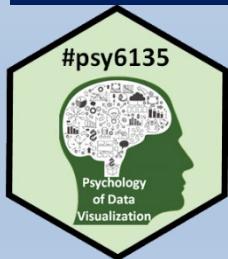


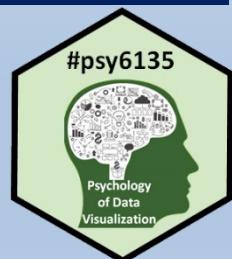
Varieties of information visualization



Michael Friendly
Psych 6135

<https://friendly.github.io/6135>

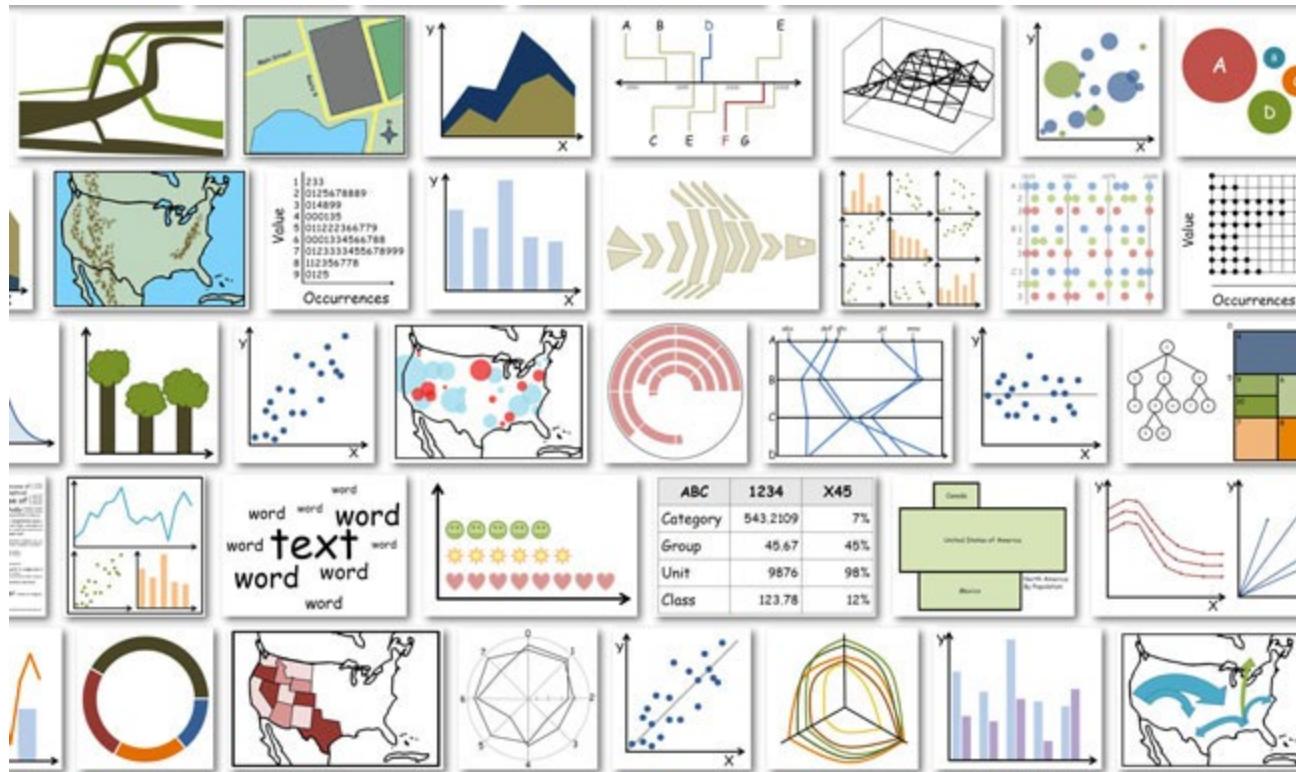
@datvisFriendly



So many types

There are so many kinds of charts, diagrams, graphs, maps

- What are their **features**?
- What **tasks** are they **good for**? – Accuracy or speed of judgment? Memorability?



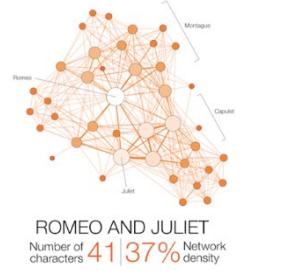
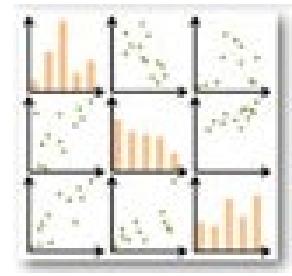
How to classify ???

For purposes of “What kind of graph should I use?” usually most useful to think:
“What do I want to show?”

Deviation	Correlation	Ranking	Distribution	Change over Time	Magnitude
Deviation Emphasise variations (+/-) from a fixed reference point. Typically the reference point is zero but it can also be a target or a long-term average. Can also be used to show movement (positive/negative/neutral).	Correlation Show the relationship between two or more variables. Be mindful that, unless you tell them otherwise, many readers will assume the relationships you show them to be causal (i.e. one causes the other).	Ranking Use where an item's position in an ordered list is more important than its absolute or relative value. Don't be afraid to highlight the points of interest.	Distribution Show values in a dataset and how often they occur. The shape (or ‘skew’) of a distribution can be a memorable way of highlighting the lack of uniformity or equality in the data.	Change over Time Give emphasis to changing trends; these can be short (inter-day) movements or extended series traversing decades or centuries. Choosing the correct time period is important to provide suitable context for the reader.	Magnitude Show size comparisons. These can be relative (just being able to see larger/larger) or absolute (need to see fine differences). Usually these show a ‘counted’ number (for example, barrels, dollars or people) rather than a calculated rate or per cent.
Example FT uses: Trade surplus/deficit, climate change	Example FT uses: Inflation & unemployment, income & life expectancy	Example FT uses: Wealth, deprivation, league tables, constituency election results	Example FT uses: Income distribution, population (geographic) distribution	Example FT uses: Share price movements, economic time series	Example FT uses: Commodity production, market capitalisation
Diverging bar  A simple standard bar chart that can handle both negative and positive magnitude values.	Scatterplot  The standard way to show the relationship between two continuous variables, each of which has its own scale.	Ordered bar  Standard bar charts display the ratio of values much more easily when sorted into order.	Histogram  The standard way to show an unimodal distribution - keep the gaps between columns small to highlight the shape of the data.	Line  The standard way to show a changing time series; if data are irregular, consider markers to represent data points.	Column  The standard way to compare the size of things. Most always start at 0 on the axis.
Diverging stacked bar  Perfect for presenting survey results which involve sentiment (e.g. disagree/neutral/agreed).	Line + Column  A good way of showing the relationship between an amount (column) and a ratio (line).	Ordered column  See above.	Boxplot  Summarises multiple distributions by showing the median (central) and range of the data.	Column  Columns work well for showing change over time - but usually best with only one series of data at a time.	Bar  See above. Good when the data are not time series and labels have long category names.
Spine chart  Splits a single value into two contrasting components (e.g. male/female).	Connected scatterplot  Usually used to show how the relationship between 2 variables has changed over time.	Ordered proportional symbol  Use when there are big variations between values and/or seeing the difference between data is not so important.	Violin plot  Similar to a box plot but more effective with complex distributions (they don't have to be associated with simple averages).	Line + column  A good way of showing the relationship over time between a component (coloured) and a rate (line).	Paired column  As per standard column but allows for multiple series to be shown. Trickier to read with more than 2 series.
Surplus/deficit filled line  The shaded area of these charts allows a balance to be shown - either against a baseline or between two series.	Bubble  Like a scatterplot, but with additional detail by sizing the circles according to a third variable.	Dot strip plot  dots placed in order on a strip are a space-efficient method of laying out data across multiple categories.	Population pyramid  A standard way for showing the age and sex breakdown of a population distribution effectively, back to back histograms.	Stack price  Usually focused on day-to-day activity. These charts show opening/bidding and high/low points of each day.	Paired bar  See above.
XY heatmap  A good way of showing the patterns between 2 categories of data, less good at showing fine differences in amounts.	Slope  Perfect for showing how ranks have changed over time or very between categories.	Dot strip plot  Good for showing individual values in a distribution, can be a problem when too many dots have the same value.	Stack chart  Good for showing changing data as long as the data can be simplified into 1 or 2 points without losing a key point of view.	Proportional stacked bar  A good way of showing the size and proportion of data at the same time - as long as the data are not too complicated.	

Topics, by graph type: Content & form

- Statistical data graphs
 - 1D: dotplot, boxplot, violin plot
 - 1.5D: time-series plot, density plot, bar chart, pie chart
 - 2D: scatterplot, ridgeline plot
 - 3D: contour plot, 3D scatterplot, surface plot
- Thematic maps
 - Choropleth map
 - Anamorphic map
 - Flow maps
- Network & tree visualization
- Animation & interactive graphics



What are dimensions

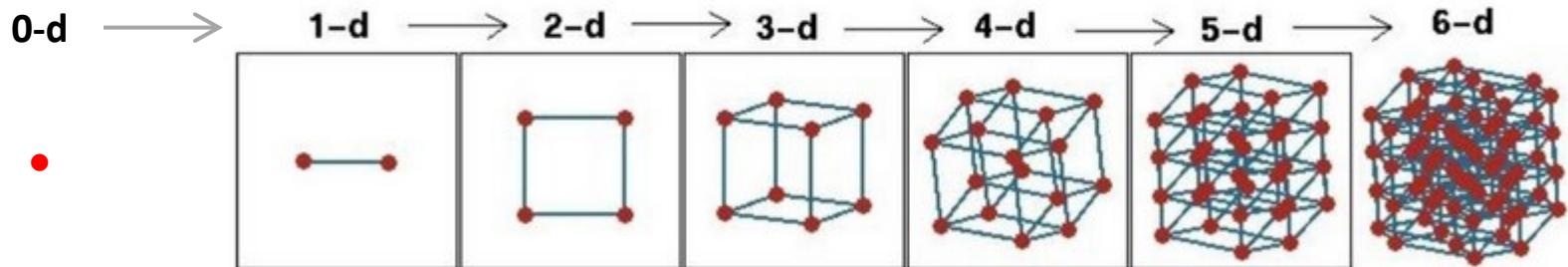


Fig credit: Di Cook [@visnutech](#)

1 D
1.5 D
2 D
3 D
 n D ?

Data graphs can be roughly ordered by the number of variables, data dimensions shown in a given graph

Data graphs

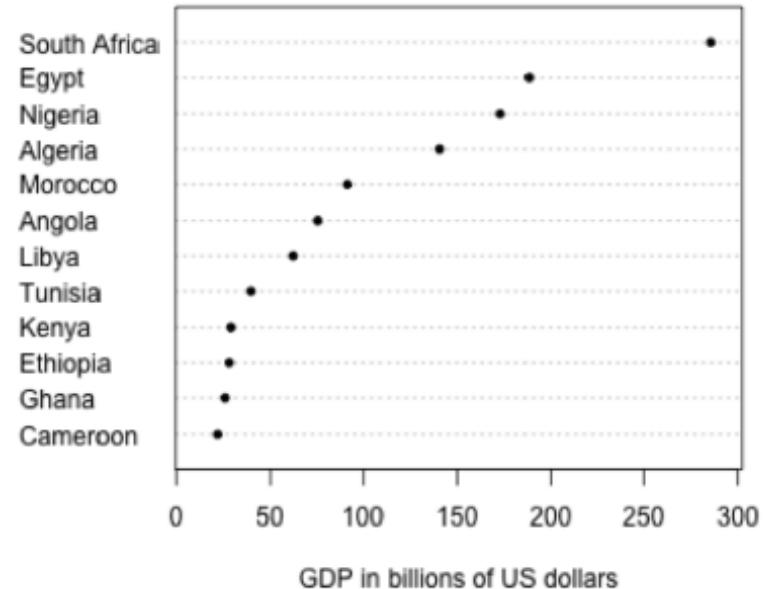
1D: Infographic vs. Data graphic

The same data can be shown in different forms, for different purposes

African Countries by GDP



African Countries by GDP



One might argue that this infographic has **greater impact** in showing the relative size of GDP

