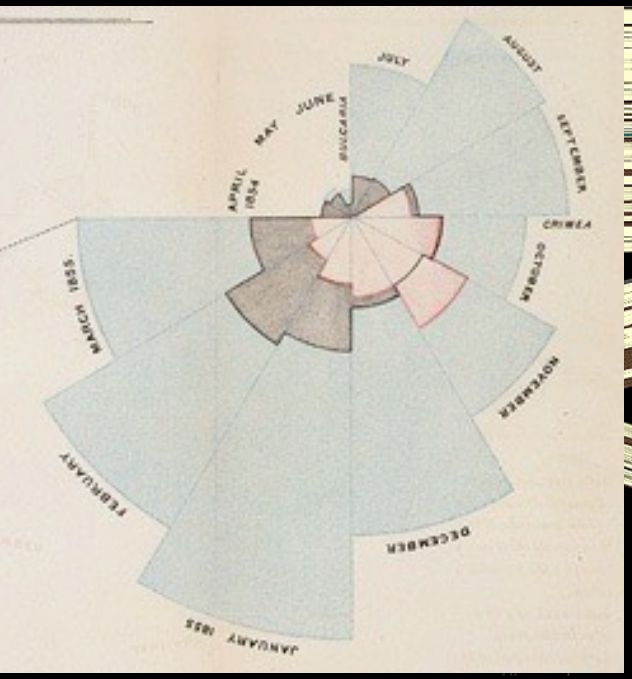
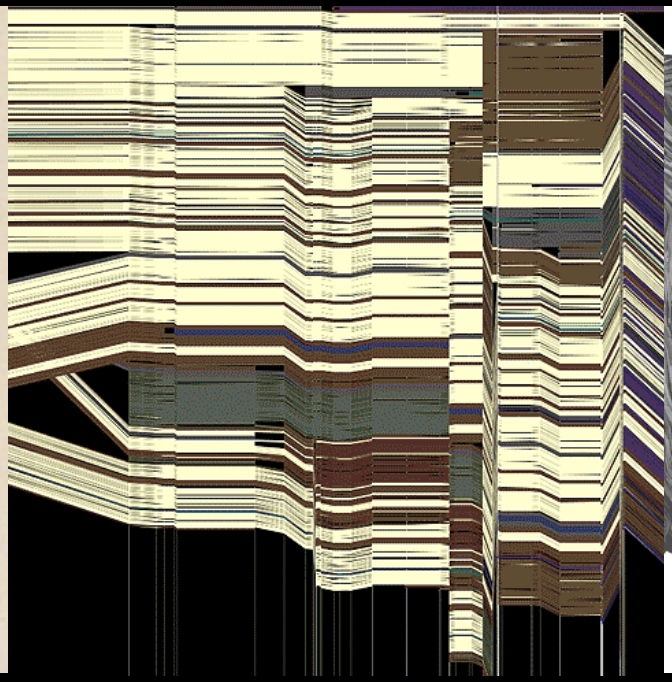
CSE 442 - Data Visualization

The Value of Visualization





Jeffrey Heer, Jane Hoffswell Univ. of Washington

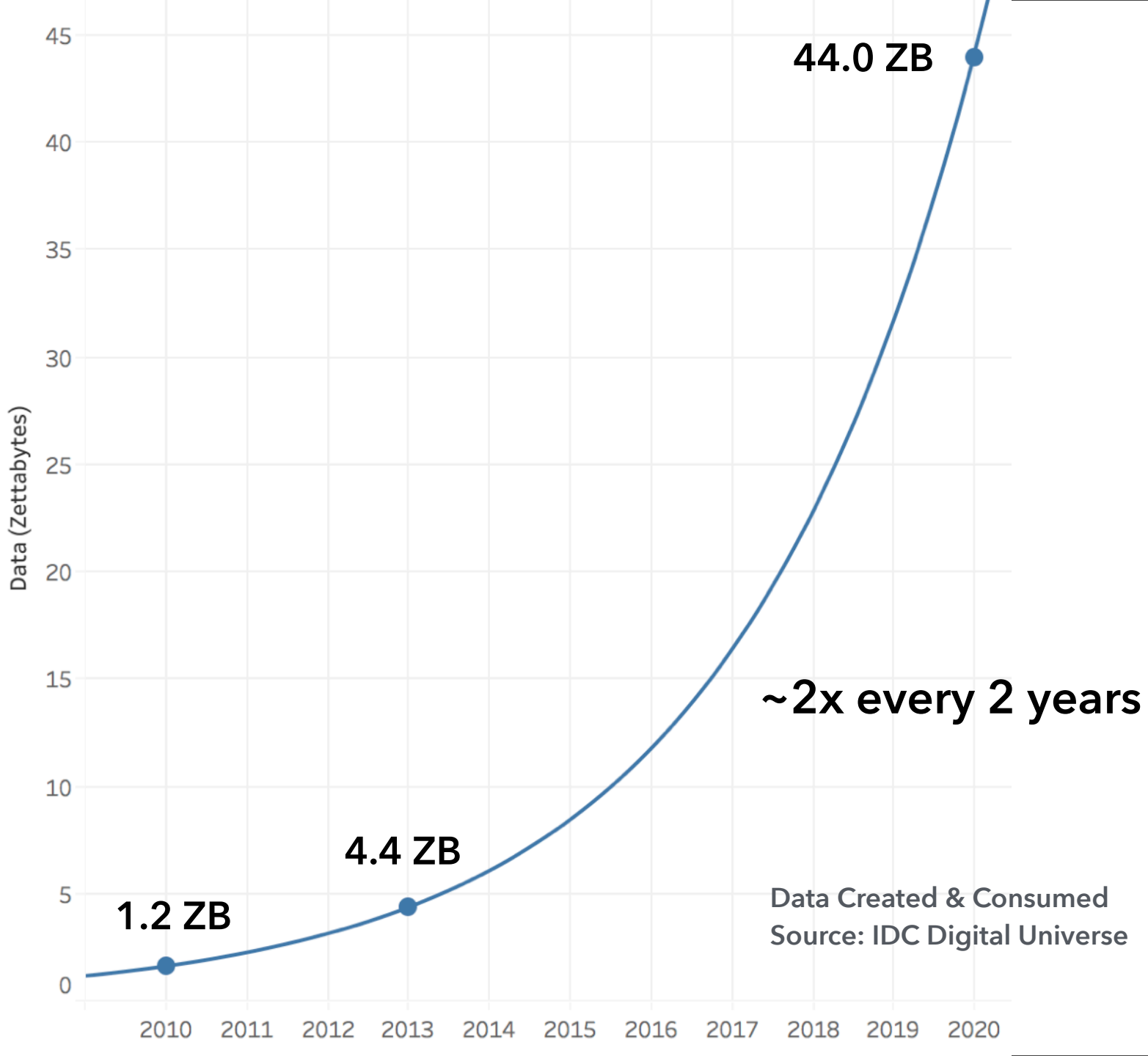
How much data (bytes) did we produce in 2010?

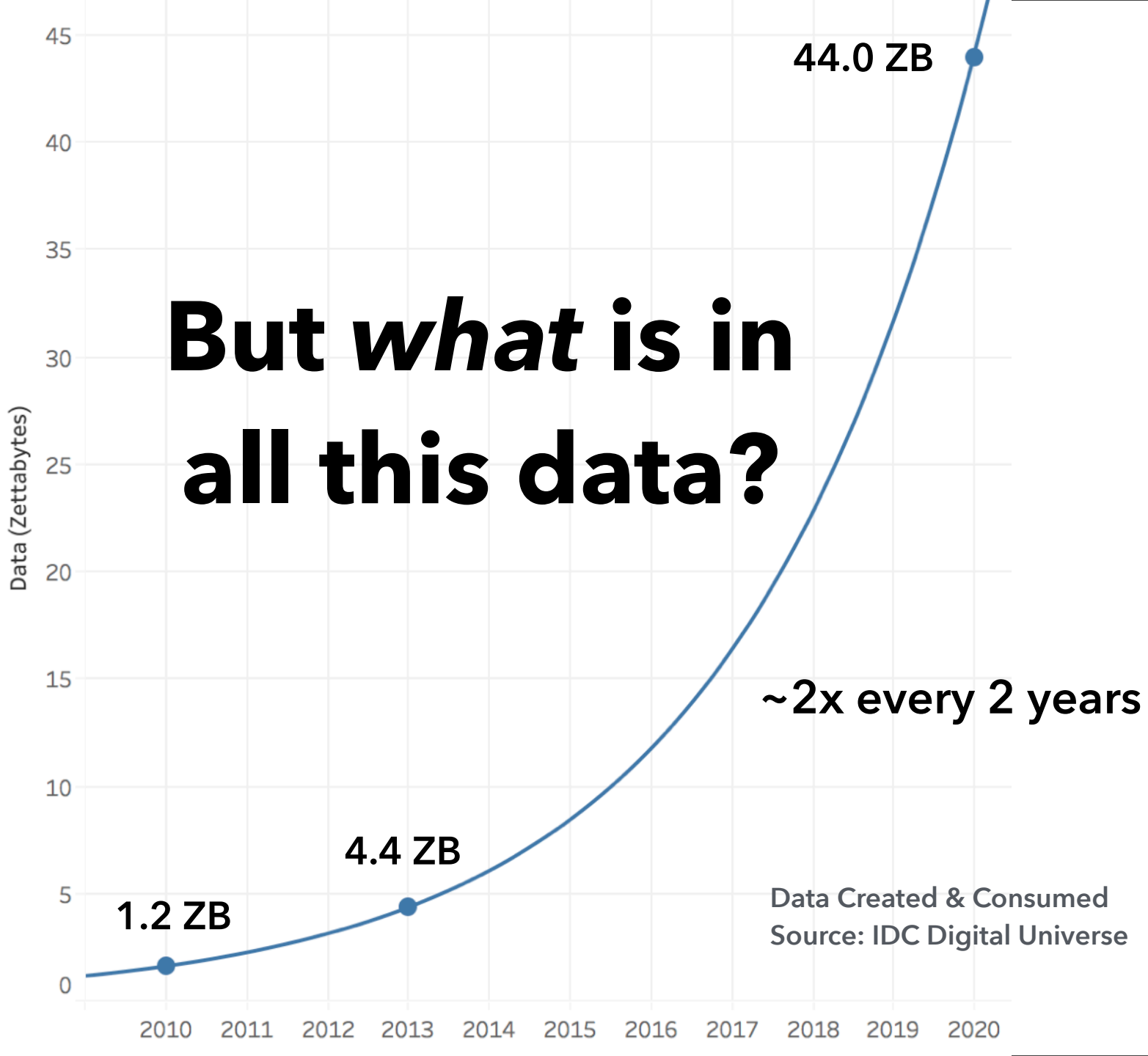
2010: 1,200 exabytes

Gantz et al., 2008, 2010

2010: 1,200 exabytes
and exponential growth…

Gantz et al., 2008, 2010


Data (Zettabytes)
0
5
10
15
20
25
30
35
40
45
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
1.2 ZB
4.4 ZB
44.0 ZB
~2x every 2 years
Data Created & Consumed
Source: IDC Digital Universe


But *what* is in all this data?
Data (Zettabytes)
45
40
35
30
25
20
15
10
5
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
1.2 ZB
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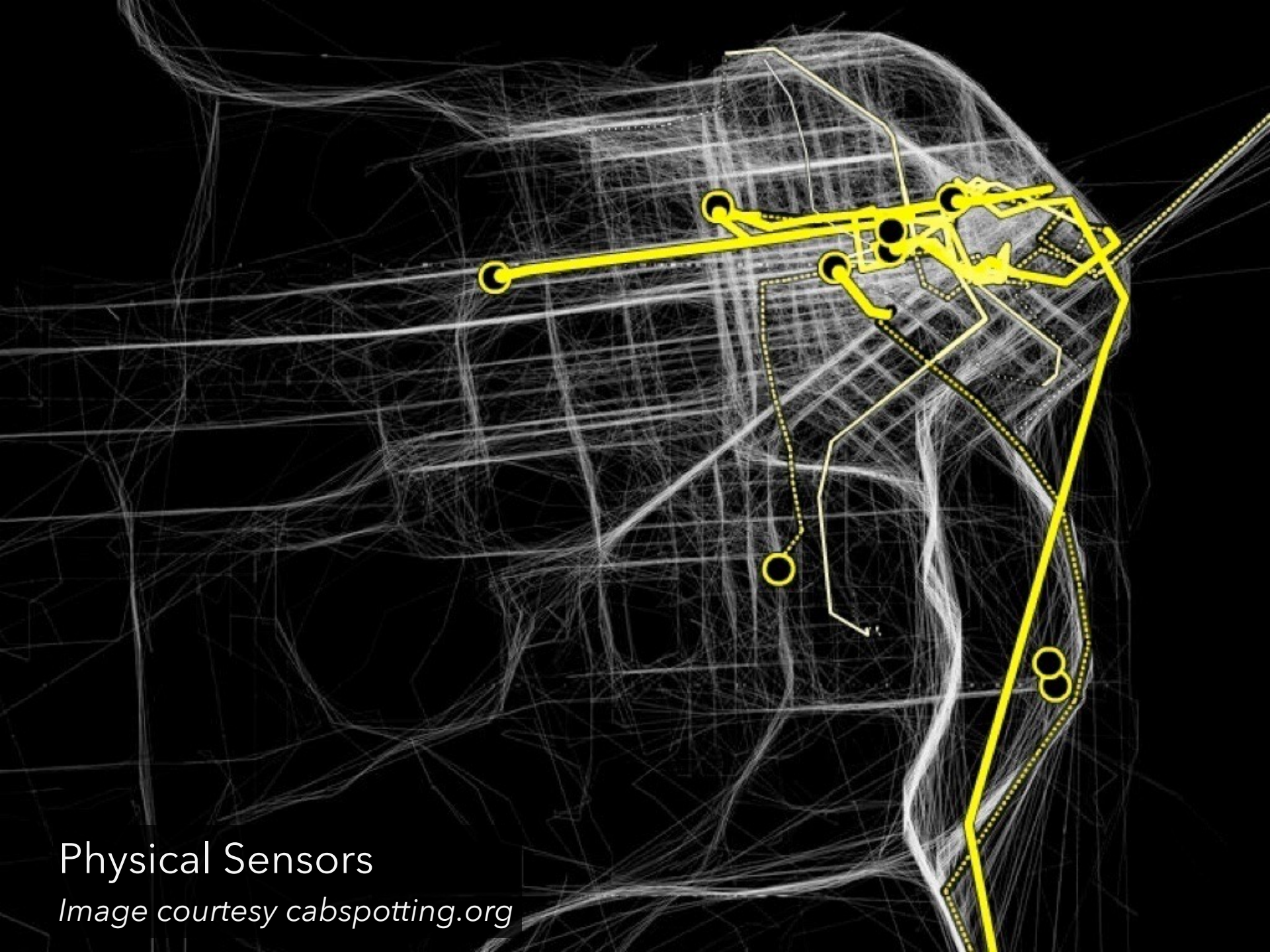
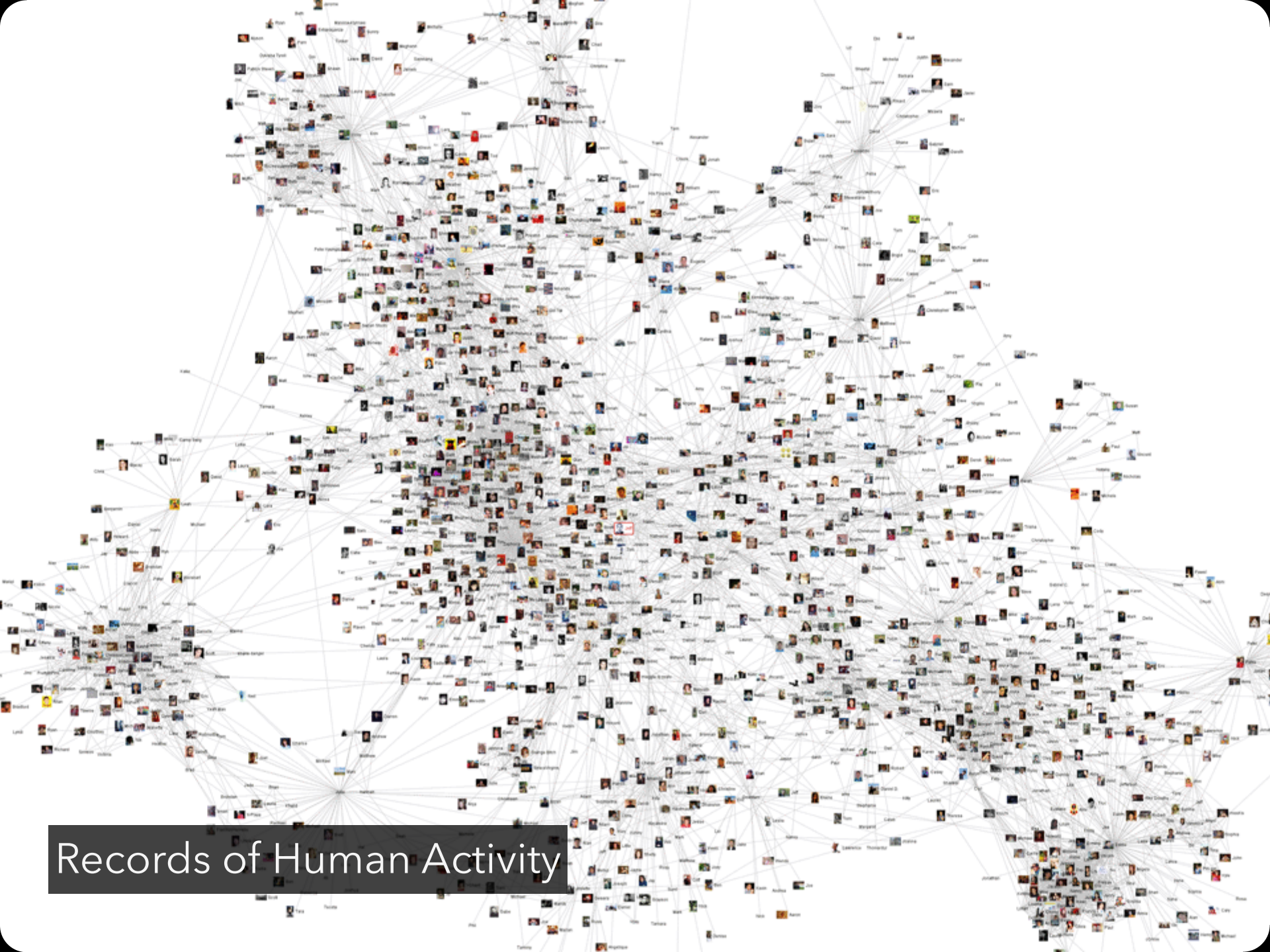


Physical Sensors

Image courtesy cabspotting.org

Health & Medicine


Records of Human Activity

The ability to take data—to be able to **understand** it, to **process** it, to **extract value** from it, to **visualize** it, to **communicate** it—that's going to be a hugely important skill in the next decades, … because now we really do have **essentially free and ubiquitous data**. So the complimentary scarce factor is the ability to understand that data and extract value from it.

Hal Varian, Google's Chief Economist
The McKinsey Quarterly, Jan 2009

But wait!

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"free" to whom?

"ubiquitous" about whom?

...to whose benefit?

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Life-size cutouts of Facebook CEO Mark Zuckerberg are displayed by a progressive advocacy group on the lawn of the U.S. Capitol on Tuesday.

Carolyn Kaster / Reuters

My Facebook Was Breached by Cambridge Analytica. Was Yours?

How to find out if you are one of the 87 million victims

ROBINSON MEYER | APR 10, 2018 | TECHNOLOGY

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Psychology's Replication Crisis Can't Be Wished Away

It has a real and heartbreaking cost.

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High potential for data abuse…

Inequality

Rise of the racist robots – how AI is learning all our worst impulses

There is a saying in computer science: garbage in, garbage out. When we feed machines data that reflects our prejudices, they mimic them – from antisemitic chatbots to racially biased software. Does a horrifying future await people forced to live at the mercy of algorithms?

…amplified by “big data” and ML systems.

Inequality

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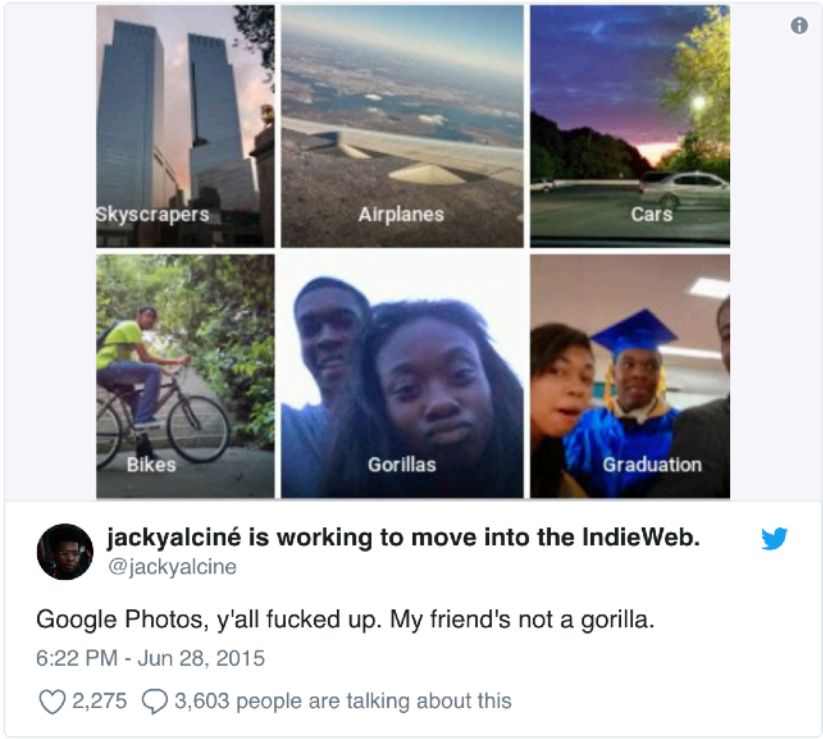

…amplified by “big data” and ML systems.

How might we use **visualization** to **empower understanding** of data and analysis processes?

What is Visualization?

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"Transformation of the symbolic into the geometric"

[McCormick et al. 1987]

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"... finding the artificial memory that best supports our natural means of perception." [Bertin 1967]

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"The use of computer-generated, interactive, visual representations of data to amplify cognition." [Card, Mackinlay, & Shneiderman 1999]

Set A

X	Y
10	8.04
8	6.95
13	7.58
9	8.81
11	8.33
14	9.96
6	7.24
4	4.26
12	10.84
7	4.82
5	5.68

Set B

X	Y
10	9.14
8	8.14
13	8.74
9	8.77
11	9.26
14	8.1
6	6.13
4	3.1
12	9.11
7	7.26
5	4.74

Set C

X	Y
10	7.46
8	6.77
13	12.74
9	7.11
11	7.81
14	8.84
6	6.08
4	5.39
12	8.15
7	6.42
5	5.73

Set D

X	Y
8	6.58
8	5.76
8	7.71
8	8.84
8	8.47
8	7.04
8	5.25
19	12.5
8	5.56
8	7.91
8	6.89

Set A		Set B		Set C		Set D	
X	Y	X	Y	X	Y	X	Y
10	8.04	10	9.14	10	7.46	8	6.58
8	6.95	8	8.14	8	6.77	8	5.76
13	7.58	13	8.74	13	12.74	8	7.71
9	8.81	9	8.77	9	7.11	8	8.84
11	8.33	11	9.26	11	7.81	8	8.47
14	9.96	14	8.1	14	8.84	8	7.04
6	7.24	6	6.13	6	6.08	8	5.25
4	4.26	4	3.1	4	5.39	19	12.5
12	10.84	12	9.11	12	8.15	8	5.56
7	4.82	7	7.26	7	6.42	8	7.91
5	5.68	5	4.74	5	5.73	8	6.89

Summary Statistics

$u_X = 9.0$ $\sigma_X = 3.317$

$u_Y = 7.5$ $\sigma_Y = 2.03$

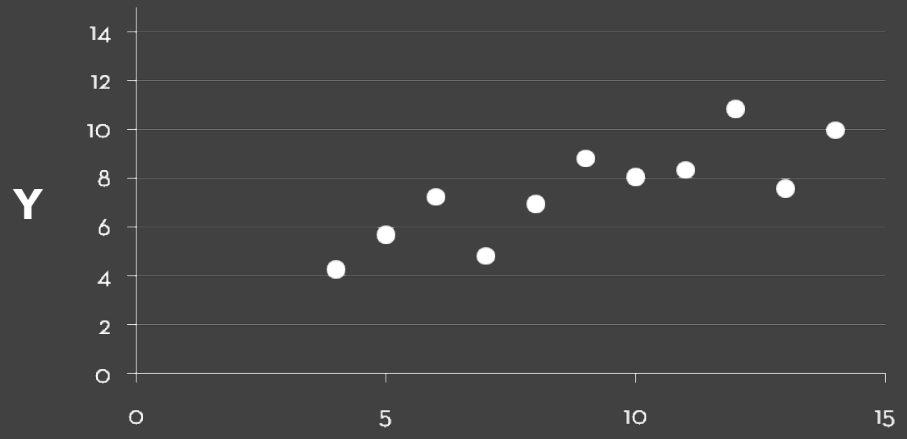
Linear Regression

$Y = 3 + 0.5\ X$

$R^2 = 0.67$

[Anscombe 1973]

Set A



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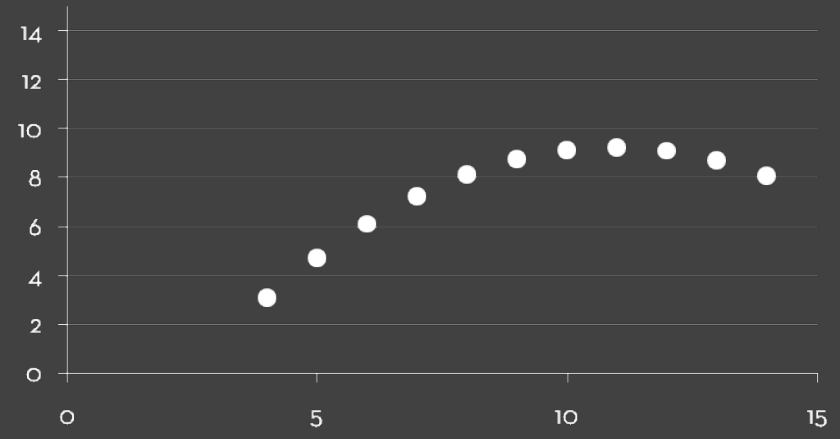

