COMP 5360 / MATH 4100
Introduction to Data Science
Visualization

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[xkcd]

visualization *pictures*

The purpose of computing is insight, not numbers.

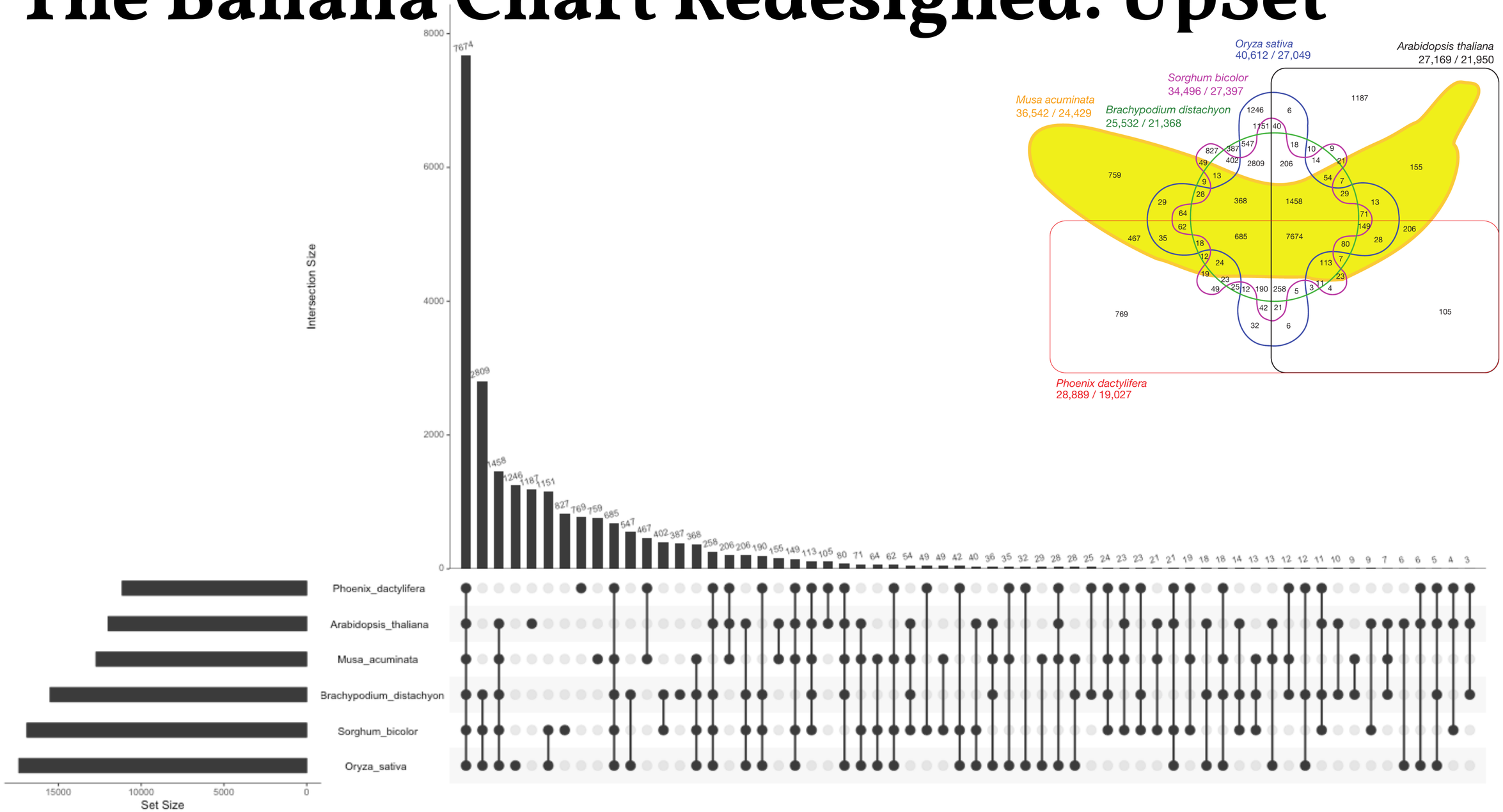
- Richard Wesley Hamming

- Card, Mackinlay, Shneiderman

Banana	*M. acuminata*
Date	*P. dactylifera*
Cress	*Arabidopsis thaliana*
Rice	*Oryza sativa*
Sorghum	*Sorghum bicolor*
Brome	*Brachypodium distachyon*

[D'Hont et al., Nature, 2012]

The Banana Chart Redesigned: UpSet



Visualization Definition

Visualization is the process that **transform**s
(abstract) **data** into
interactive graphical representations for the purpose of
exploration, confirmation, or presentation.

Good Data Visualization

… makes data accessible

… combines strengths of humans and computers

… enables insight

… communicates

Why Visualize?

To inform humans: Communication

How is ahead in the election polls?

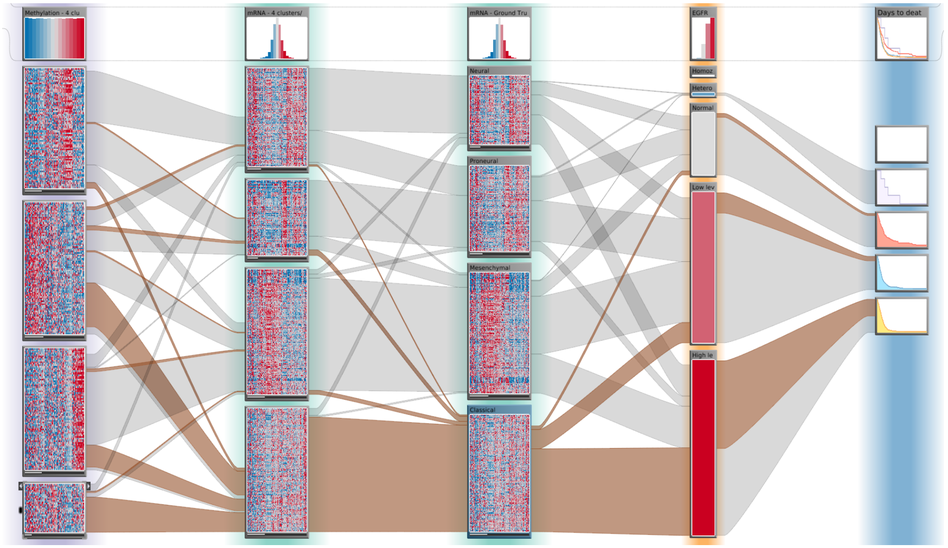
When questions are not well defined: Exploration

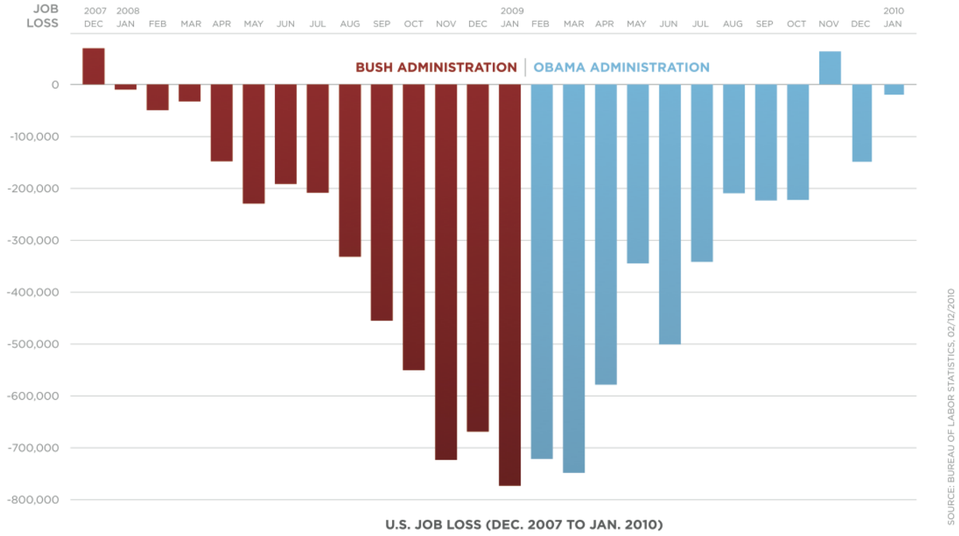
What is the structure of a terrorist network?

Which drug can help patient X?

Purpose of Visualization

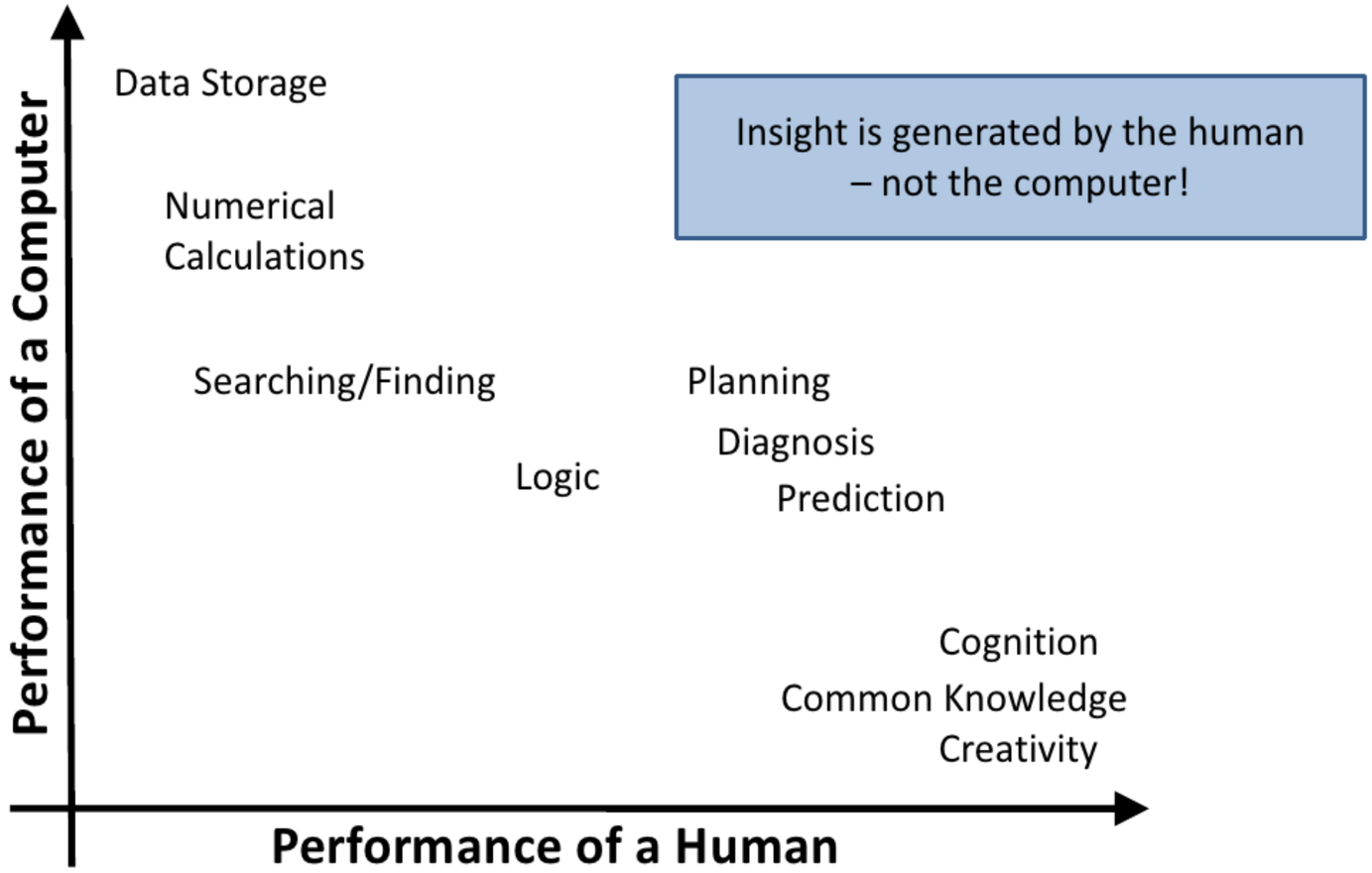
[Obama Administration]





Open Exploration — Confirmation — Communication

The Ability Matrix

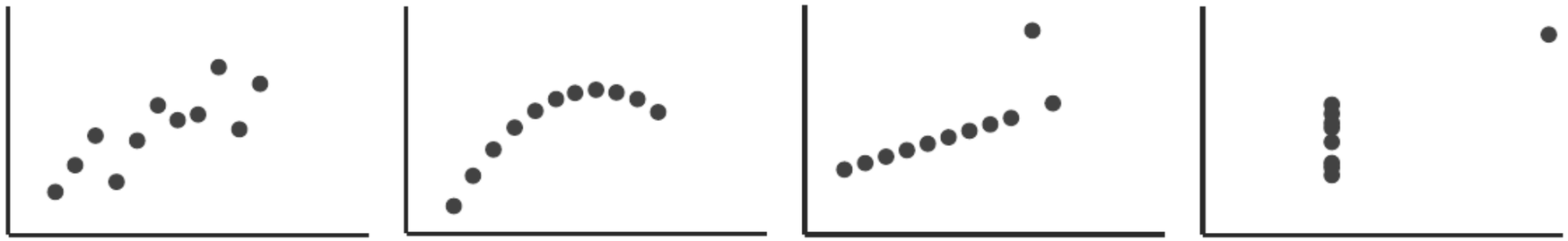


Why not just use Statistics?

I		II		III		IV	
x	y	x	y	x	y	x	y
10	8.0	10	9.1	10	7.4	8	6.5
8	6.9	8	8.1	8	6.7	8	5.7
13	7.5	13	8.7	13	12.	8	7.7
9	8.8	9	8.7	9	7.1	8	8.8
11	8.3	11	9.2	11	7.8	8	8.4
14	9.9	14	8.1	14	8.8	8	7.0
6	7.2	6	6.1	6	6.0	8	5.2
4	4.2	4	3.1	4	5.3	19	12.
12	10.	12	9.1	12	8.1	8	5.5
7	4.8	7	7.2	7	6.4	8	7.9
5	5.						6.8

Mean x: 9 y: 7.50
Variance x: 11 y: 4.122
Correlation x – y: 0.816
Linear regression: y = 3.00 + 0.500x

Anscombe’s Quartett



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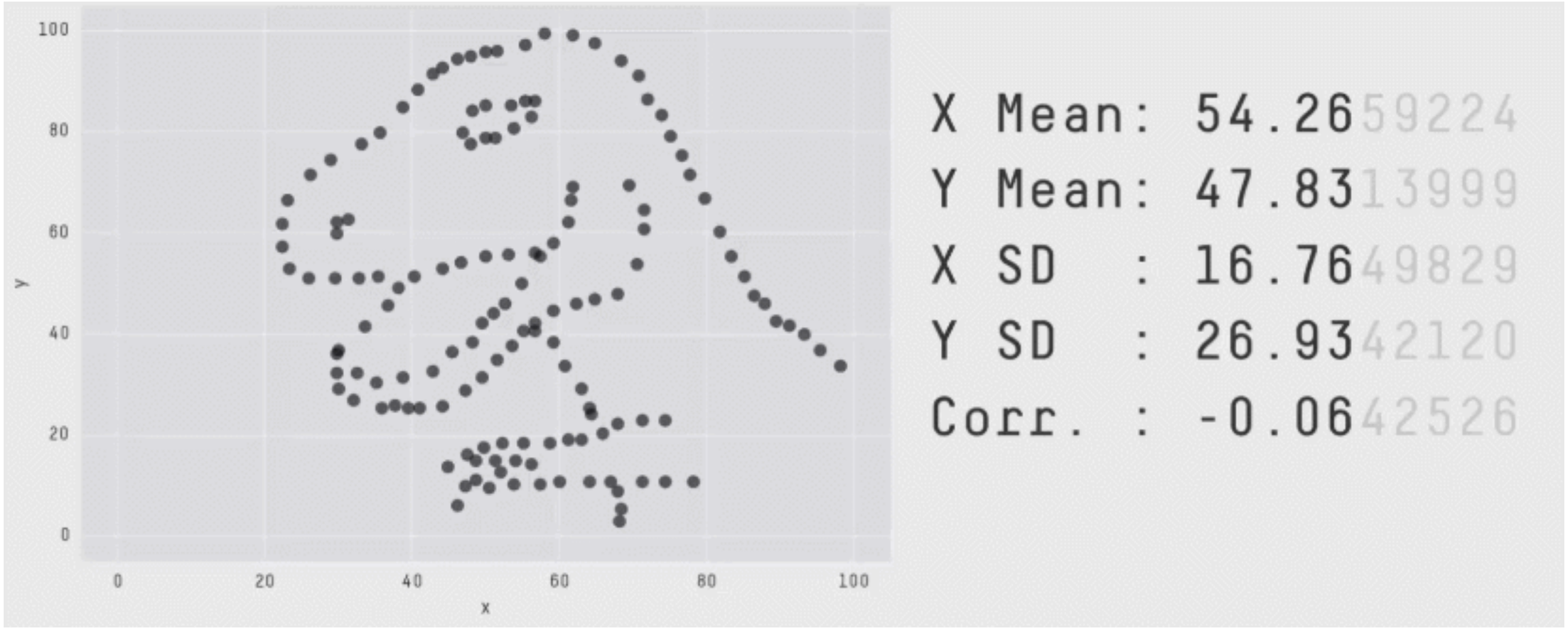


Same Stats, Different Graphs: Generating Datasets with Varied Appearance and Identical Statistics through Simulated Annealing, CHI 2017, Justin Matejka, George Fitzmaurice

Visualization =

Human Data Interaction

Visualization in the Data Science Process

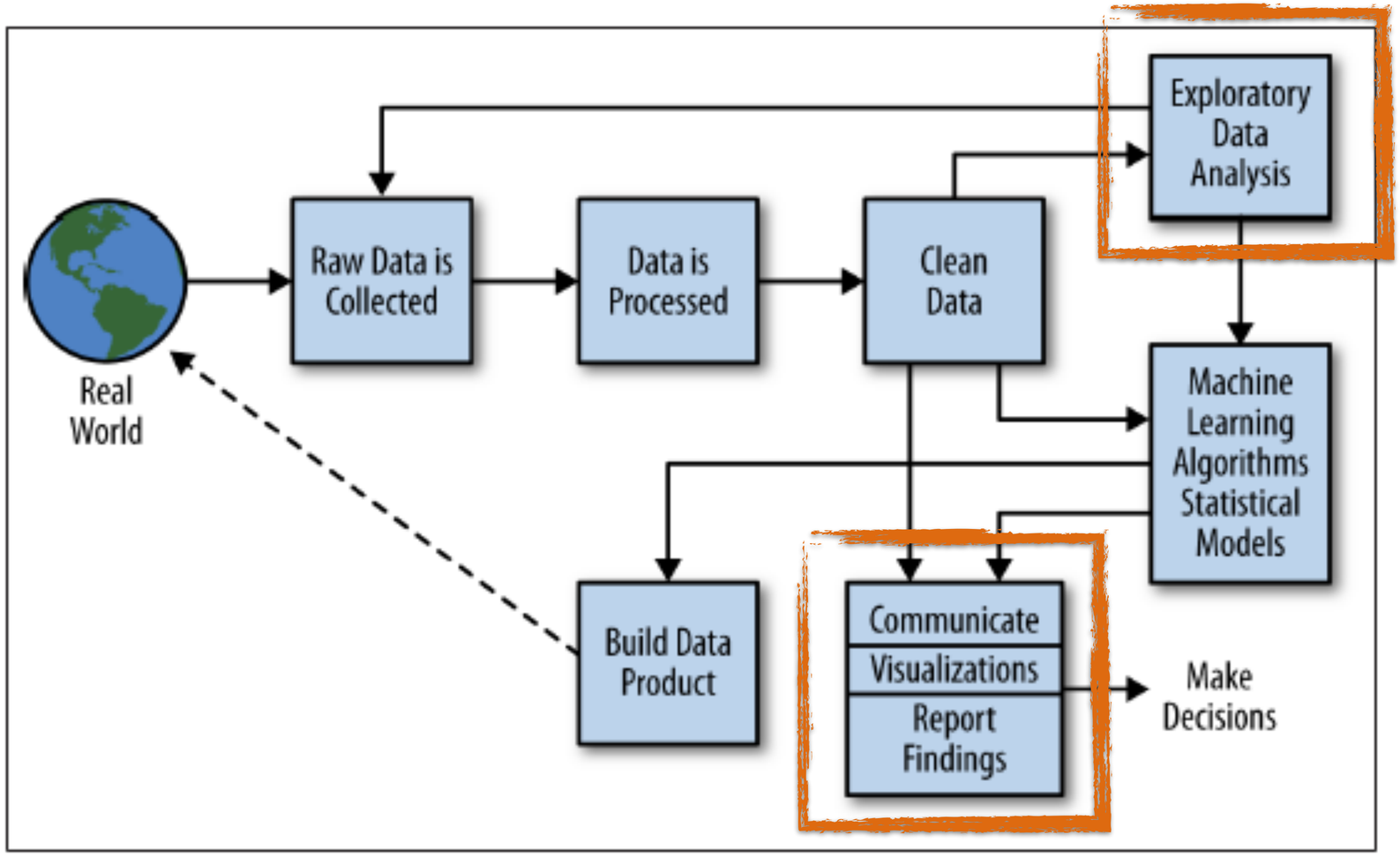


Figure 2-2. The data science process

Why Humans?