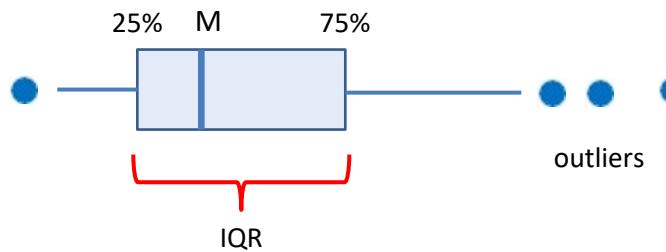
One might argue that this statistical graph **makes comparisons easier**

1.5D: Dotplots & boxplots

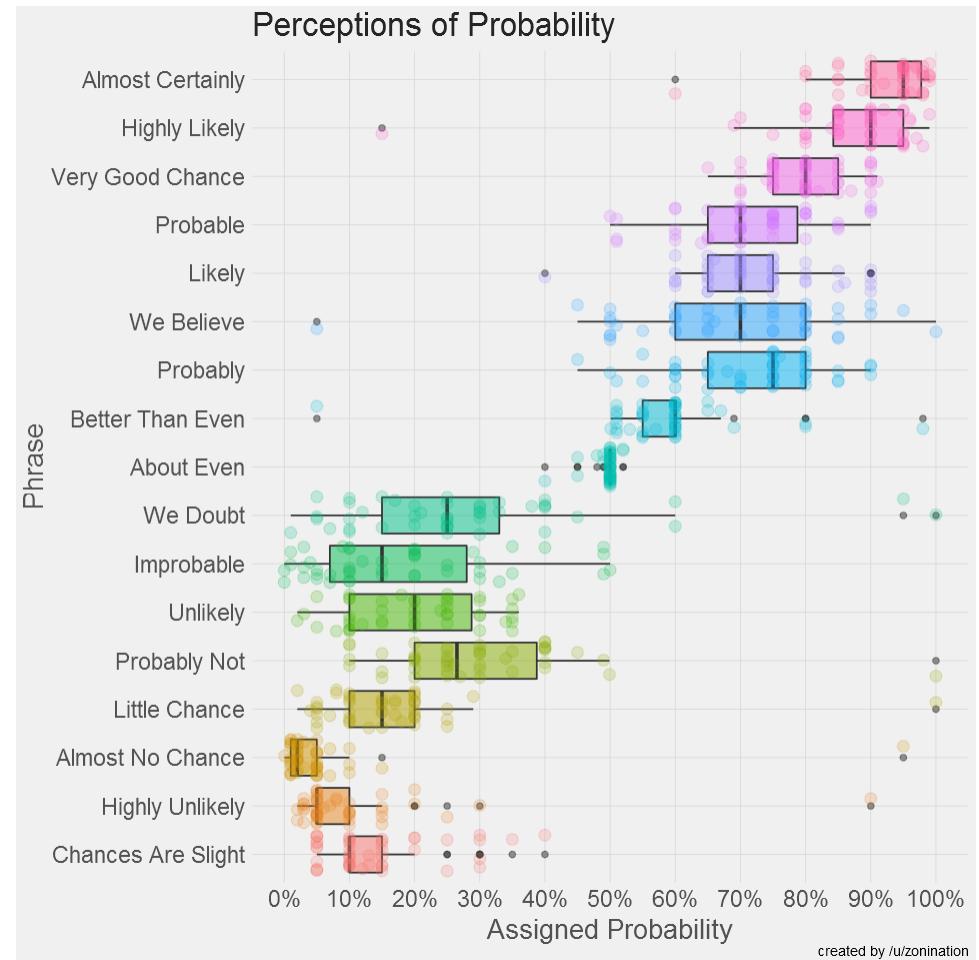
What number do you give to a probability phrase?

Boxplots summarize the important characteristics of a univariate data distribution:

- center (median)
- spread (IQR)
- shape (symmetric? skewed?)
- outliers?

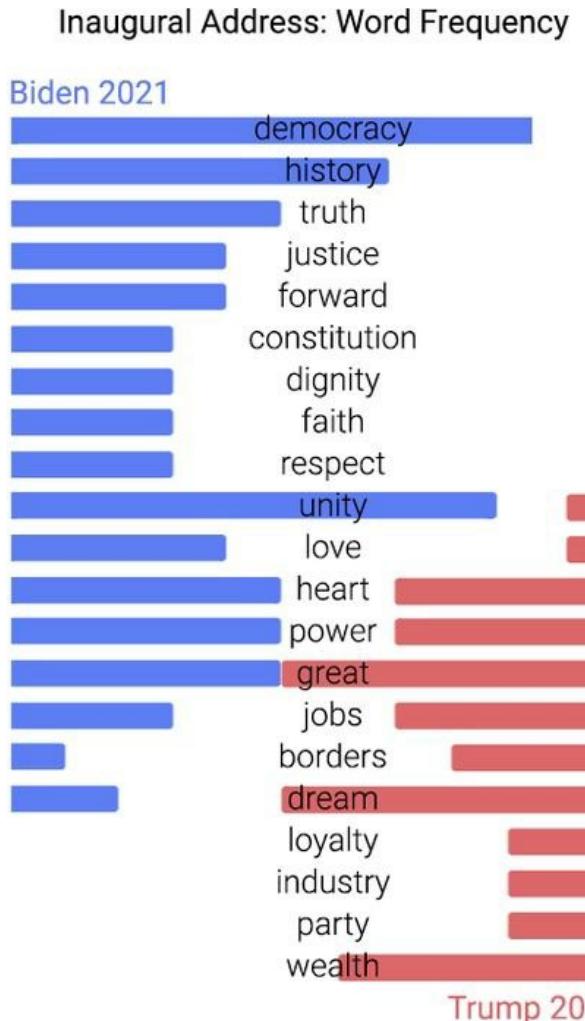


This example overlays the boxplot with a jittered dotplot, so we can also see the individual observations



This visualization made the longlist for the 2015 Kantar Information is beautiful award. Data & R code:
<https://github.com/zonation/perceptions>

1.5D: Text bar charts



- Text can be analyzed as data also, most often in frequency counts.
- This chart uses a novel design to compare the most frequent words by Biden (2021) & Trump (2017) in their inaugural addresses.
- The contrast is striking!
 - **democracy, unity** vs. **great, dream**

From:

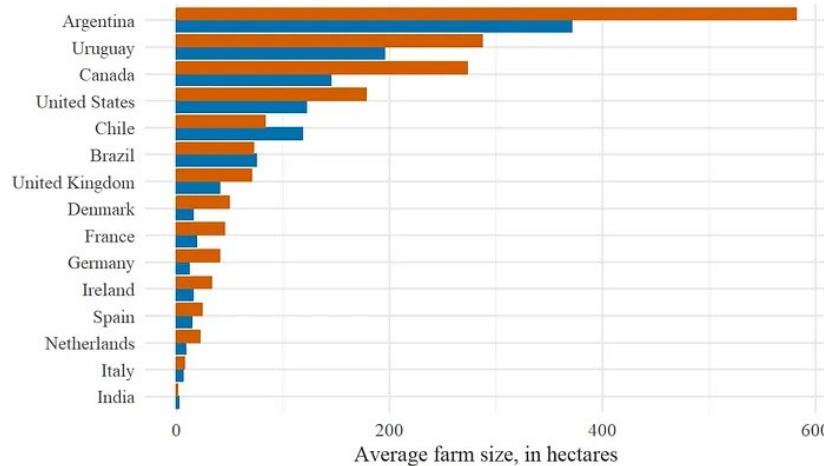
https://www.reddit.com/r/dataisbeautiful/comments/l7k0f0/us_inauguration_address_word_frequency_biden_vs/

Bar chart variations

Bar charts are often used to make comparisons between two series

But your eyes must move around to compare

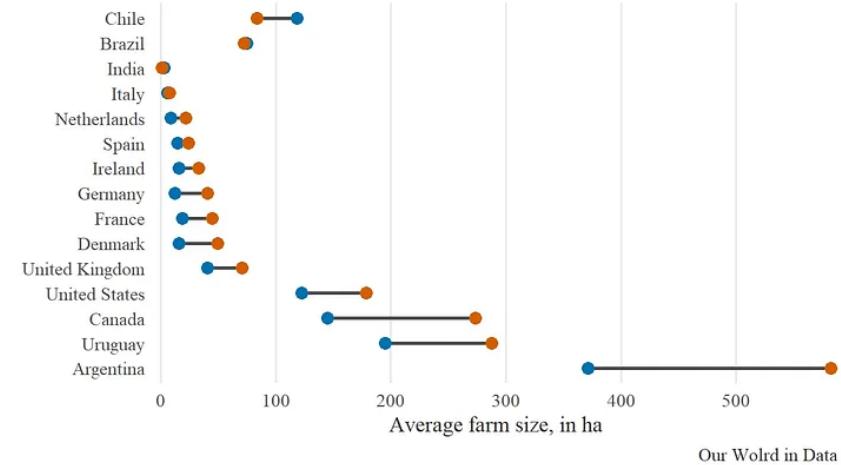
Comparison of average farm size between 1960 and 2000



An alternative is a [dumbbell](#) chart---dot plot w/ connecting lines---making comparisons direct.

[Effect ordering](#): Countries have also been sorted to show increase / decrease

Comparison of average farm size between 1960 and 2000



Our World in Data

Which countries gained the most from 1960 – 2000?

1.5D: Time series line graphs

William Playfair (1786), *The Commercial and Political Atlas*, invented the time series line graph as a way to show data on England's trade with other countries

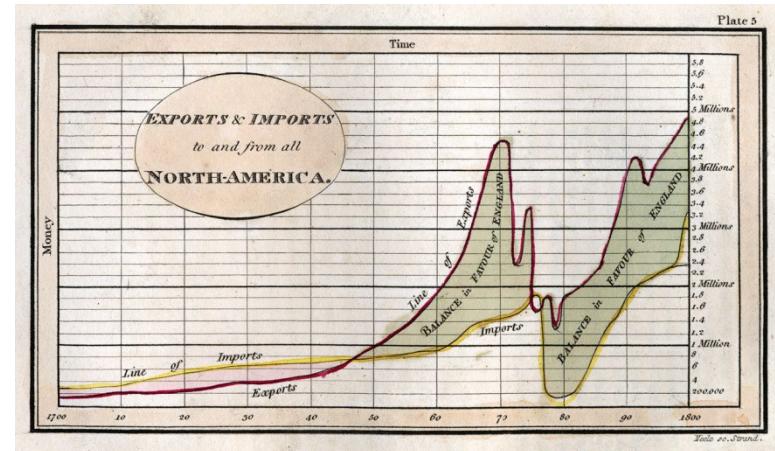
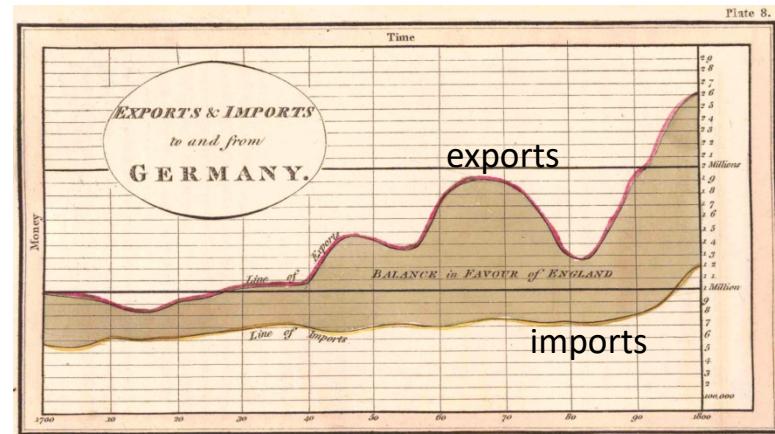
One curve for imports, one for exports

