, Jean-Daniel Fekete (INRIA)

Sections: D3 & JS: Data Structures, Layouts

No Device Policy



No Computers, Tablets, Phones in lecture hall

except when used for exercises

Switch off, mute, flight mode

Why?

It's better to take notes by hand

Notifications are designed to grab your attention

Last Week

Terms

Dataset Types

what can be visualized?

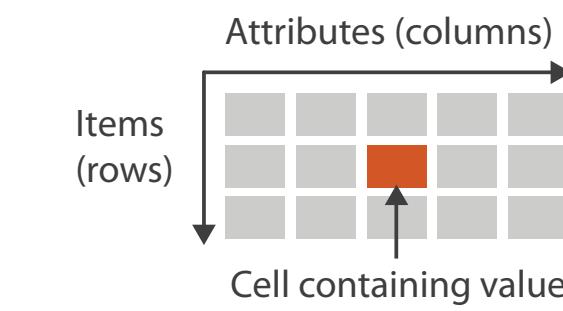
Data Types

fundamental units

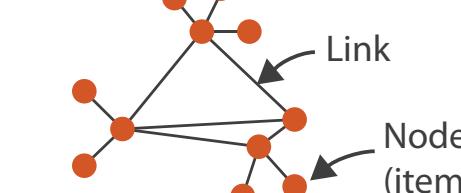
combinations make up Dataset Types

Dataset Types

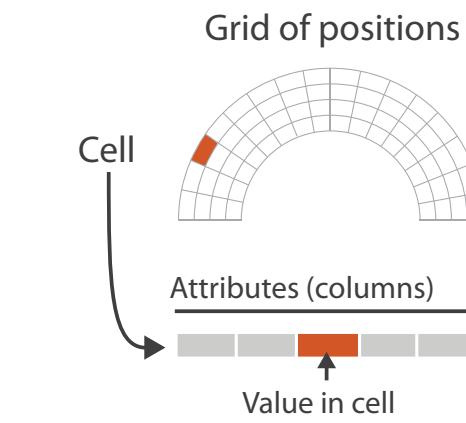
→ Tables



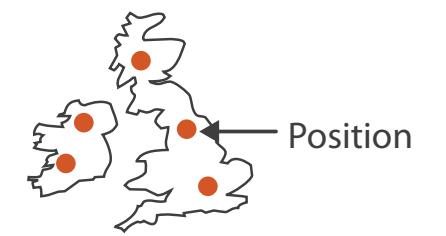
→ Networks



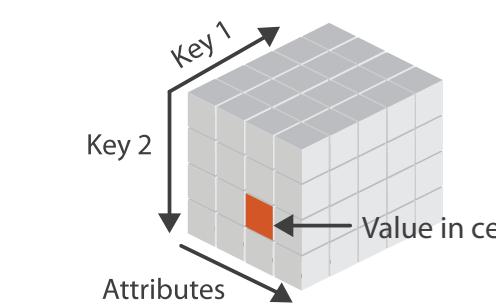
→ Fields (Continuous)



→ Geometry (Spatial)



→ Multidimensional Table



→ Trees



Data Types

→ Items

→ Attributes

→ Links

→ Positions

→ Grids

Tables

Flat Table

one item per row

each column is attribute

unique (implicit) key

no duplicates

Multidimensional Table

indexing based on multiple keys

		Attributes			
		Keys		Values	
Item	ID	Name	Age	Shirt Size	Favorite Fruit
	1	Amy	8	S	Apple
2	Basil		7	S	Pear
3	Clara		9	M	Durian
4	Desmond		13	L	Elderberry
5	Ernest		12	L	Peach
6	Fanny		10	S	Lychee
7	George		9	M	Orange
8	Hector		8	L	Loquat
9	Ida		10	M	Pear
10	Amy		12	M	Orange

Multidimensional Tables

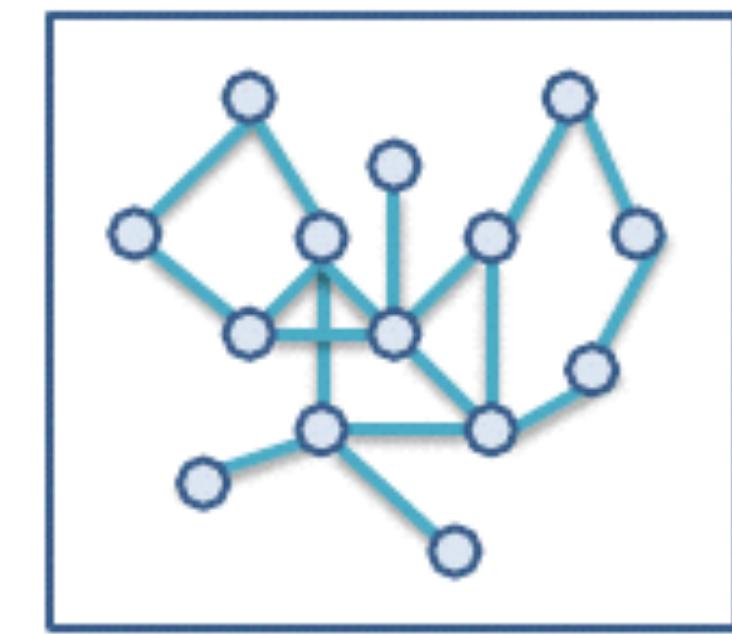
Keys: Genes

	A	B	C	D	E
1	#1.2				
2	1500	529			
3	GeneName	DESCRIPTION	TCGA-02-0001-01C-01R-0177-01	TCGA-02-0003-01A-01R-0177-01	TCGA-02-0004-01A-01R-0298-01
4	LTF	LTF	-1.265728057	2.377012066	4.123979585
5	POSTN	POSTN	2.662411805	3.932400324	5.031585377
6	TMSL8	TMSL8	-3.082217838	-2.243148513	-0.02313681
7	HLA-DQA1	HLA-DQA1	-1.739664398	4.577962344	3.127744964
8	RP11-35N6.1	RP11-35N6.1	-3.346352968	-2.895400157	-3.473035067
9	STMN2	STMN2	-2.578511106	-3.051605144	-1.729892888
10	DCX	DCX	-2.26078976	-2.529795801	-2.844966278
11	AGXT2L1	AGXT2L1	-2.639493611	-3.113204863	-0.403975027
12	IL13RA2	IL13RA2	-2.93596915	-1.873600916	2.976256911
13	SLN	SLN	-2.466718221	-2.208406749	1.025827904
14	MEOX2	MEOX2	-2.395054066	-1.062676046	1.783235317
15	COL11A1	COL11A1	1.211934832	-0.399392588	4.733608974
16	NNMT	NNMT	0.703745164	0.664082419	3.069030715
17	F13A1	F13A1	-0.224094042	2.222197544	1.171354775
18	CXCL14	CXCL14	-3.1309694	-1.395056071	2.569540659
19	MBP	MBP	-1.906390566	-2.037626447	-2.935744906
20	TF	TF	-4.334123292	-4.680680246	-2.975788866
21	KCND2	KCND2	-1.777692395	-2.100362021	-1.996306032
22	GABRB1	GABRB1	-2.214760175	-3.022654105	-3.185499425

Keys: Patients

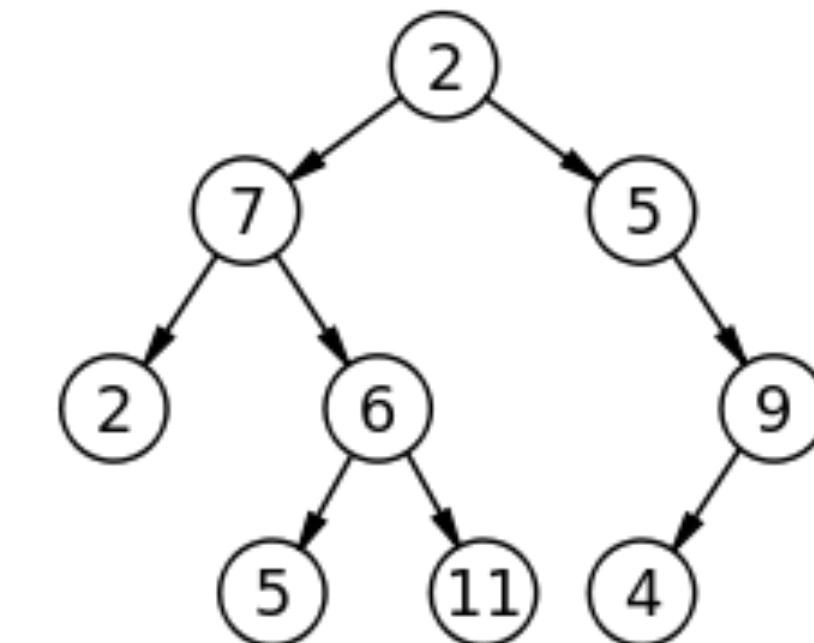
Graphs/Networks

A graph $G(V, E)$ consists of a set of **vertices (nodes)** V and a set of **edges (links)** E connecting these vertices.



Diagrammatic Example

A *tree* is a graph with *no cycles*



Fields

Attribute values associated with cells

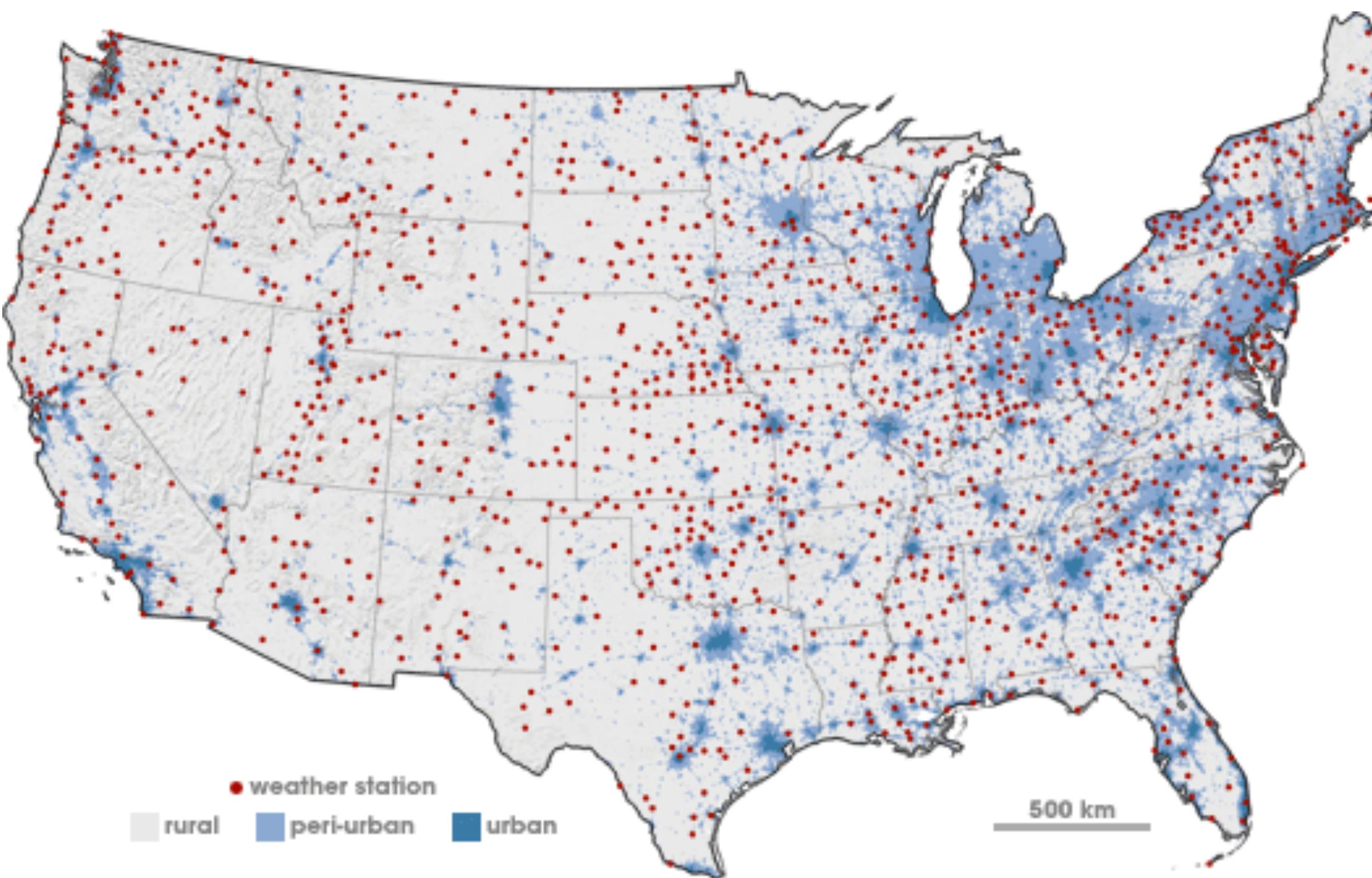
Cell contains data from continuous domain

Temperature, pressure, wind velocity

Measured or simulated

Sampling & Interpolation

Signal processing & stats



Other Collections

Sets

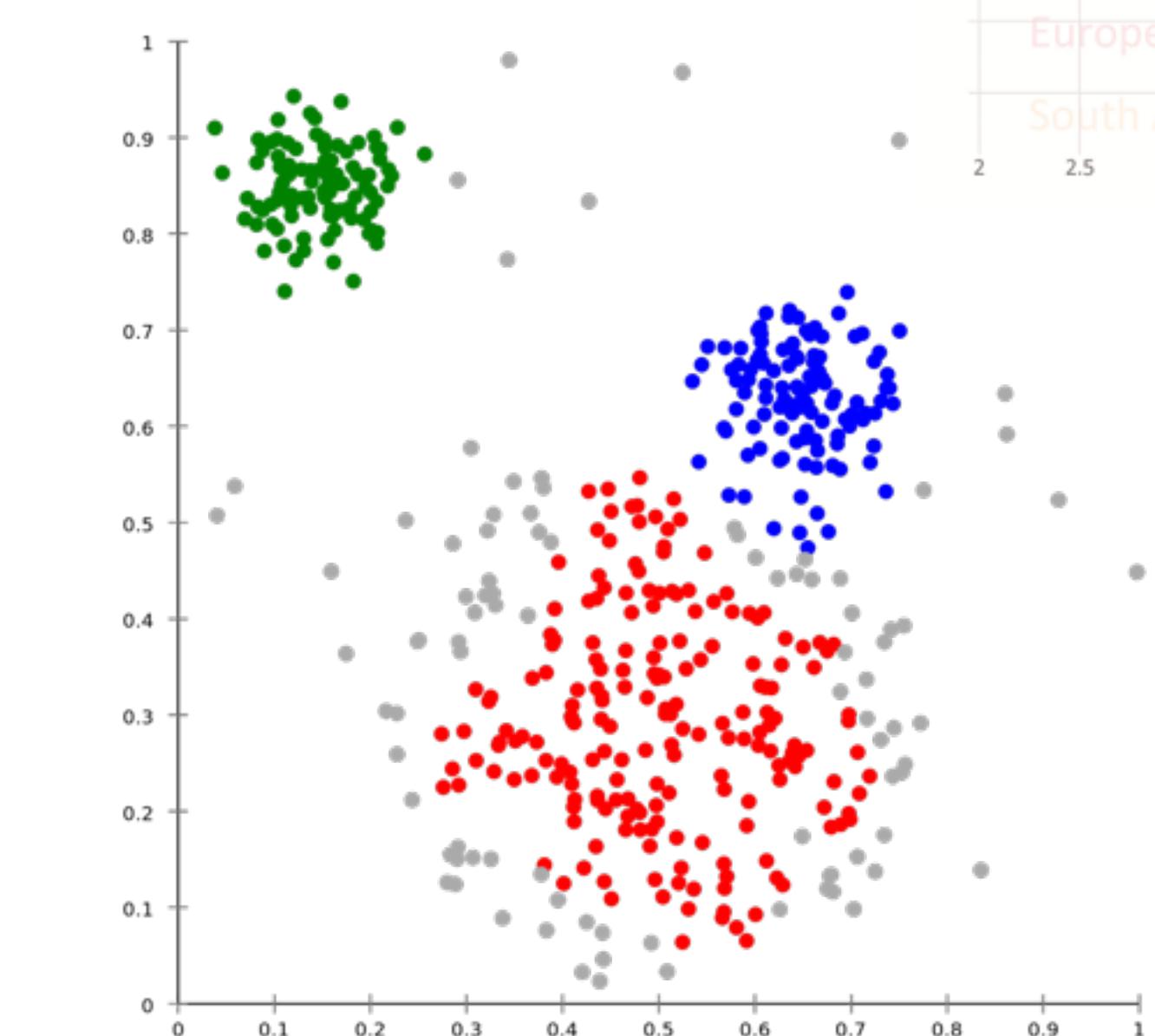
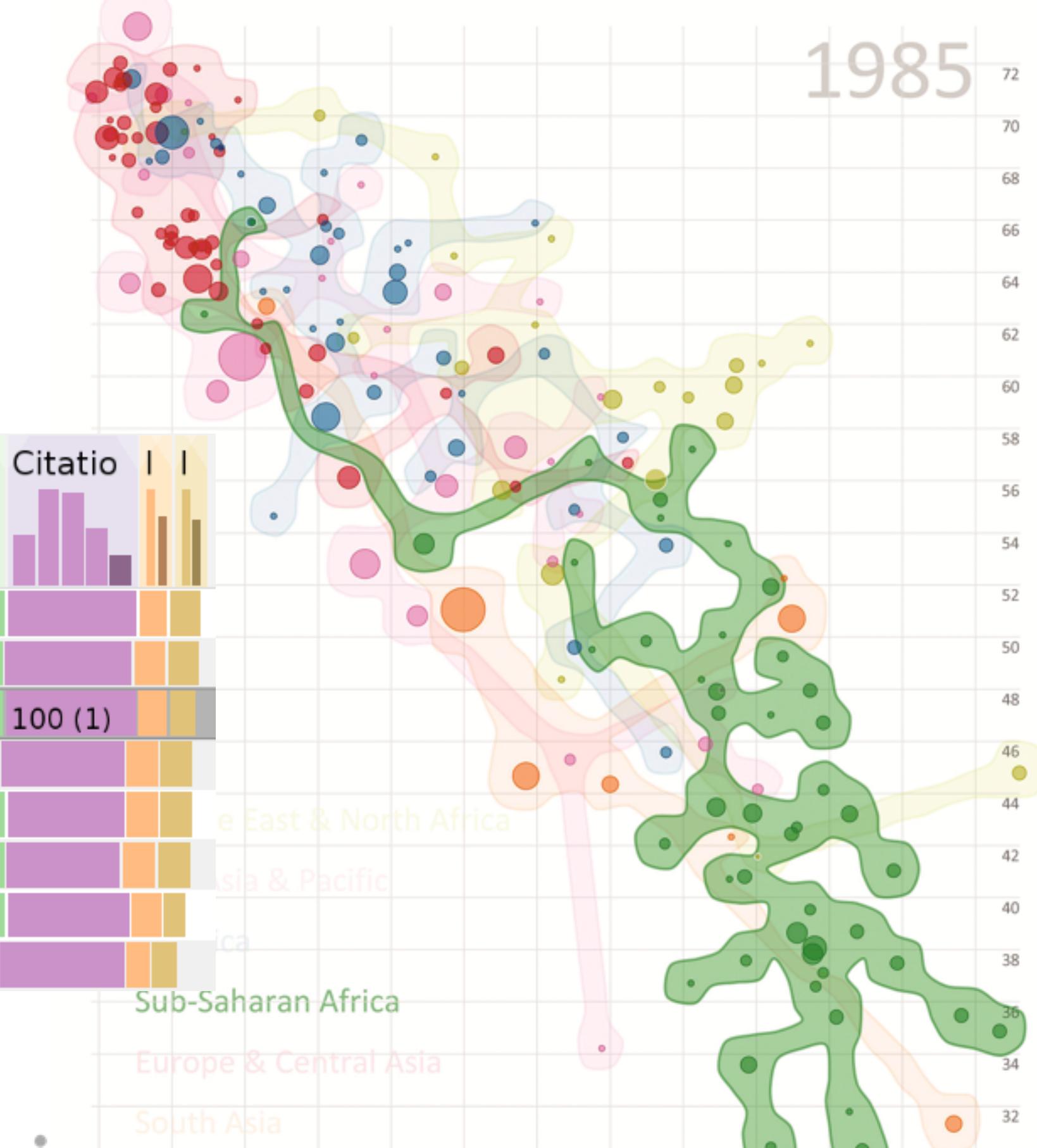
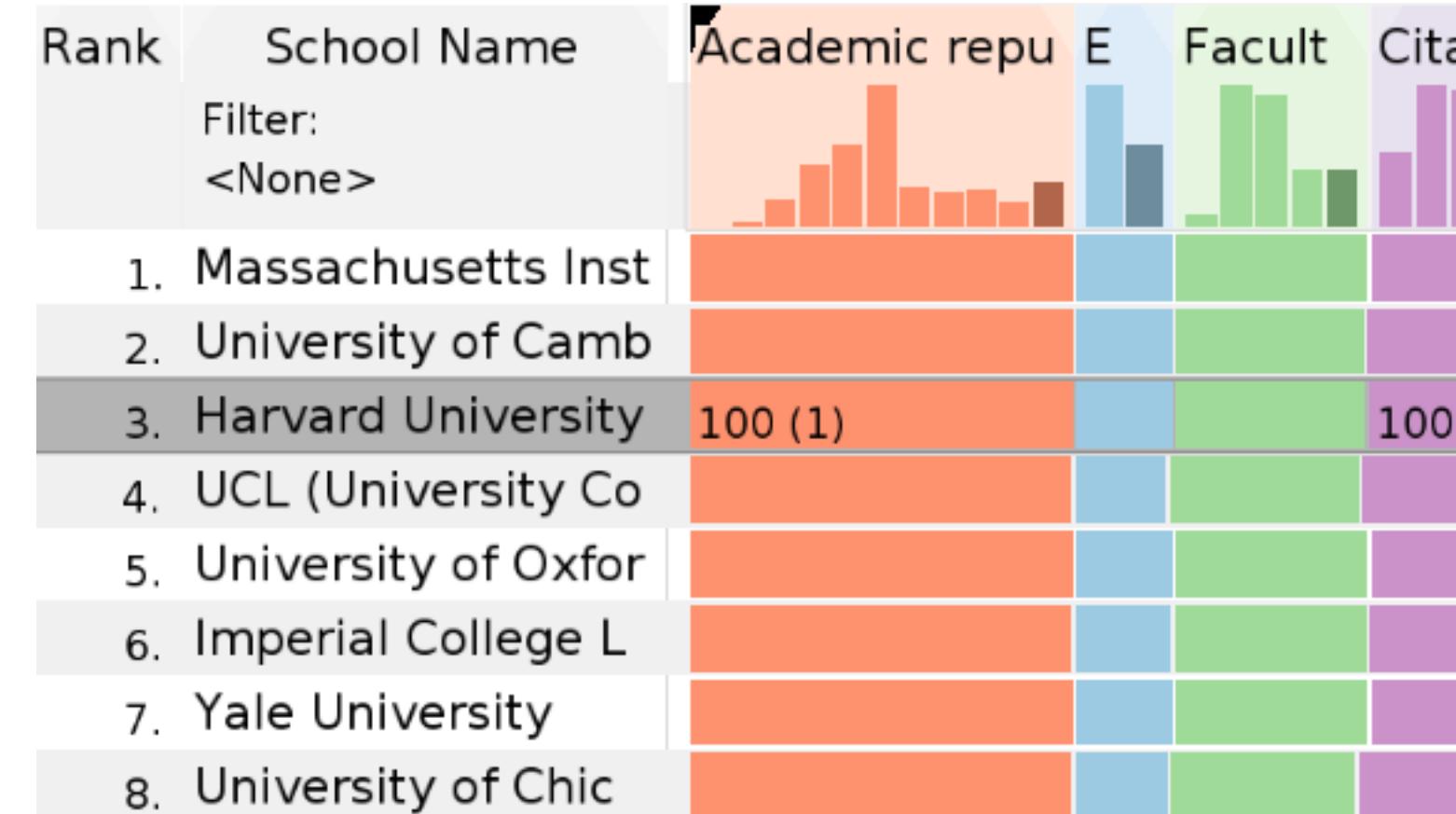
Unique items, unordered