Leveraging human capabilities

- **Pattern Discovery**: clusters, outliers, trends
- **Contextual Knowledge**: expectations for dataset, explanations for patterns
- **Action**: humans learn and take action

But: we also have to **design for Humans and their limitations**

Limits of Cognition

Daniel J. Simons and Daniel T. Levin, Failure to detect changes to people during a real world interaction, 1998

History: John Snow

John Snow, 1854

E. Tufte, Visual Explanations, 1997

Marks & Channels

Marks & Channels

Marks

Encode existence of an item (a row in a table).

Point, bar, line, etc.

Channels

Encode magnitude or category of item.

Position, size, height, color, etc.

Types of Channels

Magnitude Channels

How much?

Position

Length

Saturation …

Identity Channels

What? Where?

Shape

Color (hue)

Spatial region …

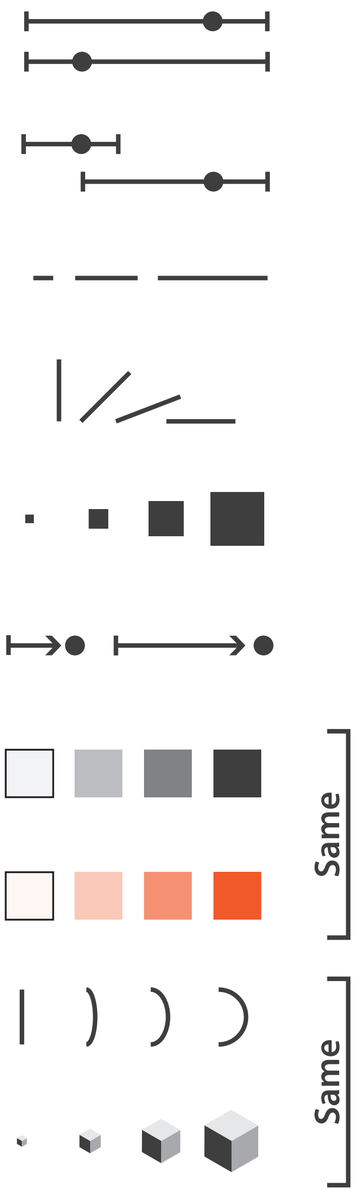
Ordinal & Quantitative Data

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)



Most ▲

Effectiveness

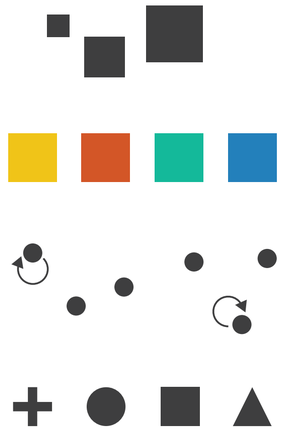
▼ Least

Same

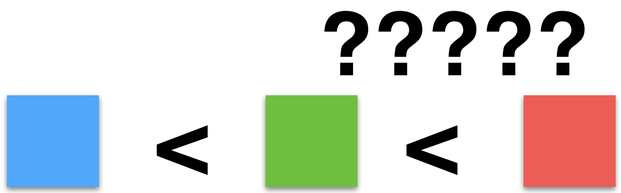
Same

Identity Channels: Categorical Attributes

- Spatial region
- Color hue
- Motion
- Shape



Color



Good for qualitative data (identity channel)

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

Does not work for quantitative data!

Lots of pitfalls! Be careful!

My rule:

- minimize color use for encoding data
- use for brushing

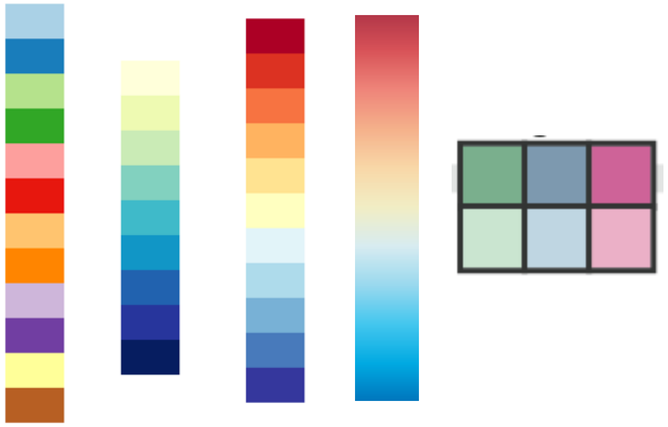
What is a colormap?

[0,8] →

specifies a mapping between color and values

- categorical vs ordered
- sequential vs diverging
- segmented vs continuous
- univariate vs bivariate

expressiveness: match colormap to attribute characteristics!



http://colorbrewer2.org/

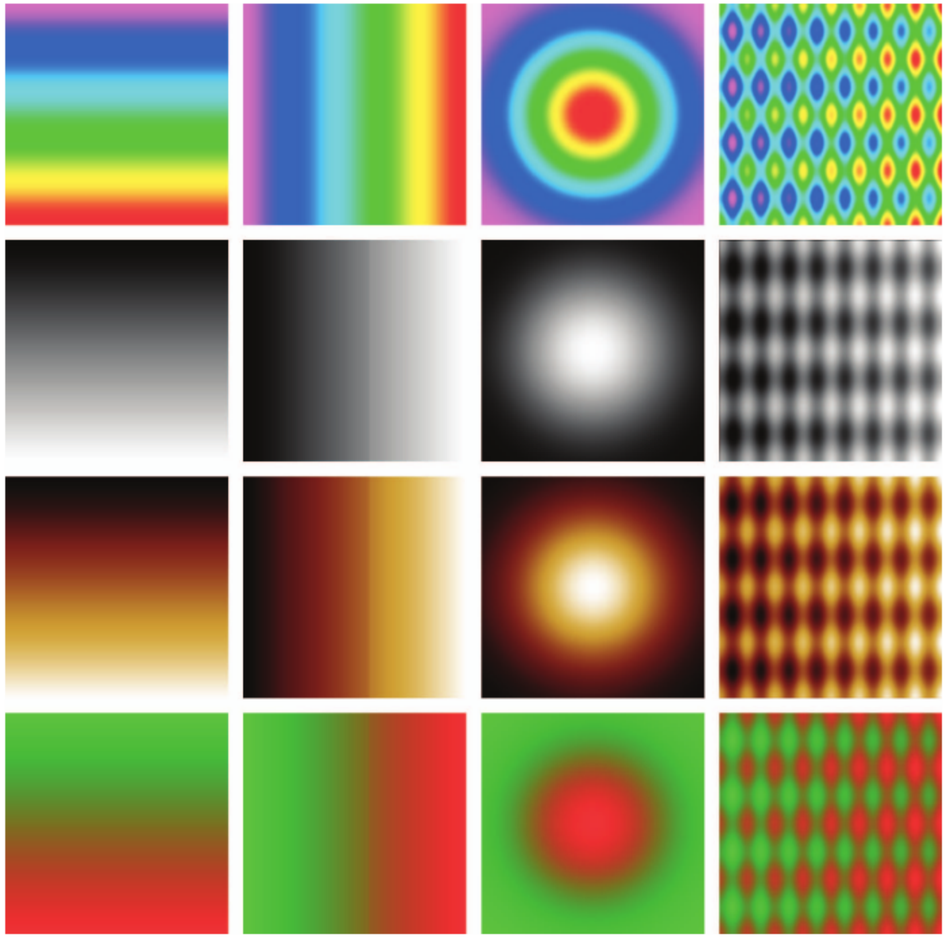
Quantitative Data Vis

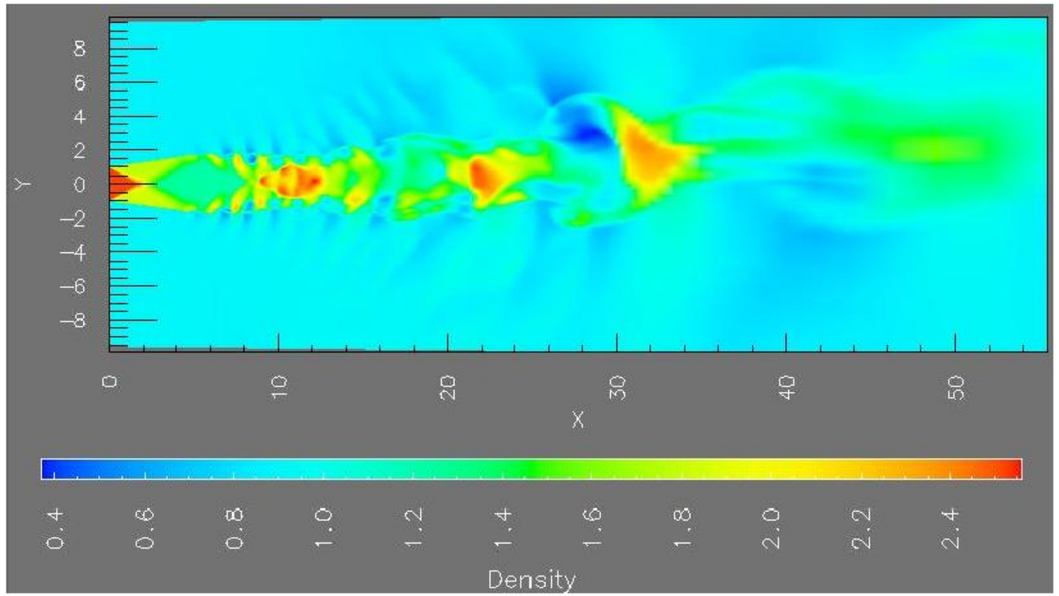
use value

saturation works but not as good

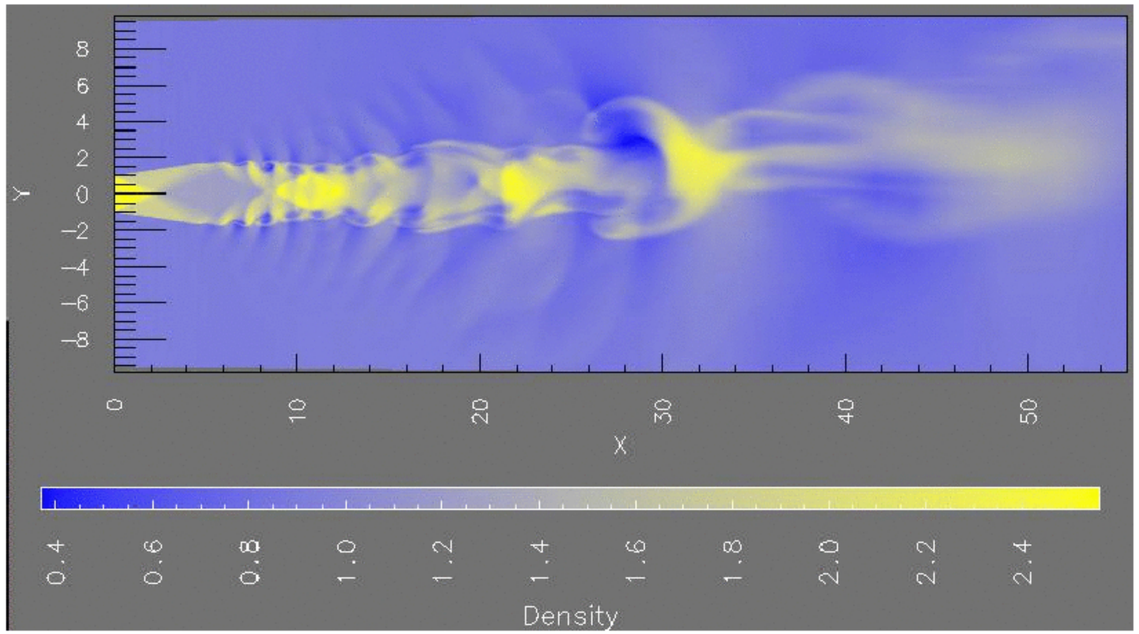
don‘t use hue!

Danger: rainbow color map





[Rogowitz and Treinish, Why Should Engineers and Scientists Be Worried About Color? http://www.research.ibm.com/people/l/lloydt/color/color.HTM]



[Rogowitz and Treinish, How NOT to Lie with Visualization, www.research.ibm.com/dx/proceedings/pravda/truevis.htm]

Color Blindness

10% of males, 1% of females (probably due to X-chromosomal recessive inheritance)

Most common: red-green weakness / blindness

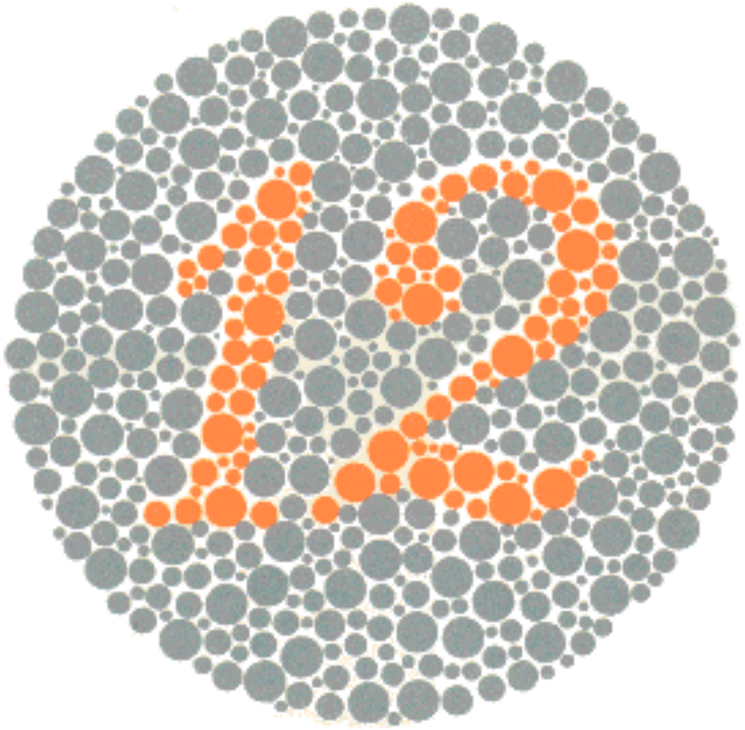
Reason: lack of medium or long wavelength receptors, or altered spectral sensitivity (most common: green shift)

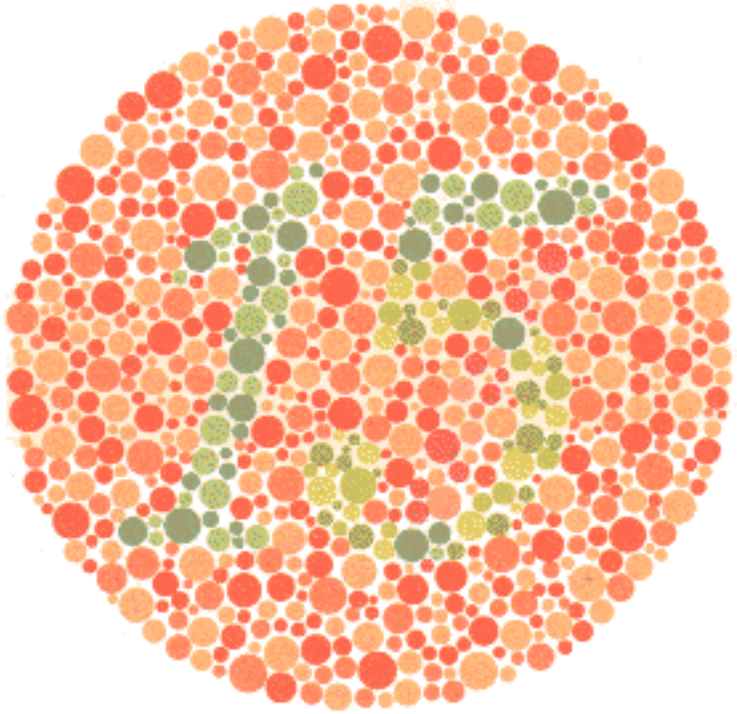
Normal Color Perception

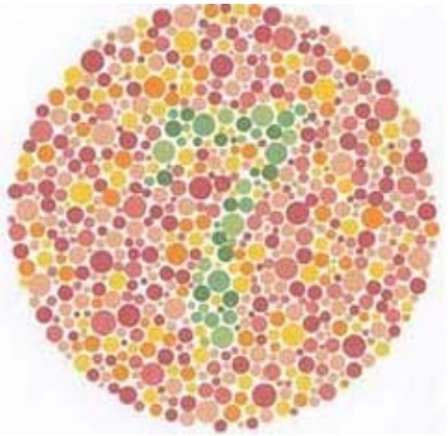
Deuteranopia (no green receptors)

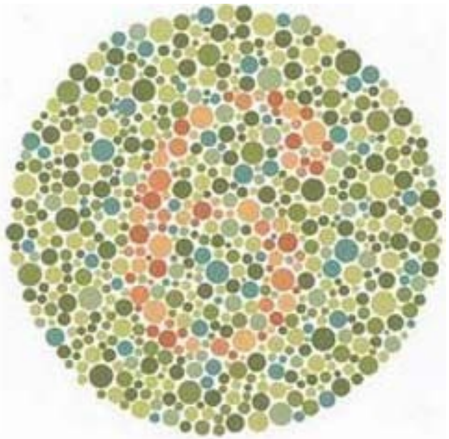
Protanopia (no red receptors)