The balance of trade could be seen as the difference between the curves

Trade with Germany was consistently in favor of England

With North America, the balance changed back and forth over time

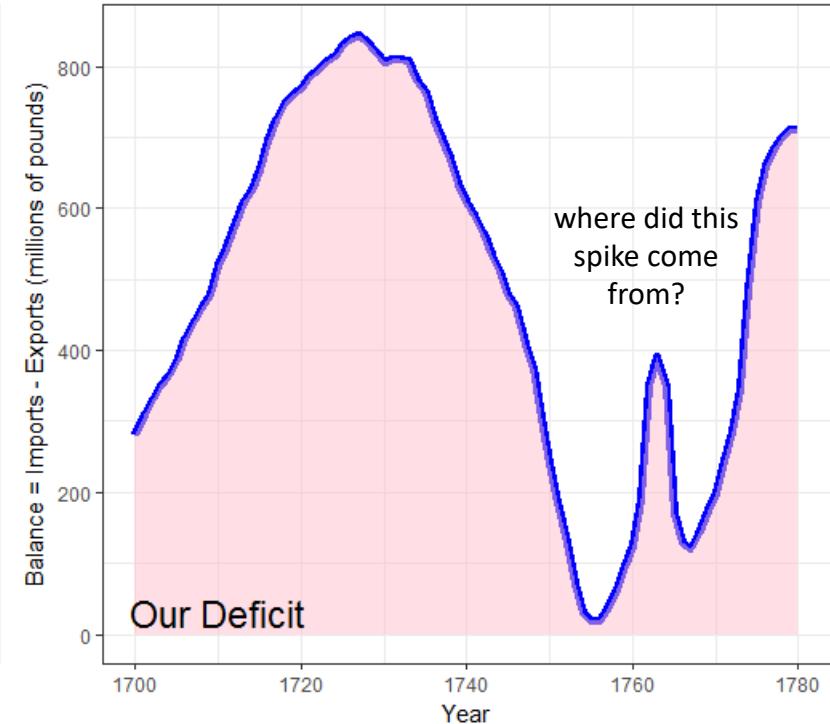
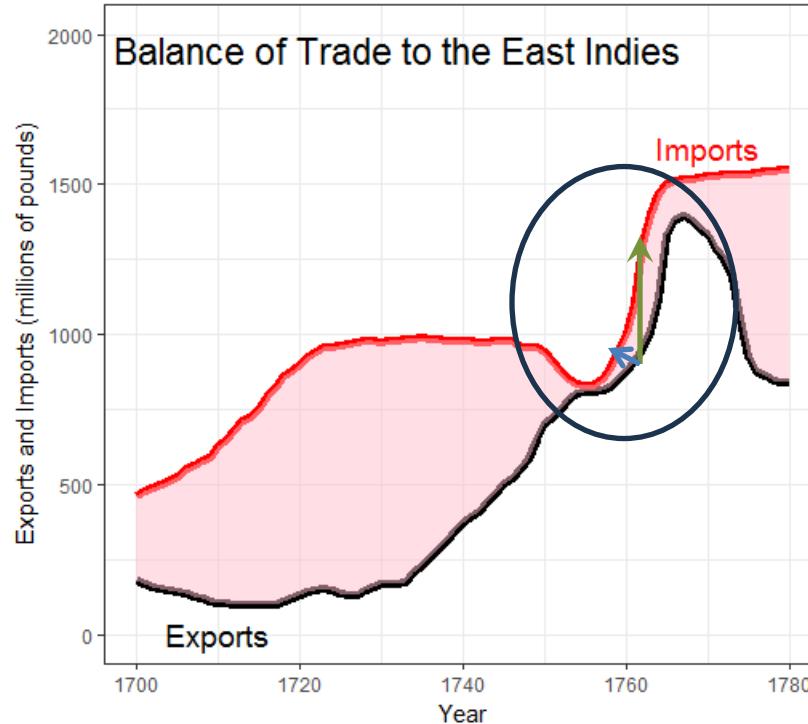
Economic 'history' could now be visualized and explained



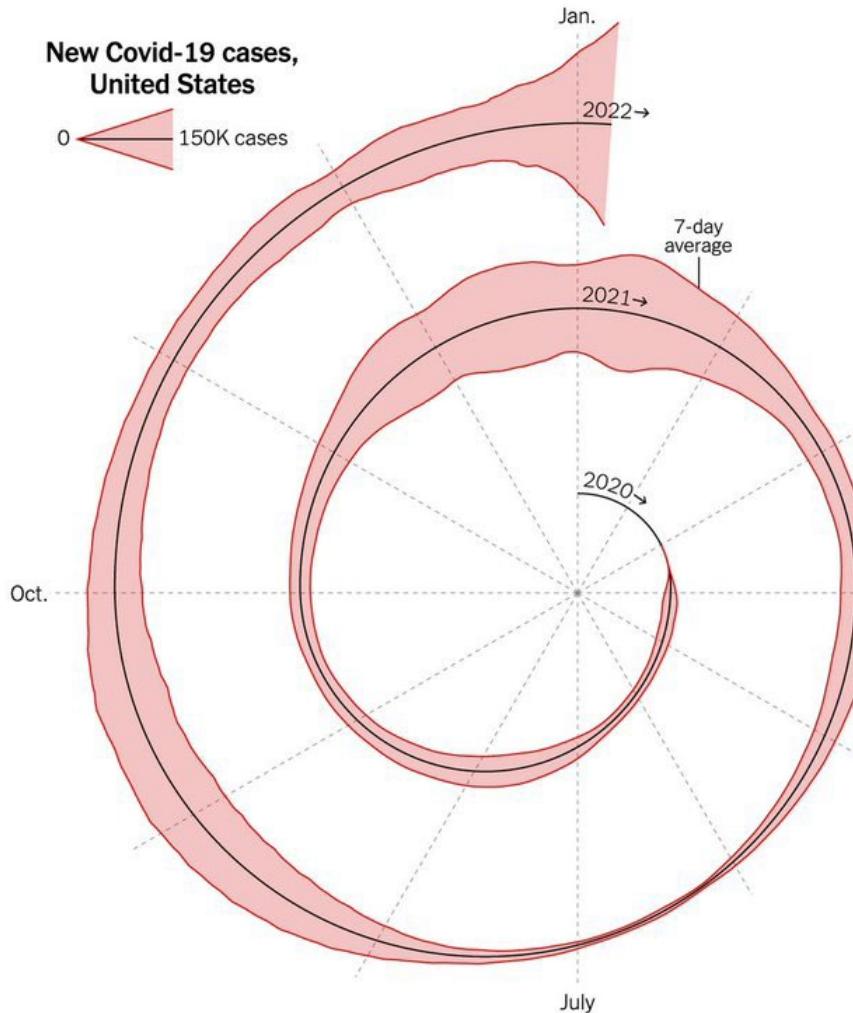
Psychology: Distances between curves

What Playfair didn't know is that judgments of **distance** between curves are **biased**
We tend to see the **perpendicular** distance rather than the **vertical** distance

Plotting balance of trade directly



Jan. 6, 2022



1.5D COVID spiral graph

This graph shows a 1.5D time series of COVID-19 cases over the entire span of the pandemic

It is wrapped into a spiral to compare **months** over years.

Does this work for you, or is it too weird?
Is it the “tapeworm of doom”?

Hey – wait
Isn’t this just a time-series in polar coordinates?

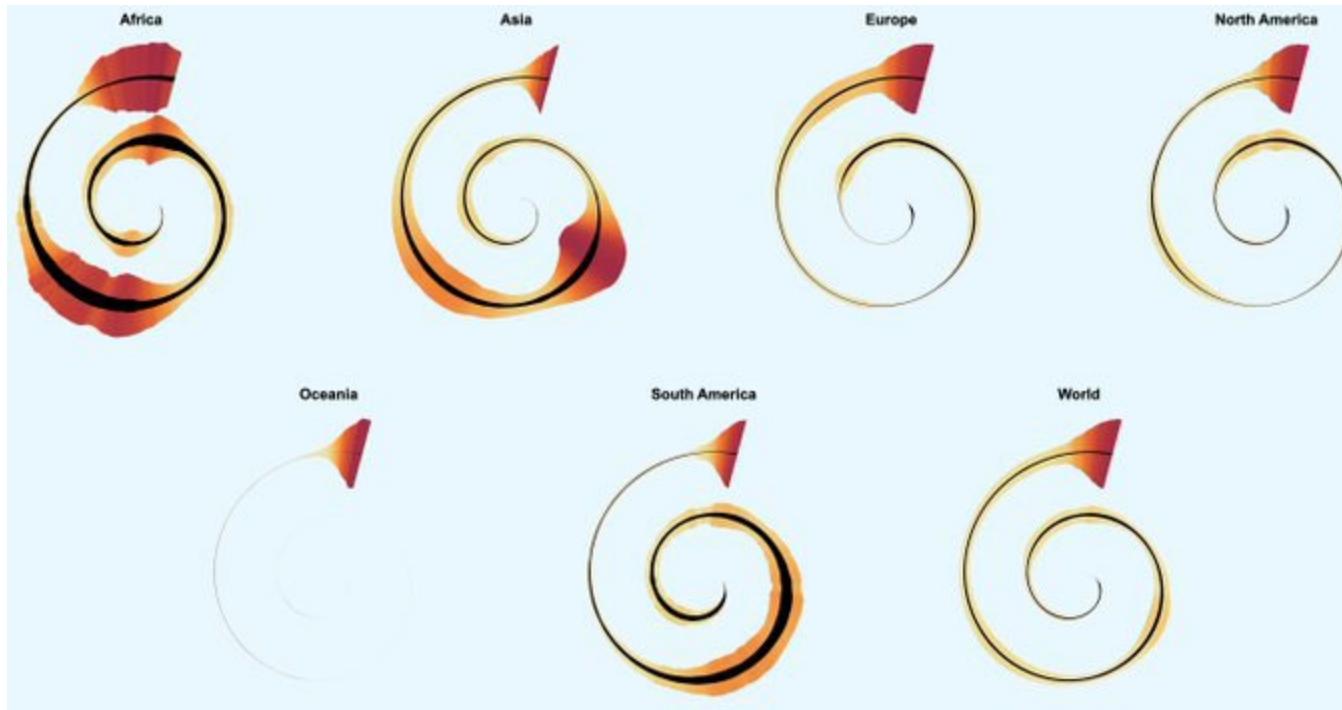
See commentary: <https://www.youtube.com/watch?v=YWowF9Vi4Mw>

Multi-spirals

Multiple spirals: Allow comparison of the patterns for different geographic units

- Overlaid time-series probably would not work here
- How could this be improved?

