

# Applied Data Analysis (CS401)



Lecture 3  
Visualizing data  
5 Oct 2022

**EPFL**

**Robert West**



# Announcements

- You must find 3 team mates and [register](#) by this Fri 7 Oct 23:59
  - Every student must register individually
  - Still looking for a team or for team members? Use Ed (see [post](#))!
- Project milestone 1 due Fri 14 Oct 23:59
- Homework 1 released Fri 14 Oct (due two weeks later)
- Friday's lab session:
  - From now on: Lab session materials to be released on Wed before lab
  - 13:15 - 13:30 (on Moodle): Quiz 2 (the first one that counts)
  - More on data visualization; working with data from the Web
  - Project milestone P1 office hours

# Feedback

Give us feedback on this lecture here:

<https://go.epfl.ch/ada2022-lec3-feedback>

- What did you (not) like about this lecture?
- What was (not) well explained?
- On what would you like more (fewer) details?
- [What's your favorite color, baby?](#)
- ...

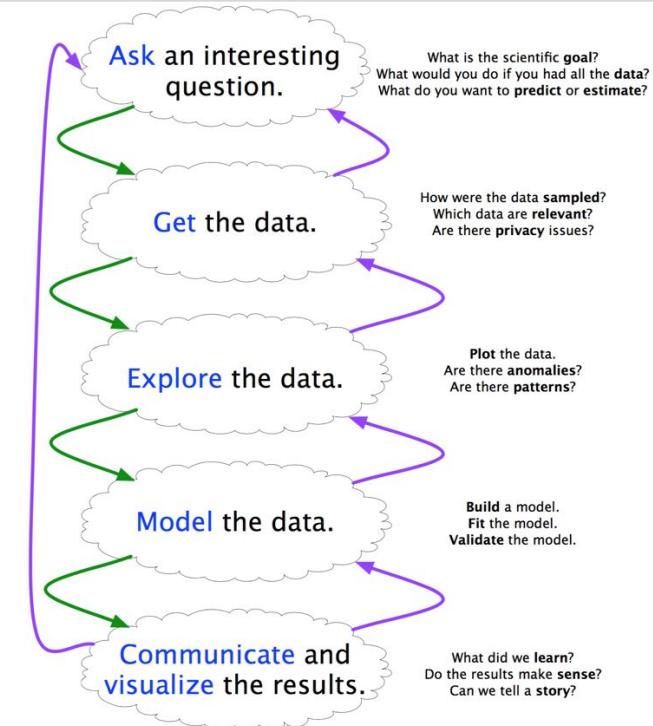
# Uses for data visualization

Support reasoning about information (**analysis**)

- Finding relationships
- Discover structure
- Quantifying values and influences
- Should be part of the data analysis cycle ➔

Inform and persuade others (**communication**)

- Capture attention, engage
- Tell a story visually
- Can focus on certain aspects and omit others



Make it easier to evaluate potential courses of action (**decision-making**)

# An unconventional example



["Garden of Eden"](#): 8 lettuces, each of which is enclosed in its own airtight plexiglas box and represents a major city. The concentration of ozone in each box is controlled in real-time to reflect the current pollution level in the city.

## **Static viz**

Great for data exploration,  
developed throughout the last few  
centuries...

## **Interactive viz**

More and more common when  
delivering the results (and also during  
exploration). New frameworks are the  
key enabler.

# Want to learn more?

Dedicated course:

[COM-480: Data Visualization](#)

# Today's lecture

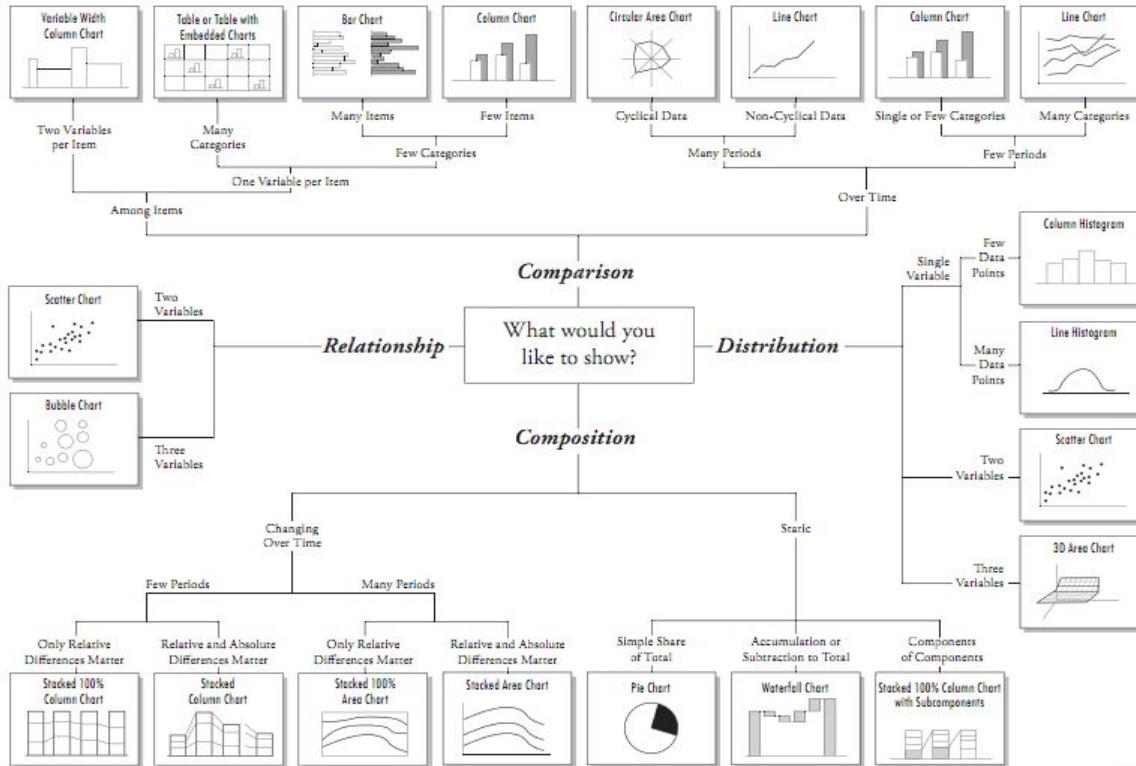
- Part 1: Navigating the chart landscape
- Part 2: Principles and best practices
- Part 3: A (small) selection of use cases for data visualization

# Part 1

# Navigating the chart landscape

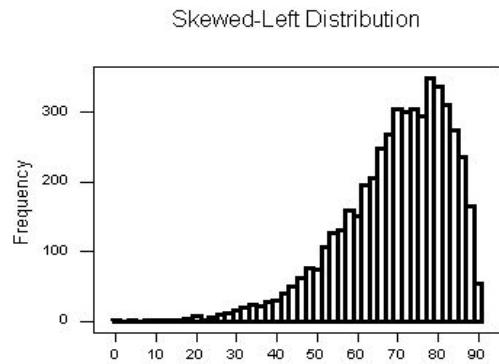
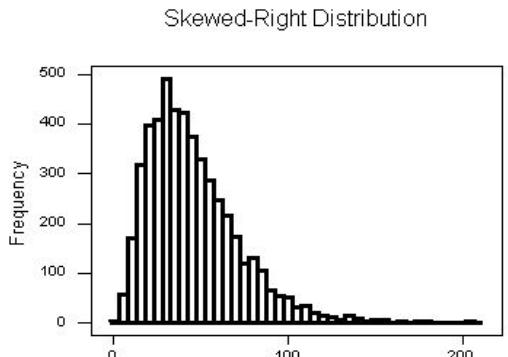
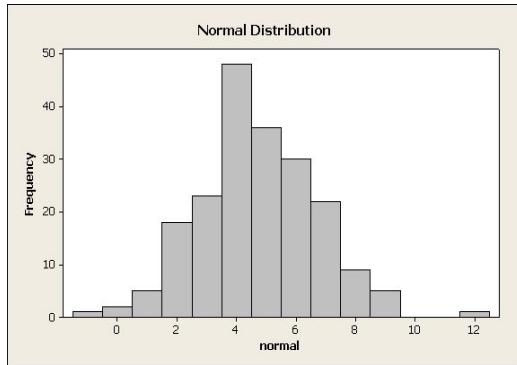
# Chart selection

## Chart Suggestions—A Thought-Starter

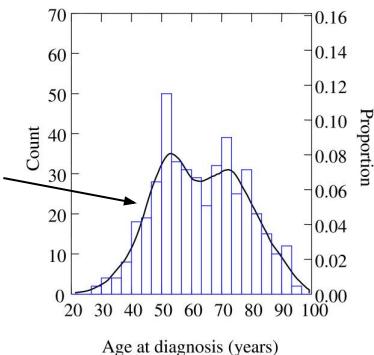


# One variable: histograms

Histograms can tell you a lot about a single variable, discrete or continuous

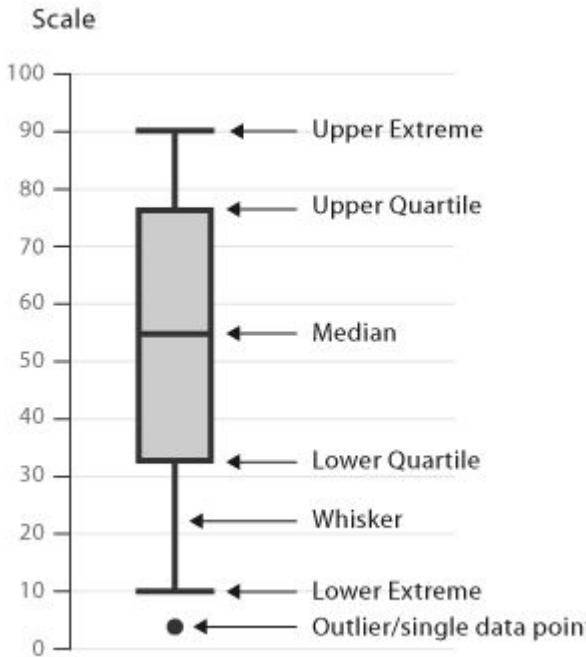


Smoothed histogram (a.k.a. kernel density estimate)

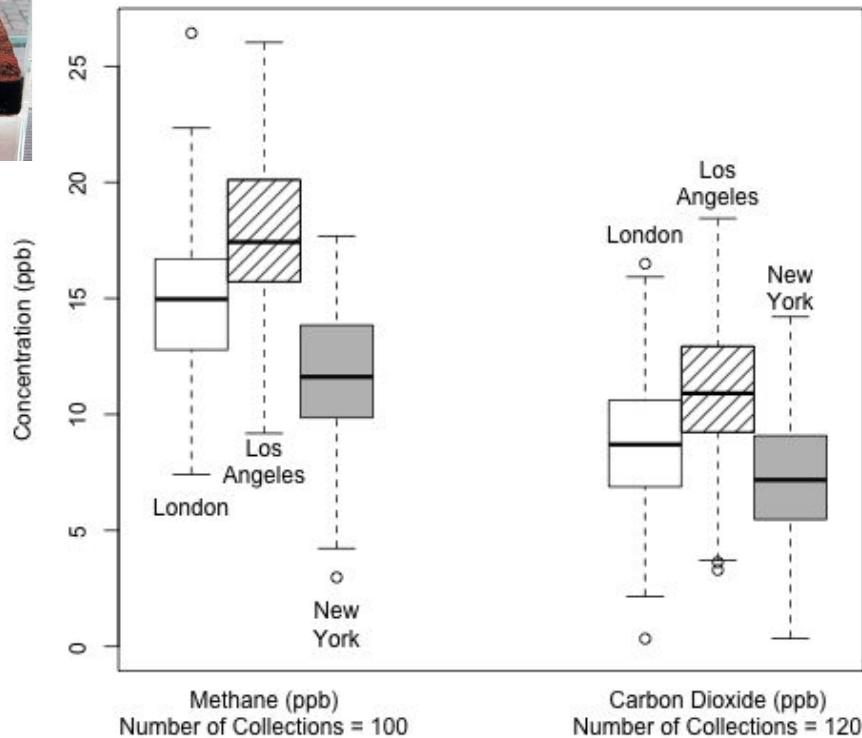


Easy to  
recognize  
skewed  
distributions!