Lists

Ordered, duplicates allowed

Clusters

Groups of similar items



Data Types

Categorical/Nominal (labels)

Operations: $=, \neq$

Ordinal (ordered)

Operations: $=, \neq, >, <$

Interval (location of zero arbitrary)

Operations: $=, \neq, >, <, +, -$ (distance)

Ratio (zero fixed)

Operations: $=, \neq, >, <, +, -, \times, \div$ (proportions)

	A	B	C	S	T	U	
1	Order ID	Order Date	Order Priority	Product Container	Product Base Margin	Ship Date	
2	3	10/14/06	5-Low	Large Box	0.8	10/21/06	
3	6	2/21/08	4-Not Specified	Small Pack	0.55	2/22/08	
4	32	7/16/07	2-High	Small Pack	0.79	7/17/07	
5	32	7/16/07	2-High	Jumbo Box	0.72	7/17/07	
6	32	7/16/07	2-High	Medium Box	0.6	7/18/07	
7	32	7/16/07	2-High	Medium Box	0.65	7/18/07	
8	35	10/23/07	4-Not Specified	Wrap Bag		10/24/07	
9	35	10/23/07	4-Not Specified	Small Box		10/25/07	
10	36	11/3/07	1-Urgent	Small Box		11/3/07	
11	65	3/18/07	1-Urgent	Small Pack		3/19/07	
12	66	1/20/05	5-Low	Wrap Bag		1/20/05	
13	69	6/4/05	4-Not Specified	Small Pack		6/6/05	
14	69	6/4/05	4-Not Specified	Wrap Bag		6/6/05	
15	70	12/18/06	5-Low	Small Box		12/23/06	
16	70	12/18/06	5-Low	Wrap Bag		12/23/06	
17	96	4/17/05	2-High	Small Box		4/19/05	
18	97	1/29/06	3-Medium	Small Box		1/30/06	
19	129	11/19/08	5-Low	Small Box		11/28/08	
20	130	5/8/08	2-High	Small Box		5/9/08	
21	130	5/8/08	2-High	Medium Box		5/10/08	
22	130	5/8/08	2-High	Small Box		5/11/08	
23	132	6/11/06	3-Medium	Medium Box		6/12/06	
24	132	6/11/06	3-Medium	Jumbo Box		6/14/06	
25	134	5/1/08	4-Not Specified	Large Box		5/3/08	
26	135	10/21/07	4-Not Specified	Small Pack		10/23/07	
27	166	9/12/07	2-High	Small Box		9/14/07	
28	193	8/8/06	1-Urgent	Medium Box		8/10/06	
29	194	4/5/08	3-Medium	Wrap Bag		4/7/08	

Item/Element/ (Independent) Variable

	A	B	C	S	T	U	
1	Order ID	Order Date	Order Priority	Product Container	Product Base Margin	Ship Date	
2	3	10/14/06	5-Low	Large Box	0.8	10/21/06	
3	6	2/21/08	4-Not Specified	Small Pack		2/22/08	
4	32	7/16/07	2-High	Small Pack		7/17/07	
5	32	7/16/07	2-High	Jumbo Box		7/17/07	
6	32	7/16/07	2-High	Medium Box		7/18/07	
7	32	7/16/07	2-High	Medium Box		7/18/07	
8	35	10/23/07	4-Not Specified	Wrap Bag		10/24/07	
9	35	10/23/07	4-Not Specified	Small Box		10/25/07	
10	36	11/3/07	1-Urgent	Small Box		11/3/07	
11	65	3/18/07	1-Urgent	Small Pack		3/19/07	
12	66	1/20/05	5-Low	Wrap Bag		1/20/05	
13	69	6/4/05	4-Not Specified	Small Pack	0.44	6/6/05	
14	69	6/4/05	4-Not Specified	Wrap Bag	0.6	6/6/05	
15	70	12/18/06	5-Low	Small Box	0.59	12/23/06	
16	70	12/18/06	5-Low	Wrap Bag	0.82	12/23/06	
17	96	4/17/05	2-High	Small Box	0.55	4/19/05	
18	97	1/29/06	3-Medium	Small Box	0.38	1/30/06	
19	129	11/19/08	5-Low	Small Box	0.37	11/28/08	
20	130	5/8/08	2-High	Small Box	0.37	5/9/08	
21	130	5/8/08	2-High	Medium Box	0.38	5/10/08	
22	130	5/8/08	2-High	Small Box	0.6	5/11/08	
23	132	6/11/06	3-Medium	Medium Box	0.6	6/12/06	
24	132	6/11/06	3-Medium	Jumbo Box	0.69	6/14/06	
25	134	5/1/08	4-Not Specified	Large Box	0.82	5/3/08	
26	135	10/21/07	4-Not Specified	Small Pack	0.64	10/23/07	
27	166	9/12/07	2-High	Small Box	0.55	9/14/07	
28	193	8/8/06	1-Urgent	Medium Box	0.57	8/10/06	
29	194	4/5/08	3-Medium	Wrap Bag	0.42	4/7/08	

	A	B	C	S	T	U
1	Order ID	Order Date	Order Priority	Product Container	Product Base Margin	Ship Date
2	3	10/14/06	5-Low	Large Box	0.9	10/21/06
3	6	2/21/08	4-Not Specified	Small Pack	0.5	2/22/08
4	32	7/16/07	2-High	Small Pack	0.9	7/17/07
5	32	7/16/07	2-High	Jumbo Box	0.72	7/17/07
6	32	7/16/07	2-High	Medium Box	0.6	7/18/07
7	32	7/16/07	2-High	Medium Box	0.65	7/18/07
8	35	10/23/07	4-Not Specified	Wrap Bag	0.52	10/24/07
9	35	10/23/07	4-Not Specified	Small Box	0.58	10/25/07
10	36	11/3/07	1-Urgent	Small Box	0.55	11/3/07
11	65	3/18/07	1-Urgent	Small Pack	0.49	3/19/07
12	66	1/20/05	5-Low	Wrap Bag	0.56	1/20/05
13	69	6/4/05	4-Not Specified	Small Pack	0.44	6/6/05
14	69	6/4/05	4-Not Specified	Wrap Bag	0.6	6/6/05
15	70	12/18/06	5-Low	Small Box	0.59	12/23/06
16	70	12/18/06	5-Low	Wrap Bag	0.82	12/23/06
17	96	4/17/05	2-High	Small Box	0.55	4/19/05
18	97	1/29/06	3-Medium	Small Box	0.38	1/30/06
19	129	11/19/08	5-Low	Small Box	0.37	11/28/08
20	130	5/8/08	2-High	Small Box	0.37	5/9/08
21	130	5/8/08	2-High	Medium Box	0.38	5/10/08
22	130	5/8/08	2-High	Small Box	0.6	5/11/08
23	132	6/11/06	3-Medium	Medium Box	0.6	6/12/06
24	132	6/11/06	3-Medium	Jumbo Box	0.69	6/14/06
25	134	5/1/08	4-Not Specified	Large Box	0.82	5/3/08
26	135	10/21/07	4-Not Specified	Small Pack	0.64	10/23/07
27	166	9/12/07	2-High	Small Box	0.55	9/14/07
28	193	8/8/06	1-Urgent	Medium Box	0.57	8/10/06
29	194	4/5/08	3-Medium	Wrap Bag	0.42	4/7/08

	A	B	C	S	T	U	
1	Order ID	Order Date	Order Priority	Product Container	Product Base Margin	Ship Date	
2	3	10/14/06	5-Low	Large Box	0.8	10/21/06	
3	6	2/21/08	4-Not Specified	Small Pack	0.55	2/22/08	
4	32	7/16/07	2-High	Small Pack	0.79	7/17/07	
5	32	7/16/07	2-High	Jumbo Box	0.72	7/17/07	
6	32	7/16/07	2-High	Medium Box	0.6	7/18/07	
7	32	7/16/07	2-High	Medium Box		7/18/07	
8	35	10/23/07	4-Not Specified	Wrap Bag		10/24/07	
9	35	10/23/07	4-Not Specified	Small Box	0.58	10/25/07	
10	36	11/3/07	1-Urgent	Small Box	0.55	11/3/07	
11	65	3/18/07	1-Urgent	Small Pack	0.49	3/19/07	
12	66	1/20/05	5-Low	Wrap Bag	0.56	1/20/05	
13	69	6/4/05	4-Not Specified	Small Pack	0.44	6/6/05	
14	69	6/4/05	4-Not Specified	Wrap Bag	0.6	6/6/05	
15	70	12/18/06	5-Low	Small Box	0.59	12/23/06	
16	70	12/18/06	5-Low	Wrap Bag	0.82	12/23/06	
17	96	4/17/05	2-High	Small Box	0.55	4/19/05	
18	97	1/29/06	3-Medium	Small Box	0.38	1/30/06	
19	129	11/19/08	5-Low	Small Box	0.37	11/28/08	
20	130	5/8/08	2-High	Small Box	0.37	5/9/08	
21	130	5/8/08	2-High	Medium Box	0.38	5/10/08	
22	130	5/8/08	2-High	Small Box	0.6	5/11/08	
23	132	6/11/06	3-Medium	Medium Box	0.6	6/12/06	
24	132	6/11/06	3-Medium	Jumbo Box	0.69	6/14/06	
25	134	5/1/08	4-Not Specified	Large Box	0.82	5/3/08	
26	135	10/21/07	4-Not Specified	Small Pack	0.64	10/23/07	
27	166	9/12/07	2-High	Small Box	0.55	9/14/07	
28	193	8/8/06	1-Urgent	Medium Box	0.57	8/10/06	
29	194	4/5/08	3-Medium	Wrap Bag	0.42	4/7/08	

	A	B	C	S	T	U	
1	Order ID	Order Date	Order Priority	Product Container	Product Base Margin	Ship Date	
2	3	10/14/06	5-Low	Large Box	0.8	10/21/06	
3	6	2/21/08	4-Not Specified	Small Pack	0.55	2/22/08	
4	32	7/16/07	2-High	Small Pack	0.79	7/17/07	
5	32	7/16/07	2-High	Jumbo Box	0.72	7/17/07	
6	32	7/16/07	2-High	Medium Box	0.6	7/18/07	
7	32	7/16/07	2-High	Medium Box	0.65	7/18/07	
8	35	10/23/07	4-Not Specified	Wrap Bag	0.52	10/24/07	
9	35	10/23/07	4-Not Specified	Small Box	0.58	10/25/07	
10	36	11/3/07	1-Urgent	Small Box	0.55	11/3/07	
11	65	3/18/07	1-Urgent	Small Pack	0.49	3/19/07	
12	66	1/20/05	5-Low	Wrap Bag	0.56	1/20/05	
13	69	6/4/05	4-Not Specified	Small Pack	0.44	6/6/05	
14	69	6/4/05	4-Not Specified	Wrap Bag	0.6	6/6/05	
15	70	12/18/06	5-Low	Small Box	0.59	12/23/06	
16	70	12/18/06	5-Low	Wrap Bag	0.82	12/23/06	
17	96	4/17/05	2-High	Small Box	0.55	4/19/05	
18	97	1/29/06	3-Medium	Small Box	0.38	1/30/06	
19	129	11/19/08	5-Low	Small Box	0.37	11/28/08	
20	130	5/8/08	2-High	Small Box	0.37	5/9/08	
21	130	5/8/08	2-High	Medium Box	0.38	5/10/08	
22	130	5/8/08	2-High	Small Box		5/11/08	
23	132	6/11/06	3-Medium	Medium Box		6/12/06	
24	132	6/11/06	3-Medium	Jumbo Box		6/14/06	
25	134	5/1/08	4-Not Specified	Large Box		5/3/08	
26	135	10/21/07	4-Not Specified	Small Pack		10/23/07	
27	166	9/12/07	2-High	Small Box	0.55	9/14/07	
28	193	8/8/06	1-Urgent	Medium Box	0.57	8/10/06	
29	194	4/5/08	3-Medium	Wrap Bag	0.42	4/7/08	

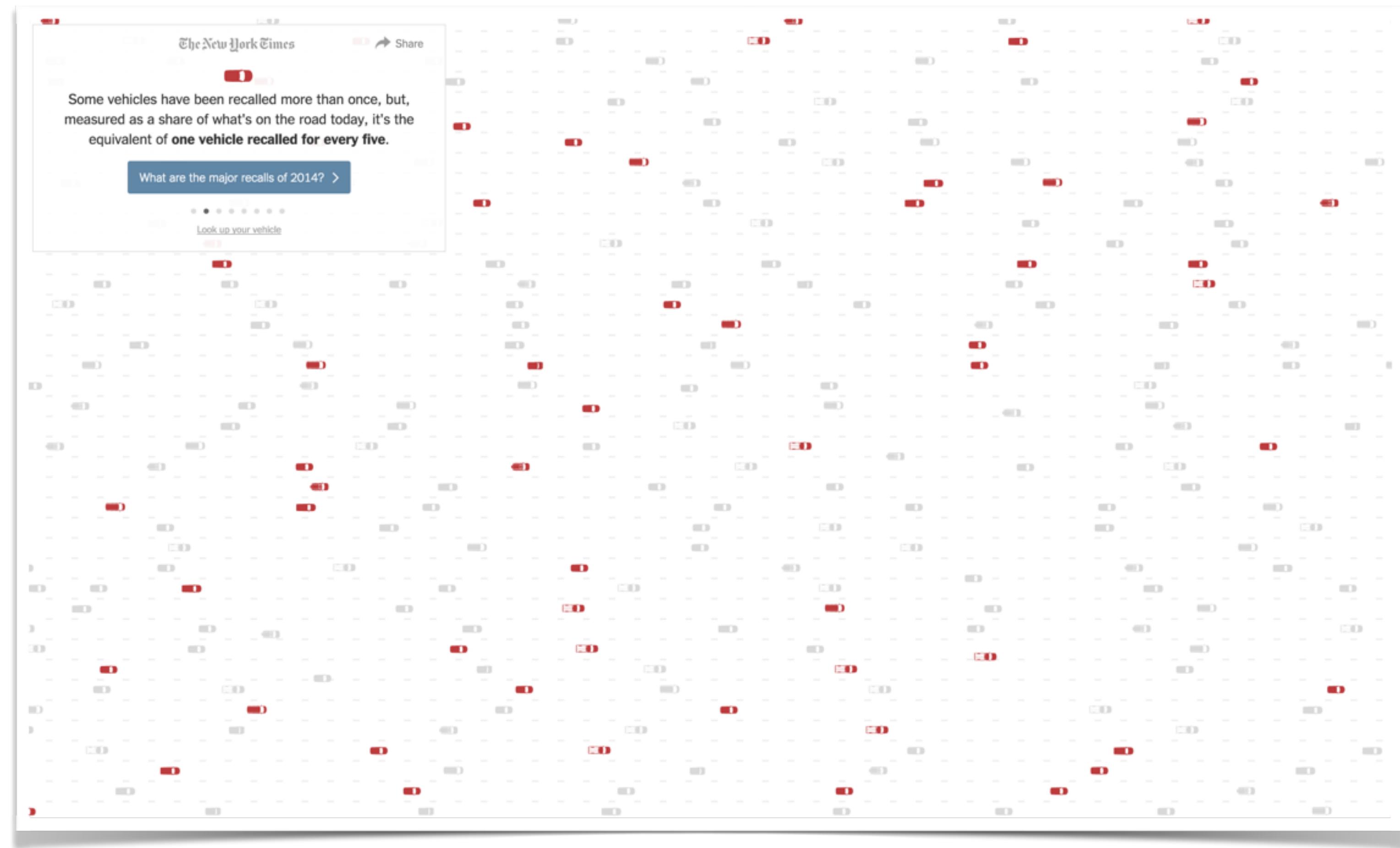
Attribute Types?