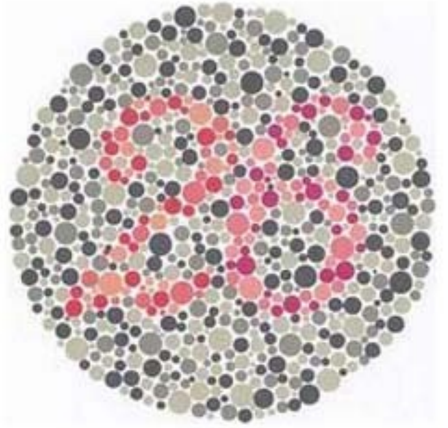
Color Blindness Tests

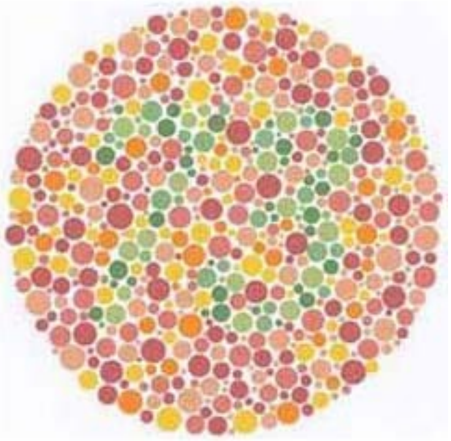


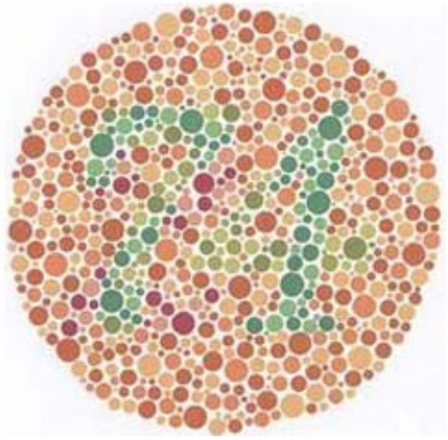


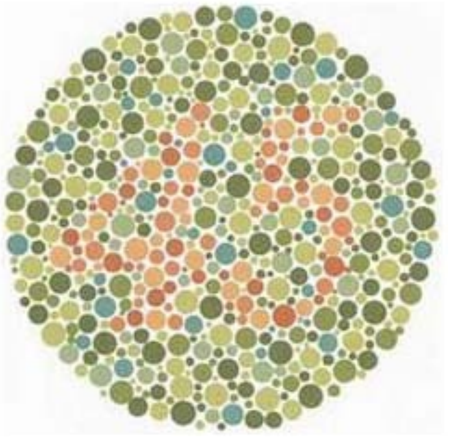


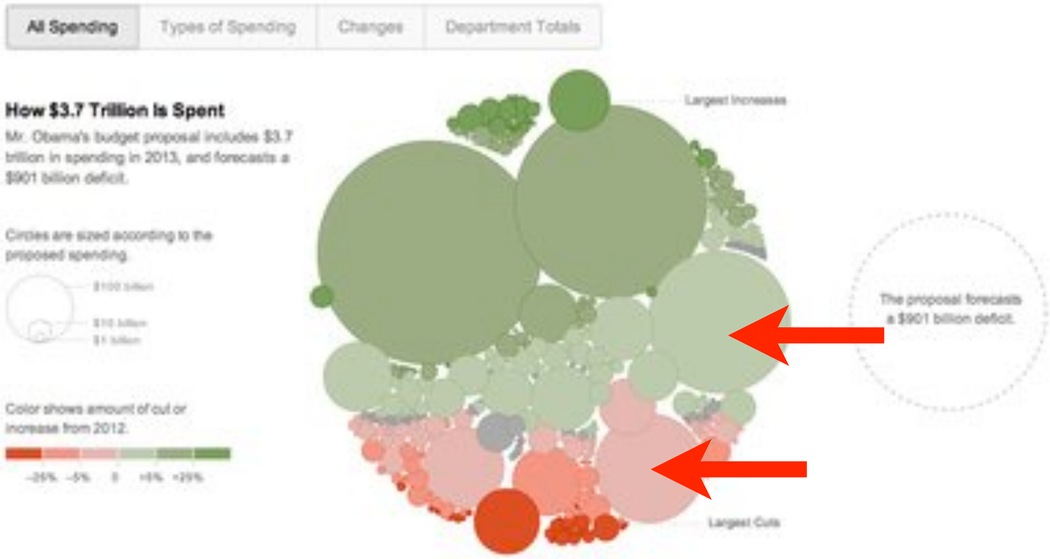


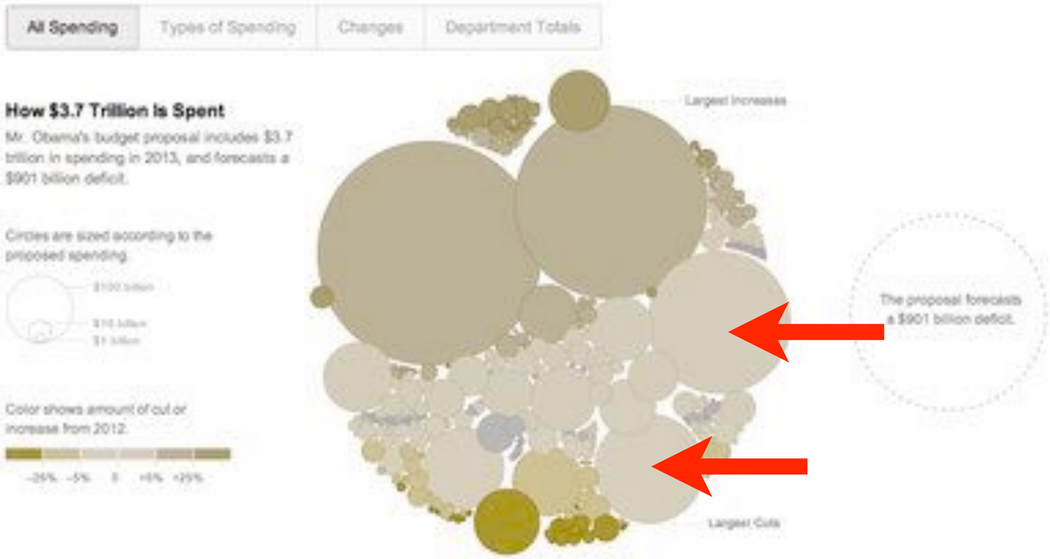






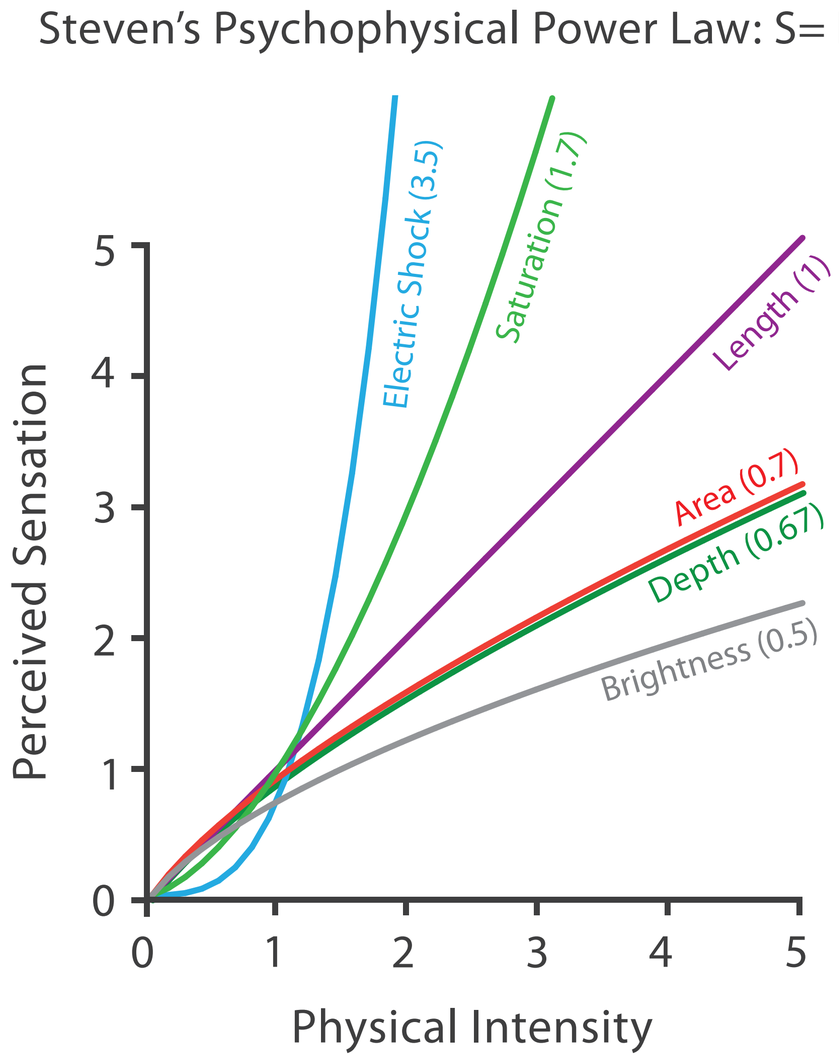






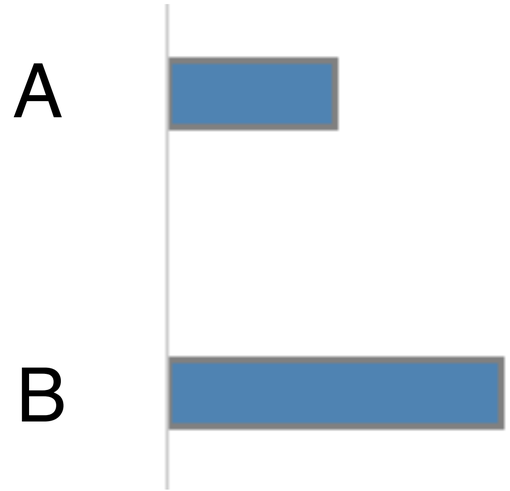
NYT, Feb 12, 2012

Why are quantitative channels different?



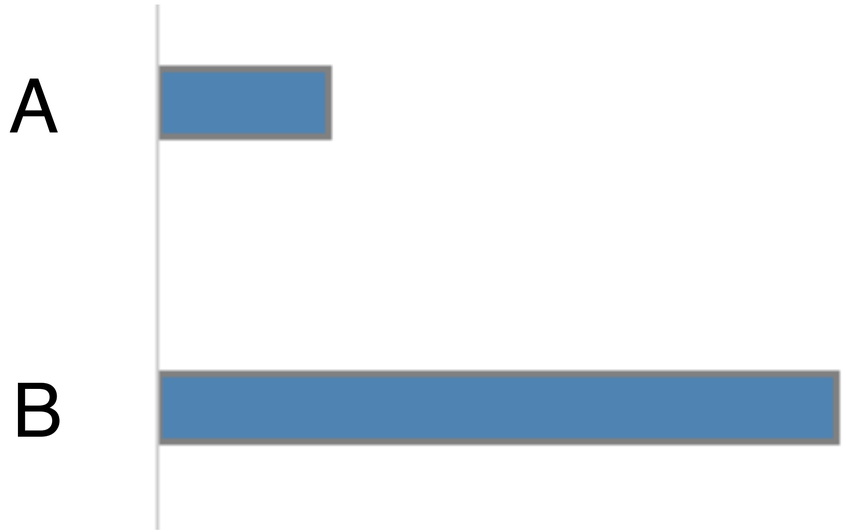
S = sensation
I = intensity

How much longer?



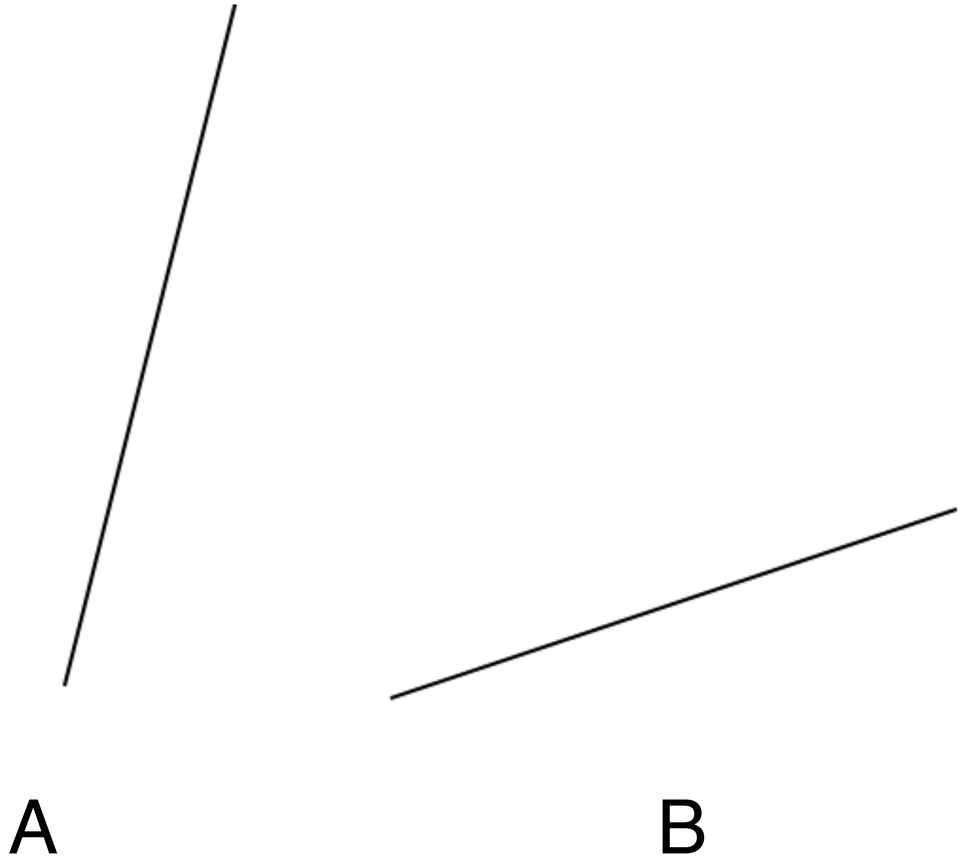
2x

How much longer?



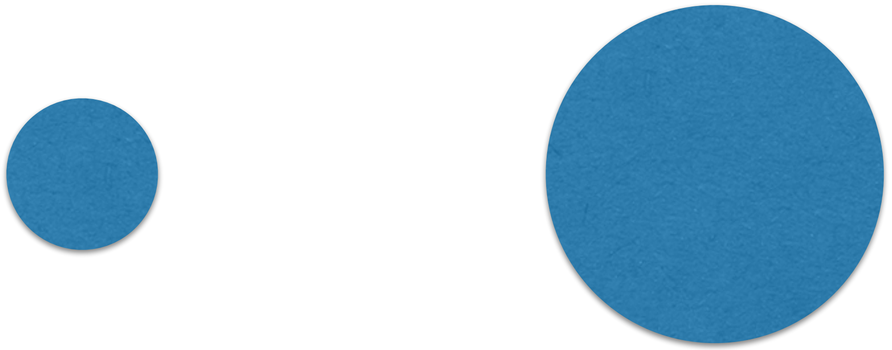
4x

How much steeper?



~4x

How much larger?

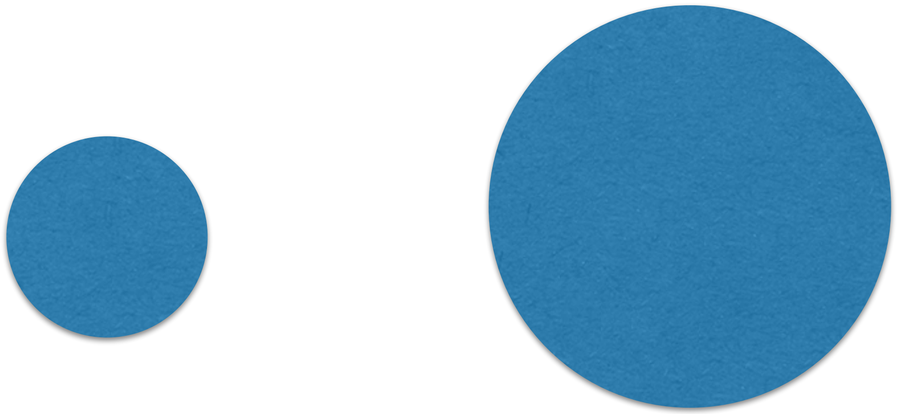


A

B

5x

How much larger?



A B

2x diameter

4x area

area is proportional to diameter squared

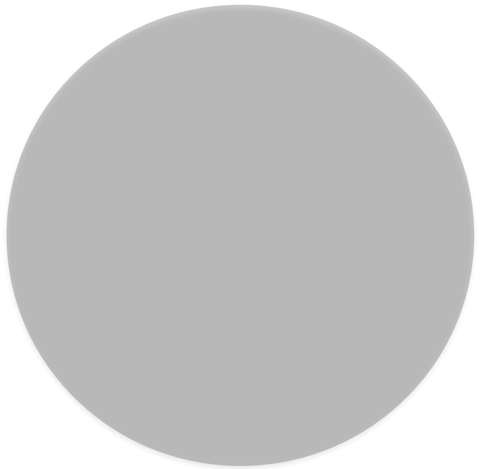
How much larger (area)?

A

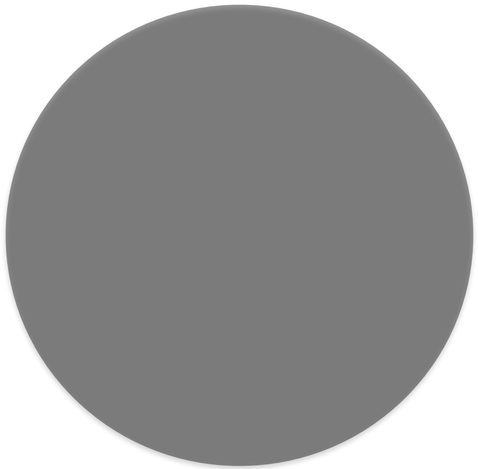
B

3x

How much darker?



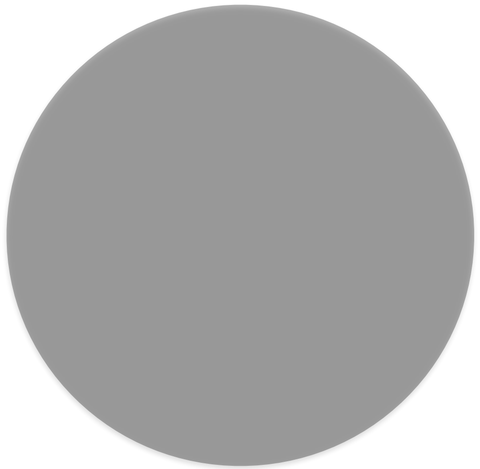
A



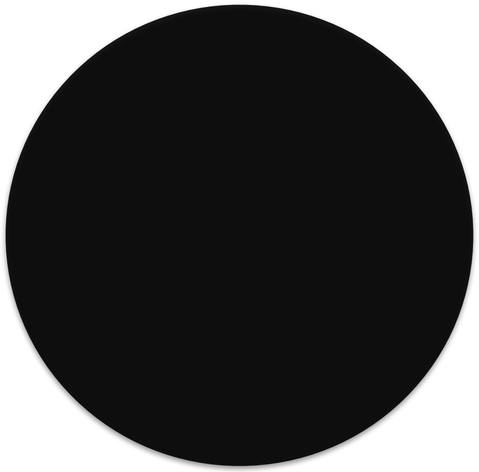
B

2x

How much darker?



