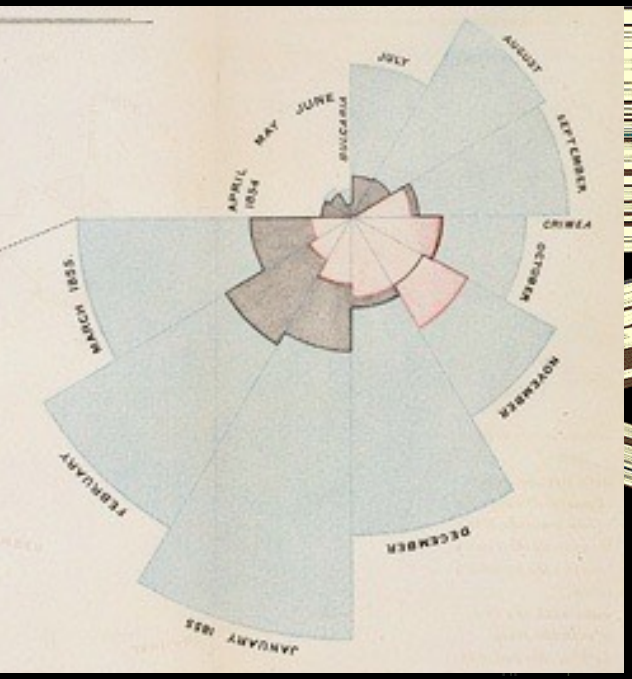
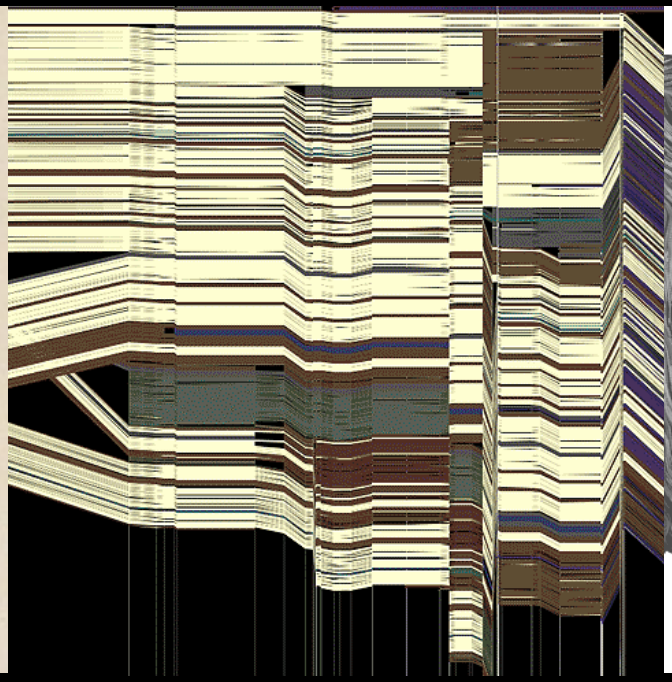
CSE 442 - Data Visualization

The Value of Visualization



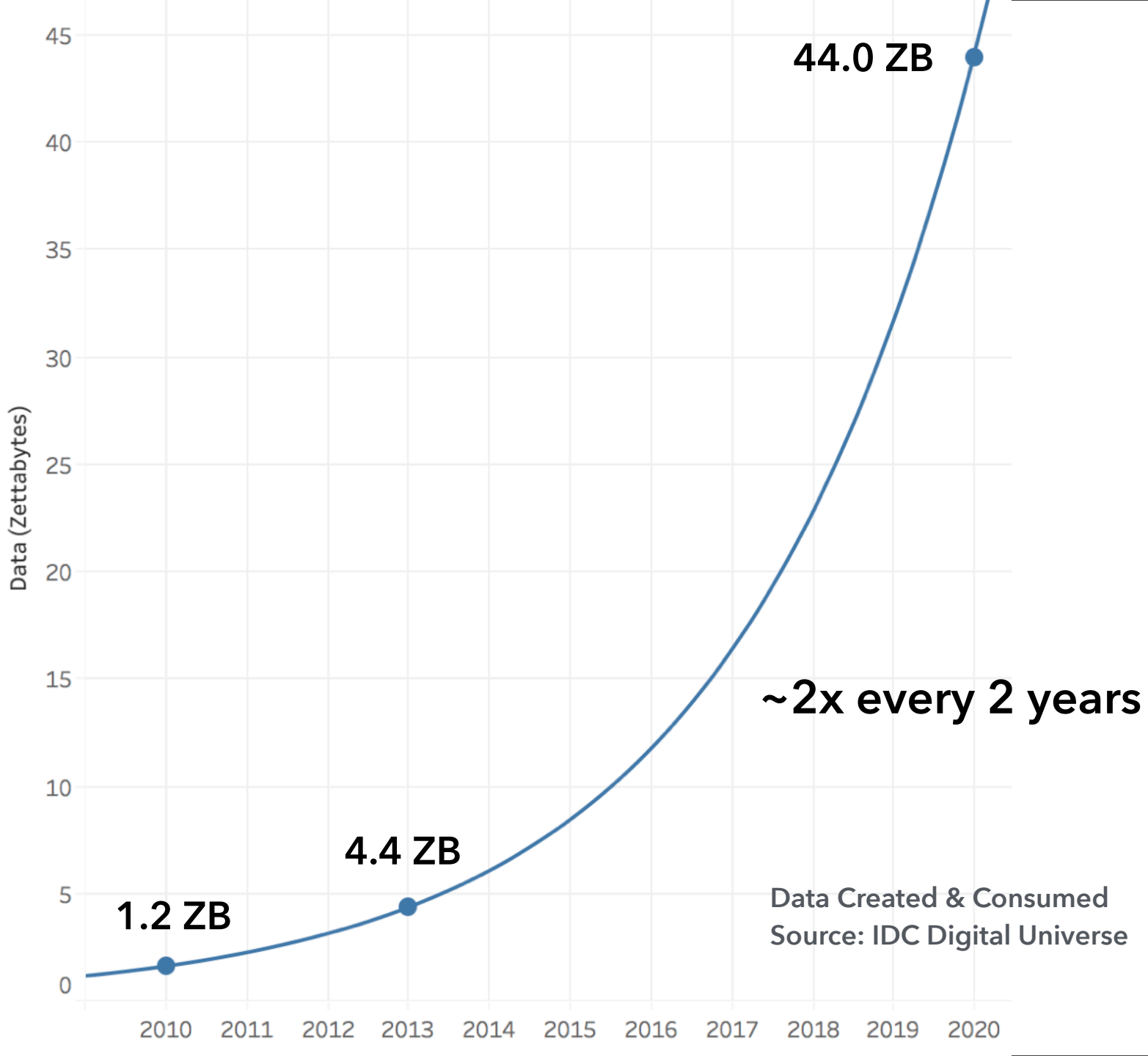


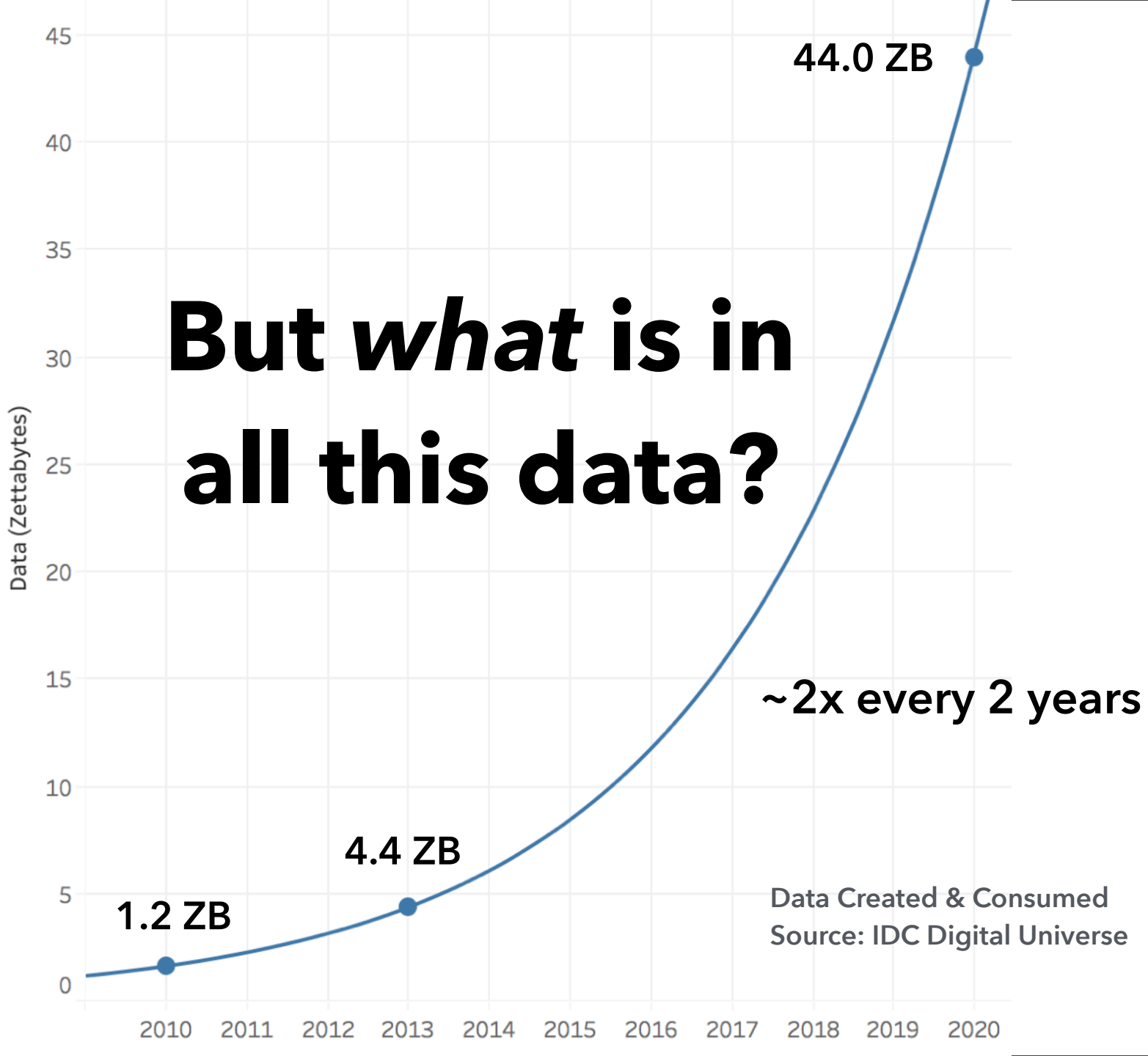
Jeffrey Heer University of Washington

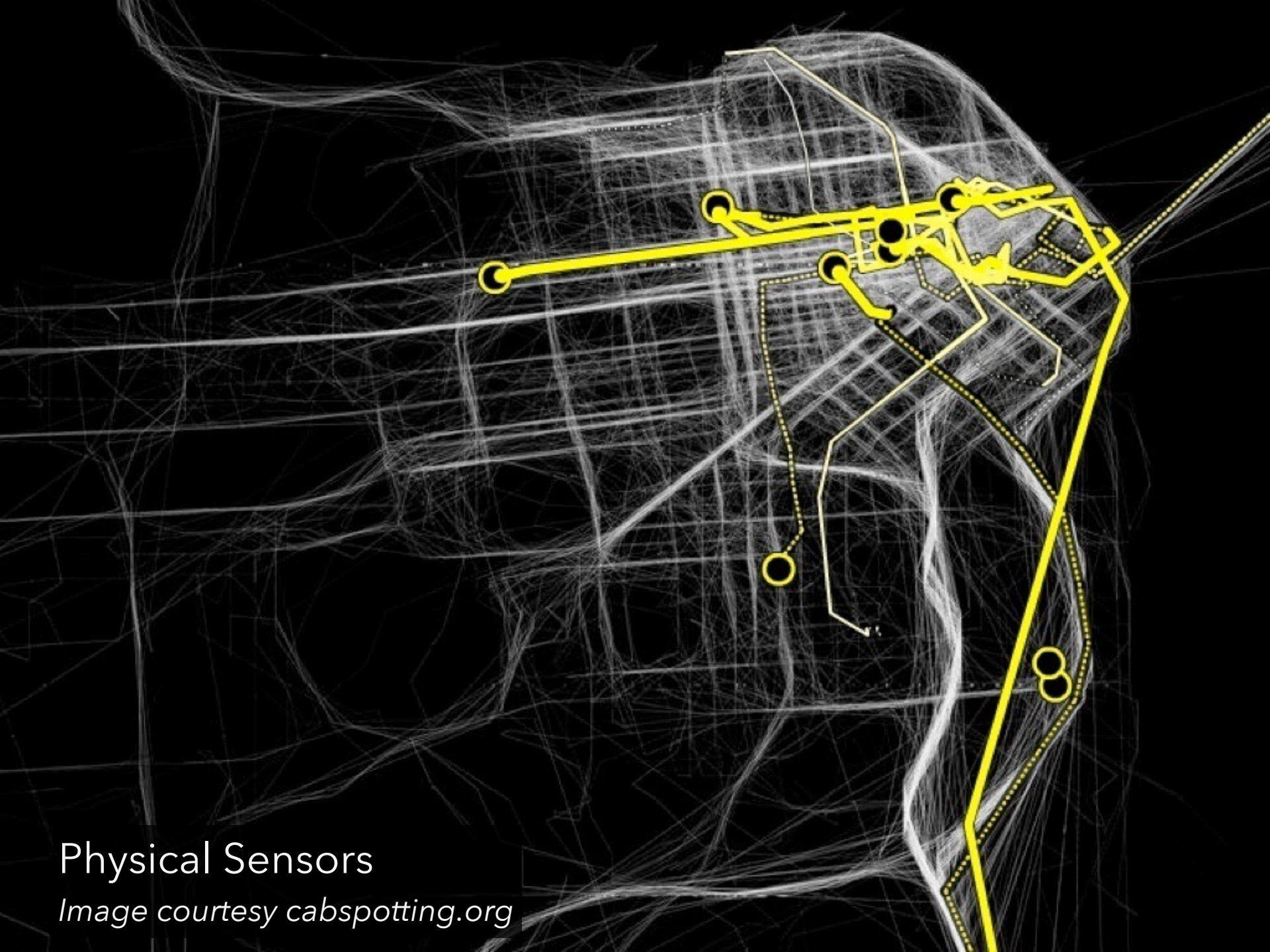
How much data (bytes) did we produce in 2010?

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

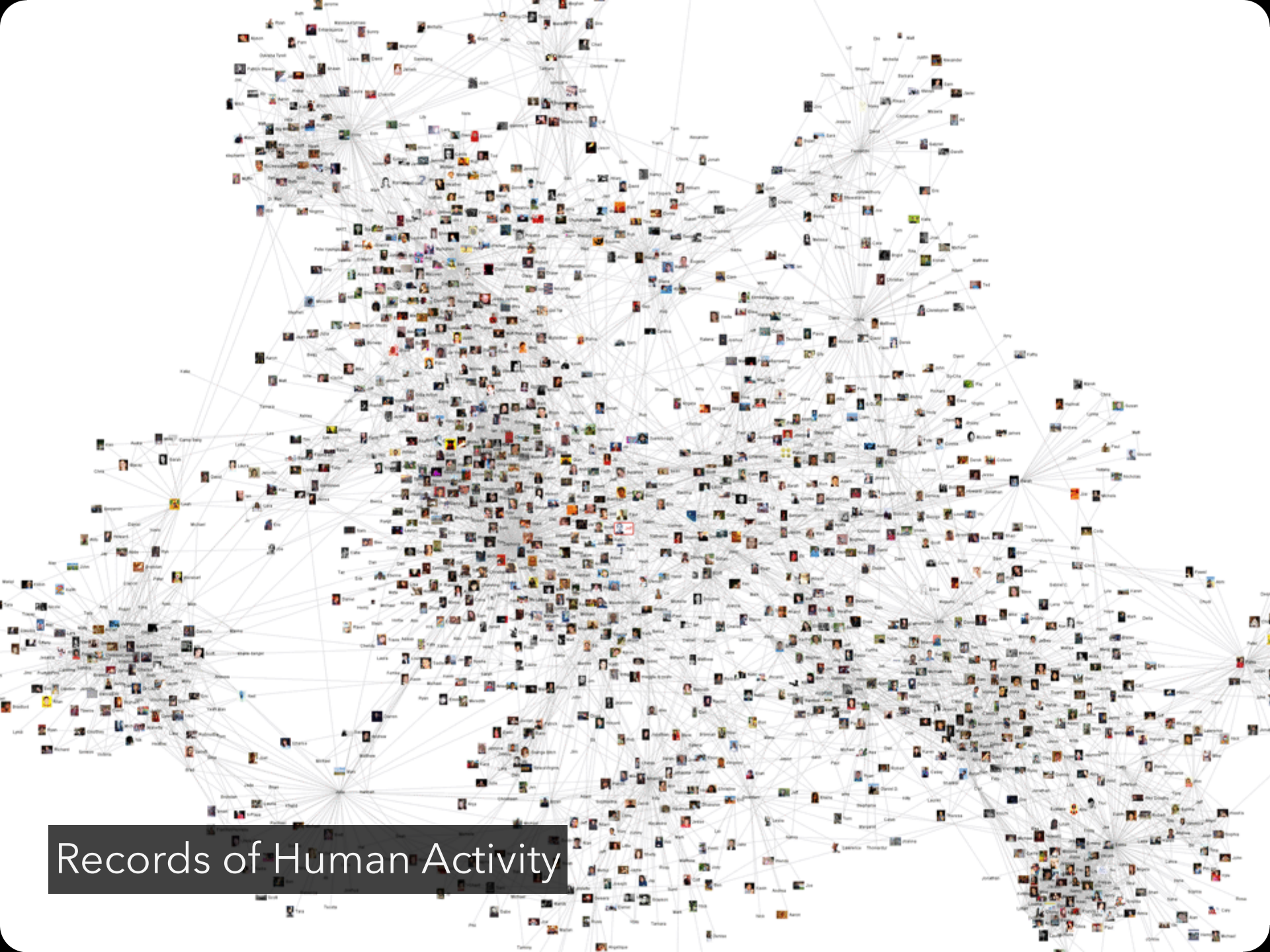

But *what* is in all this data?
Data (Zettabytes)
45
40
35
30
25
20
15
10
5
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
1.2 ZB
4.4 ZB
44.0 ZB
~2x every 2 years
Data Created & Consumed
Source: IDC Digital Universe



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!

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.

"free" to whom?

"ubiquitous" about whom?

...to whose benefit?

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

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

Share Tweet ...

TEXT SIZE − +

Psychology's Replication Crisis Can't Be Wished Away

It has a real and heartbreaking cost.

ED YONG | MAR 4, 2016 | SCIENCE

Share Tweet ...

TEXT SIZE − +

High potential for data abuse…

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

What is Visualization?