◆	A	B	C	S	T	U
1	Order ID	Order Date	Order Priority	Product Container	Product Base Margin	Ship Date
2	3	10/14/06	5-Low	Large Box	0.8	10/21/06
3	6	2/21/08	4-Not Specified	Small Pack	0.55	2/22/08
4	32	7/16/07	2-High	Small Pack	0.79	7/17/07
5	32	7/16/07	2-High	Jumbo Box	0.72	7/17/07
6	32	7/16/07	2-High	Medium Box	0.6	7/18/07
7	32	7/16/07	2-High	Medium Box	0.65	7/18/07
8	35	10/23/07	4-Not Specified	Wrap Bag	0.52	10/24/07
9	35	10/23/07	4-Not Specified	Small Box	0.58	10/25/07
10	36	11/3/07	1-Urgent	Small Box	0.55	11/3/07
11	65	3/18/07	1-Urgent	Small Pack	0.49	3/19/07
12	66	1/20/05	5-Low	Wrap Bag	0.56	1/20/05
13	69	6/4/05	4-Not Specified	Small Pack	0.44	6/6/05
14	69	6/4/05	4-Not Specified	Wrap Bag	0.6	6/6/05
15	70	12/18/06	5-Low	Small Box	0.59	12/23/06
16	70	12/18/06	5-Low	Wrap Bag	0.82	12/23/06
17	96	4/17/05	2-High	Small Box	0.55	4/19/05
18	97	1/29/06	3-Medium	Small Box	0.38	1/30/06
19	129	11/19/08	5-Low	Small Box	0.37	11/28/08
20	130	5/8/08	2-High	Small Box	0.37	5/9/08
21	130	5/8/08	2-High	Medium Box	0.38	5/10/08
22	130	5/8/08	2-High	Small Box	0.6	5/11/08
23	132	6/11/06	3-Medium	Medium Box		
24	132	6/11/06	3-Medium	Jumbo Box		
25	134	5/1/08	4-Not Specified	Large Box		
26	135	10/21/07	4-Not Specified	Small Pack		
27	166	9/12/07	2-High	Small Box		
28	193	8/8/06	1-Urgent	Medium Box		
29	194	4/5/08	3-Medium	Wrap Bag		
30	194	4/5/08	3-Medium	Wrap Bag		

Categorical
Ordinal
Quantitative

Design Critique

Recalled Cars NY Times



<http://goo.gl/82tE6b>

The Visualization Alphabet: Marks and Channels

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

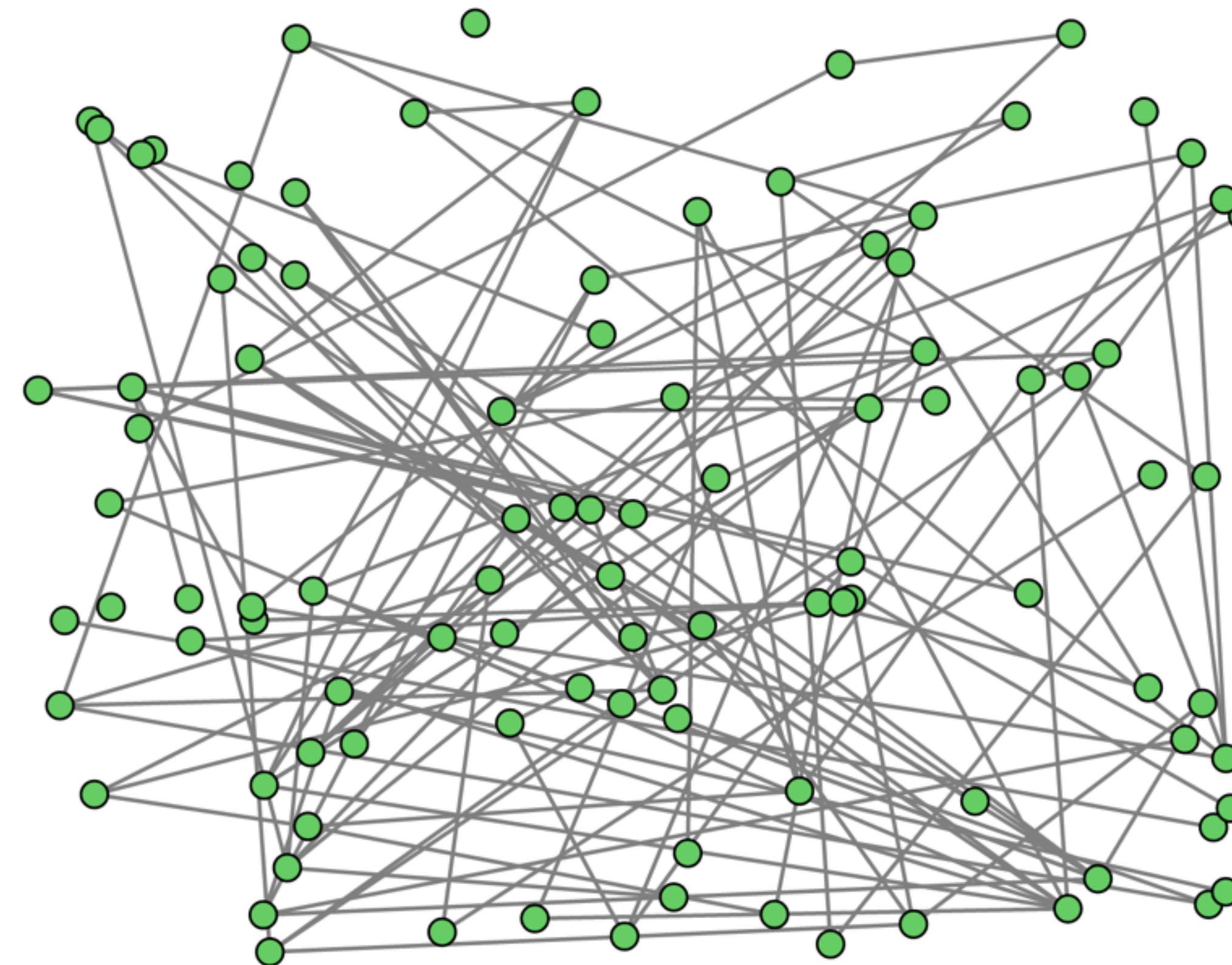
Marks & Channels

Marks: represent items or links

Channels: change appearance based on **attribute**

Channel = Visual Variable

Example: Homework 2



Marks for Items

Basic geometric elements

→ Points



0D

→ Lines



1D

→ Areas

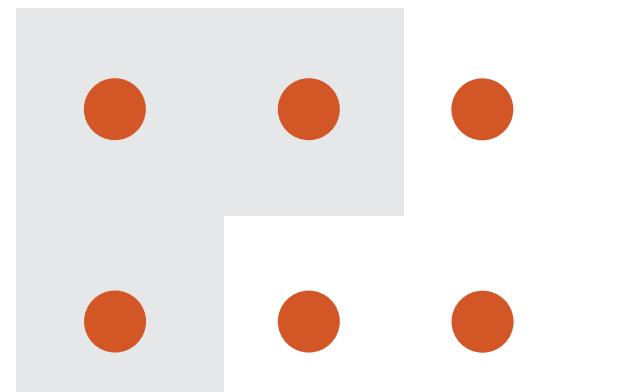


2D

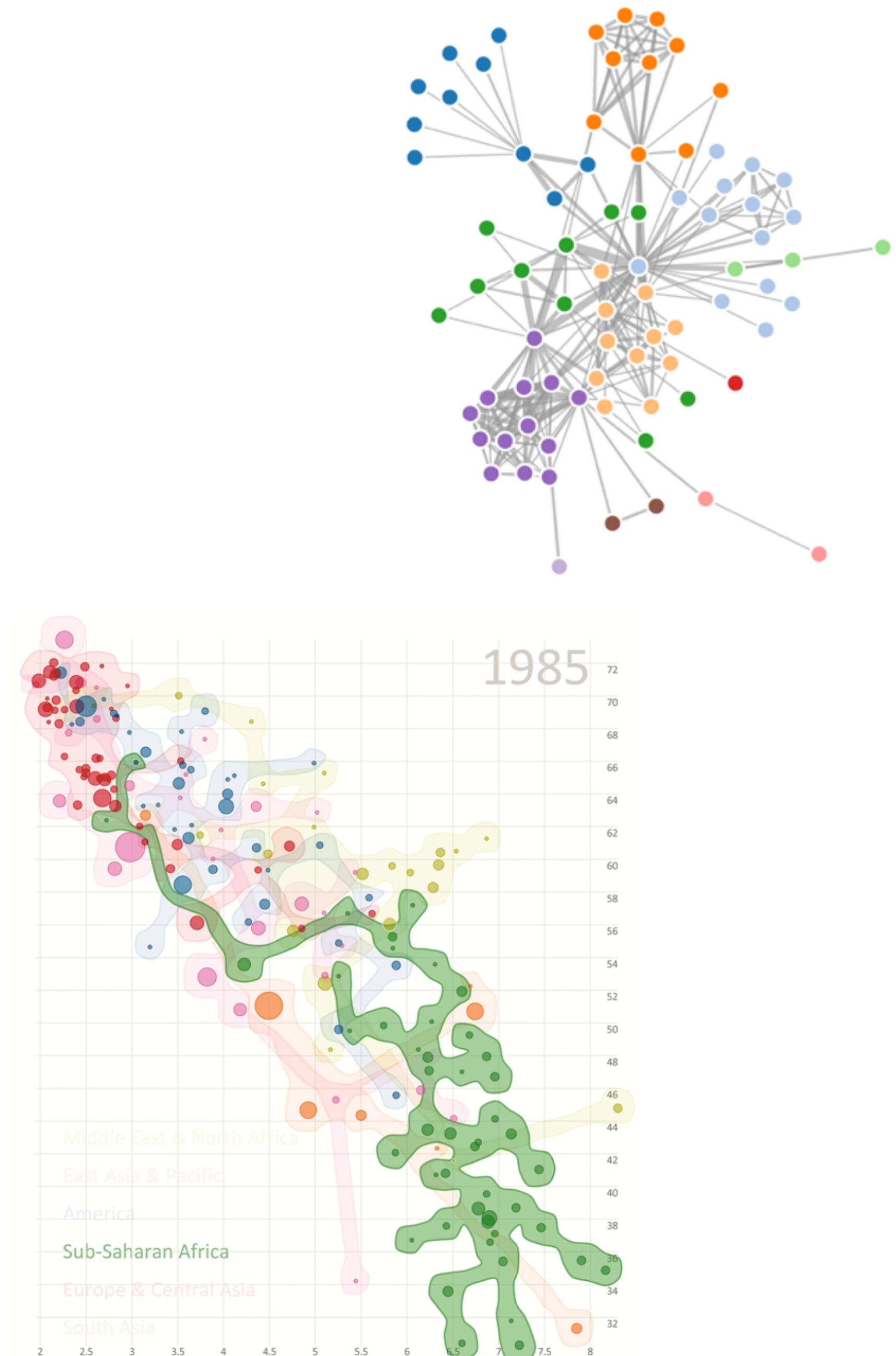
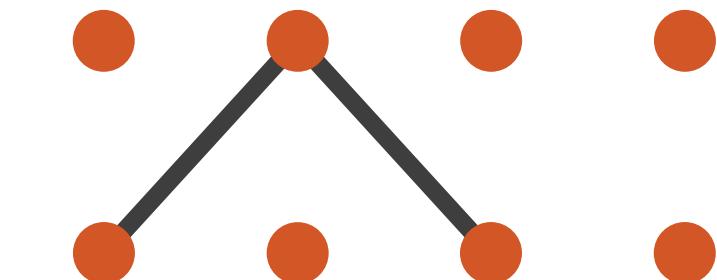
3D mark: Volume, but rarely used

Marks for Links

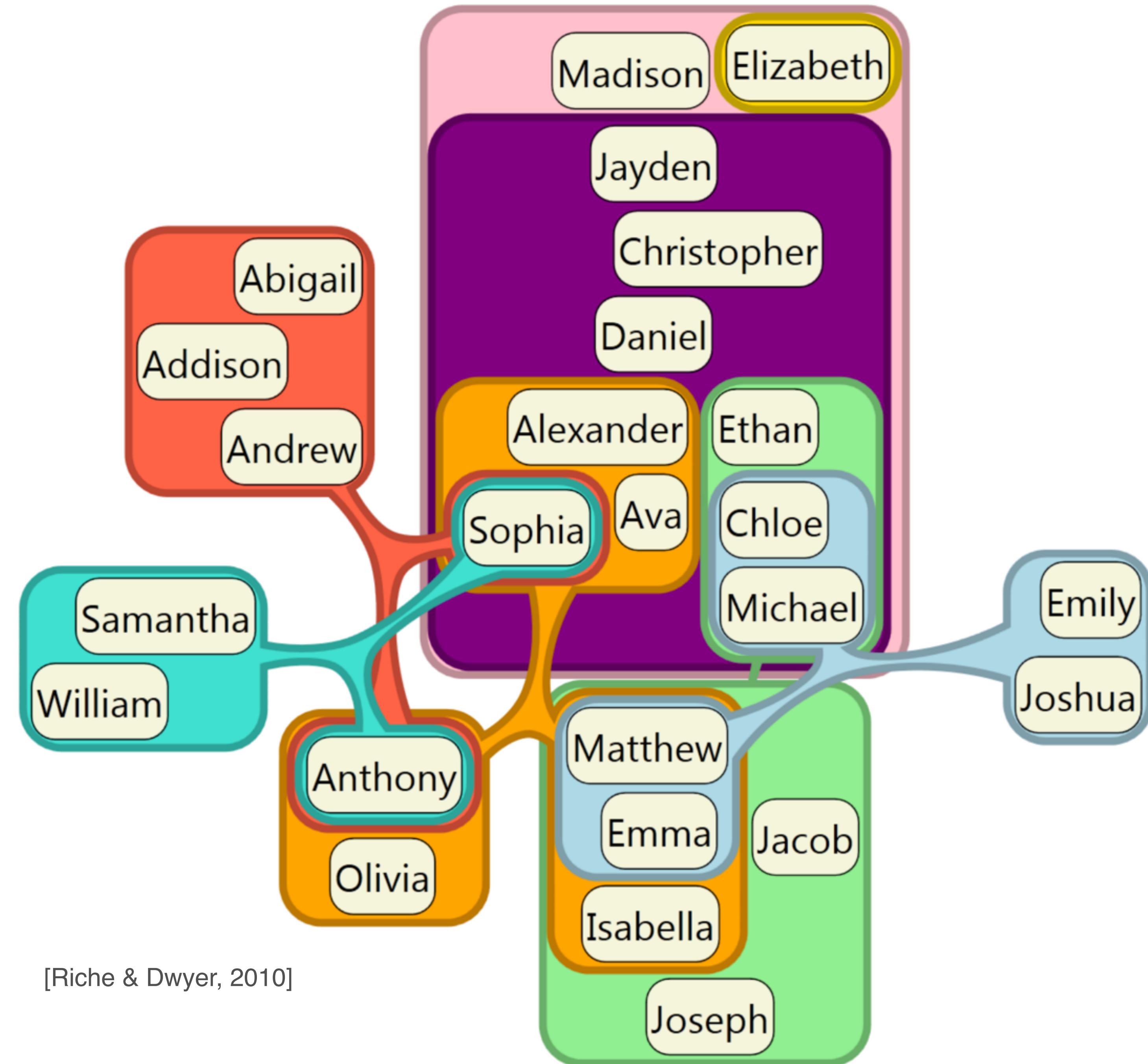
→ Containment



→ Connection



Containment can be nested



Channels (aka Visual Variables)

Control appearance
proportional to or
based on attributes

④ Position

→ Horizontal



→ Vertical



→ Both



④ Color



④ Shape



④ Tilt



④ Size

→ Length



→ Area



→ Volume



Jacques Bertin

French cartographer
[1918-2010]

Semiology of Graphics [1967]

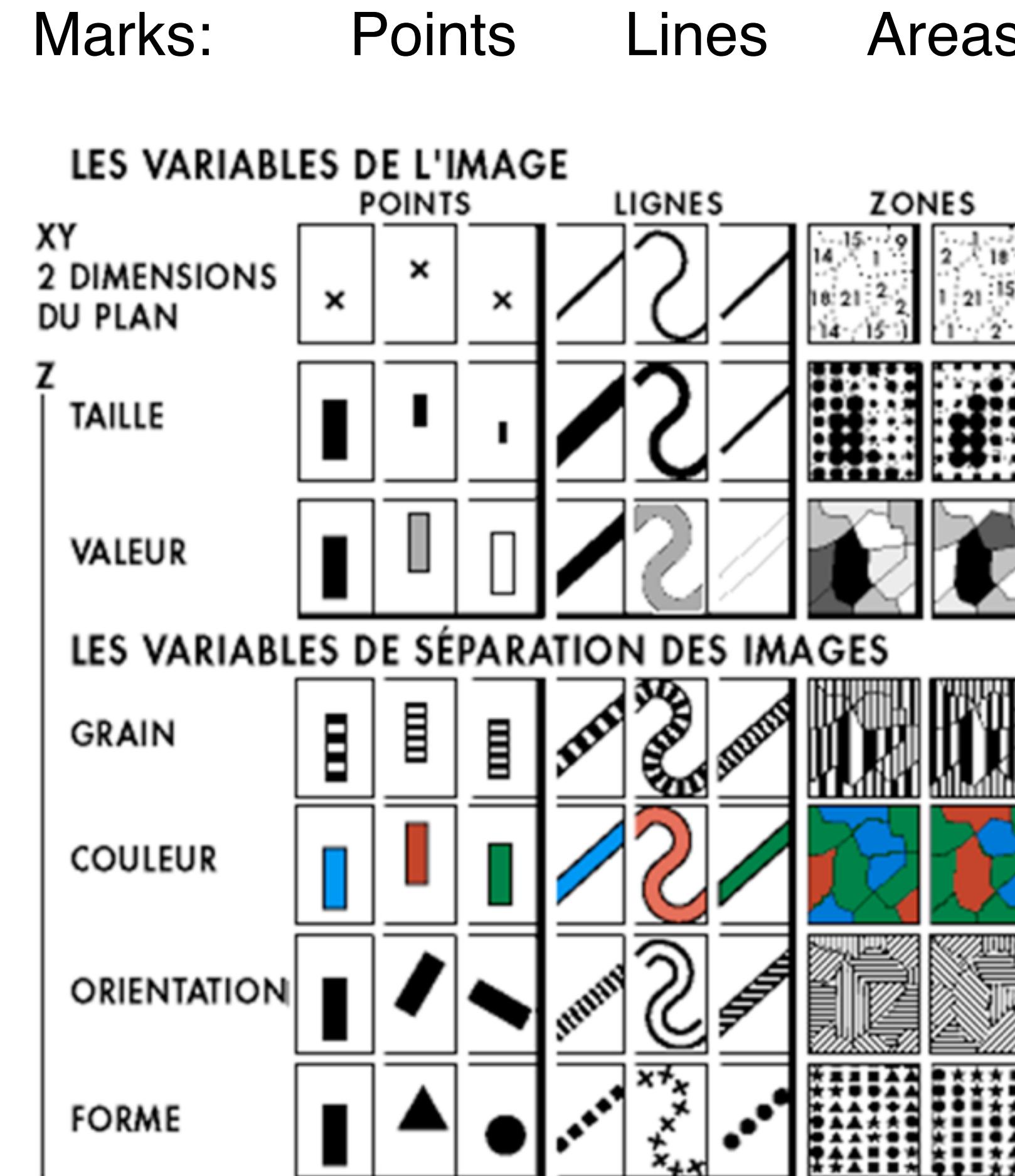
Theoretical principles for visual
encodings