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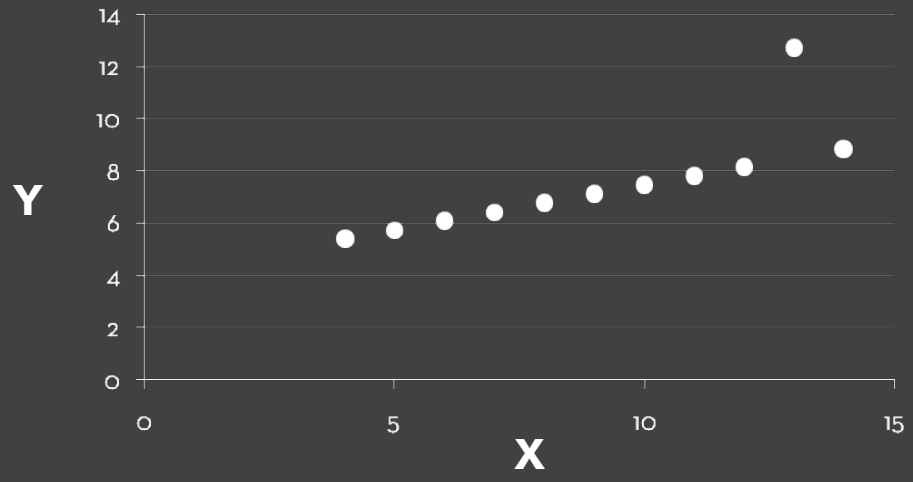
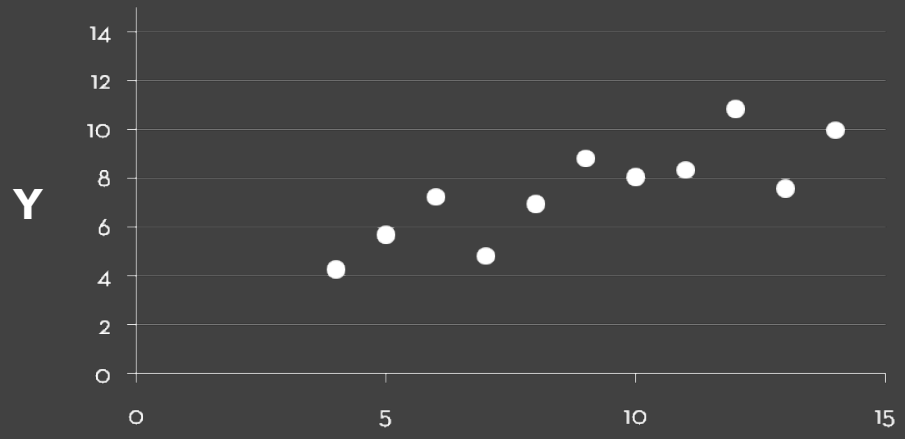


Set D

Set A



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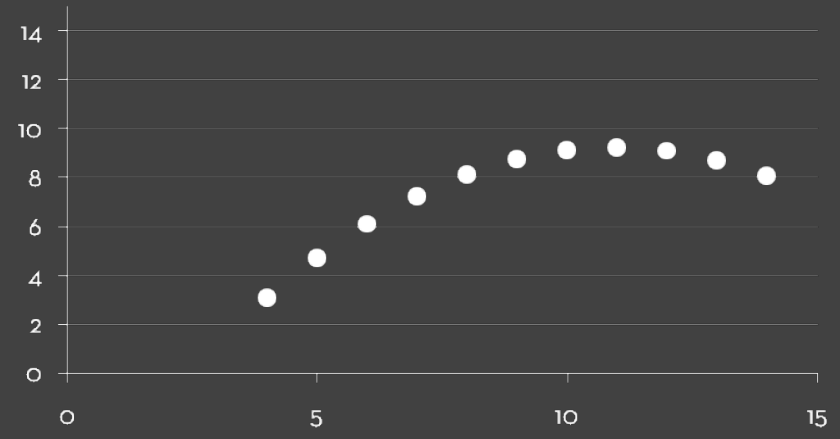

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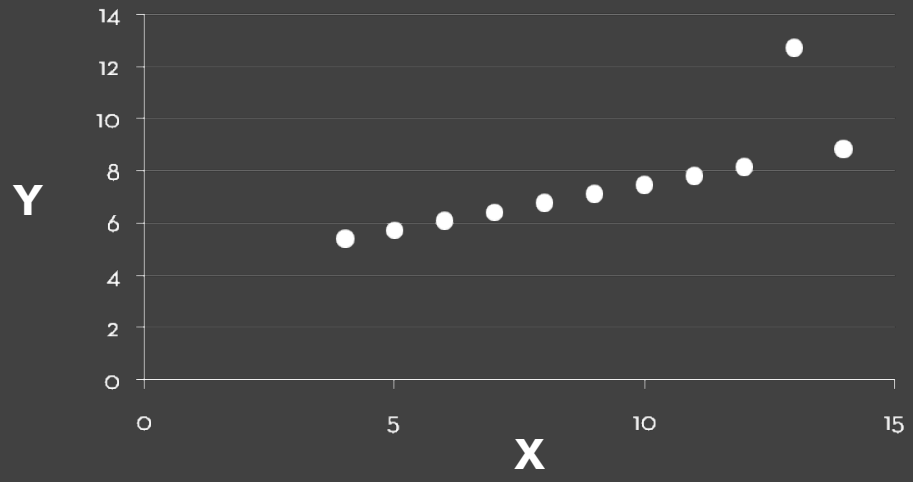
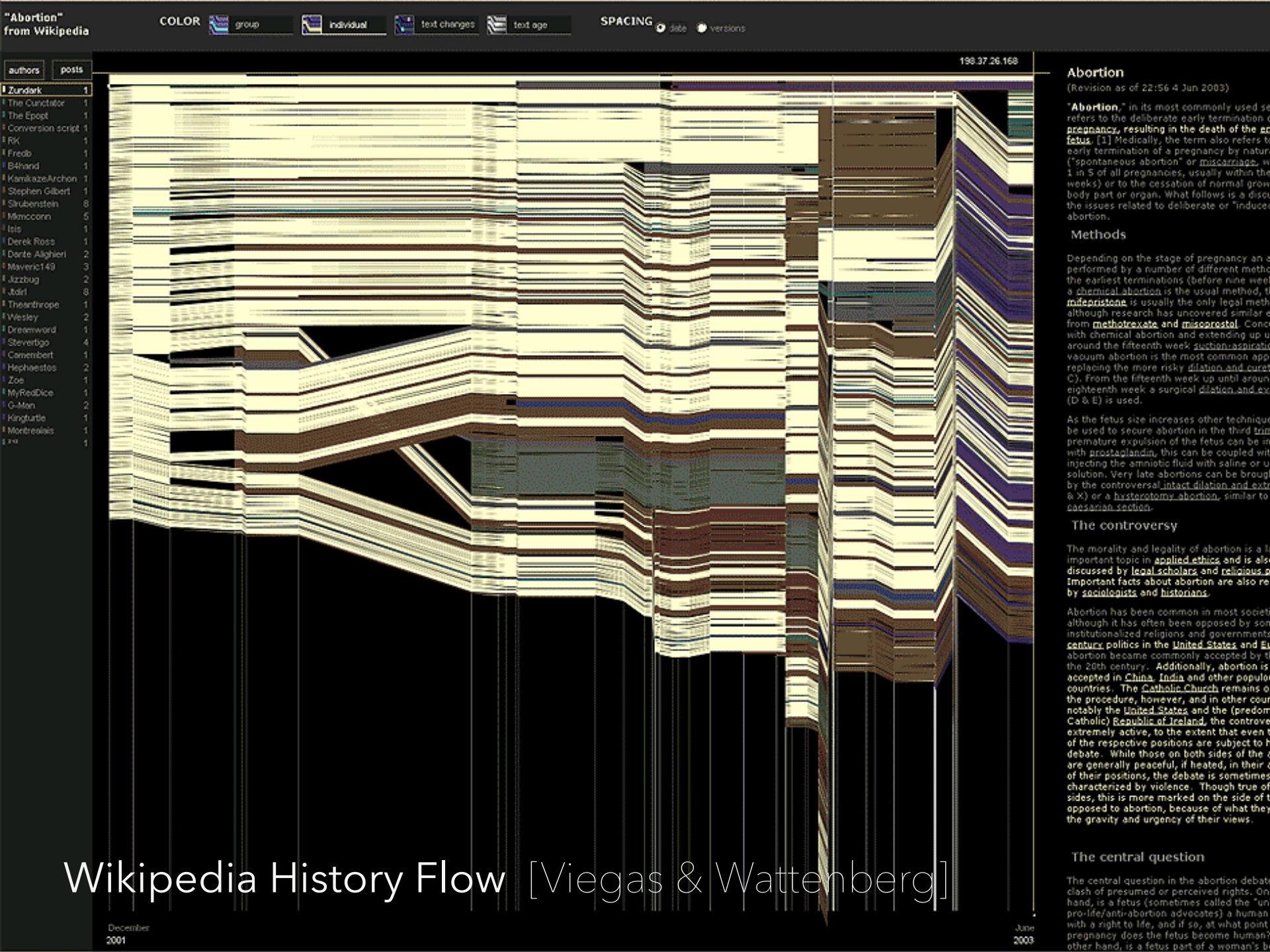
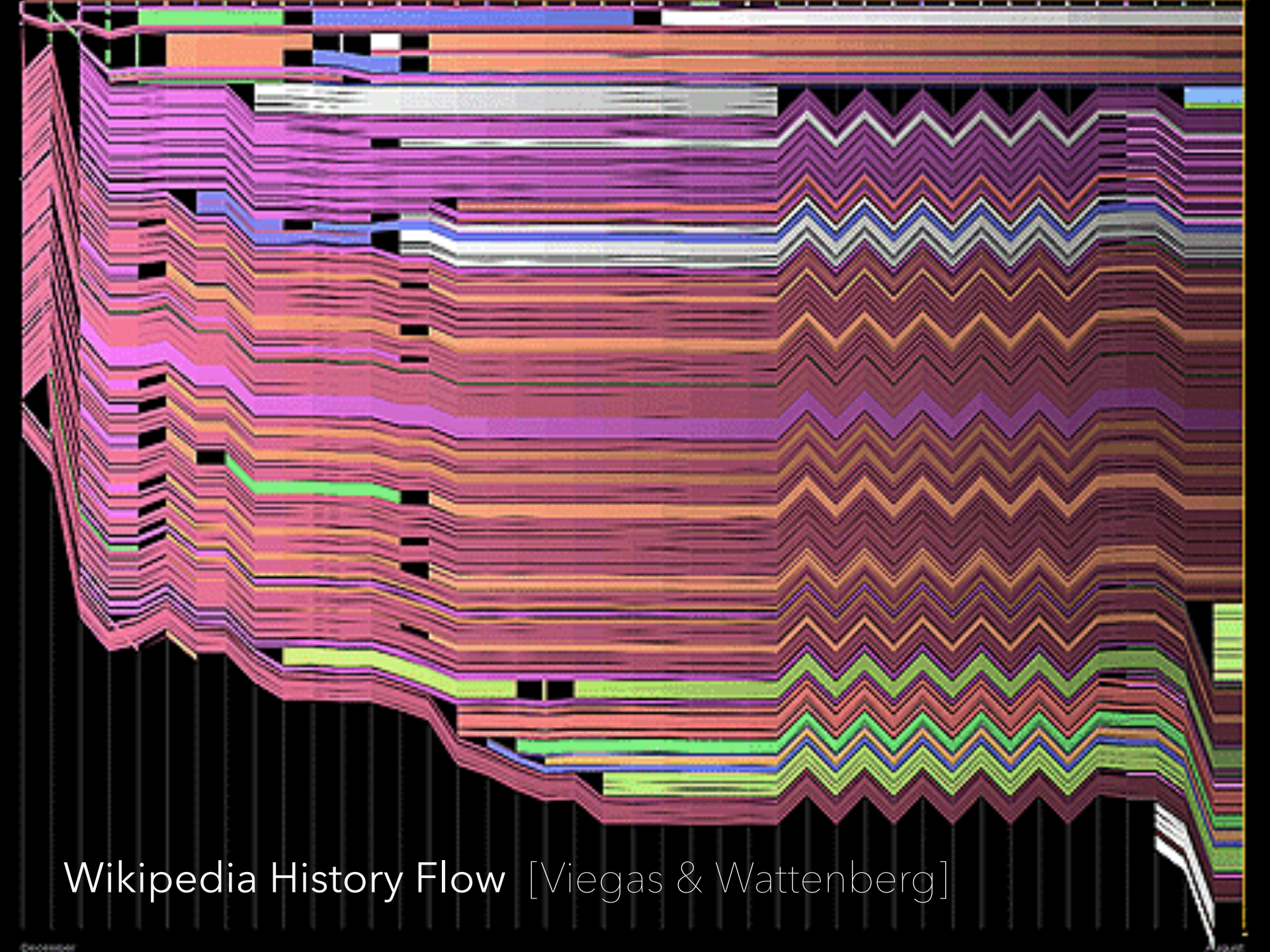


Set D

[Anscombe 1973]



Wikipedia History Flow [Viegas & Wattenberg]



Wikipedia History Flow [Viegas & Wattenberg]

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Why Create Visualizations?

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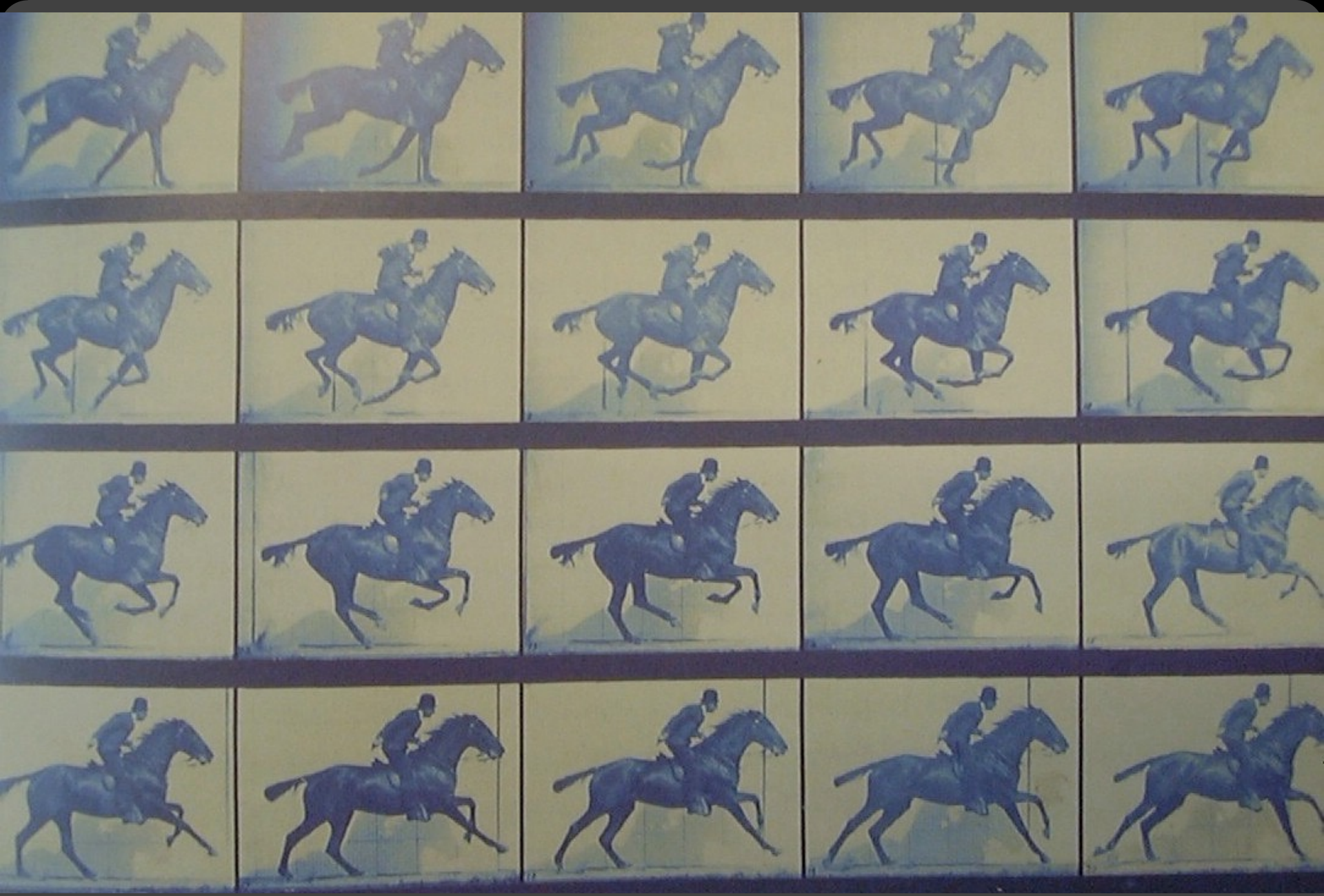
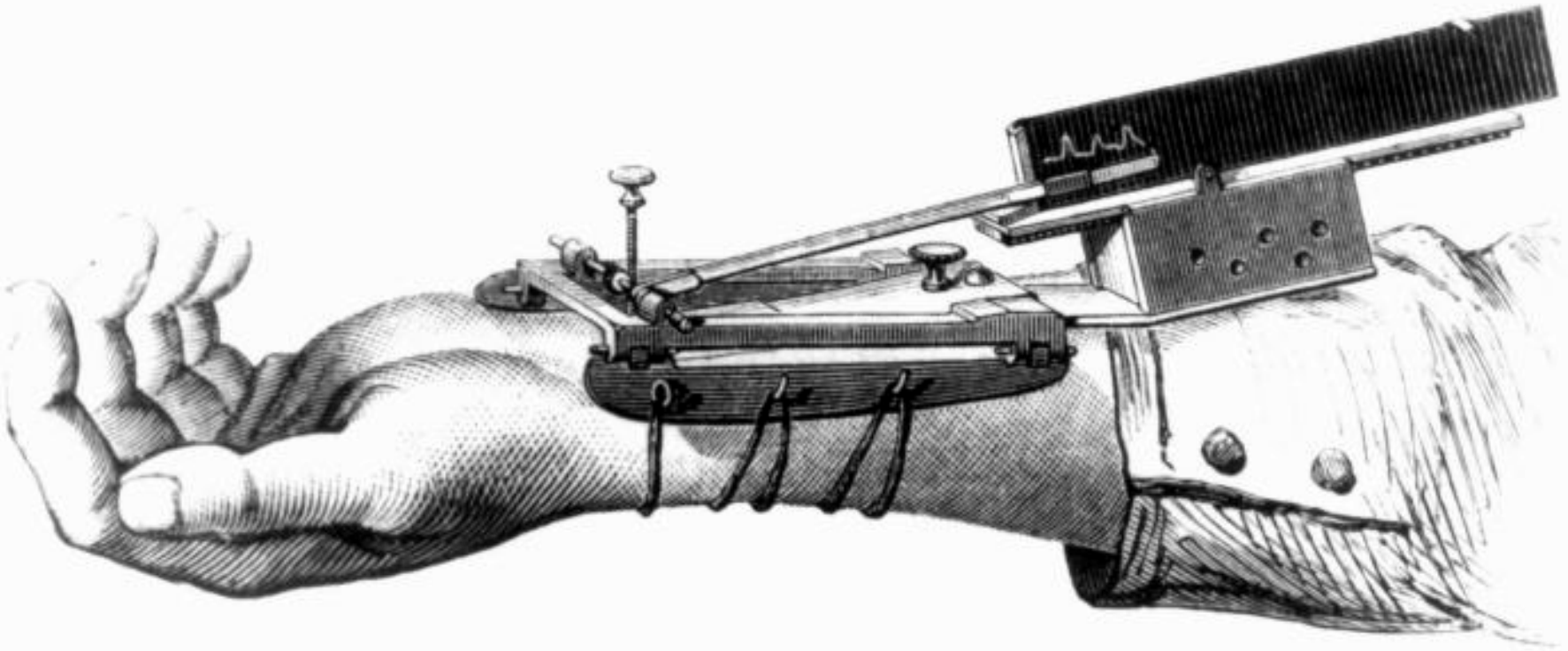
Answer questions (or discover them)
Make decisions
See data in context
Expand memory
Support graphical calculation
Find patterns
Present argument or tell a story
Inspire

Record Information

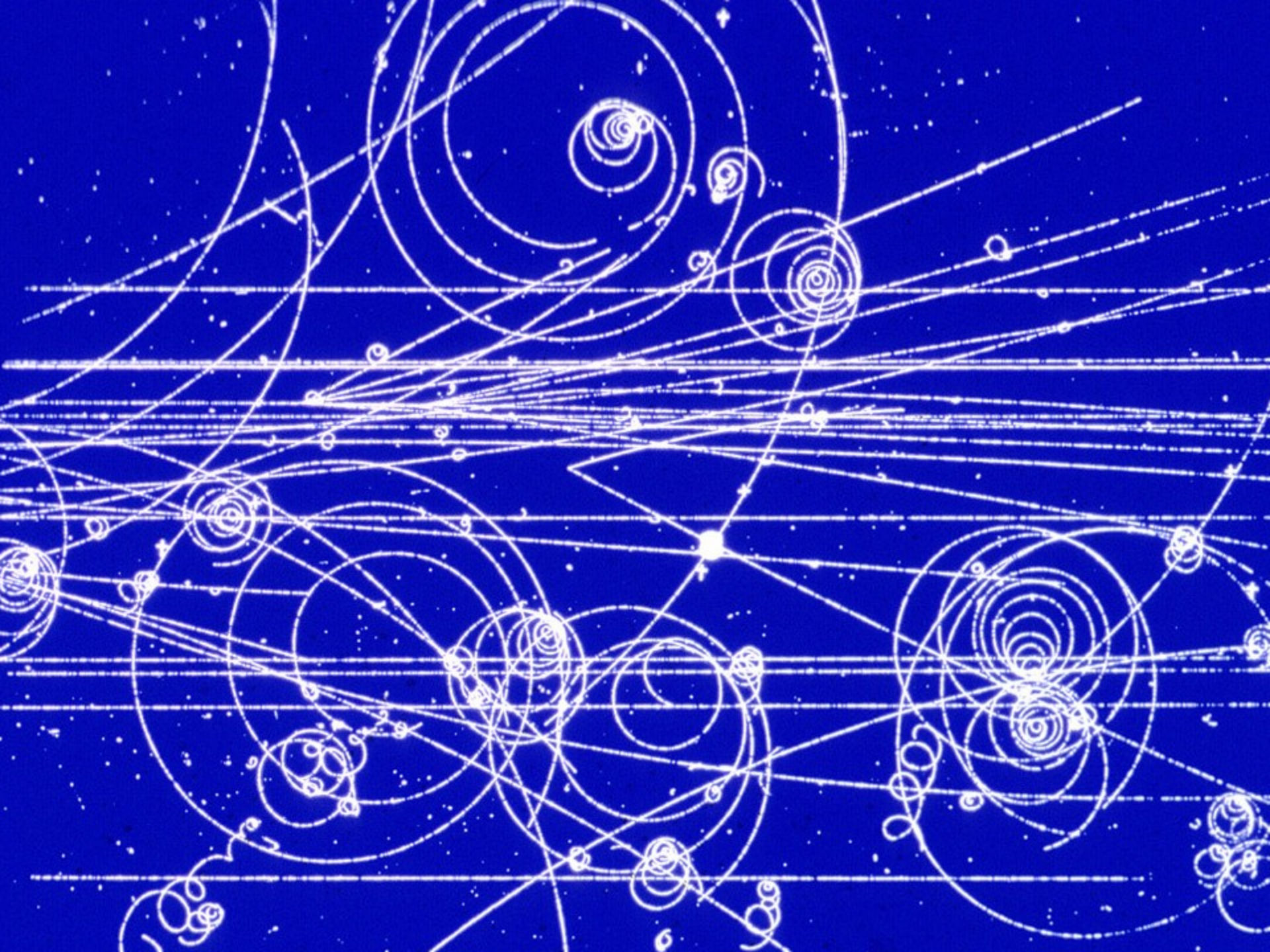


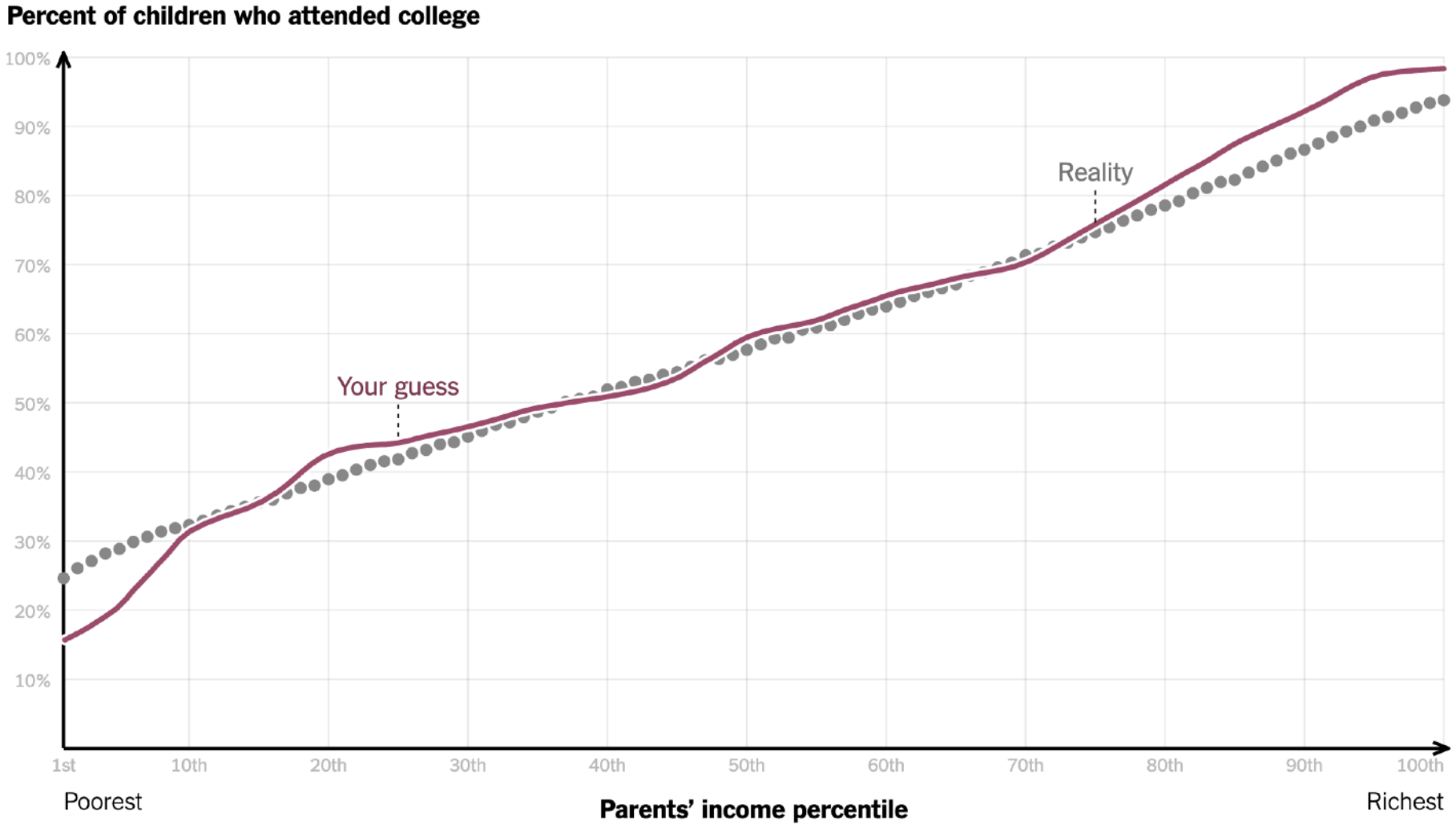
Gallop, Bay Horse “Daisy” [Muybridge]



1.
Marey's sphygmograph in use, 1860. *La méthode graphique dans les sciences expérimentales et principalement en physiologie et en médecine.*

E.J. Marey's sphygmograph [from Braun 83]





You Draw It: How Family Income Predicts Children's College Chances

[New York Times, May 28, 2015]