# One variable: box plots

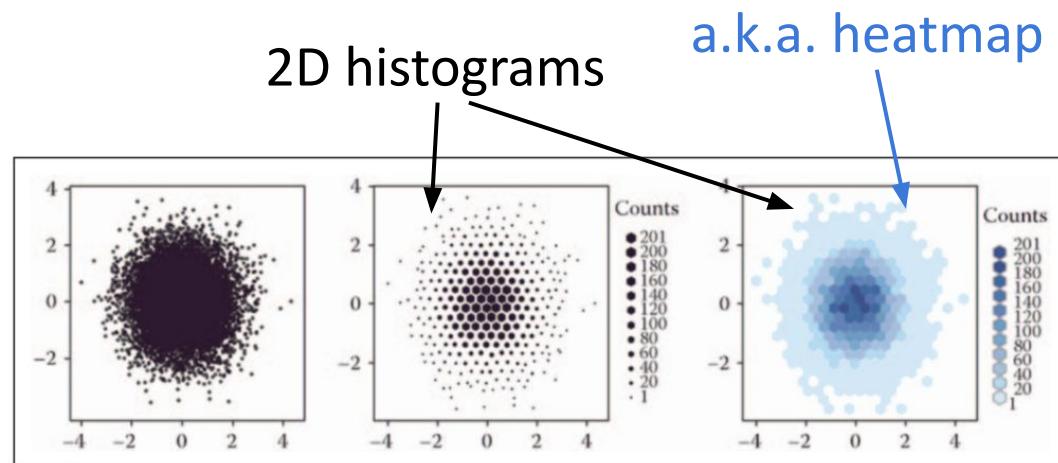
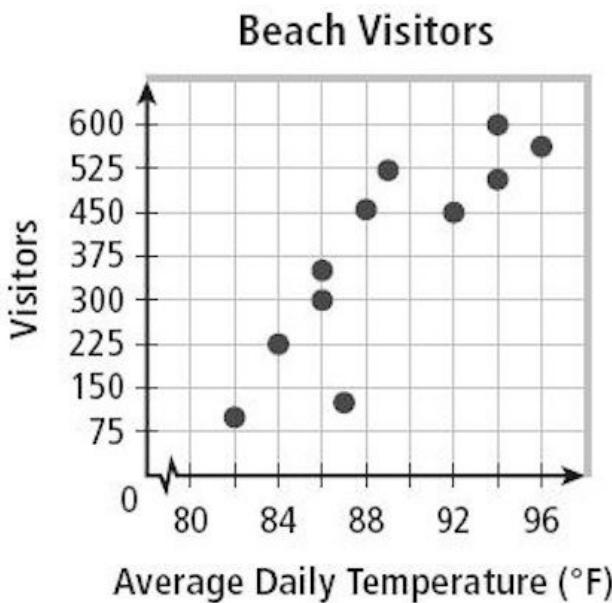


Comparing Pollution in London, Los Angeles, and New York



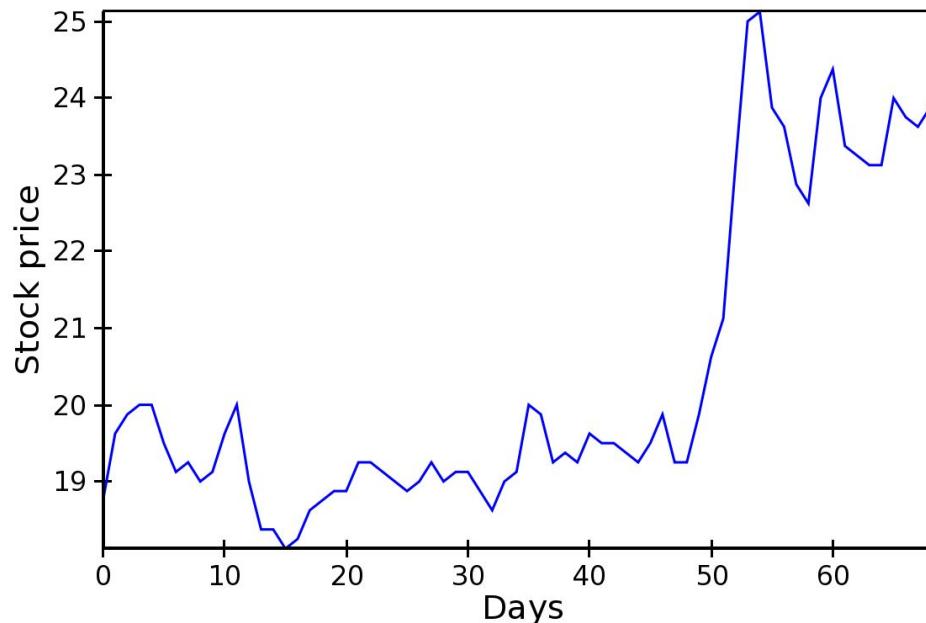
# Two variables: scatter plots

Scatter plots quickly expose the relationships between two variables

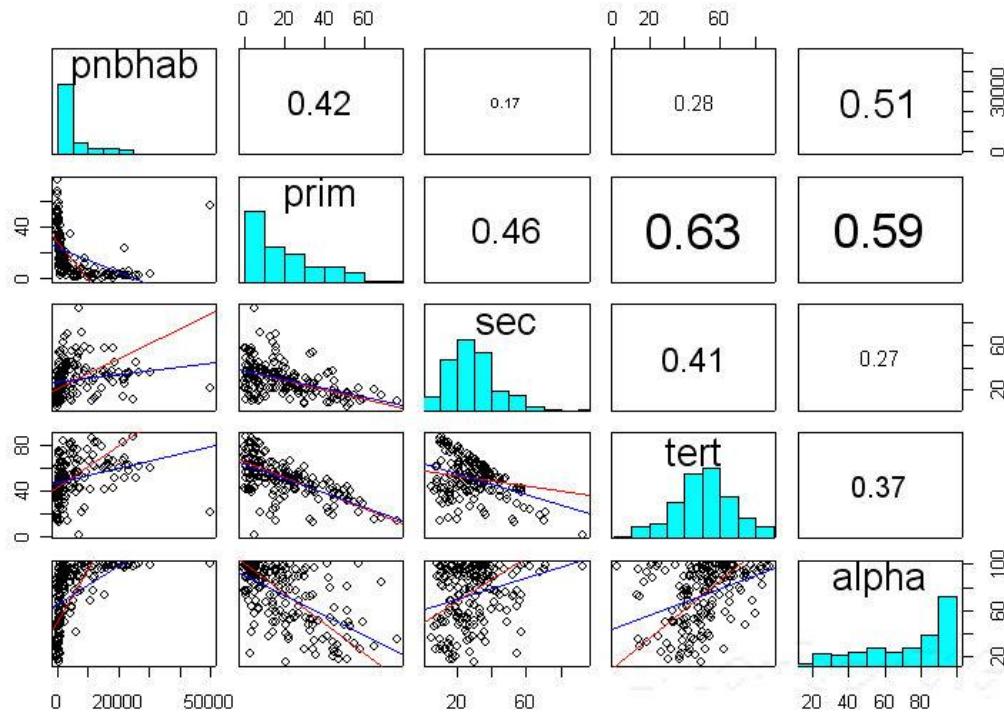


# Two variables: line plots

If relationship is functional (for instance, after binning and aggregating)



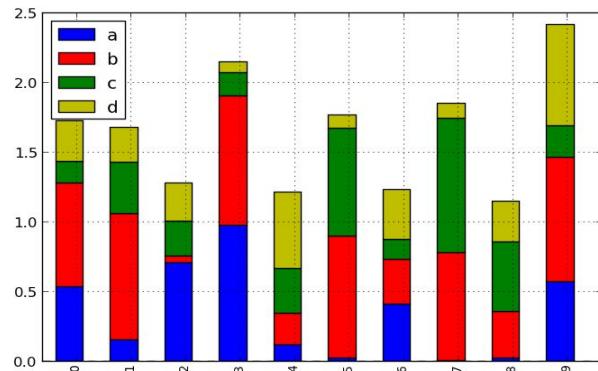
# > 2 variables: scatter plot matrix



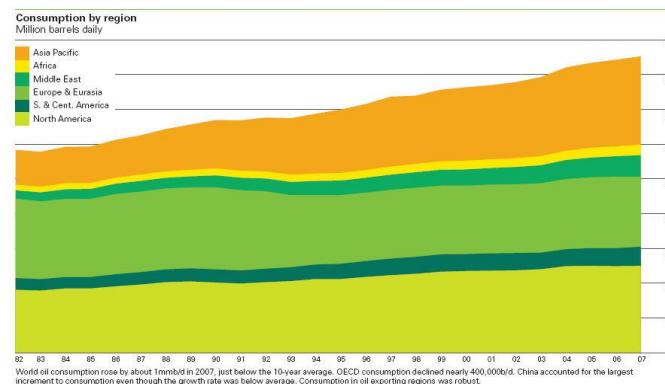
# > 2 variables: stacked plots

Here: 3 variables: stack index, height, color

Stack variable and color variables categorical,  
height variable continuous:

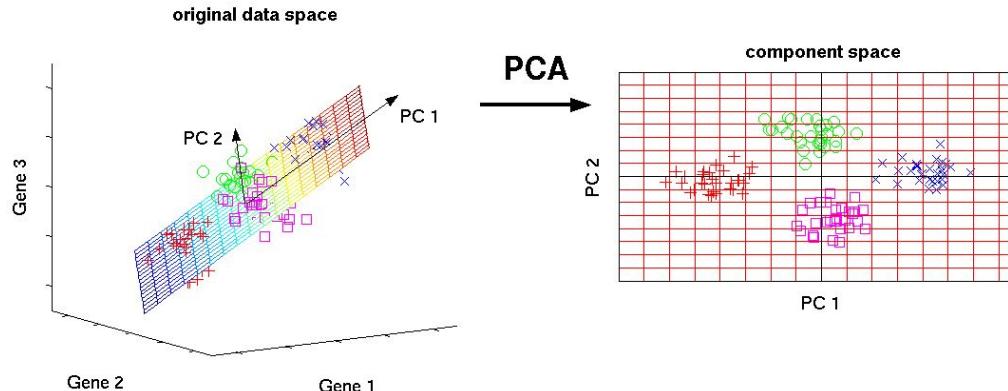


Color variable categorical,  
stack and height variables continuous:

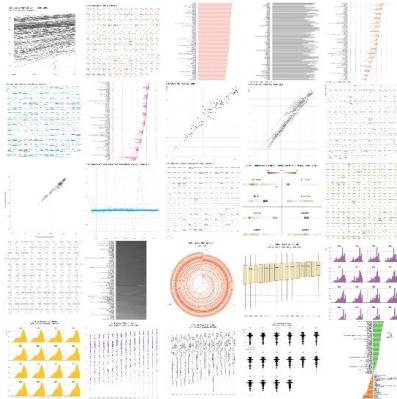


# Dimensionality reduction

- For example, **PCA**: allows visualization of high-dimensional continuous data in 2D using principal components
- The principal components are the strongest (highest variation) dimensions in the dataset, and are orthogonal



# One dataset, visualized 25 ways



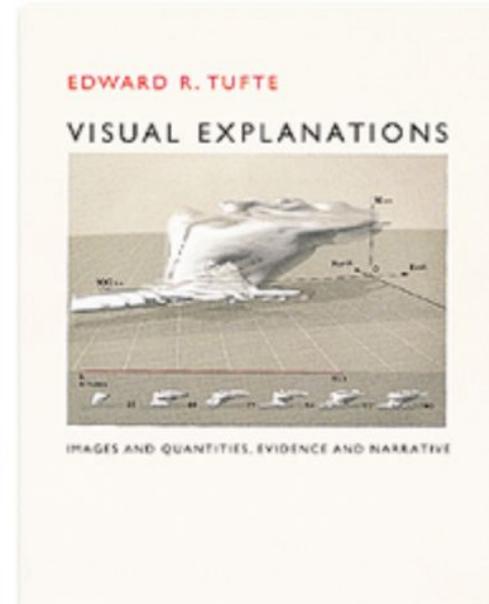
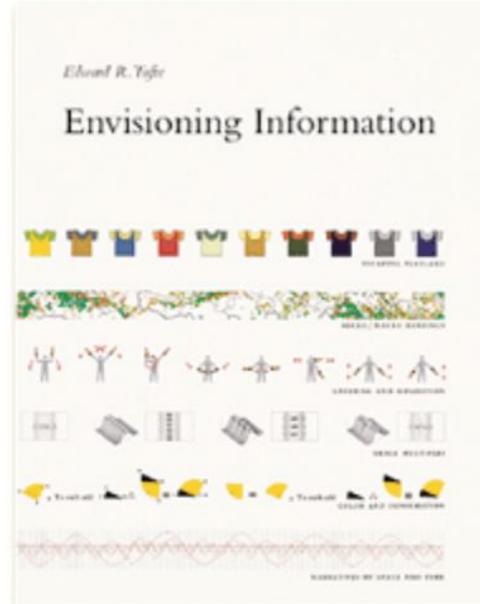
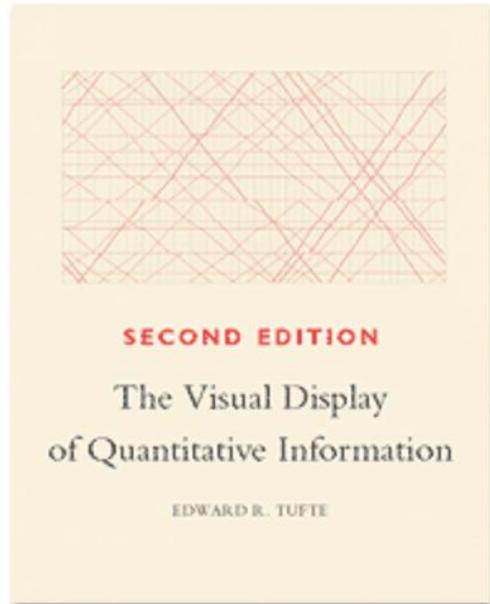
<http://flowingdata.com/2017/01/24/one-dataset-visualized-25-ways>

“You must help the data focus and get to the point. Otherwise, it just ends up rambling about what it had for breakfast this morning and how the coffee wasn’t hot enough.”

# Part 2

# Principles and best practices

# Instructive coffee table books by Edward Tufte



[\[demo\]](#)

[\[another great coffee table book\]](#)

# Perception of magnitudes

(128, 128, 128)



(144, 144, 144)



Which is brighter?