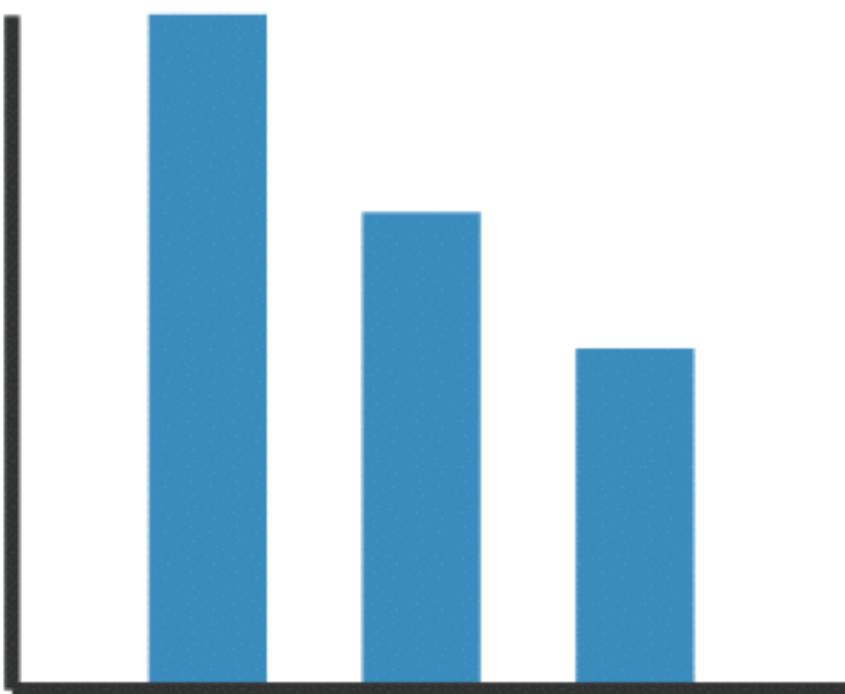
Bertin's Visual Variables

Position
Size
(Grey)Value

Texture
Color
Orientation
Shape



Using Marks and Channels

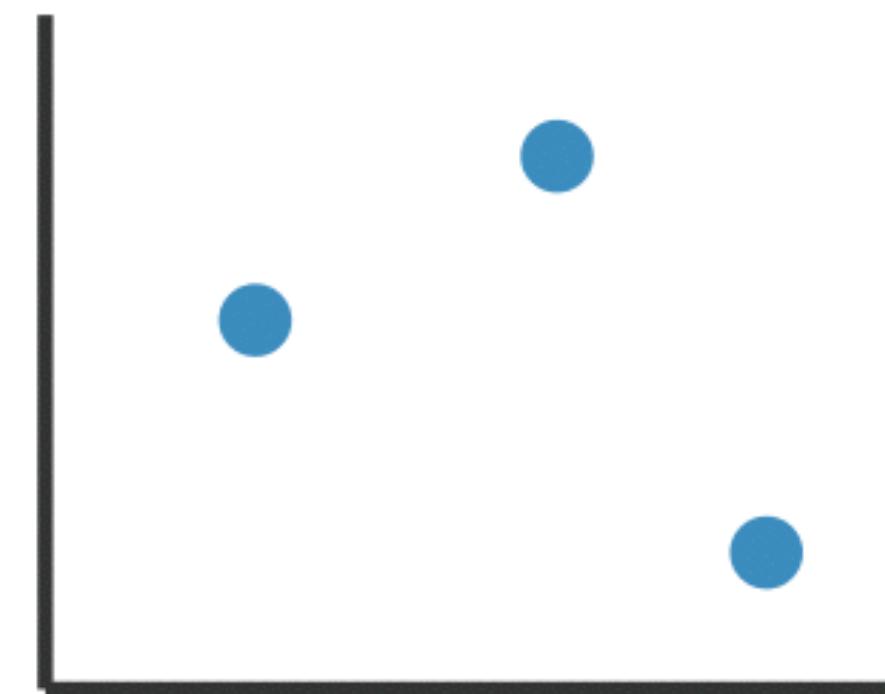


Mark: Line

Channel: Length/Position

1 quantitative attribute

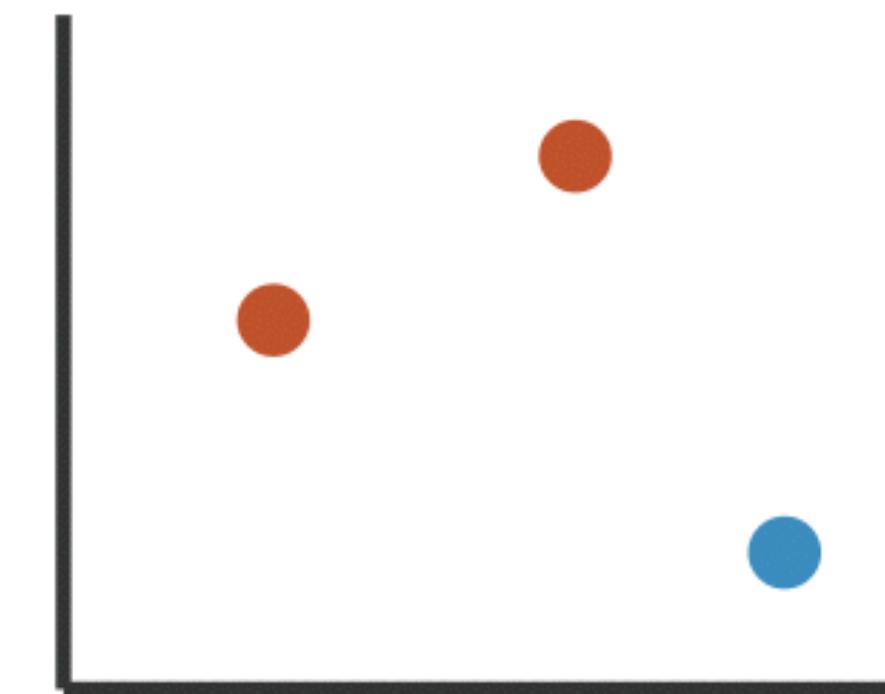
1 categorical attribute



Mark: Point

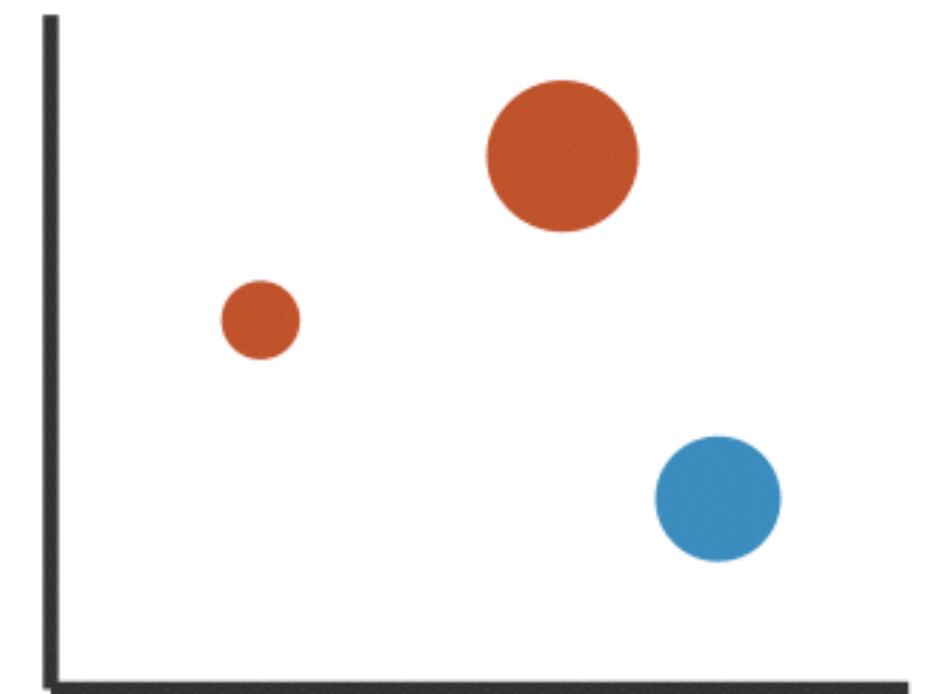
Channel: Position

2 quantitative attr.



Adding Hue

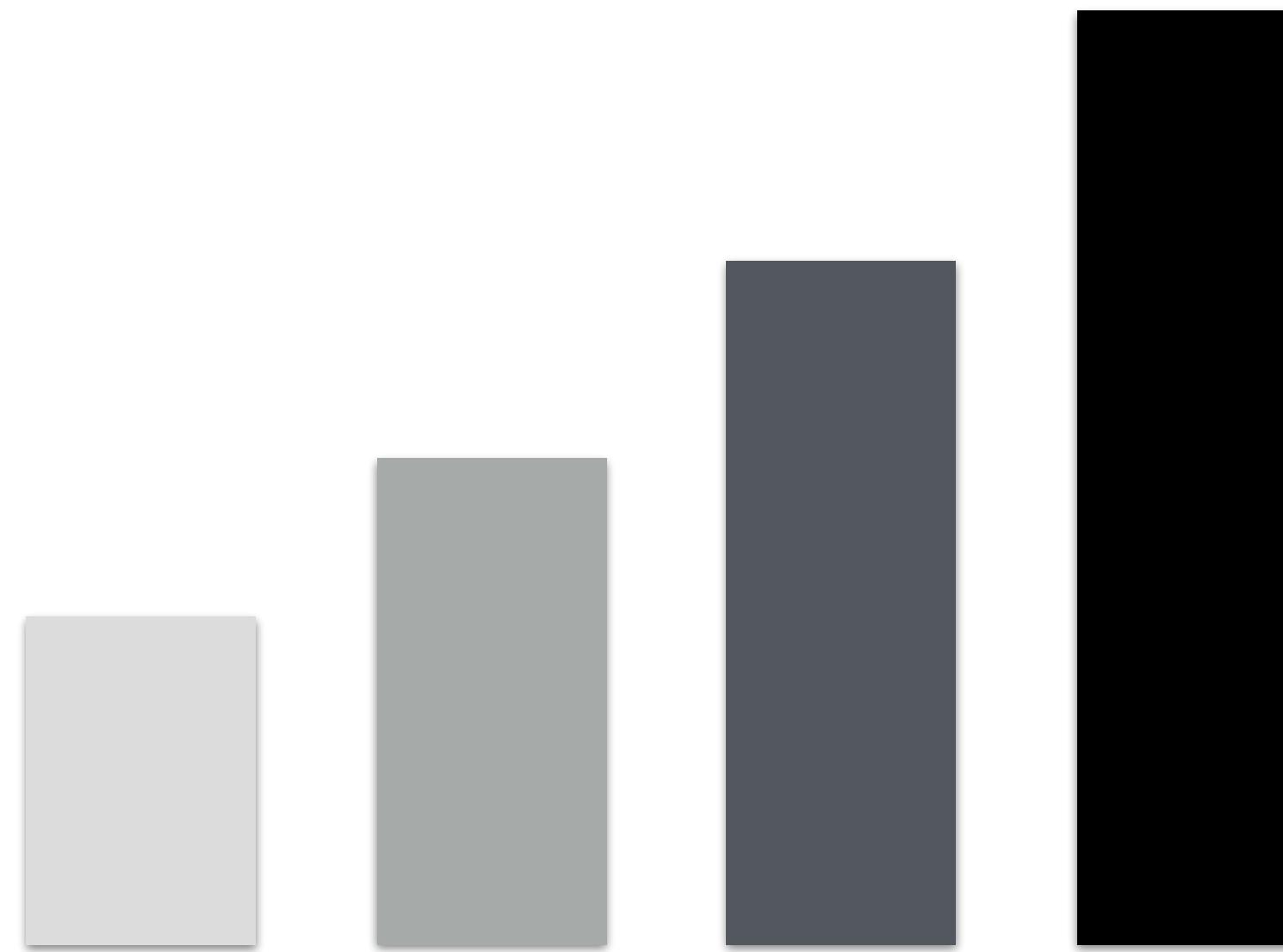
+1 categorical attr.



Adding Size

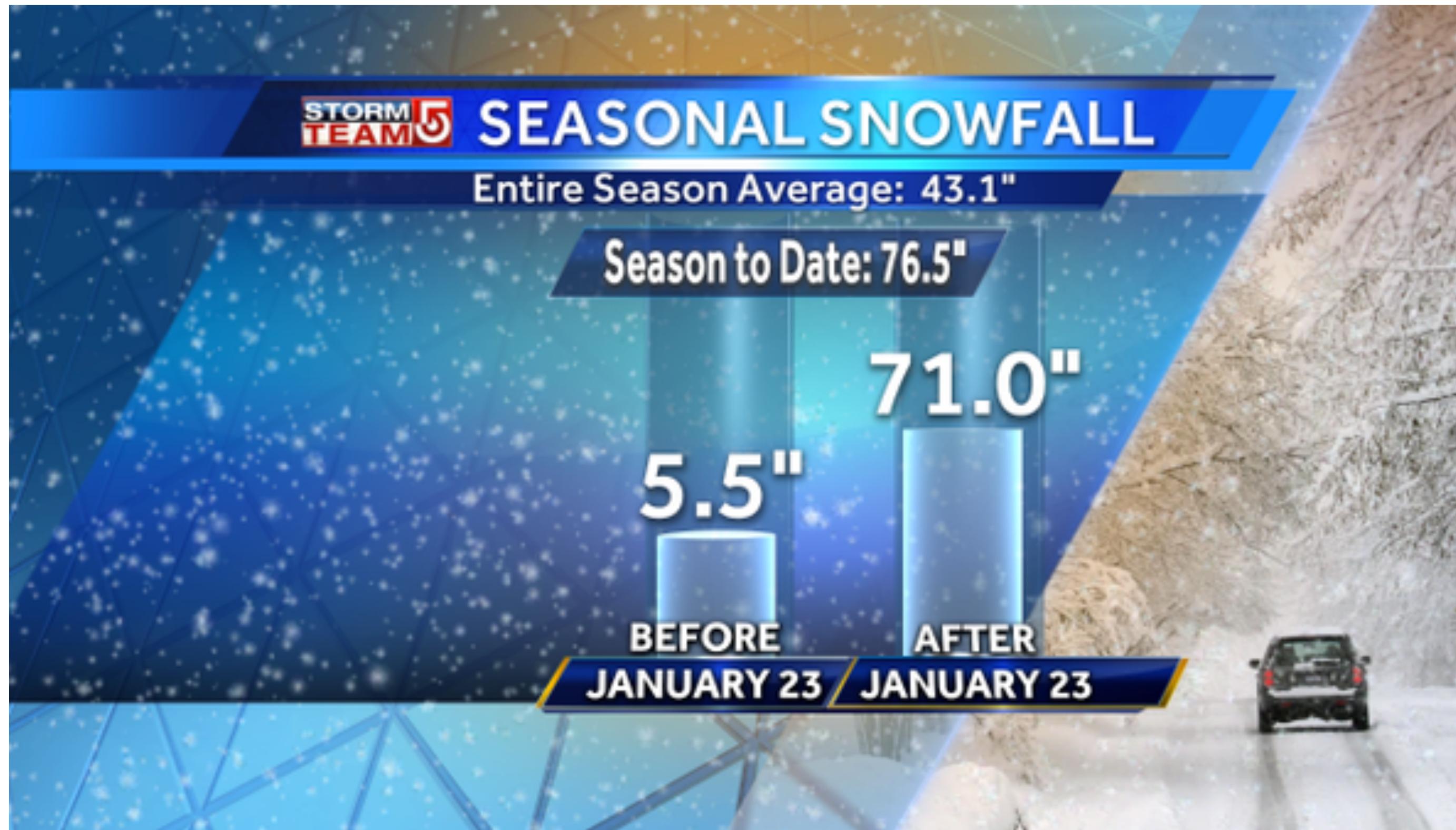
+1 quantitative attr.

Redundant encoding



Length, Position and Value

Good bar chart?



Rule: Use channel proportional to data!

Types of Channels

Magnitude Channels

How much?

Position

Length

Saturation ...

Identity Channels

What? Where?

Shape

Color (hue)

Spatial region ...

Ordinal & Quantitative Data

Categorical Data

Channels: Expressiveness Types and Effectiveness Ranks

→ Magnitude Channels: Ordered Attributes

Position on common scale



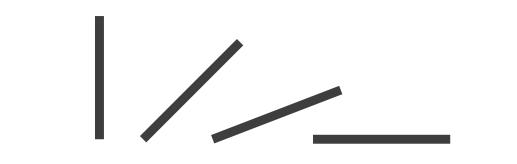
Position on unaligned scale



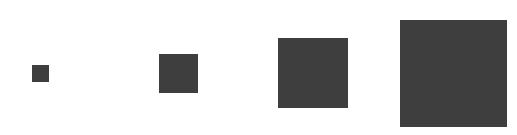
Length (1D size)



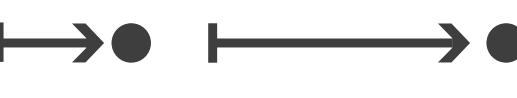
Tilt angle



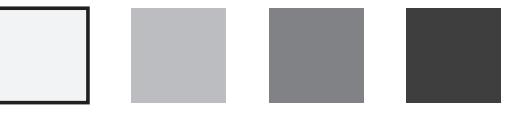
Area (2D size)



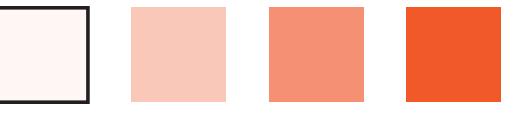
Depth (3D position)



Color luminance



Color saturation



Curvature



Volume (3D size)



Effectiveness ↑
Same
Least ↓

→ Identity Channels: Categorical Attributes

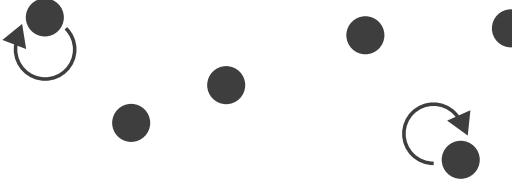
Spatial region



Color hue



Motion



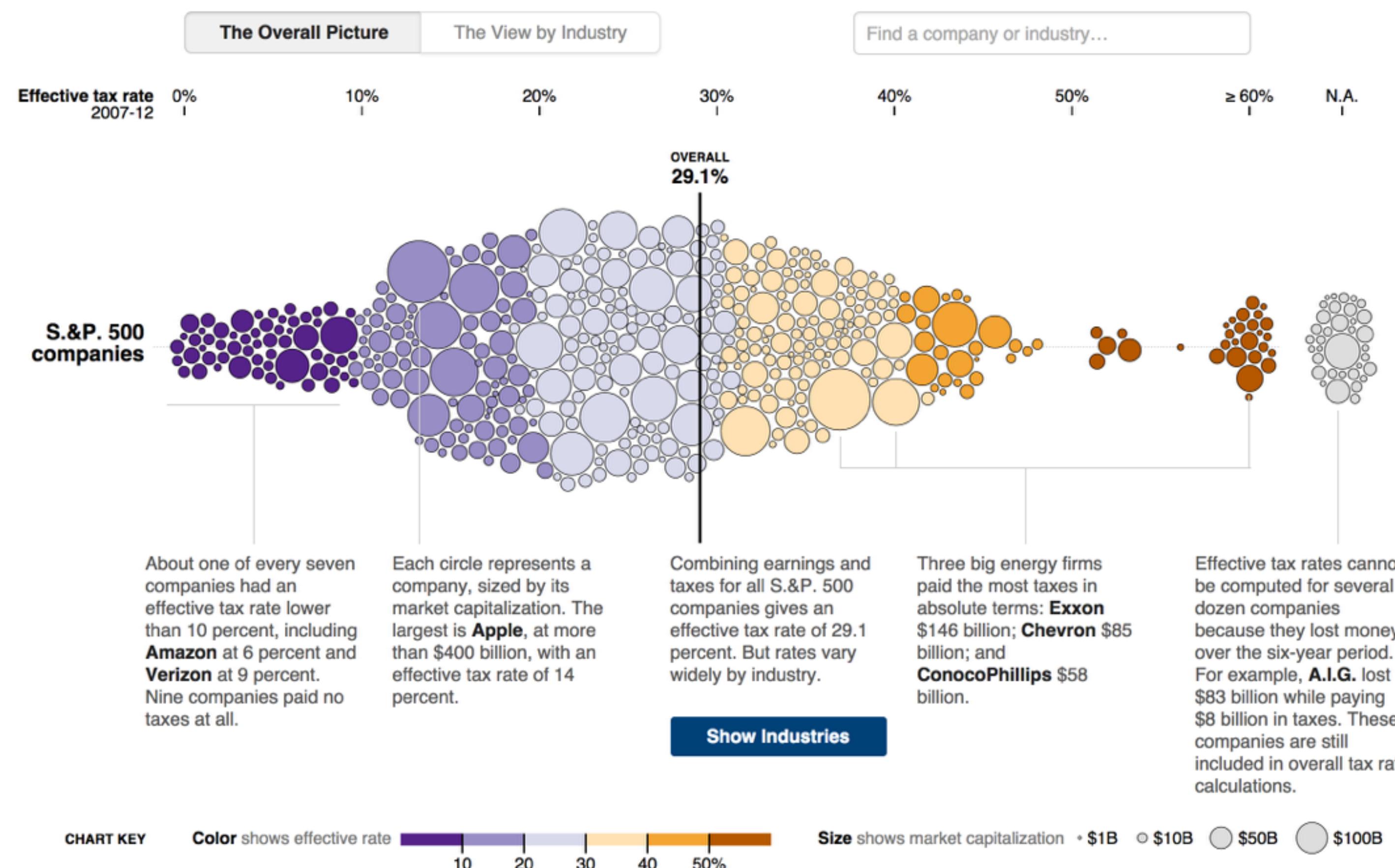
Shape



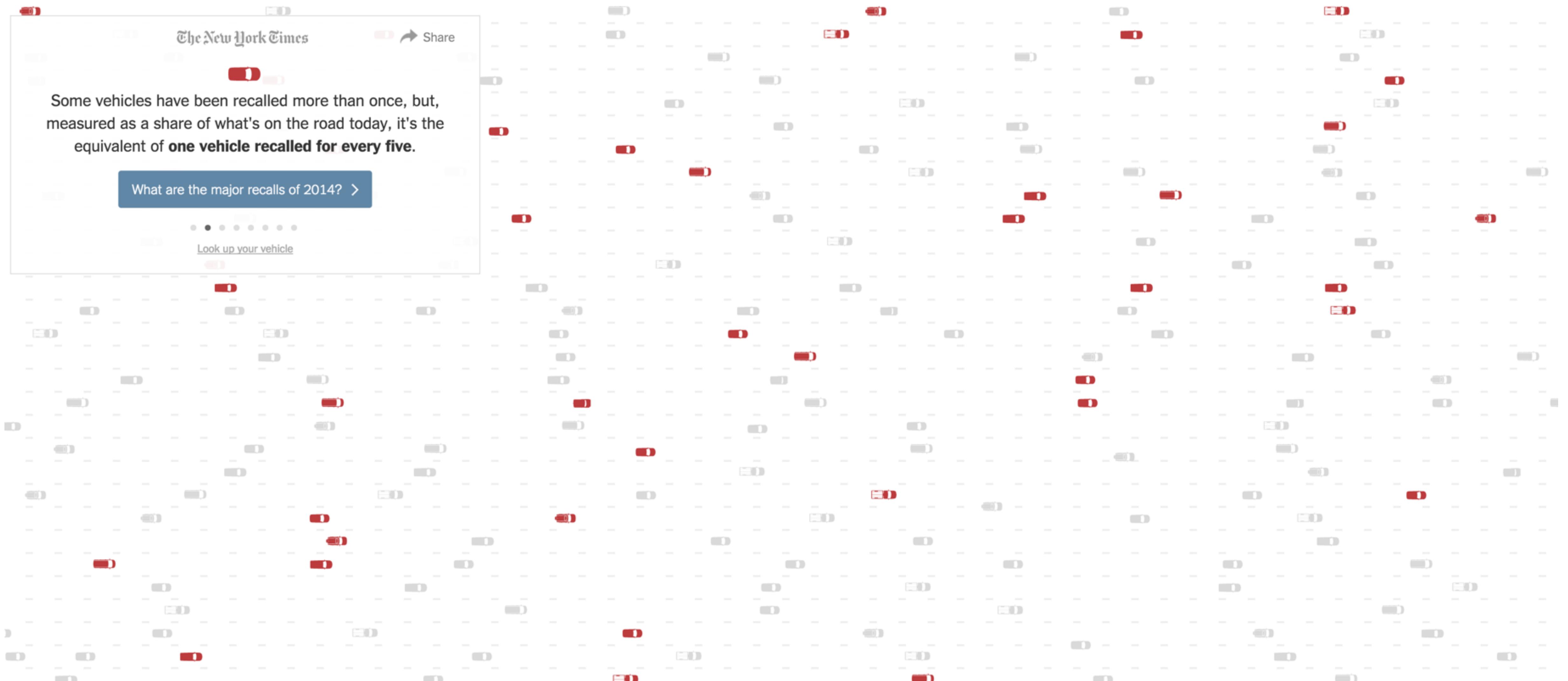
What visual variables are used?

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 »](#)



What visual variables are used?



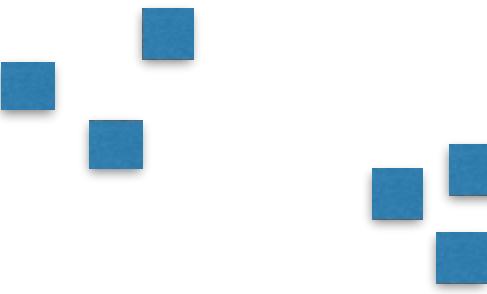
Characteristics of Channels

Selective



Is a mark distinct from other marks?