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Support Reasoning

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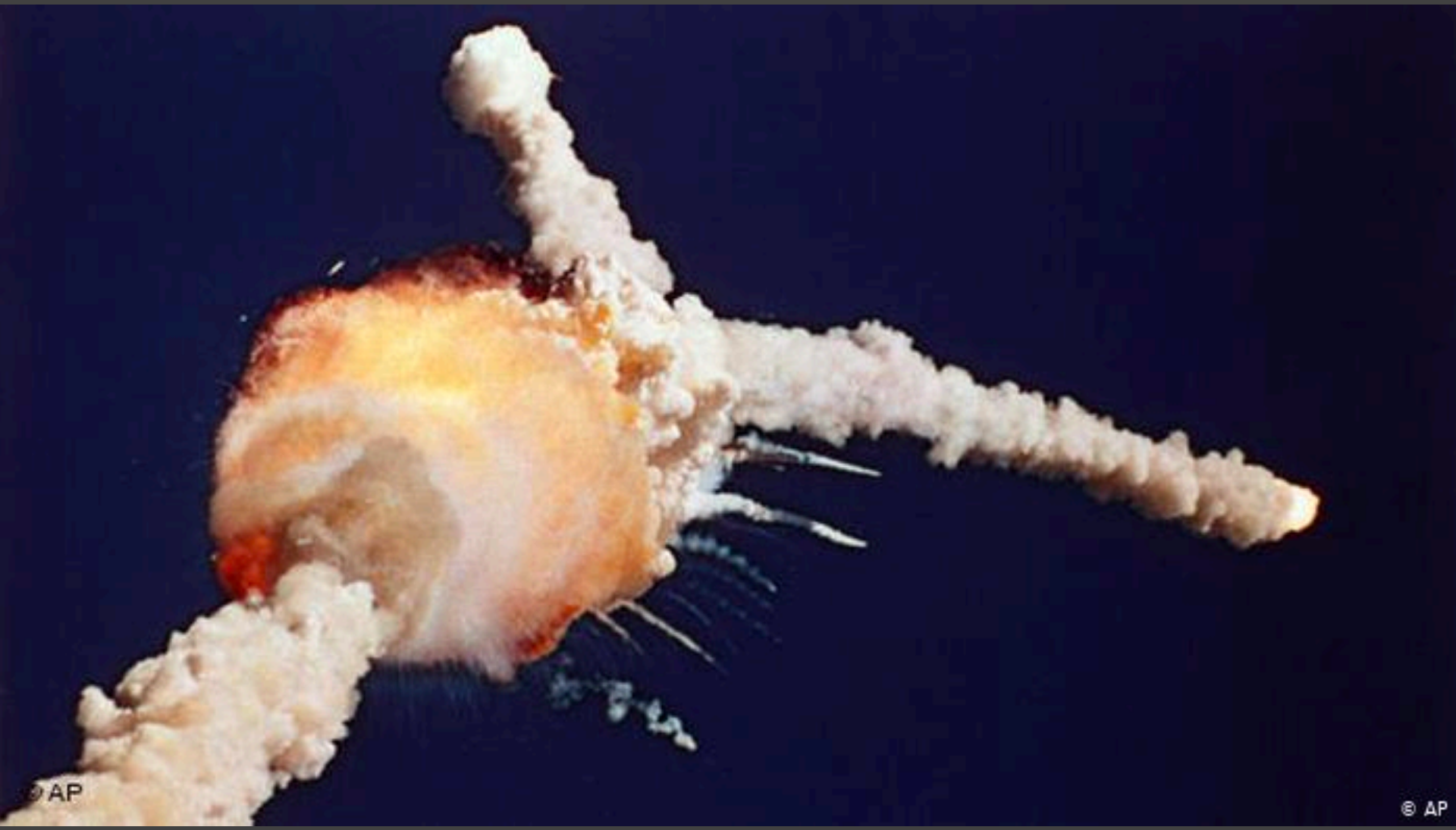
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HISTORY OF O-RING DAMAGE ON SRM FIELD JOINTS

	SRM No.	Cross Sectional View: Erosion Depth (in.)	Cross Sectional View: Perimeter Affected (deg)	Cross Sectional View: Nominal Dia. (in.)	Top View: Length Of Max Erosion (in.)	Top View: Total Heat Affected Length (in.)	Clocking Location (deg)
61A LH Center Field**	22A	None	None	0.280	None	None	36° --66°
61A LH ~~CENTER~~ FIELD**	22A	NONE	NONE	0.280	NONE	NONE	338°-18°
51C LH Forward Field**	15A	0.010	154.0	0.280	4.25	5.25	163
51C RH Center Field (prim)***	15B	0.038	130.0	0.280	12.50	58.75	354
51C RH Center Field (sec)***	15B	None	45.0	0.280	None	29.50	354
41D RH Forward Field	13B	0.028	110.0	0.280	3.00	None	275
41C LH Aft Field*	11A	None	None	0.280	None	None	--
41B LH Forward Field	10A	0.040	217.0	0.280	3.00	14.50	351
STS-2 RH Aft Field	2B	0.053	116.0	0.280	--	--	90

*Hot gas path detected in putty. Indication of heat on O-ring, but no damage.
**Soot behind primary O-ring.
***Soot behind primary O-ring, heat affected secondary O-ring.

Clocking location of leak check port - 0 deg.

OTHER SRM-15 FIELD JOINTS HAD NO BLOWHOLES IN PUTTY AND NO SOOT NEAR OR BEYOND THE PRIMARY O-RING.

SRM-22 FORWARD FIELD JOINT HAD PUTTY PATH TO PRIMARY O-RING, BUT NO O-RING EROSION AND NO SOOT BLOWBY. OTHER SRM-22 FIELD JOINTS HAD NO BLOWHOLES IN PUTTY.

Blow By History

SRM-15 worst Blow-By
- 2 case joints (80°), (110°) arc
- much worse visually than SRM-22

SRM 22 Blow-By
- 2 case joints (30-40°)

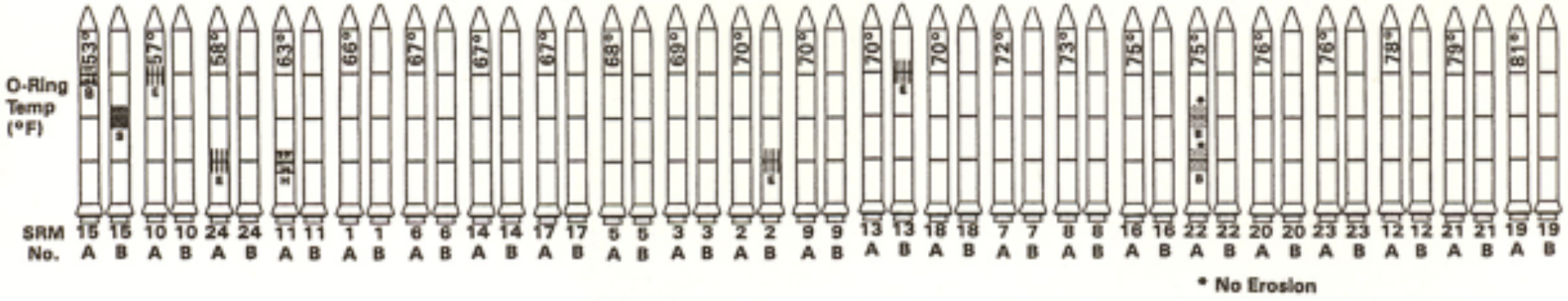
SRM-13A, 15, 16A, 18, 23A 24A
- nozzle Blow-By

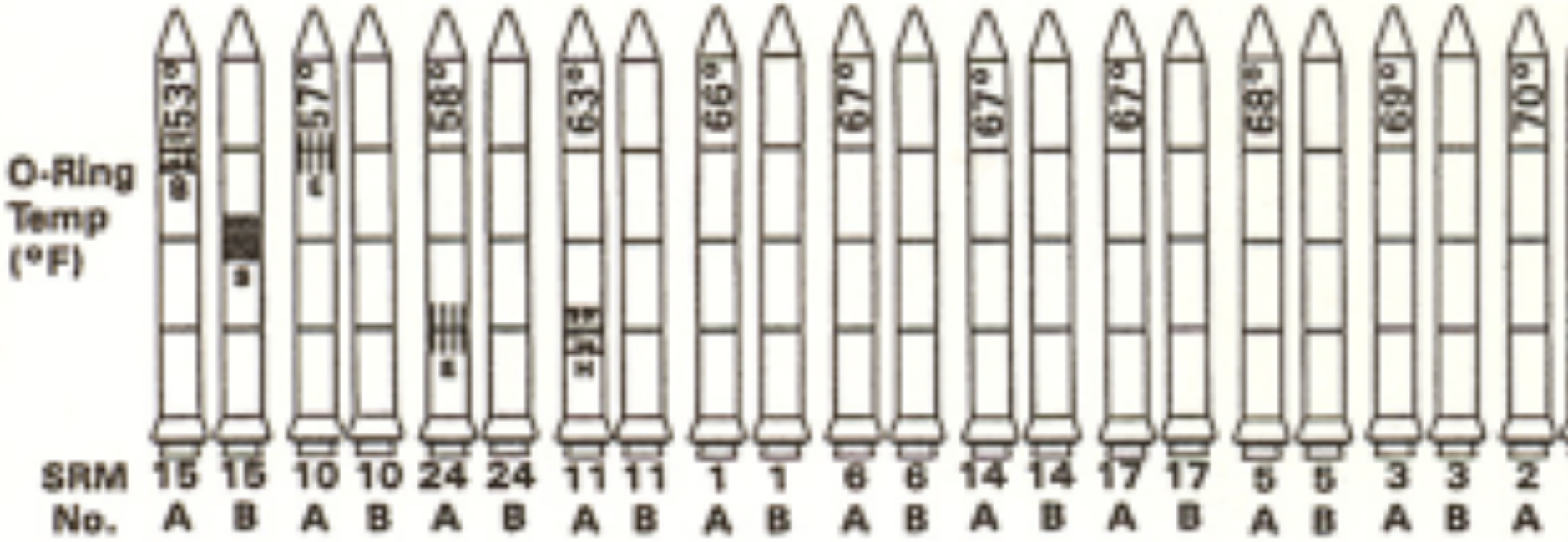
History of O-ring Temperatures (Degrees-F)

Motor	MBT	Amb	O-ring	Wind
DM-1	68	36	47	10 mph
DM-2	76	45	52	10 mph
QM-3	72.5	40	48	10 mph
QM-4	76	48	51	10 mph
SRM-15	52	64	53	10 mph
SRM-22	77	78	75	10 mph
SRM-25	55	26	29 27	10 mph 25 mph

2 of 13 pages of material faxed to NASA by Morton Thiokol [from Tufte 1997]

Make Decisions: Challenger





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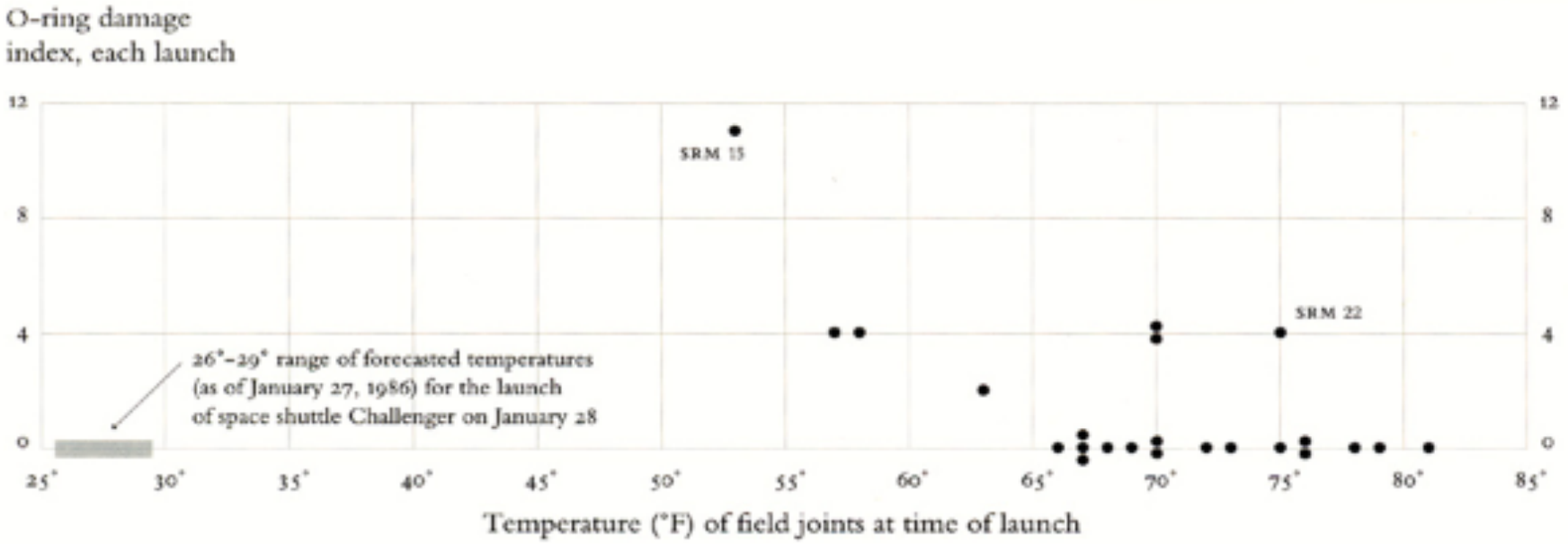
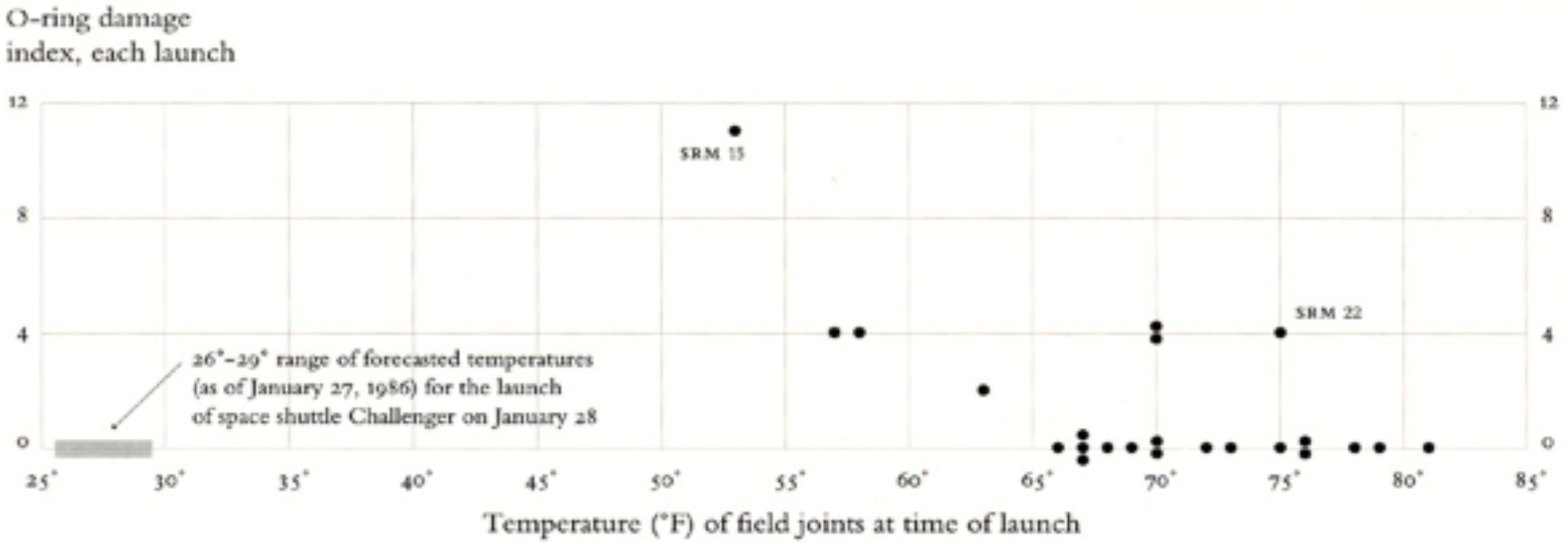


Chart of temperatures vs. O-ring damage [Tufte 97]

Make Decisions: Challenger



But wait! What is an appropriate "damage index"?
Which temperatures, O-ring or outside air?

Chart of temperatures vs. O-ring damage [Tufte 97]

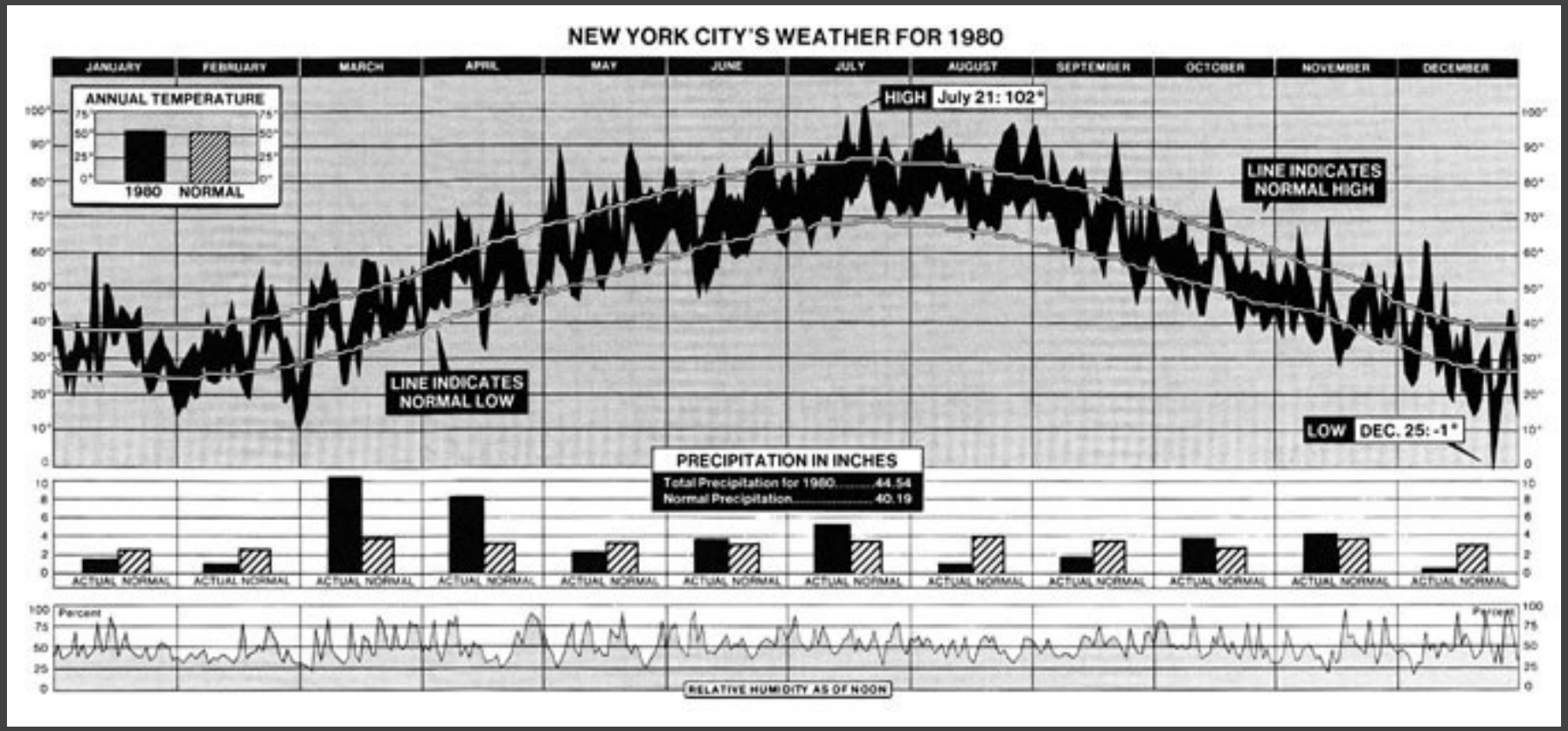
Data in Context: Cholera Outbreak

In 1854 John Snow plotted the position of each cholera case on a map. [from Tufte 83]

Data in Context: Cholera Outbreak

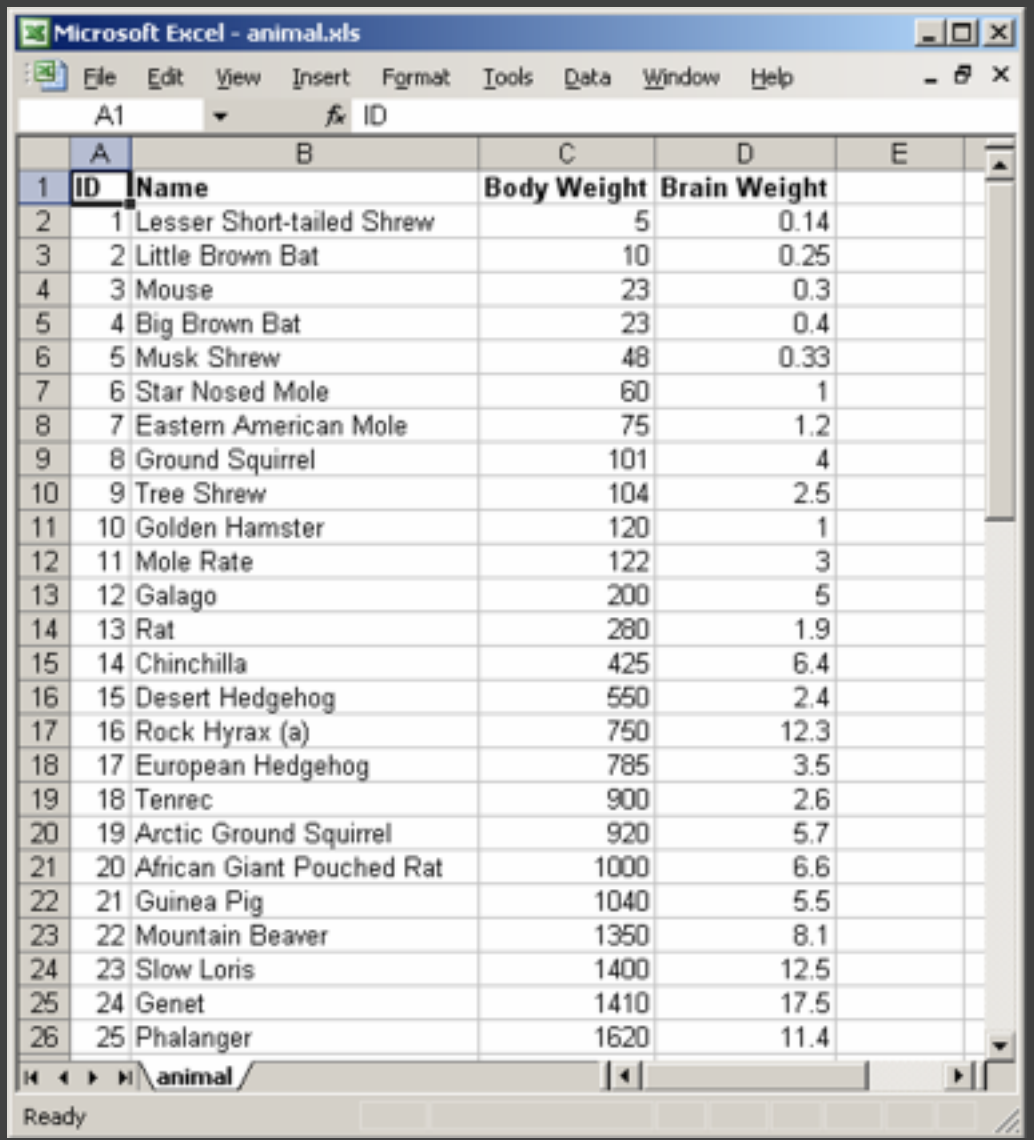
Used map to hypothesize that pump on Broad St. was the cause. [from Tufte 83]

Find Patterns: NYC Weather

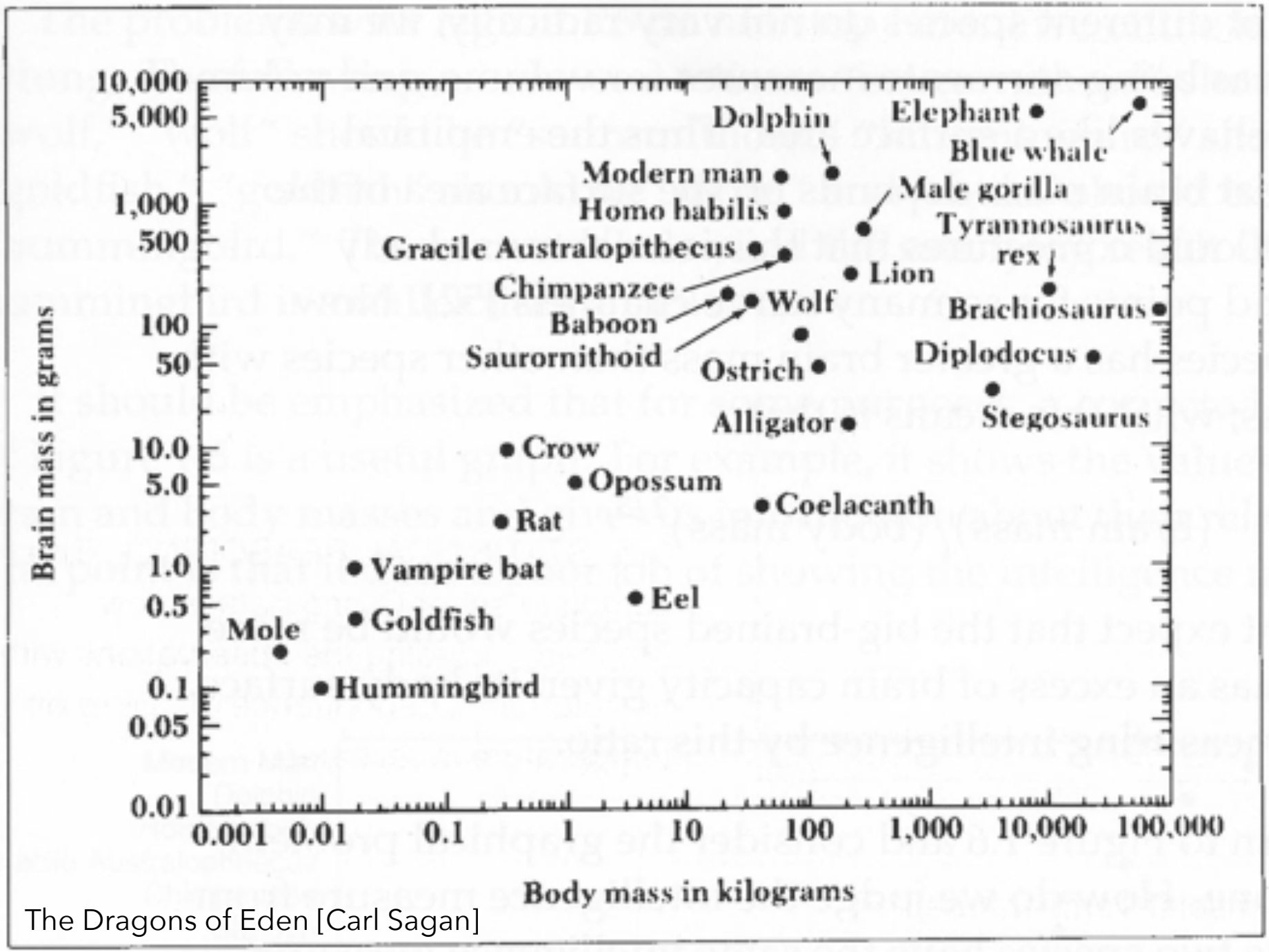


[New York Times 1981]

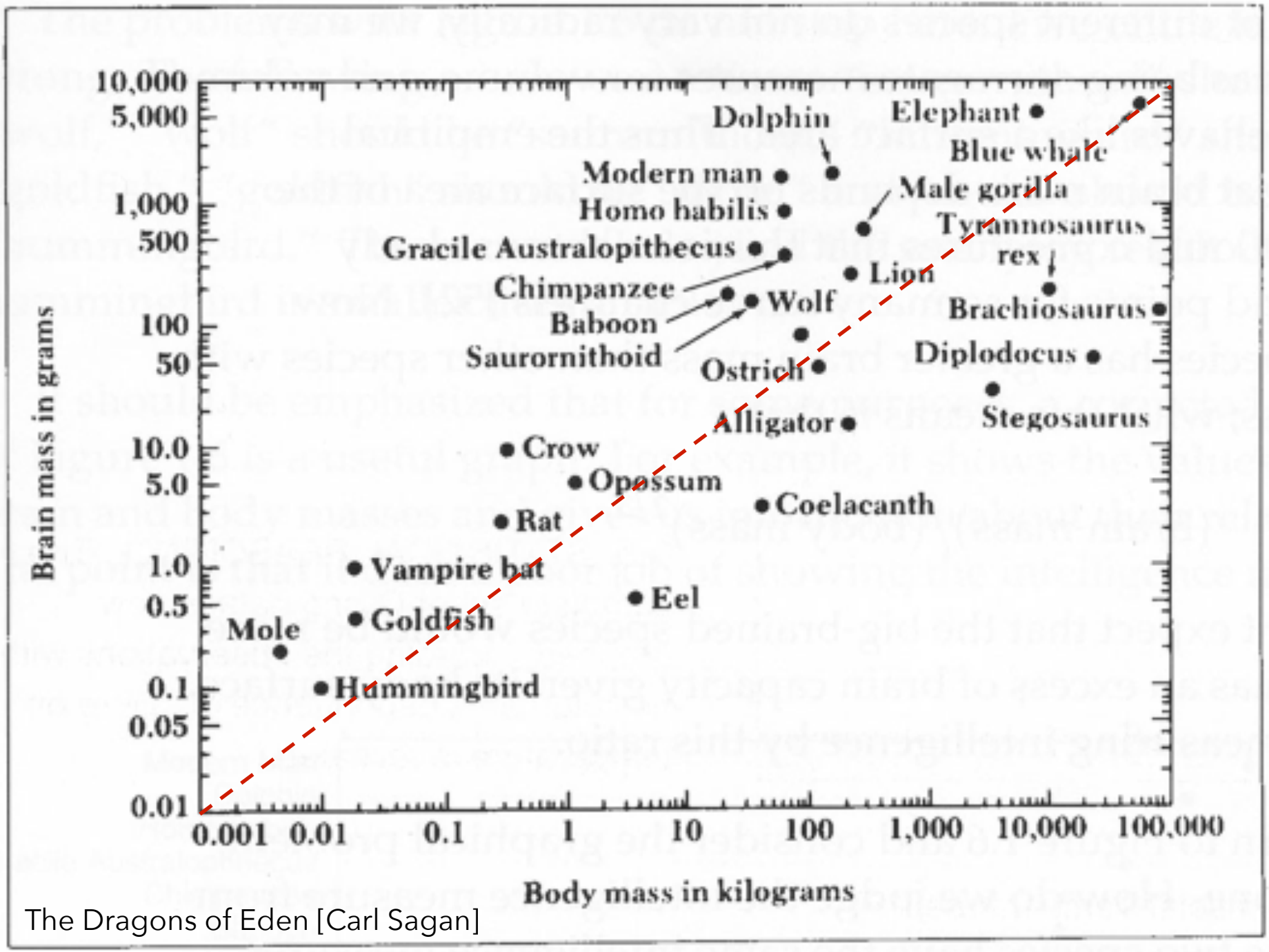
Answer Questions: Brain Power?