A



B

3x

Other Factors Affecting Accuracy

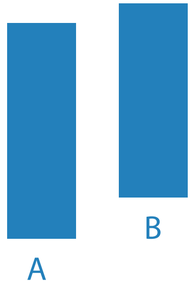
Alignment

Distractors

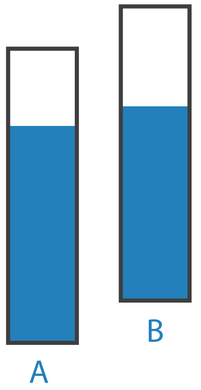
Distance

Common scale

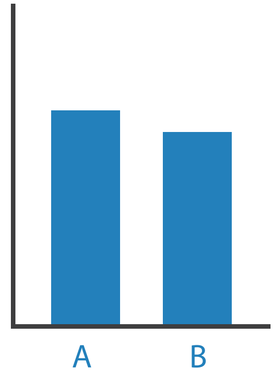
…



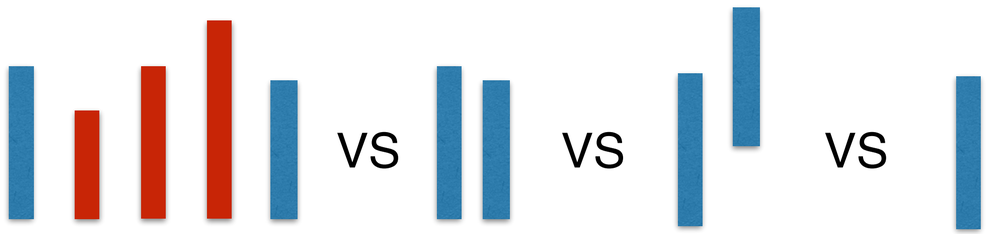
Unframed
Unaligned



Framed
Unaligned



Unframed
Aligned



Design Guidelines

Rule #1: Use the Best Visual Channel Available for the Most Important Aspect of your Data

Rule #2: The visualization should show all of the data, and only the data

Tufte's Integrity Principles

Show **data variation**, not design variation

Clear, detailed, and thorough **labeling** and **appropriate scales**

Size of the **graphic effect** should be **directly proportional to the numerical quantities** ("lie factor")

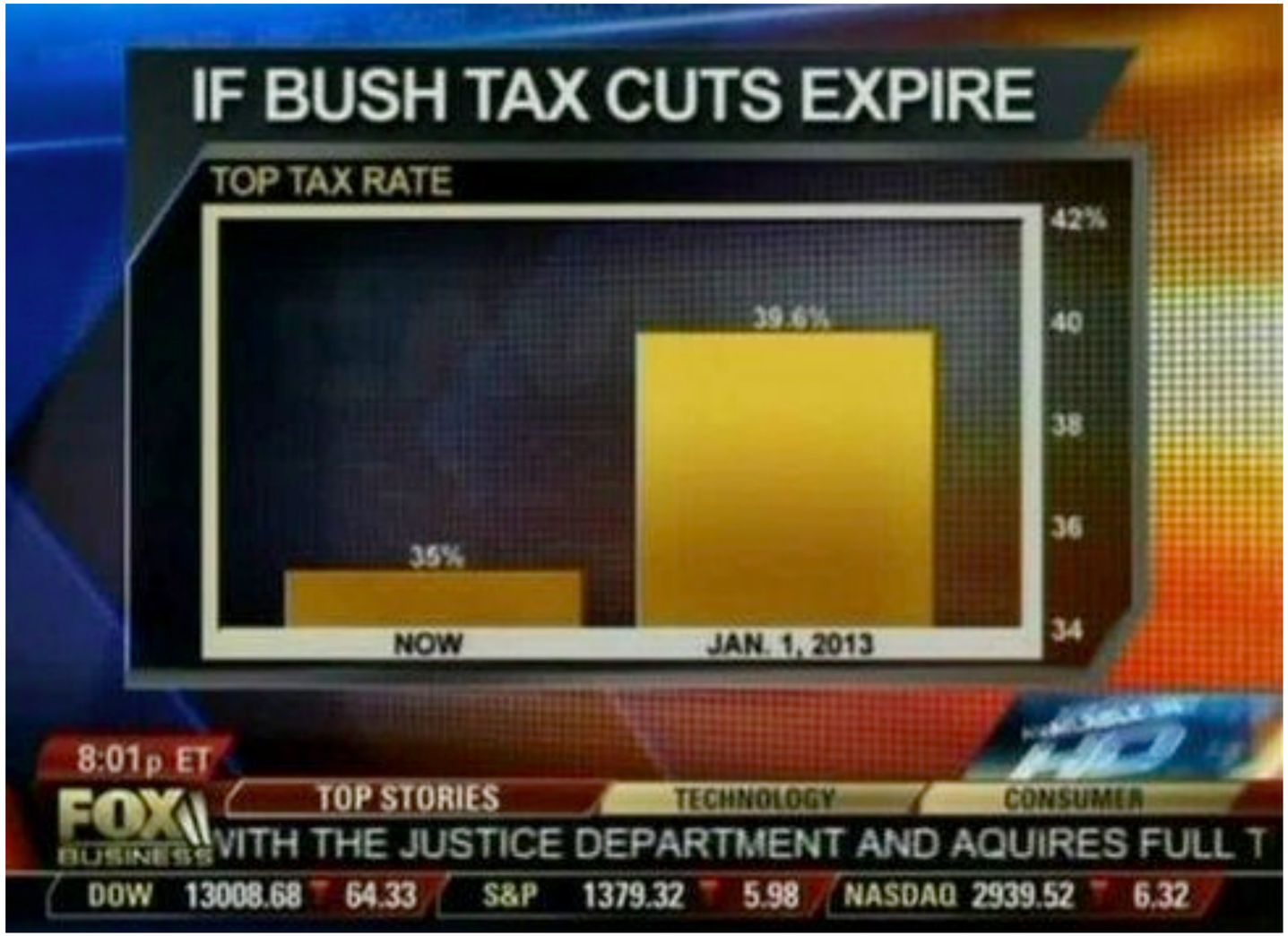
The Lie Factor

$$\frac{\text{Size of effect shown in graphic}}{\text{Size of effect in data}}$$

Lie Factor - Graphical Integrity

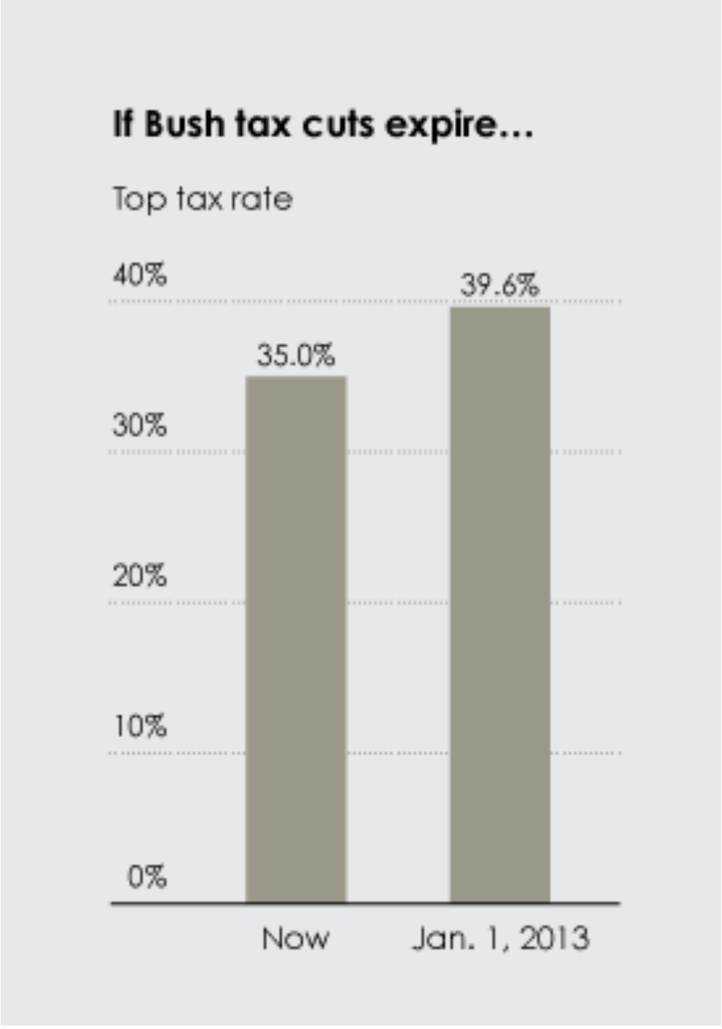
Magnitude in data must correspond to magnitude of mark

Effect in Data: factor 1.14
Effect in Graphic: factor 5
Lie Factor: 5/1.14 = 4.38



Flowing Data

Scale Distortions



Flowing Data

What’s wrong?

Viele Bezieher mit "ungeklärter Staatsbürgerschaft"

Die größte Gruppe in der Liste der Mindestsicherungsbezieher ist aber jene der "ungeklärten Staatsbürgerschaft". Dass es sich bei den 16.712 Personen um

What’s wrong?

Viele Bezieher mit "ungeklärter Staatsbürgerschaft"

Die größte Gruppe in der Liste der Mindestsicherungsbezieher ist aber jene der "ungeklärten Staatsbürgerschaft". Dass es sich bei den 16.712 Personen um

1
2
3

Asyl
Opf
frei
"Kr
Räd
geh
Zwe
Mit
Wol
Am
Stre
Mes
Abe

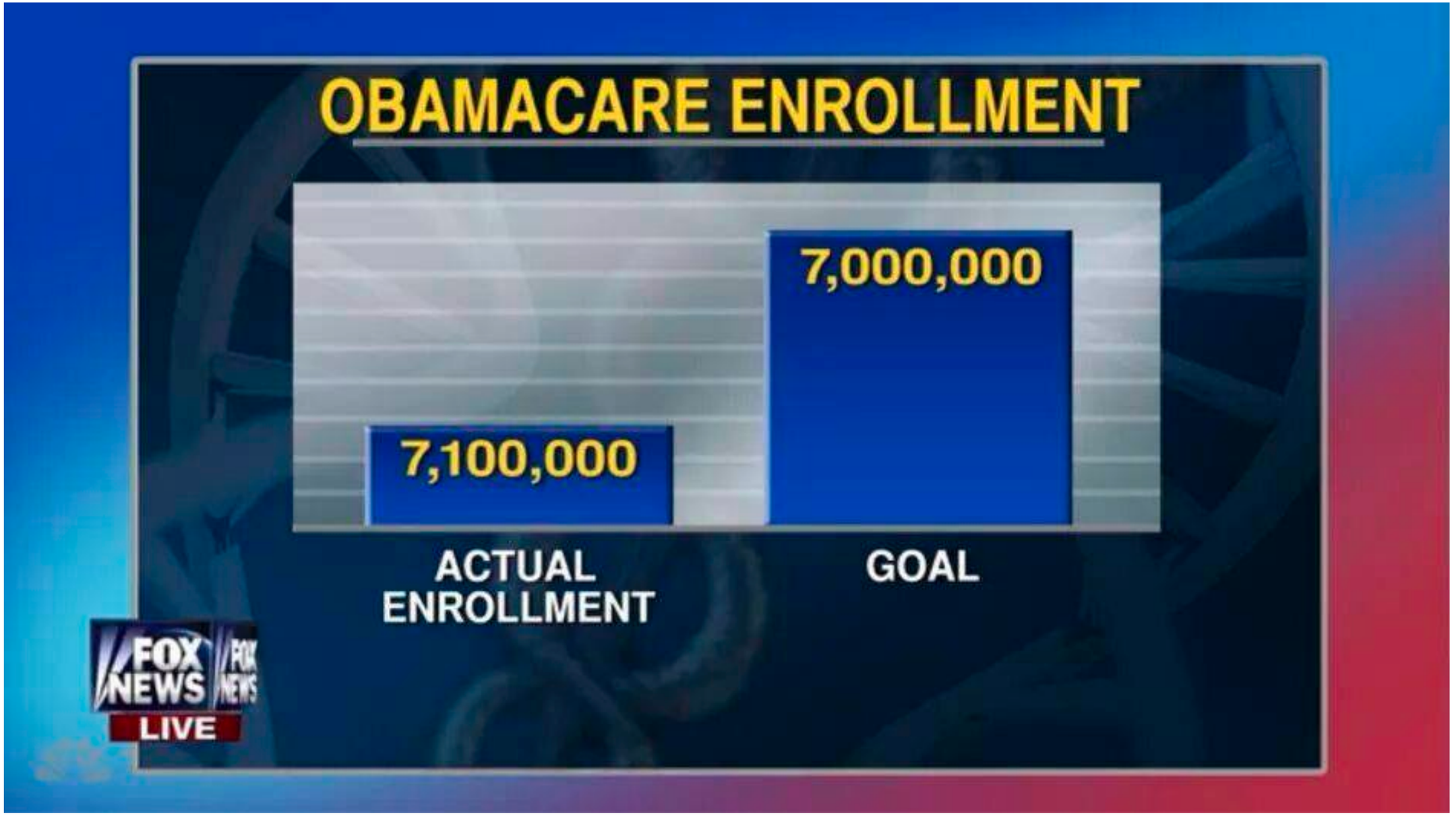
Viele Bezieher mit "ungeklärter Staatsbürgerschaft"

Die größte Gruppe in der Liste der Mindestsicherungsbezieher ist aber jene der "ungeklärten Staatsbürgerschaft". Dass es sich bei den 16.712 Personen um

What’s wrong?

Grafik der Kronen-zeitung

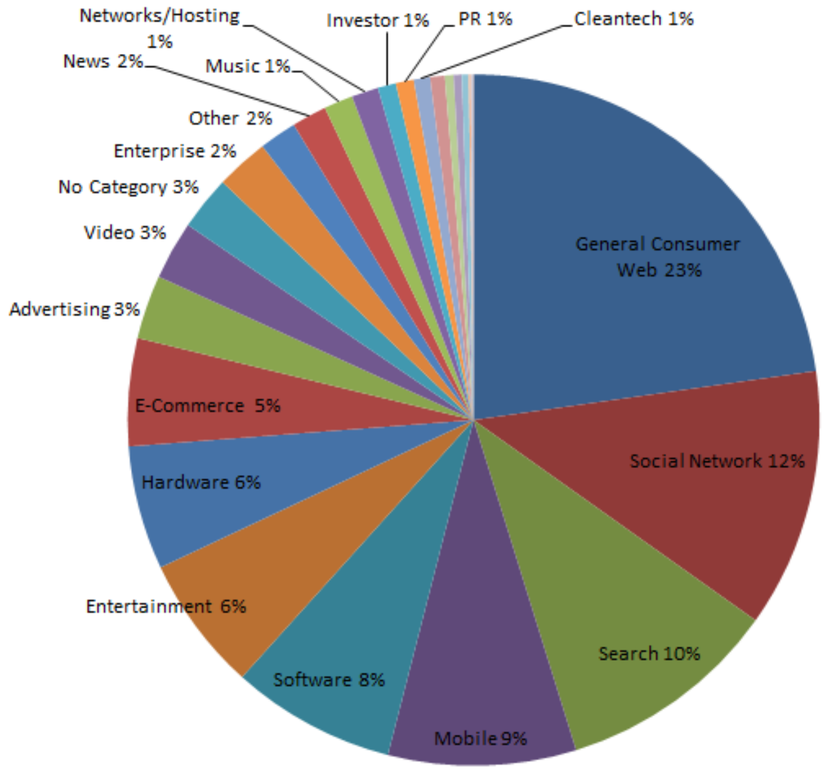
Grafik in echt


OBAMACARE ENROLLMENT
7,100,000
7,000,000
ACTUAL ENROLLMENT
GOAL
FOX NEWS
LIVE

Scales at 0

Use a baseline that shows the data, not the zero-point.

Death to Pie Charts



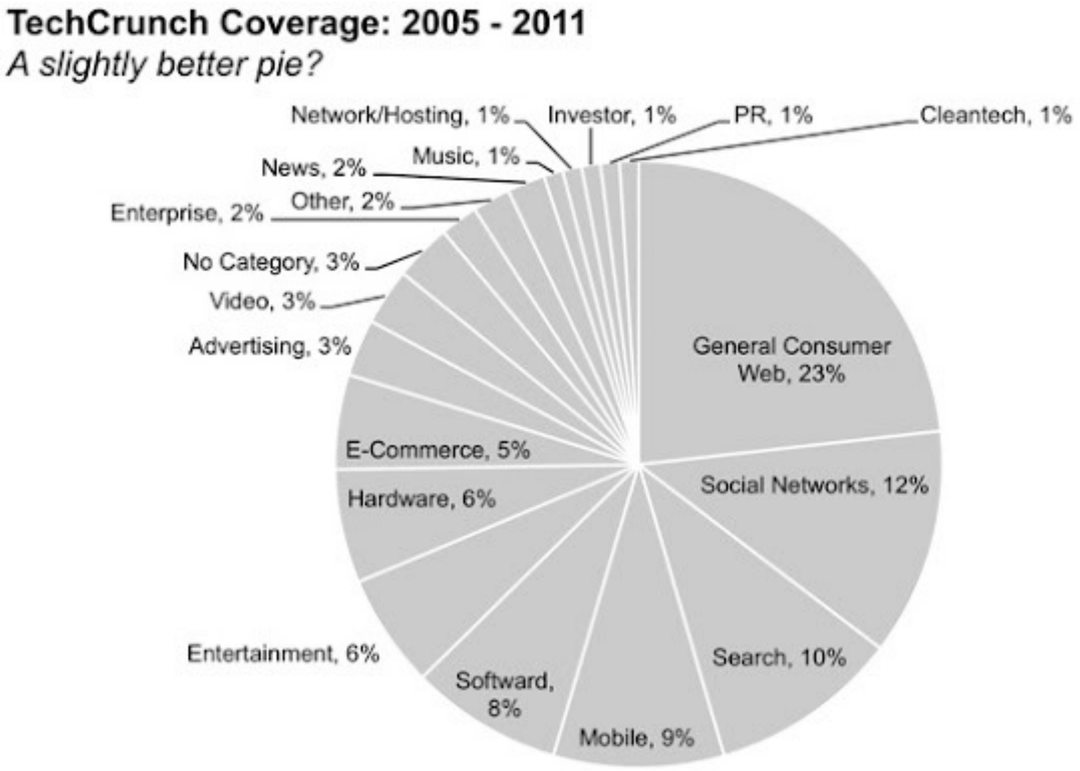
Share of coverage on TechCrunch

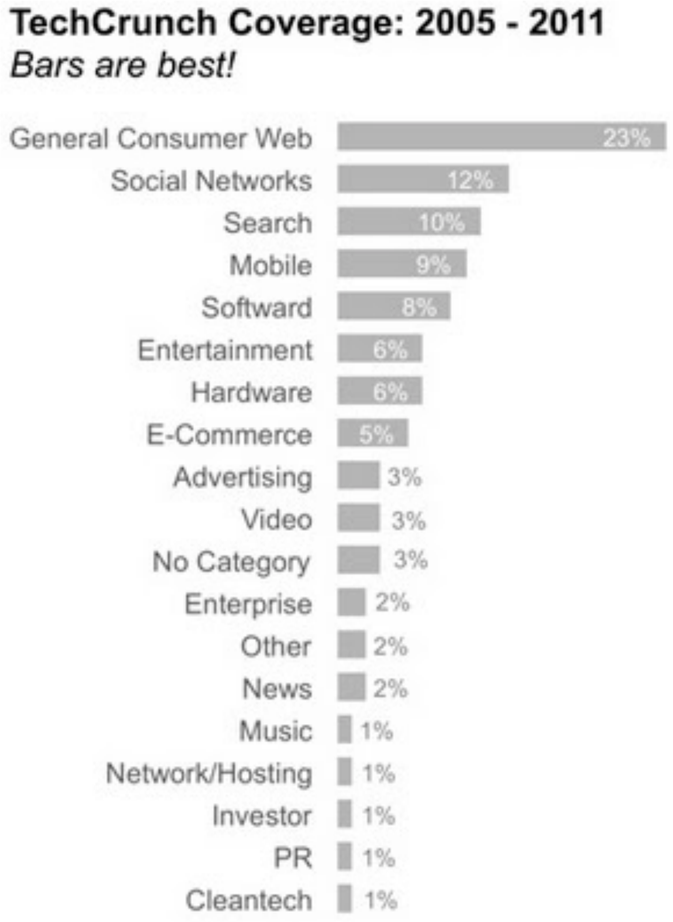
"I hate pie charts.
I mean, really hate them."