Can we make out the difference between two marks?

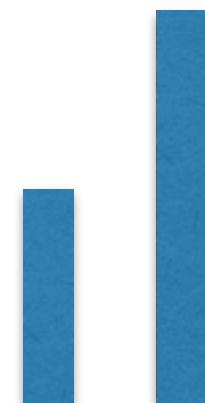


Associative

Does it support grouping?

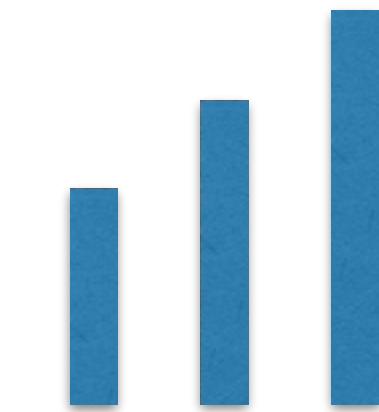
Quantitative (Magnitude vs Identity Channels)

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

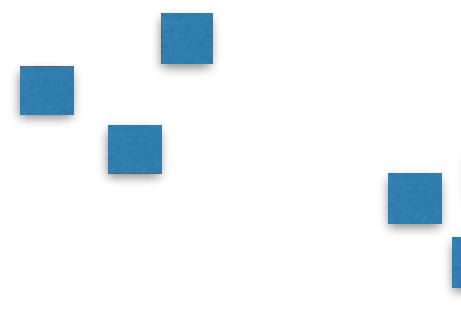
Selective: yes

Associative: yes

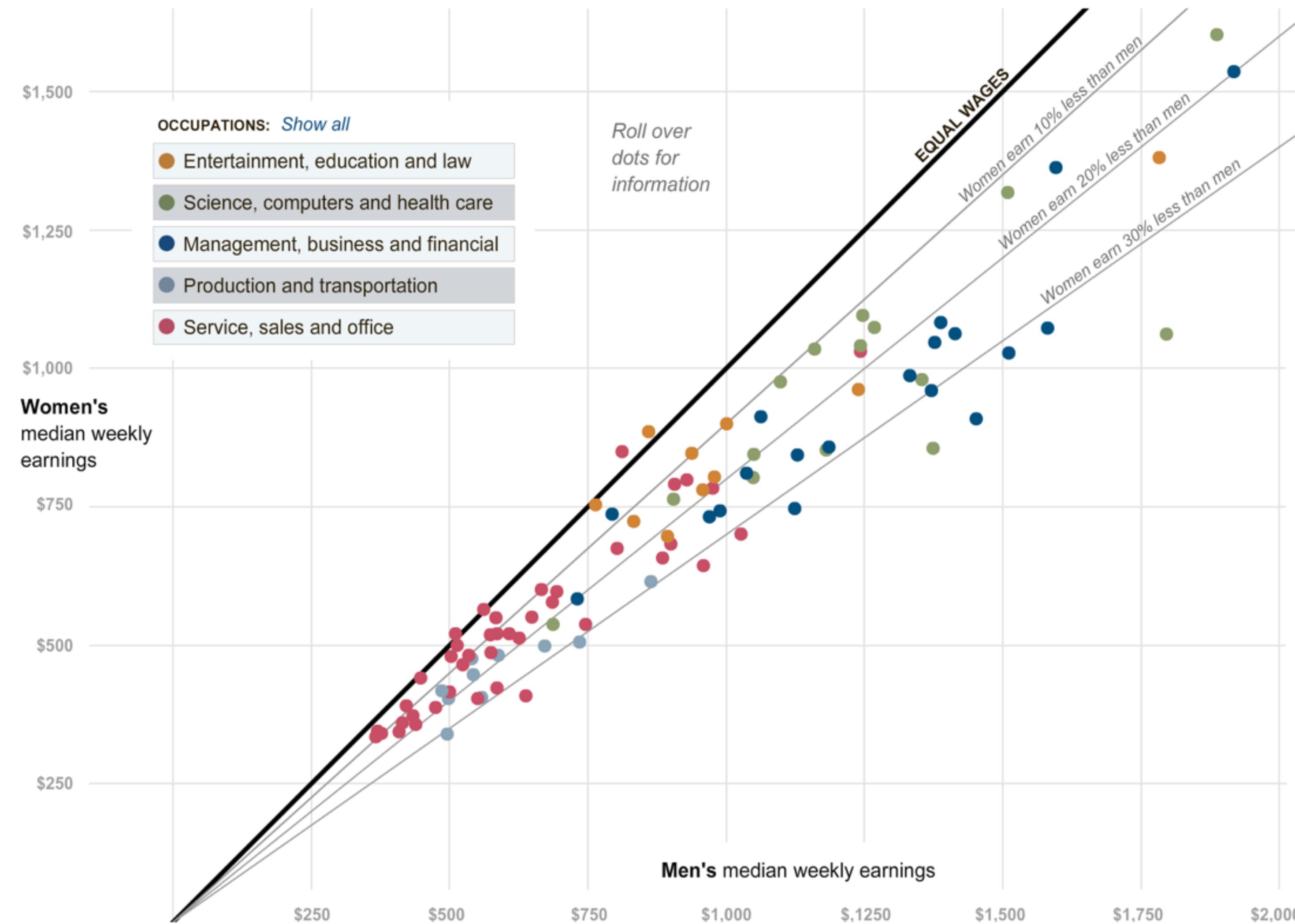
Quantitative: yes

Order: yes

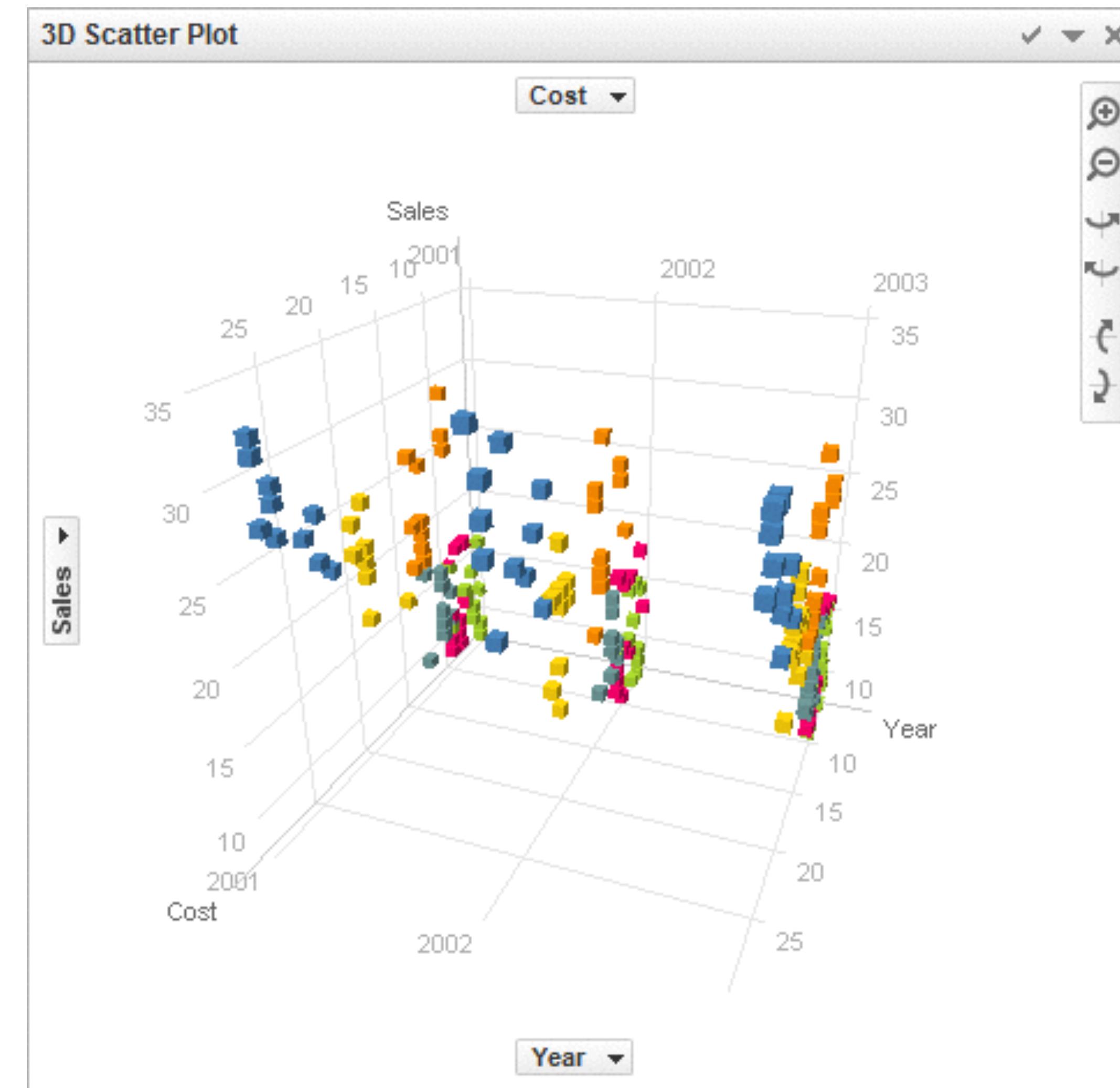
Length: fairly big



Example: Scatterplot



Position in 3D?



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

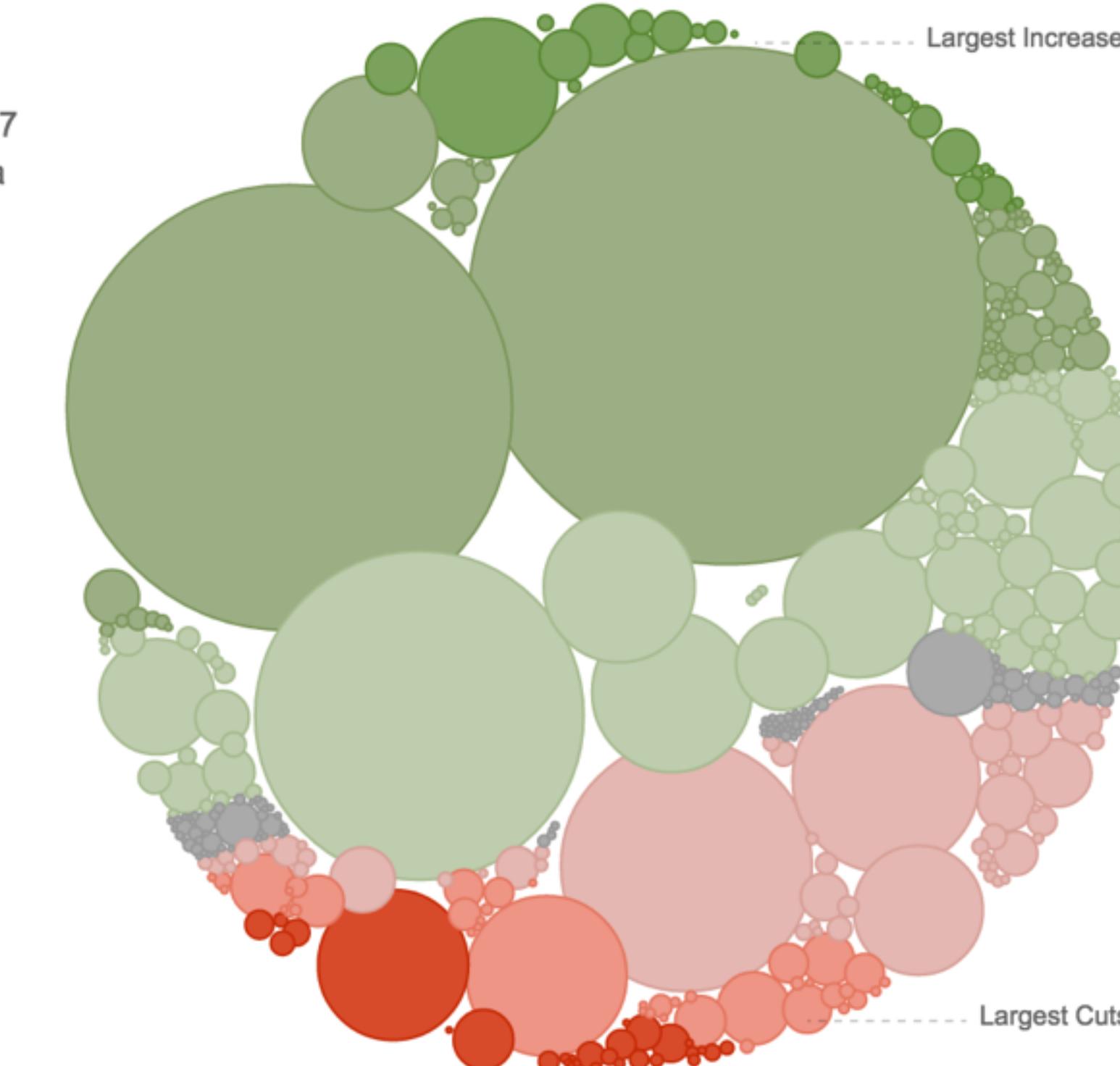
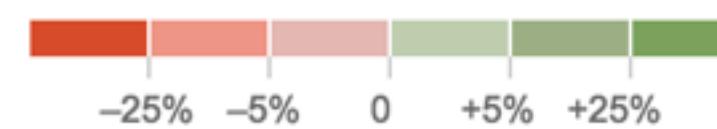
How \$3.7 Trillion Is Spent

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

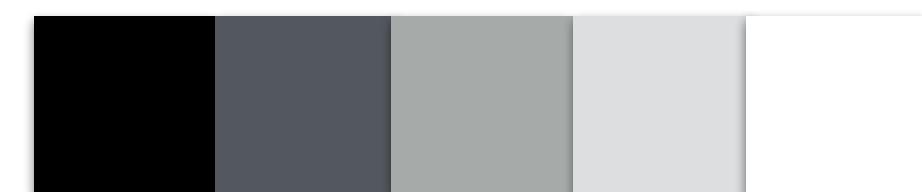
Selective: yes

Associative: yes

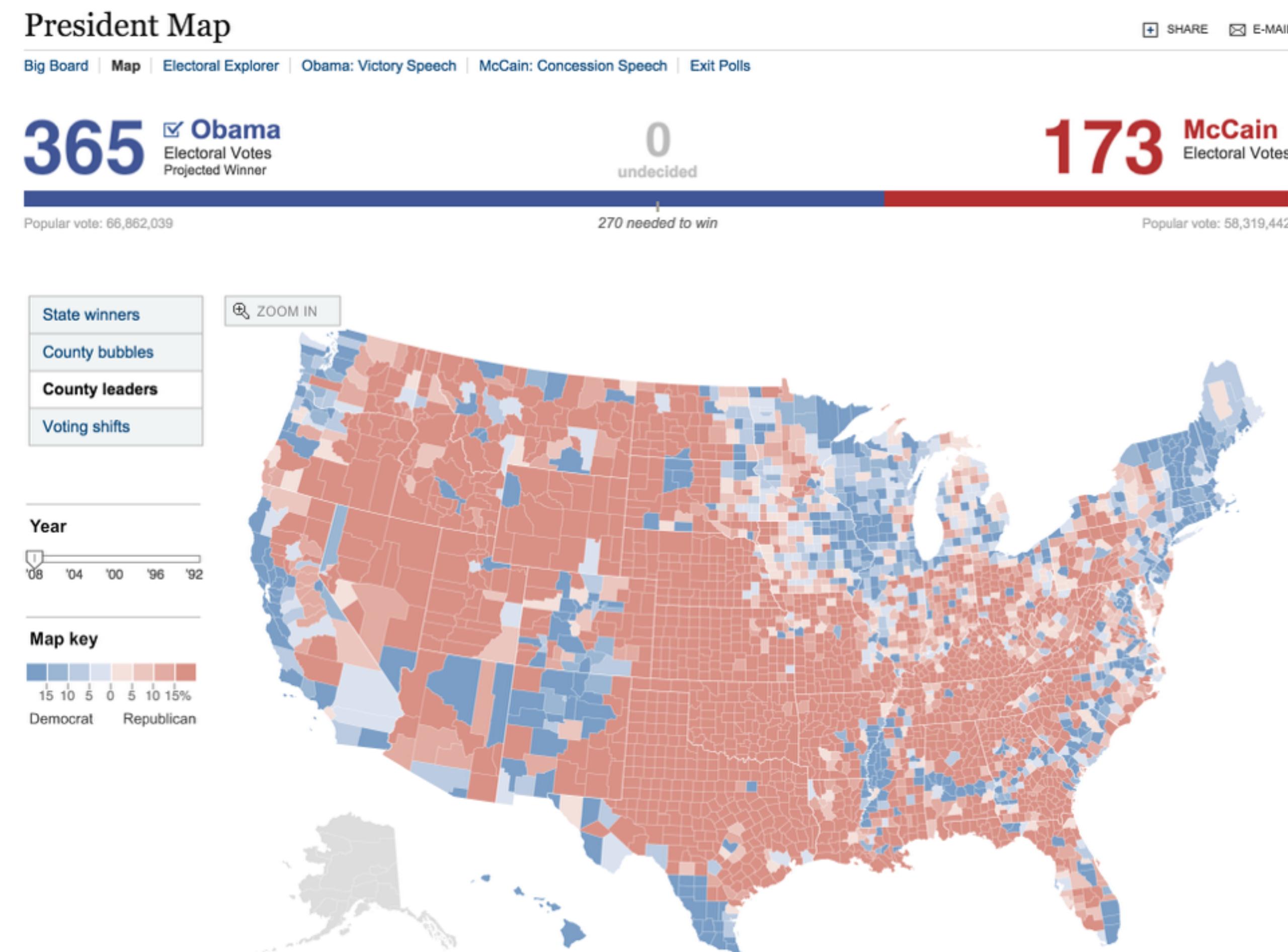
Quantitative: somewhat (with problems)

Order: yes

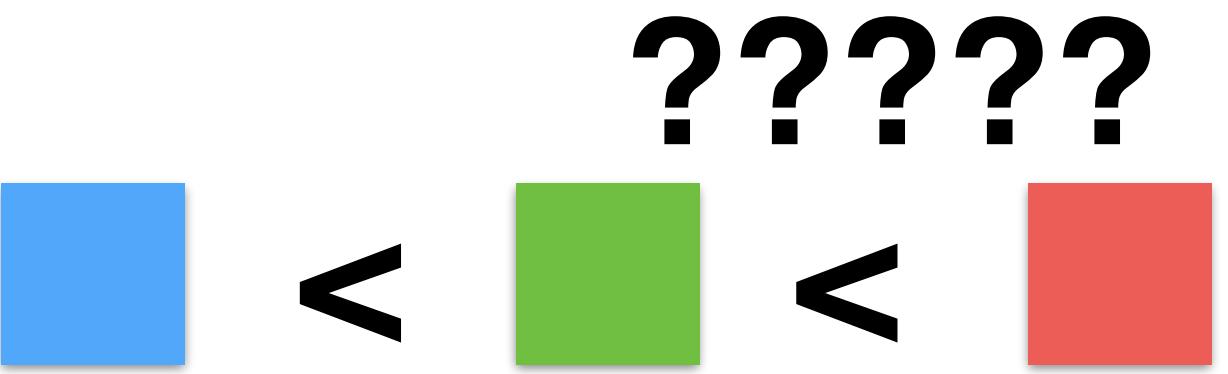
Length: limited



Example: Diverging Value-Scale



Color



Good for qualitative data (identity channel)

Selective: yes

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

Associative: yes

Does not work for quantitative data!

Quantitative: no

Lots of pitfalls! Be careful!