"Transformation of the symbolic into the geometric" [McCormick et al. 1987]

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

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

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

$u_X = 9.0$ $\sigma_X = 3.317$

$u_Y = 7.5$ $\sigma_Y = 2.03$

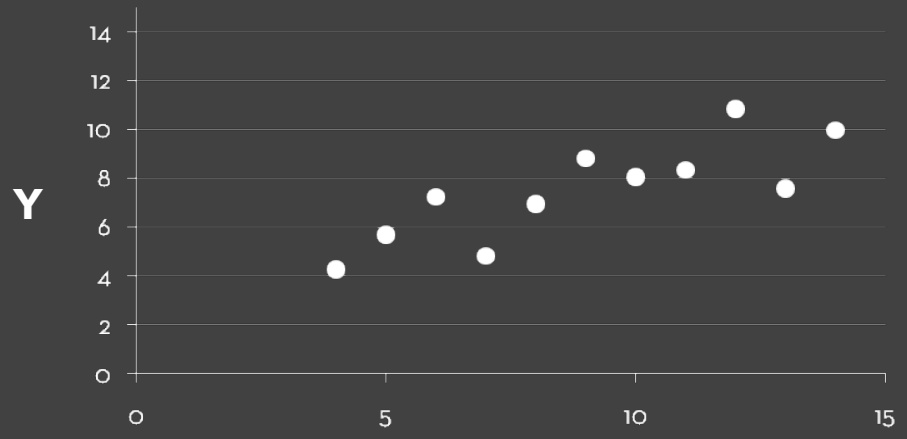
Linear Regression

$Y = 3 + 0.5\ X$

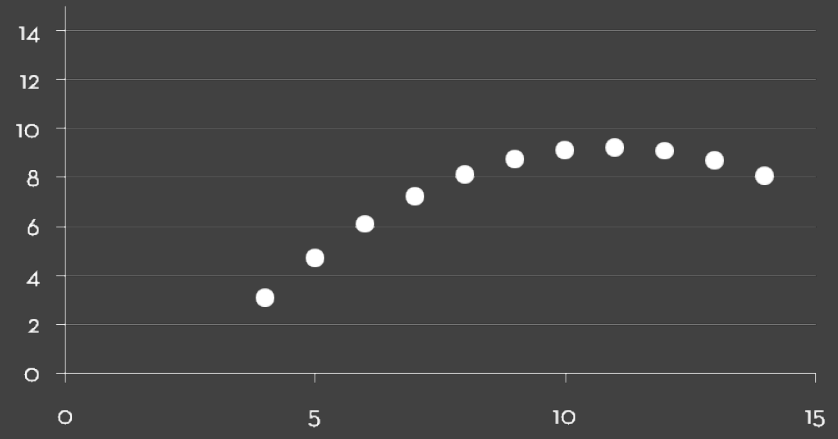
$R^2 = 0.67$

[Anscombe 1973]

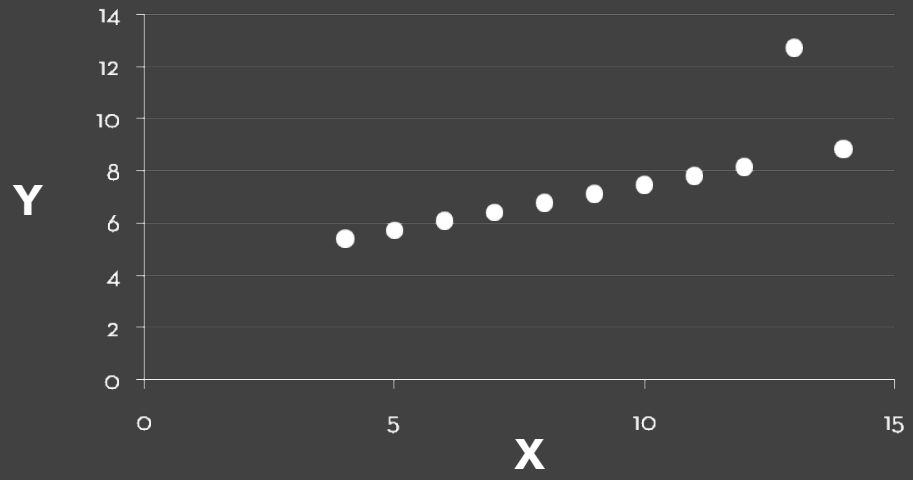
Set A



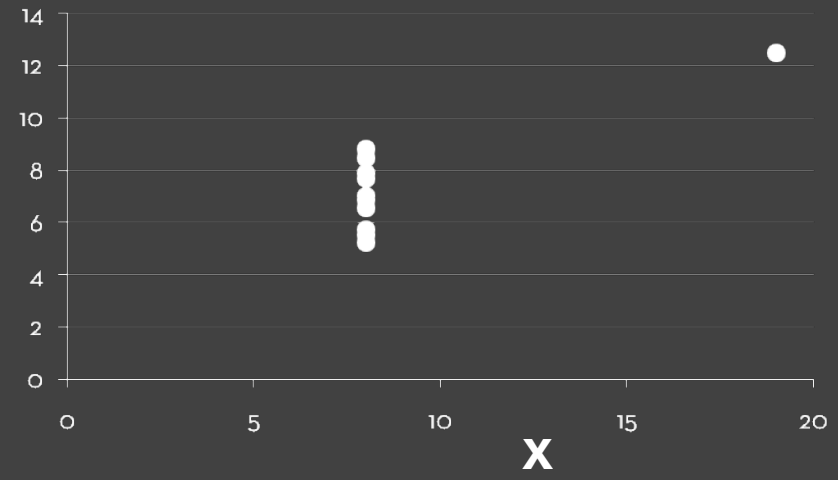
Set B



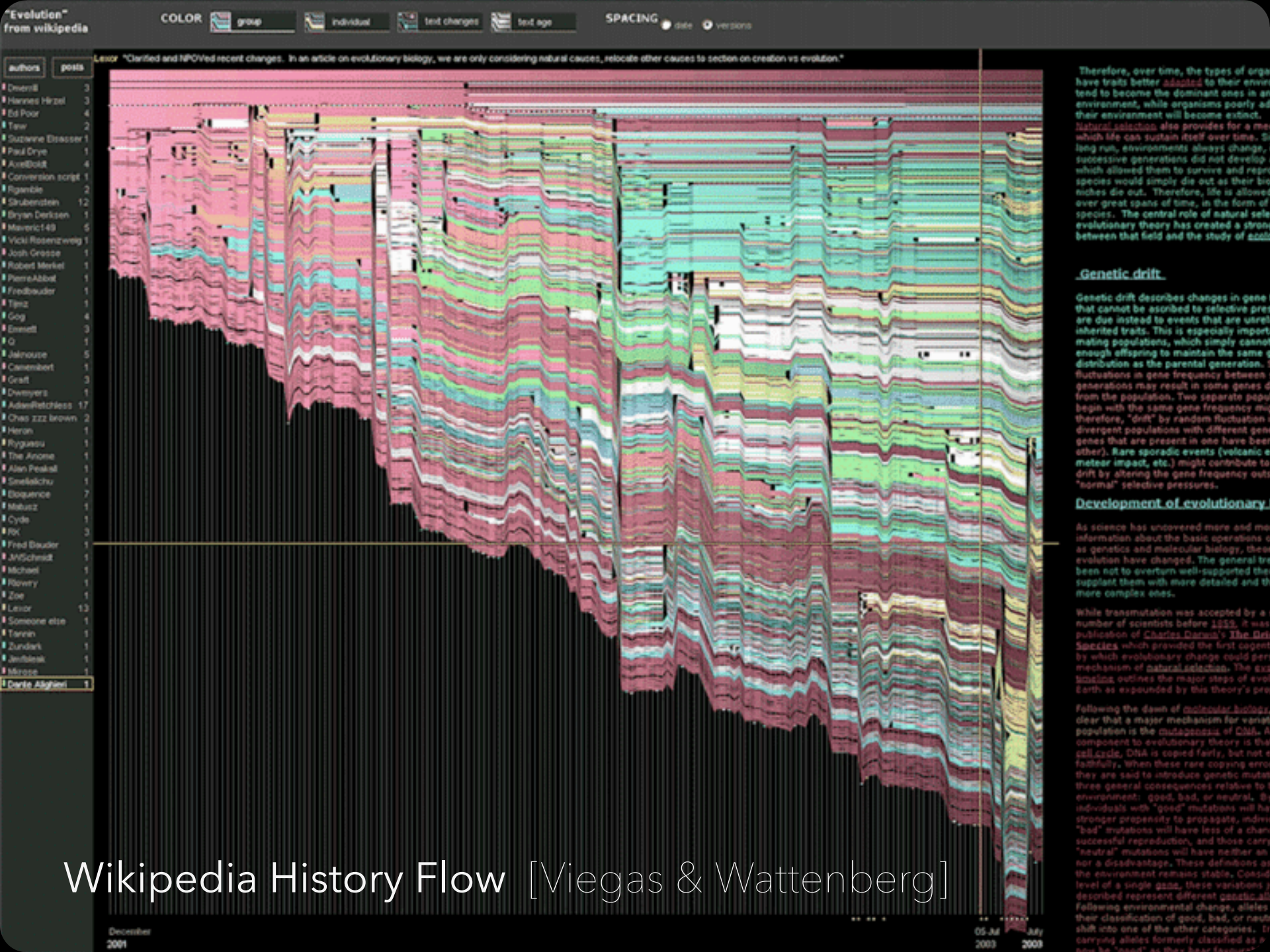
Set C



Set D



[Anscombe 1973]



Wikipedia History Flow [Viegas & Wattenberg]

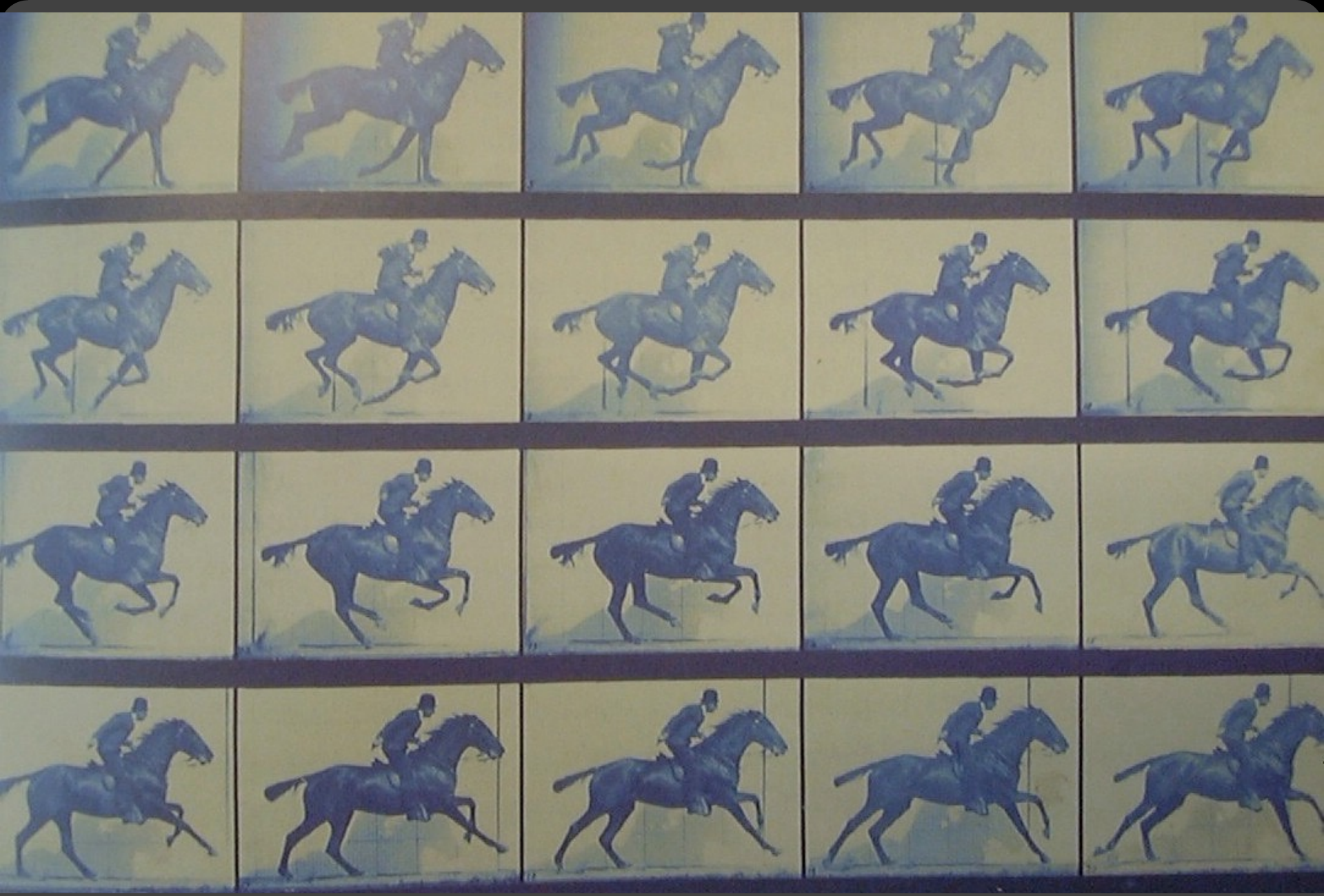
Wikipedia History Flow [Viegas & Wattenberg]

Why Create Visualizations?

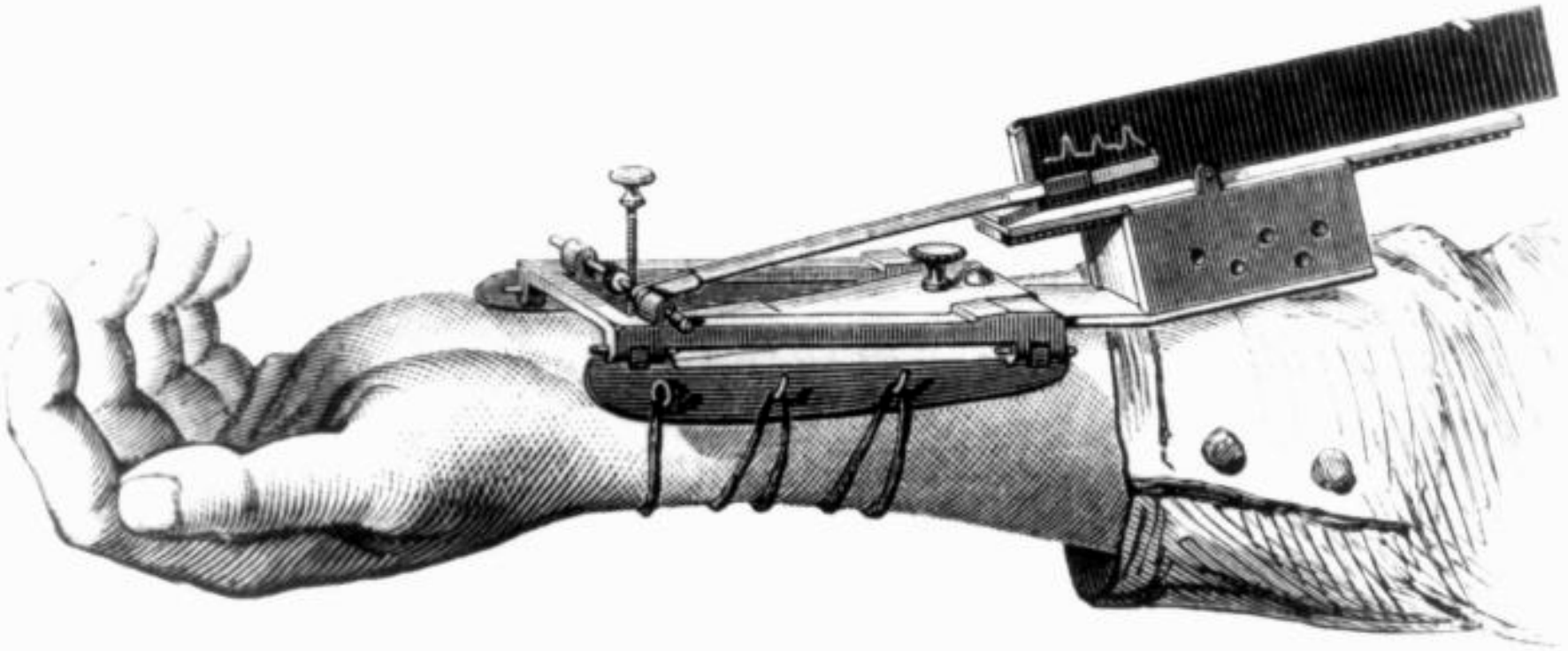
Why Create Visualizations?

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

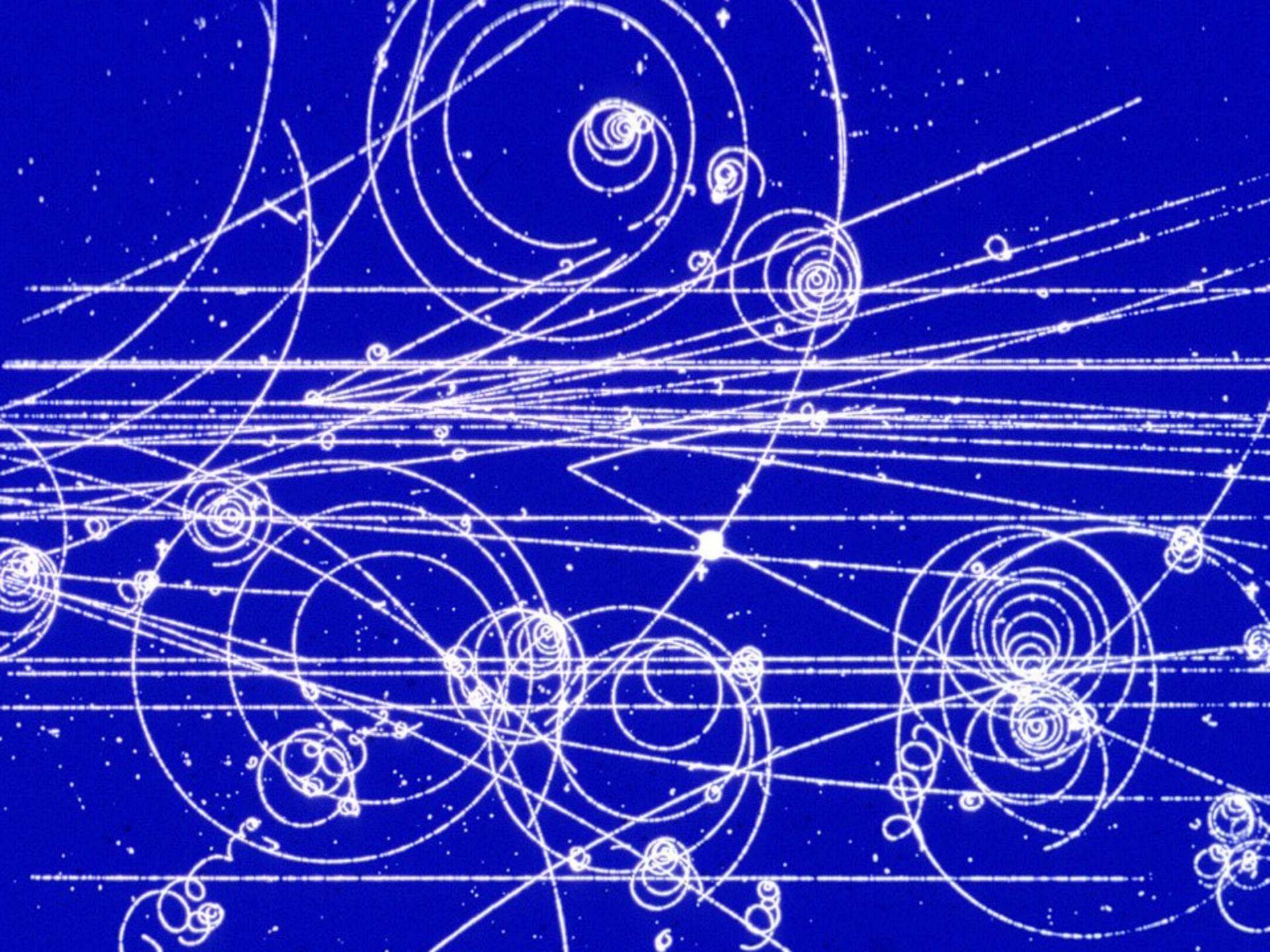


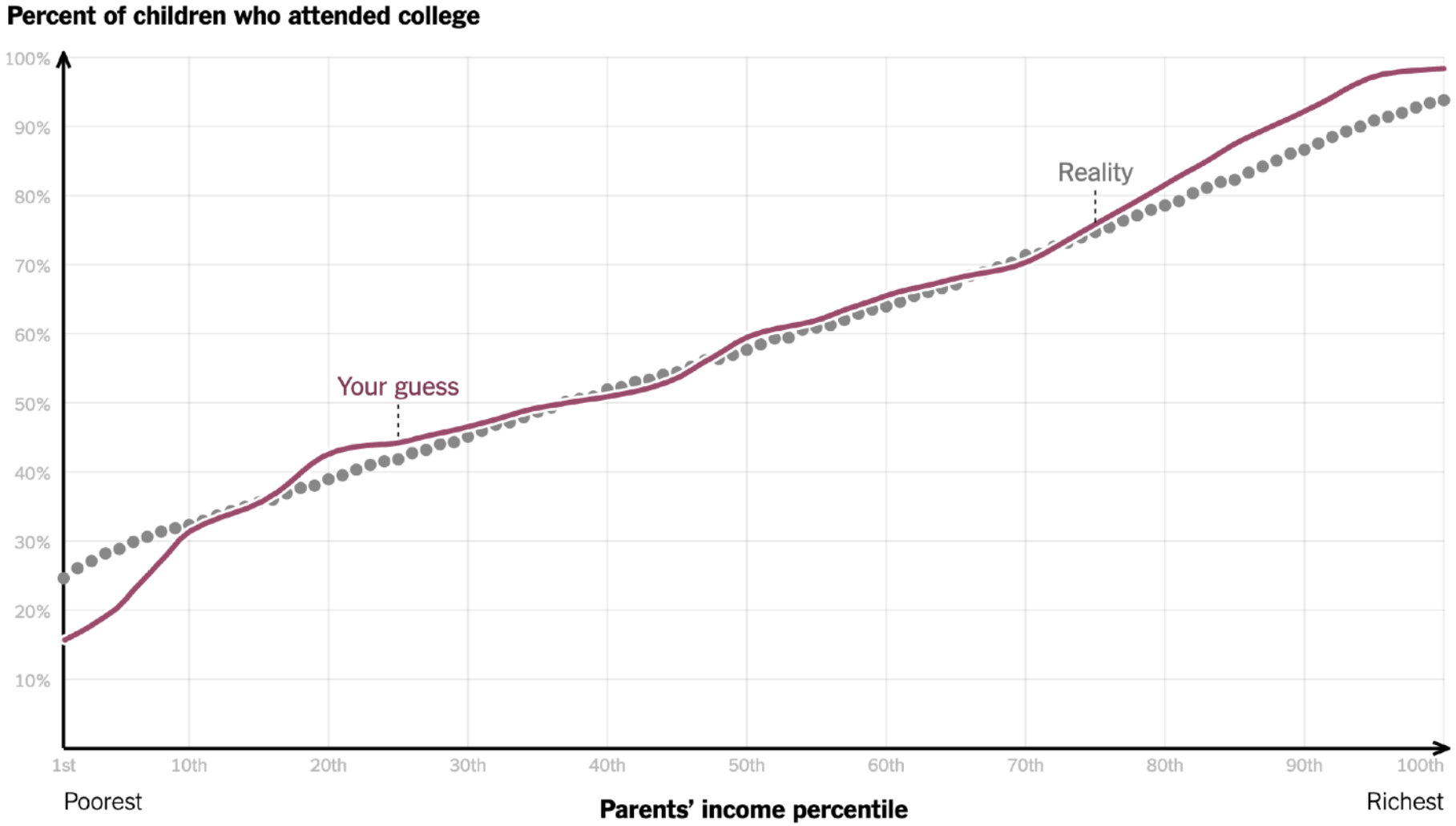
Gallop, Bay Horse “Daisy” [Muybridge]