www.storytellingwithdata.com/2011/07/death-to-pie-charts.html

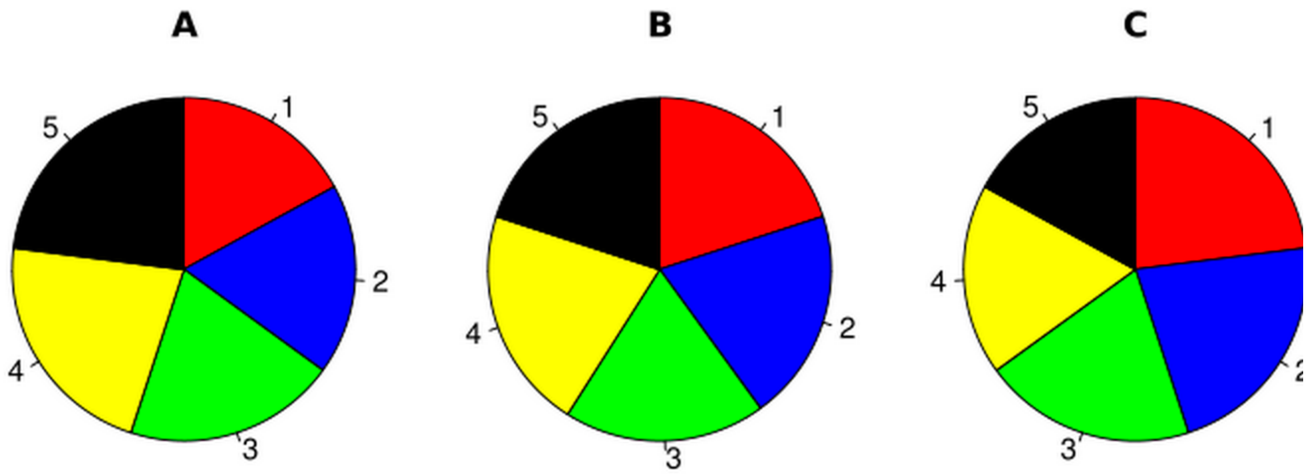
Cole Nussbaumer

Redesign

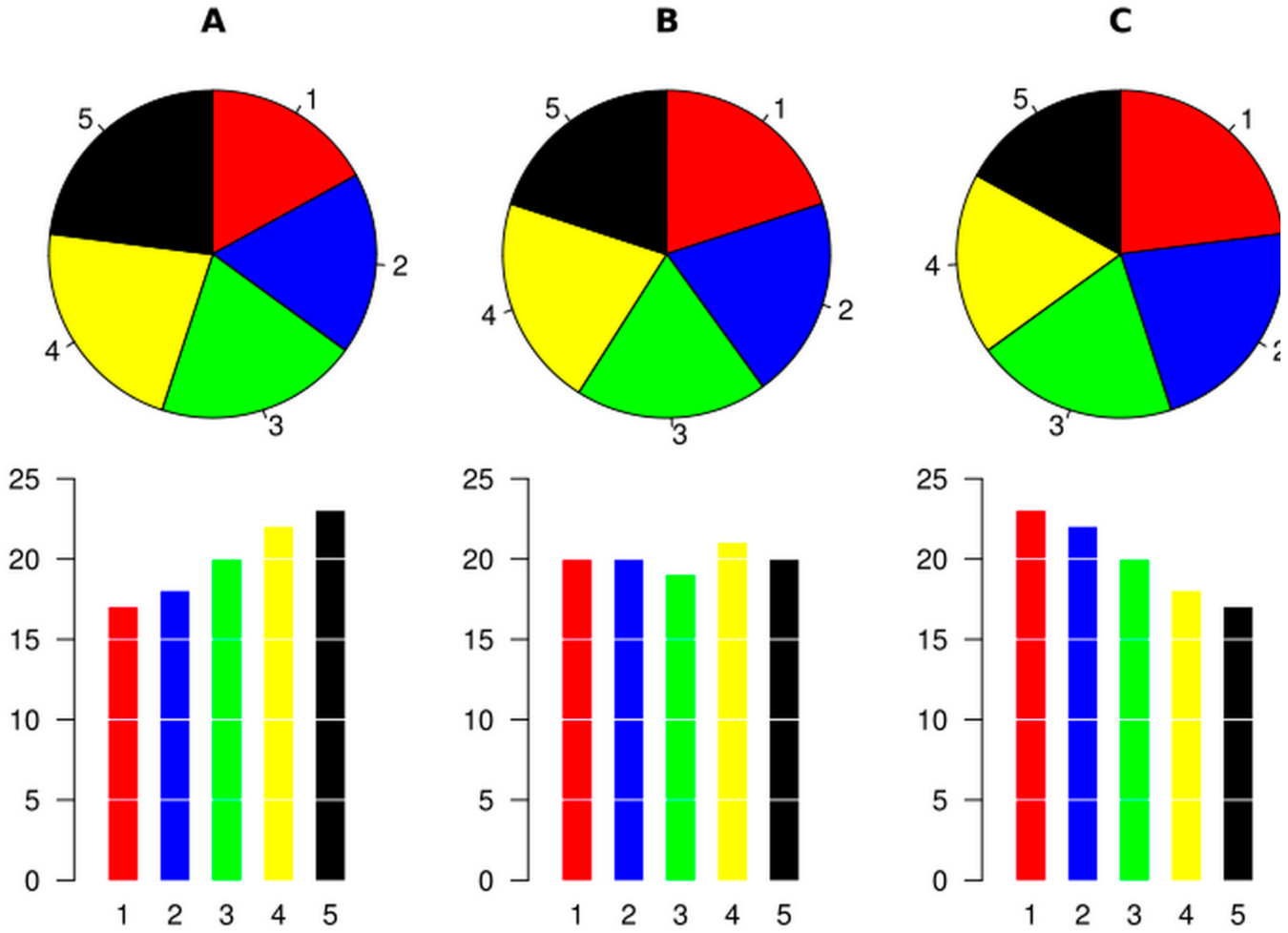

TechCrunch Coverage: 2005 - 2011
A slightly better pie?
Network/Hosting, 1%
Investor, 1%
PR, 1%
Cleantech, 1%
News, 2%
Music, 1%
Enterprise, 2%
Other, 2%
No Category, 3%
Video, 3%
Advertising, 3%
General Consumer Web, 23%
E-Commerce, 5%
Social Networks, 12%
Hardware, 6%
Entertainment, 6%
Softward, 8%
Search, 10%
Mobile, 9%


TechCrunch Coverage: 2005 - 2011
Bars are best!
General Consumer Web 23%
Social Networks 12%
Search 10%
Mobile 9%
Softward 8%
Entertainment 6%
Hardware 6%
E-Commerce 5%
Advertising 3%
Video 3%
No Category 3%
Enterprise 2%
Other 2%
News 2%
Music 1%
Network/Hosting 1%
Investor 1%
PR 1%
Cleantech 1%

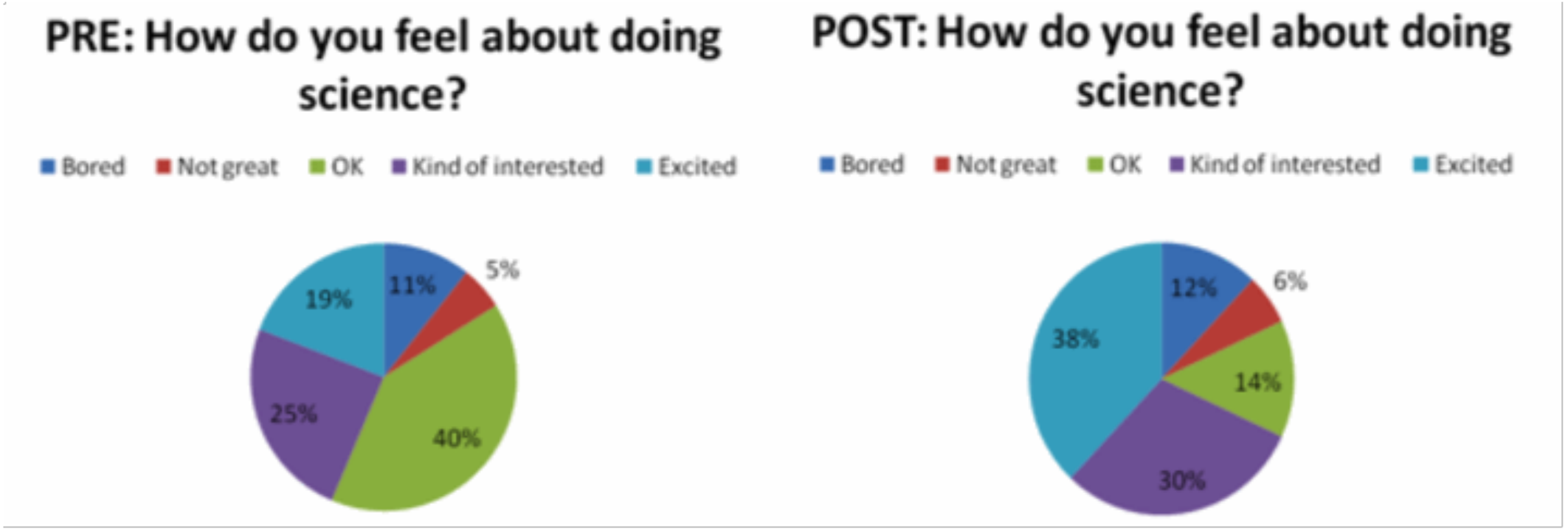
Can you spot the differences?



Can you spot the differences?



So, what to use instead?

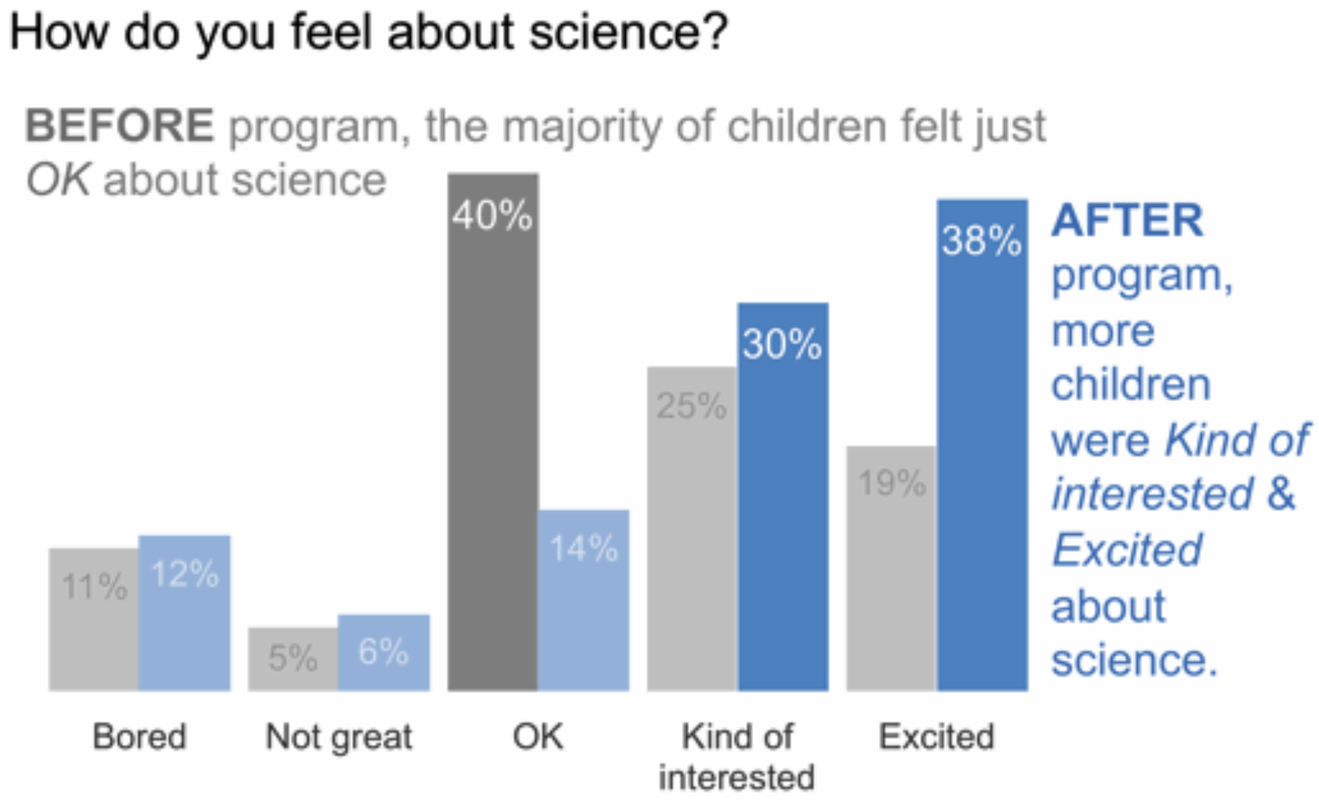


imagine you just completed a pilot summer learning program on science aimed at improving perceptions of the field among 2nd and 3rd grade elementary children

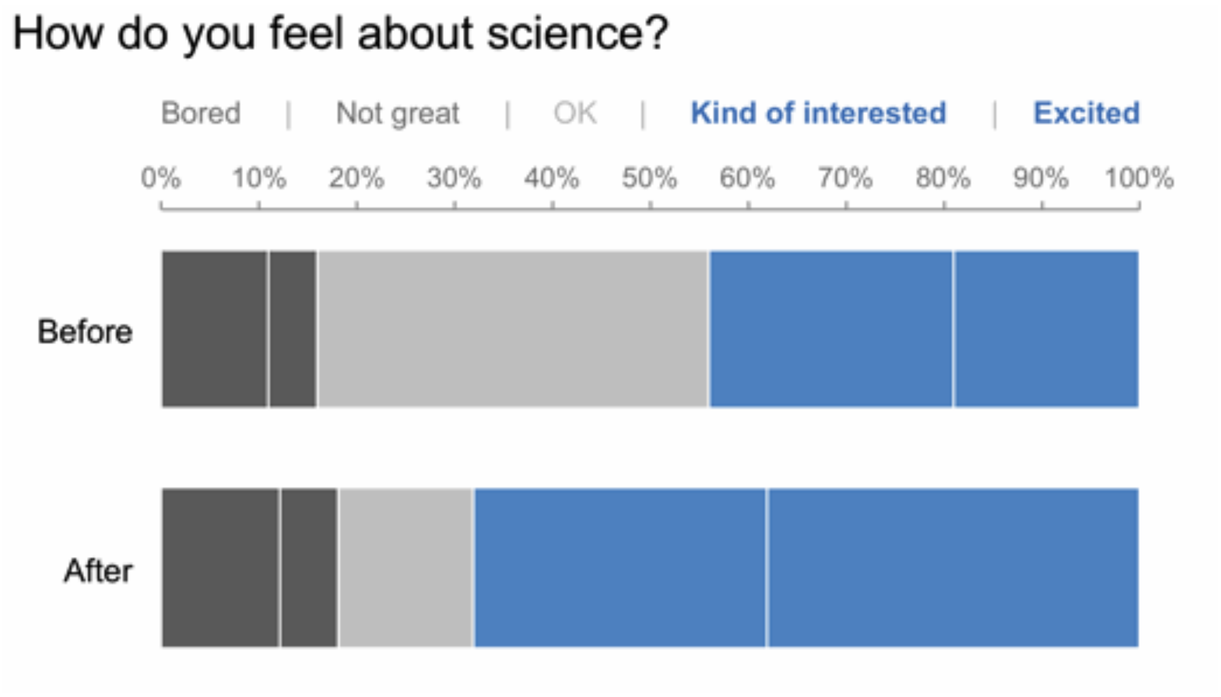
http://www.storytellingwithdata.com/blog/2014/06/alternatives-to-pies