Order: no

My rule:

Length: limited

minimize color use for encoding data

use for brushing



Color: Bad Example

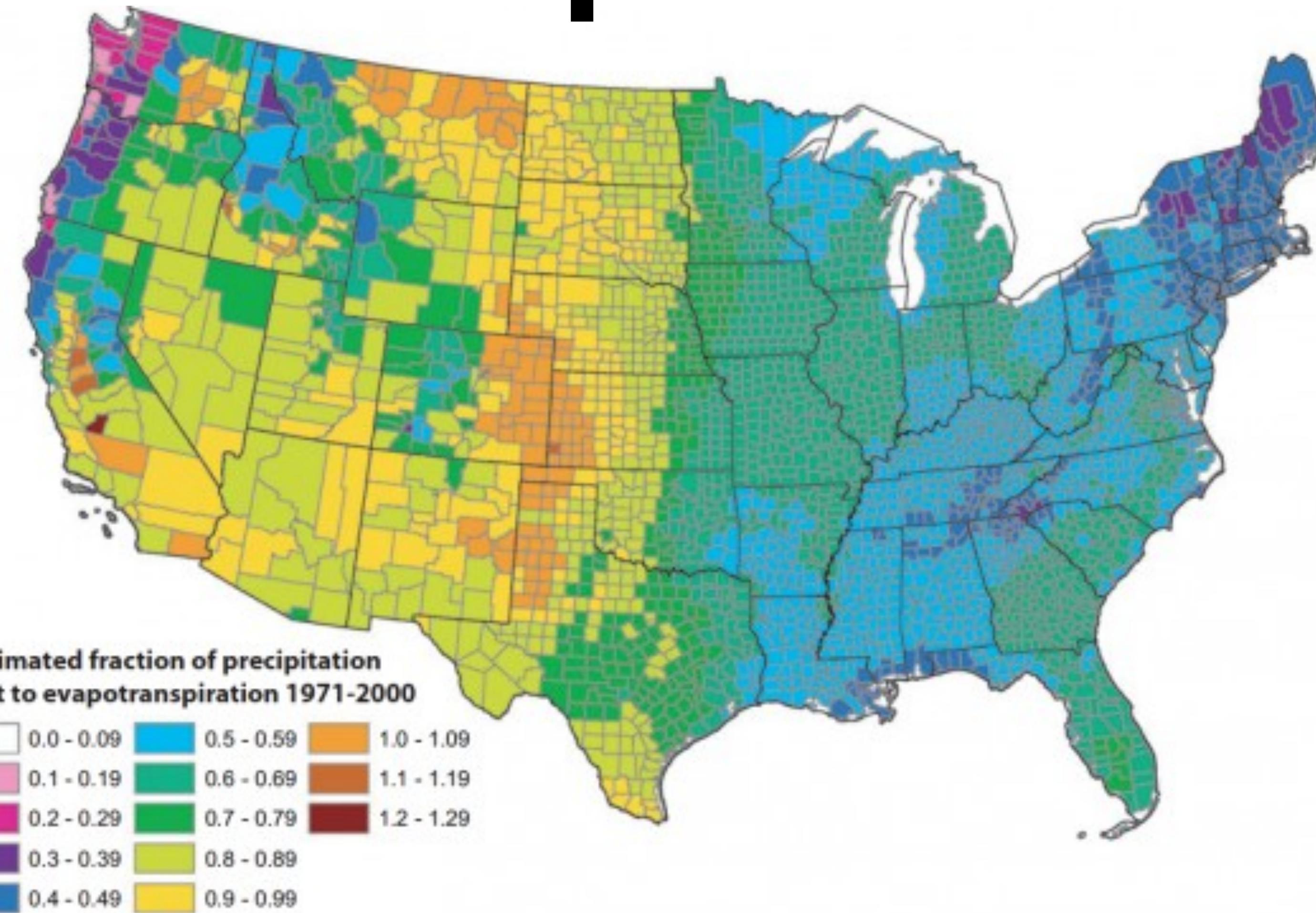


FIGURE 13. Estimated Mean Annual Ratio of Actual Evapotranspiration (ET) to Precipitation (P) for the Conterminous U.S. for the Period 1971-2000. Estimates are based on the regression equation in Table 1 that includes land cover. Calculations of ET/P were made first at the 800-m resolution of the PRISM 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.

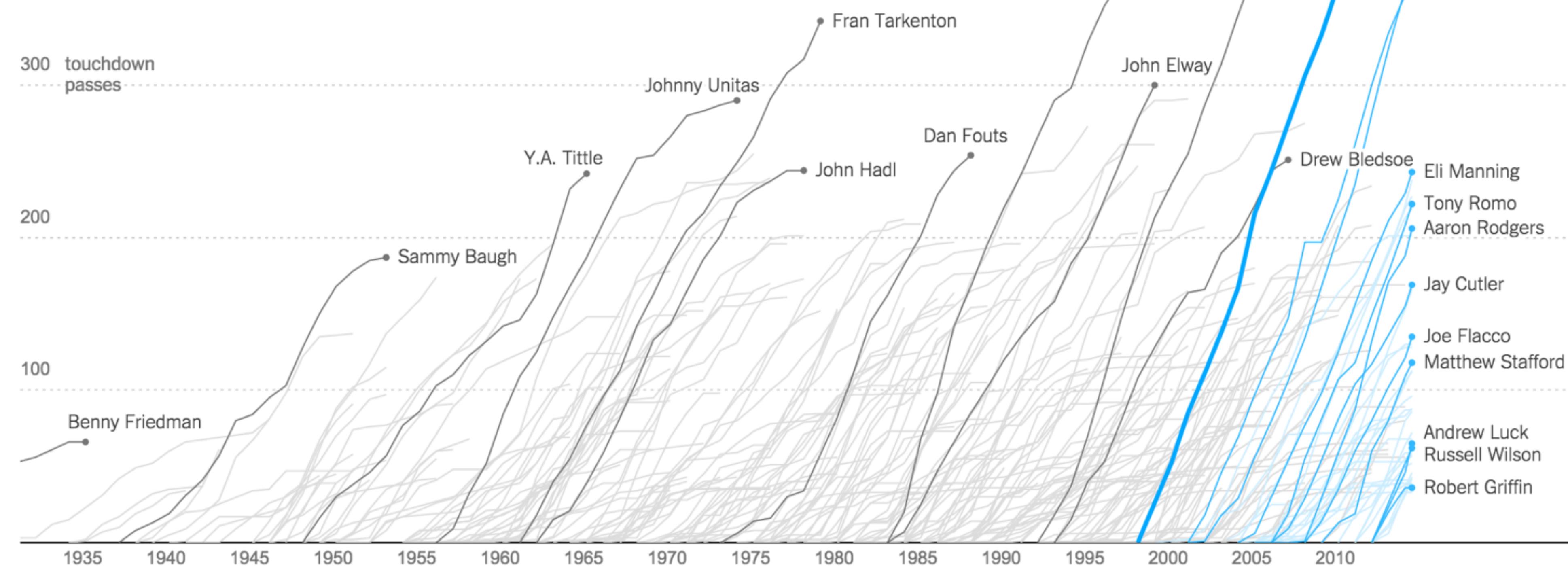
Cliff Mass

Color: Good Example

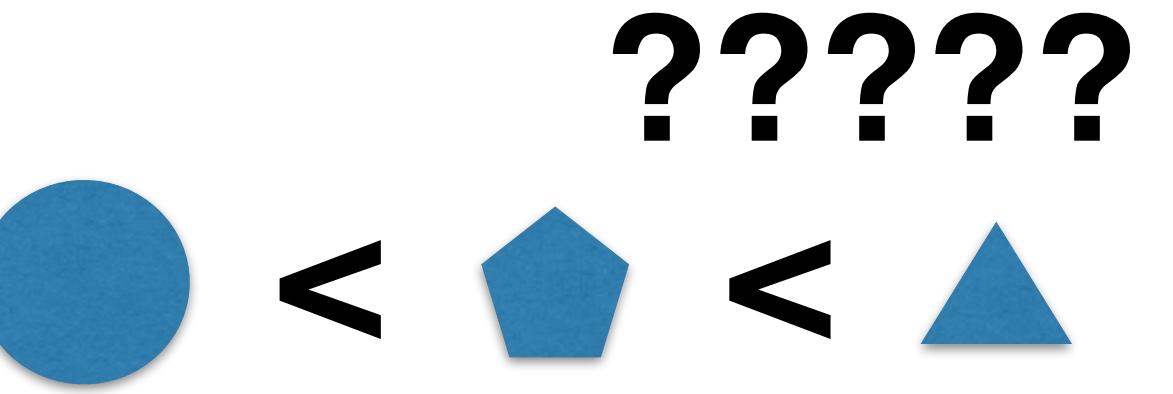
Why Peyton Manning's Record Will Be Hard to Beat

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.

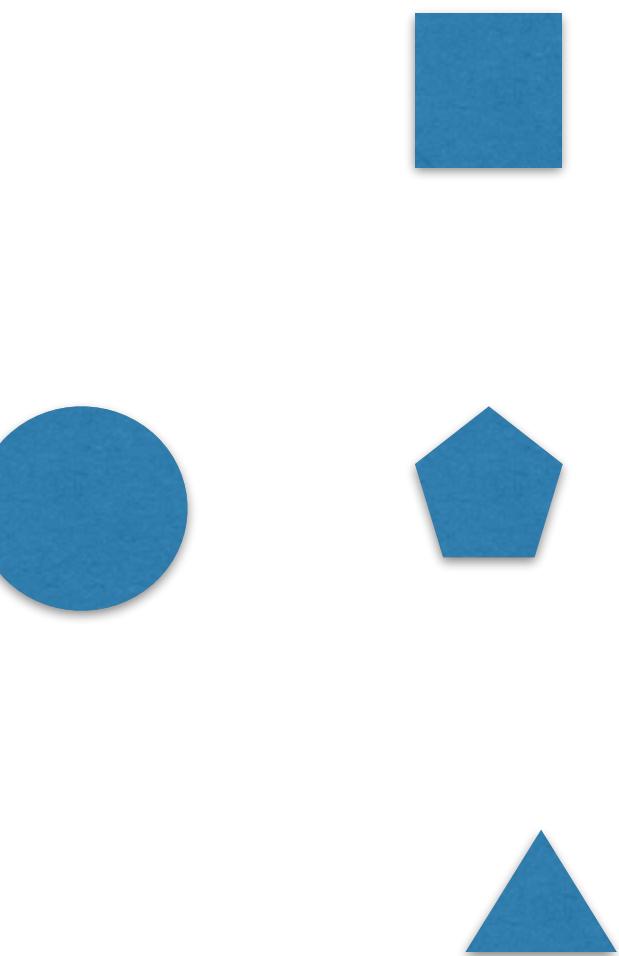
Selective: yes

Associative: limited

Quantitative: no

Order: no

Length: vast





ASTON MARTIN



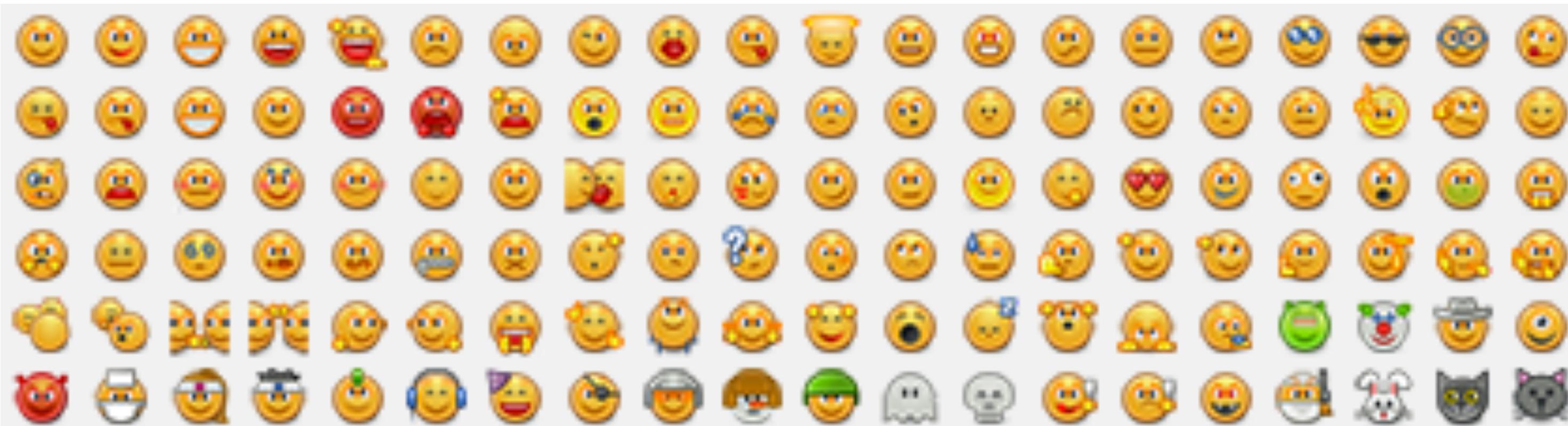
Audi

MITSUBISHI
MOTORS

BENTLEY

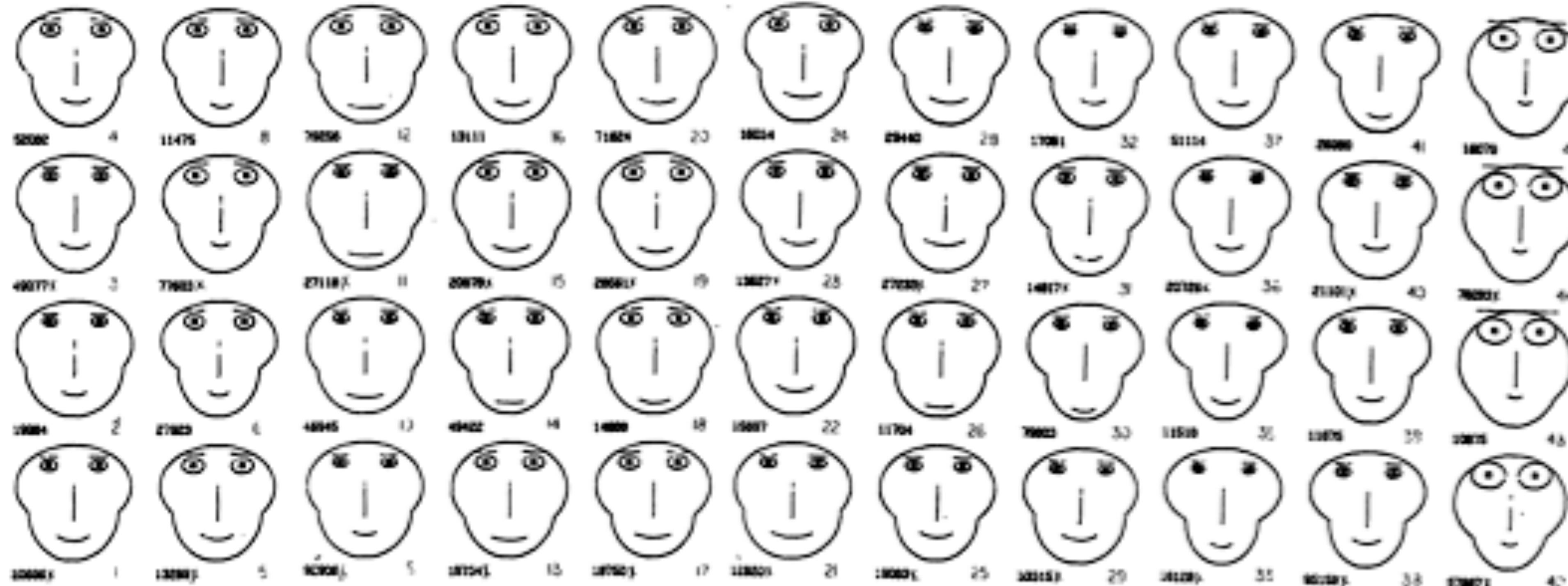


FOR SAFETY You must know German trafficsigns																



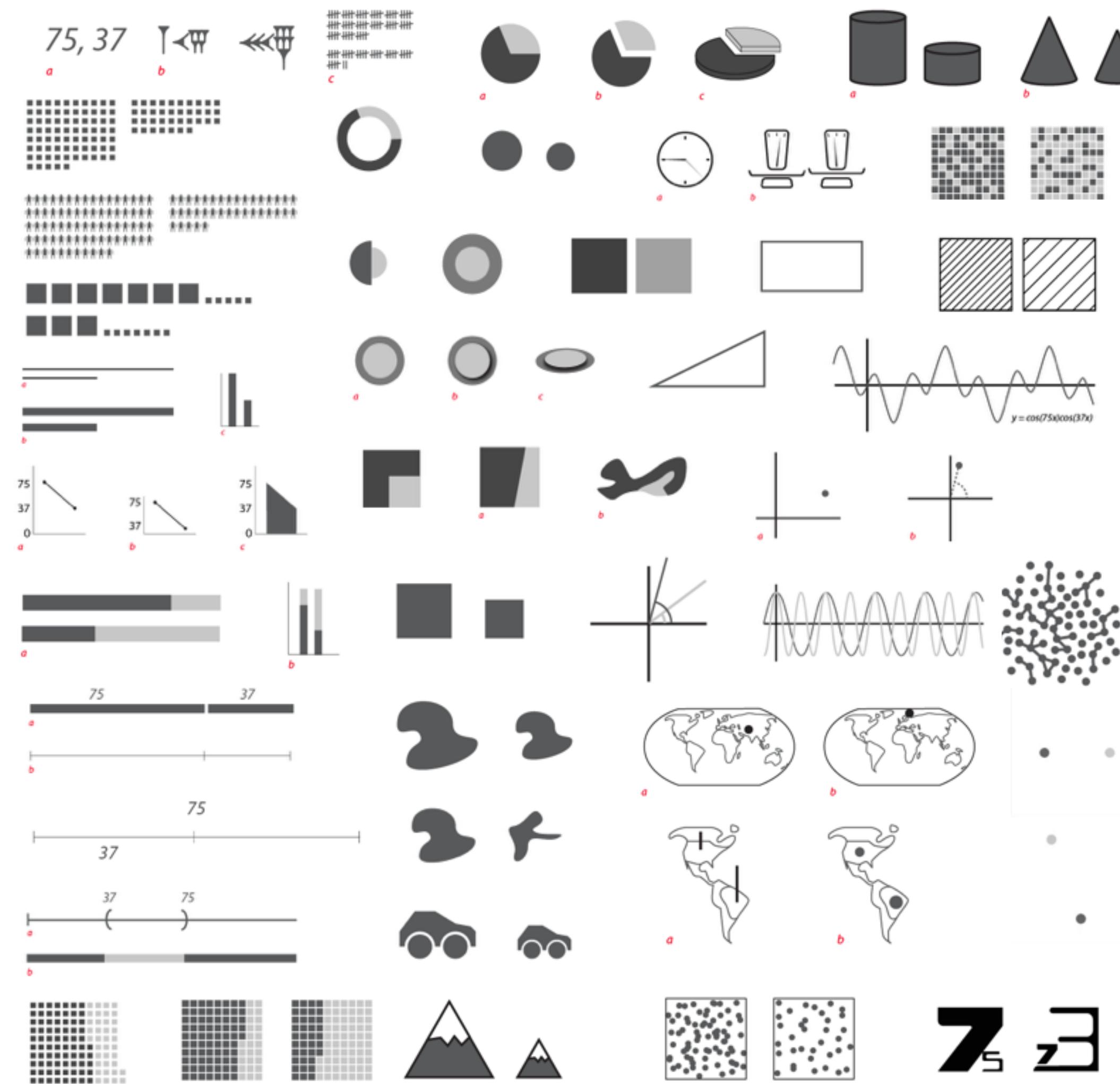
Chernoff Faces

Idea: use facial parameters to map quantitative data



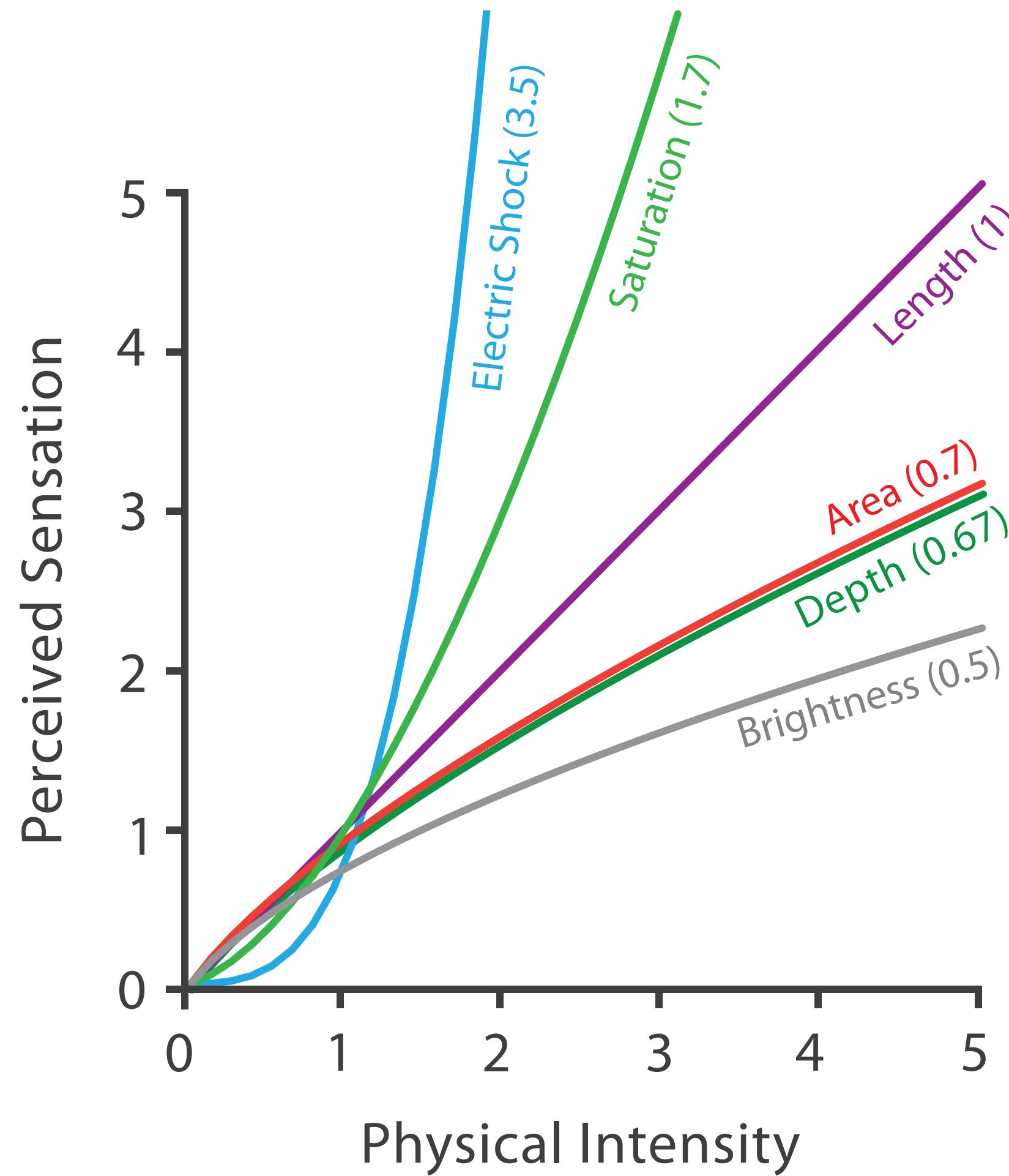
Does it work?
Not really!