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

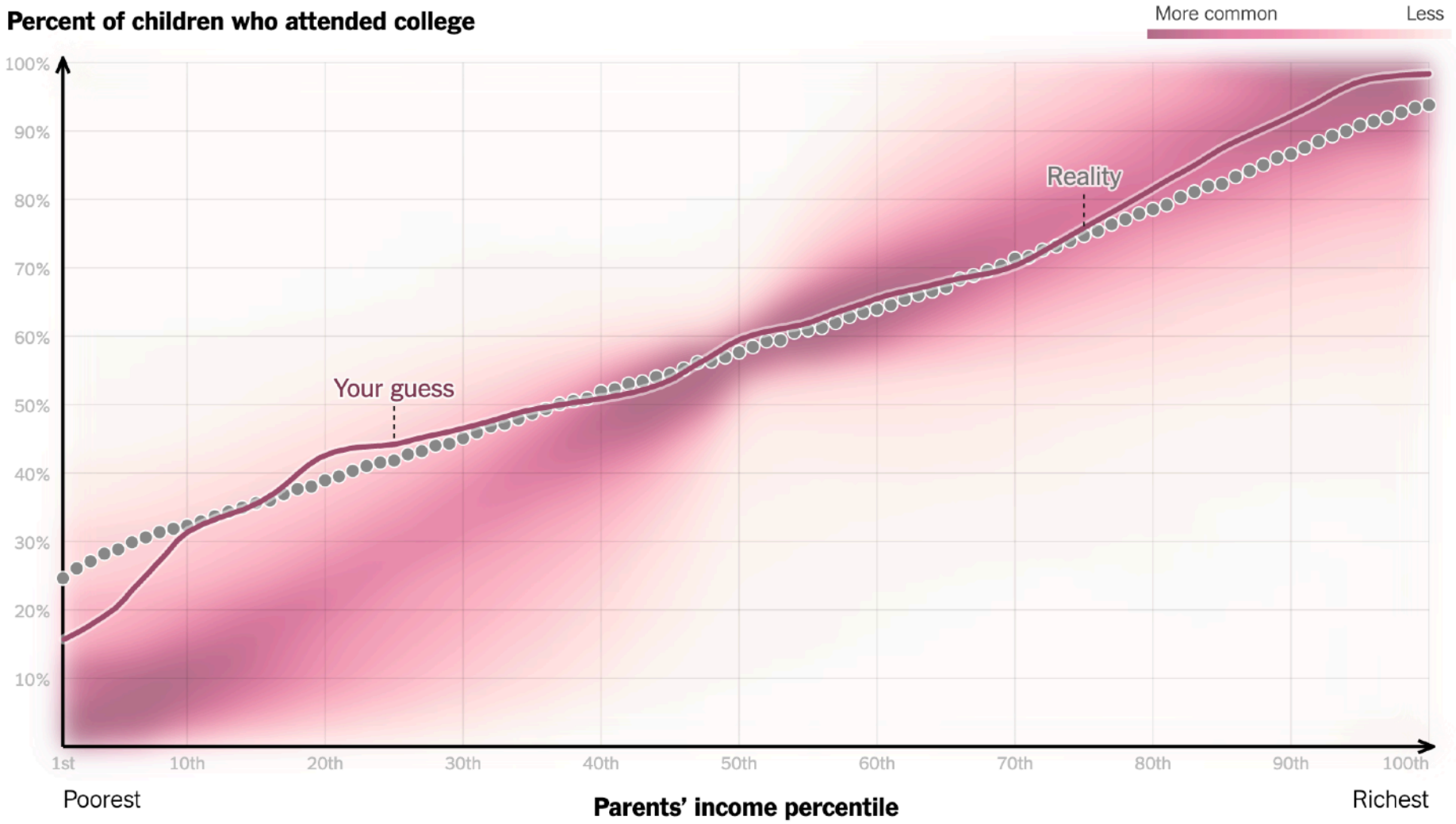
E.J. Marey's sphygmograph [from Braun 83]





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

[New York Times, May 28, 2015]



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

[New York Times, May 28, 2015]

Support Reasoning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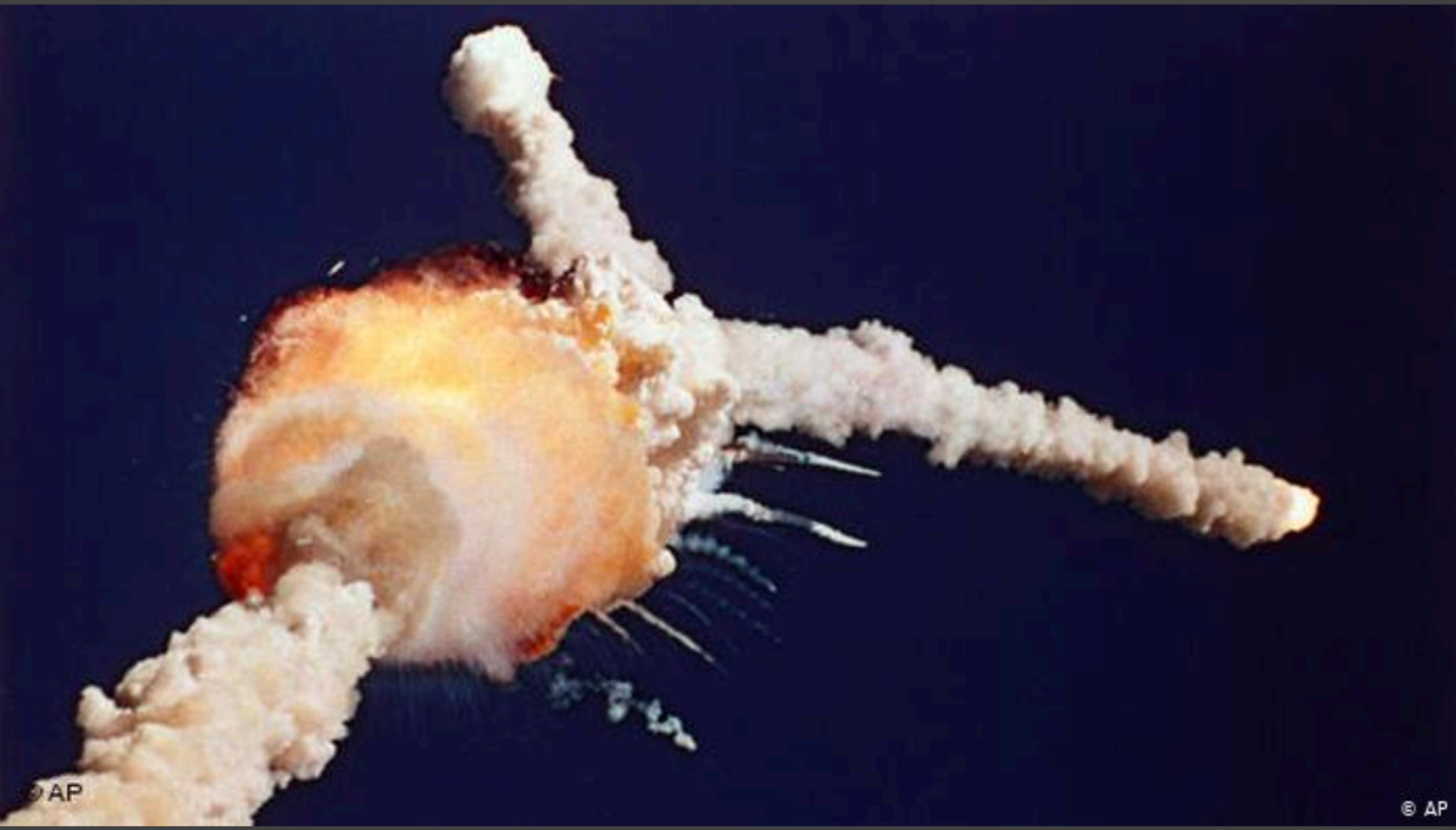
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HISTORY OF O-RING DAMAGE ON SRM FIELD JOINTS

	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°)

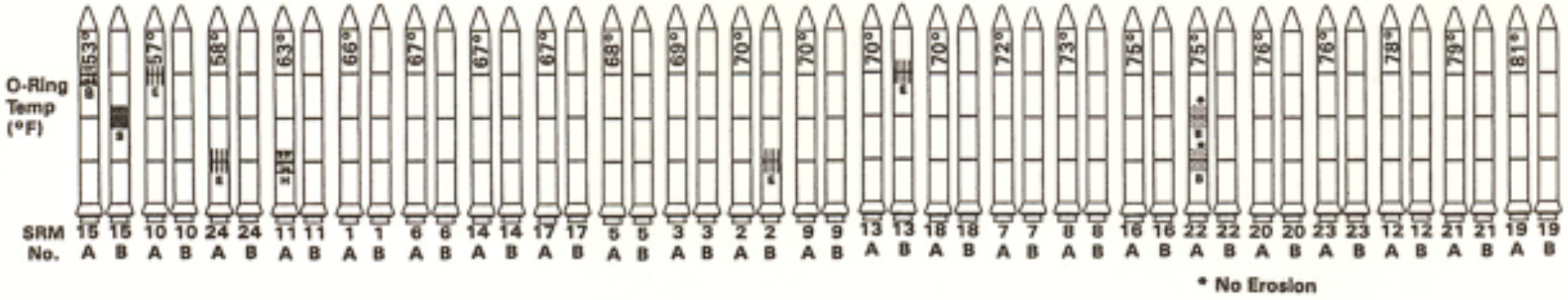
SRM-13A, 15, 16A, 18, 23A 24A
- nozzle Blow-By

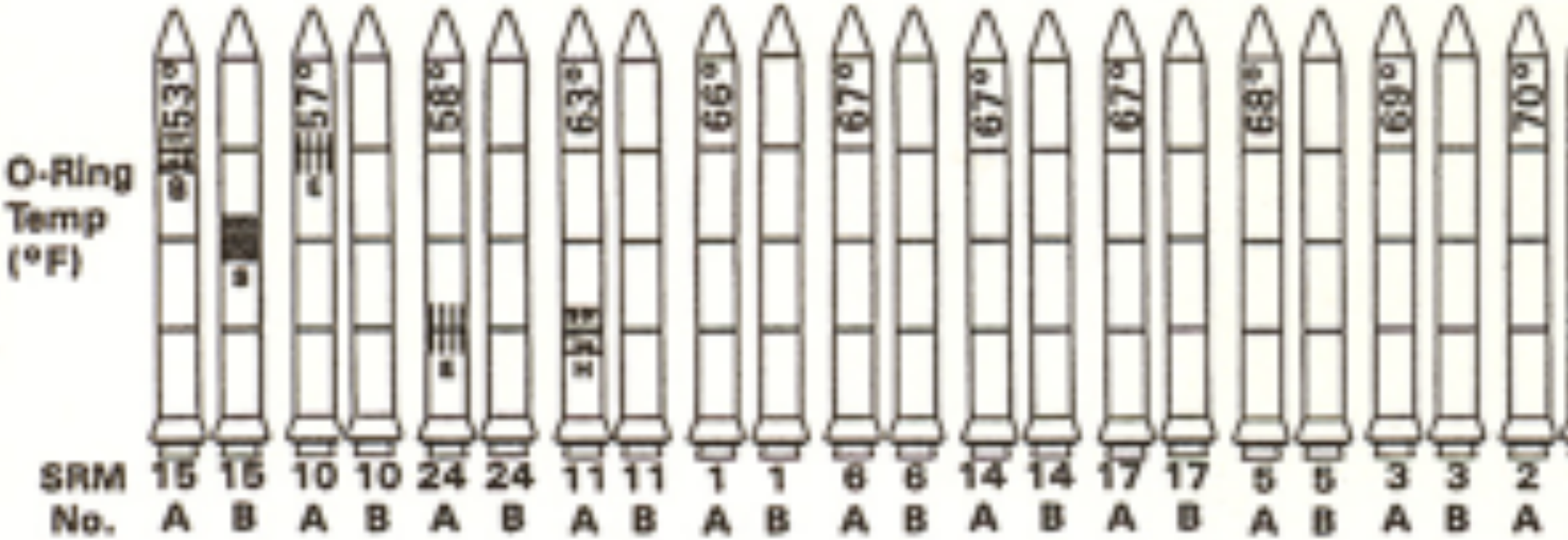
History of O-ring Temperatures (Degrees - F)

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

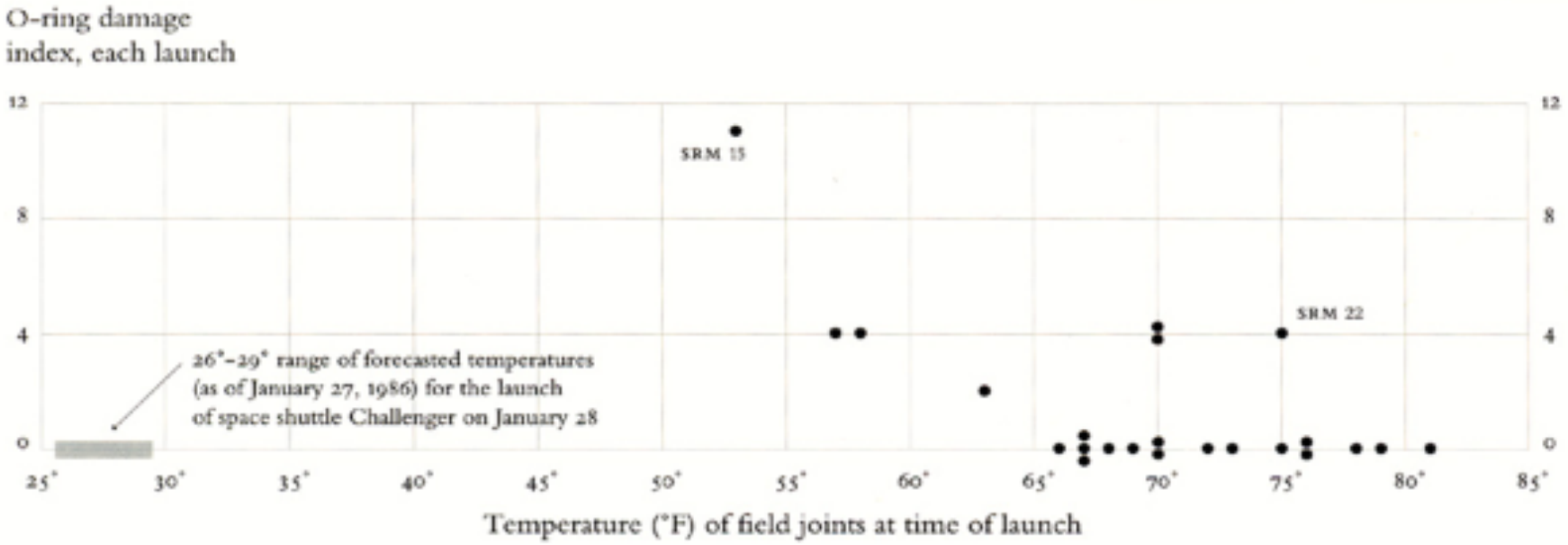
2 of 13 pages of material faxed to NASA by Morton Thiokol [from Tufte 1997]

Make Decisions: Challenger





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]