Color: smoothed new Covid-19 cases
Black: Deaths (10x scale)

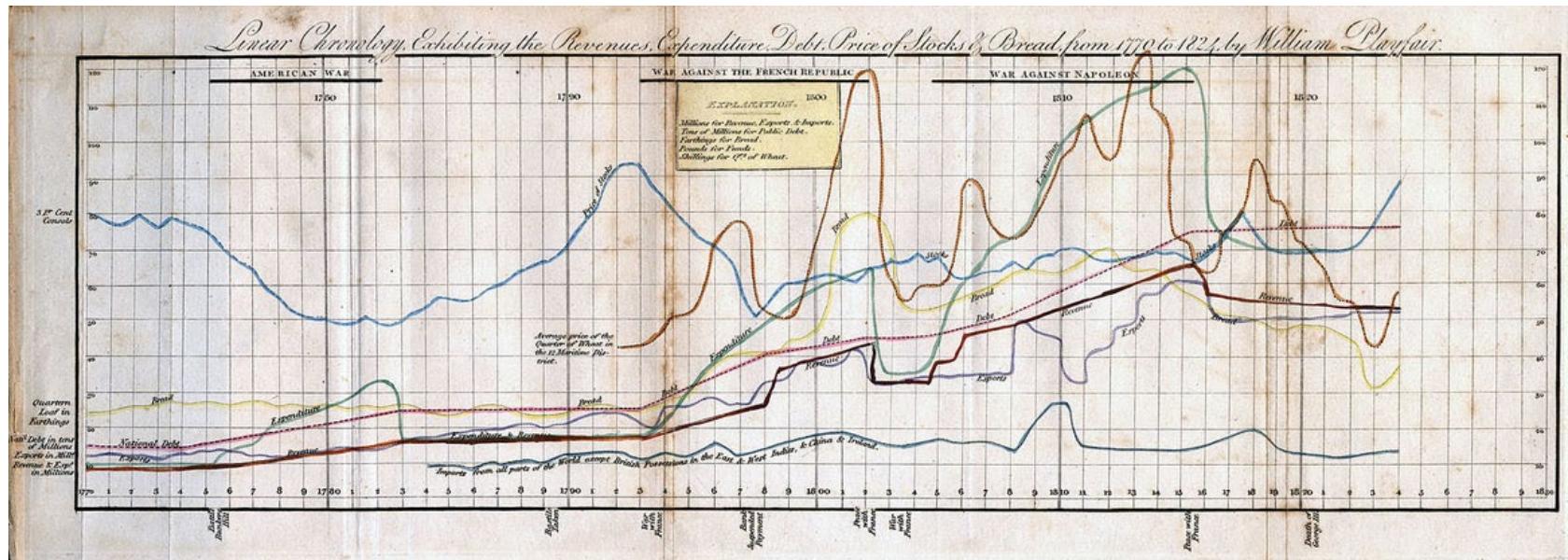


https://twitter.com/h_i_g_s_c_h/status/1483195230404947968

Multiple time series graphs

Things get messy when there are many series to be compared

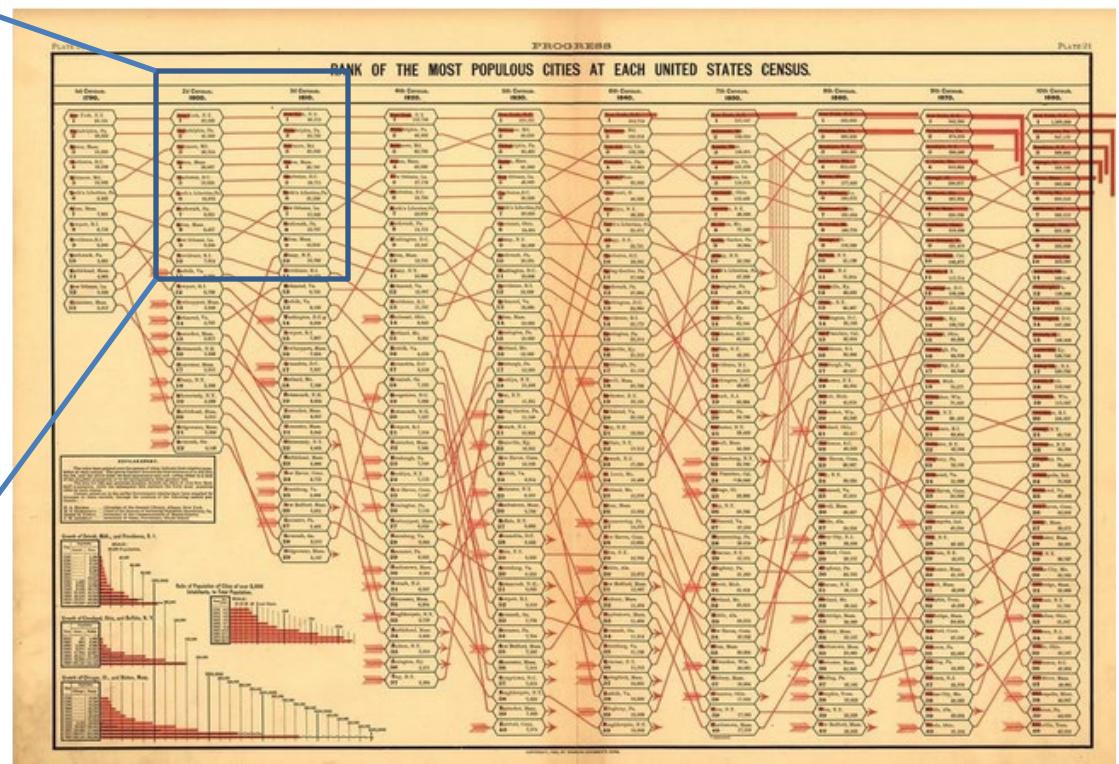
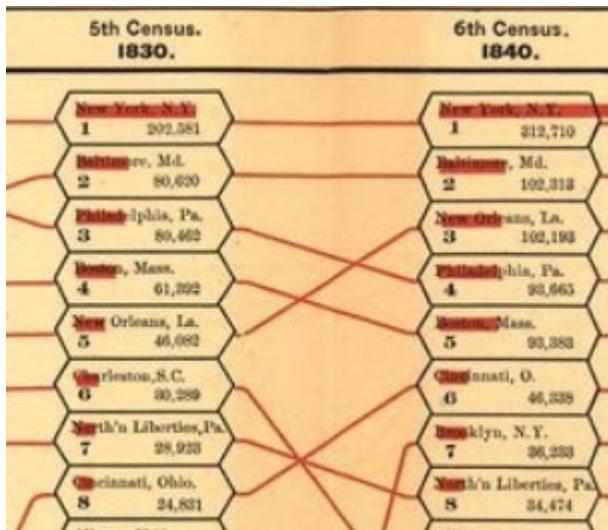
- To be fair, this was designed as **timeline of history** – a visual story of economics (prices, wages, imports, exports, debt)
- History shown as a **strip-chart recording** (e.g., EKG)
- It was Playfair's last graph.
- Perhaps the earliest example of **visual storytelling**



Playfair, W. (1824) *Chronology of Public Events and Remarkable Occurrences*.

Parallel ranked list charts

Another solution for multiple time series is to chart the **ranks** of observations and connect them with lines to show changes in relative position.



Slopes of lines reflect change
in rank
Red bars try to show the
numbers

Ranks of populations of US cities across census years
From: *Statistical Atlas of the United States* (1880)

Propensity of crimes across age

André-Michel Guerry (1833), rank order of crimes at different ages

- sexual assault **against adults** decreases with age
- sexual assault **against children** increases with age
- **parricide** relatively low until 60-70

INFLUENCE DE L'AGE.

DISTRIBUTION DES CRIMES AUX DIFFÉRENS ÂGES, PAR PÉRIODE DE DIX ANNÉES.

IV.

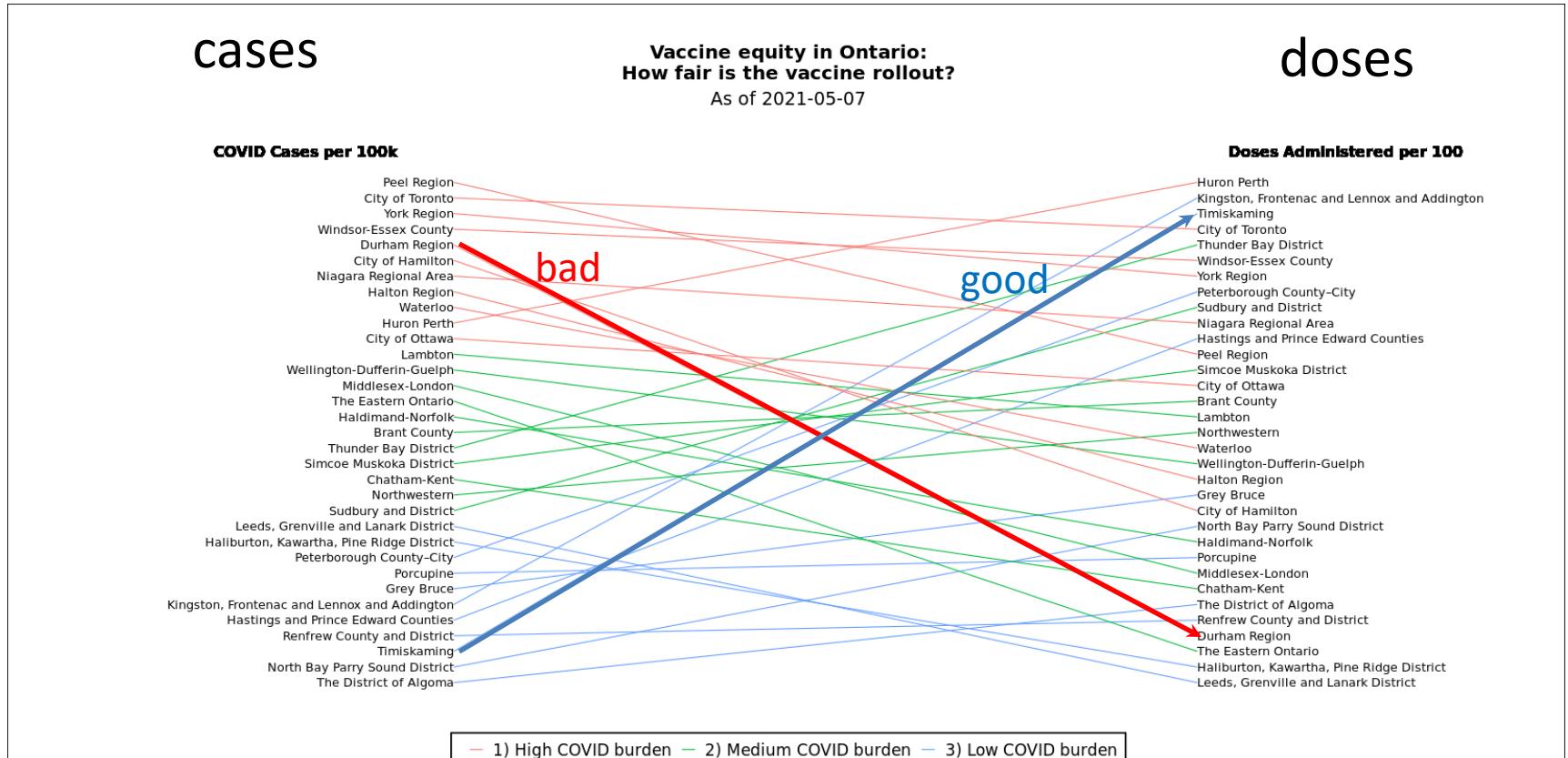
CRIMES CONTRE LES PERSONNES.												AU-DESSUS DE 70 ANS.		
AU-DESSOUS DE 21 ANS.			DE 21 À 30.		DE 30 À 40.		DE 40 À 50.		DE 50 À 60.		DE 60 À 70.		AU-DESSUS DE 70 ANS.	
	NATURE DES CRIMES.	Sur 1,000	NATURE DES CRIMES.	Sur 1,000	NATURE DES CRIMES.	Sur 1,000	NATURE DES CRIMES.	Sur 1,000	NATURE DES CRIMES.	Sur 1,000	NATURE DES CRIMES.	Sur 1,000	NATURE DES CRIMES.	Sur 1,000
1	Blessures et coups.	184	Blessures et coups.	216	Blessures et coups.	179	Assassinat	194	Meurtre	185	Meurtre	173	Viol sur des enfants	318
2	Viol sur des adultes.	169	Viol sur des adultes.	157	Assassinat	157	Blessures et coups.	161	Assassinat	182	Viol sur des enfants	165	Blessures et coups	187
3	Meurtre	147	Meurtre	146	Meurtre	152	Meurtre	155	Blessures et coups.	175	Assassinat	159	Meurtre	125
4	Viol sur des enfants	145	Viol sur des enfants	141	Viol sur des enfants	110	Rébellion	100	Rébellion	98	Blessures et coups	135	Assassinat	102
5	Assassinat	101	Viol sur des adultes	105	Viol sur des adultes	73	Viol sur des enfants	94	Viol sur des enfants	68	Faux témoignage	98	Faux témoignage	102
6	Rébellion	79	Infanticide	83	Infanticide	63	Faux témoignage	69	Faux témoignage	76	Rébellion	78	Rébellion	91
7	Infanticide	48	Viol sur des enfants	58	Viol sur des enfants	59	Viol sur des adultes	61	Viol sur des adultes	52	Infanticide	42	Empoisonnement	25
8	Bless. env. ascend.	47	Bless. env. ascend.	50	Bless. env. ascend.	59	Infanticide	44	Infanticide	24	Empoisonnement	35	Infanticide	25
9	Associat. de malfait.	52	Faux témoignage	33	Faux témoignage	49	Empoisonnement	40	Parricide	21	Viol sur des adultes	23	Viol sur des adultes	23
10	Faux témoignage	29	Empoisonnement	18	Empoisonnement	25	Associat. de malfait	29	Avortement	18	Associat. de malfait	11	Voies de fait, etc.	11
11	Empoisonnement	11	Crim. env. des enf.	10	Crim. env. des enf.	10	Associat. de malfait	39	Avortement	14	Viol sur des adultes	14	Voies de fait, etc.	11
12	Crim. env. des enf.	6	Associat. de malfait	10	Associat. de malfait	12	Bigamie	13	Crin. env. des enf.	11	Bless. env. ascend.	7	Bigamie	11
13	Mend. av. violence.	6	Parricide	9	Parricide	9	Bigamie	13	Bless. env. ascend.	7	Parricide	7	Parricide	7
14	Crim. env. des enf.	5	Voies de fait, etc.	8	Crim. env. des enf.	8	Mendicité	8	Mendicité	10	Associat. de malfait	7	Crim. env. les enf.	7
15	Parricide	5	Avortement	5	Avortement	8	Parricide	7	Parricide	10	Bigamie	7	Avortement	7
16	Avortement	5	Bigamie	5	Bigamie	7	Associat. de malfait	15	Crin. env. des enf.	11	Bigamie	7	Bigamie	7
17	Bigamie	5	Avortement	2	Avortement	6	Parricide	4	Bless. env. ascend.	7	Voies de fait, etc.	7	Mend. av. violence.	7
Autres crimes	4	Bigamie	1	Voies de fait, etc.	6	Voies de fait, etc.	4	Crim. env. des enf.	6	Mend. av. violence.	7	Mend. av. violence.	7	
	TOTALE	1,000	Autres crimes	7	Autres crimes	12	Autres crimes	12	Autres crimes	26	Autres crimes	11	Autres crimes	34
		1,000		1,000		1,000		1,000		1,000		1,000		1,000