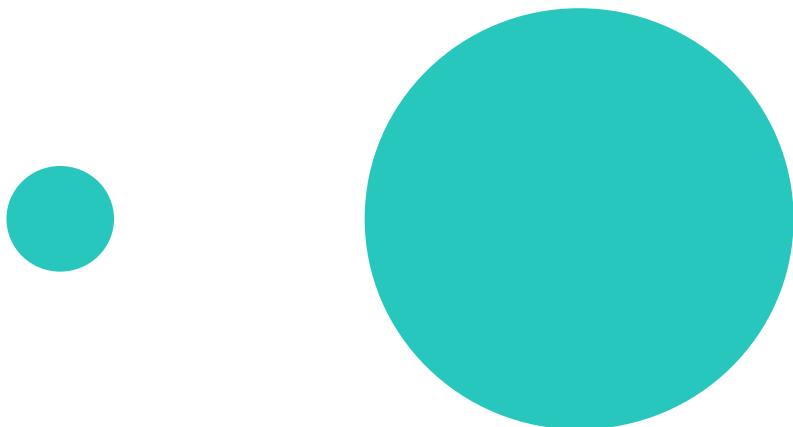
# Just noticeable difference (JND)

- Weber's law:

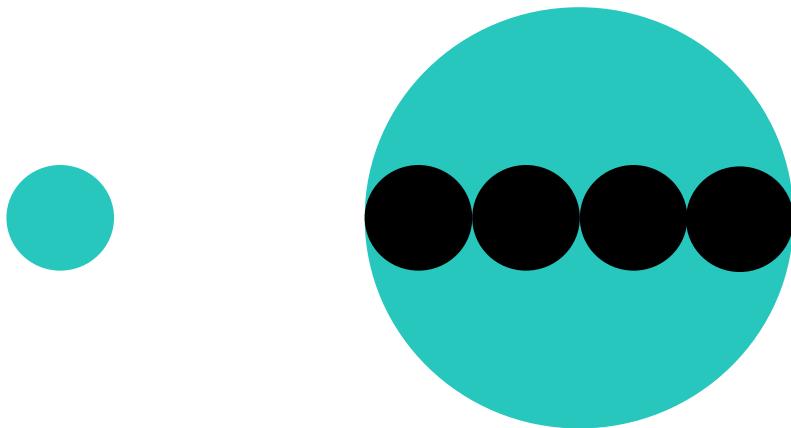
$$\frac{\Delta I}{I} = k,$$

- $I$ : intensity;  $\Delta I$ : increase from  $I$  to notice a difference;  $k$ : constant
- Required increase  $\Delta I$  depends on original intensity  $I$
- Most continuous variations in stimuli are perceived in discrete (multiplicative) steps





Compare area of circles



Compare area of circles

# Perception of magnitudes

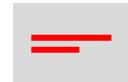
Most accurate



Least accurate



Position



Length



Slope



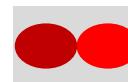
Angle



Area



Volume

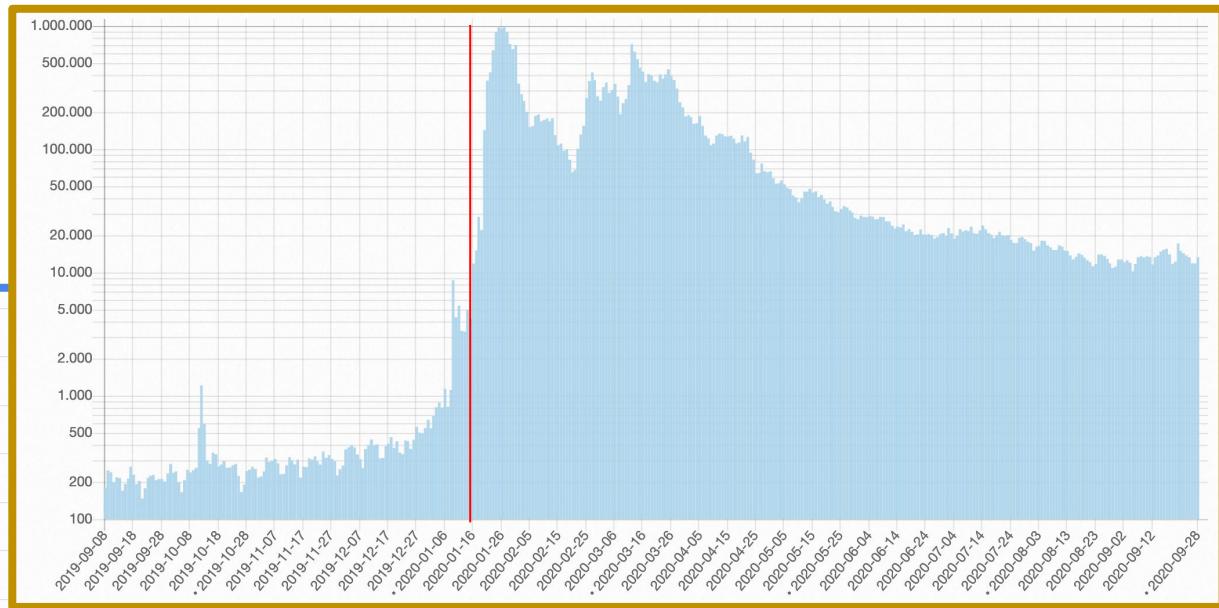
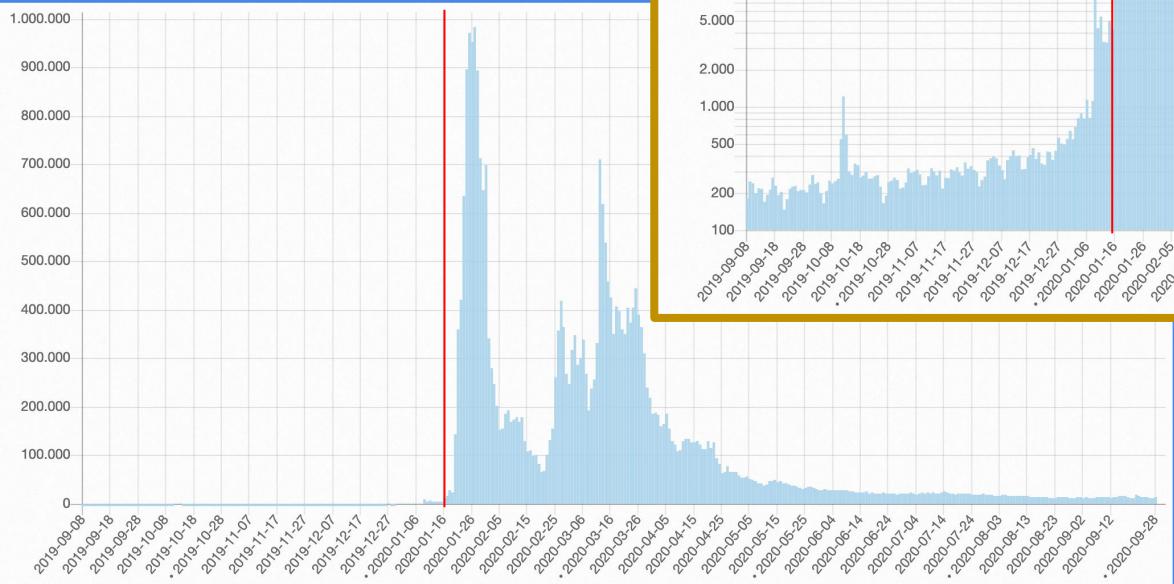


Color hue-saturation-density

Cleveland & McGill (1984)  
*Graphical Perception:  
Theory, Experimentation,  
and Application to the  
Development of Graphical  
Methods*

# Choose your axes wisely!

Time series of pageviews  
of Wikipedia article about  
“Coronavirus”  
(linear y-axis)



(logarithmic y-axis)

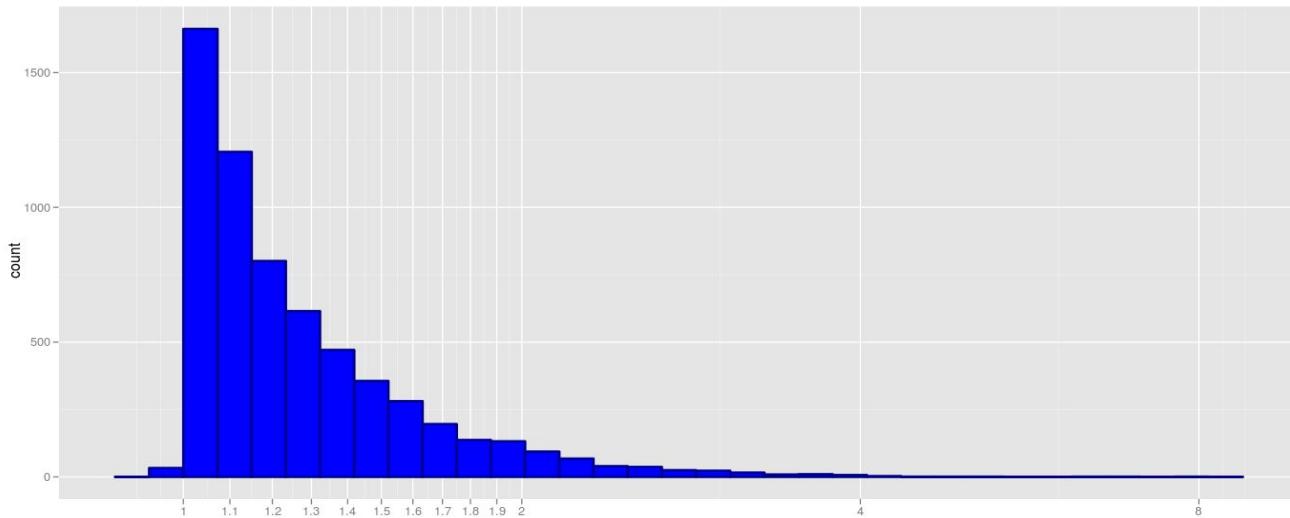
ROBERT MAYER  
THE DREAMS OF  
ADA



A TRUE STORY  
OF MURDER,  
OBSESSION,  
AND A  
SMALL TOWN

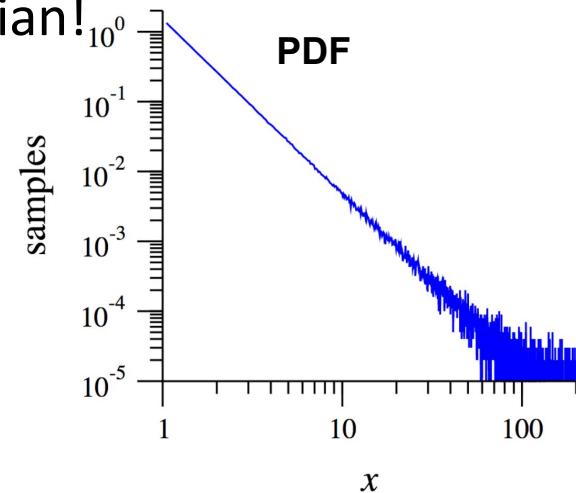
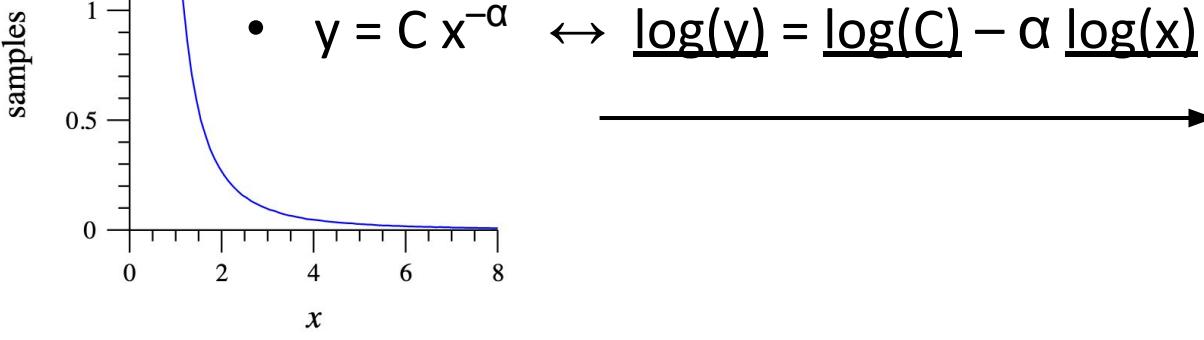


# Choose your axes wisely: Visualizing heavy-tailed distributions



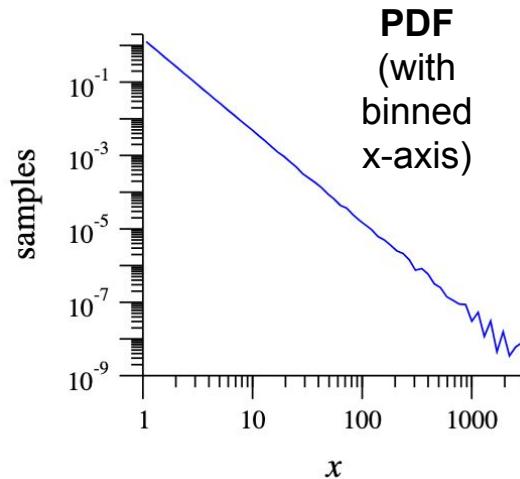
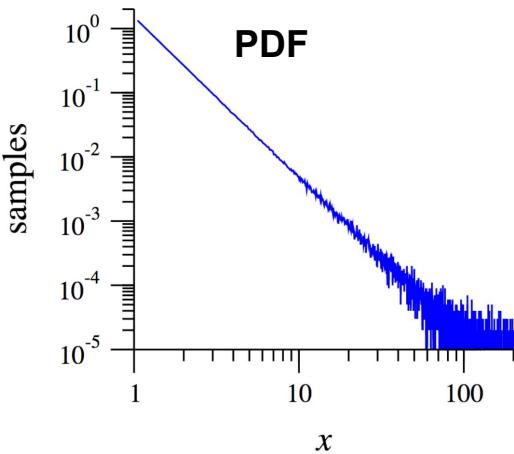
# Heavy-tailed data: power laws