More Channels



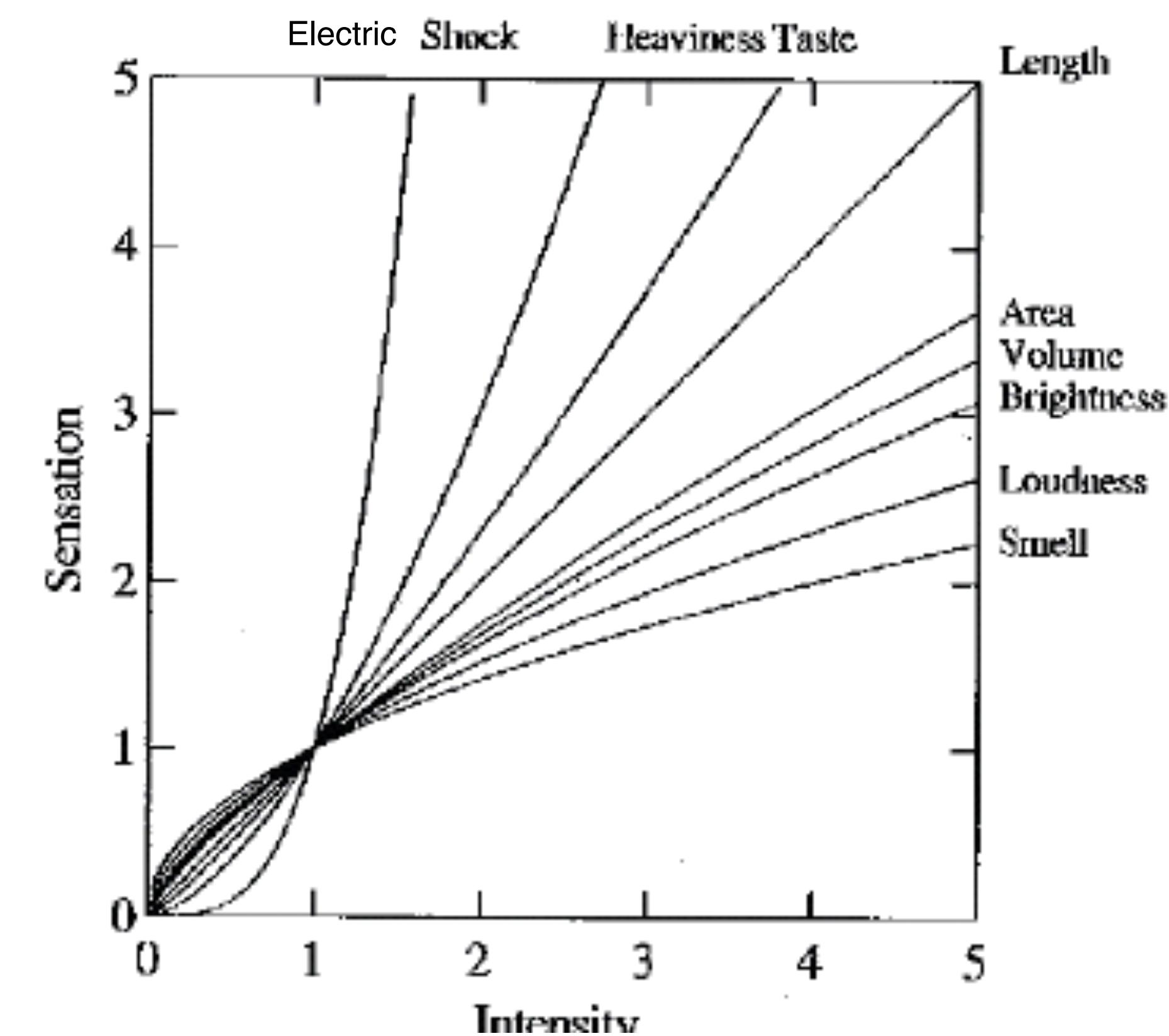
Why are quantitative channels different?

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



S = sensation
 I = intensity

Steven's Power Law, 1961



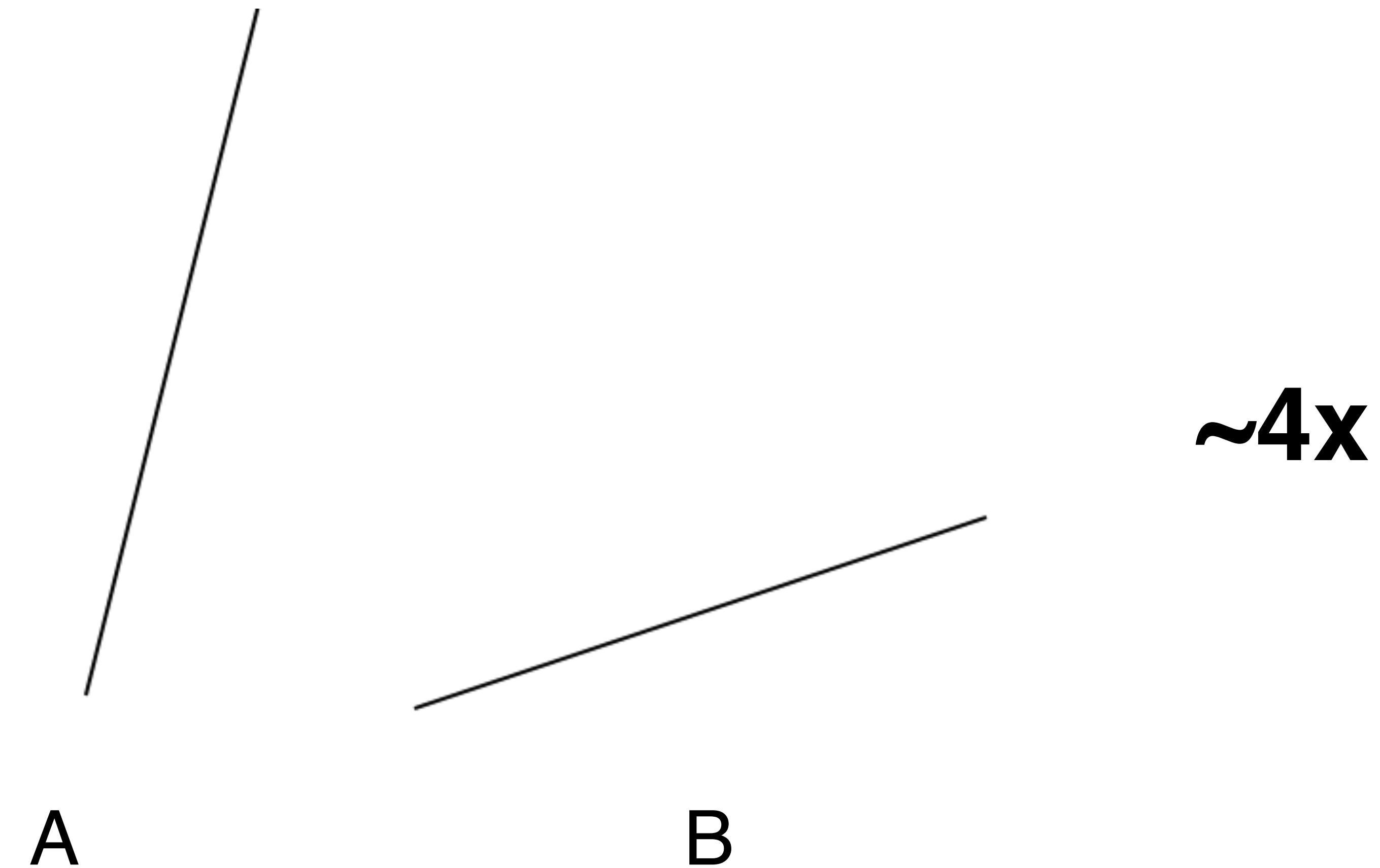
How much longer?



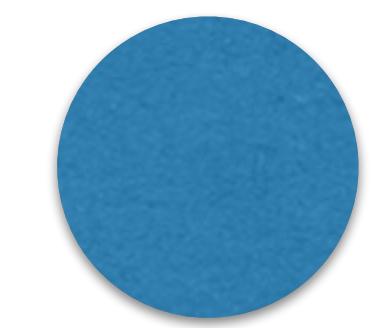
How much longer?



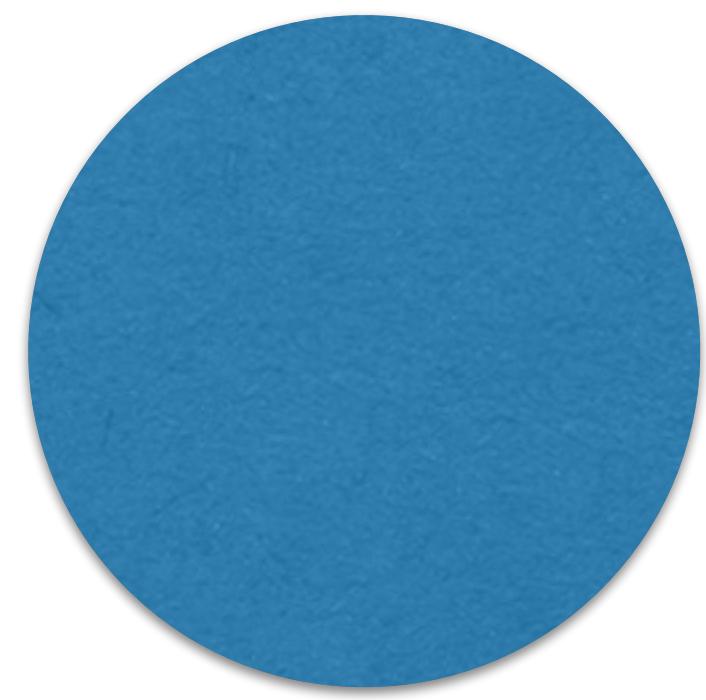
How much steeper?



How much larger (area)?



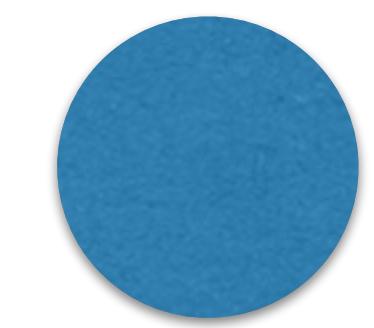
A



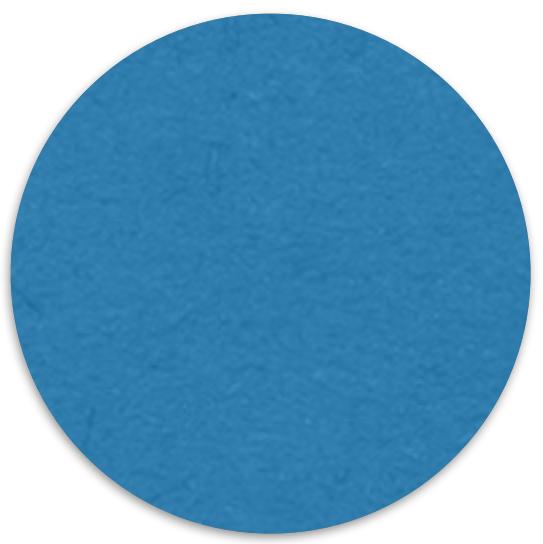
B

5x

How much larger (area)?



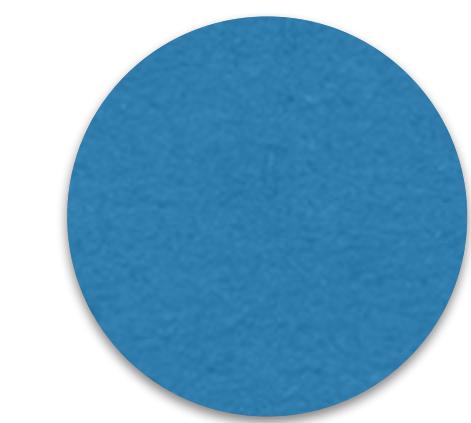
A



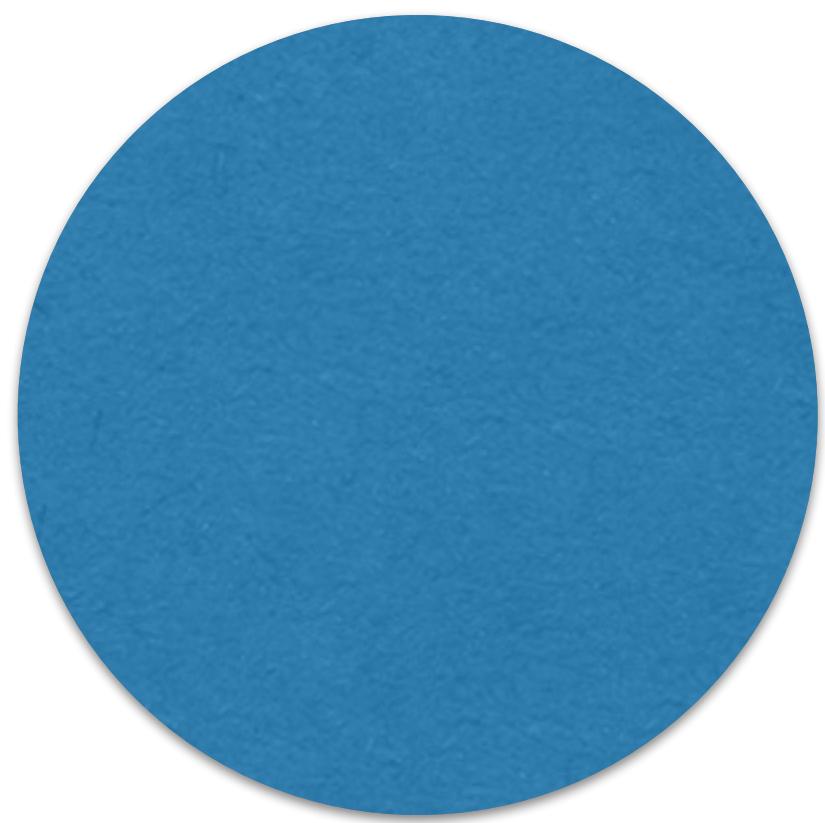
B

3x

How much larger (diameter)?



A



B

2x

How much darker?



A



B

2x

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

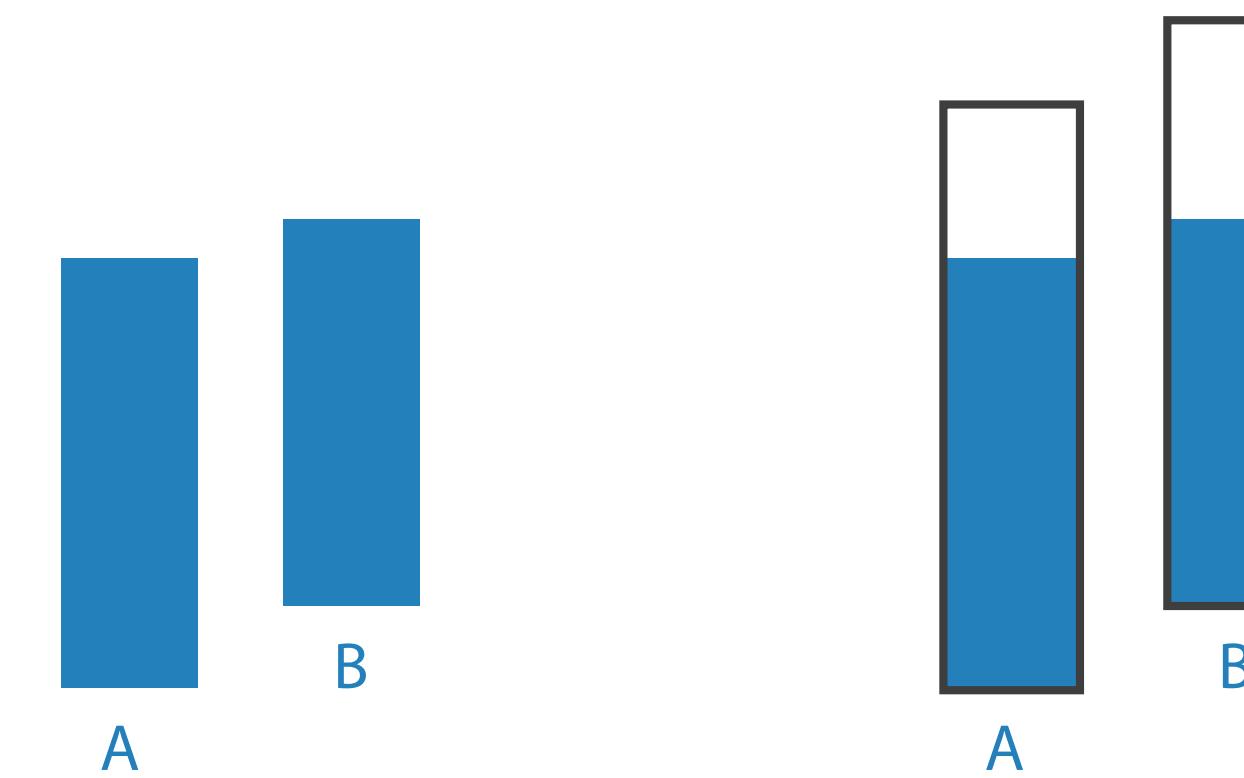
Best of last 500 score and time: [\(more\)](#)

- 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

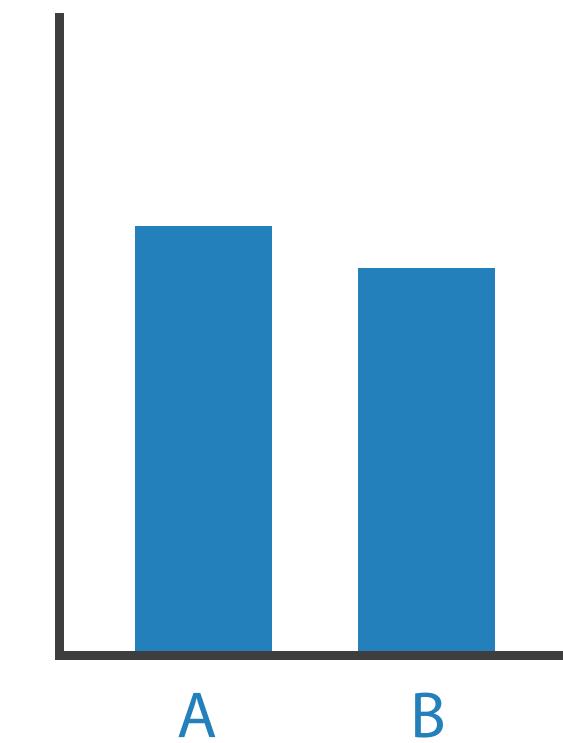
Best on this computer score and time:

Other Factors Affecting Accuracy

Alignment



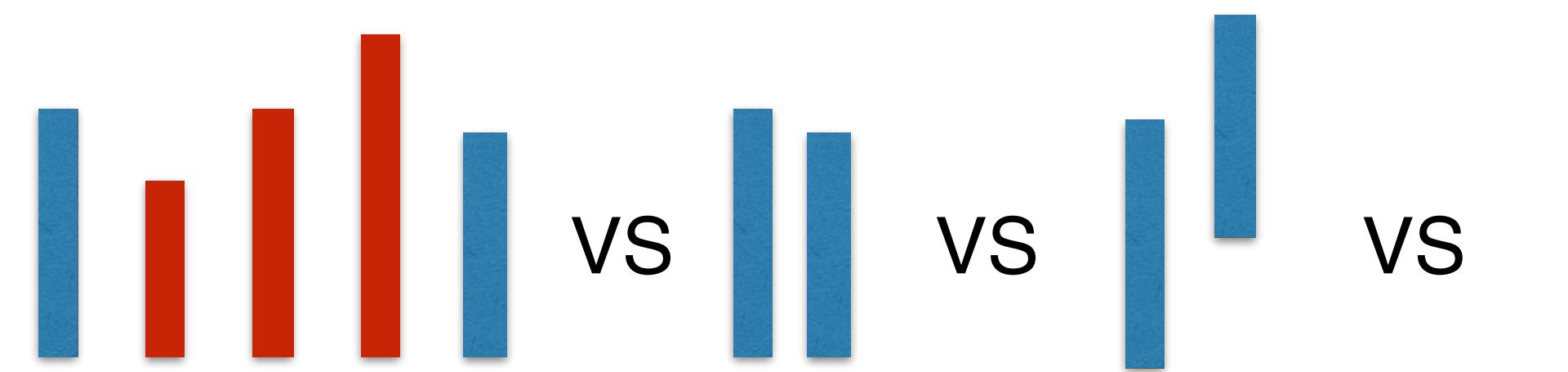
Distractors



Distance

Common scale

...