Alternative #1: Show the Number(s) Directly

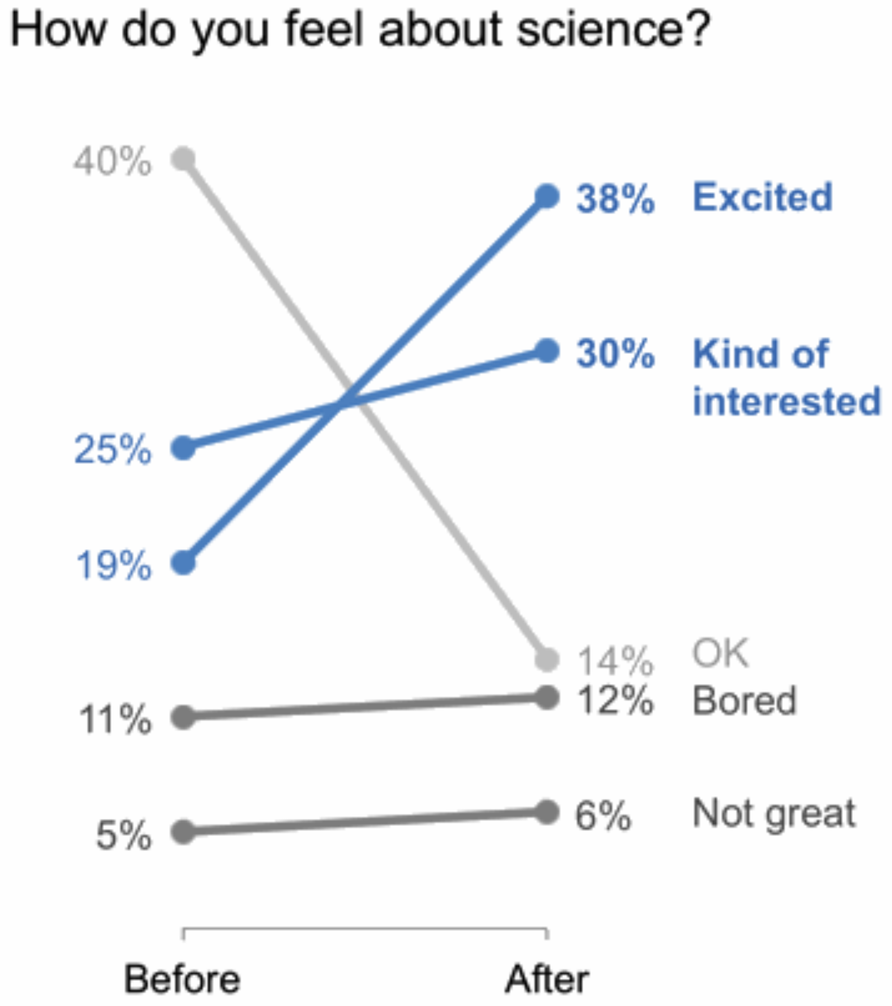
Alternative #2: Simple Bar Graph



Alternative #3: 100% Stacked Horizontal Bar Graph



Alternative #4: Slopegraph

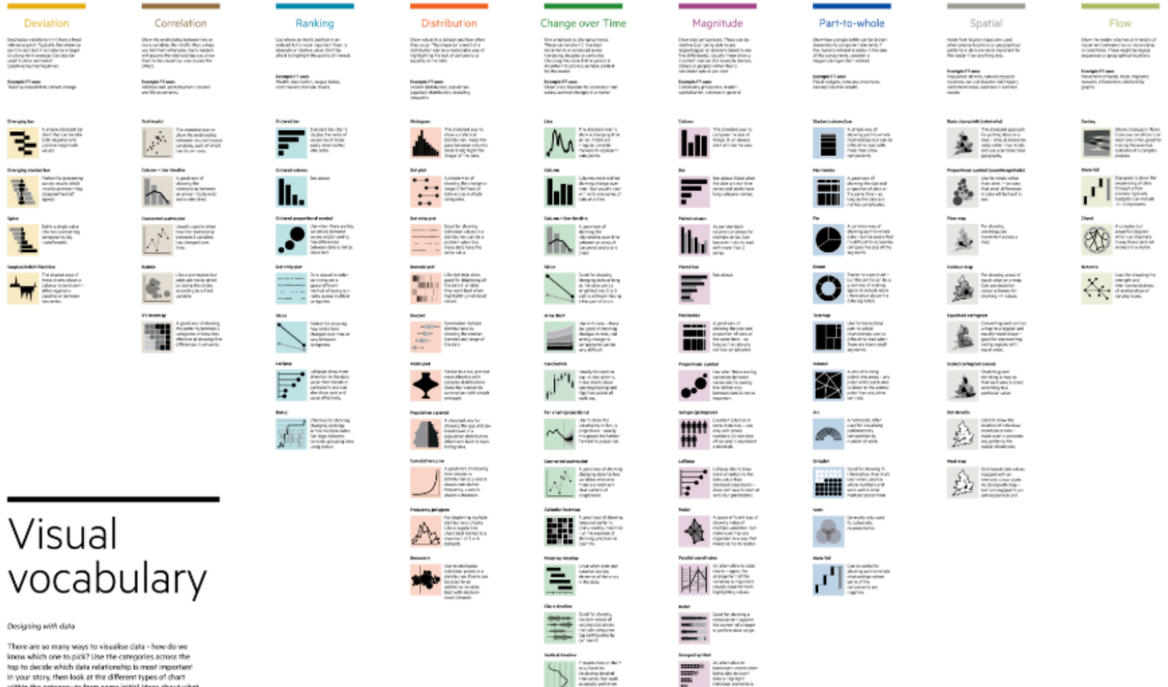


Tabular Data

Techniques and Tasks

Magnitude Distribution Deviation Correlation

Ranking Part to whole Change over Time



https://github.com/ft-interactive/chart-doctor/tree/master/visual-vocabulary
https://gramener.github.io/visual-vocabulary-vega/#/Magnitude/

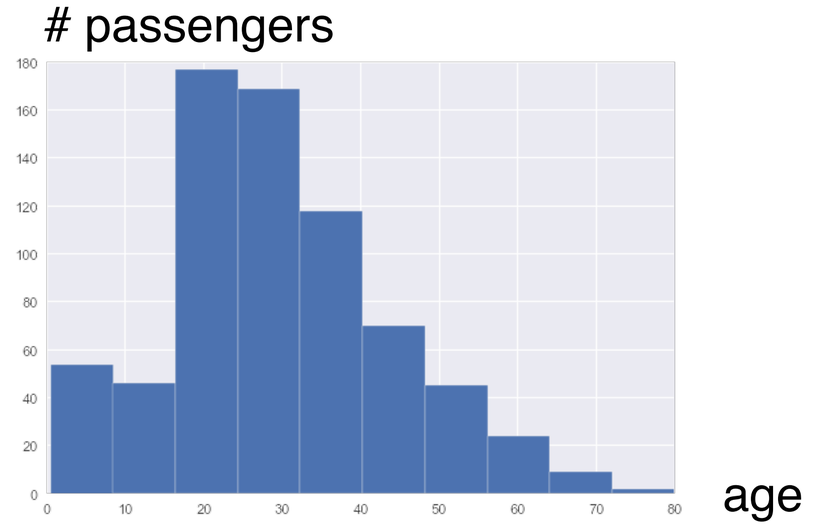
Histogram

Good #bins hard to predict

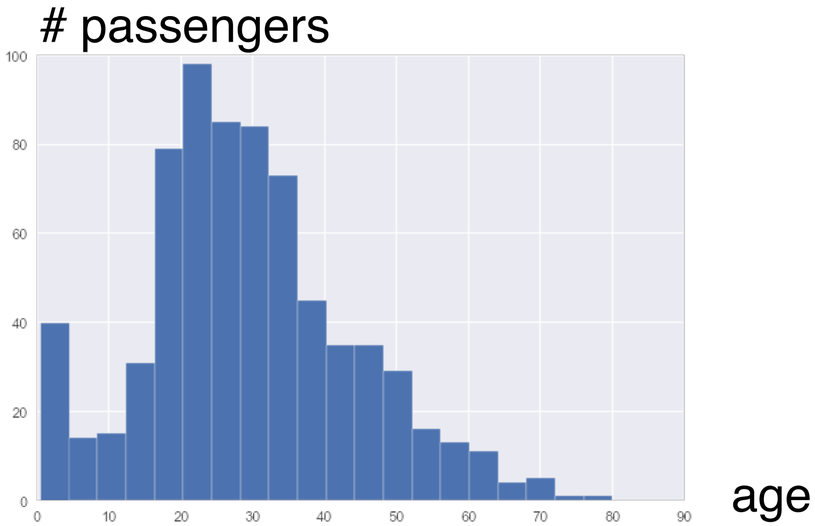
make interactive!

rules of thumb:

- #bins = sqrt(n)
- #bins = log2(n) + 1



10 Bins



20 Bins

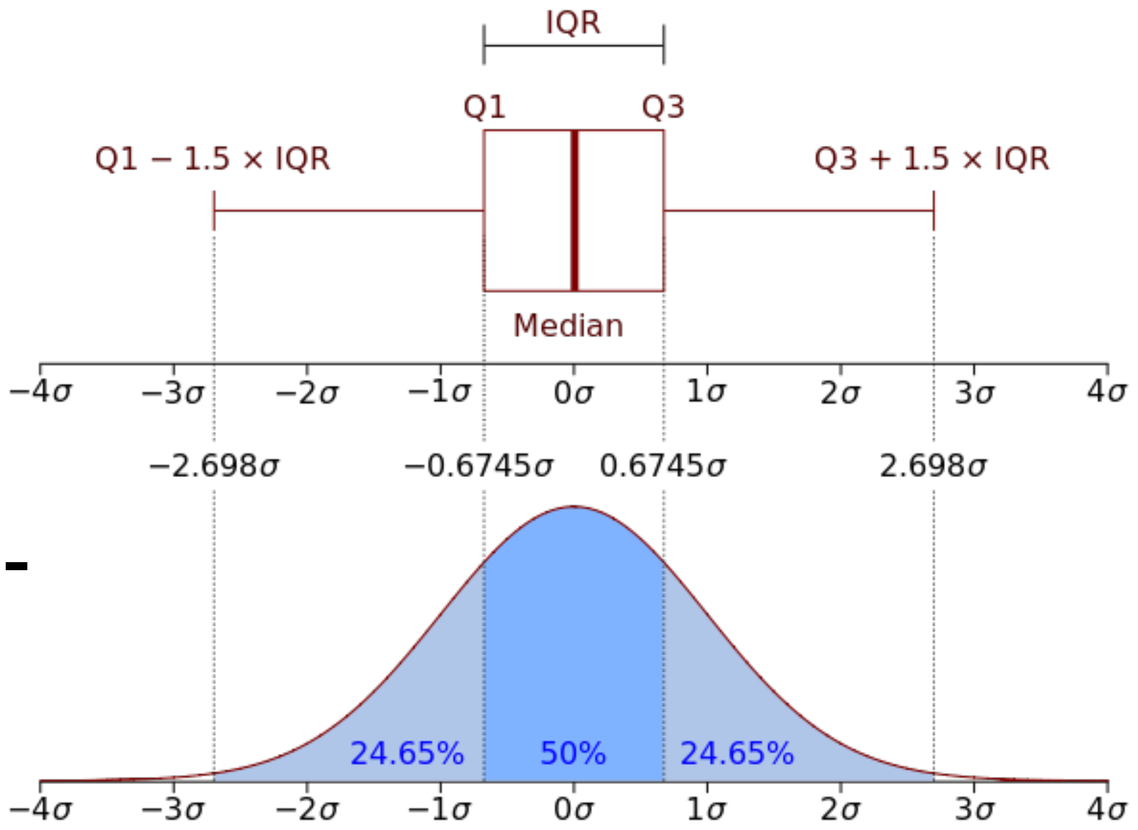
Box Plots

aka Box-and-Whisker Plot

Show outliers as points!

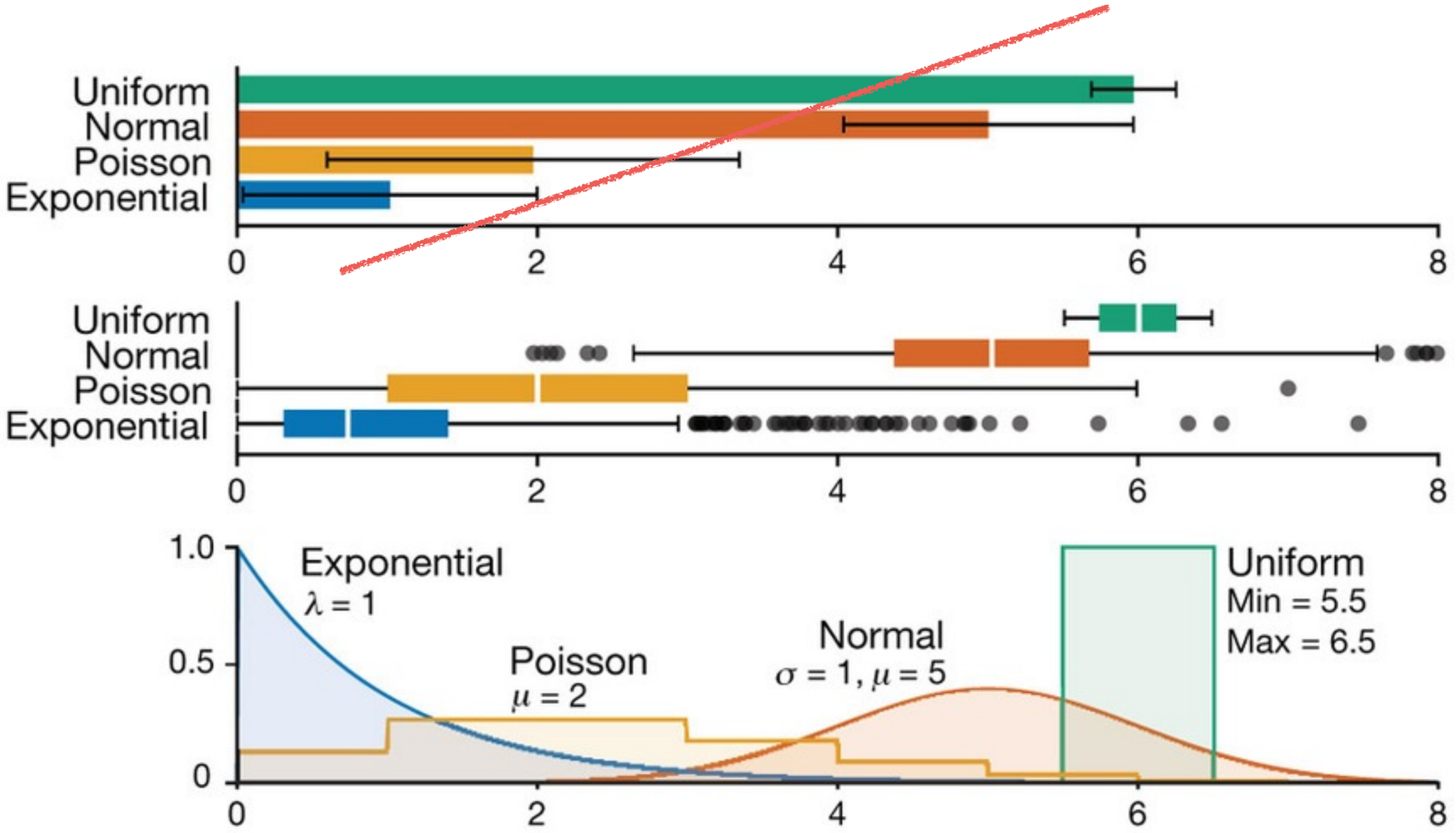
Not so great for non-normal distributed data

Especially bad for bi- or multi-modal distributions



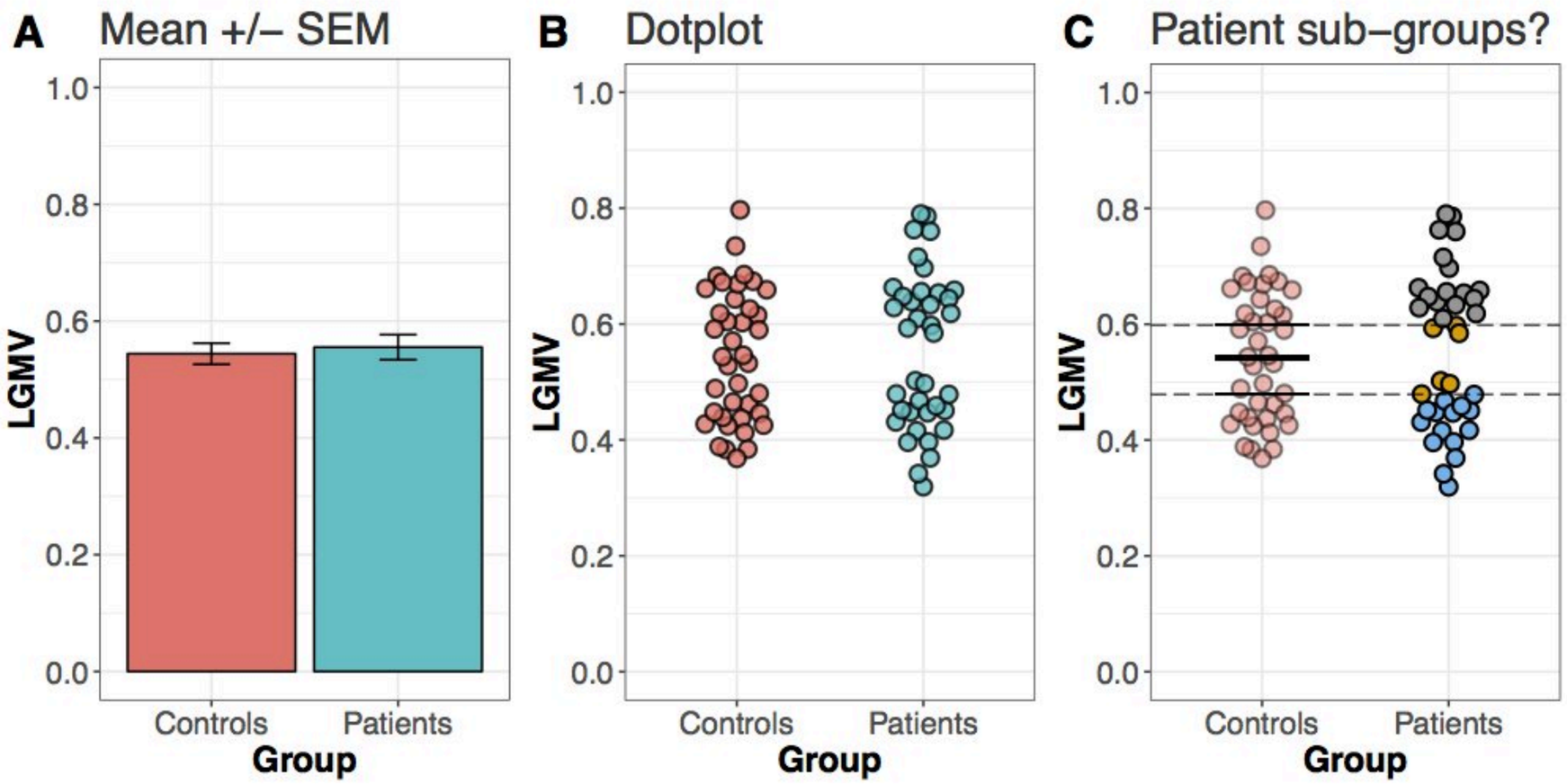
Wikipedia

Comparison



Streit & Gehlenborg, PoV, Nature Methods, 2014

Bar Charts vs Dot Plots

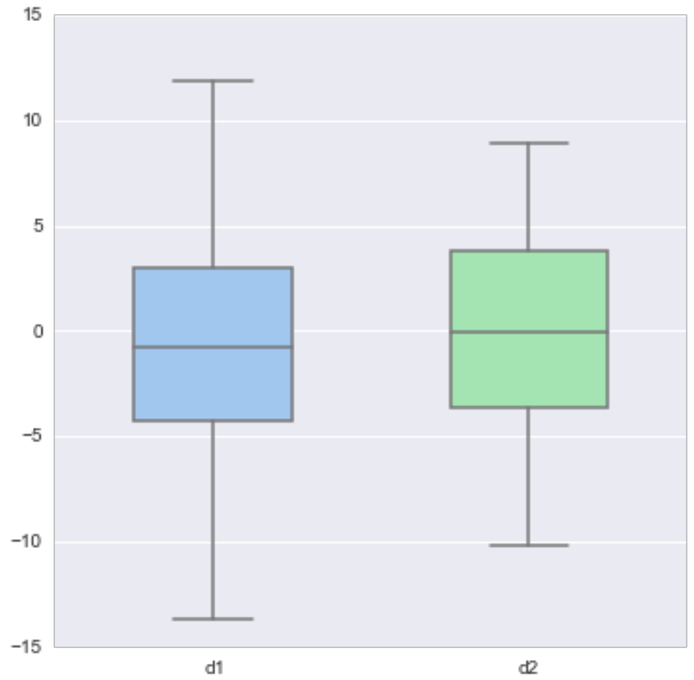


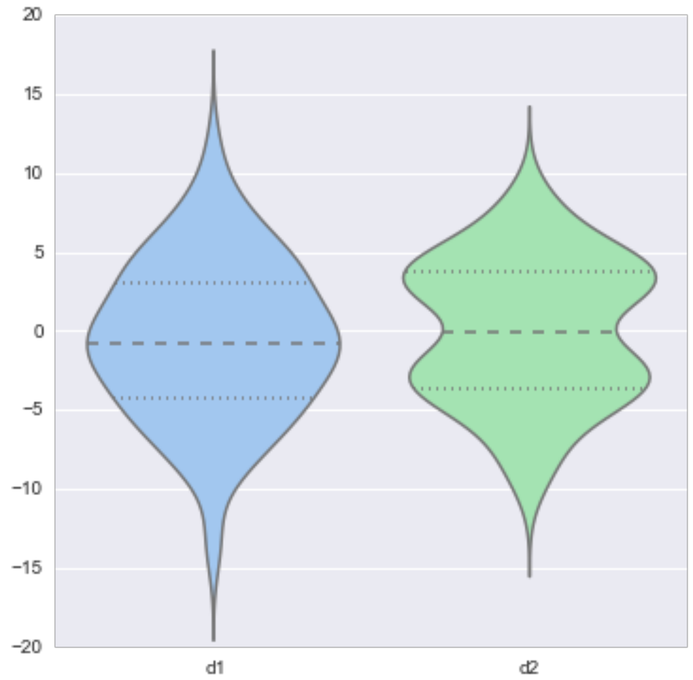
Data Source https://bmcneurosci.biomedcentral.com/articles/10.1186/1471-2202-10-67