- $p(x) = Cx^{-\alpha}$ ,
  - Very large values are rare, “but not very rare”
  - Body size vs. city size
  - Many natural phenomena are power laws (e.g., # of friends)
  - For dealing with them, need to know some tricks
    - E.g., for small  $\alpha$ , mean & var =  $\infty \rightarrow$  use median!
    - E.g., straight line on log-log axes:
      - $y = C x^{-\alpha} \leftrightarrow \log(y) = \log(C) - \alpha \log(x)$



# Heavy-tailed data: power laws

- Complementary cumulative distribution function (CCDF):  
 $P(x) := \Pr\{X \geq x\}$



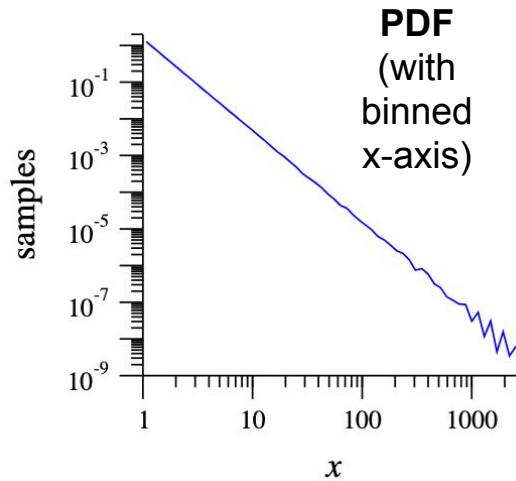
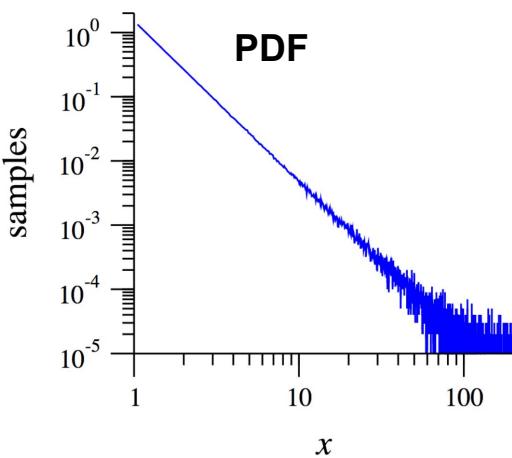
## POLLING TIME

- “What shape does the CCDF of a power law have when plotted on log-log axes?”
- Scan QR code or go to <https://web.speakup.info/room/join/66626>

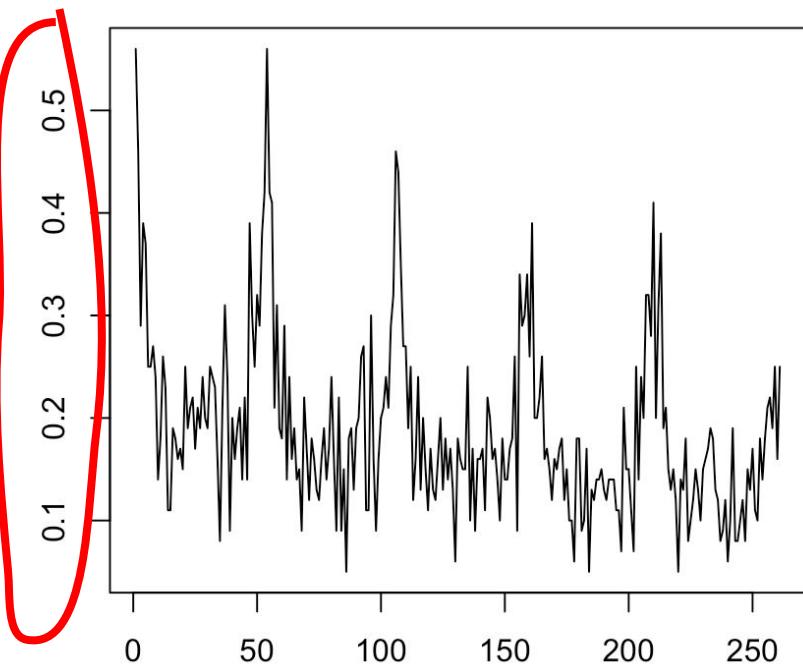
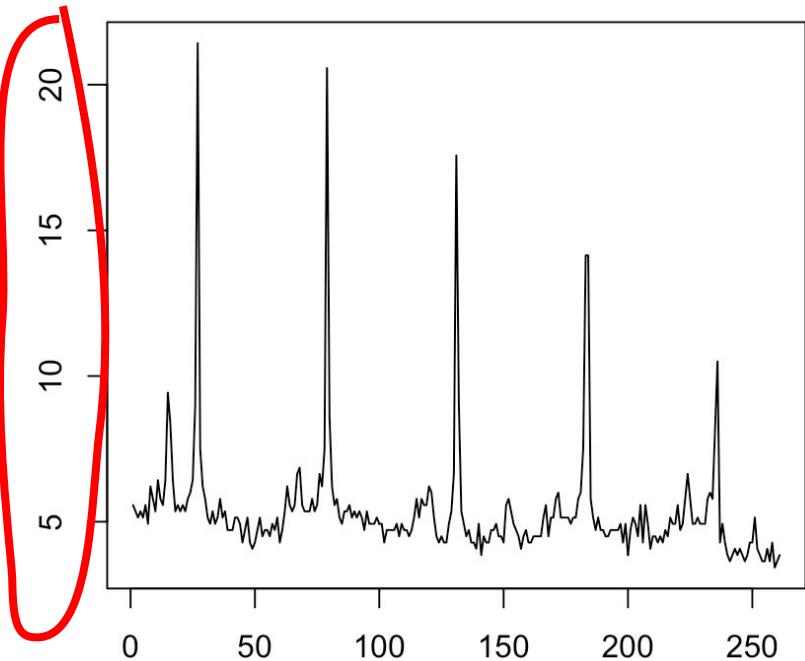


# Heavy-tailed data: power laws

- Complementary cumulative distribution function (CCDF):  
 $P(x) := \Pr\{X \geq x\}$
- CCDF of power law is also a power law (with exponent  $\alpha - 1$ )  
$$P(x) = C \int_x^{\infty} x'^{-\alpha} dx' = \frac{C}{\alpha - 1} x^{-(\alpha - 1)}.$$
- CCDF plot is monotonically decreasing

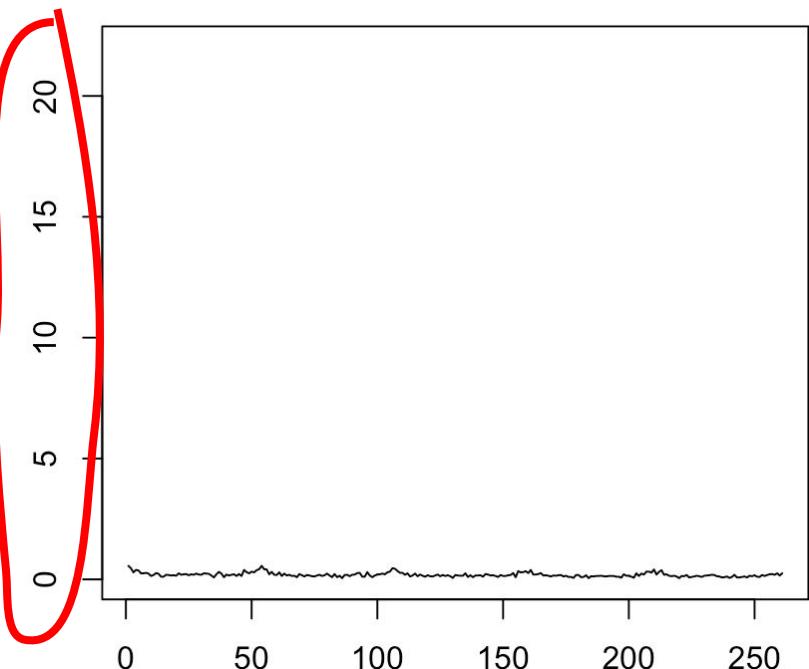
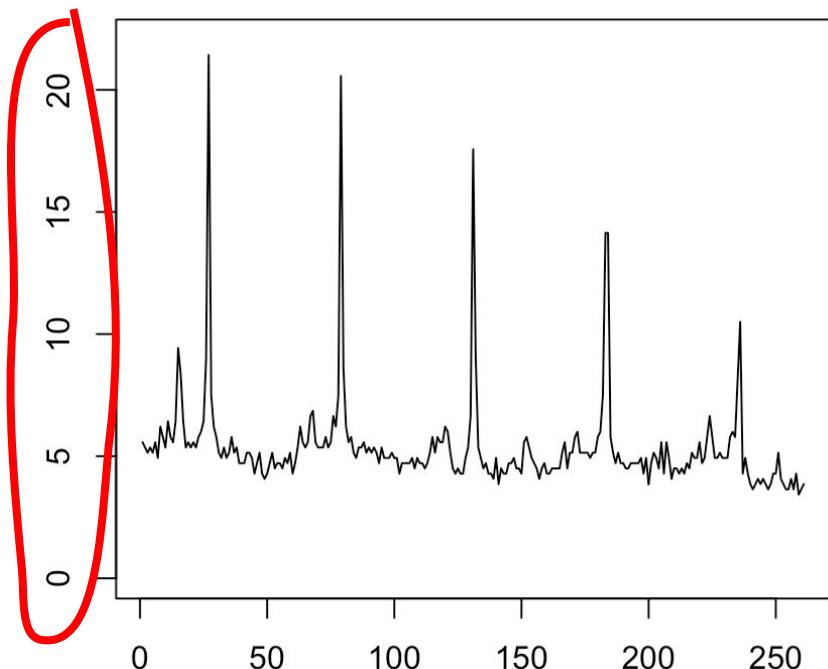


**Answer fast:** which time series has a higher mean value?

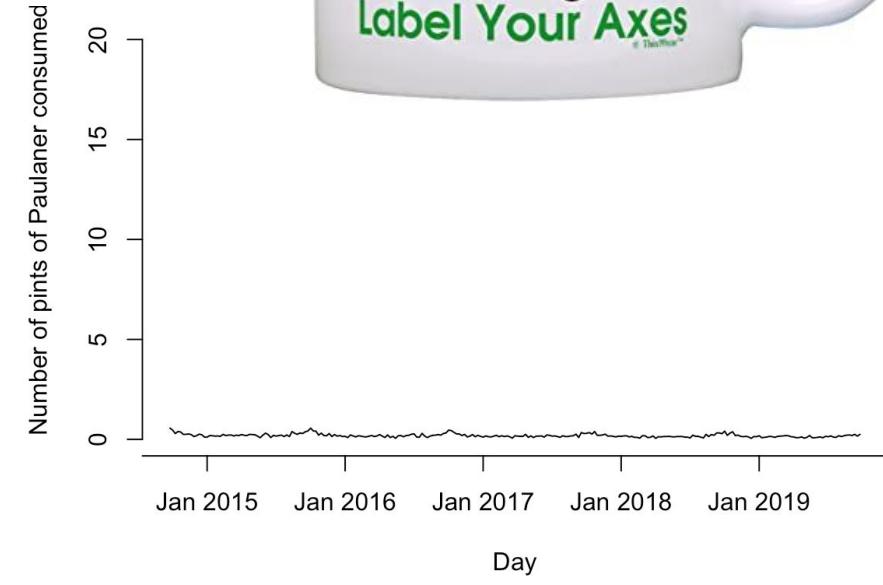
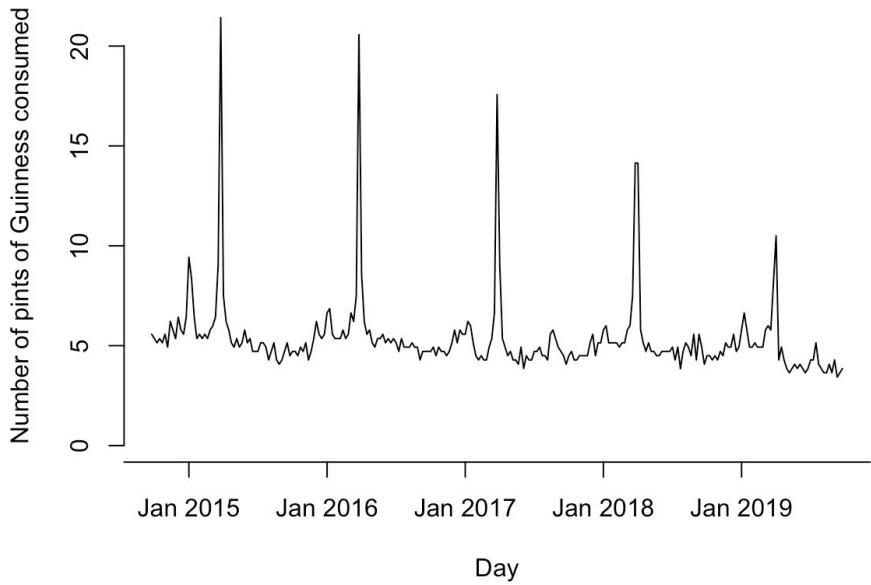


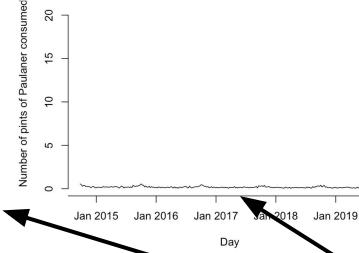
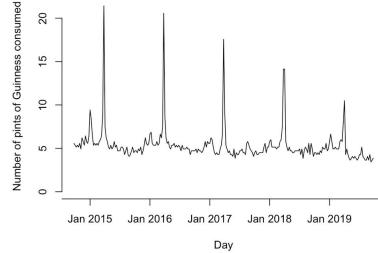
# Use consistent axes!