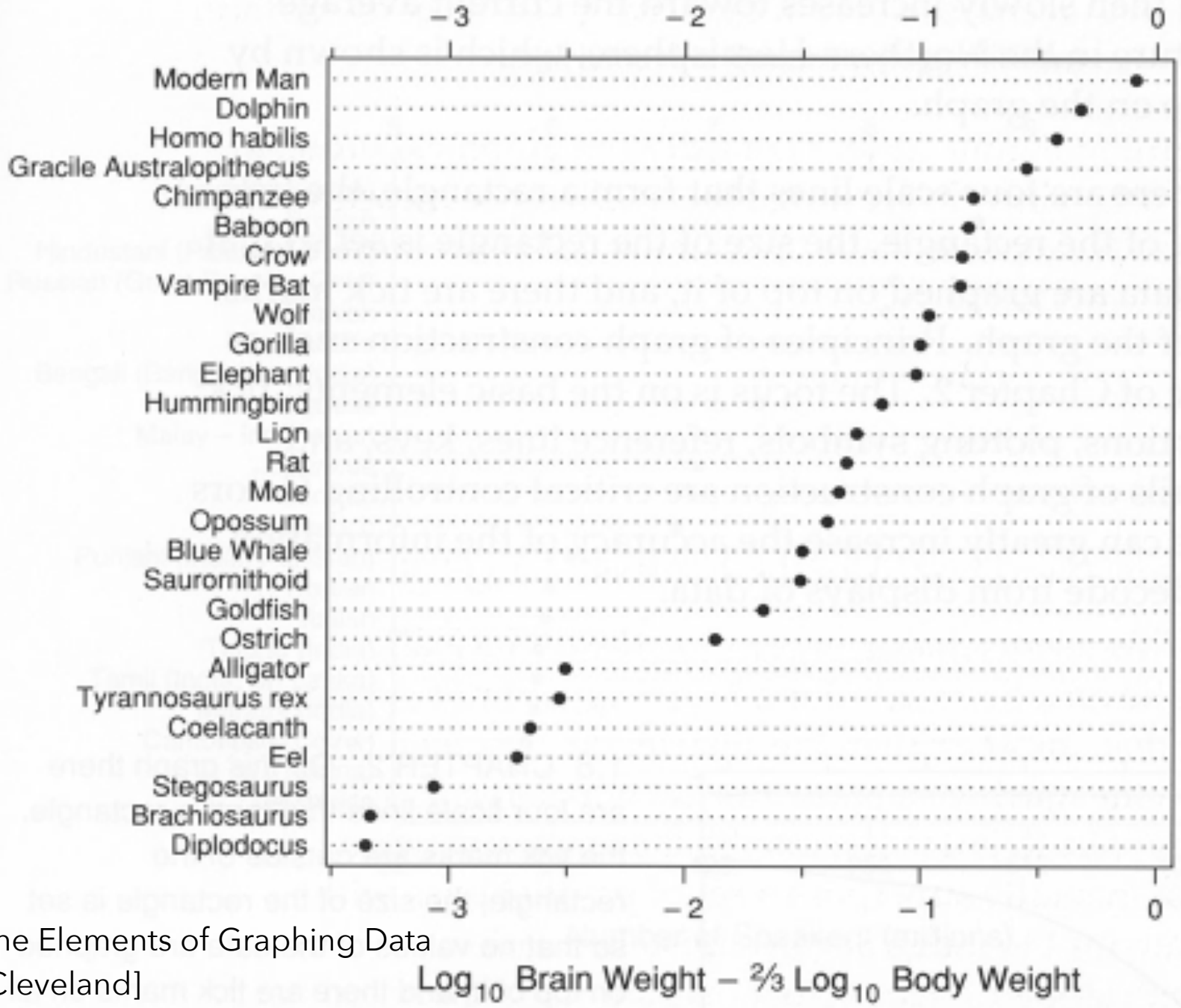
	A	B	C	D	E
1	ID	Name	Body Weight	Brain Weight	
2	1	Lesser Short-tailed Shrew	5	0.14	
3	2	Little Brown Bat	10	0.25	
4	3	Mouse	23	0.3	
5	4	Big Brown Bat	23	0.4	
6	5	Musk Shrew	48	0.33	
7	6	Star Nosed Mole	60	1	
8	7	Eastern American Mole	75	1.2	
9	8	Ground Squirrel	101	4	
10	9	Tree Shrew	104	2.5	
11	10	Golden Hamster	120	1	
12	11	Mole Rate	122	3	
13	12	Galago	200	5	
14	13	Rat	280	1.9	
15	14	Chinchilla	425	6.4	
16	15	Desert Hedgehog	550	2.4	
17	16	Rock Hyrax (a)	750	12.3	
18	17	European Hedgehog	785	3.5	
19	18	Tenrec	900	2.6	
20	19	Arctic Ground Squirrel	920	5.7	
21	20	African Giant Pouched Rat	1000	6.6	
22	21	Guinea Pig	1040	5.5	
23	22	Mountain Beaver	1350	8.1	
24	23	Slow Loris	1400	12.5	
25	24	Genet	1410	17.5	
26	25	Phalanger	1620	11.4	



The Dragons of Eden [Carl Sagan]

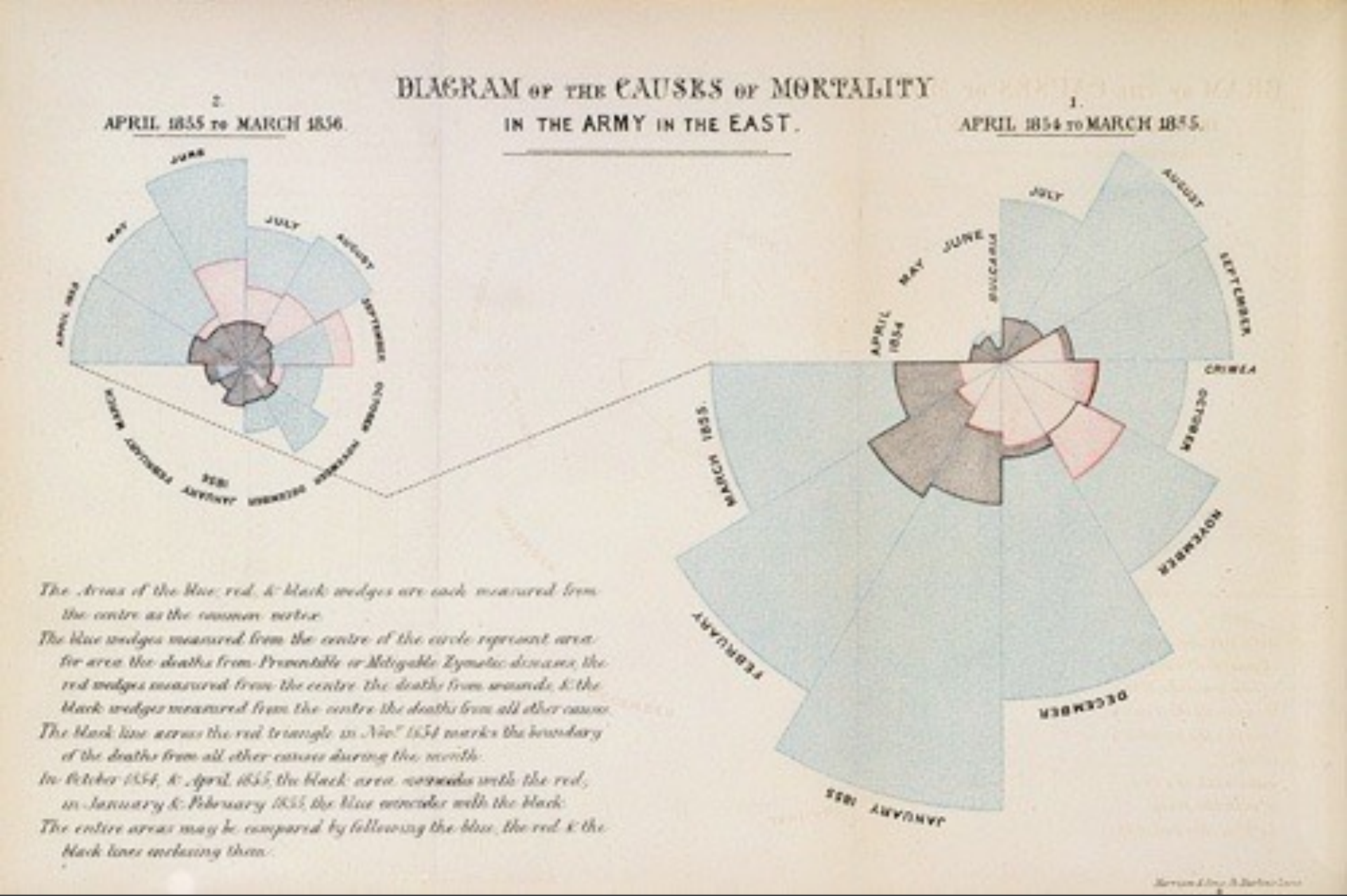


The Dragons of Eden [Carl Sagan]

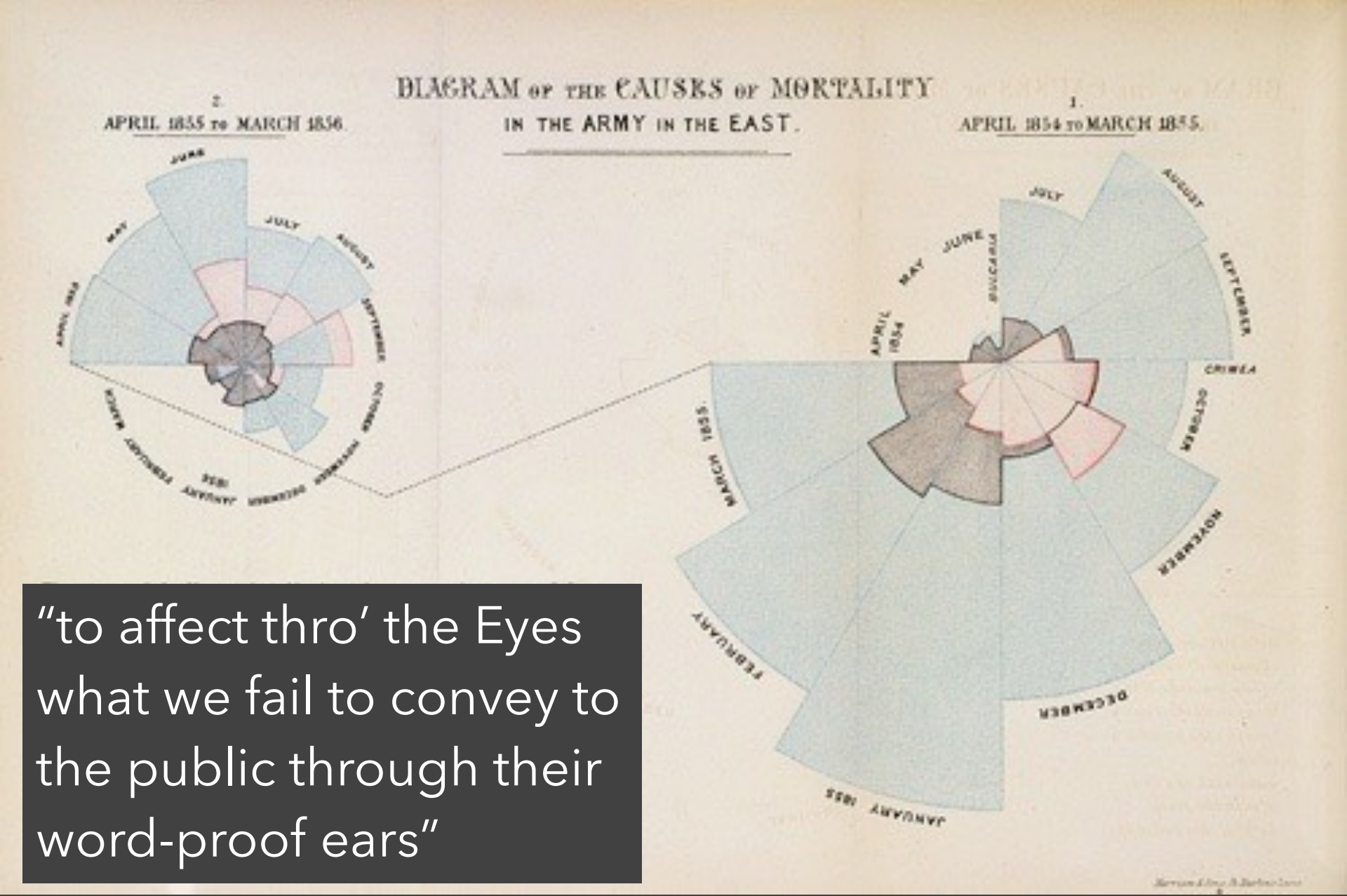


The Elements of Graphing Data
[Cleveland]

Convey Information



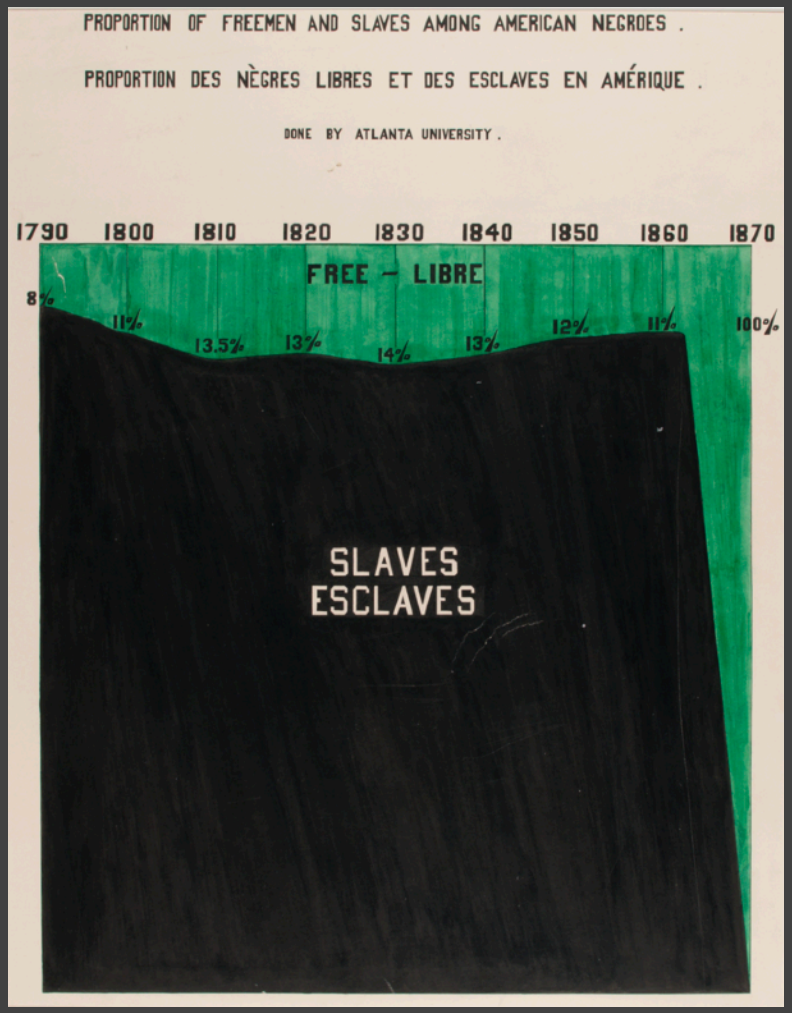
1856 “Coxcomb” of Crimean War Deaths, Florence Nightingale



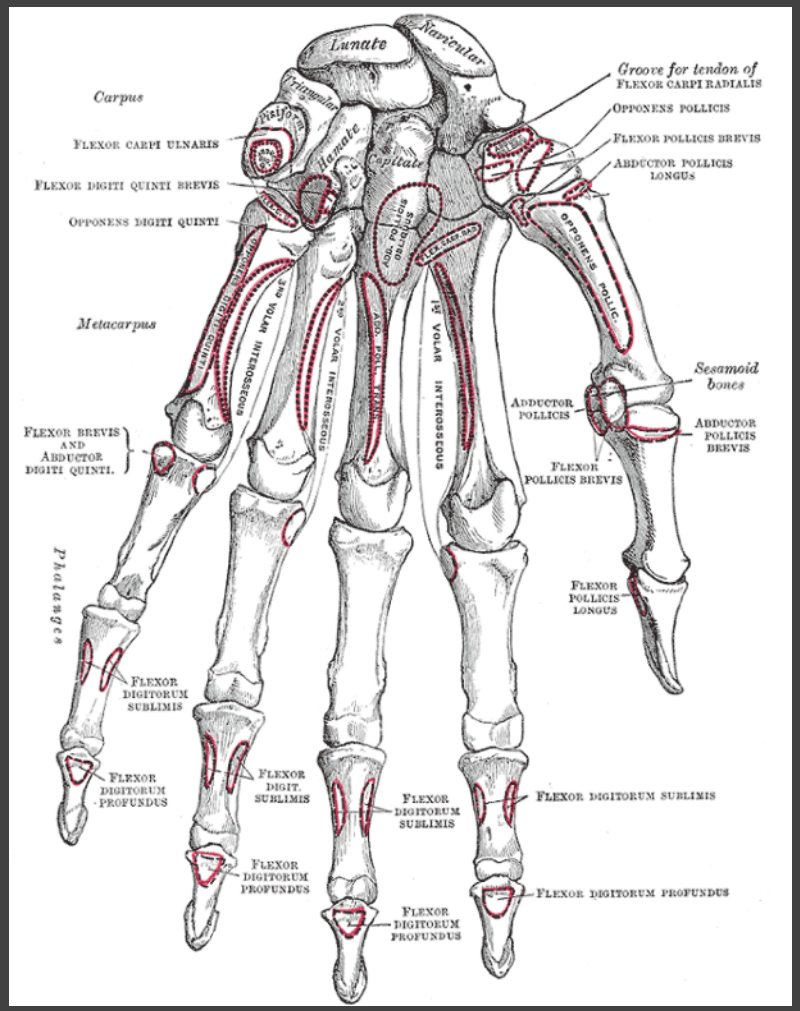
"to affect thro' the Eyes what we fail to convey to the public through their word-proof ears"

1856 "Coxcomb" of Crimean War Deaths, Florence Nightingale

Communicate, Inform, Inspire



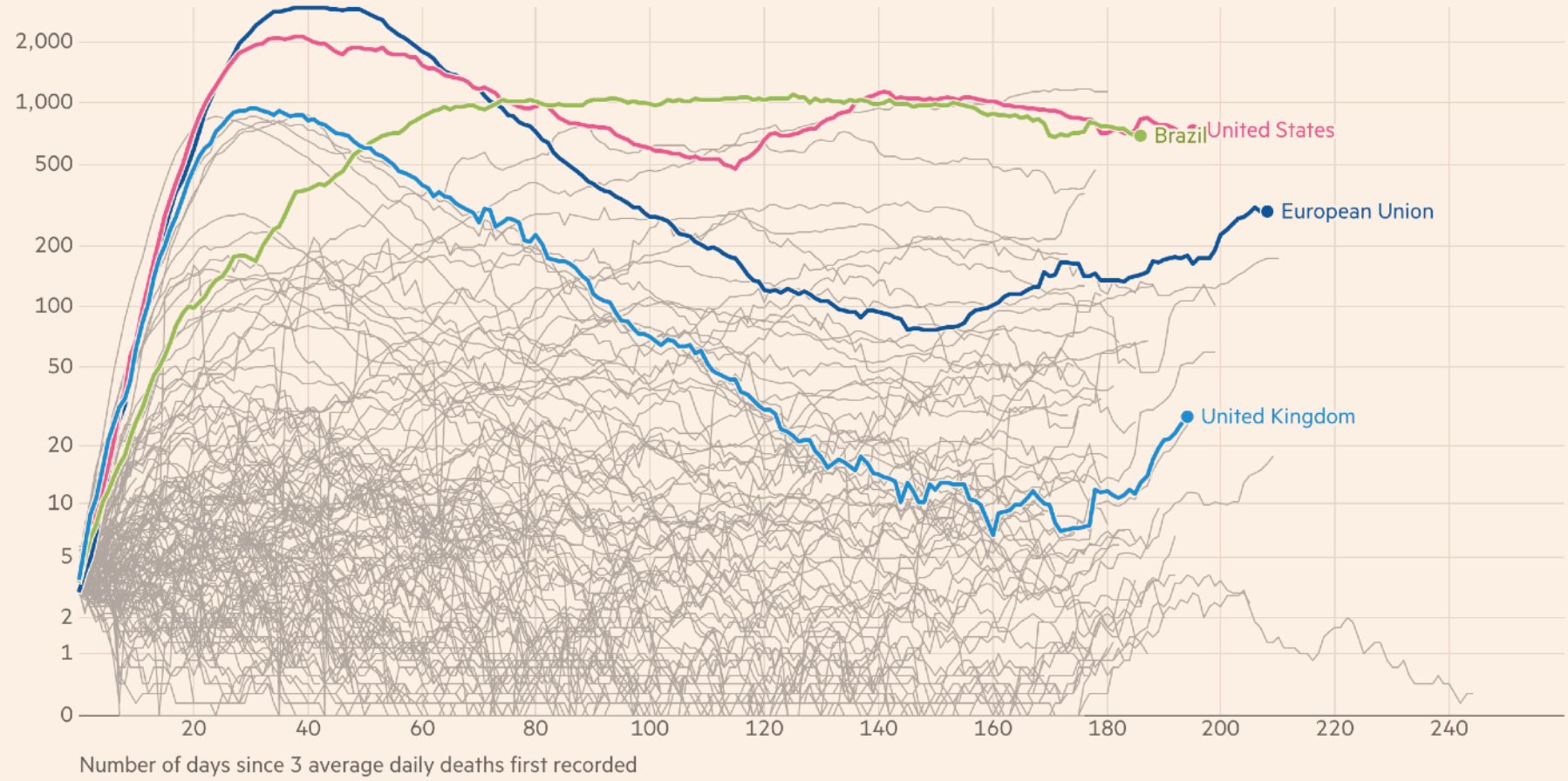
Visualizing Black America, Du Bois et al. 1900



Bones in hand, Gray's Anatomy 1918 ed.