Friendly, (2007). "A.-M. Guerry's Moral Statistics of France: Challenges for Multivariable Spatial Analysis," *Statistical Science*, vol. 22, no. 3. <https://www.datavis.ca/papers/guerry-STS241.pdf>

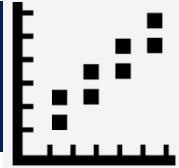
Slope graph of COVID: Cases vs. Doses

Vaccine equity → all lines should be ≈ flat

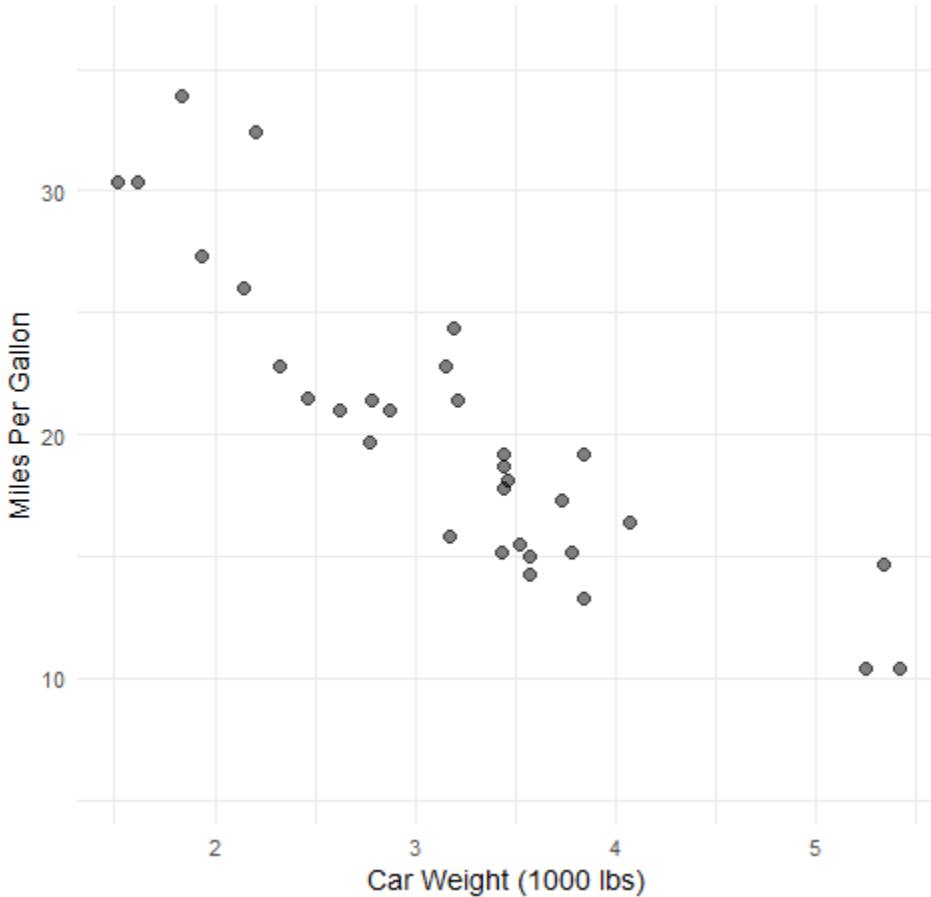
Which health regions stand out? How could this graph be better?



2D: Scatterplots



1974 Motor Trend Cars: Gas Mileage vs. Weight [Frame 1]



Goals: Want to see--

- Overall pattern:
 - direction
 - form
 - strength
- Deviations from pattern:
 - residuals
 - outliers

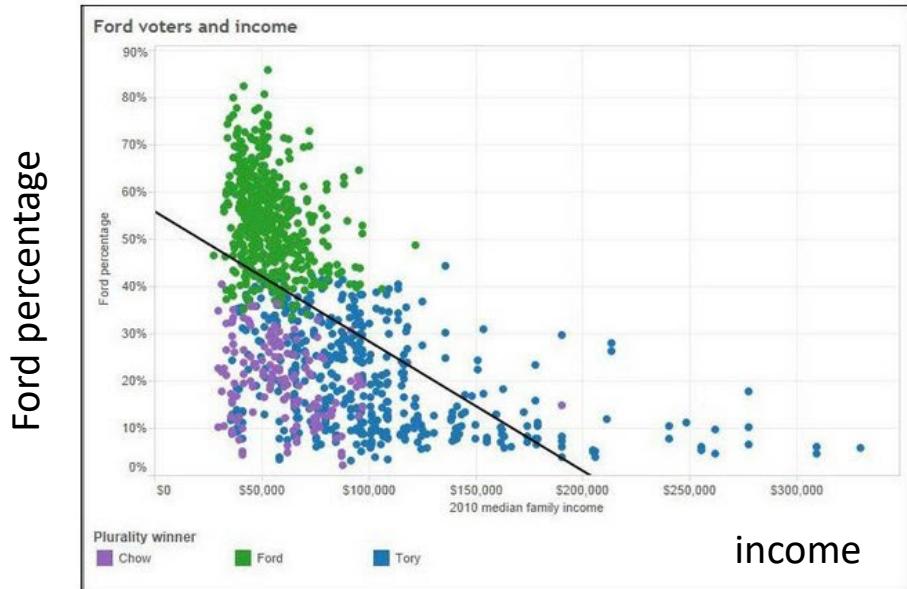
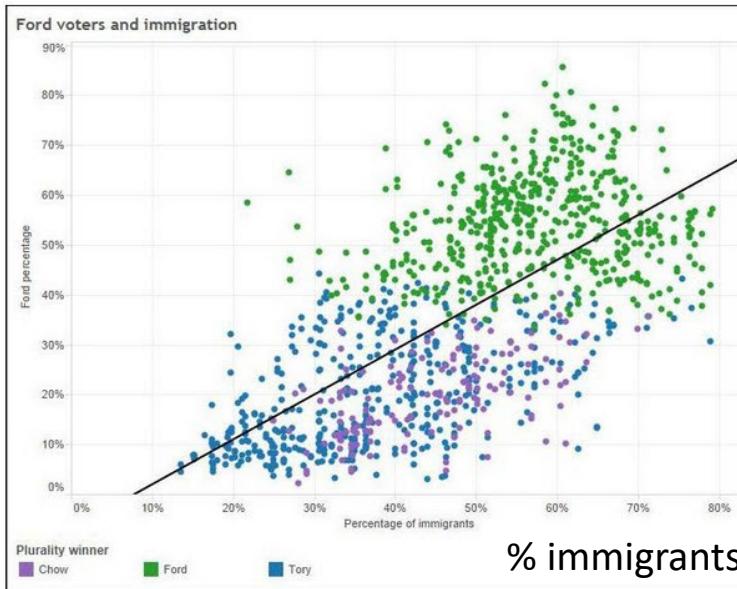
Annotations can help:

- regression line
- confidence band
- smoothed curve (nonlinear?)
- residuals

2D: Scatterplots: Ford Nation



Who voted for Rob Ford in the 2014 Toronto mayoral election?