Cleveland / McGill, 1984

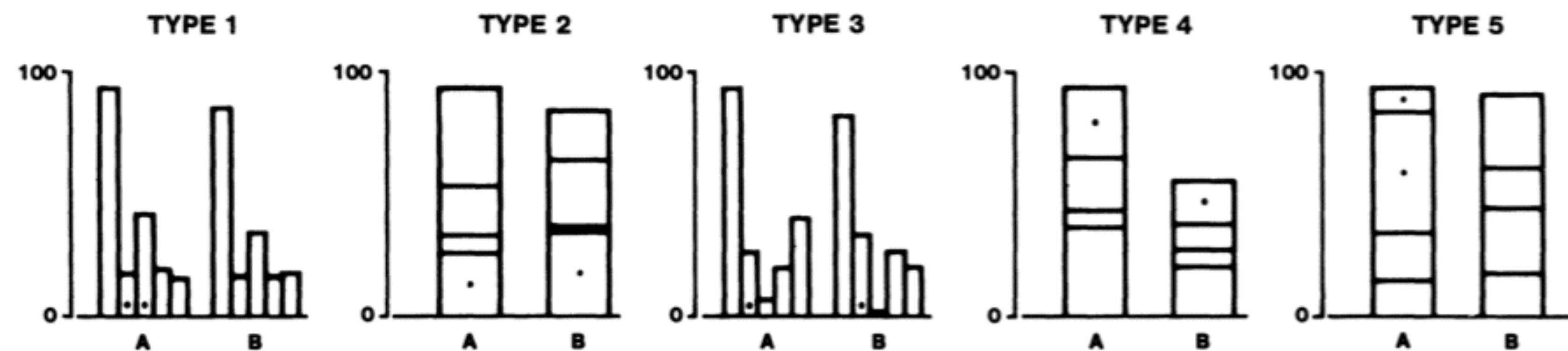


Figure 4. Graphs from position-length experiment.

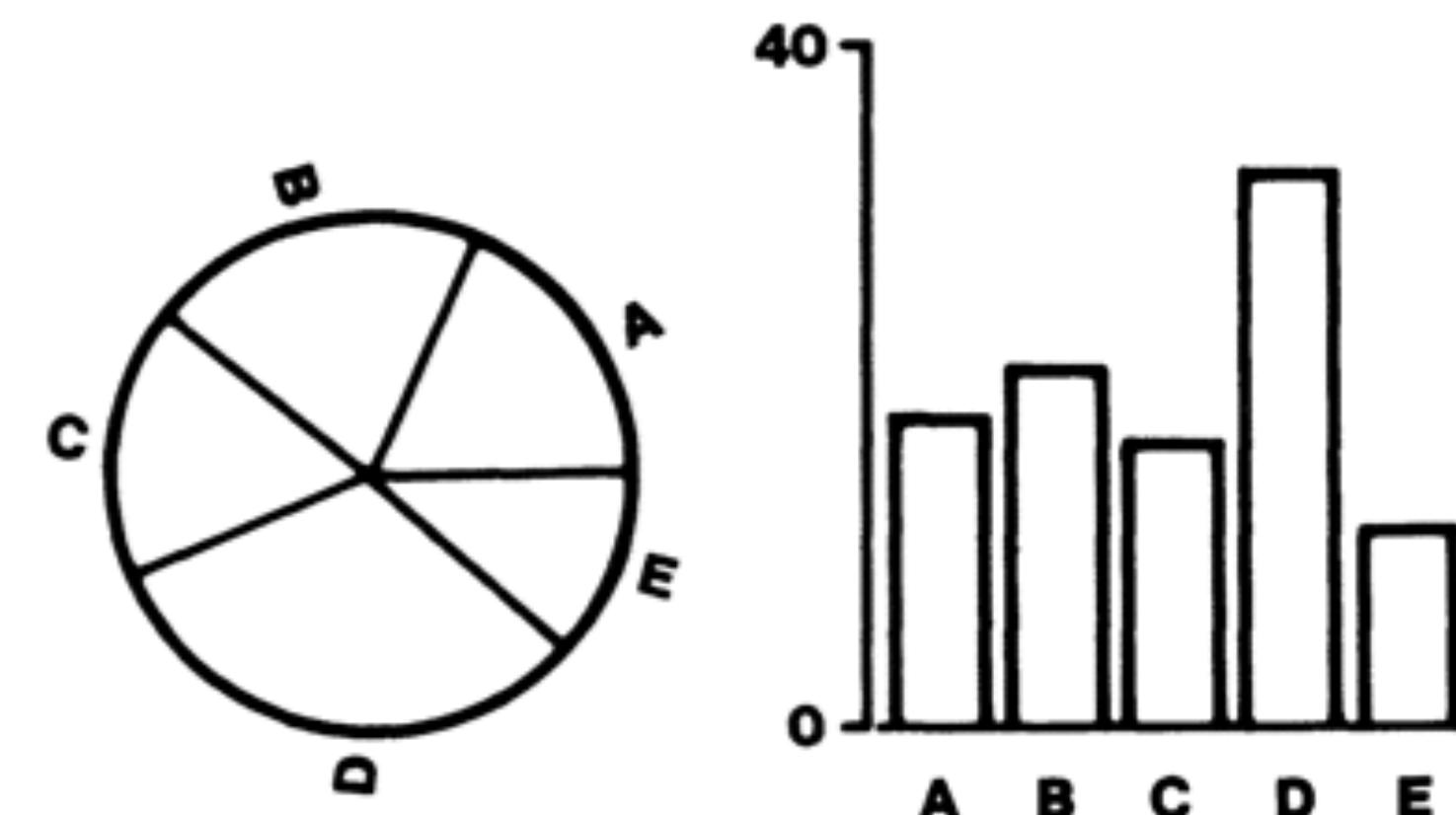
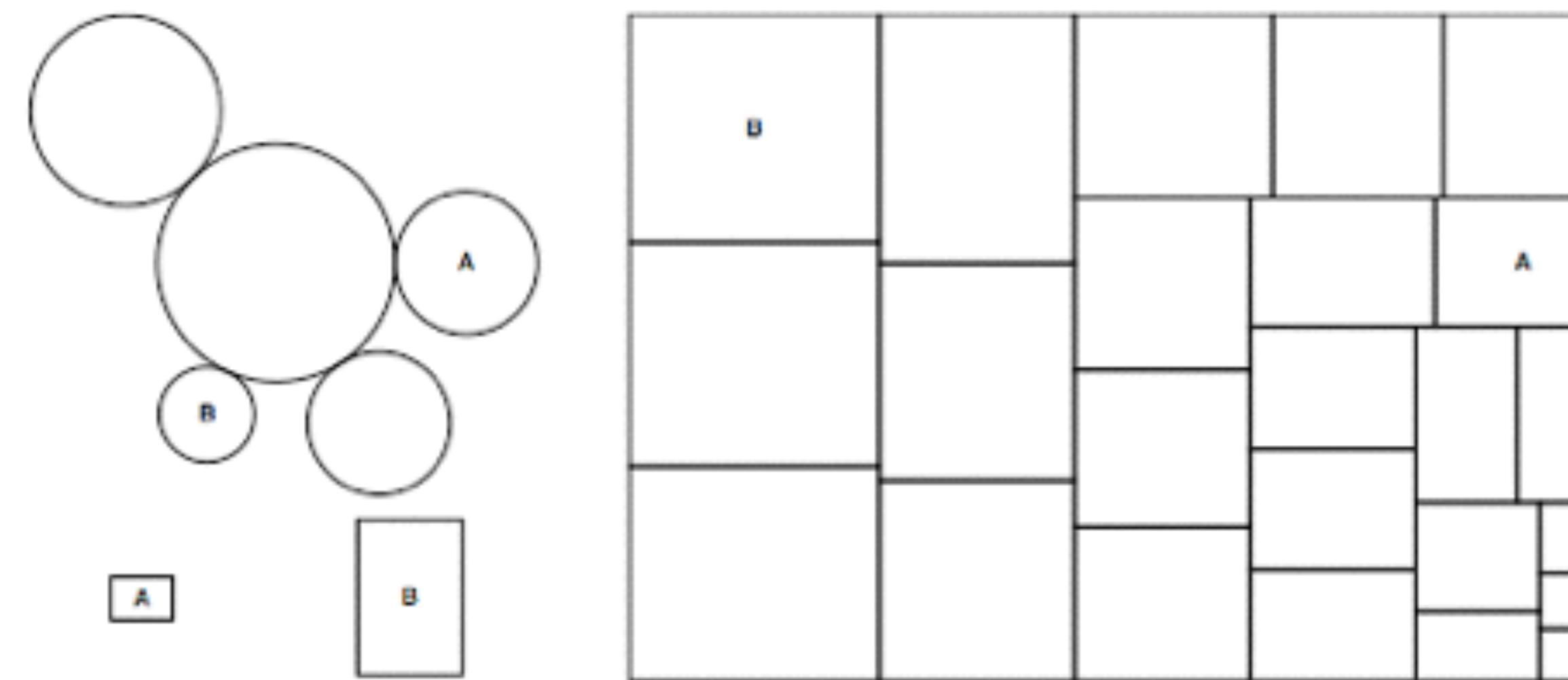
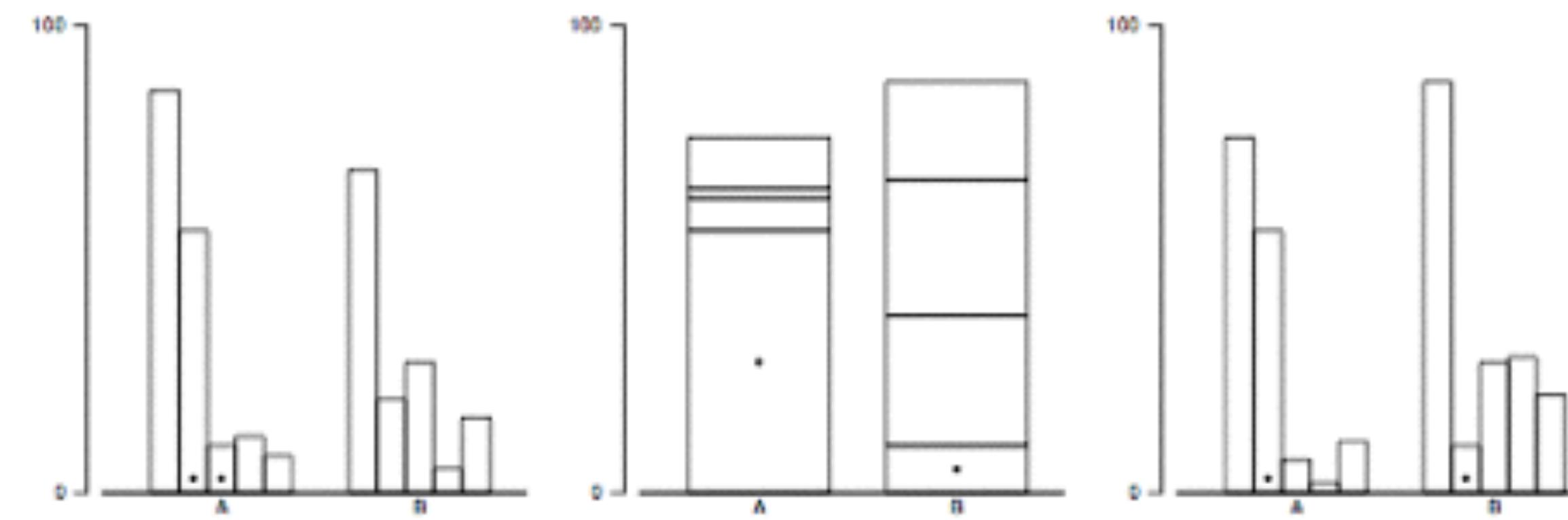
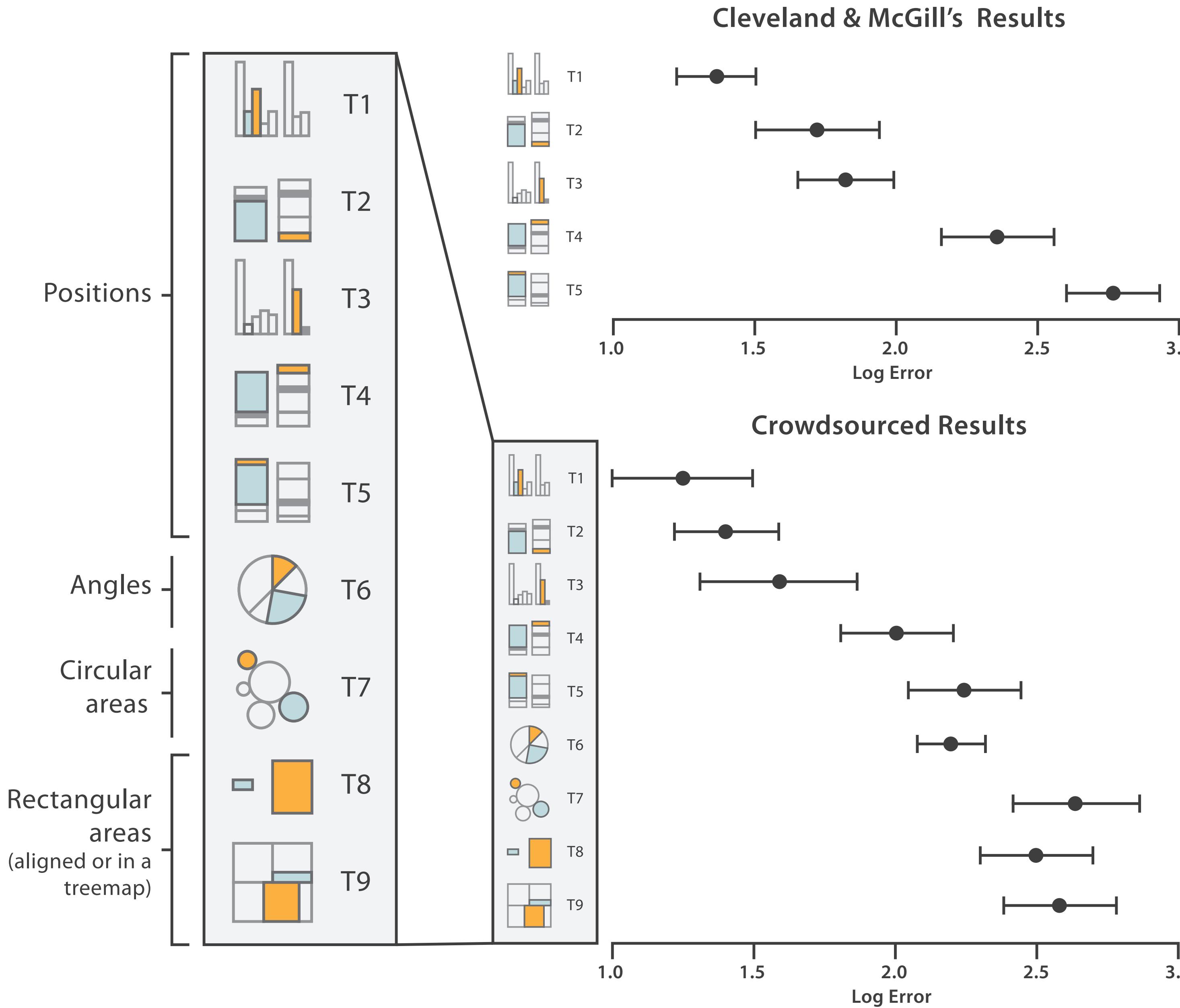


Figure 3. Graphs from position-angle experiment.

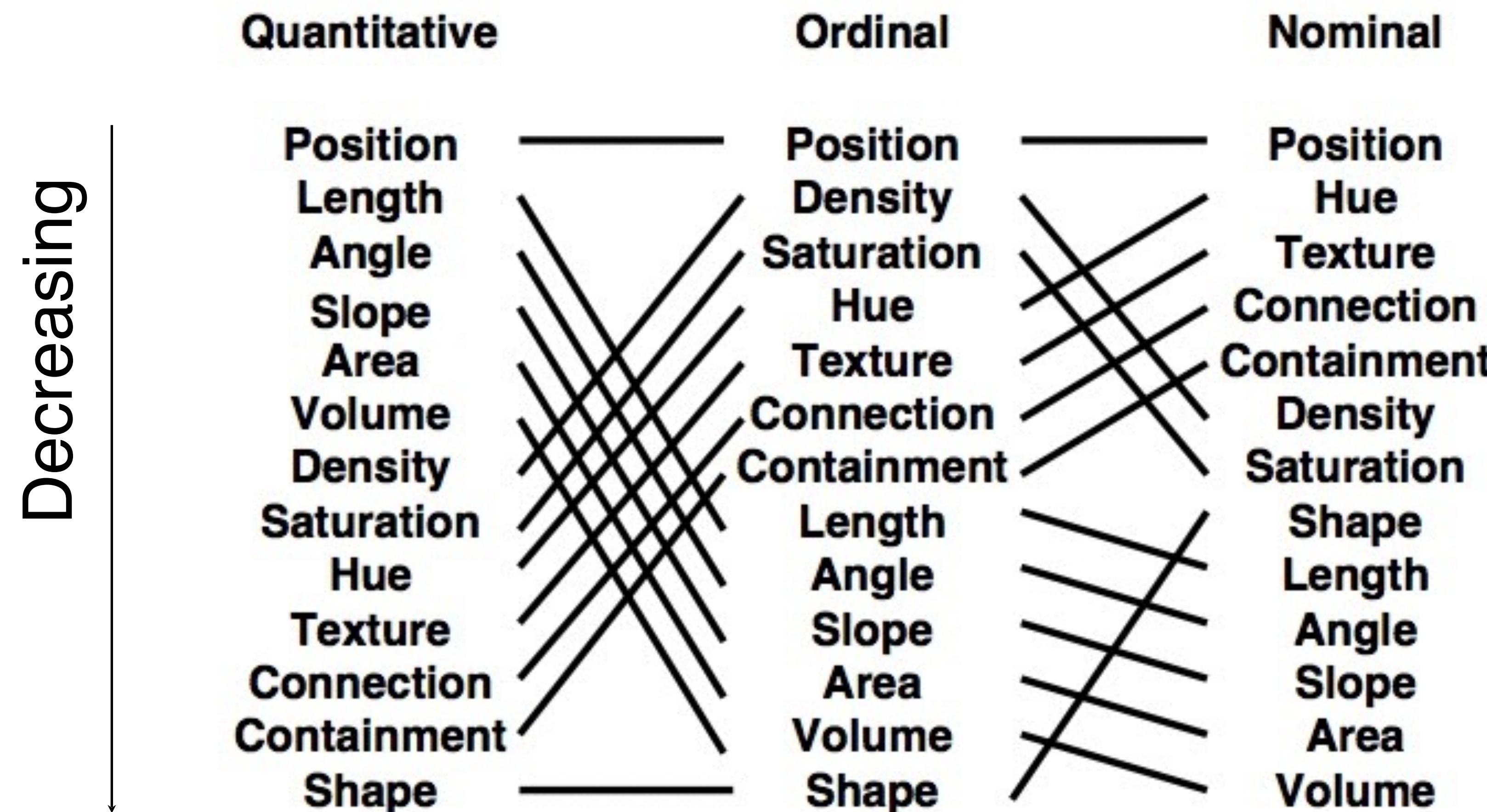
William S. Cleveland; Robert McGill ,
"Graphical Perception: Theory,
Experimentation, and Application to
the Development of Graphical
Methods." 1984

Heer & Bostock, 2010





Jock Mackinlay, 1986



Channels: Expressiveness Types and Effectiveness Ranks

→ Magnitude Channels: Ordered Attributes

Position on common scale



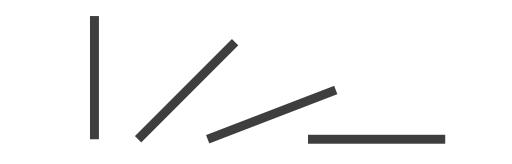
Position on unaligned scale



Length (1D size)



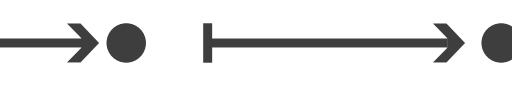
Tilt angle



Area (2D size)



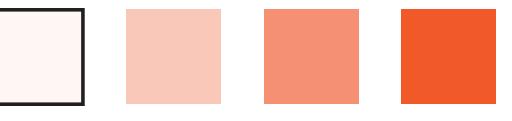
Depth (3D position)



Color luminance



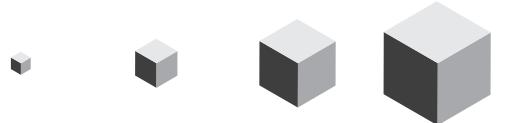
Color saturation



Curvature



Volume (3D size)



Effectiveness
Least ↑ Most ↓

→ Identity Channels: Categorical Attributes

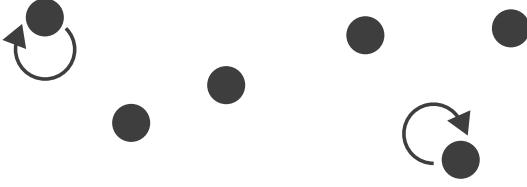
Spatial region



Color hue



Motion



Shape



Same

Separability of Attributes

Can we combine multiple visual variables?