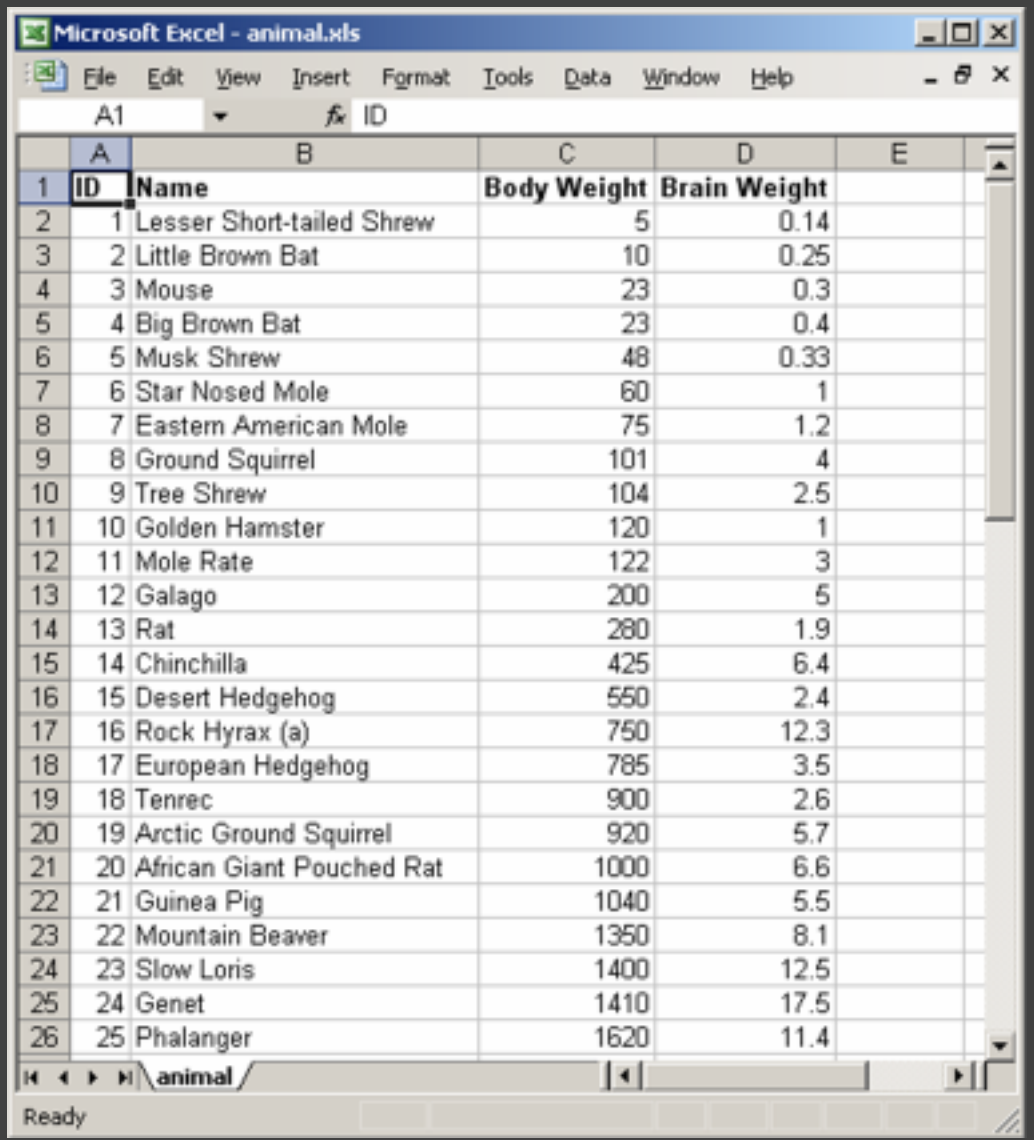
Data in Context: Cholera Outbreak

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

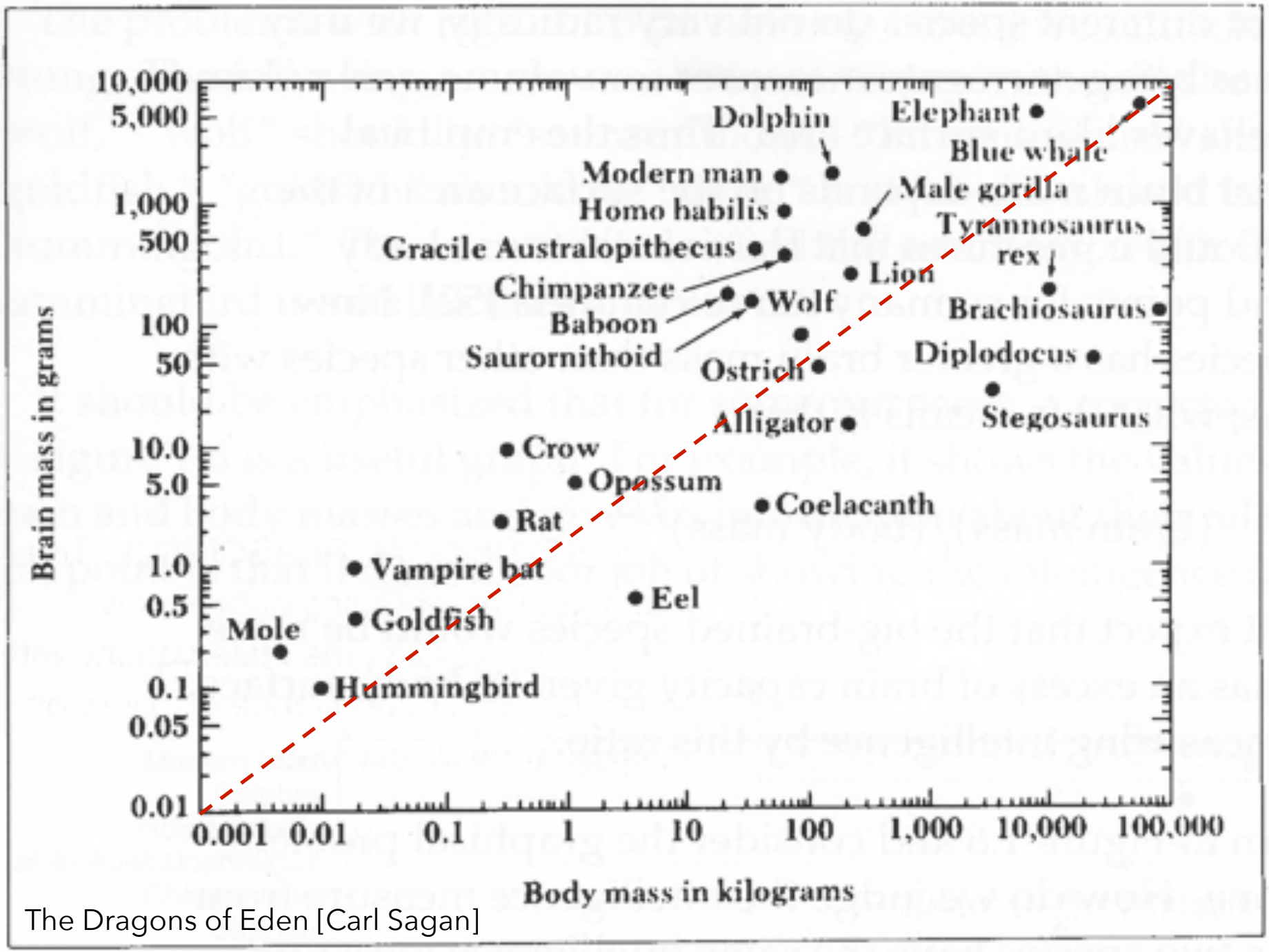
Data in Context: Cholera Outbreak

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

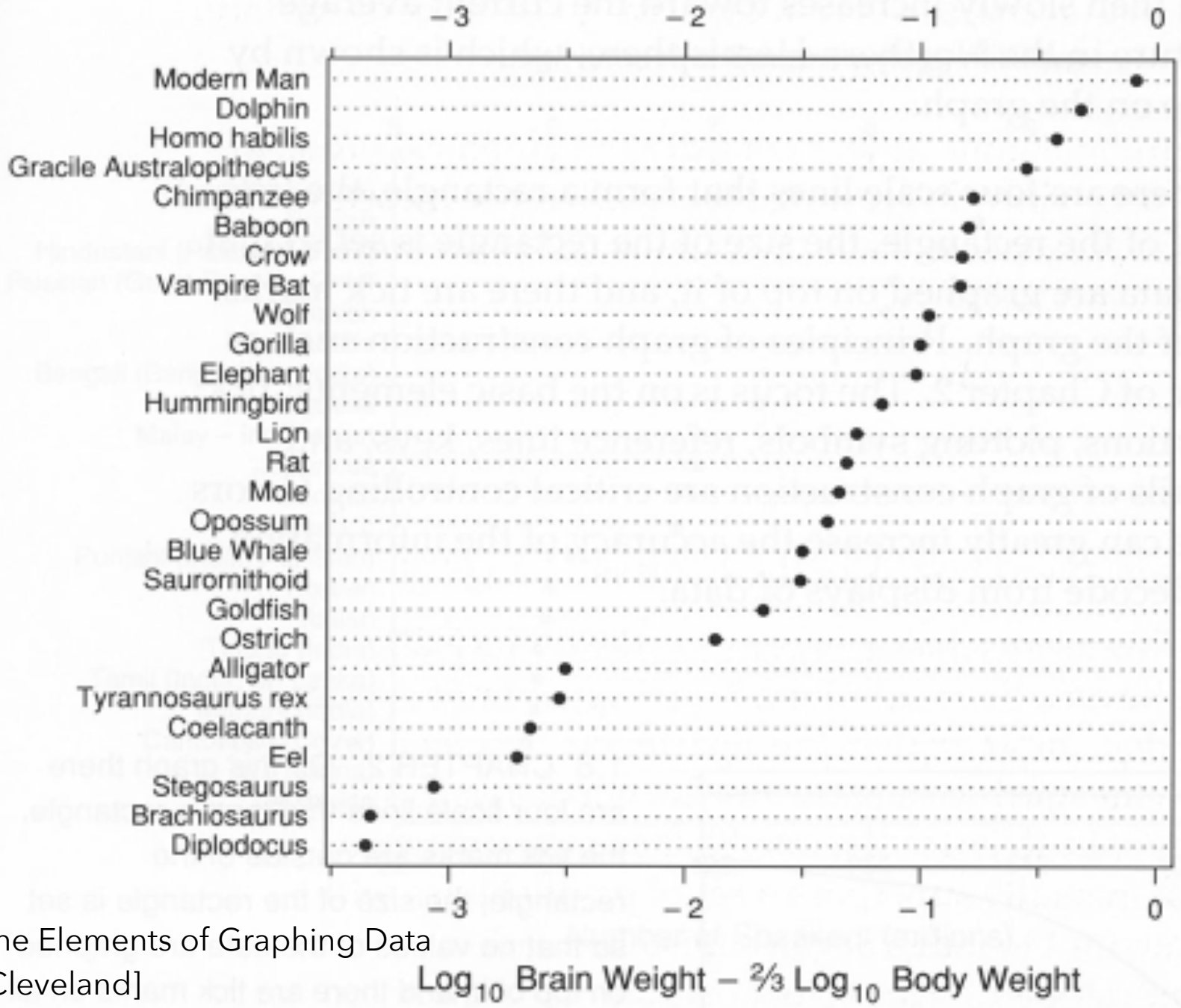
Answer Questions: Brain Power?



	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	

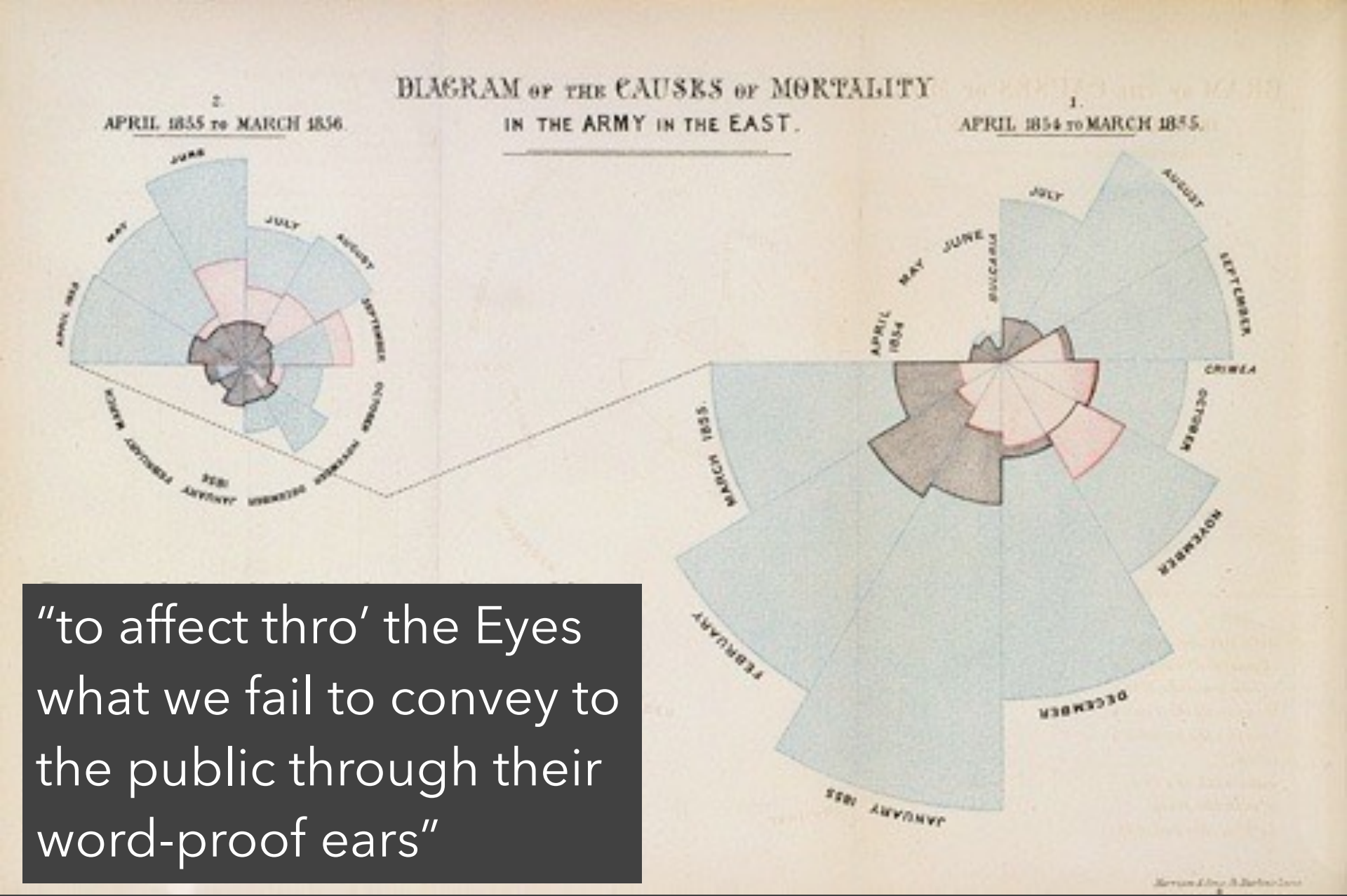


The Dragons of Eden [Carl Sagan]



The Elements of Graphing Data
[Cleveland]

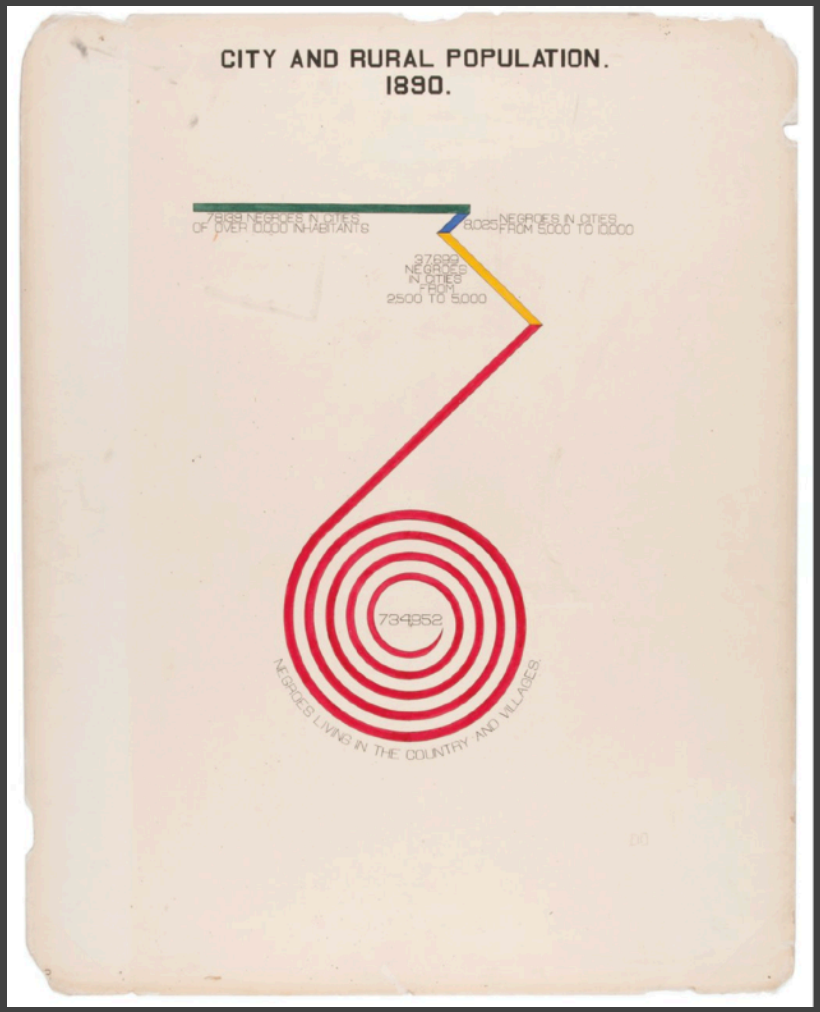
Convey Information



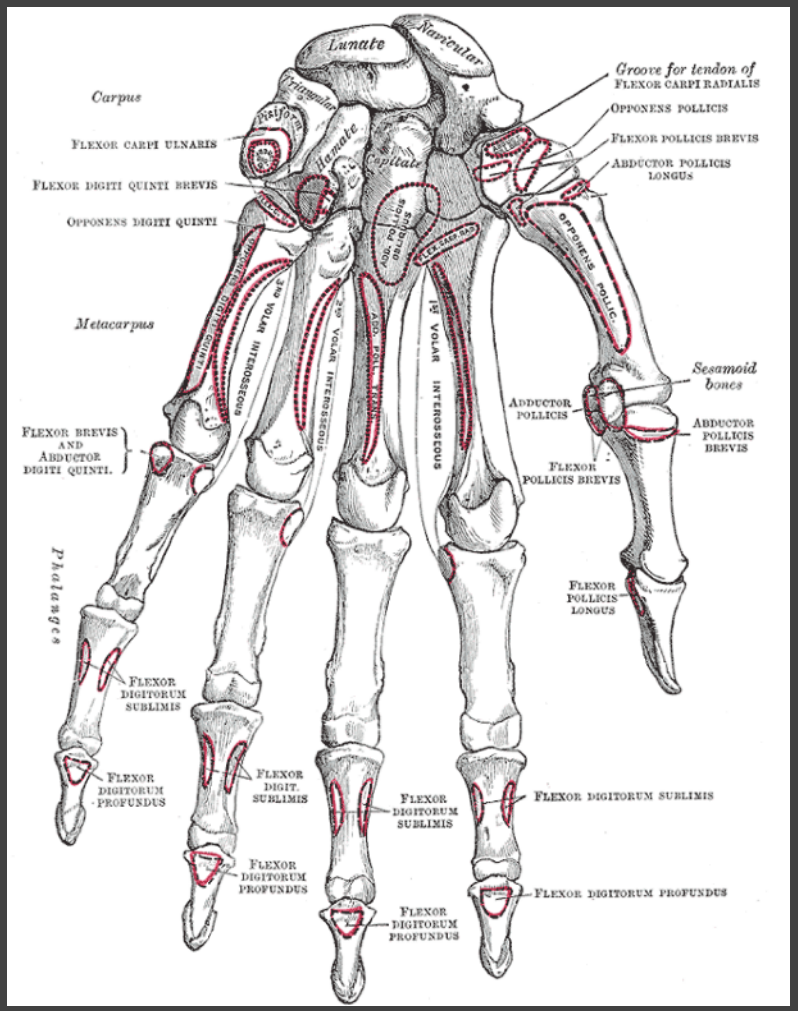
"to affect thro' the Eyes what we fail to convey to the public through their word-proof ears"