https://twitter.com/robustgar/status/859318971920769024

Violin Plot

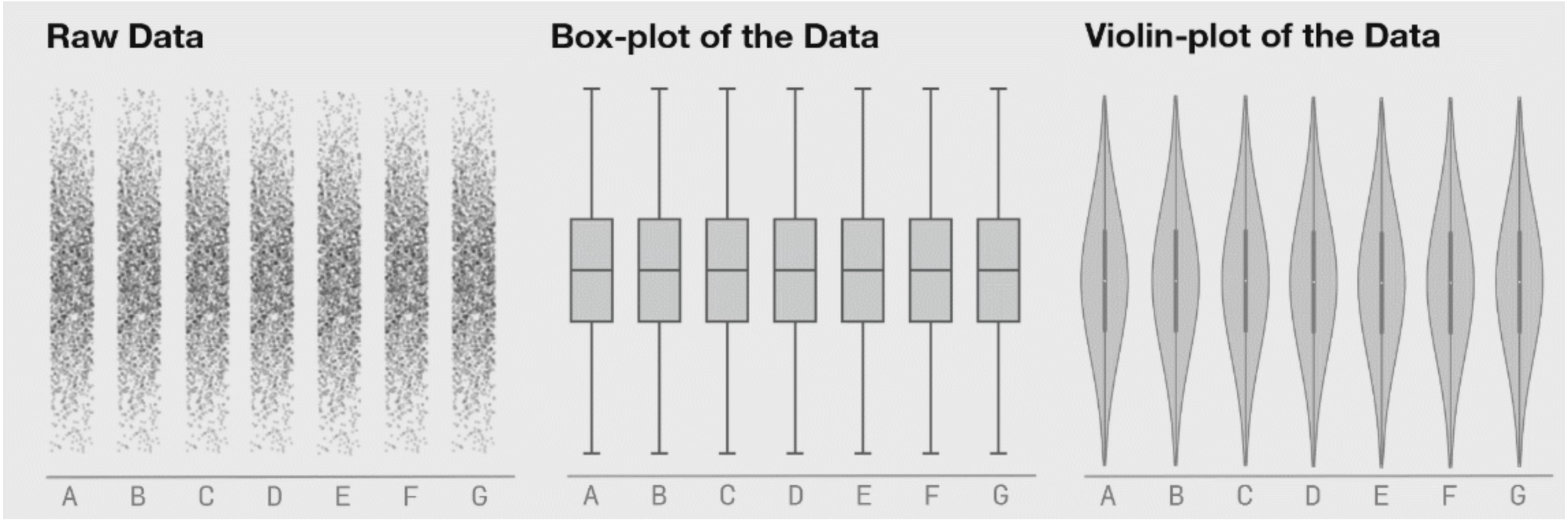
= Box Plot + Probability Density Function





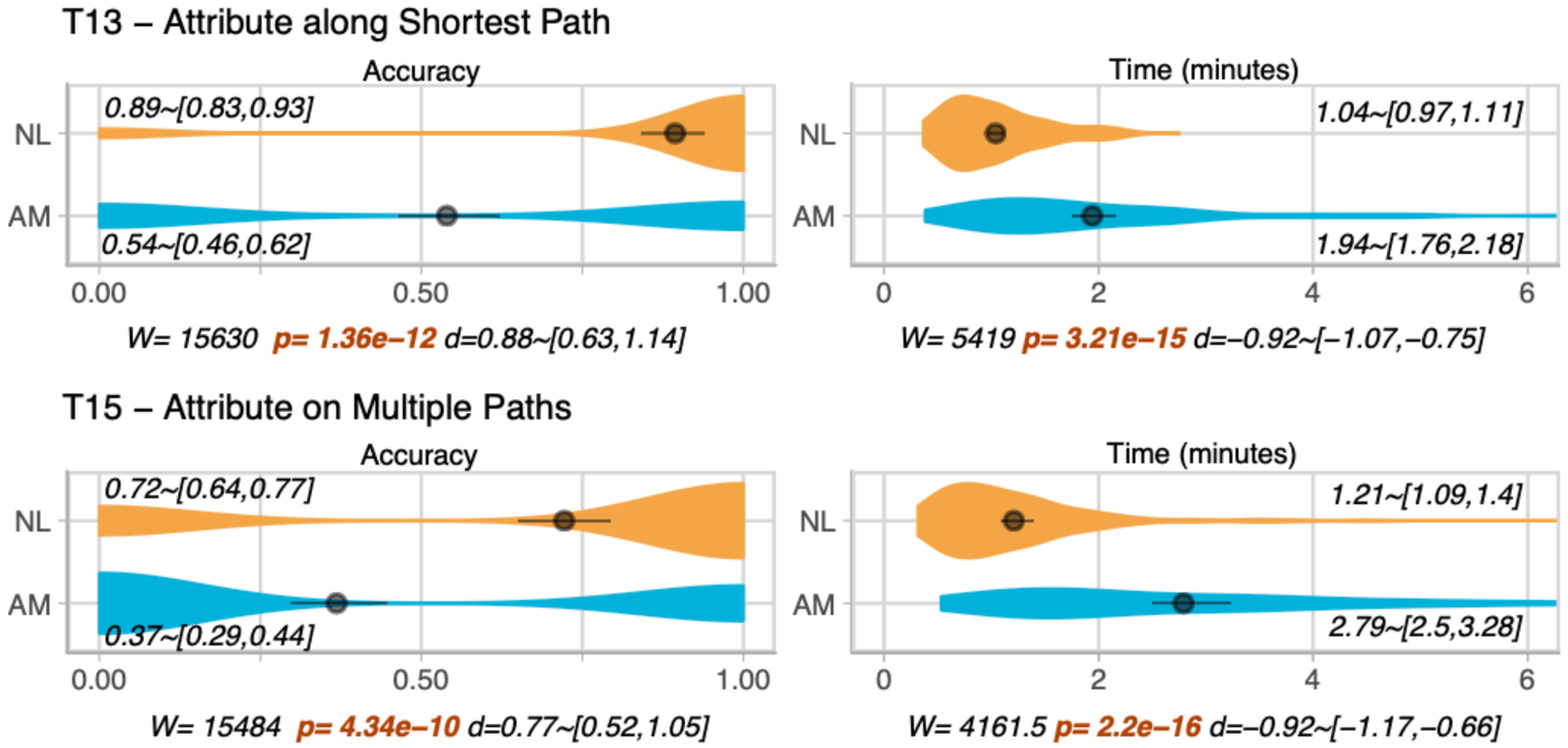
http://web.stanford.edu/~mwaskom/software/seaborn/tutorial/plotting_distributions.html

Different Distributions



https://blog.bioturing.com/2018/05/16/5-reasons-you-should-use-a-violin-graph/

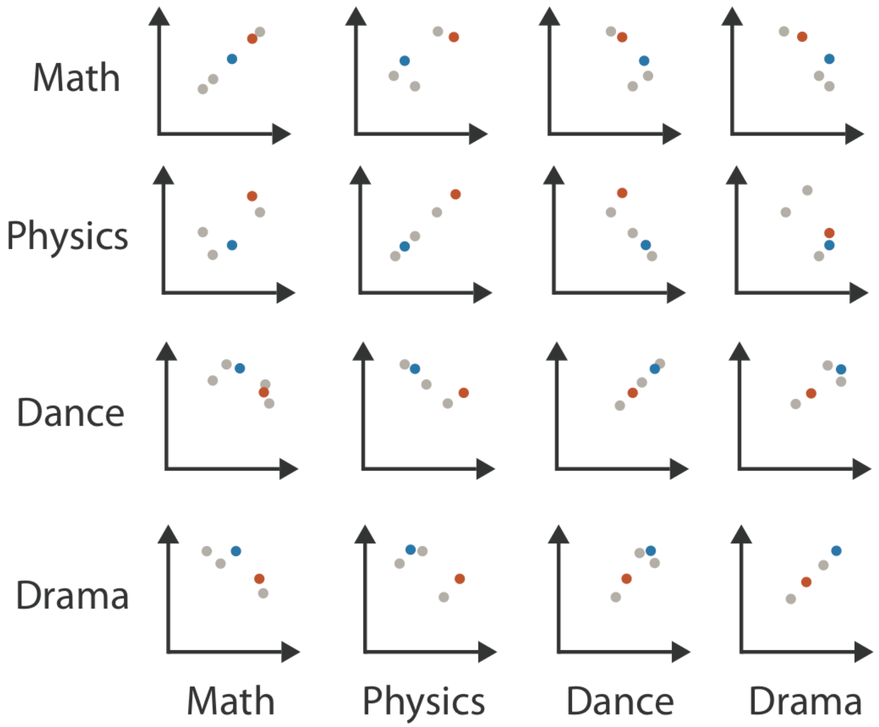
How to Visually Report Distributions for Experiments



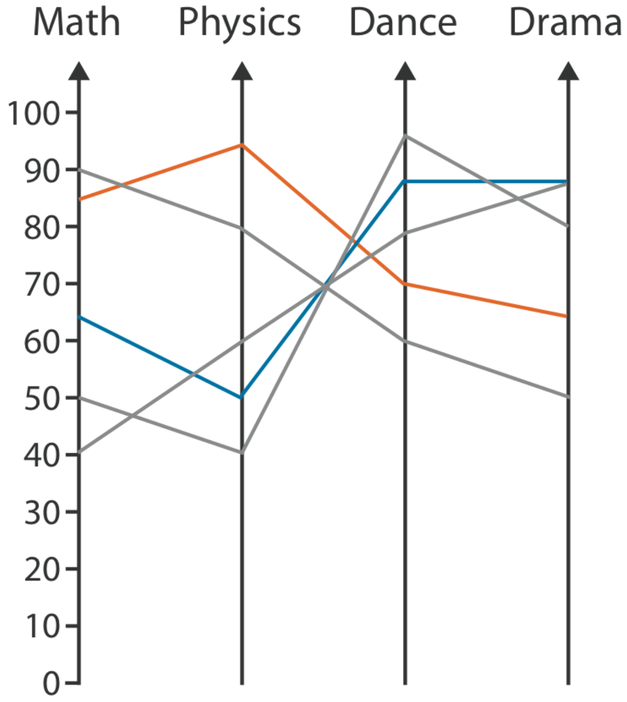
[Nobre 2019]

Scatterplot Matrix & PCs

Scatterplot Matrix



Parallel Coordinates



Table

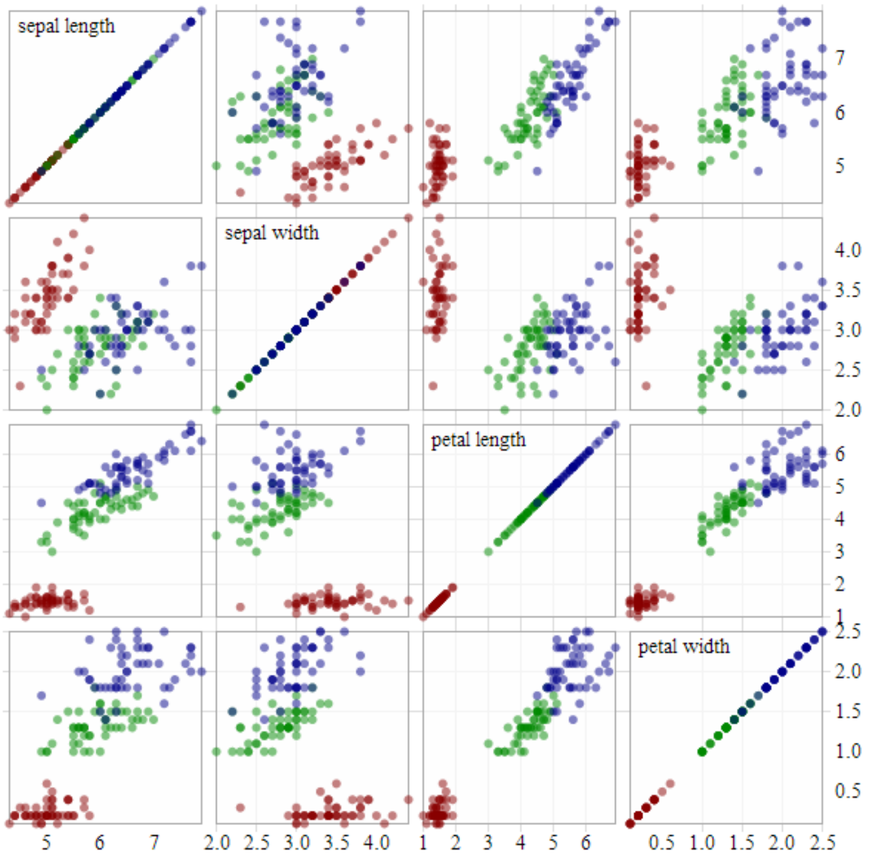
Math	Physics	Dance	Drama
85	95	70	65
90	80	60	50
65	50	90	90
50	40	95	80
40	60	80	90

Scatterplot Matrices (SPLOM)

Matrix of size d*d

Each row/column is one dimension

Each cell plots a scatterplot of two dimensions

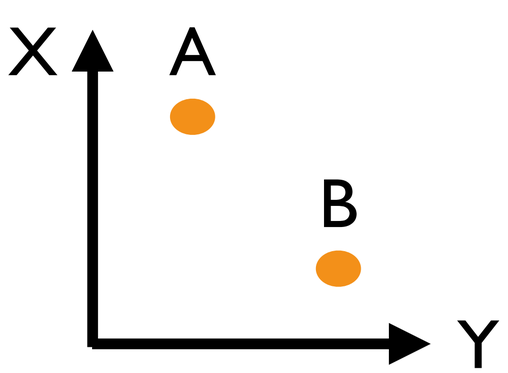


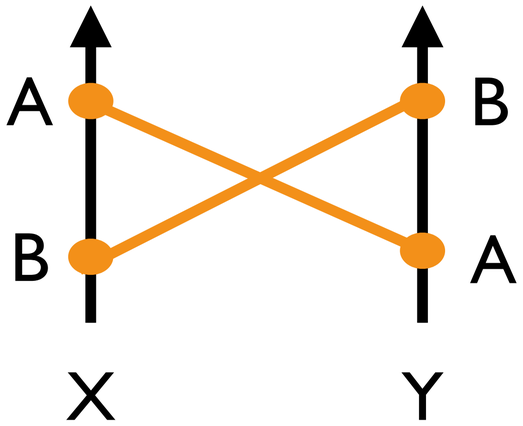
Parallel Coordinates (PC)