New deaths attributed to Covid-19 in European Union, United States, Brazil and United Kingdom

Seven-day rolling average of new deaths, by number of days since 3 average daily deaths first recorded



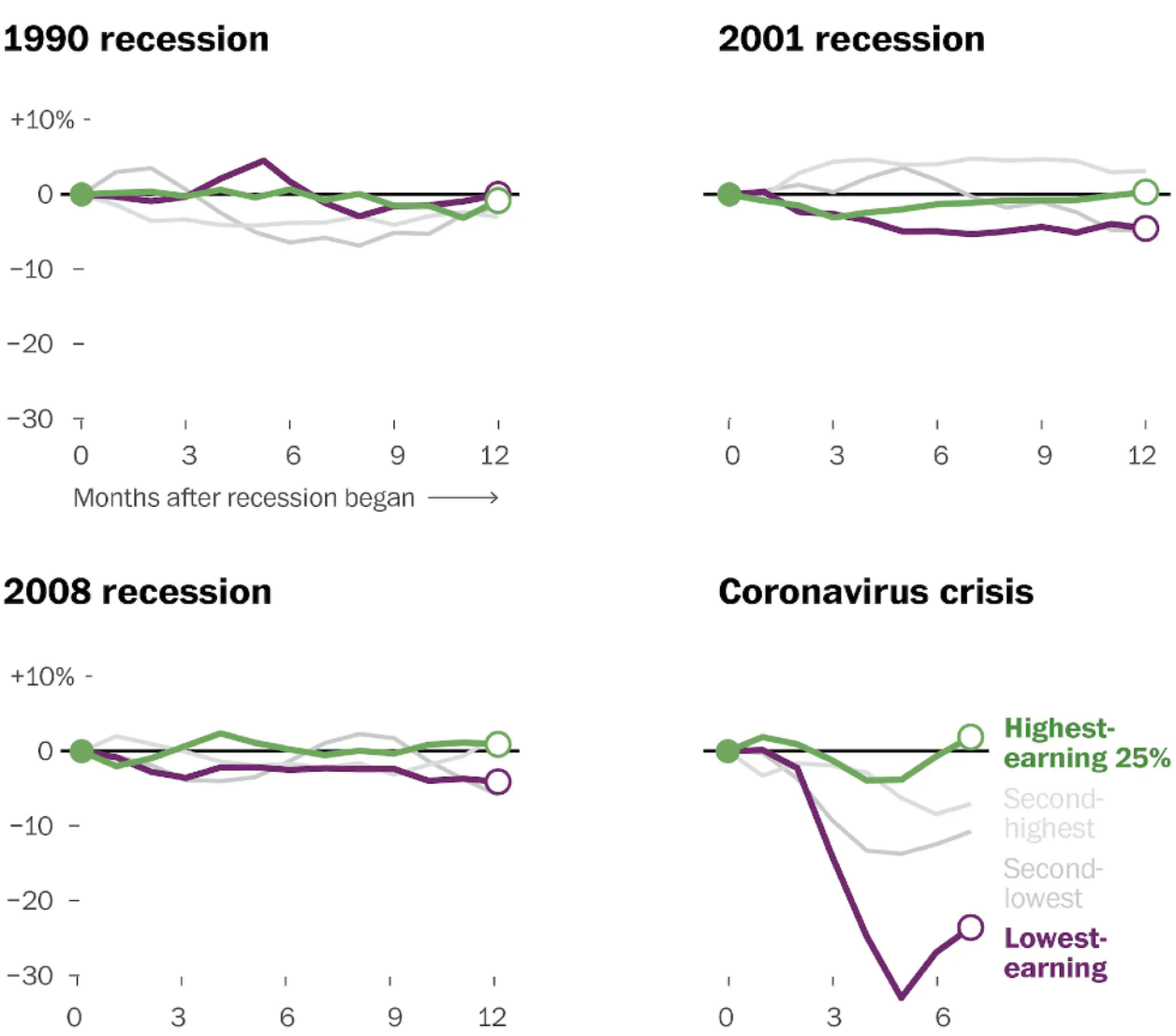
Source: Financial Times analysis of data from the European Centre for Disease Prevention and Control, the Covid Tracking Project, the UK Dept of Health & Social Care and the Spanish Ministry of Health.
Data updated September 25 2020 12.46pm BST. Interactive version: ft.com/covid19

FINANCIAL TIMES

Coronavirus Tracked John Burn-Murdoch & Financial Times

The coronavirus crisis is different

Job growth (or loss) since each recession began, based on weekly earnings



Notes: Based on a three-month average to show the trend in volatile data.

Source: Labor Department via IPUMS, with methodology assistance from Ernie Tedeschi of Evercore ISI

THE WASHINGTON POST

The Covid Economy

Washington Post

The Value of Visualization

Record information

- Blueprints, photographs, seismographs, …

Analyze data to support reasoning

- Develop and assess hypotheses
- Find patterns / Discover errors in data
- Expand memory

Convey information

- Communicate, inform, inspire
- Collaborate and revise

Goals of Visualization Research

1. **Understand** how visualizations convey information

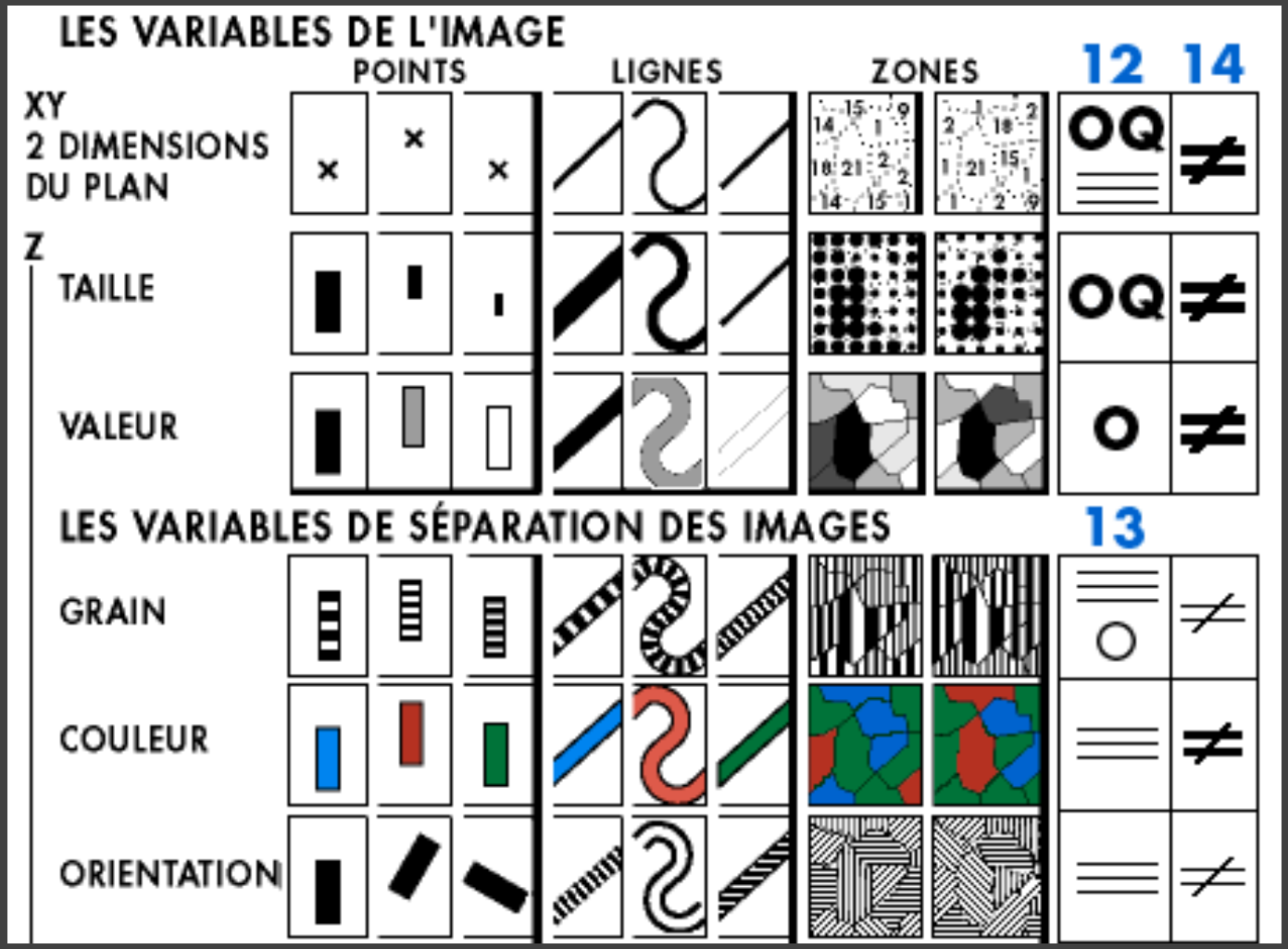
   What do people perceive / comprehend?
   How do visualizations inform mental models?

2. **Develop principles and techniques** for creating effective visualizations and supporting analysis

   Leverage perception & augment cognition
   Improve ties between visualization & mental model

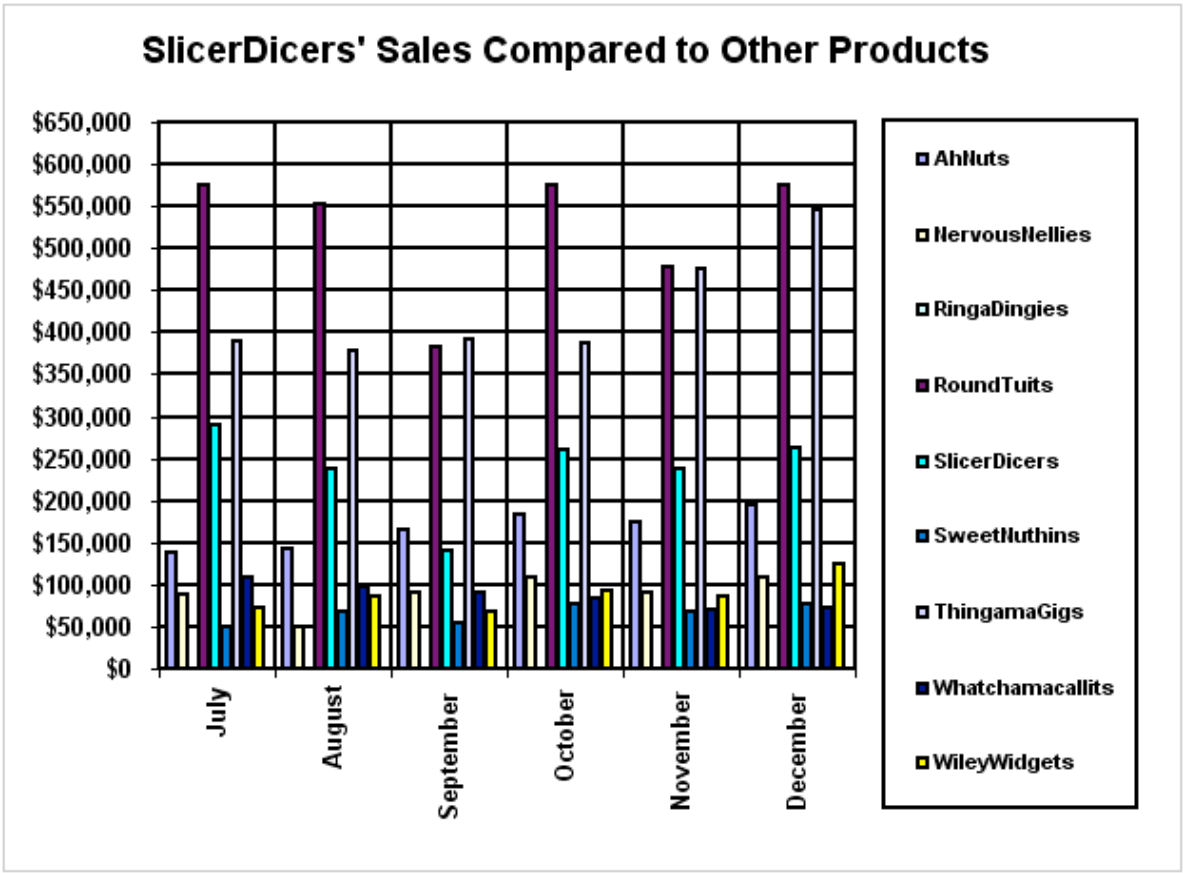
Course Topics

Data and Image Models



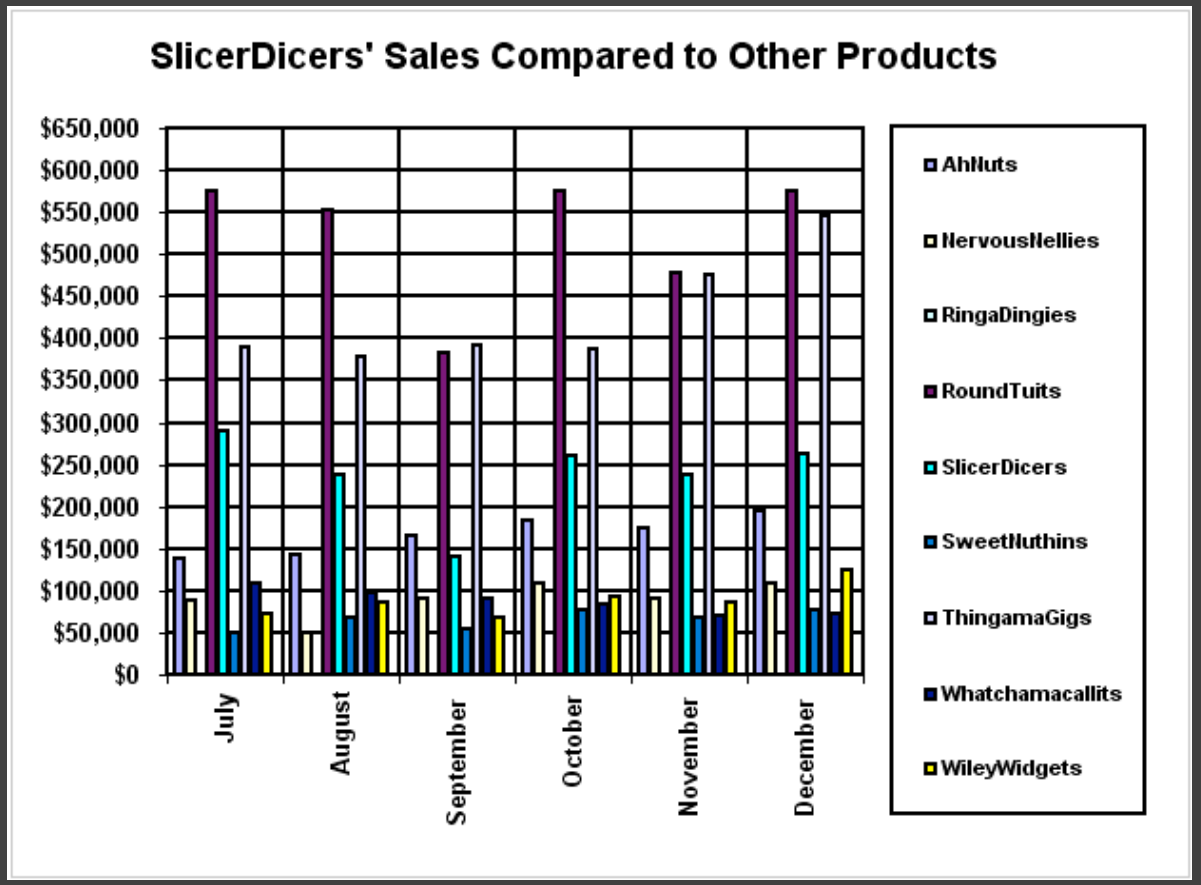
Sémiologie Graphique [Bertin 67]

Visualization Design

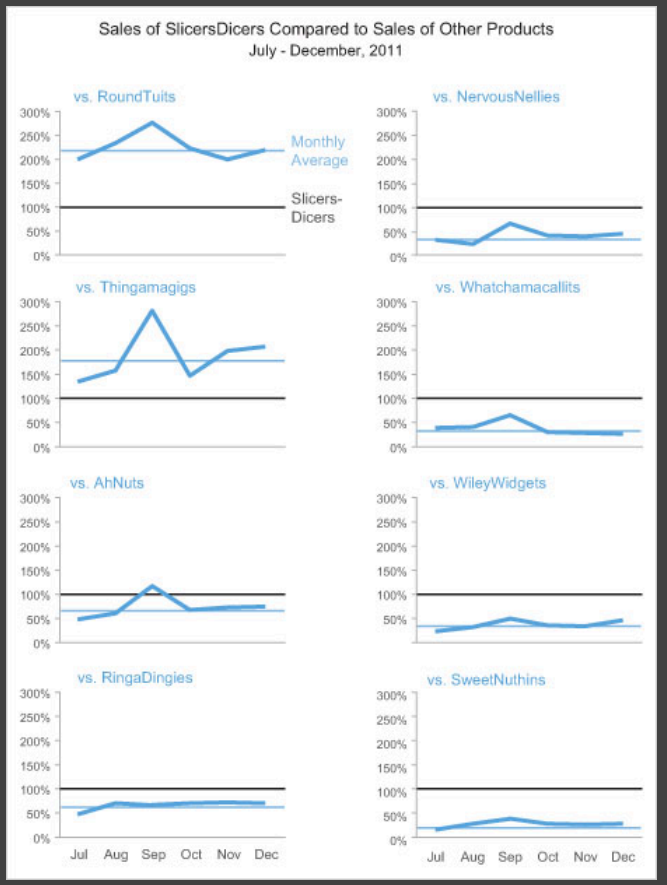


Problematic design

Visualization Design

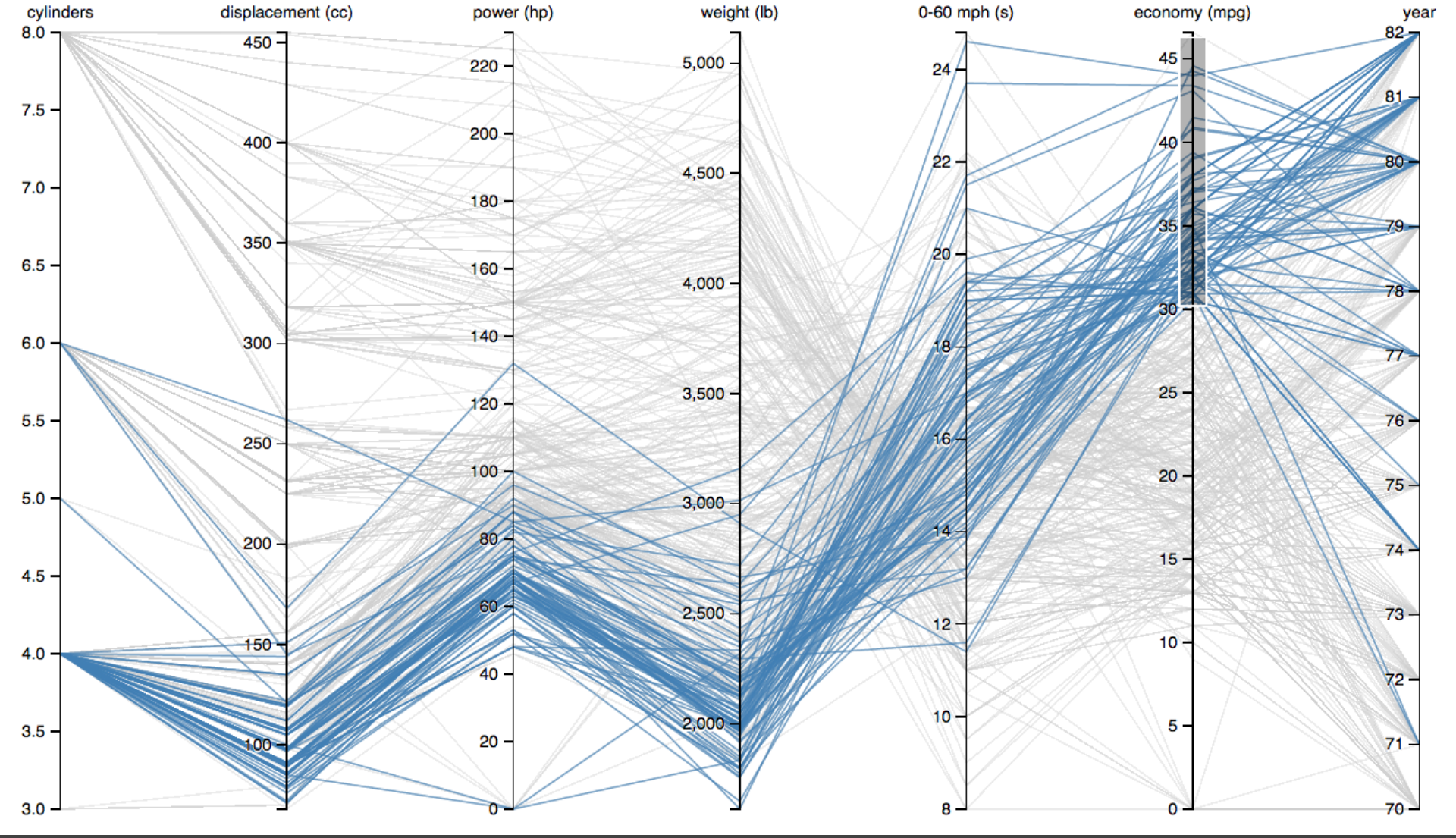


Problematic design

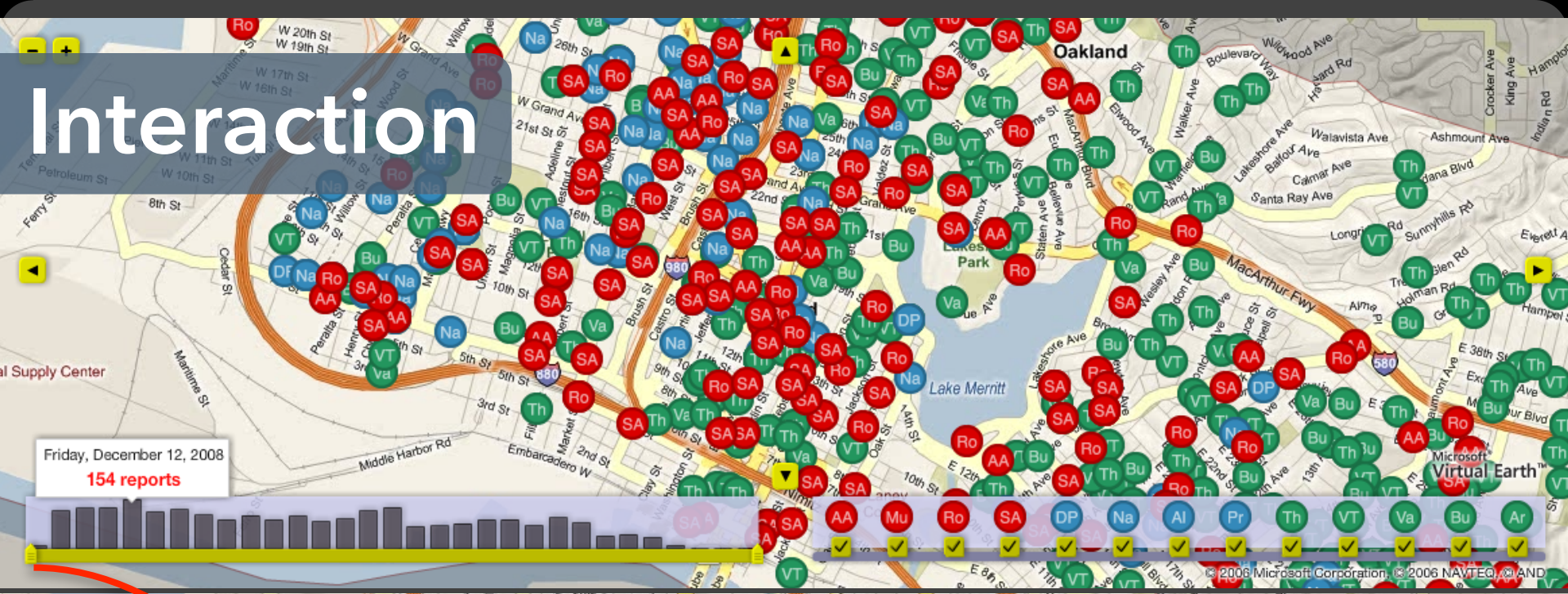


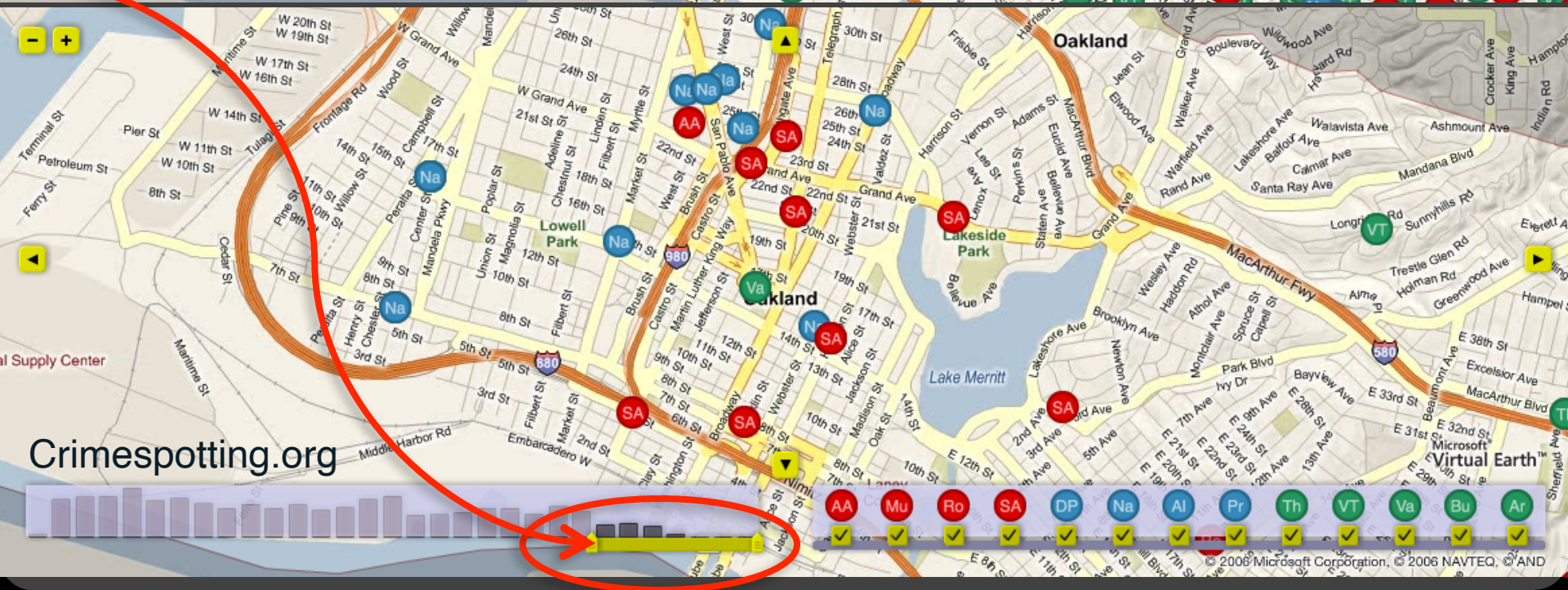
Redesign

Exploratory Data Analysis



Interaction





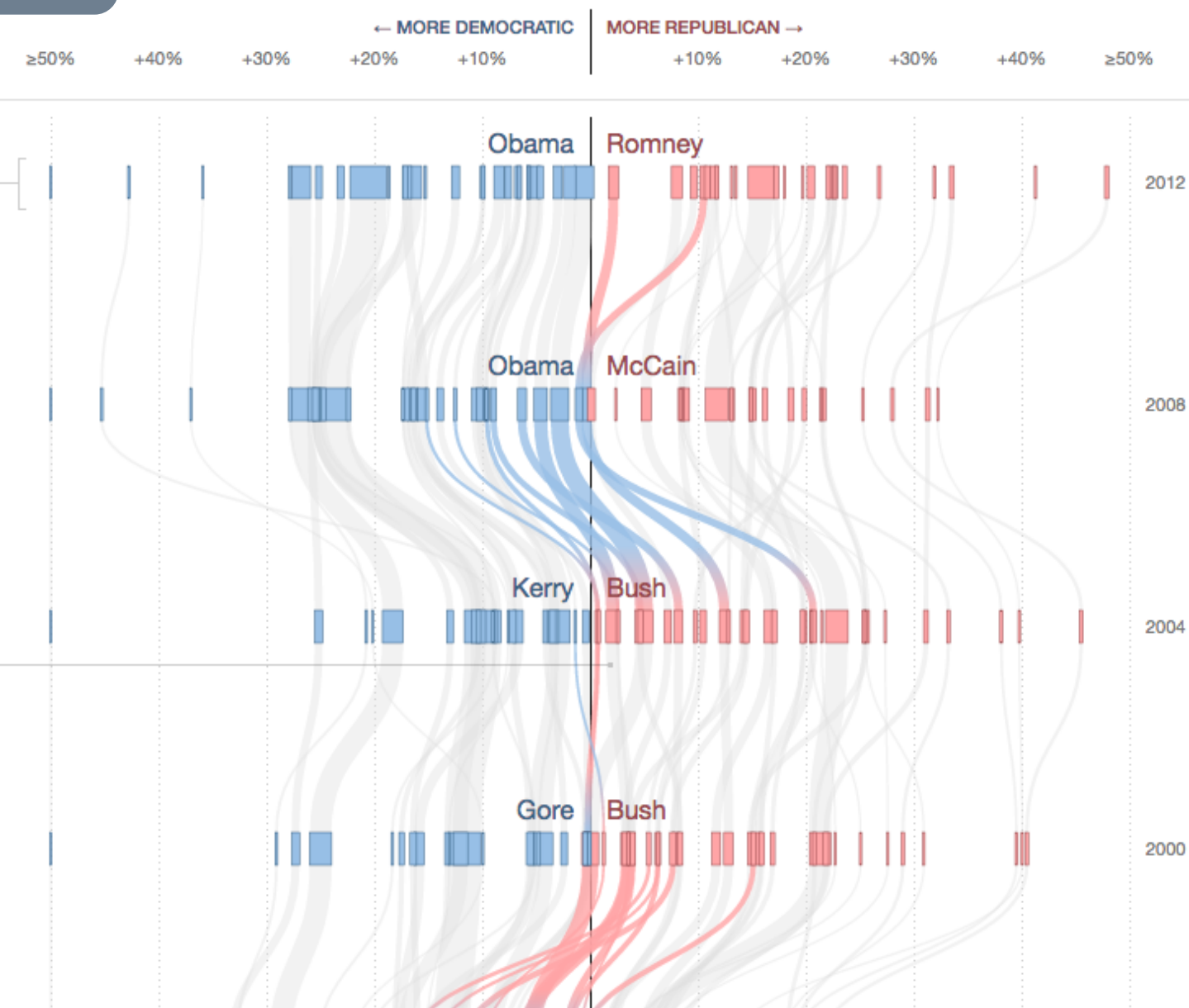
Narrative

Recent elections have placed a heavy emphasis on "swing states" — Ohio, Florida and the other competitive states. Yet in the past, many more states shifted between the Democratic and Republican parties. A look at how the states stack up in the [illegible] they have shifted over past elections.