1856 "Coxcomb" of Crimean War Deaths, Florence Nightingale

Communicate, Inform, Inspire



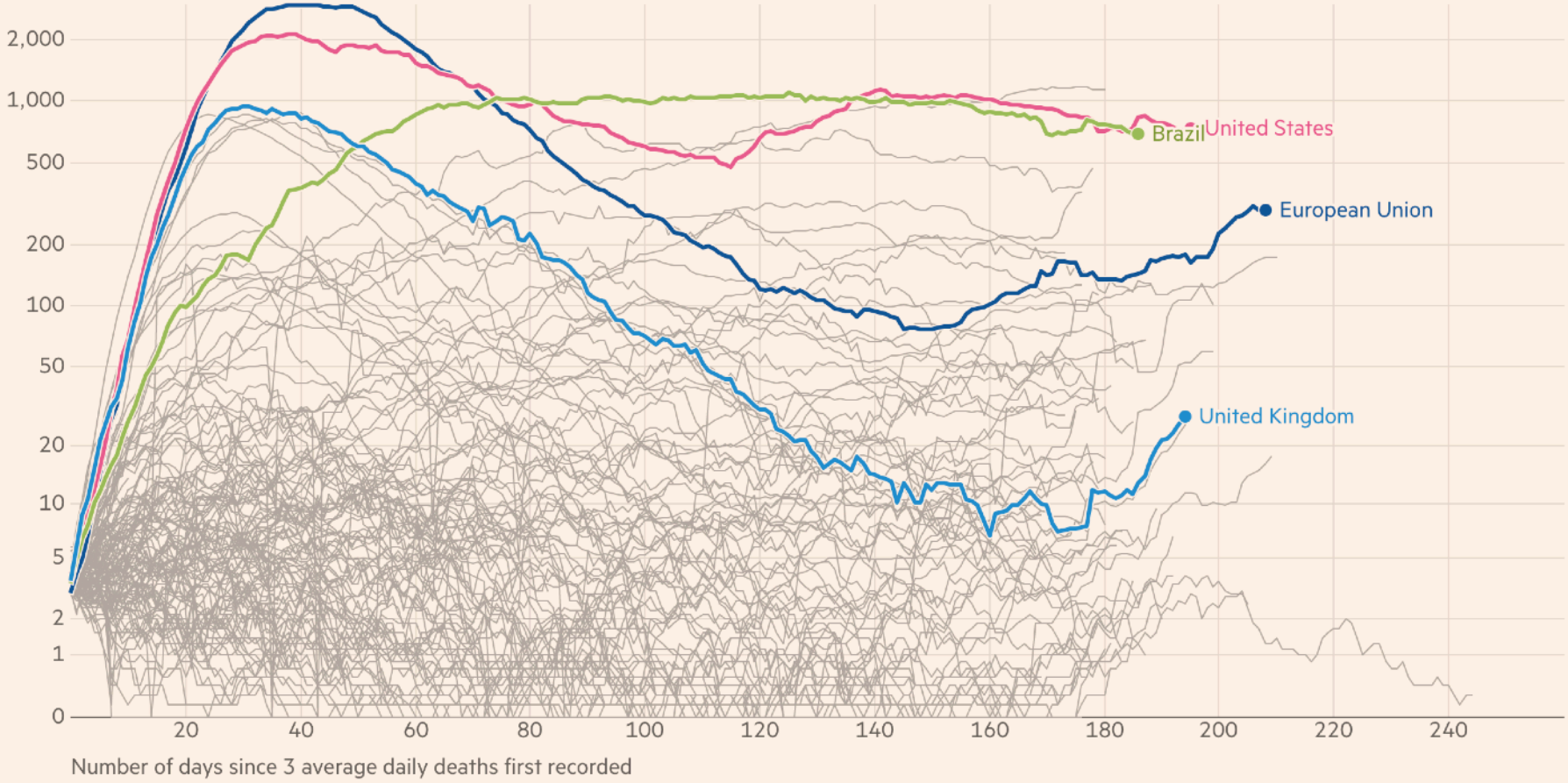
Visualizing Black America, Du Bois et al. 1900



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



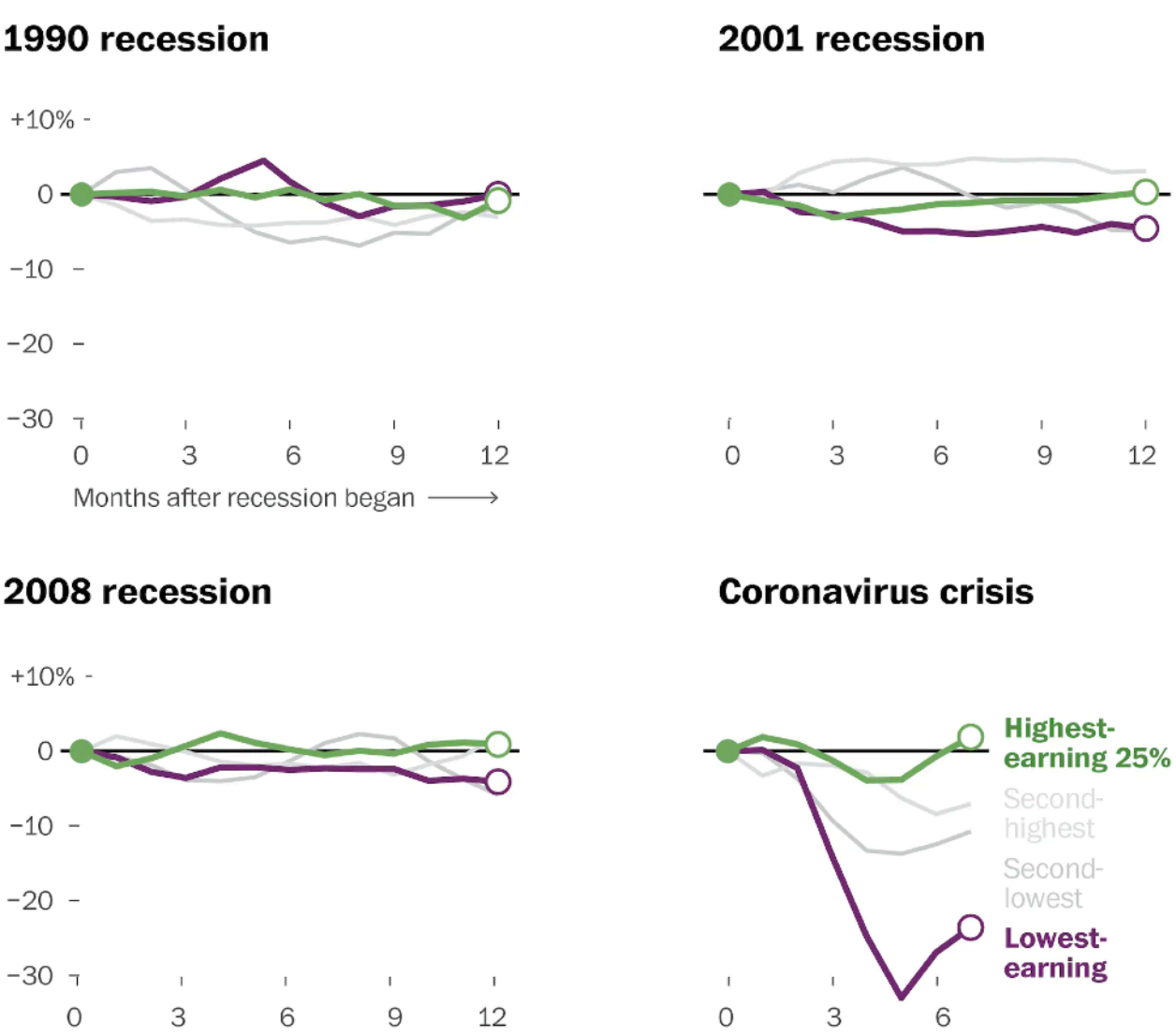
Source: Financial Times analysis of data from the European Centre for Disease Prevention and Control, the Covid Tracking Project, the UK Dept of Health & Social Care and the Spanish Ministry of Health.
Data updated September 25 2020 12.46pm BST. Interactive version: ft.com/covid19

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

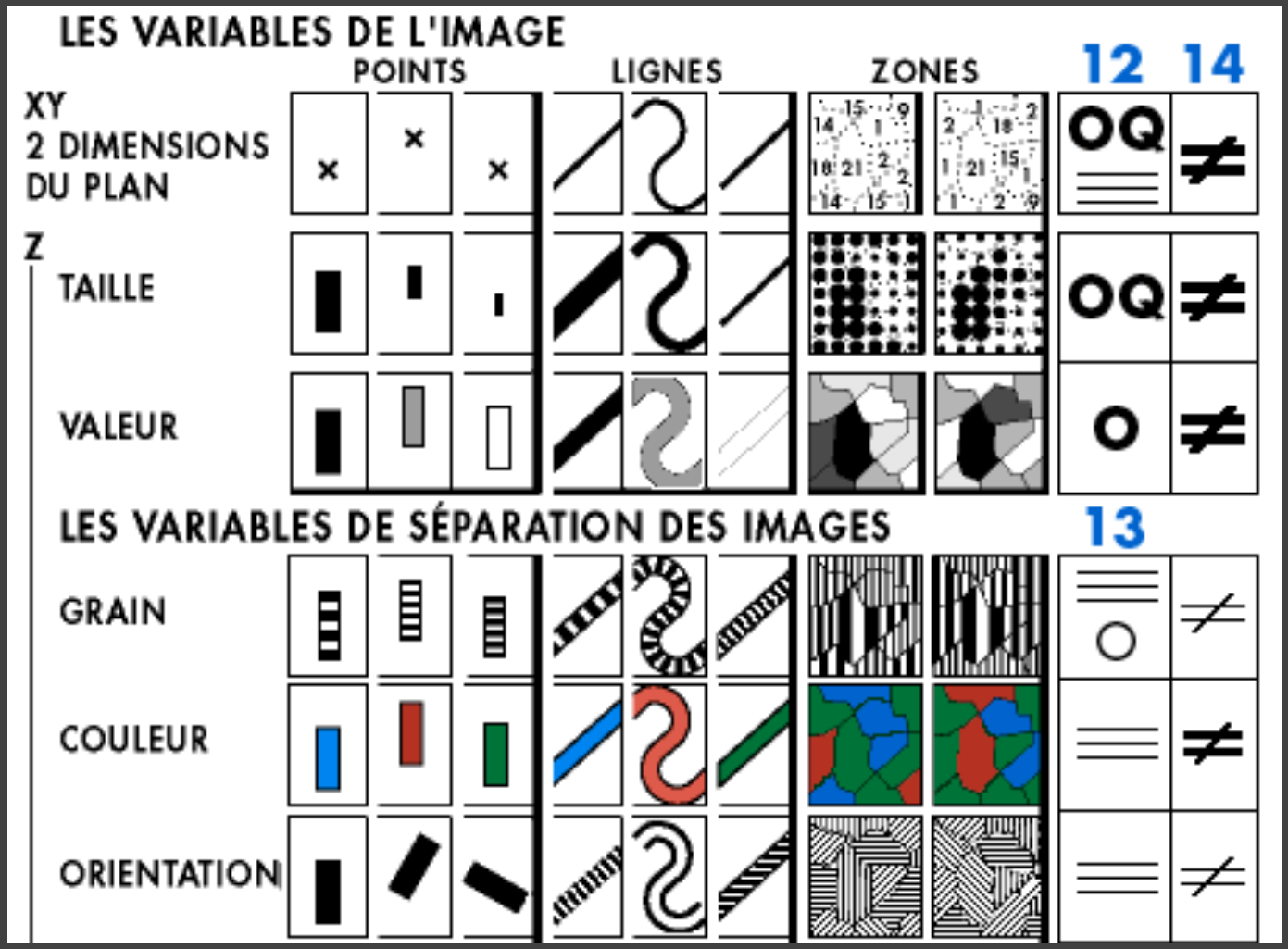
   What do people perceive / comprehend?
   How do visualizations inform mental models?

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

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

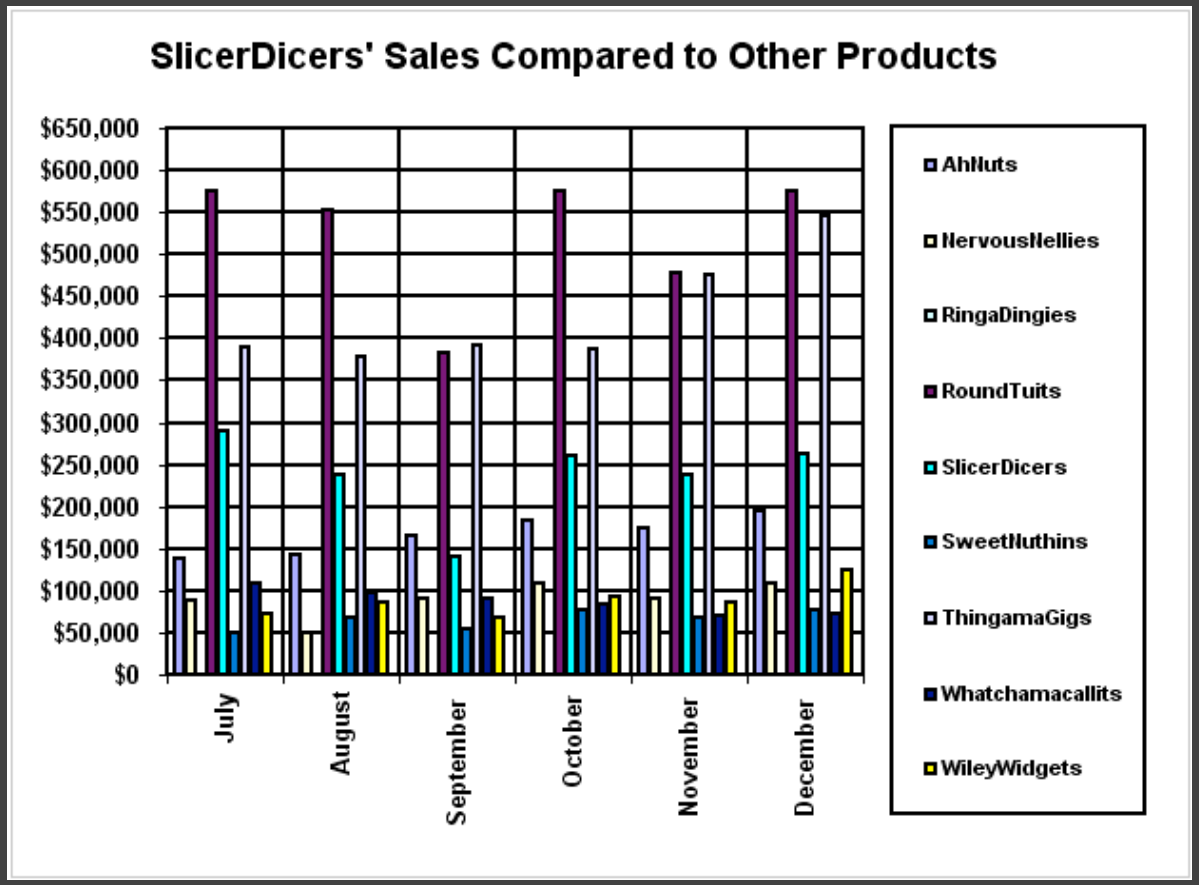
Course Topics

Data and Image Models

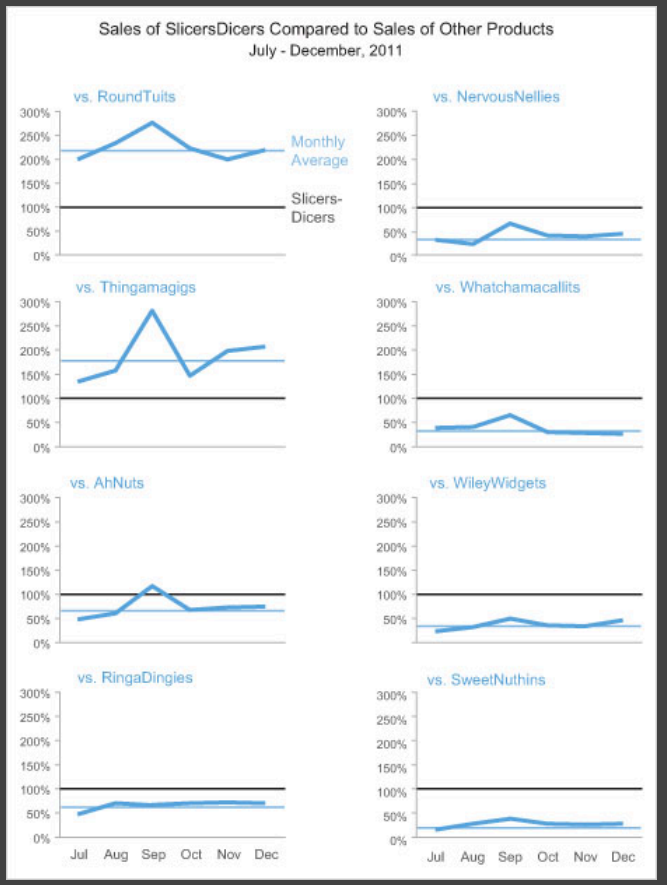


Sémiologie Graphique [Bertin 67]