These simple scatterplots by data journalist Patrick Cain use simple enhancements:

- Color, for candidate (Chow, Ford, Tory)
- Overall regression line

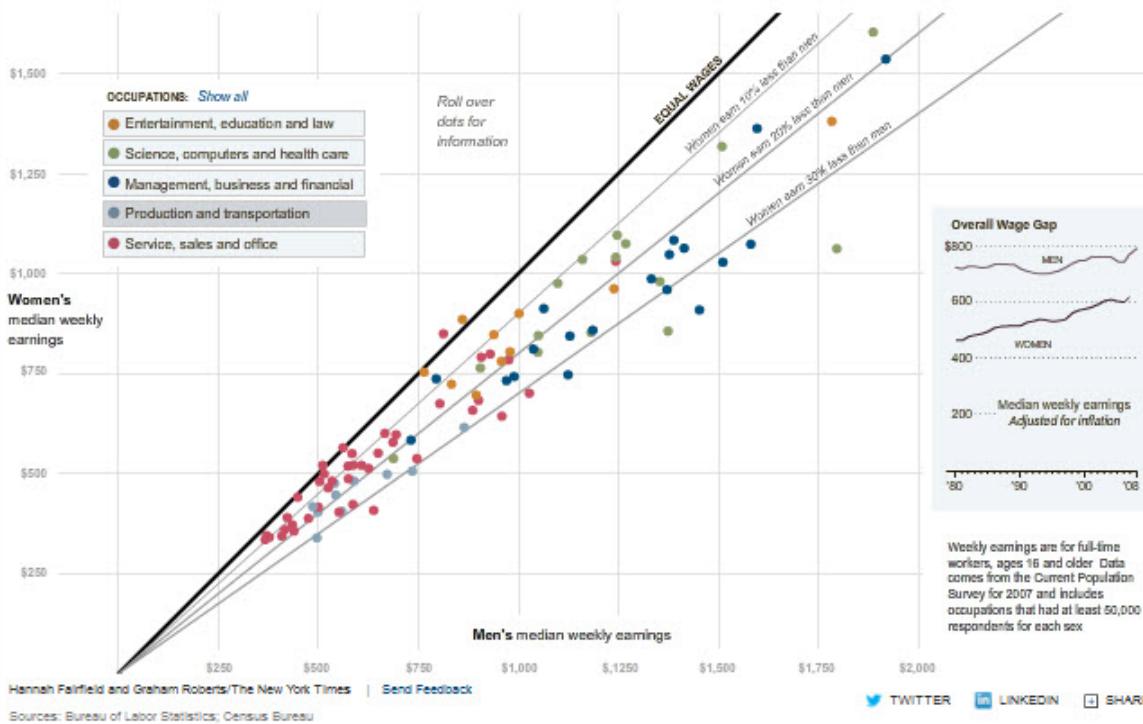
Source: <https://globalnews.ca/news/1652571/ford-nation-2014-15-things-demographics-tell-us-about-toronto-voters/>

Scatterplots: Wage gap

Published: May 18, 2010

Why Is Her Paycheck Smaller?

Nearly every occupation has the gap — the seemingly unbridgeable chasm between the size of the paycheck brought home by a woman and the larger one earned by a man doing the same job. Economists cite a few reasons: discrimination as well as personal choices within occupations are two major factors, and part of the gap can be attributed to men having more years of experience and logging more hours.



How to compare salaries of men & women in different occupations?

The NYT chose to plot median salaries for women against those for men, in different occupational groups

The 45° line represents wage parity
Other lines show 10, 20, 30% less for women

How else to show this?

Alberto Cairo, *The Truthful Art*, Fig 9.19, from:

http://www.nytimes.com/interactive/2009/03/01/business/20090301_WageGap.html

Scatterplots: InfoVis

This graph, from fivethirtyeight.com was designed to show how some presidential candidates had shifted positions before the 2016 election.

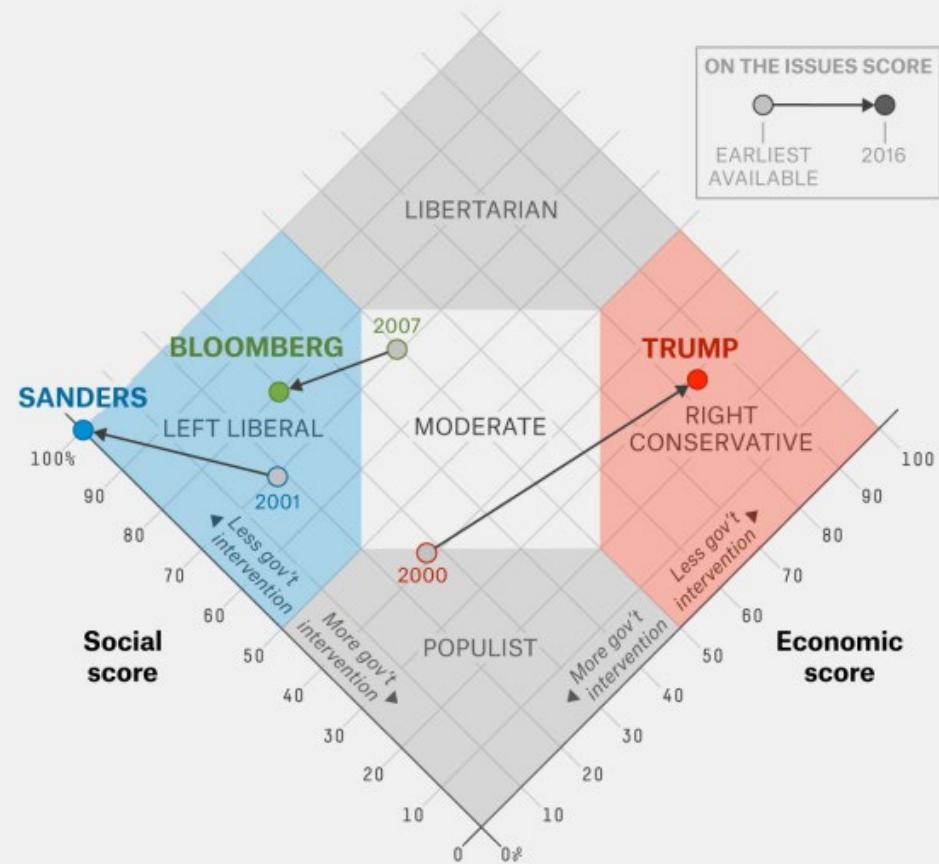
The axes are a score on **social** and **economic** policy, but they rotate the axes by 45° to create zones related to political thought.

This info graphic is **eye-catching** and **self-explanatory**:

- colored/labeled zones
- interpretive labels on axes
- arrows showing movement to extremes

Candidates abandoning the middle ground

Earliest available and current OnTheIssues score for Bernie Sanders, Donald Trump and Michael Bloomberg



Scatterplots: Annotations enhance perception

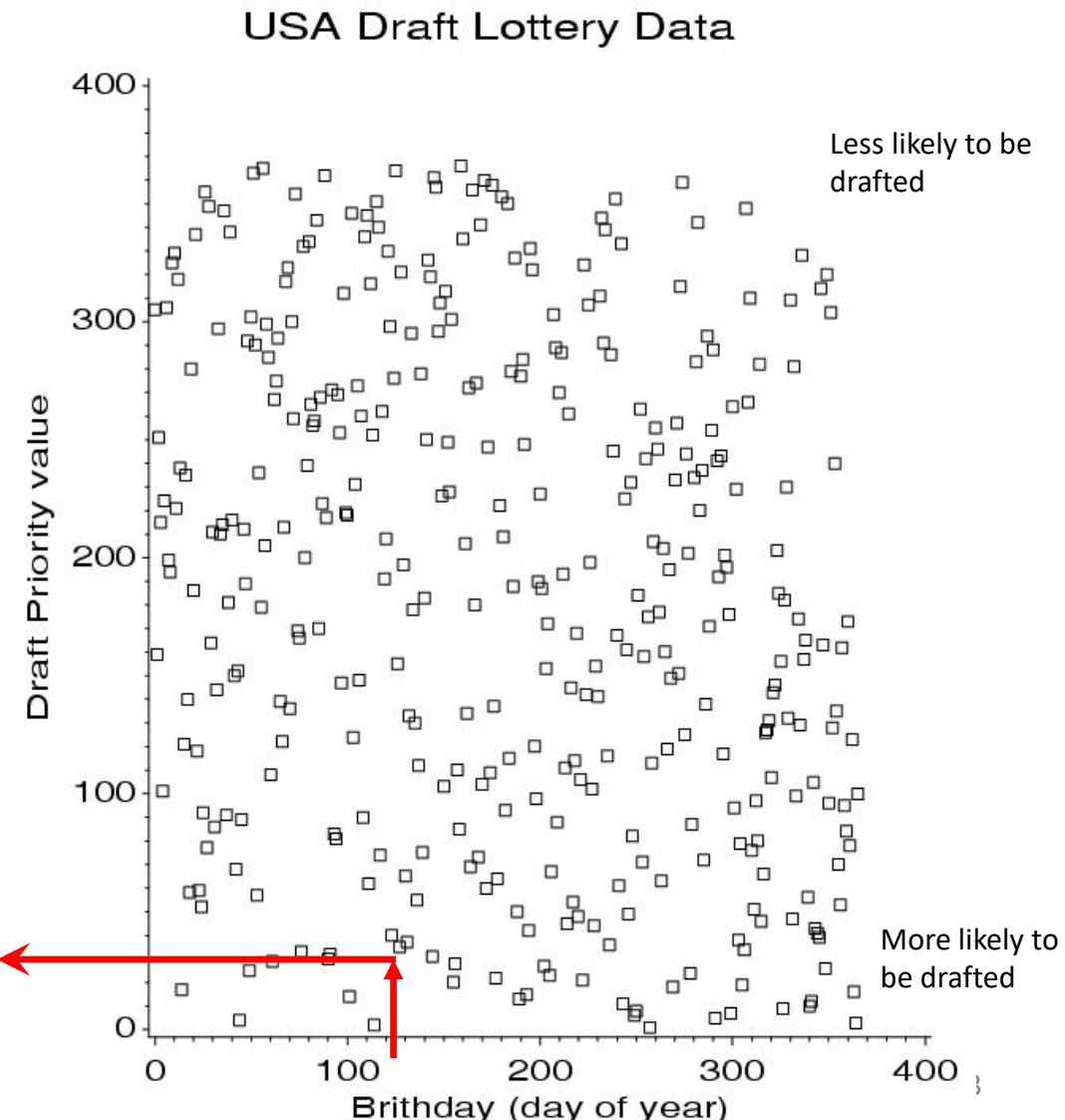
Data from the US draft lottery,
1970

- Birth dates were drawn at random to assign a “draft priority value” (1=bad)
- Can you see any pattern or trend?