**Answer fast:** which time series has a higher mean value?



# Label your axes!

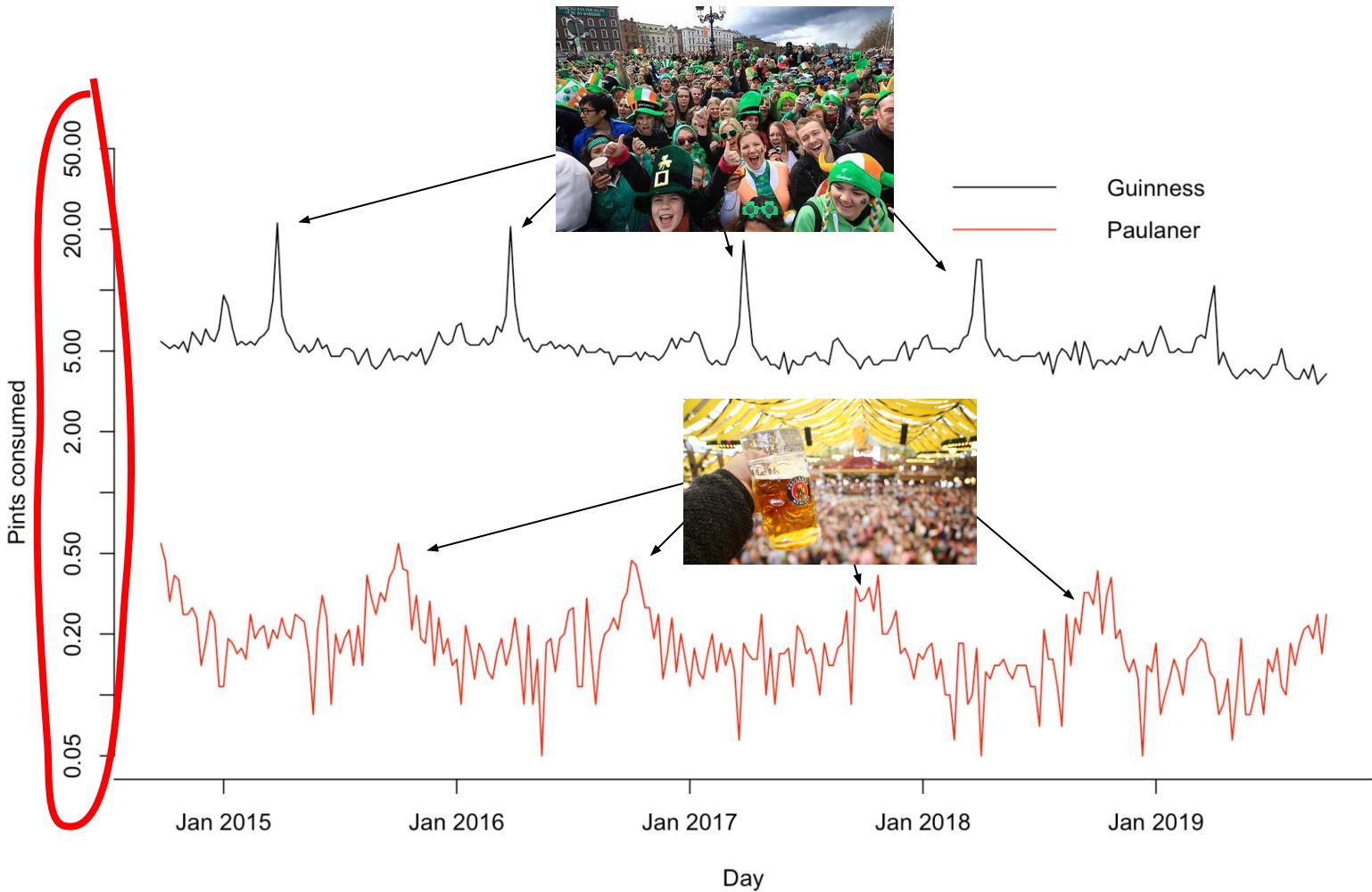




# THINK FOR A MINUTE:

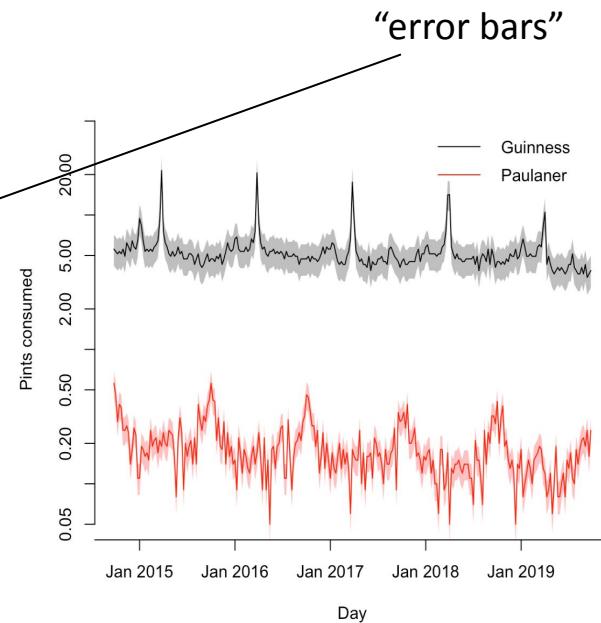
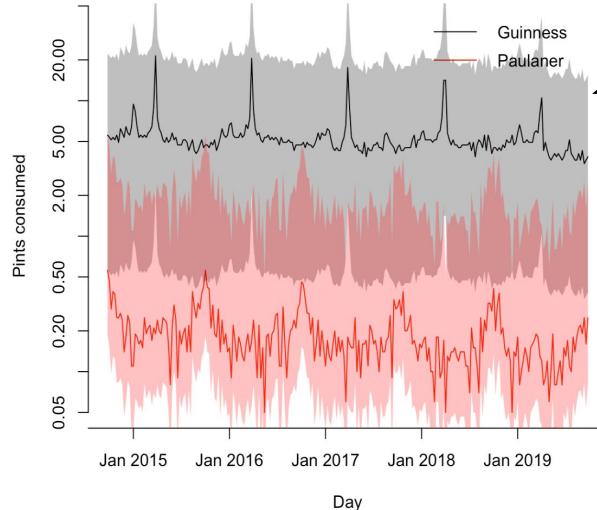
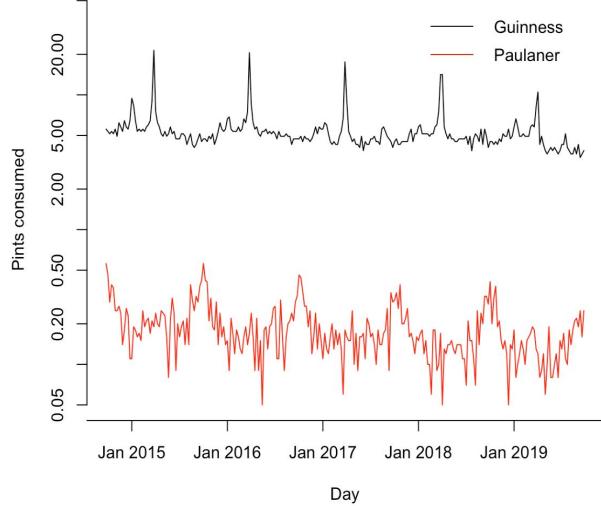
**How could we show details of both time series without using different y-axes?**

(Feel free to discuss with your neighbor.)

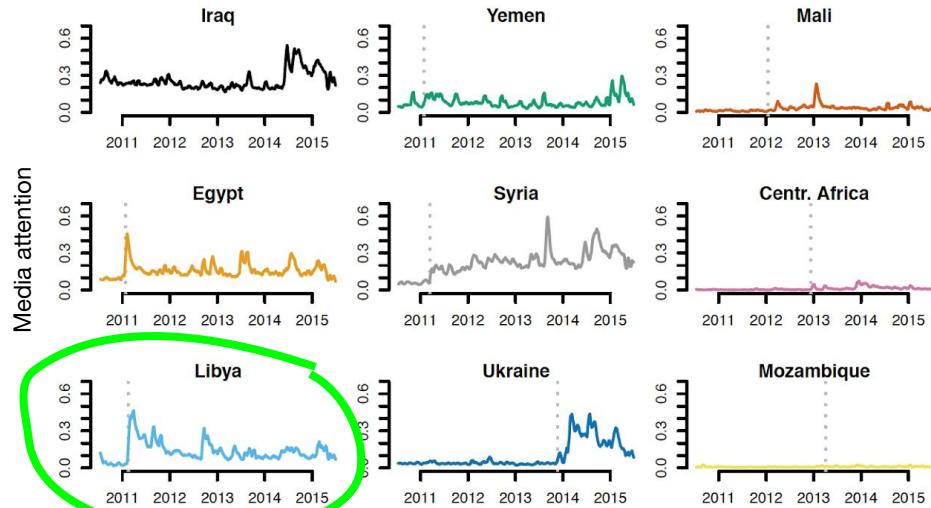


# Show data uncertainty!

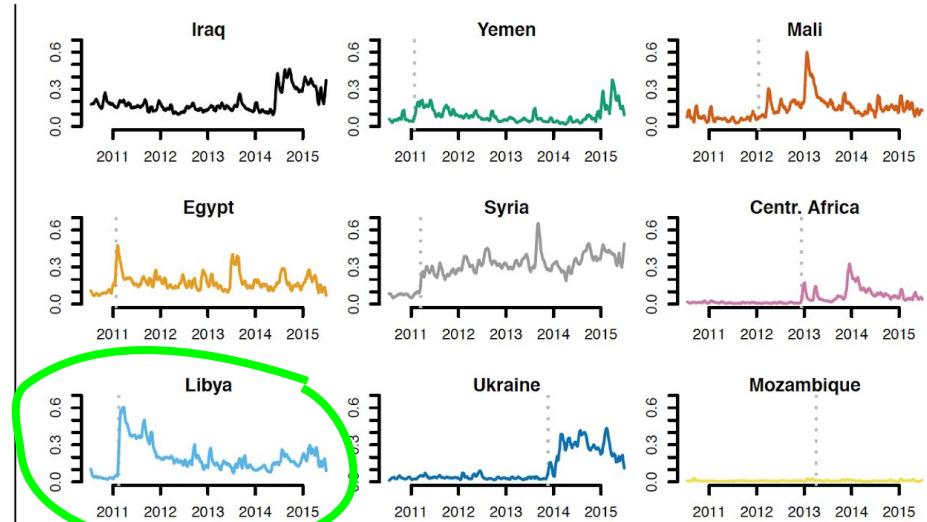
Which beer is more popular, **Guinness** or **Paulaner**?



# Consider using small multiples!



(a) English



(b) French

Use colors consistently!

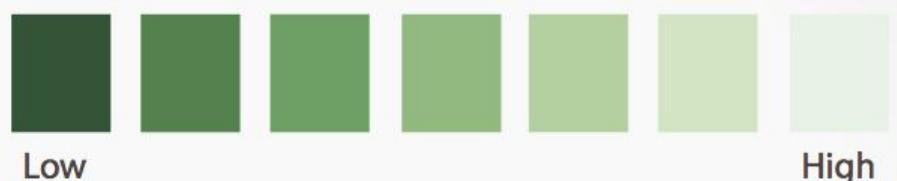
[link]

# Use colors wisely!

Choose colors based on the information you want to convey

## Sequential

Colors can be ordered from low to high



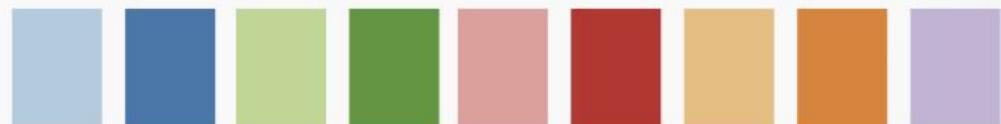
## Diverging

Two sequential schemes extended out from a critical midpoint value



## Categorical

Lots of contrast between each adjacent color



Number of data classes: 3

[how to use](#) | [updates](#) | [downloads](#) | [credits](#)

Nature of your data:

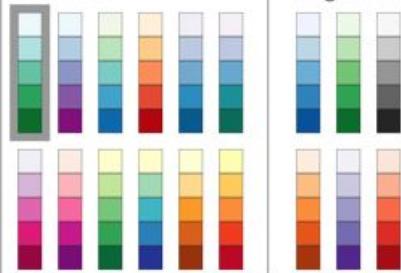
sequential  diverging  qualitative

# COLORBREWER 2.0

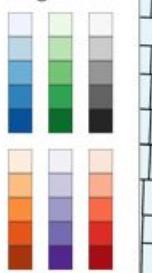
color advice for cartography

Pick a color scheme:

Multi-hue:



Single hue:



Only show:

- colorblind safe
- print friendly
- photocopy safe

Context:

- roads
- cities
- borders

Background:

- solid color
- terrain

3-class BuGn

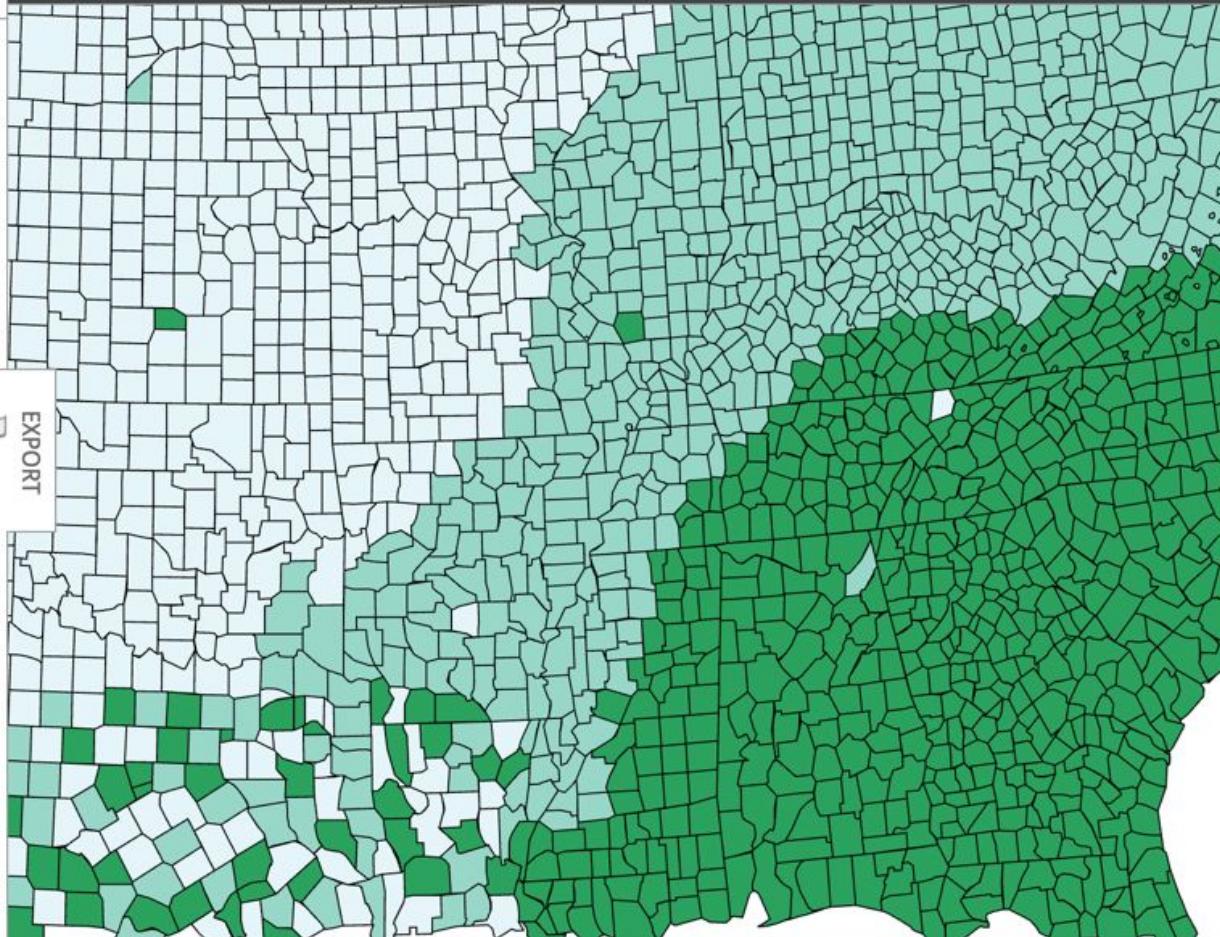
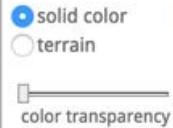


EXPORT

#e5f5f9

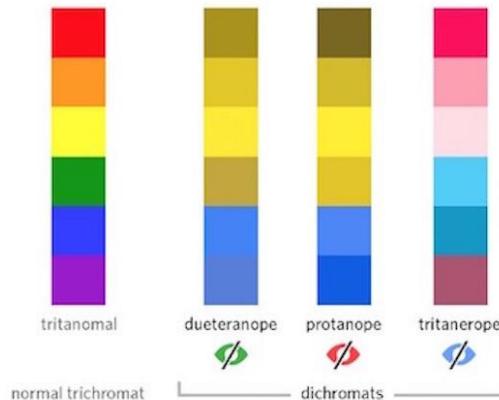
#99d8c9

#2ca25f



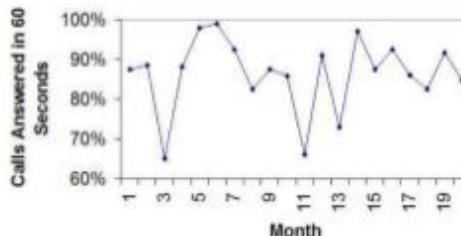
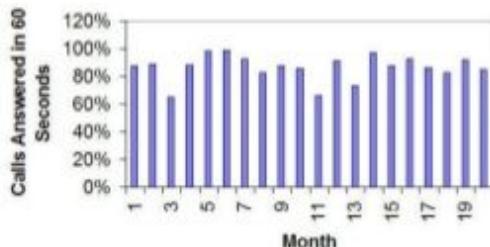
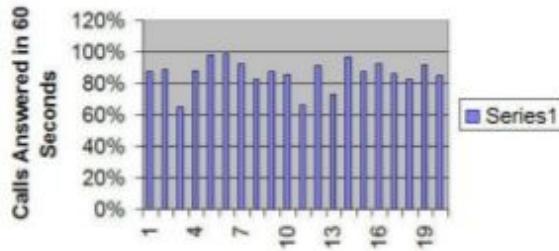
# Use colorblind-safe palettes!

- Remember: 10% of males have some form of colorblindness



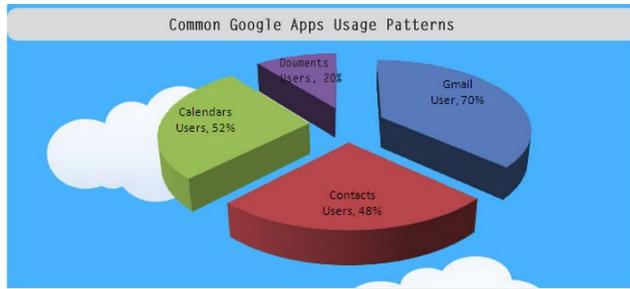
| Original | Simulation     |        |        | Hue  | for Photoshop, Illustrator, Freehand, etc. |               | for Word, Power Point, Canvas, etc. |  |
|----------|----------------|--------|--------|------|--|---------------|-------------------------------------|--|
|          | Protan         | Deutan | Tritan |      | C,M,Y,K (%)                                | R,G,B (0-255) | R,G,B (%)                           |  |
| 1        | Black          | Black  | Black  | -°   | (0,0,0,100)                                | (0,0,0)       | (0,0,0)                             |  |
| 2        | Orange         | Orange | Pink   | 41°  | (0,50,100,0)                               | (230,159,0)   | (90,60,0)                           |  |
| 3        | Sky Blue       | Blue   | Cyan   | 202° | (80,0,0,0)                                 | (86,180,233)  | (35,70,90)                          |  |
| 4        | bluish Green   | Brown  | Teal   | 164° | (97,0,75,0)                                | (0,158,115)   | (0,60,50)                           |  |
| 5        | Yellow         | Yellow | Pink   | 56°  | (10,5,90,0)                                | (240,228,66)  | (95,90,25)                          |  |
| 6        | Blue           | Blue   | Cyan   | 202° | (100,50,0,0)                               | (0,114,178)   | (0,45,70)                           |  |
| 7        | Vermilion      | Brown  | Pink   | 27°  | (0,80,100,0)                               | (213,94,0)    | (80,40,0)                           |  |
| 8        | reddish Purple | Blue   | Pink   | 326° | (10,70,0,0)                                | (204,121,167) | (80,60,70)                          |  |

# Use data ink wisely! Avoid chart junk!

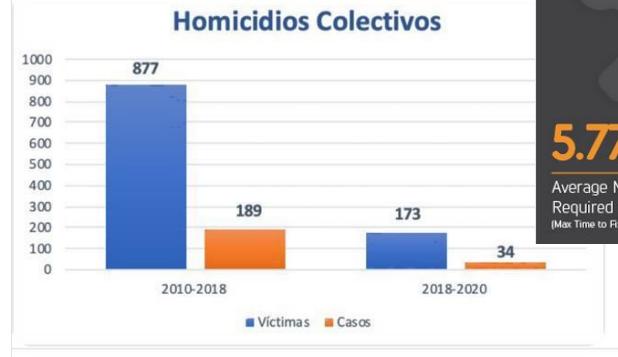


Graphical excellence gives  
the viewer the greatest  
number of ideas in the  
shortest time with the least  
ink in the smallest space.  
-Edward Tufte

# Toilet exercise: Which principles and best practices do these graphics violate?



90% of US Households Consume Peanut Butter

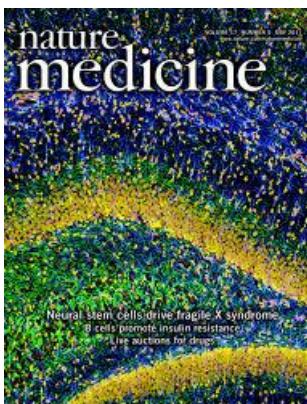
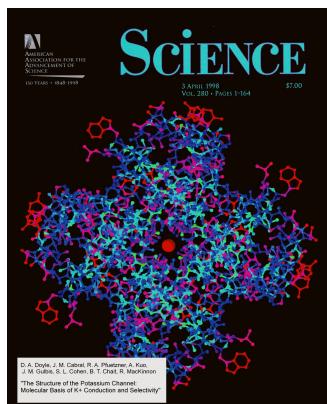
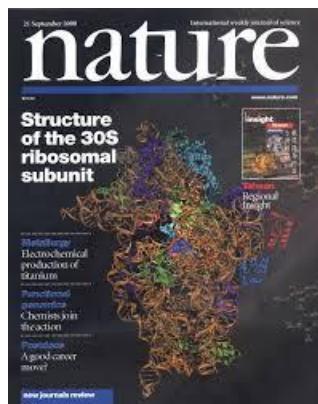
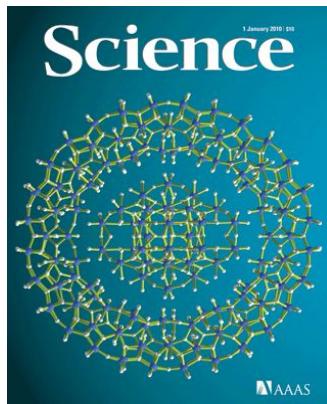
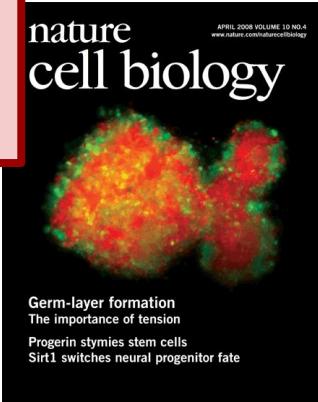


Courtesy of [viz.wtf](http://viz.wtf)

# Part 3

## A (small) selection of use cases for data visualization

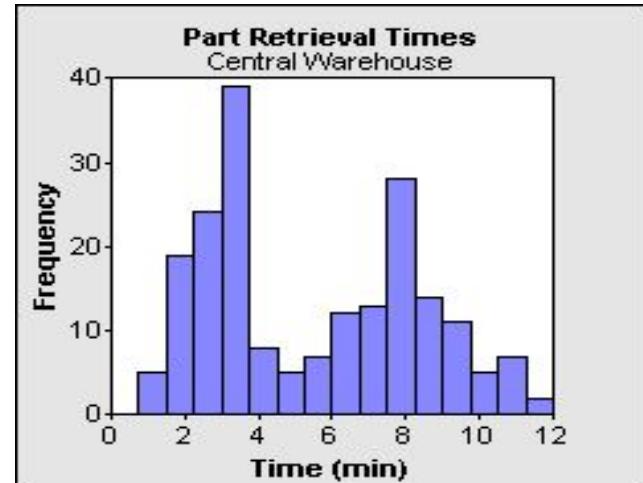
# Use case: Presenting scientific results



## Use case: Data wrangling

# Multimodal data

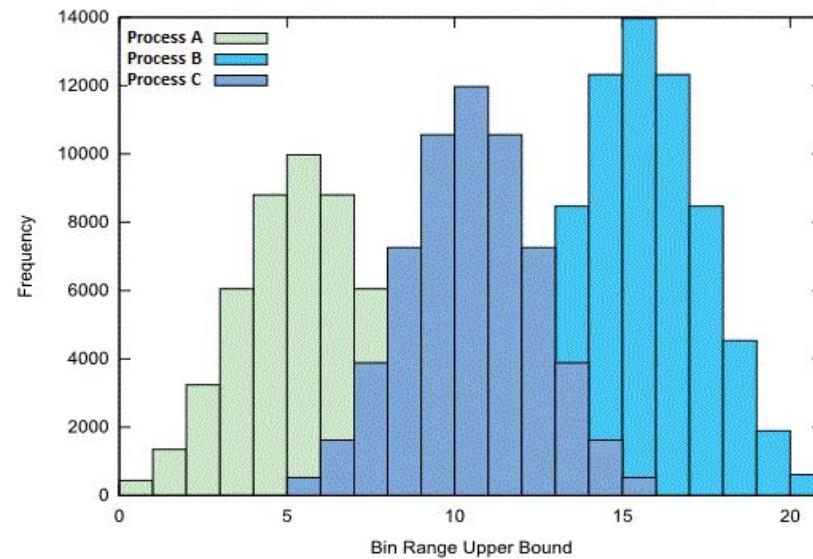
- Two or more distinct peaks in a histogram often **suggest 2 or more distinct populations** of samples.
- But don't guess! Explore further by using, e.g., color and a histogram of multiple populations (p.t.o.).