Visualization Design

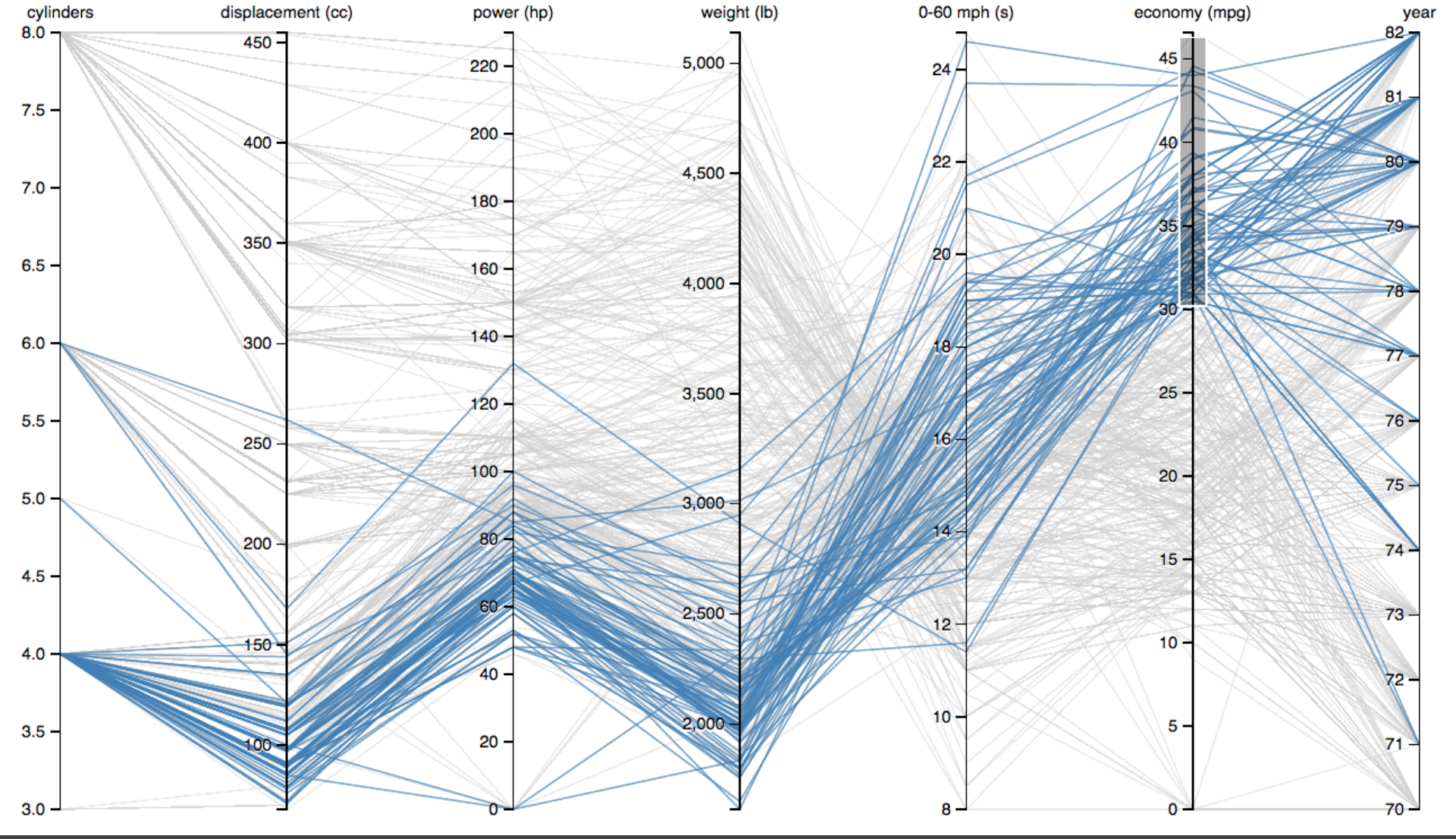


Problematic design

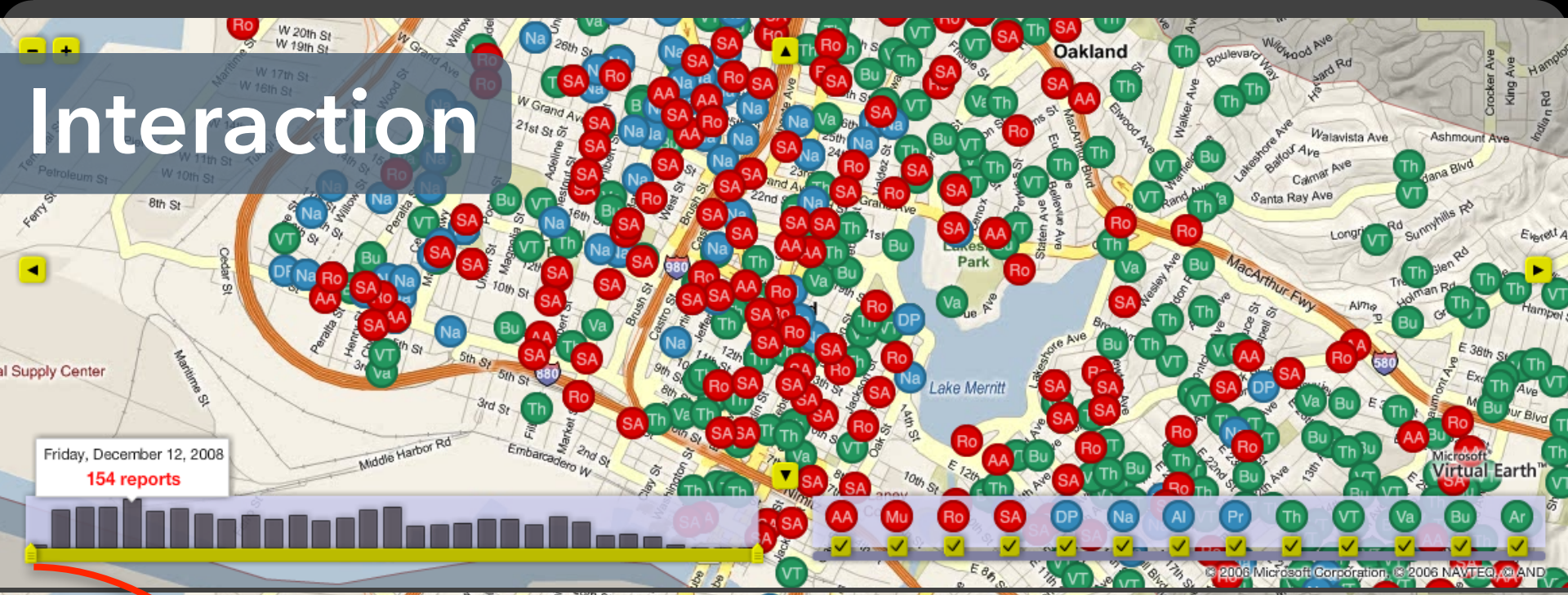


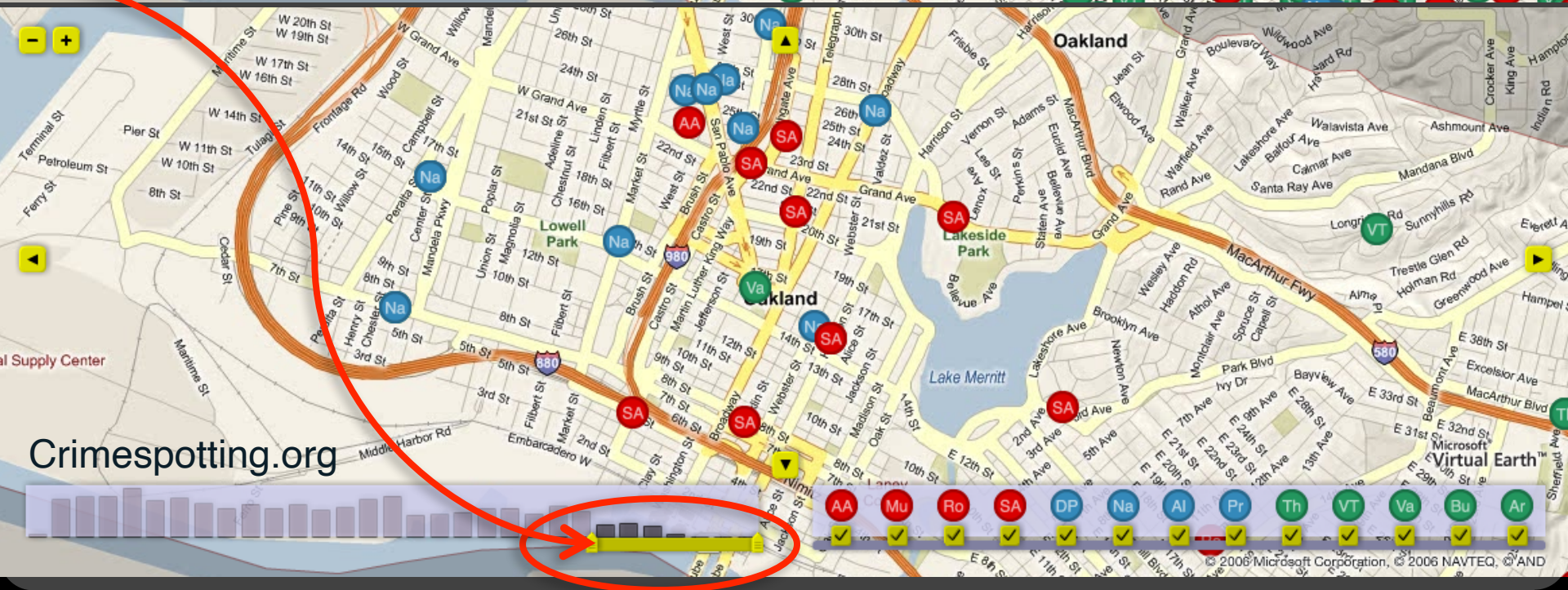
Redesign

Exploratory Data Analysis

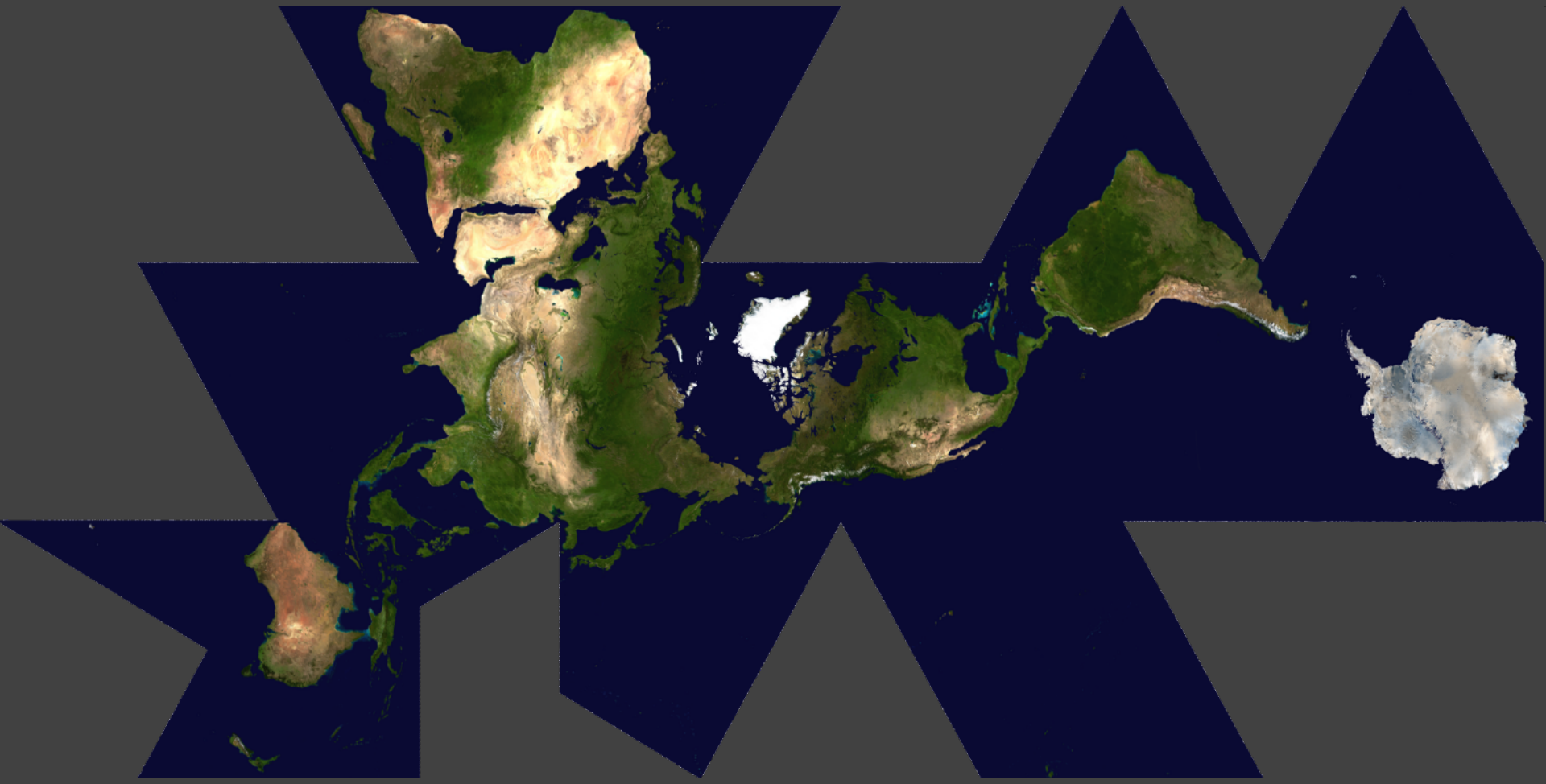


Interaction



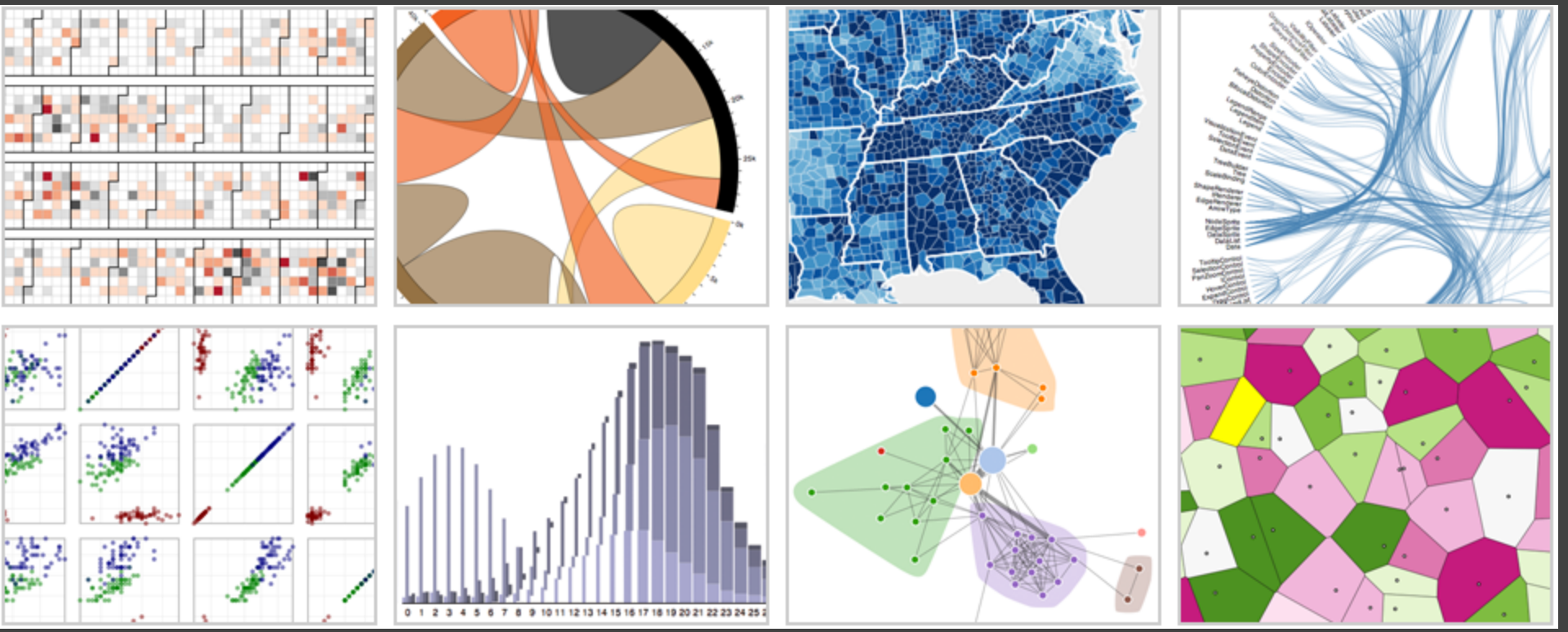


Maps



Dymaxion Maps [Fuller 46]

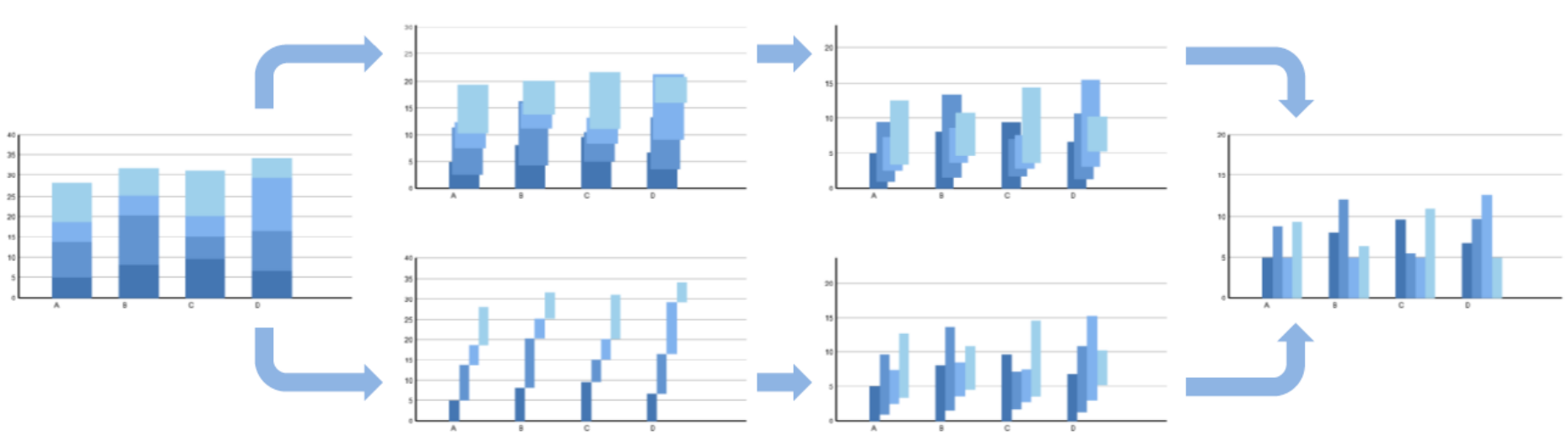
Visualization Software



D3: Data-Driven Documents

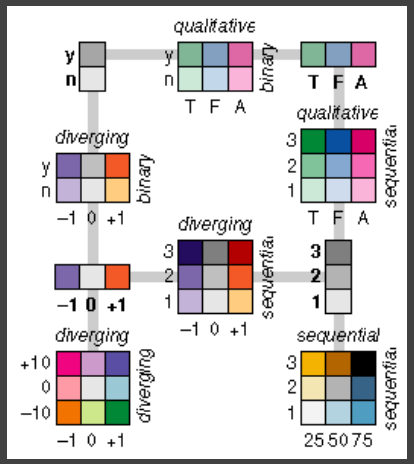
Vega-Lite / Altair

Animation

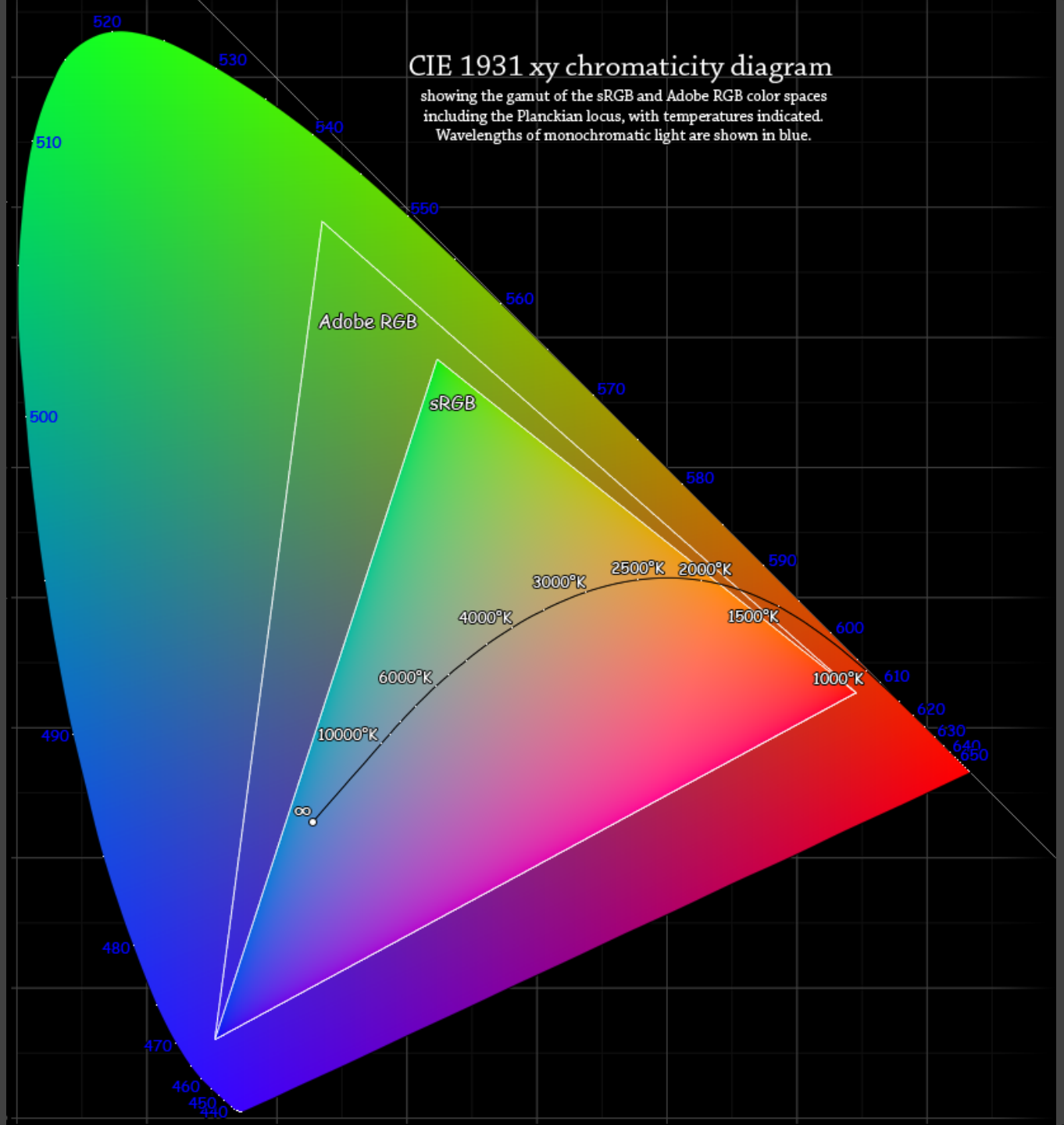


Animated transitions in statistical data graphics [Heer & Robertson 07]