This is an example of data with a weak signal and a lot of noise



Me (May 7):
127 → priority = 35

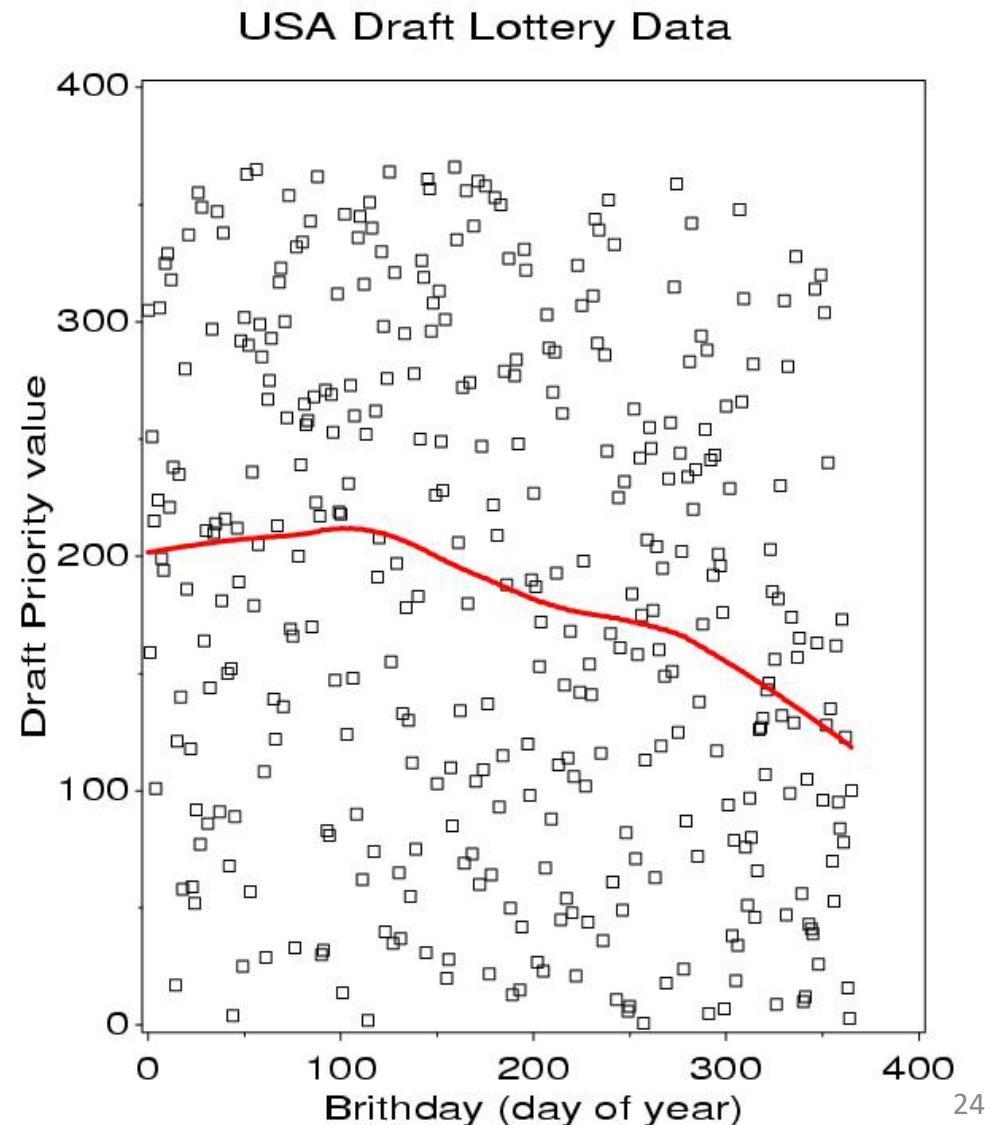


Scatterplots: Smoothing enhances perception

Drawing a smooth curve shows a systematic decrease toward the end of the year.

- The smooth curve is fit by **loess**, a form of non-parametric regression.

Visual explanation:

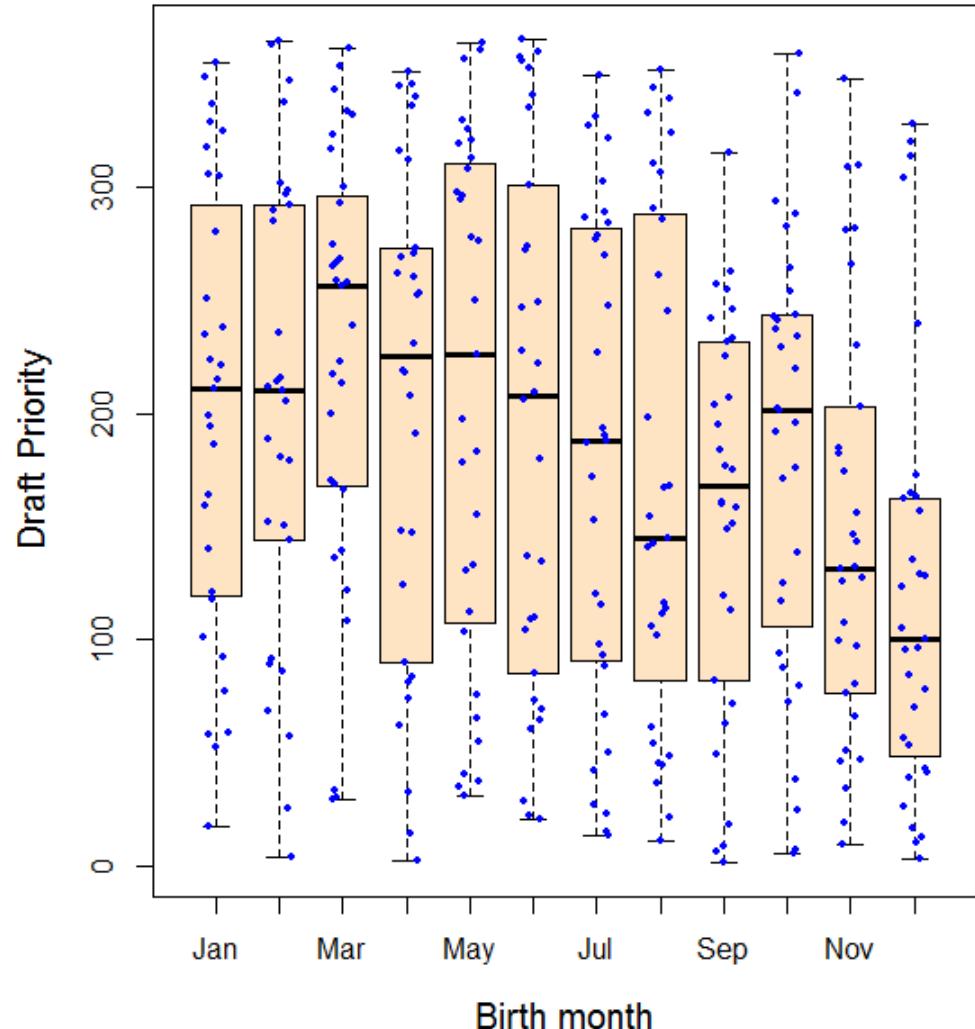


Smoothing by grouping and summarization

Another form of smoothing is to make one variable discrete & show a graphical summary – here a boxplot

The decrease in later months becomes apparent

Perception: the boxplots form the foreground; the jittered points show the data

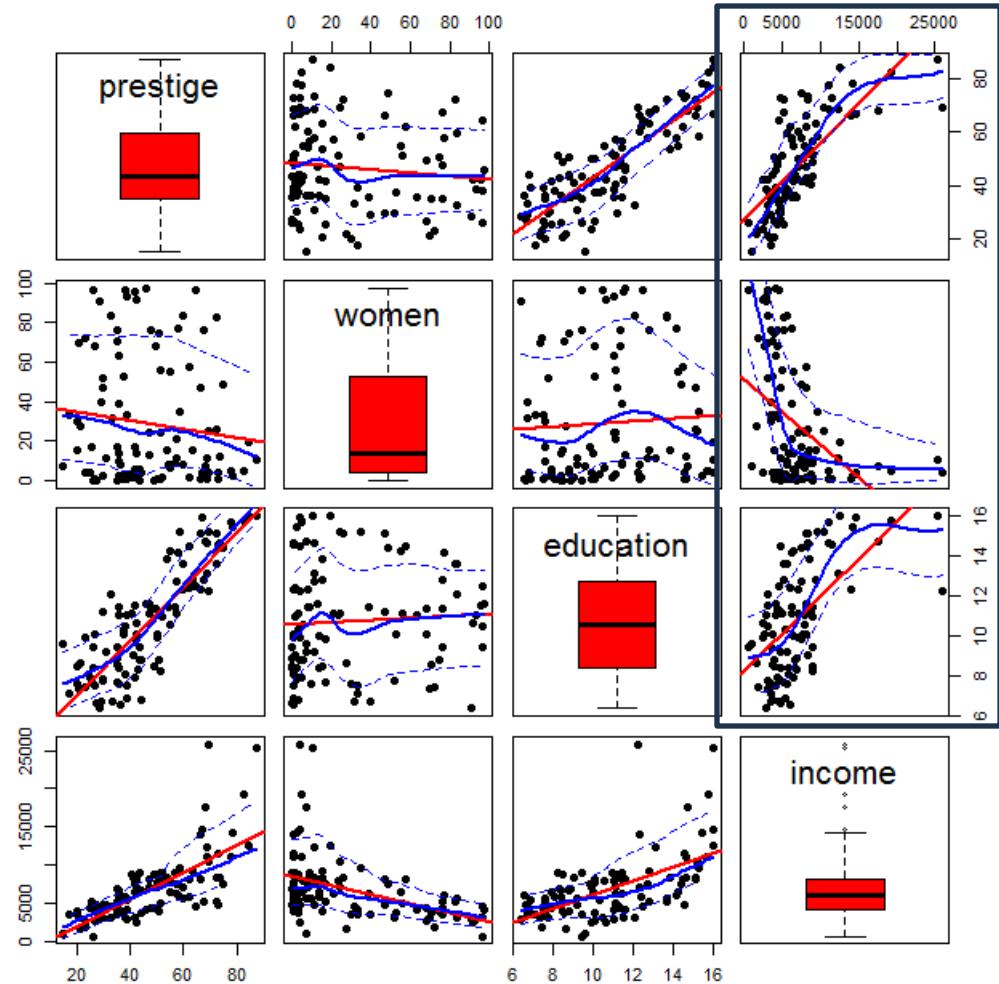


Scatterplot matrices

A scatterplot matrix shows the bivariate relation between all **pairs** of variables. Seeing these all together is more useful than a collection of separate plots.

Q: How does occupational prestige depend on %women, education and income?

The individual plots are enhanced with linear regression lines and non-parametric smoothes to show non-linearity



This figure uses `scatterplotMatrix()` in the [car](#) package. There are many options.

Scatterplot matrices

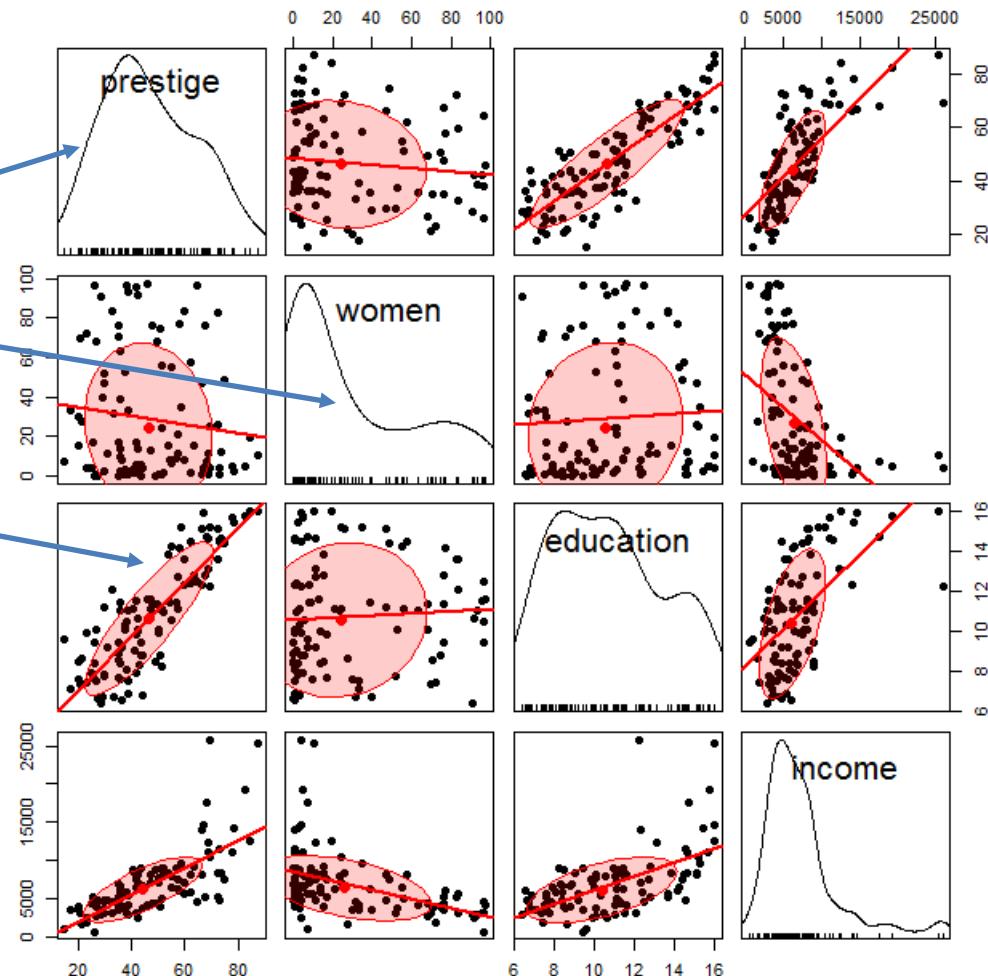
Essential idea: You can choose different methods to render the diagonal & off-diagonal panels

Density plots are often more useful for showing the shapes of distributions

- prestige: ~ symmetric
- women: bimodal
- income: highly skewed

A data ellipse gives a visual summary of the direction and strength of the relationship

Again, graphical annotation aids interpretation.