## Use case: Data wrangling

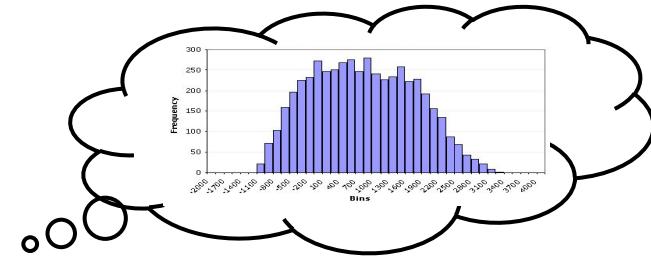
# Multimodal data

Explore further by using, e.g., color and a histogram of multiple populations

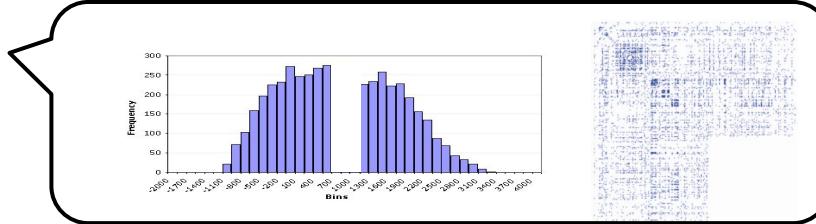


## Use case: Data wrangling

# Weird data



- Maintain a **theory of what the data should look like**.
- Some data is **very hard to explain**.
- Never just blink it away!
- First, assume a bug. Try to fix it.
- If not a bug: you might have made an interesting discovery!
- Some of science's most important findings were made by not ignoring weird data, but dwelling on it!



[[link](#)]

## Use case: Journalism

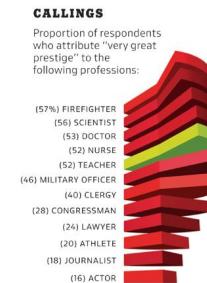
NY Times interactive visualizations (recession/recovery 2014)

<http://www.nytimes.com/interactive/2014/06/05/upshot/how-the-recession-reshaped-the-economy-in-255-charts.html>

And 2014 “the year in interactive storytelling”

[http://www.nytimes.com/interactive/2014/12/29/us/year-in-interactive-storytelling.html?\\_r=0](http://www.nytimes.com/interactive/2014/12/29/us/year-in-interactive-storytelling.html?_r=0)

NY Times graphics are a great source of  
best practices in viz (except for when they’re not...)



## Use case: Educating the public

### Hans Rosling:

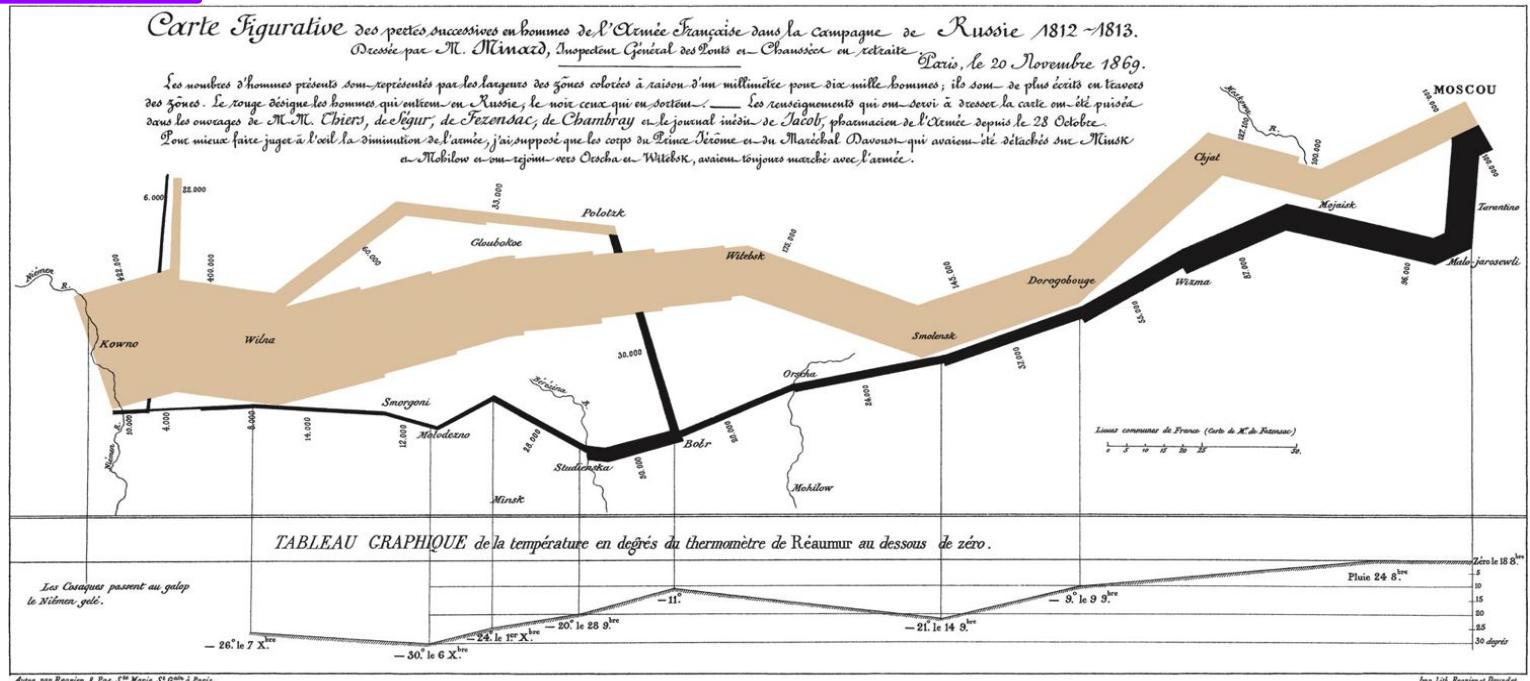
# 200 countries, 200 years, 4 minutes

<https://www.youtube.com/watch?v=jbkSRLYSojo>



# Use case: Give new perspectives

# Charles Joseph Minard 1869 Napoleon's march



According to Tufte: "It may well be the best statistical graphic ever drawn."  
 5 variables: army size, location, dates, direction, temperature during retreat

# Tools

(remaining slides for your personal perusal)

# Interactive toolkits: D3

Without doubt, the most widely used interactive visualization framework is **D3**.

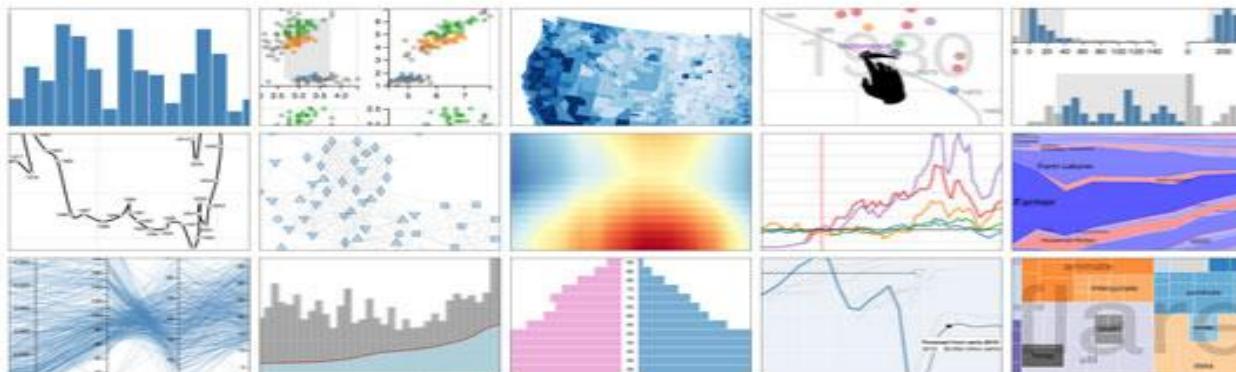
Note from the authors: *D3 is intentionally a low-level system.*  
*During the early design of D3, we even referred to it as a "visualization kernel" rather than a "toolkit" or "framework"*

# Interactive toolkits: Vega

Vega is a “visualization grammar” developed on top of D3.js

It specifies graphics in JSON format.

vega

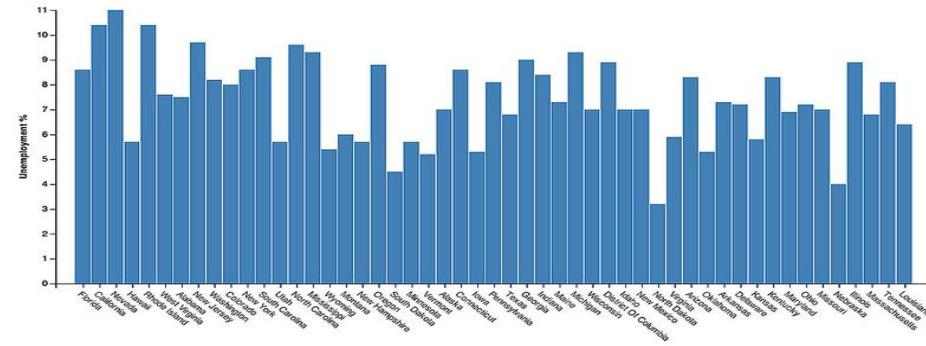
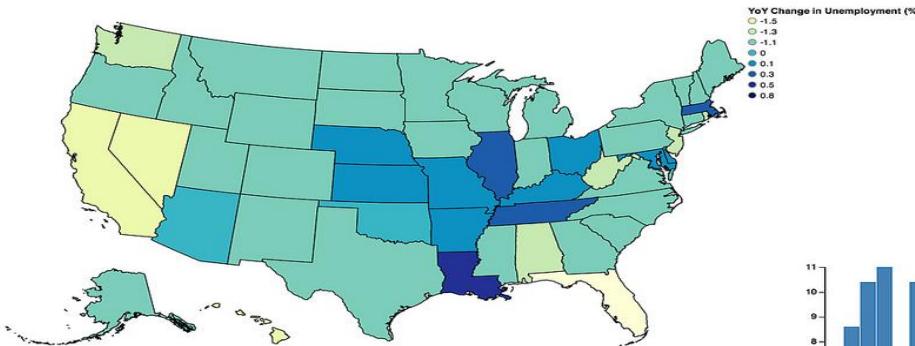


Vega is a *visualization grammar*, a declarative format for creating, saving, and sharing interactive visualization designs.

# Interactive toolkits: Vincent

Vincent is a Python-to-Vega translator.

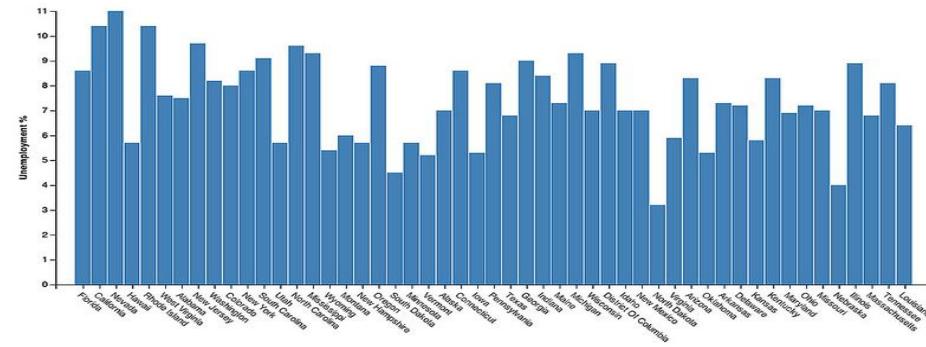
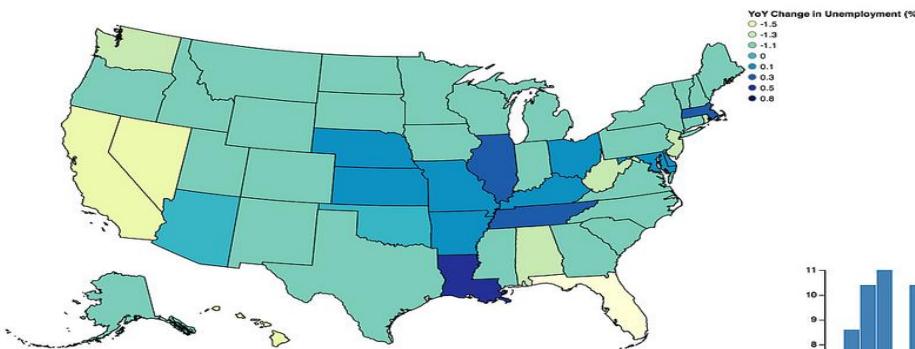
Trivia question: why is it called Vincent? Hint: Vincent+Vega= ?