Each box represents a state sized by number of electoral votes.

Each curve shows how much it shifted left or right between elections

Chart **Size of Lead** | Chart **Electoral Votes**



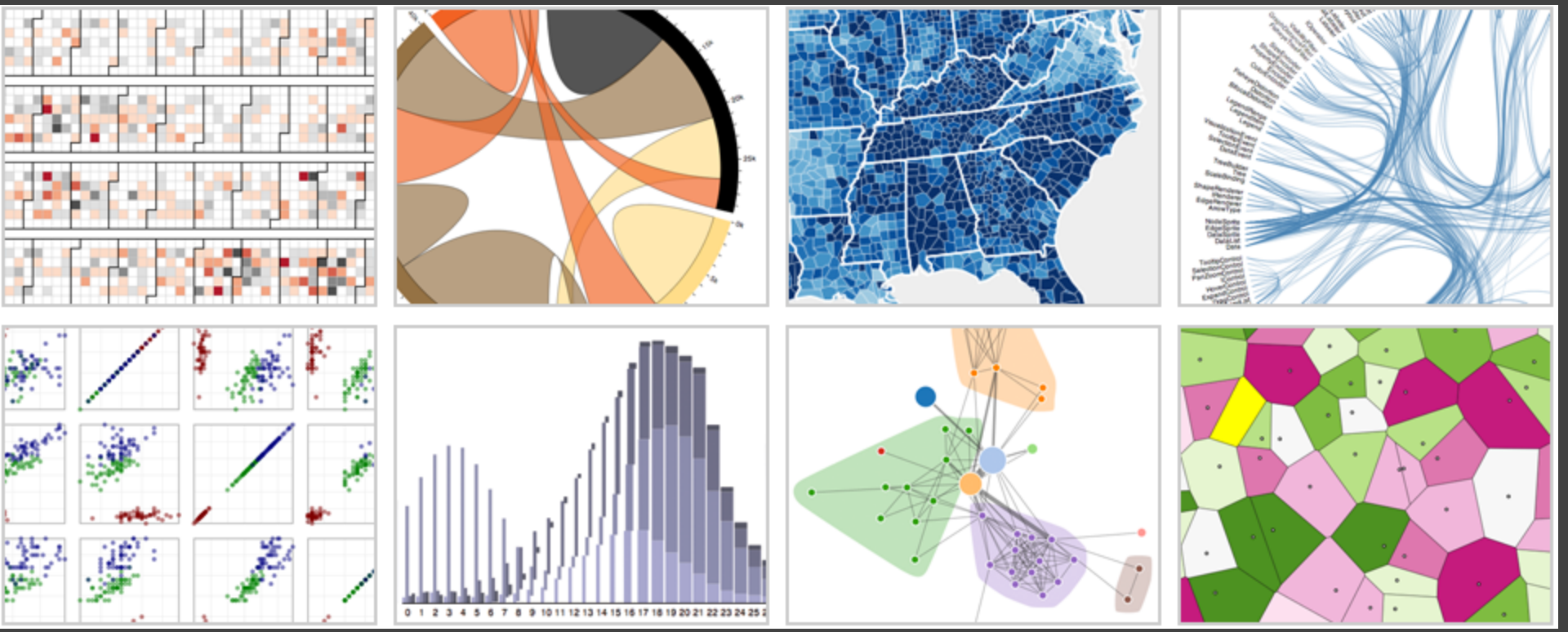
Obama Re-elected
The country voted about 5 percentage points more Republican in 2012 than in 2008. Obama lost North Carolina and Indiana, but won every tossup except Florida, which remains too close to call.

Highlight Tossups

As Goes Ohio
Ohio, which has voted for the winner in every election since 1964, provided the decisive electoral votes in 2004, and it is the state likeliest to play that role again this year, according to the FiveThirtyEight model.

Highlight Ohio

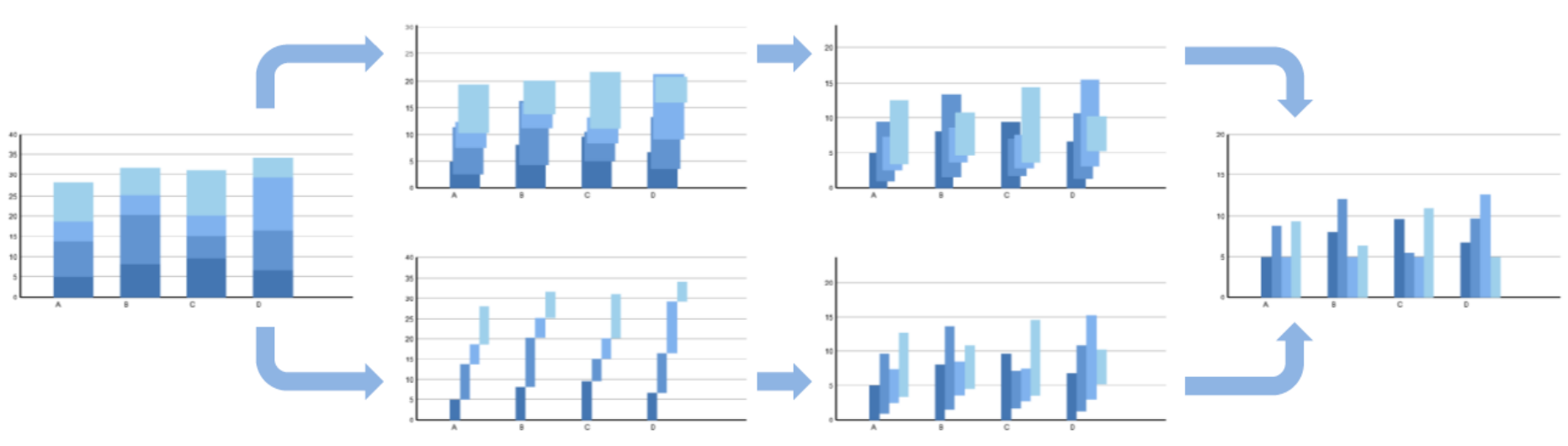
Visualization Software



D3: Data-Driven Documents

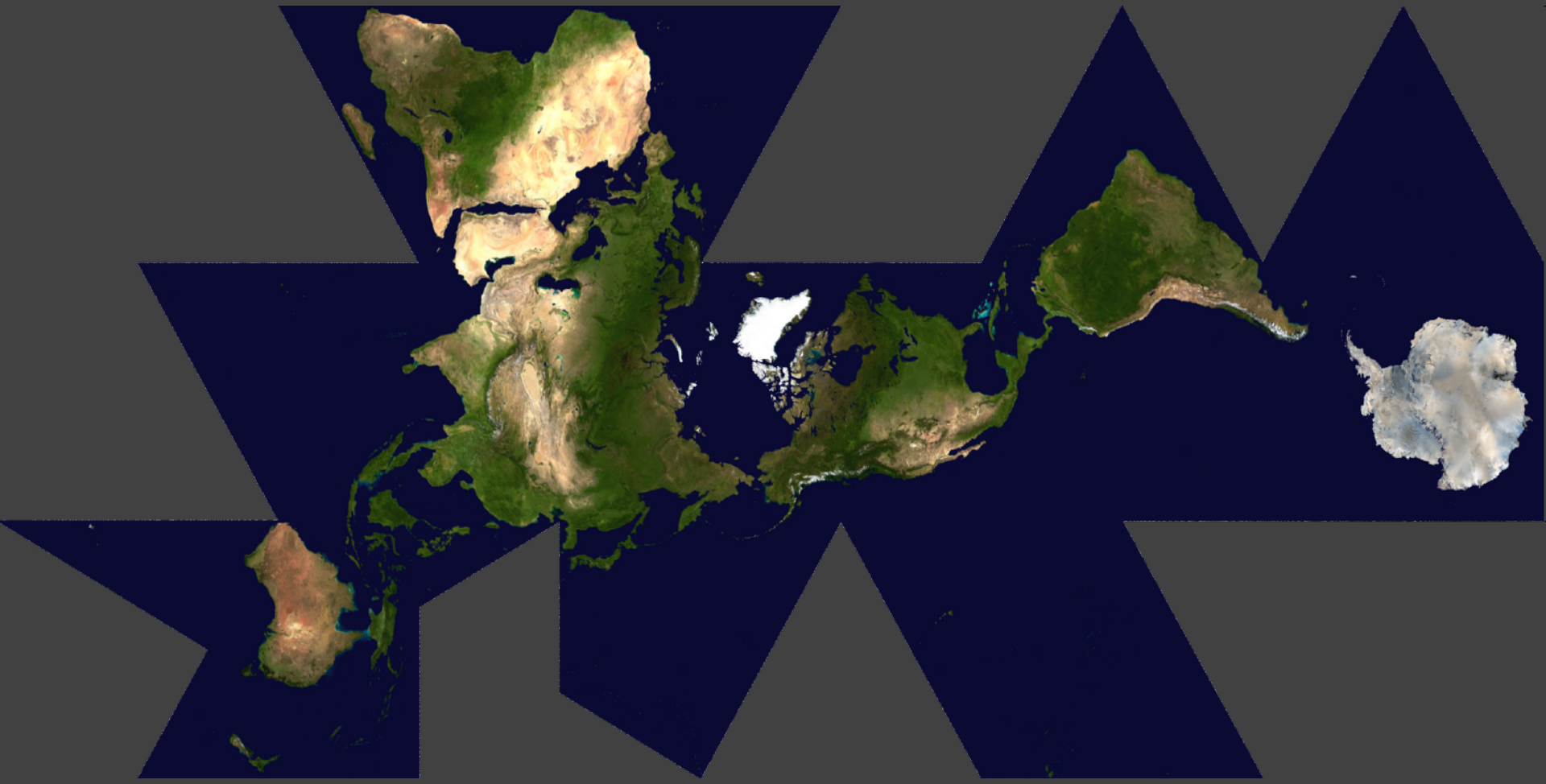
Vega-Lite / Altair

Animation



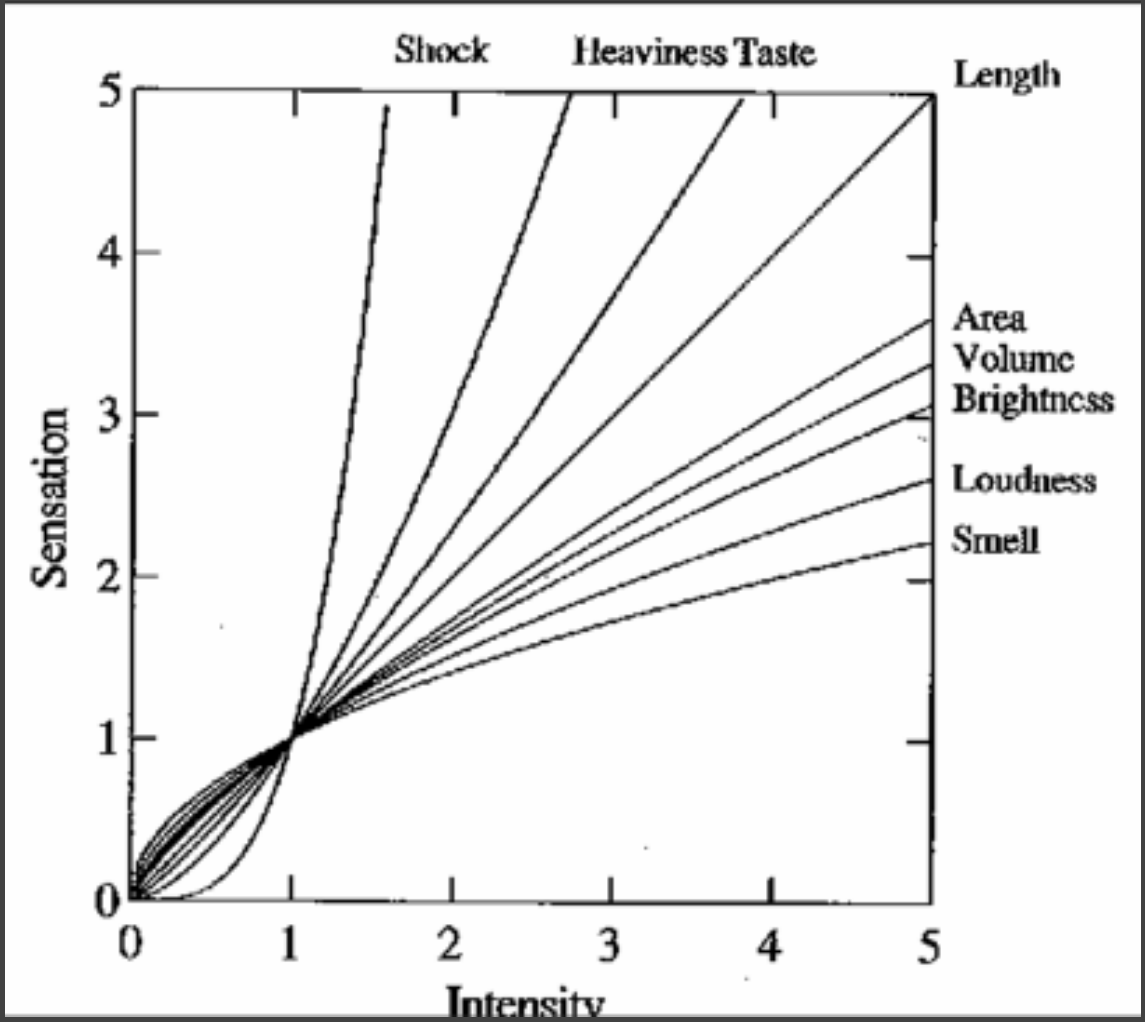
Animated transitions in statistical data graphics [Heer & Robertson 07]

Maps



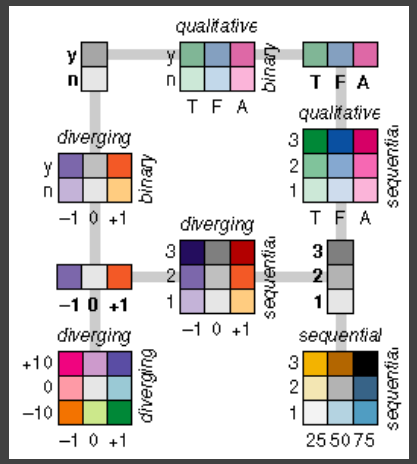
Dymaxion Maps [Fuller 46]

Graphical Perception

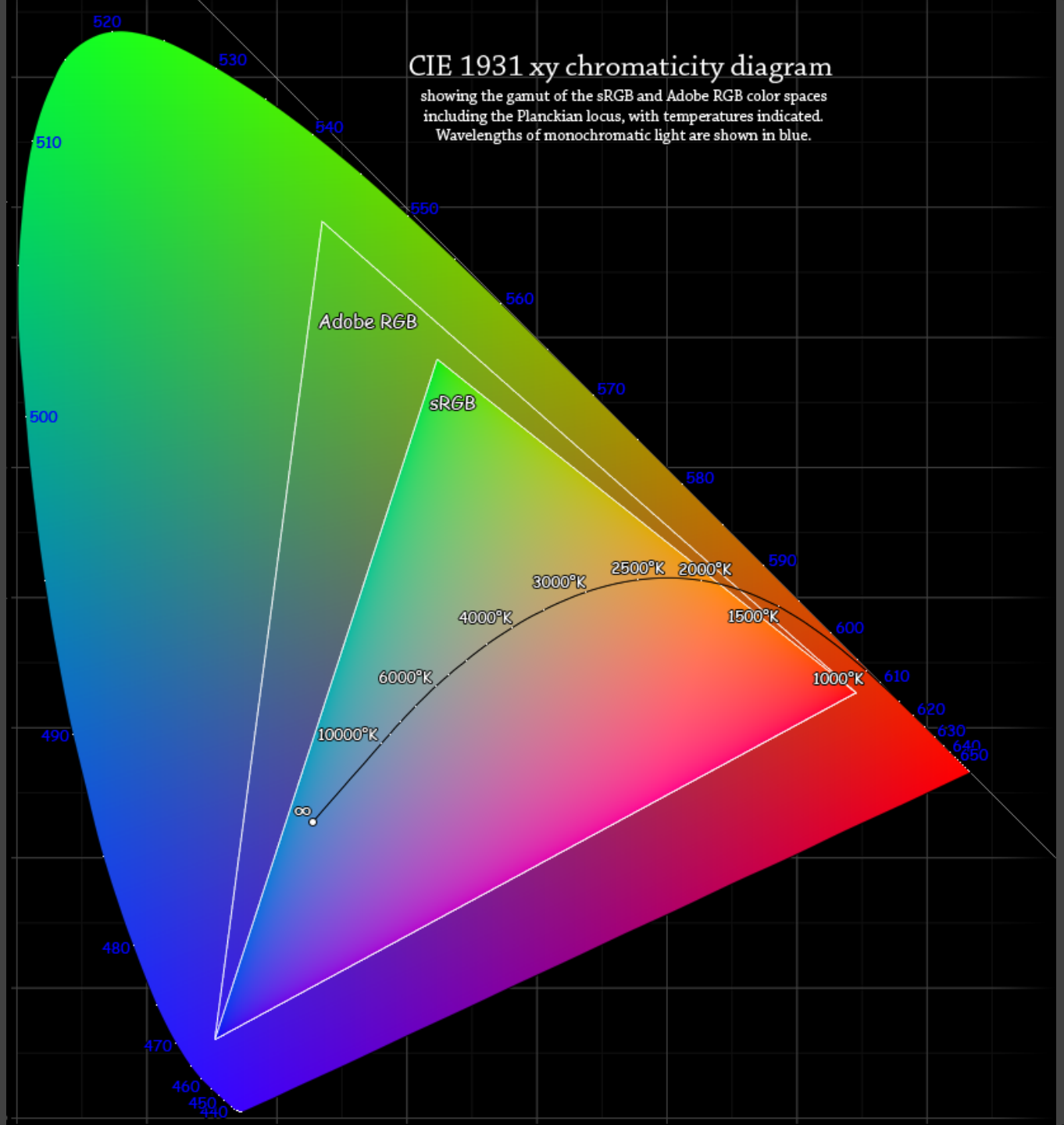


The psychophysics of sensory function [Stevens 61]

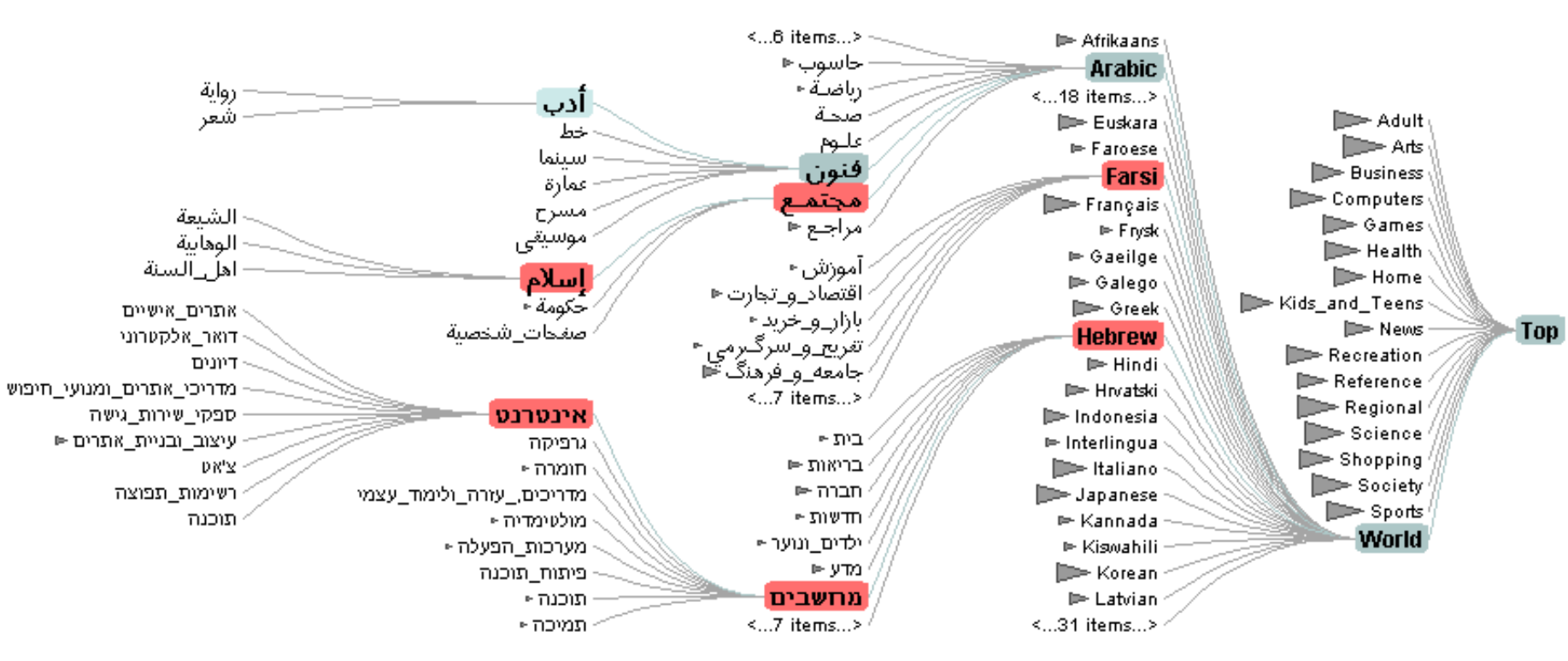
Color



Color Brewer

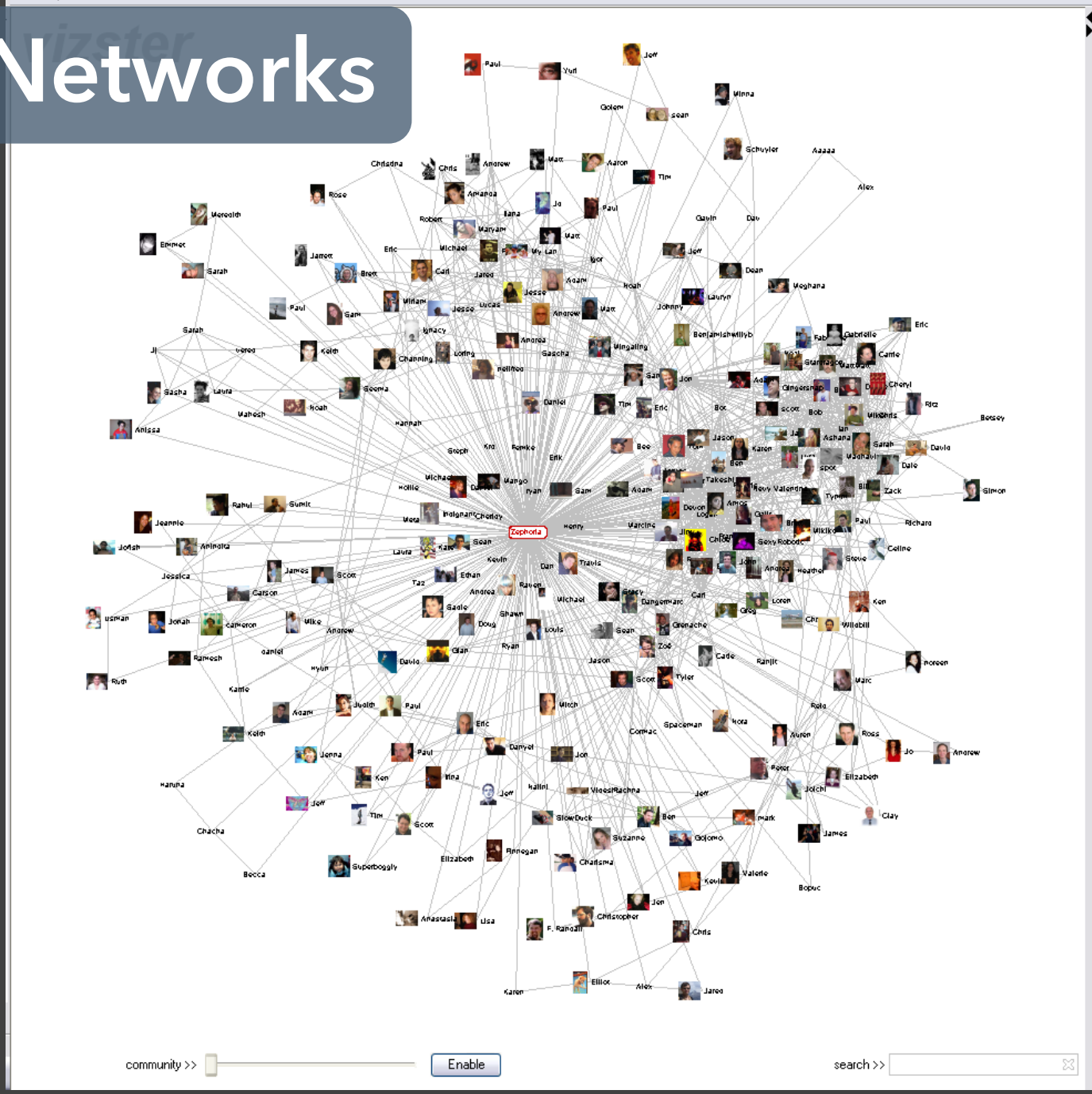


Hierarchies



Degree-Of-Interest Trees [Heer & Card 04]