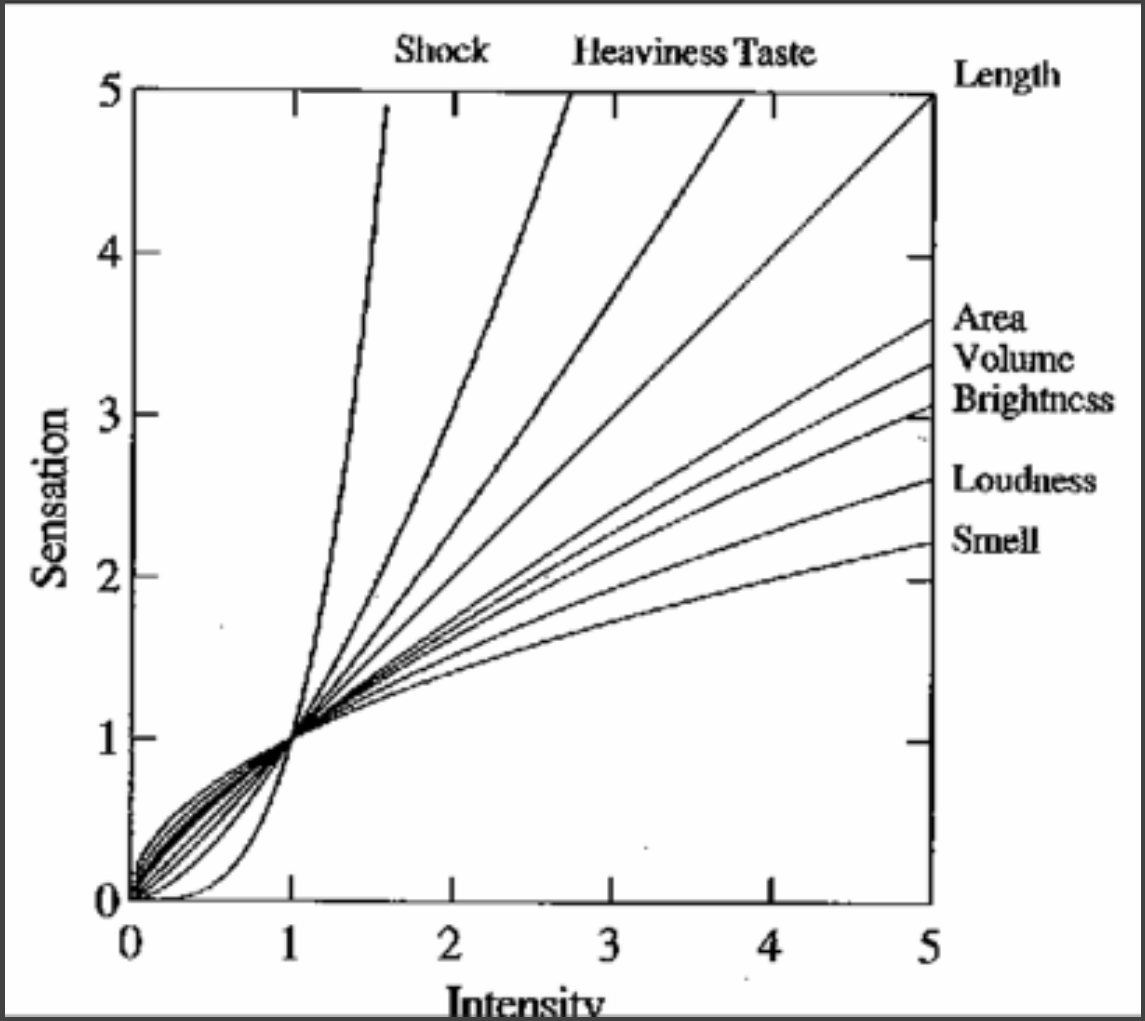
Color



Color Brewer

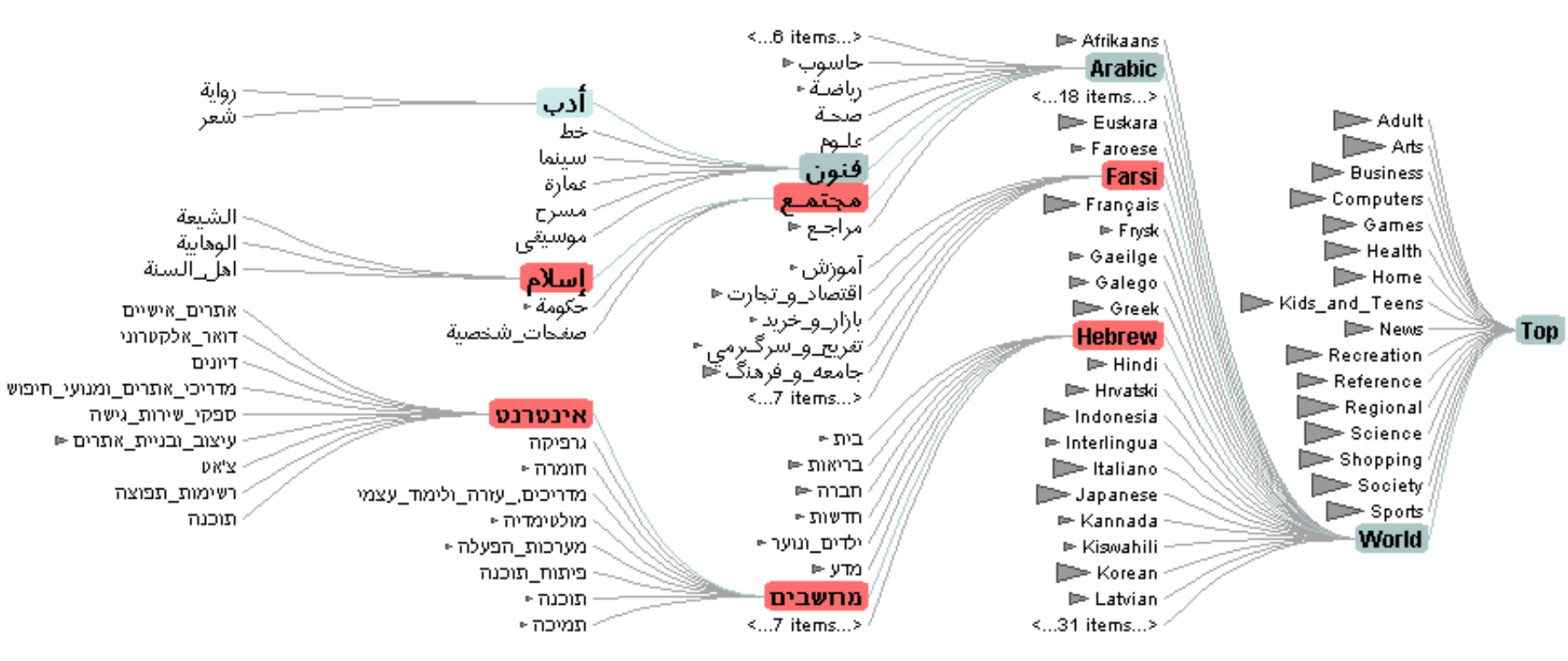


Graphical Perception



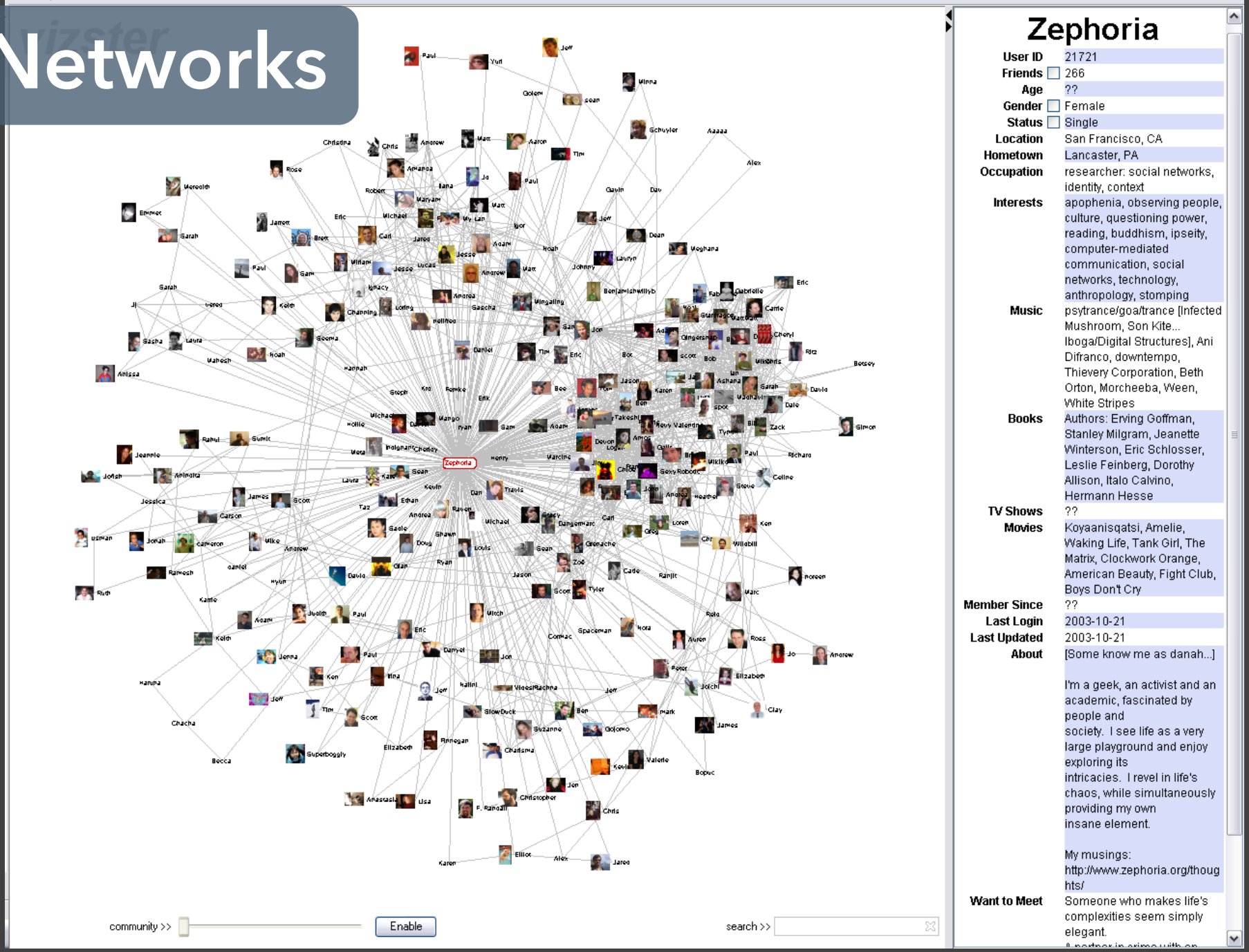
The psychophysics of sensory function [Stevens 61]

Hierarchies



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

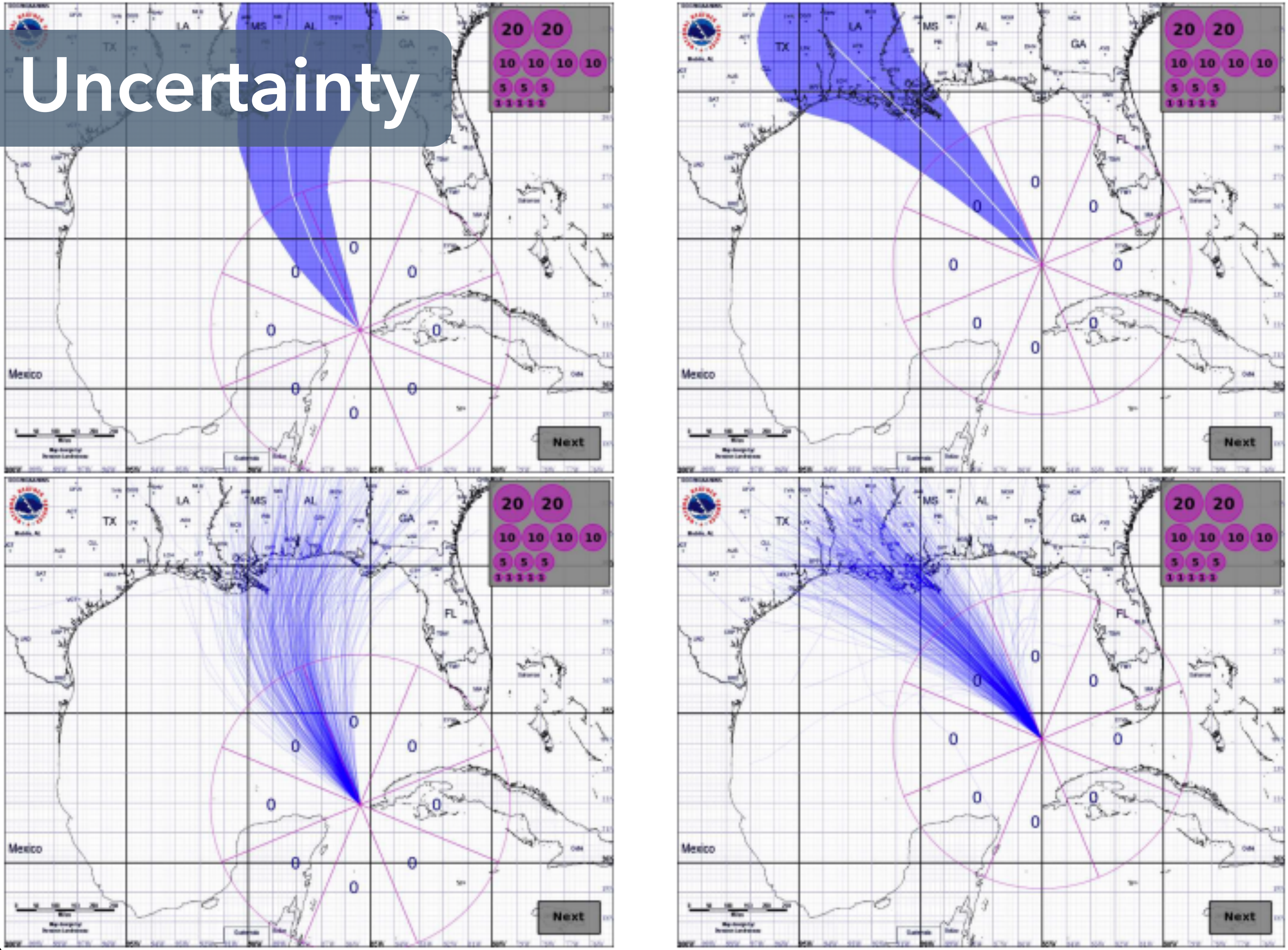
Networks



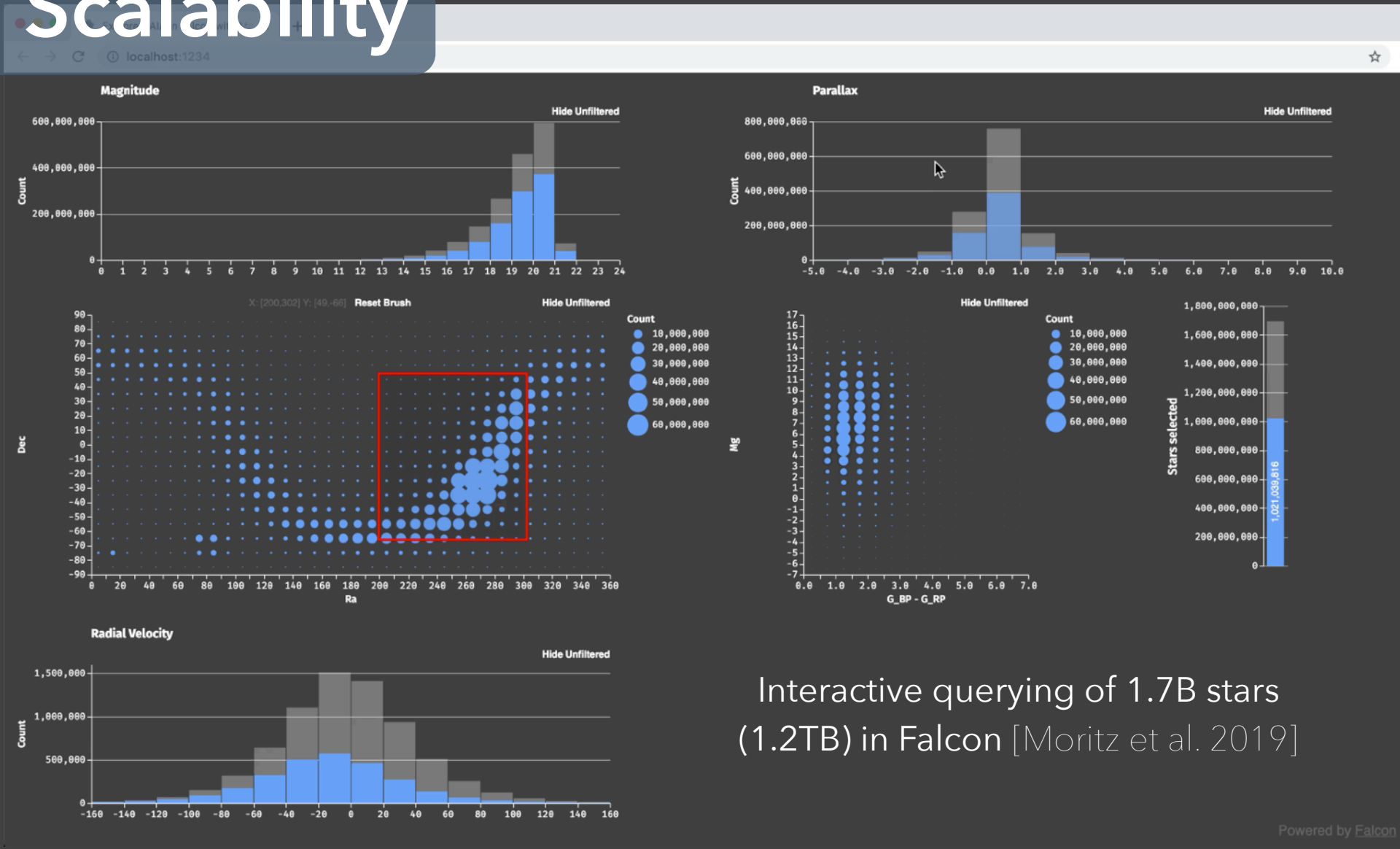
Zephoria

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.

Uncertainty



Scalability



Interactive querying of 1.7B stars (1.2TB) in Falcon [Moritz et al. 2019]

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

Instructor

Jeffrey Heer	OH: *Tue 10-11am*

Teaching Assistants

Shaan Chopra	OH: *Thu 10:30-11:30am*
Lisa Elkin	OH: *Mon 4:30-5:30pm*
Madeleine G-McL.	OH: *Online / By Appt.*
Tae Jones	OH: *Fri 11am-12pm*
Heer Patel	OH: *Wed 10-11am*
Yilun Sheng	OH: *Online / By Appt.*

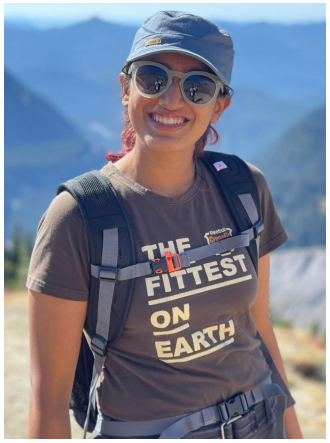
Shaan Chopra *(she/her)* | 4th year, CSE PhD

Research:

- Human-Computer Interaction
- Health Equity & Community-Based Health
- Personal Data Use in Clinical Settings
- AI & Personal Health Informatics
- Participatory & Inclusive Design of Health Technologies

Personal Interests / Hobbies:

- Outdoor / sports: hiking, biking, running, basketball, discus throw, swimming…
- Creative: painting, live sketching, crocheting
- Food-related: mastering the art of mochas, baking & eating desserts



Office Hours:
Thurs TBD

https://shaan15.github.io/

Lisa Elkin (She/Her)

Academic Background

BMath, C&O and Pure Math, University of Waterloo, 2012
MET, Entertainment Technology, Carnegie Mellon, 2015
MMath, Computer Science, University of Waterloo, 2018
PhD, UW CSE, 2018 - ???

TA Experience

HCI, Data Viz, Linear Algebra, Calculus, Intro CS, CS for non-majors

Industry Internships

MSR 2018, Apple 2021, Meta 2022, Meta 2023

Madeleine Grunde-McLaughlin

4rd year PhD Student, UW CSE
mgrunde@cs.washington.edu
OH: Ed / By appointment

Research background: Cognitive Science, Data Visualization, Computer Vision, Explainable AI, LLM workflows

Current research: Extracting analytic workflows from papers

Hobbies: Cooking, crochet, gardening, dancing

Tae Jones

4th Year PhD Student, CSE

Office Hours: Friday 11am-12pm, Zoom

Email: taejones@cs.washington.edu

Research Interests

- User/Patient Engagement, Physical-Mental Health Comorbidities, Mental Health & Wellbeing, Behavioural Change Support

Current Project

- Increasing patient engagement in long term collaborative interventions by understanding and reducing barriers

Current Hobbies

- Gardening & Vermicomposting, Woodland Park Zoo Ambassador, Yoga

... and Miyazaki

Heer Patel

heerpate@cs.washington.edu

- 4th year BS/MS
- **Interests**
  - Data Science
  - HCI
  - Business
- **Hobbies**
  - Squash (sport, not veggie)
  - Traveling to sunny locations :)
  - Henna

Yilun Sheng (or **Simon**)

Third-year CSE Ph.D. student

Research Interests: Computational Biology, ML

Hobbies:

- Soccer (watching > playing), Premier League, Chelsea!
- Pokémon
- Bridge (the card game)

Contact: ylsheng@cs.washington.edu

Lectures, Activities & Office Hours

Course sessions will alternate among lecture and in-class activities. Thursdays will typically be activity days.