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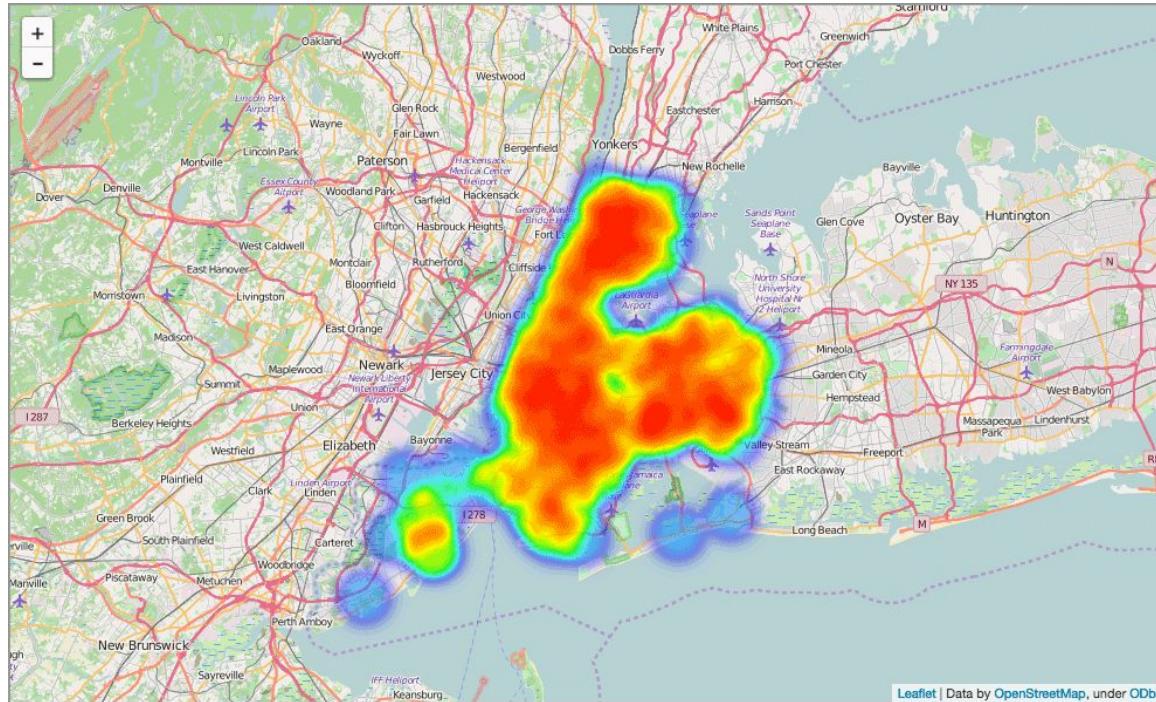
# Bokeh: another interactive viz library

Bokeh is an independent Viz library focused more heavily on big data visualization. Has both Python and Scala bindings.



# Visualizing maps: Folium

More in tomorrow's lab session!



# Feedback

Give us feedback on this lecture here:

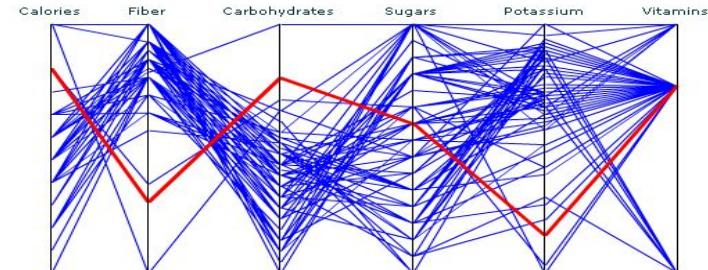
<https://go.epfl.ch/ada2022-lec3-feedback>

- What did you (not) like about this lecture?
- What was (not) well explained?
- On what would you like more (fewer) details?
- [What's your favorite color, baby?](#)
- ...

# > 2 variables: parallel-coord. plots

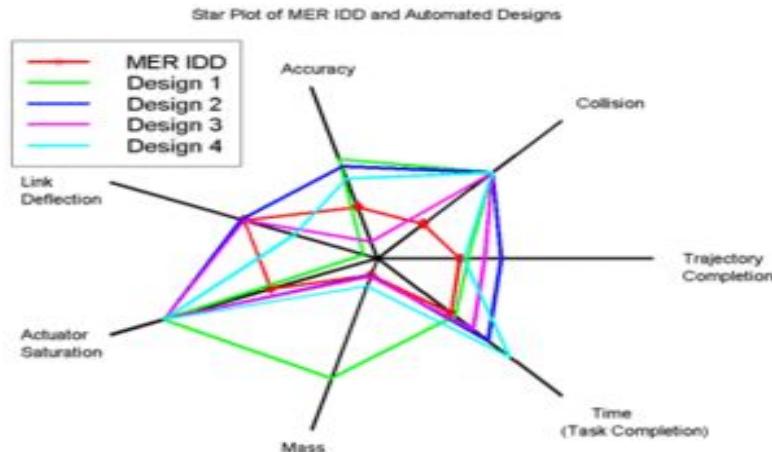
Color, x, y

Color variable is categorical, others arbitrary



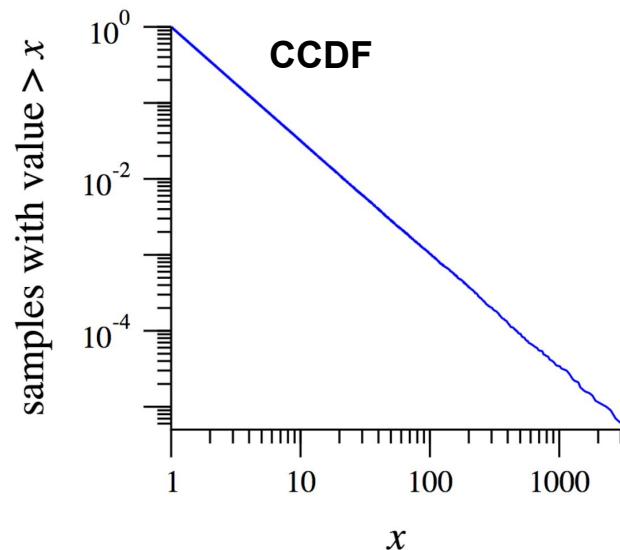
# > 2 variables: radar charts

- Similar to parallel-coord. plots
- Doesn't pretend that x axis has meaningful order
- Also good for periodic data



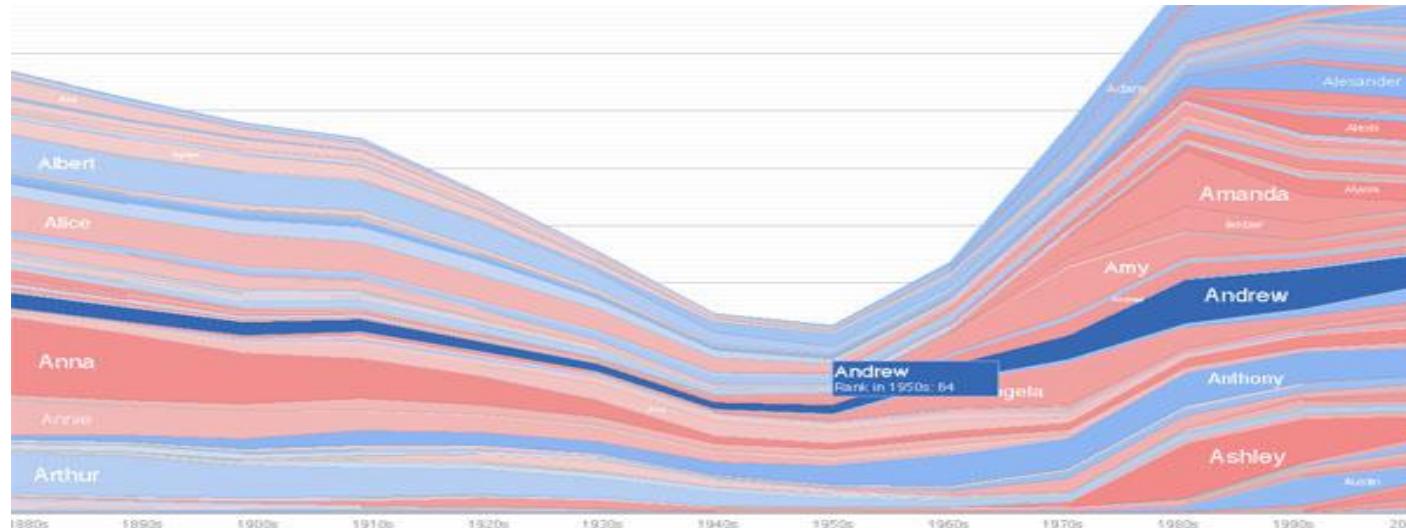
# Heavy-tailed data: power laws

- Smart trick for plotting CCDF of any distribution:
  - x-axis: data sorted in ascending order
  - y-axis:  $(n:1)/n$  (where n is number of data points)



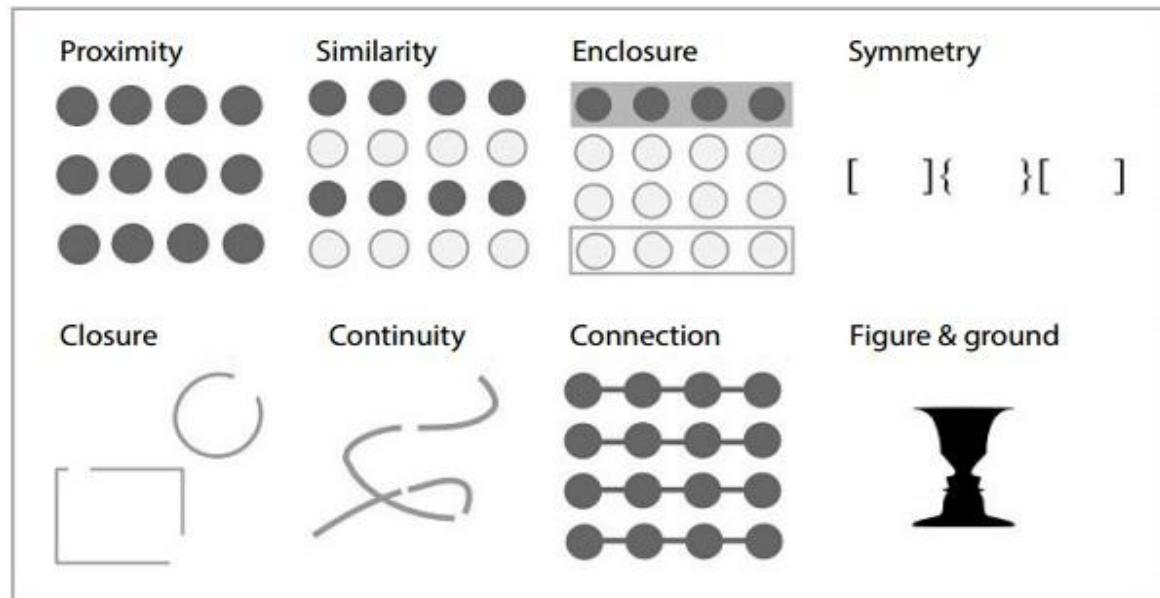
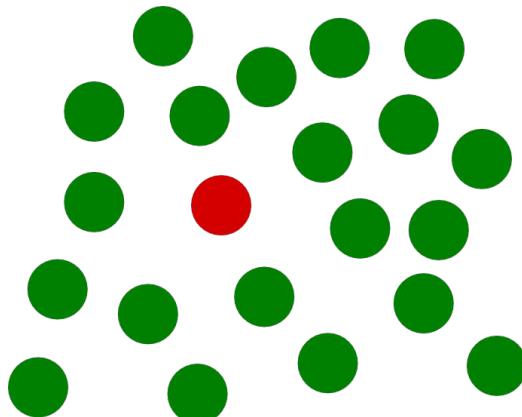
# Interactive chart design: simplifying

- With interactive charts you can keep things very simple by **hiding** and **dynamically revealing** important structure.
- On an interactive chart, you reveal the information most useful for **navigating** the chart.



# Use structure!

## Gestalt psychology principles (1912)

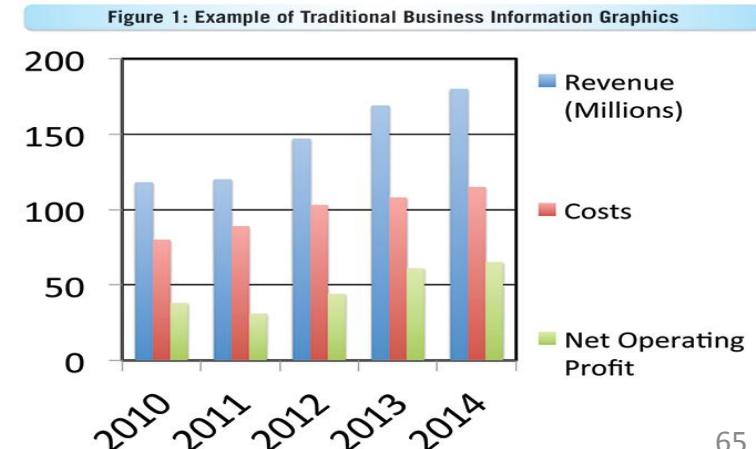


# A case for ugly visualizations

People instinctively gravitate to attractive visualizations, and they have a better chance of getting on the cover of a journal.

But does this **conflict with the goals of visualization?**

- Rapid exploration
- Focus on most important details
- Easy and fast to develop and customize



# Guide your audience!