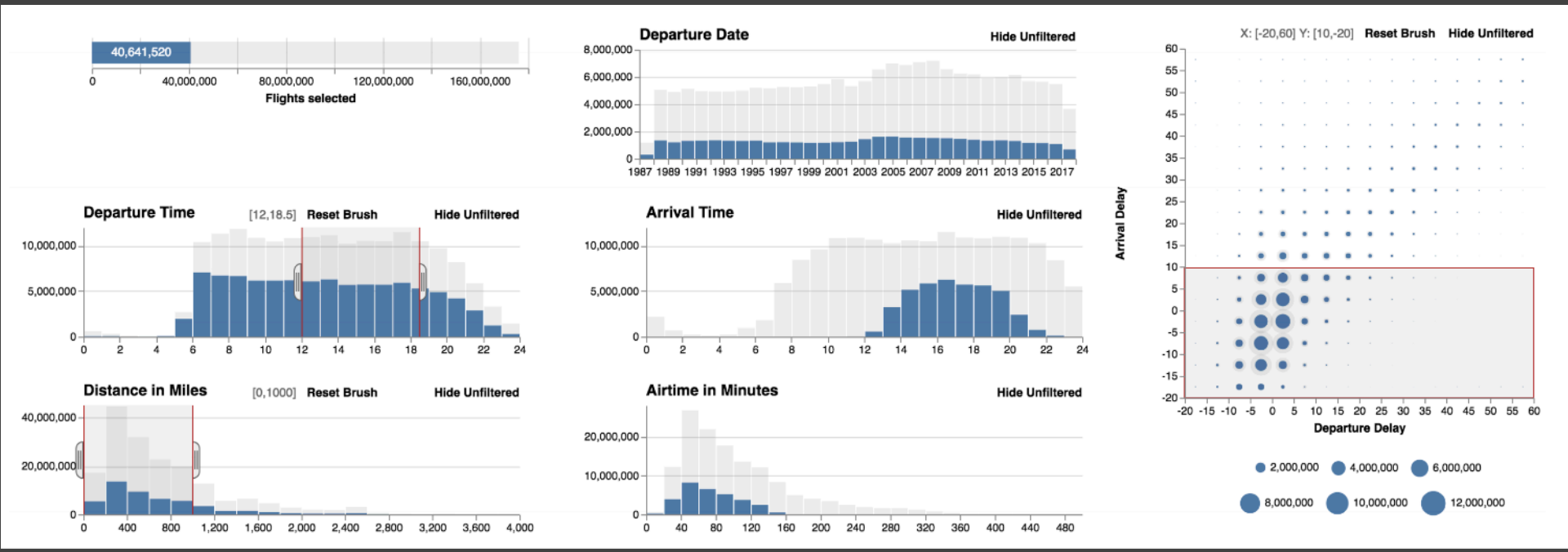
Networks



Zephoria

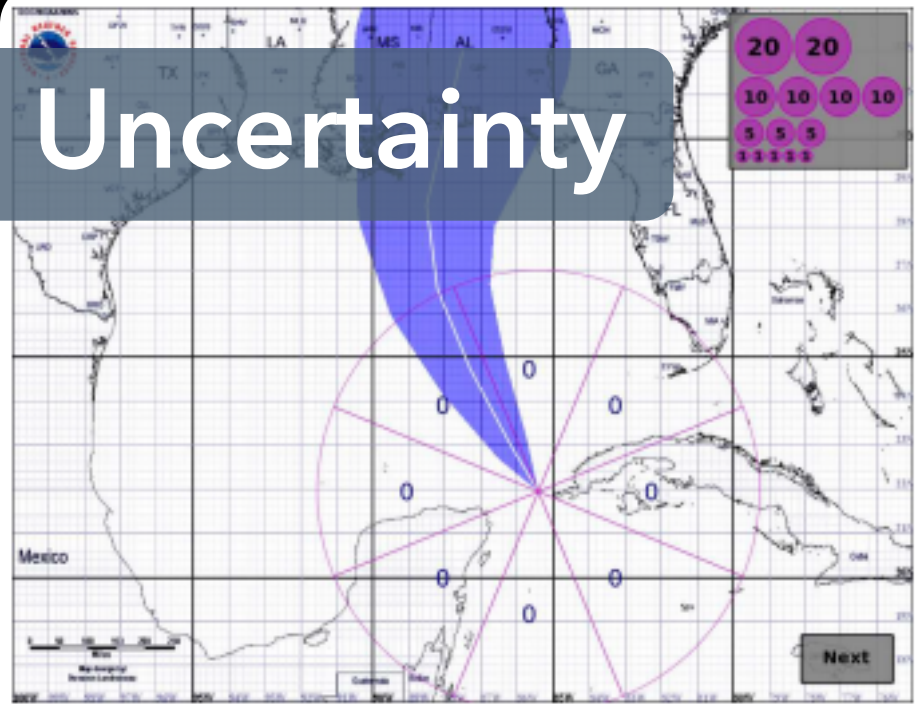
User ID	21721
Friends	266
Age	??
Gender	Female
Status	Single
Location	San Francisco, CA
Hometown	Lancaster, PA
Occupation	researcher: social networks, identity, context
Interests	apophenia, observing people, culture, questioning power, reading, buddhism, ipseity, computer-mediated communication, social networks, technology, anthropology, stomping
Music	psytrance/goa/trance [Infected Mushroom, Son Kite... Iboga/Digital Structures], Ani Difranco, downtempo, Thievery Corporation, Beth Orton, Morcheeba, Ween, White Stripes
Books	Authors: Erving Goffman, Stanley Milgram, Jeanette Winterson, Eric Schlosser, Leslie Feinberg, Dorothy Allison, Italo Calvino, Hermann Hesse
TV Shows	??
Movies	Koyaanisqatsi, Amelie, Waking Life, Tank Girl, The Matrix, Clockwork Orange, American Beauty, Fight Club, Boys Don't Cry
Member Since	??
Last Login	2003-10-21
Last Updated	2003-10-21
About	[Some know me as danah...] I'm a geek, an activist and an academic, fascinated by people and society. I see life as a very large playground and enjoy exploring its intricacies. I revel in life's chaos, while simultaneously providing my own insane element. My musings: http://www.zephoria.org/thoughts/
Want to Meet	Someone who makes life's complexities seem simply elegant.

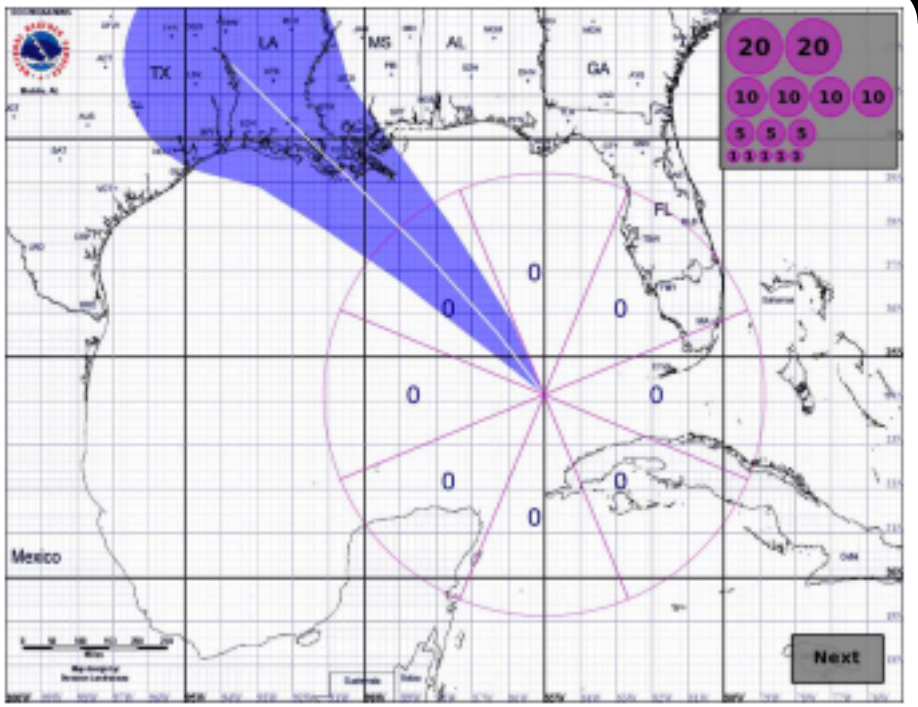
Scalability

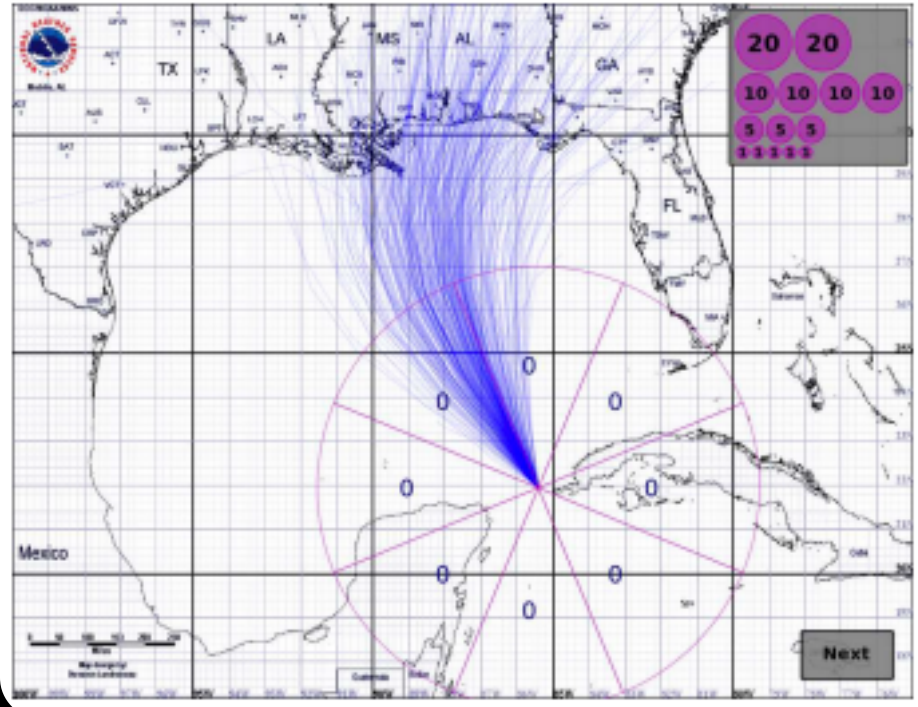


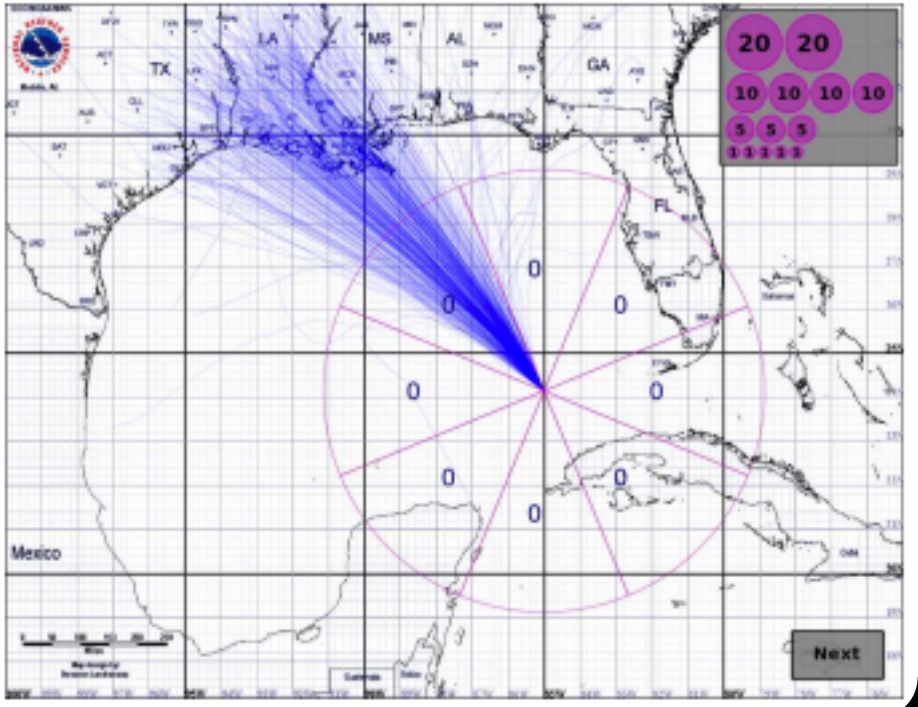
Interactive querying of 180M flight records in Falcon [Moritz et al. 2019]

Uncertainty









Course Mechanics

You should expect to:

1. *Evaluate and critique* visualization designs
2. *Learn* visualization techniques & theory
3. *Implement* interactive data visualizations
4. *Develop* a substantial visualization project

Instructors

cse442@cs

Instructors

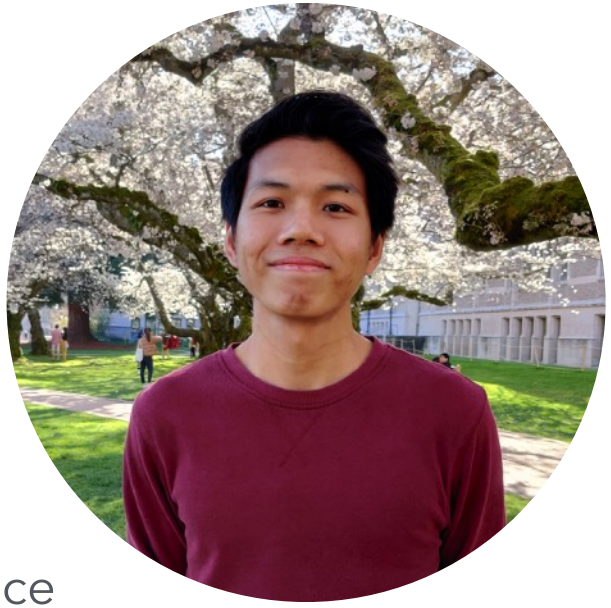
Jeffrey Heer	OH: *Thu After Lecture*
Jane Hoffswell	OH: *Tue After Lecture*

Teaching Assistants

Mick Kittivorawang	OH: *Online / Ed*
Kevin Chang	OH: *Mon 3-4p*
Naveena Karusala	OH: *Wed 11a-12p*
Yang Liu	OH: *Fri 1:30-2:30p*

Mick Kittivorawong

chanwutk@cs.washington.edu



Research

- Labeling algorithm for chart annotation
- Data Visualization toolkit

Work Experience @OctoML

- Visualization of Relay IR and its TVM performance

Technical Experience

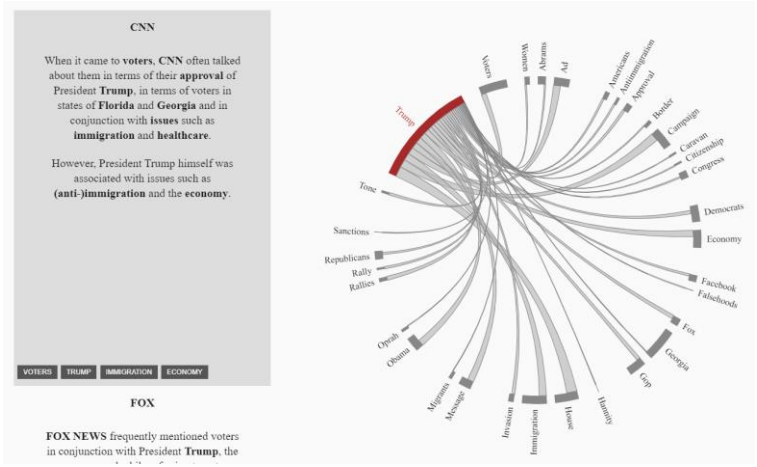
- TypeScript, D3, Vega/Vega-Lite, and general web programming

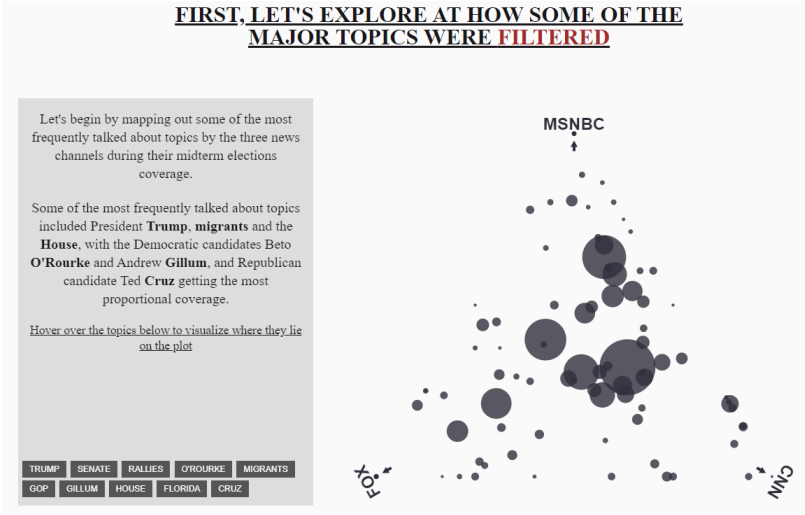
OH: by appointment + Discussion Board

Kevin Chang

kwchang2 @ cs

I'm a 5th year master's student interested in ML and data visualization.





My 442 final project:

https://cse442-18f.github.io/fp-divided-congress-and-coverage/

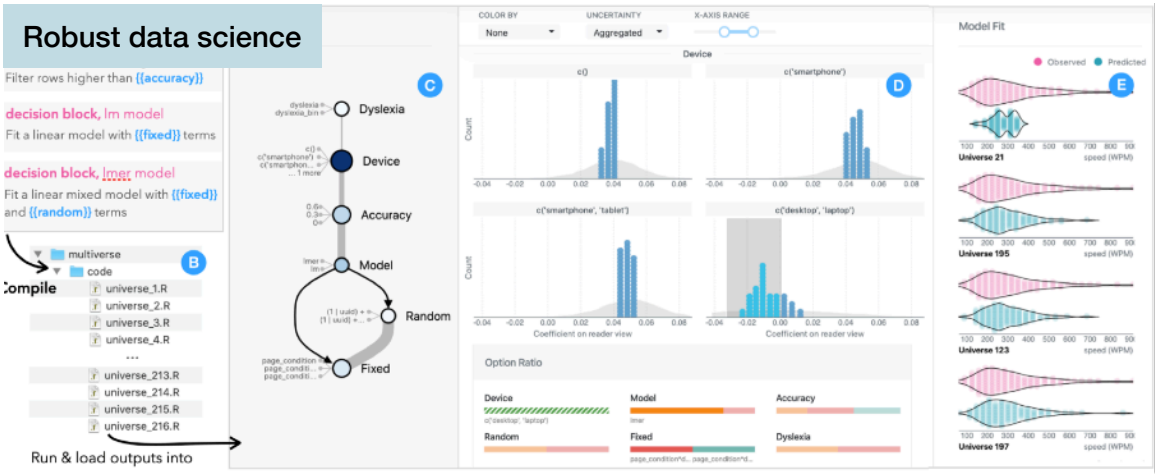
Naveena

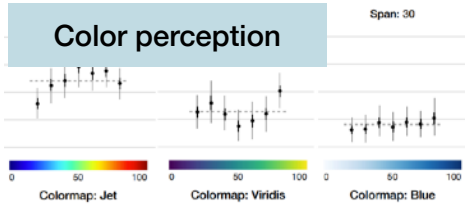
- 4th year PhD student in the ICTD Lab
- Research in HCI and global development, specifically on health messaging to underserved populations
- Office hours: 11am-12pm on Wednesdays
- Excited to talk about: data ethics, using data as a tool for empowerment and advocacy

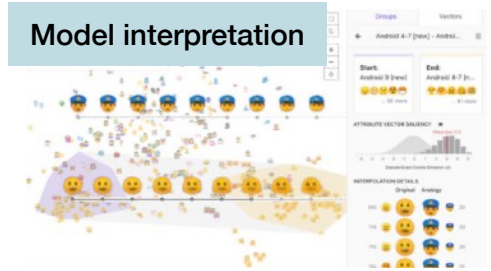
Yang Liu

Office Hours:
Fri 1:30 - 2:30 pm (Tableau tutorial 10/16)

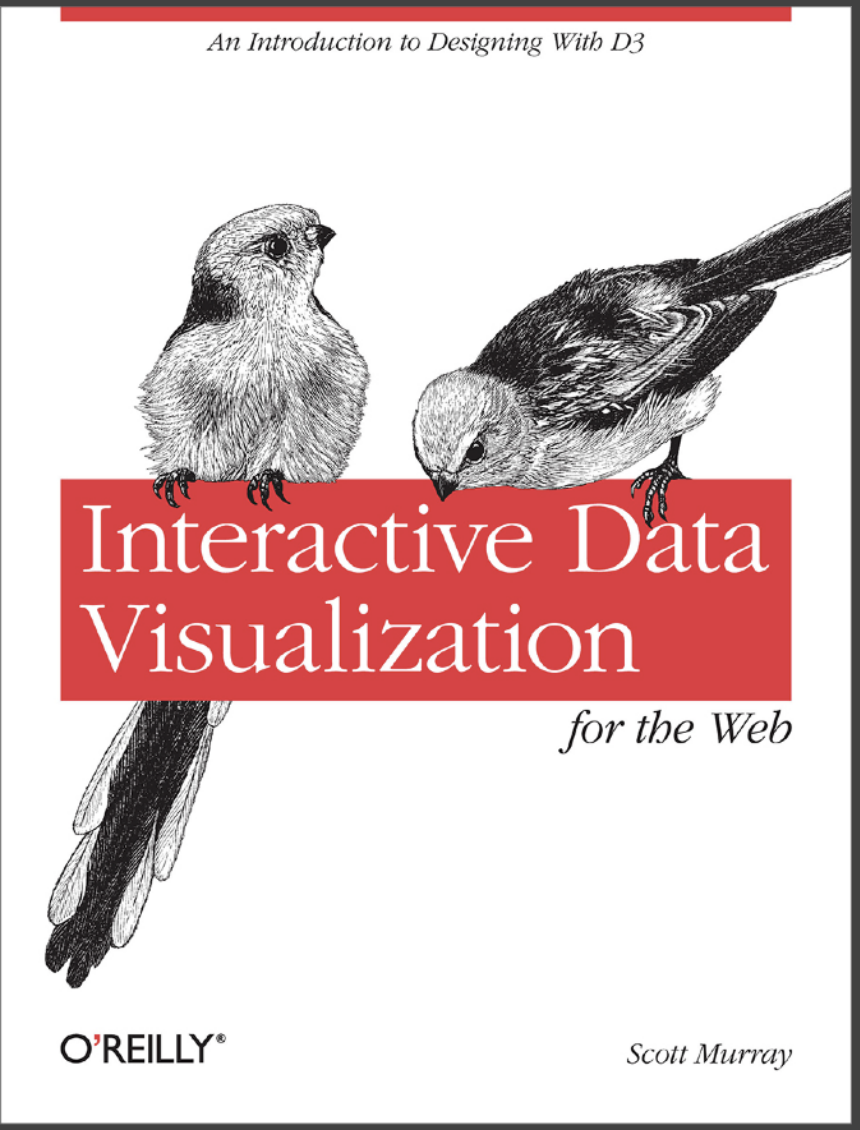
I'm a PhD student working on visualization and HCI. I took and TA-ed the graduate version of this class before. Looking forward to a new quarter!







Textbook

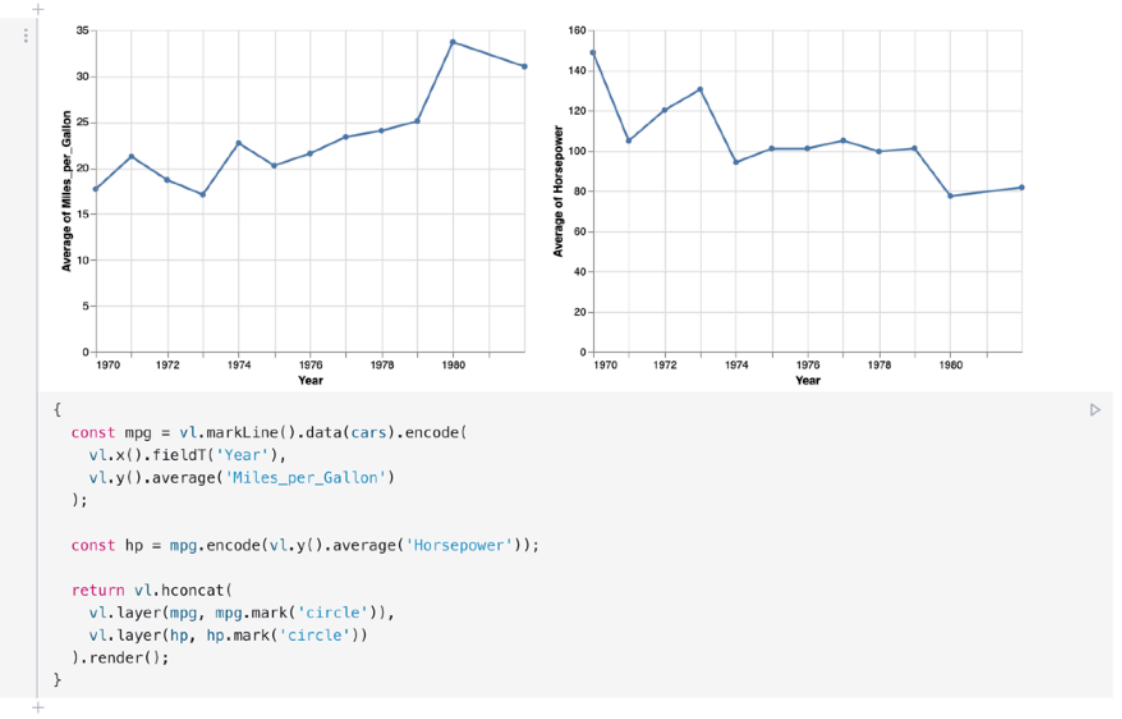


Interactive Data Visualization for the Web, 2nd Edition

For learning D3!
Book available online.
Code / examples on GitHub.

We will be using **D3 v6**.
https://d3js.org

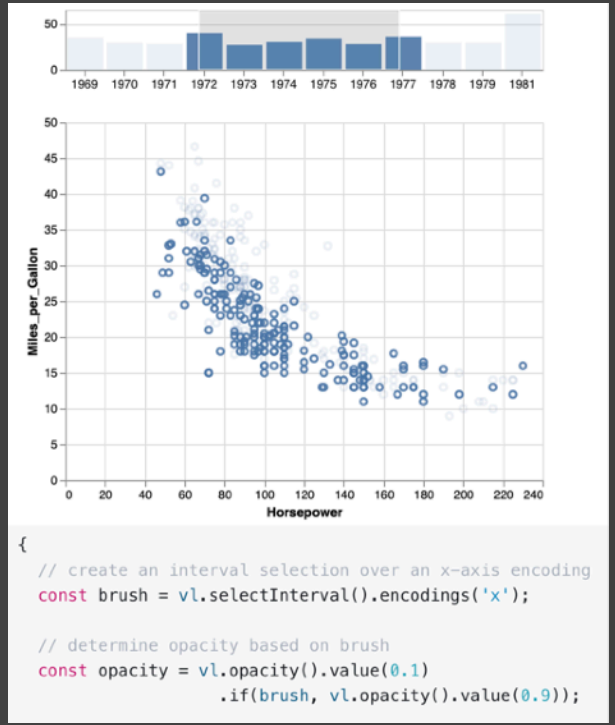
Interactive Vega-Lite Notebooks




```
{
  const mpg = vl.markLine().data(cars).encode(
    vl.x().fieldT('Year'),
    vl.y().average('Miles_per_Gallon')
  );

  const hp = mpg.encode(vl.y().average('Horsepower'));

  return vl.hconcat(
    vl.layer(mpg, mpg.mark('circle')),
    vl.layer(hp, hp.mark('circle'))
  ).render();
}
```




```
{
  // create an interval selection over an x-axis encoding
  const brush = vl.selectInterval().encodings('x');

  // determine opacity based on brush
  const opacity = vl.opacity().value(0.1)
                    .if(brush, vl.opacity().value(0.9));
```

Hands-on engagement with course concepts and tools using Observable (JavaScript) notebooks.