Inselberg 1985

Axes represent attributes

Lines connecting axes represent items





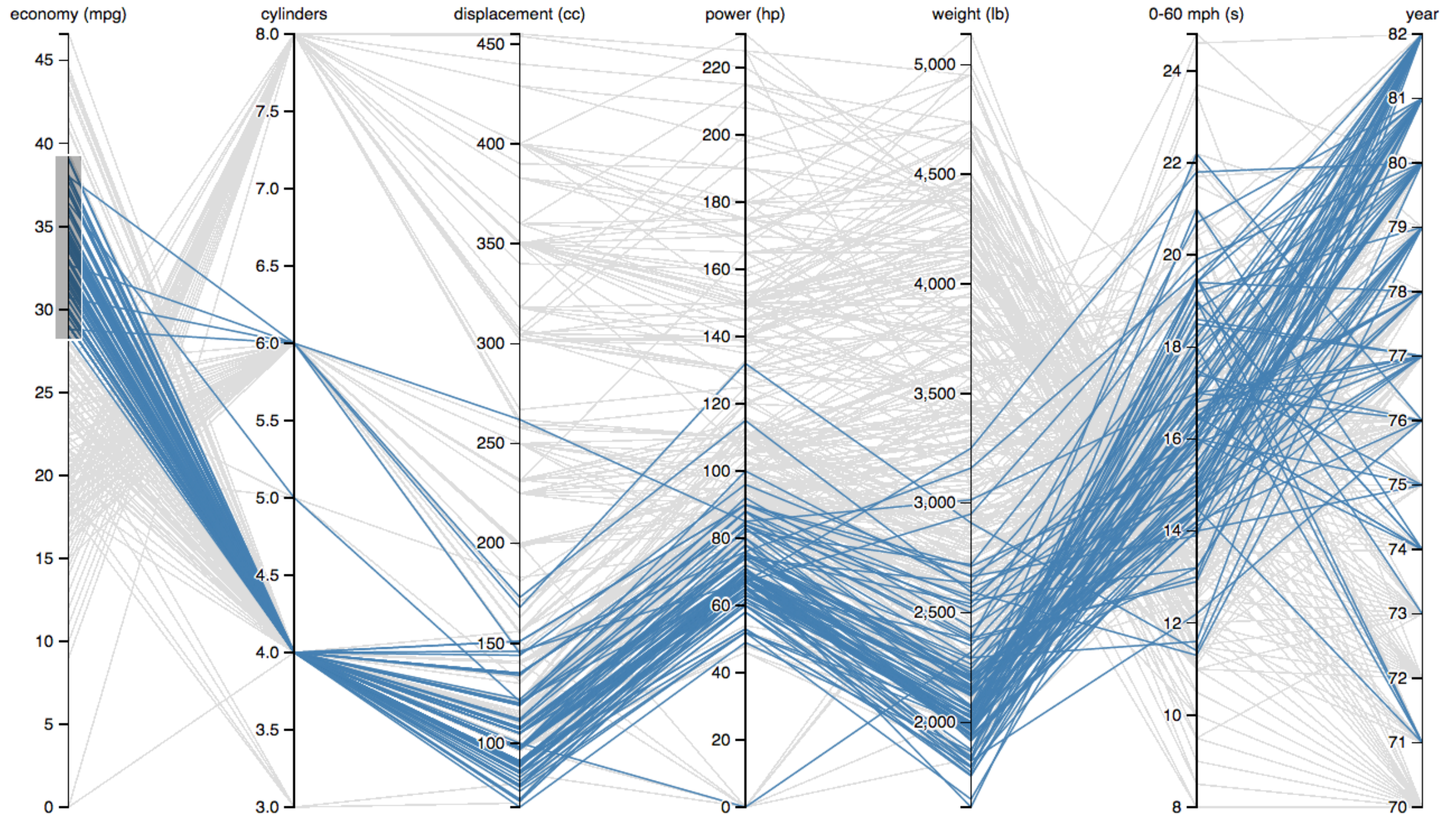
Parallel Coordinates

Each axis represents dimension

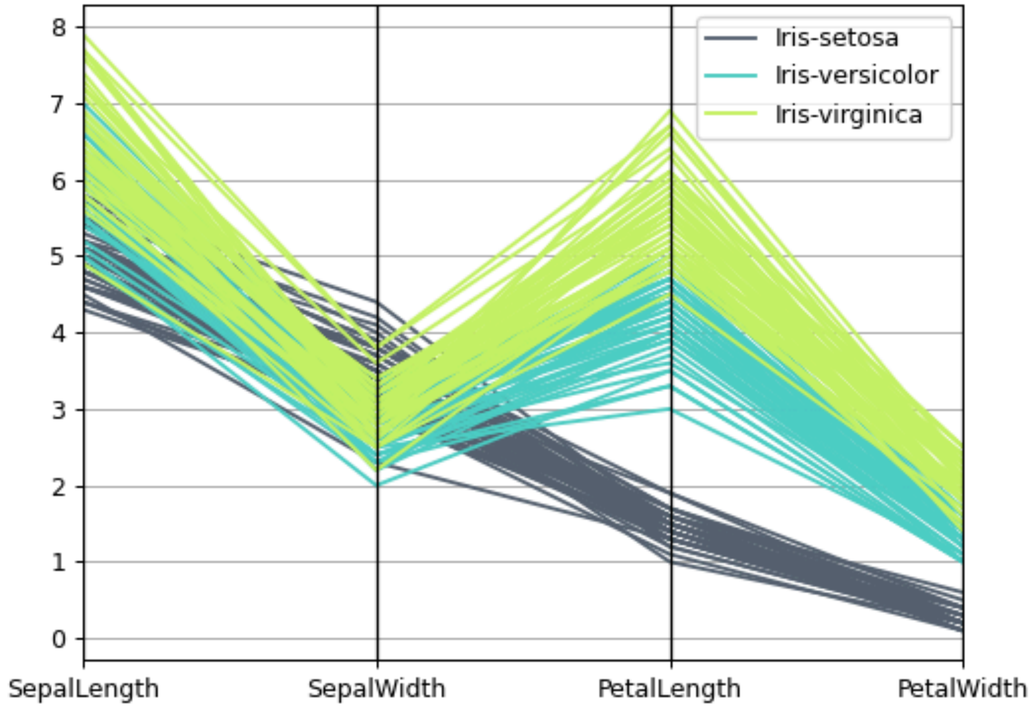
Lines connecting axis represent records

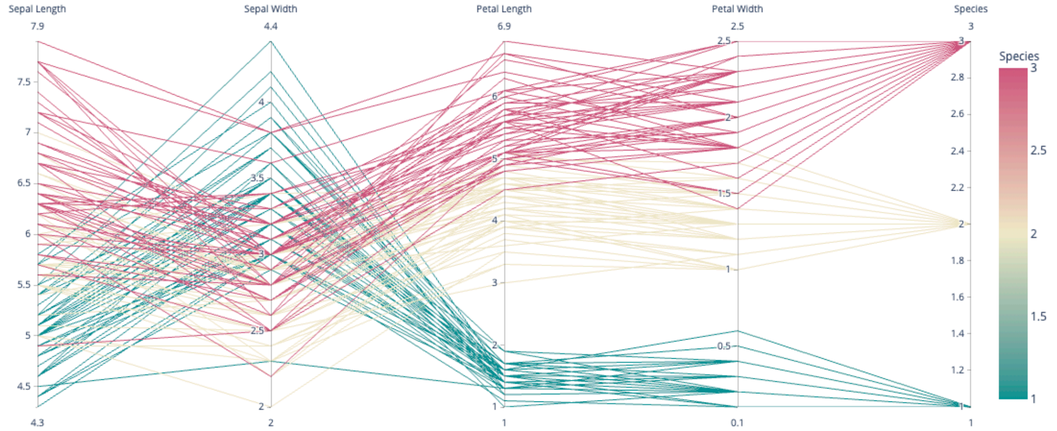
Suitable for

- all tabular data types
- heterogeneous data



Pandas and Plotly PCs





https://pandas.pydata.org/docs/reference/api/pandas.plotting.parallel_coordinates.html

https://plotly.com/python/parallel-coordinates-plot/

Pixel Based Displays

Each cell is a “pixel”, value encoded in color / value

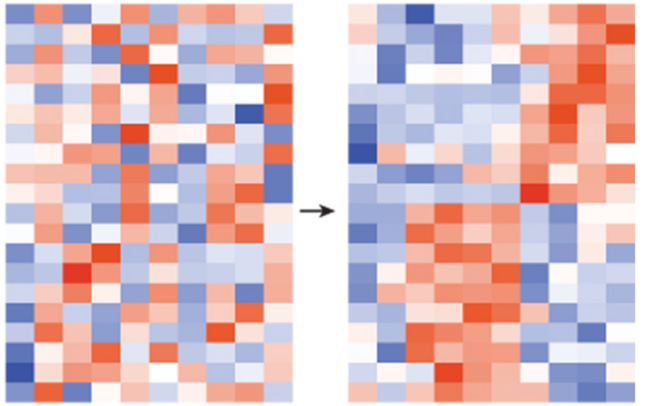
Ordering critical for interpretation

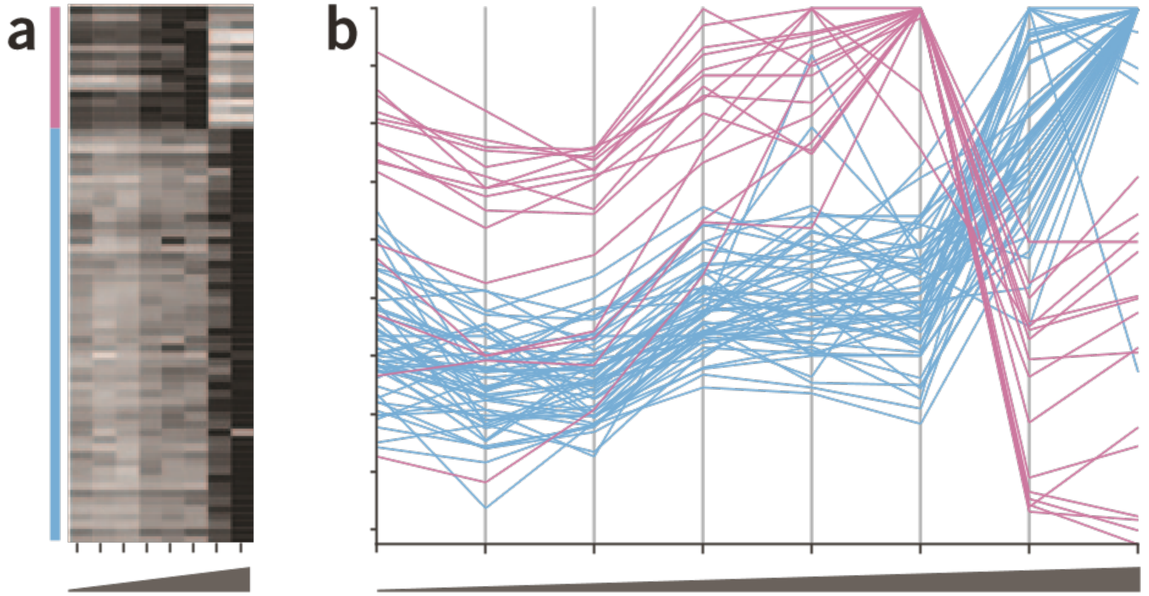
If no ordering inherent, clustering is used

Scalable – 1 px per item

Good for homogeneous data

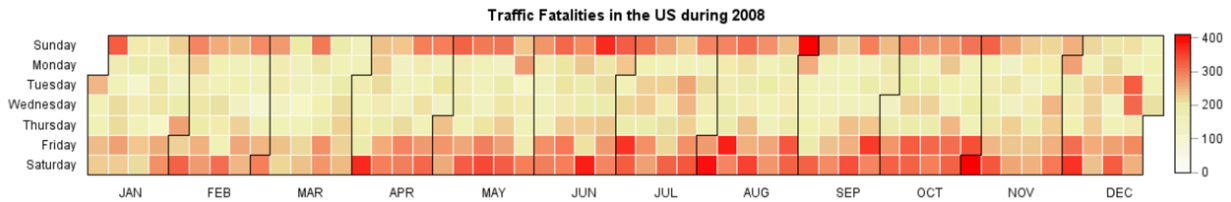
same scale & type





[Gehlenborg & Wong 2012]

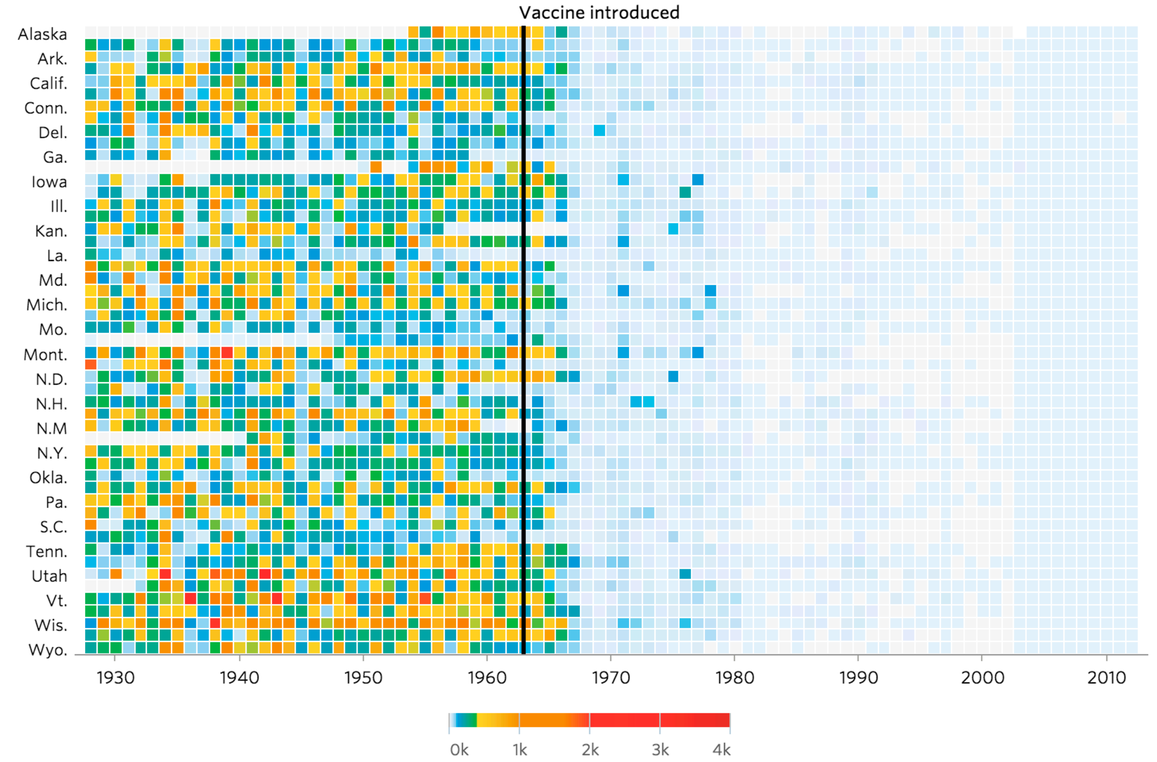
Heat Map and Calendar Heat Map



https://blogs.sas.com/content/graphicallyspeaking/2011/12/08/calendar-heatmaps-in-gtl/

The heat maps below show number of cases per 100,000 people.

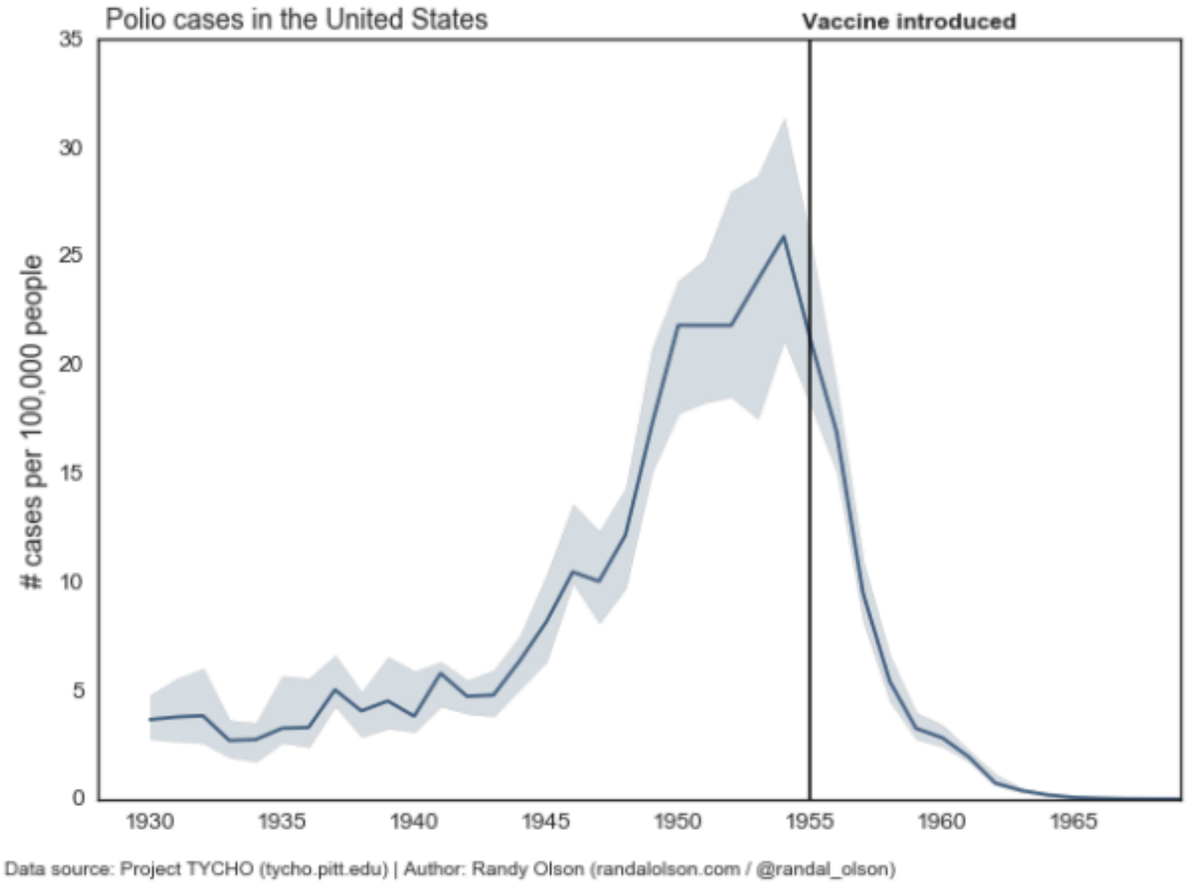
Measles



Note: CDC data from 2003-2012 comes from its Summary of Notifiable Diseases, which publishes yearly rather than weekly and counts confirmed cases as opposed to provisional ones.

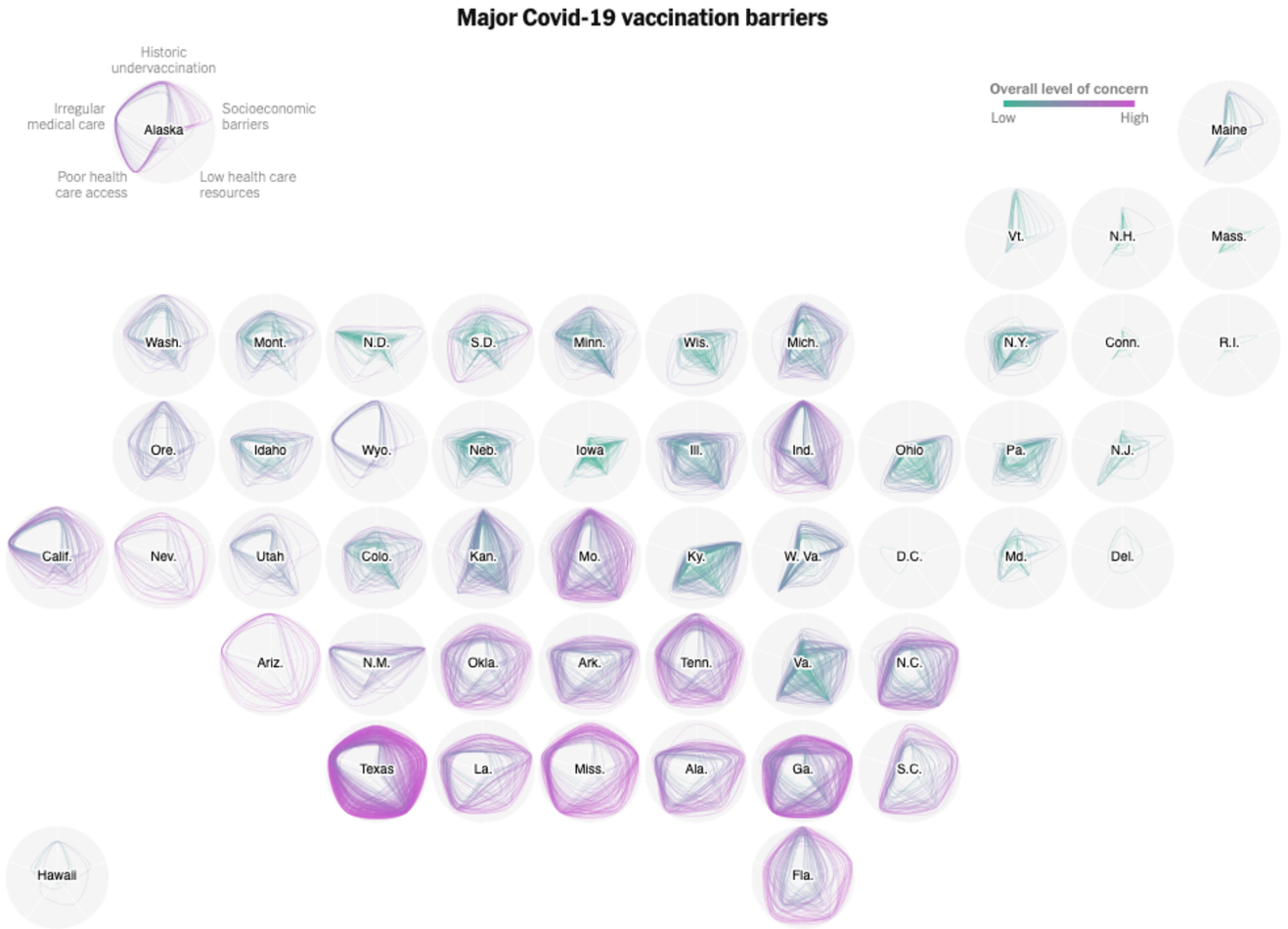
https://www.informationisbeautifulawards.com/showcase/660-vaccines-and-infectious-diseases

Sometimes you can Show Too Much Data



http://www.randalolson.com/2016/03/04/revisiting-the-vaccine-visualizations/

Critique: Vaccine Roadblocks



https://www.nytimes.com/interactive/2021/02/25/opinion/covid-vaccination-barriers.html