All lectures will be in-person and recorded.

Please attend in-person but **NOT** if you feel ill.

Office hours are a mix of in-person and Zoom.

Links for virtual office hours are on Canvas.

Use Ed to post questions and seek help!

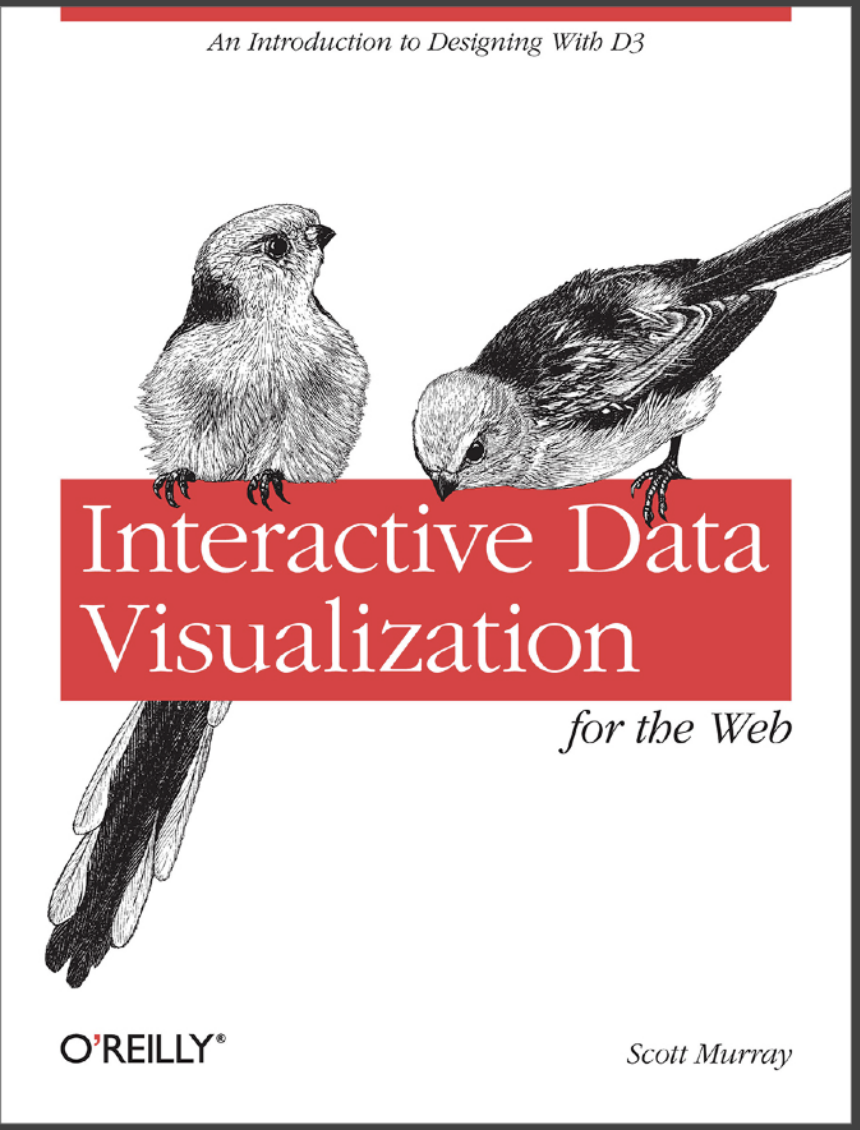
Readings

From books, notebooks, and linked articles.

Material in class will loosely follow readings.

Readings should be read by start of class.

Textbook

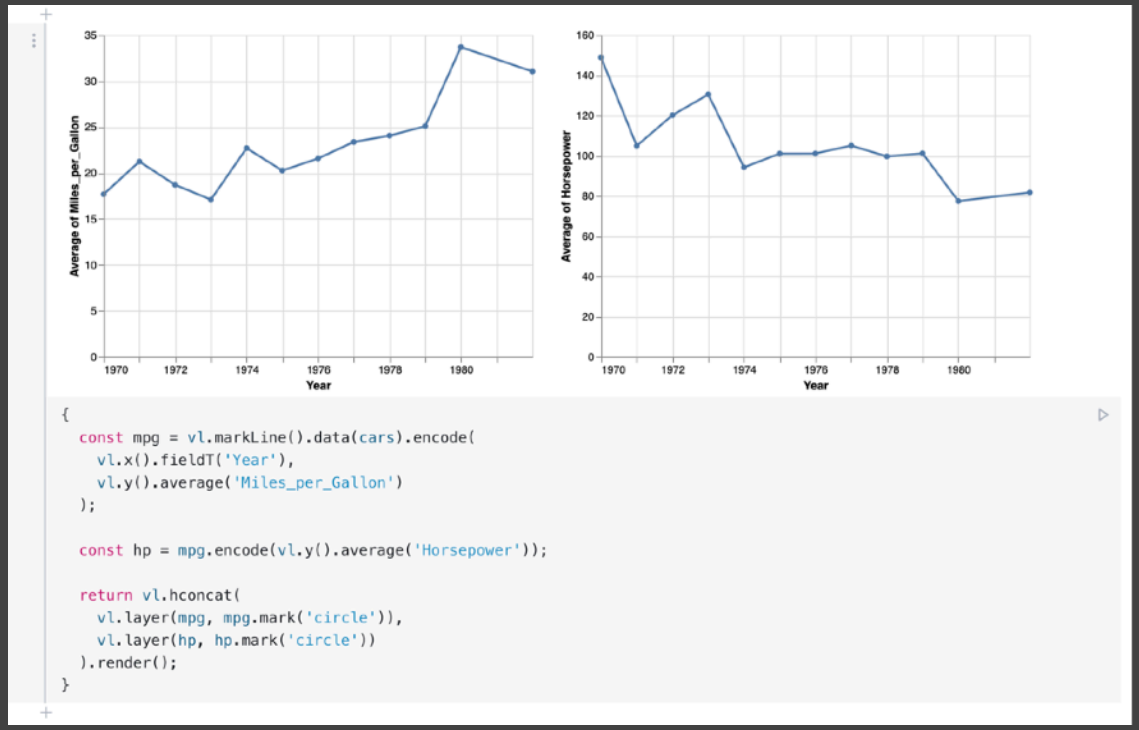


Interactive Data Visualization for the Web, 2nd Edition

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

We will be using **D3 v7**.
https://d3js.org

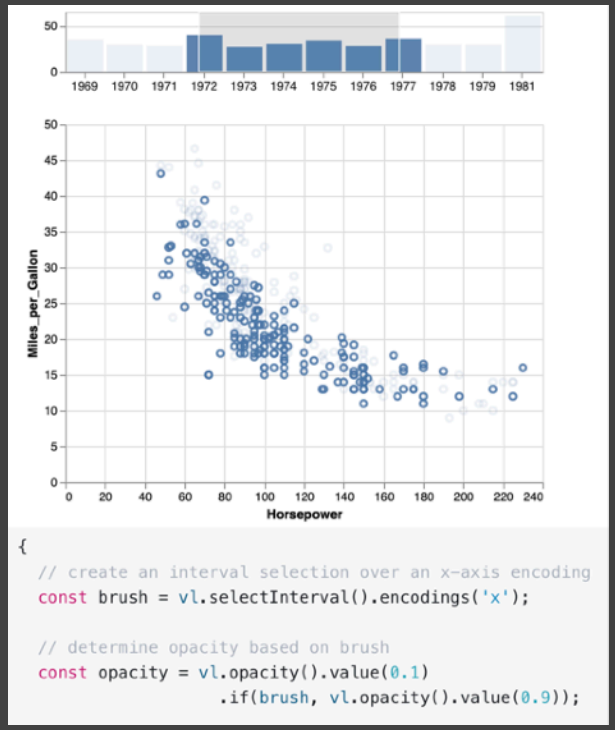
Interactive Vega-Lite Notebooks




```
{
  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.

Assignments

CP Class Participation (10%)

A1 Expository Visualization (10%) *- Due 10/4*

A2 Deceptive Visualization (15%) *- Due 10/16*

Peer Review (5%) *- Due 10/22*

A3 Interactive Prototype (20%) *- Due 11/04*

Peer Review (5%) *- Due 11/13*

FP Final Project (35%)

Proposal *- Due 11/08*

Demonstration Video *- Due 12/4*

Final Prototype *- Due 12/9*

Grading Philosophy

A *great* submission gets a *great grade* (A- to A, 3.6 – 3.8), but an *exceptional* grade (A+, 3.9 – 4.0) requires *exceptional* effort.

Example: Typical A1 grades (out of 10 points).

Everyone starts with a high score (9/10).

We then *deduct* points for errors and also *add* points for going above and beyond the assignment requirements.

The median score for A1 is typically 8.5 out of 10, which maps to an A-.

Course Participation

Lecture attendance and engagement

In-class exercises: team submissions

Online quizzes, submitted on Canvas

Note: You may miss up to 2 in-class exercise days without penalty.

Online Practice Quizzes

Weeks 2-8 have online quizzes to emphasize important concepts.

Quizzes are due Friday by 11:59pm. They may be retaken as many times as needed to get full points.

Quiz completion counts towards course participation. Raw quiz “points” will not be added directly to your course grade.

Final Project

Produce an **explorable visual explanation**

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

Final deliverables and **video presentation**

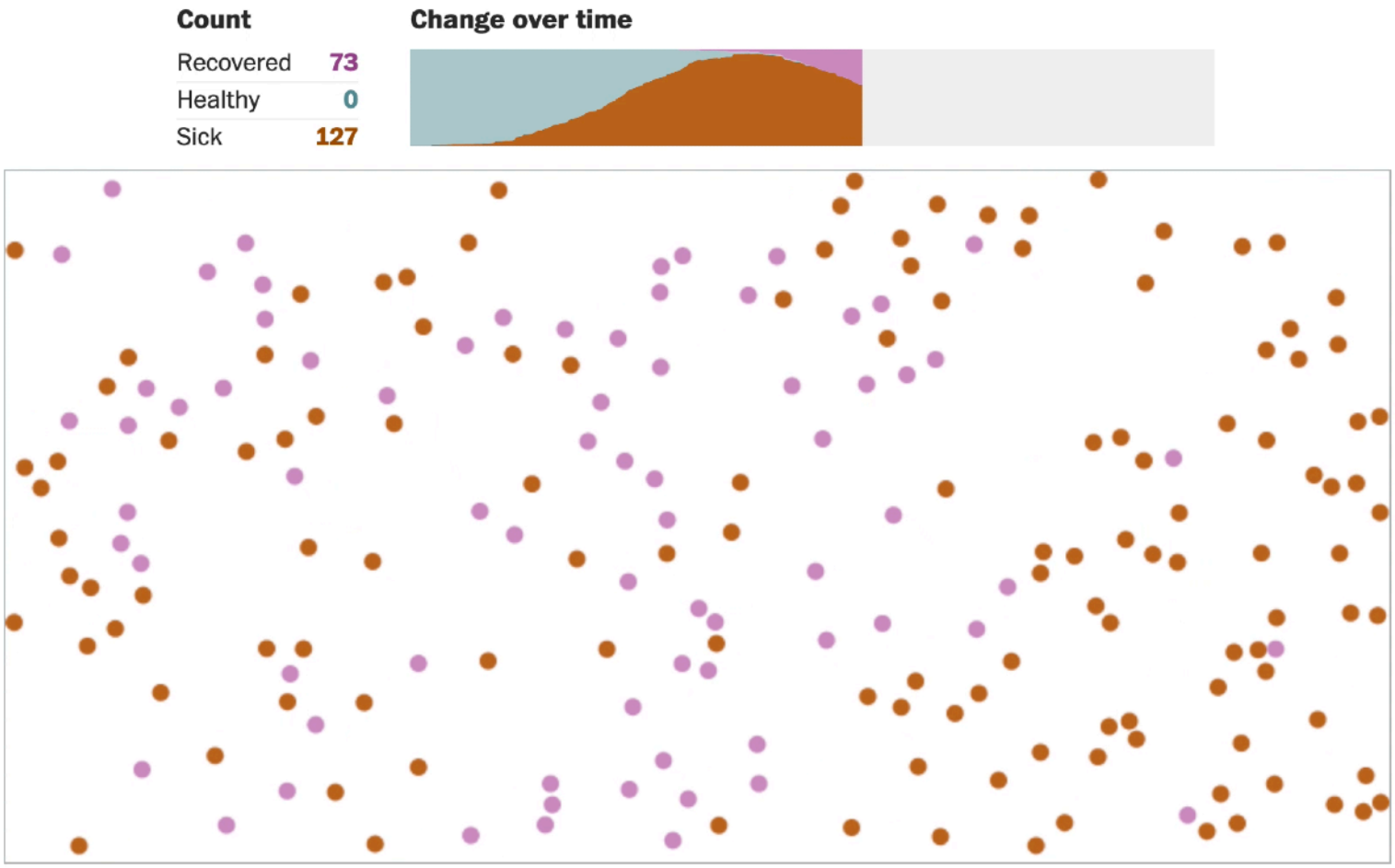
Submit and **publish online** (GitLab)

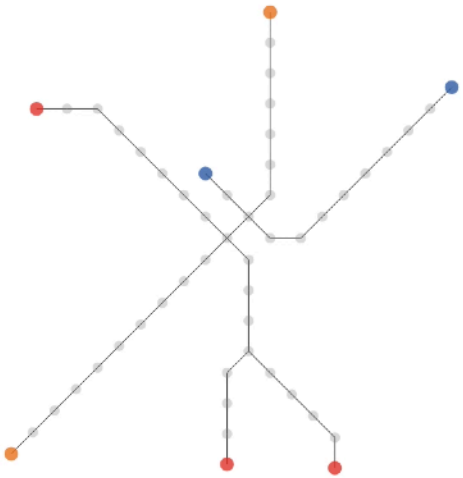
Projects from **previous classes** have been:

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

Why outbreaks like coronavirus spread exponentially, and how to “flatten the curve”

Harry Stevens, Washington Post 2020

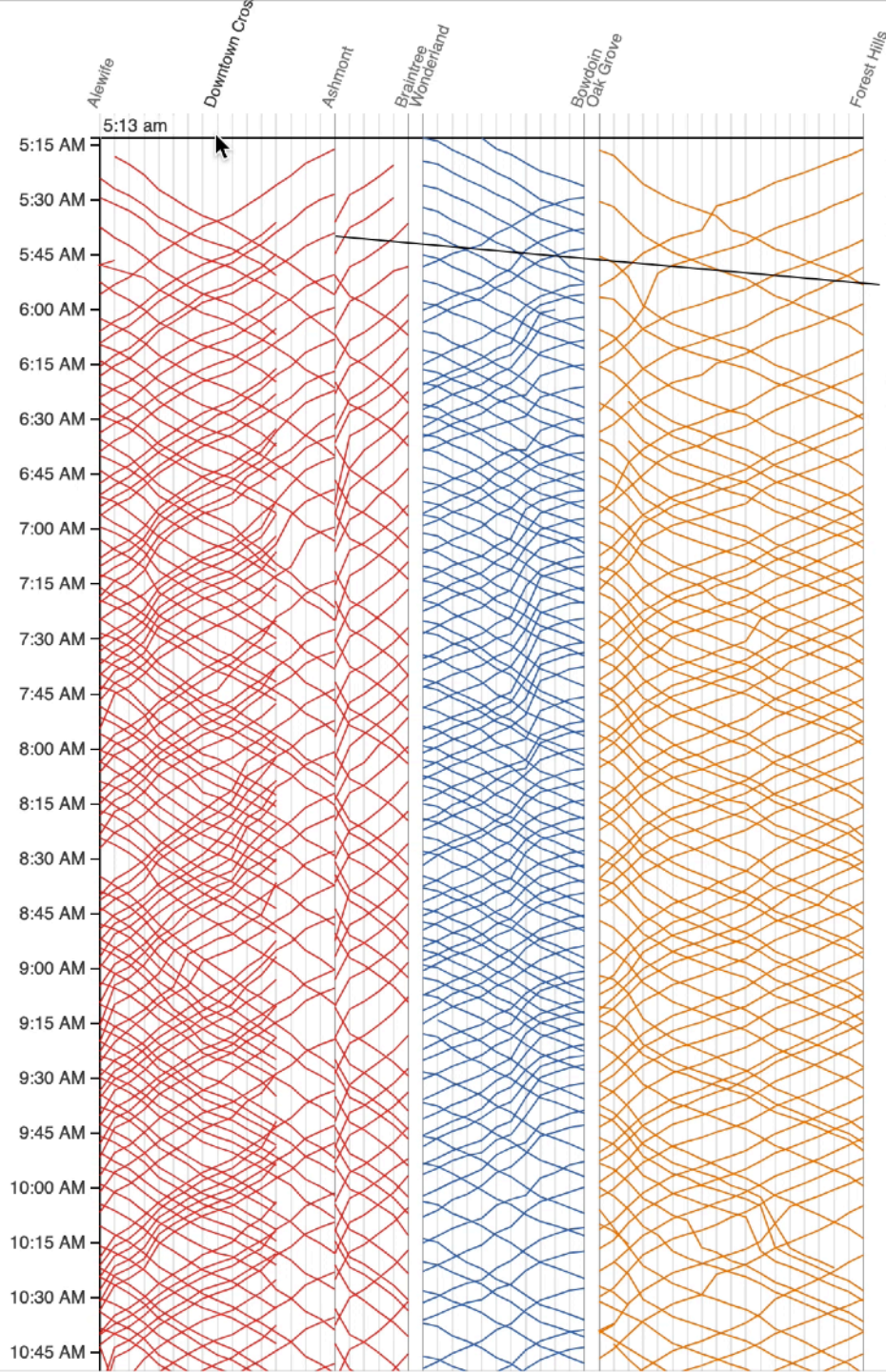




Locations of each train on the red, blue, and orange lines at 5:13 am. Hover over the diagram to the right to display trains at a different time.

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

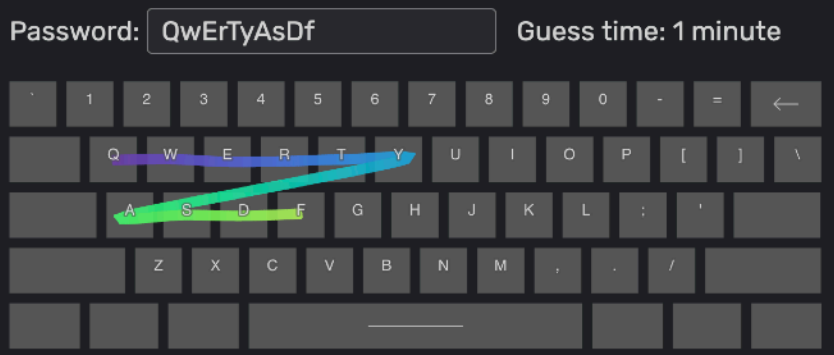
Barry & Card

KEYBOARD WALKING

Passwords with a “keyboard walking” pattern start at an arbitrary key, then move in a direction (usually right or down) while continuing to hit keys. Sometimes this is combined with holding down the SHIFT key, so that some characters are uppercase or symbols to improve complexity.

While the generated password may seem to be random and unhackable, password crackers check for these keyboard patterns and guess them early on.

Many passwords in the leaked passwords dataset have a spatial pattern. Other than the numeric passwords like 123456, common keyboard walking offenders include qwerty and 1qaz@wsx.



Semantic Passwords

Vishal Devireddy (CSE 512, Spring '21)

Questions?

Observable + Data Tutorial

Friday Sep. 27, 4:00-5:30pm on Zoom

Introduction to Observable notebooks, JavaScript basics, and data management and transformation, led by Yilun.

Zoom link is available on Canvas.
The tutorial will be recorded.

A1: Expository Visualization

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: Expository Visualization

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

Due by **11:59 pm, Fri Oct 4**.