Readings

From books, notebooks, and linked articles.

Material in class will loosely follow readings.

Readings should be read by start of class.

Post quizzes / comments on class forum.

- One comment per week (up through week 8).
- Post comments by Monday 11:59pm.
- You have 1 “pass” for the quarter.

Assignments

CP Class Participation (10%)

A1 Visualization Design (10%) - *Due 10/12*

A2 Exploratory Data Analysis (15%) - *Due 10/26*

A3 Interactive Prototype (25%) - *Due 11/9*

Peer Evaluation - *Due 11/16*

FP Final Project (40%)

Proposal - *Due 11/13*

Milestone Prototype - *Due 12/1*

Demonstration Video - *Due 12/9*

Final Prototype - *Due 12/14*

Final Project

Produce **interactive web-based visualizations**

Initial **prototype** and **design review**

Final deliverables and **video presentation**

Submit and **publish online** (GitHub)

Projects from **previous classes** have been:

- Published as research papers
- Shared widely (some in the New York Times!)
- Released as successful open source projects

Final Project Theme

Final Project Theme

Data Visualization for Social Good

Final Project Theme

Data Visualization for Social Good

Goal: find data of social or scientific import, design visualizations to explore or communicate it effectively.

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Data Visualization for Social Good

Goal: find data of social or scientific import, design visualizations to explore or communicate it effectively.

The specific data domain is open-ended. Possibilities include transportation, housing, public health, education, climate, campaign finance, scientific research, and so on…

Final Project Theme

Data Visualization for Social Good

Goal: find data of social or scientific import, design visualizations to explore or communicate it effectively.

The specific data domain is open-ended. Possibilities include transportation, housing, public health, education, climate, campaign finance, scientific research, and so on…

You must identify a target audience. May be general (residents, voters) or specialized (scientists, policy makers).

Final Project Theme

Data Visualization for Social Good

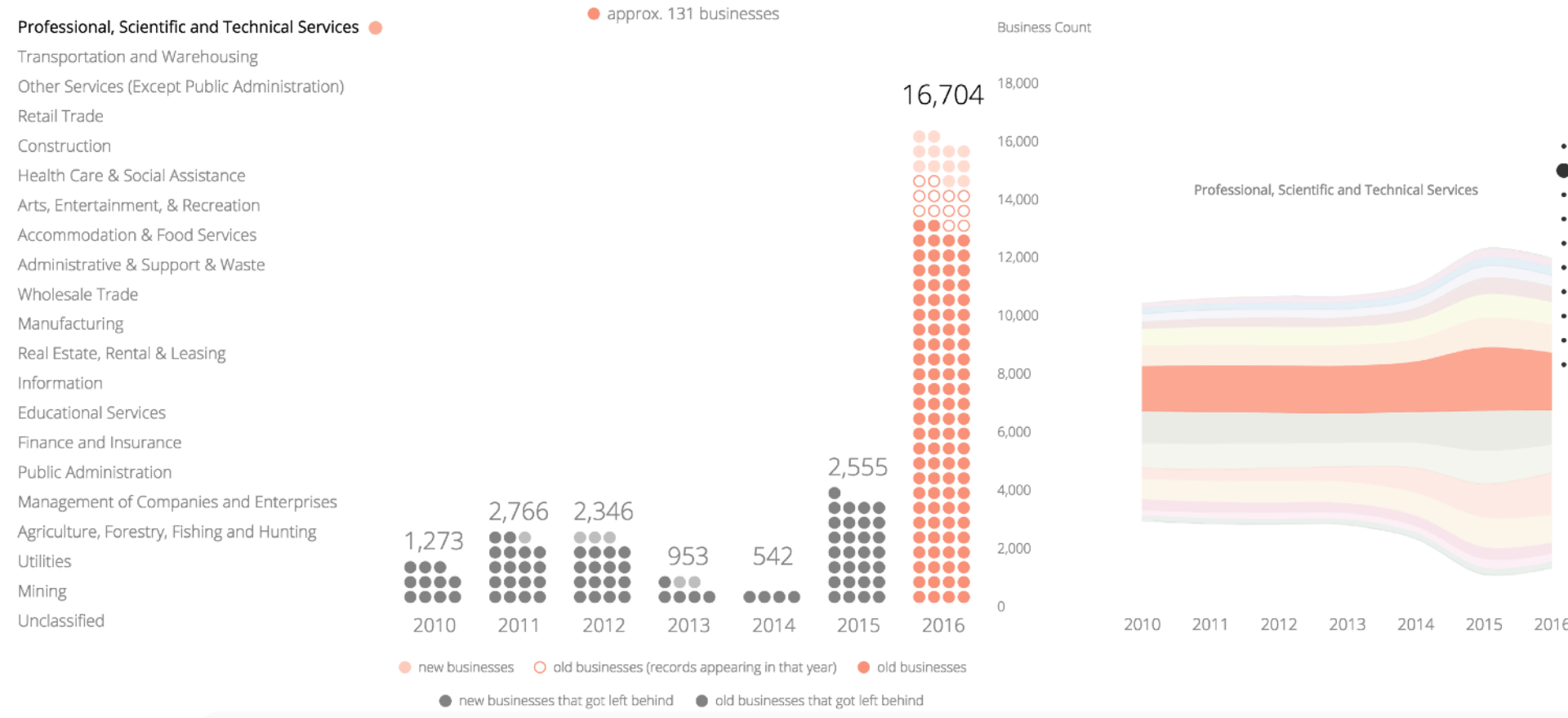
Goal: find data of social or scientific import, design visualizations to explore or communicate it effectively.

The specific data domain is open-ended. Possibilities include transportation, housing, public health, education, climate, campaign finance, scientific research, and so on…

You must identify a target audience. May be general (residents, voters) or specialized (scientists, policy makers).

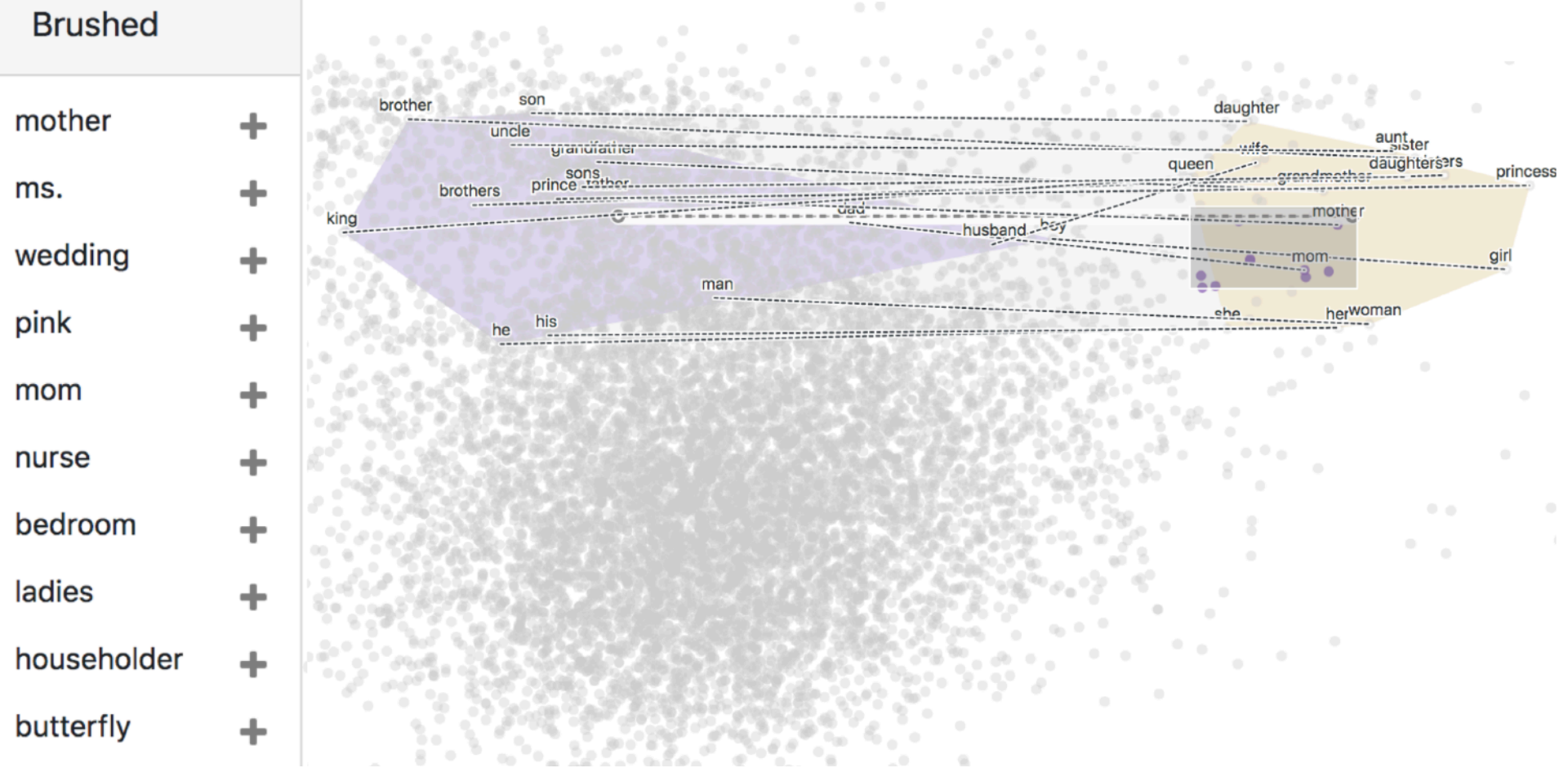
Use Assignment 2 to explore a data set of interest prior to committing to final project teams and topic!

Inspiration…



Change In Times (CSE 442, Spring '17)

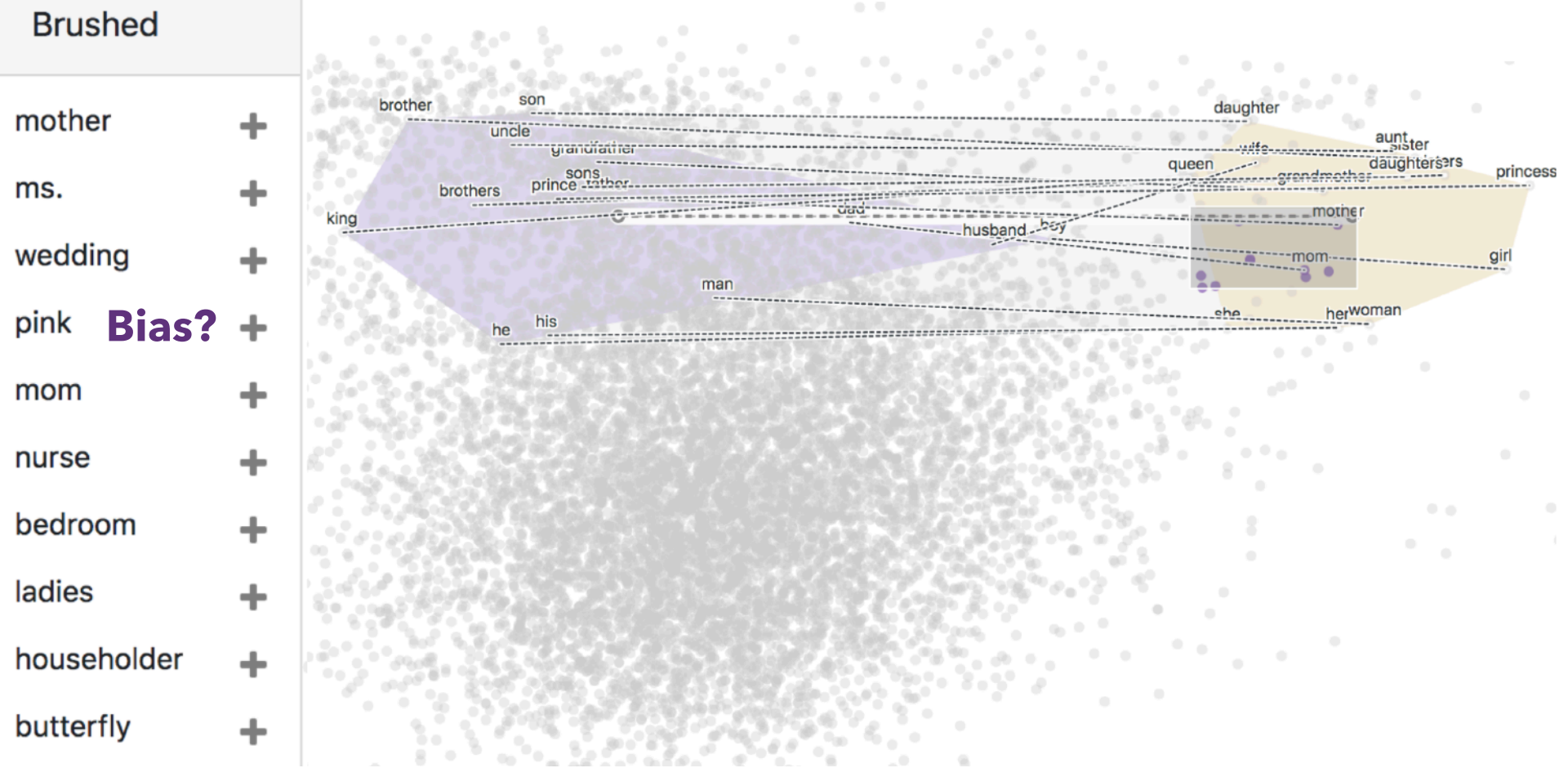
Gunnar Olson, Halden Lin, Lilian Liang, and Shobhit Hathi



Latent Space Cartography

Visual Analysis of Vector Space Embeddings

Yang Liu, Eunice Jun, Qisheng Li (CSE 512, Spring '18)



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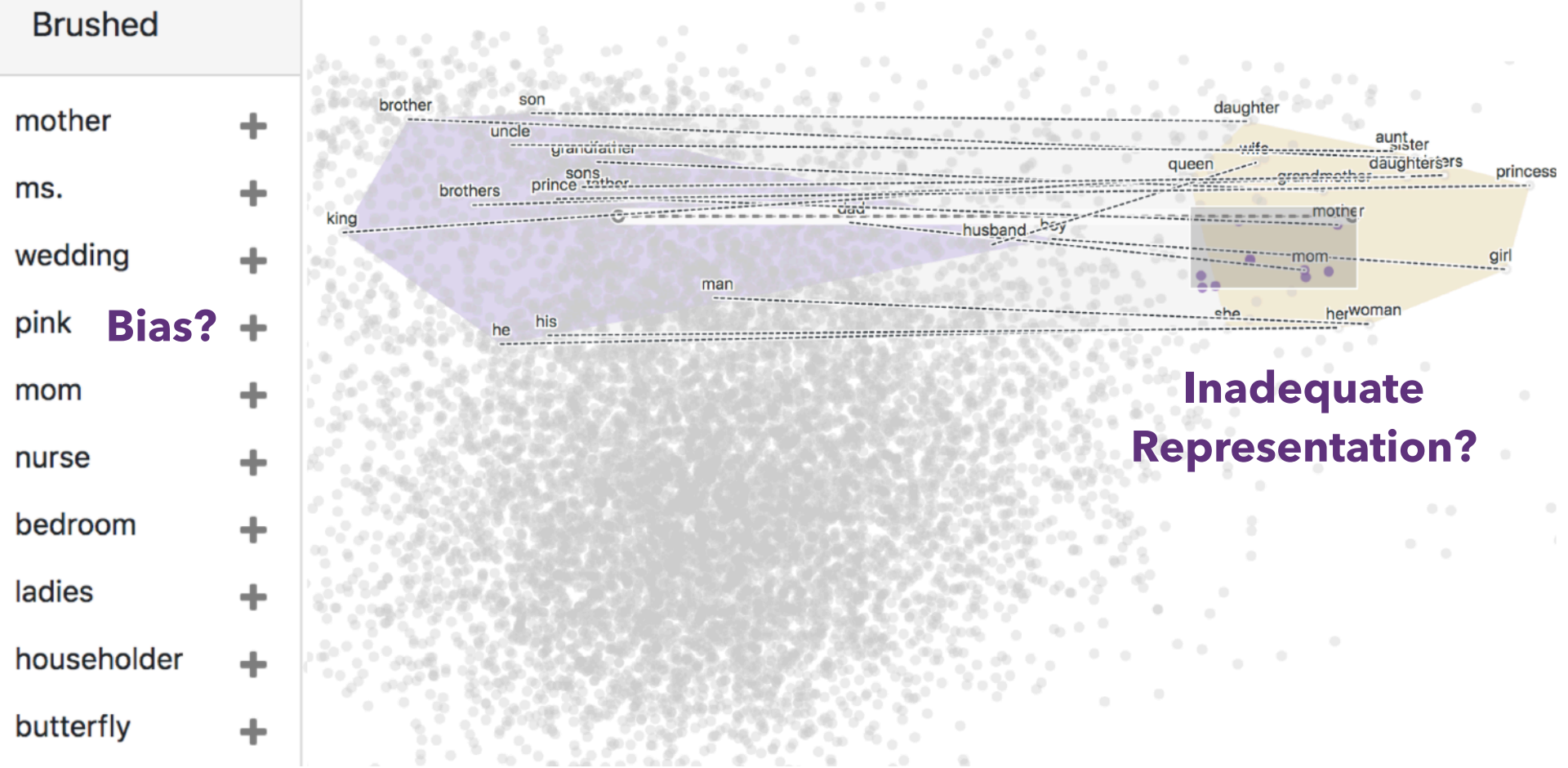

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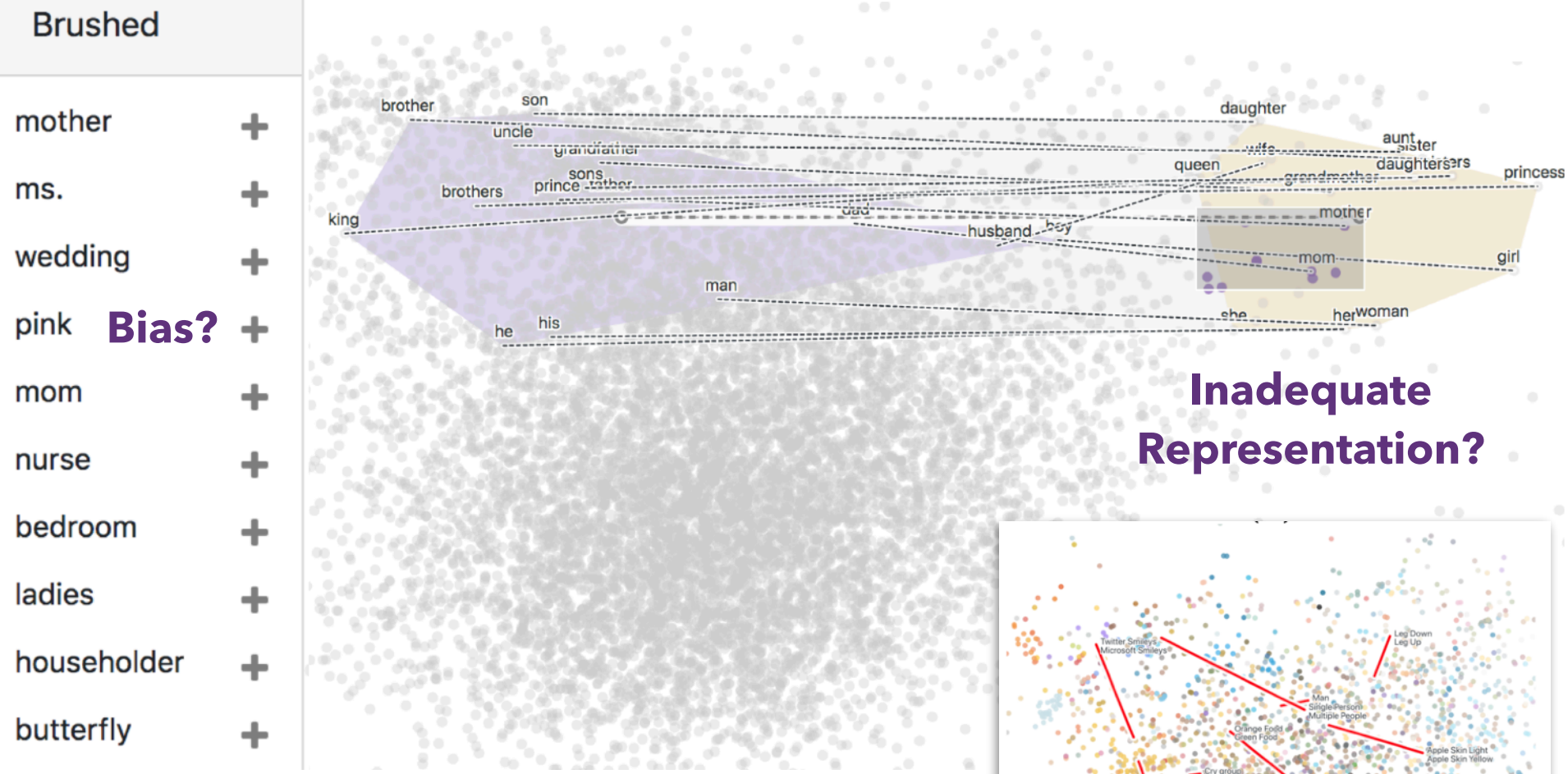

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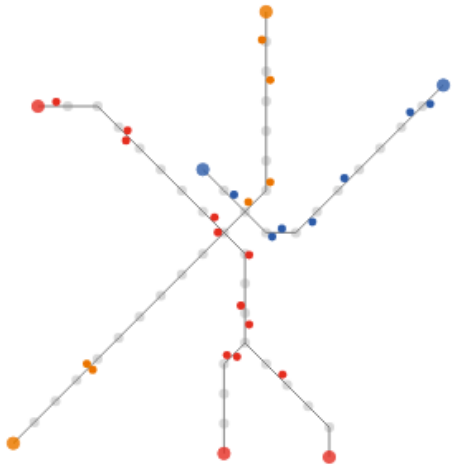
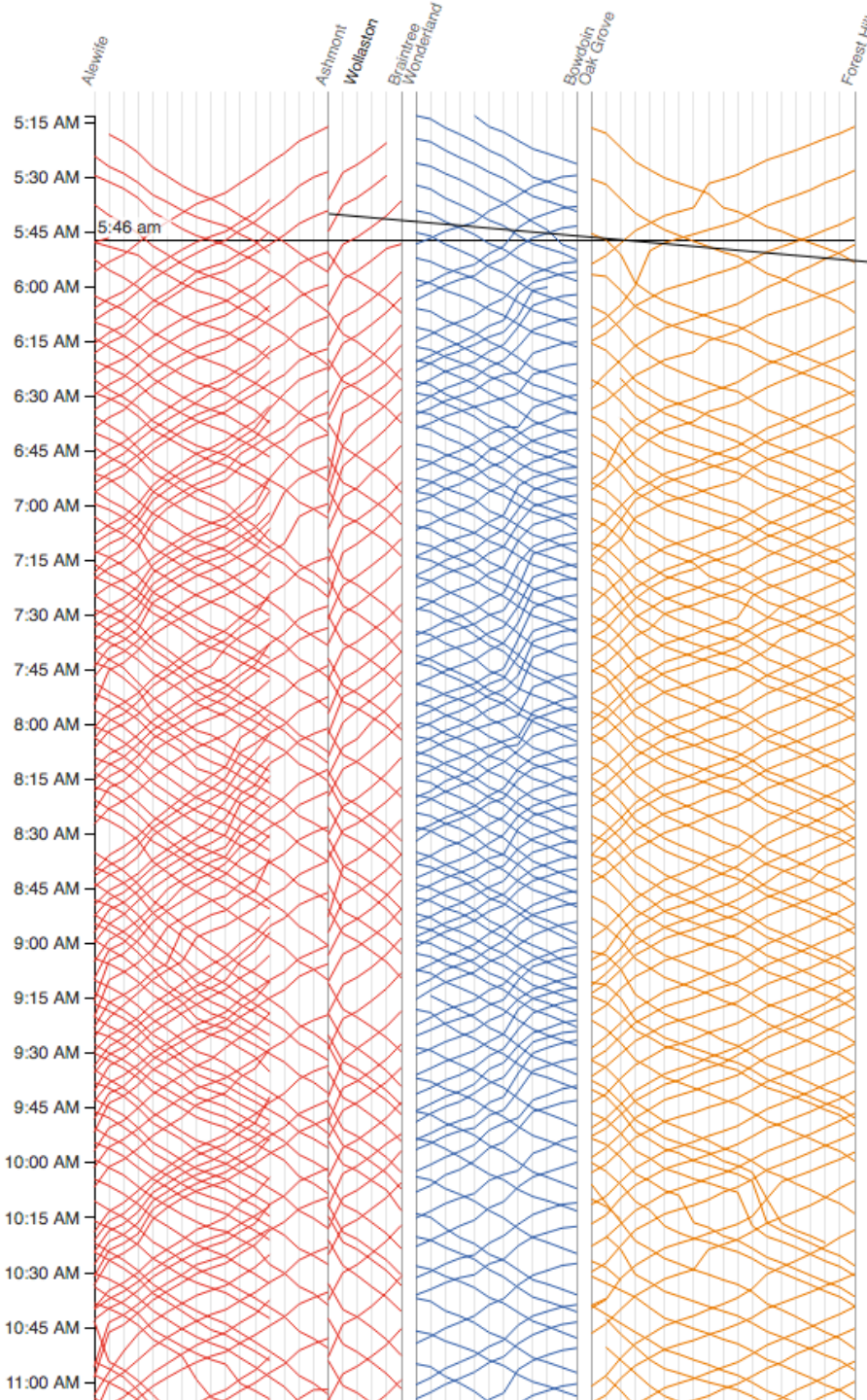


Locations of each train on the red, blue, and orange lines at 5:46 am. Hover over the diagram to the right to display trains at a different time.

Trains are on the right side of the track relative to the direction they are moving.

See the morning rush-hour, midday lull, afternoon rush-hour, and the evening lull.



Service starts at 5AM on Monday morning. Each line represents the path of one train. Time continues downward, so steeper lines indicate slower trains.

Since the red line splits, we show the Ashmont branch first then the Braintree branch. Trains on the Braintree branch "jump over" the Ashmont branch.

Train frequency increases around 6:30AM as morning rush hour begins.

MBTA Viz

Barry & Card

Questions?

A1: Visualization Design

Design a static visualization for a data set.

The climate of a place can have a tremendous impact on people's lived experience. You will examine average monthly climate measurements for six major U.S. cities, roughly covering the edges of the continental United States.

You must choose the message you want to convey. What question(s) do you want to answer? What insight do you want to communicate?

A1: Visualization Design

Pick a **guiding question**, use it to title your vis.
Design a **static visualization** for that question.
You are free to **use any tools** (inc. pen & paper).

Deliverables (upload via Canvas; see A1 page)
Image of your visualization (PNG or JPG format)
Short description + design rationale (≤ 4 paragraphs)

Due by **11:59 pm, Monday October 12**.