Larger data sets

Scatterplot matrices hold up reasonably well with a larger number of variables

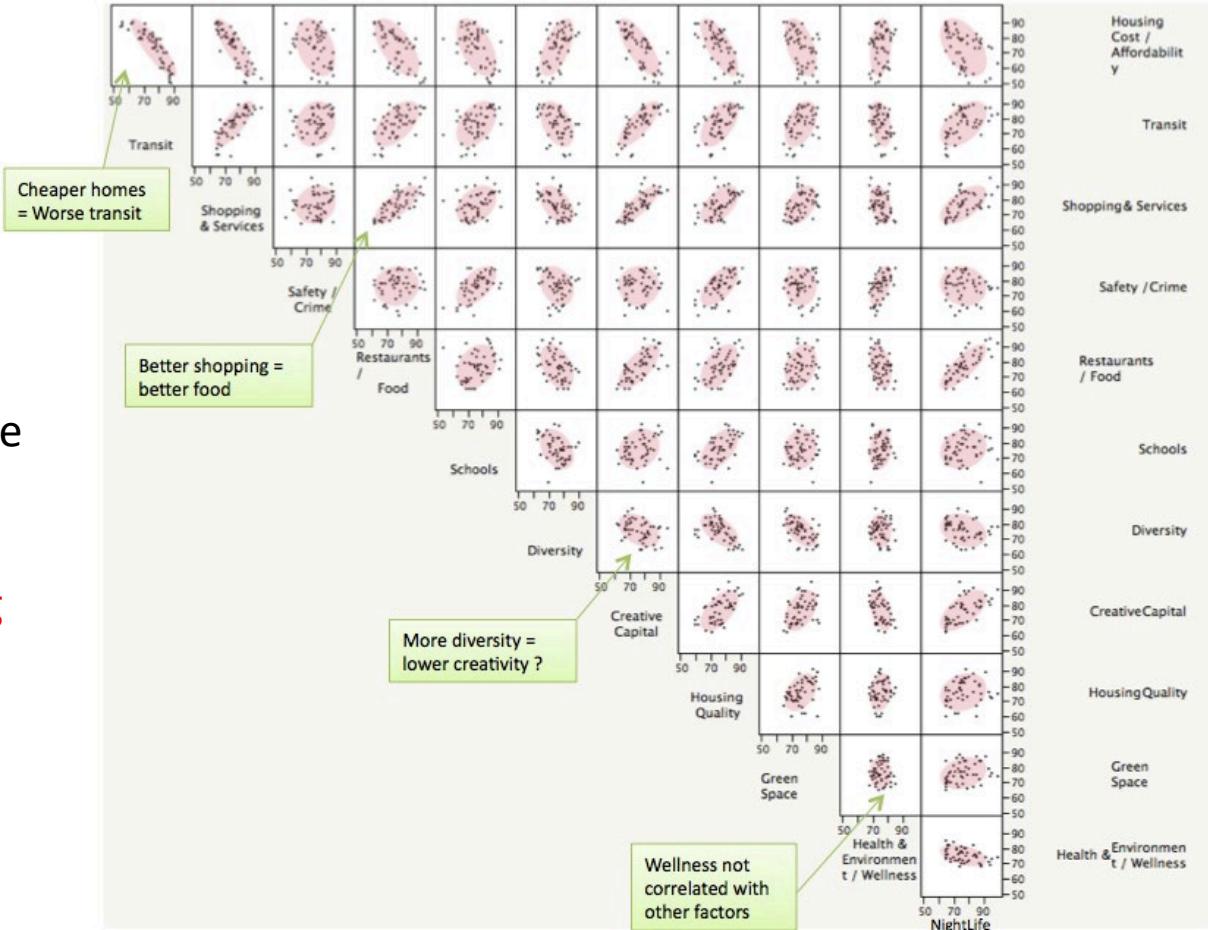
Where to live in NYC?

This SPM shows 12 variables on ~ 60 neighborhoods

The data **ellipses** provide a visual summary

I call this **visual thinning** – reducing details in a larger picture

In an interactive display we can **zoom** in/out



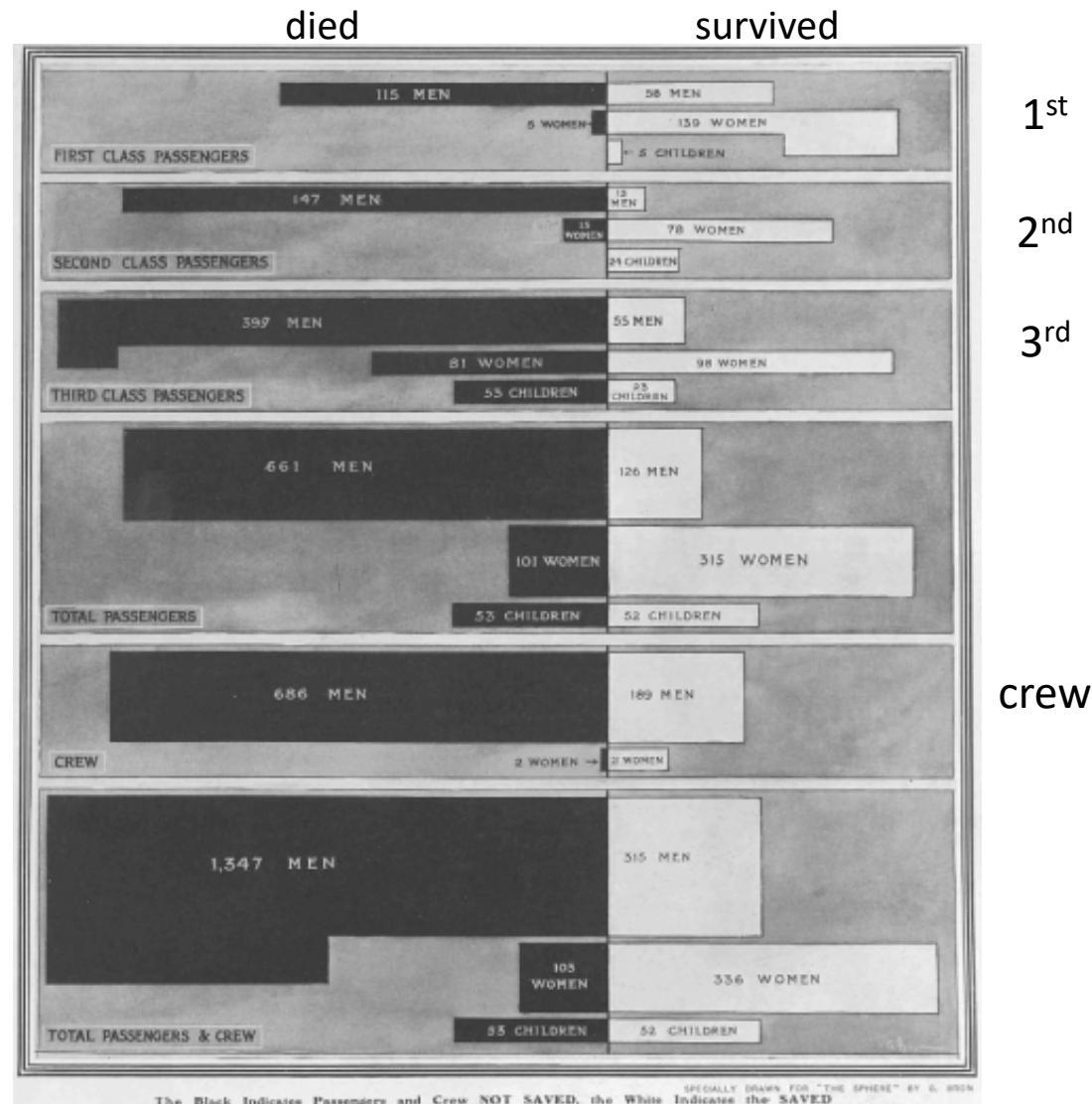
Categorical data

This remarkable chart shows survival on the *Titanic*, by Class for passengers and Gender and Age.

It was drawn by G. Bron, a graphic artist, and published in *The Sphere*, one month after the *Titanic* sank.

It uses back-to-back bar charts, with area ~ frequency

See our web page:
<http://datavis.ca/papers/titanic/>



Categorical data: Mosaic plots

Similar to a grouped bar chart

Shows a frequency table with tiles,
area \sim frequency

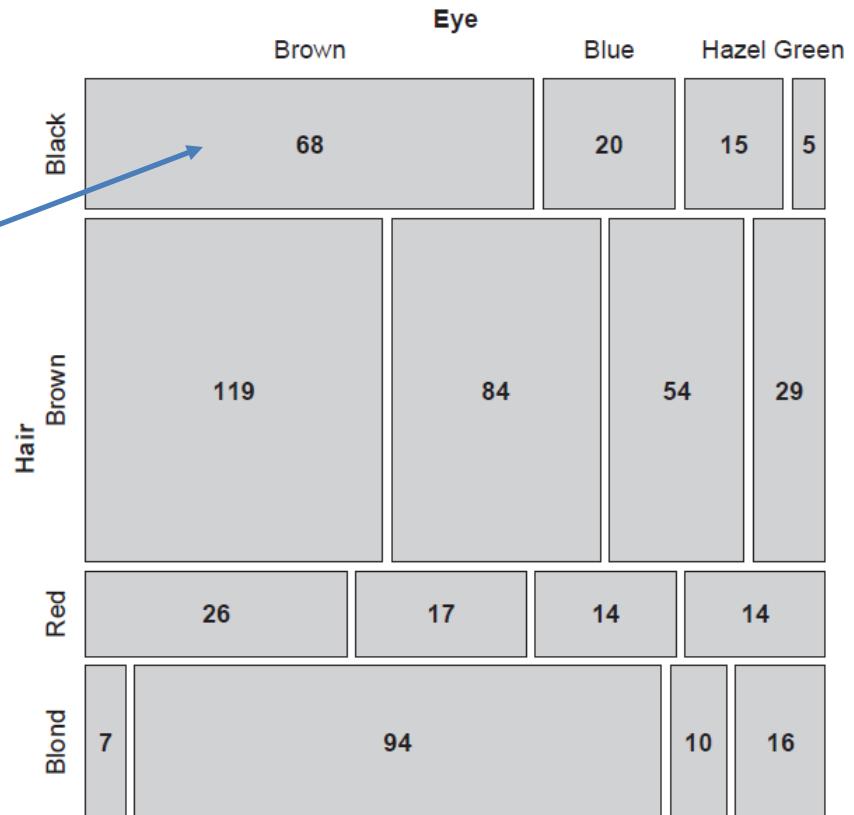
```
> data(HairEyeColor)
> HEC <- margin.table(HairEyeColor, 1:2)
> HEC
```

Hair	Eye			
	Brown	Blue	Hazel	Green
Black	68	20	15	5
Brown	119	84	54	29
Red	26	17	14	14
Blond	7	94	10	16

```
> chisq.test(HEC)
```

Pearson's Chi-squared test

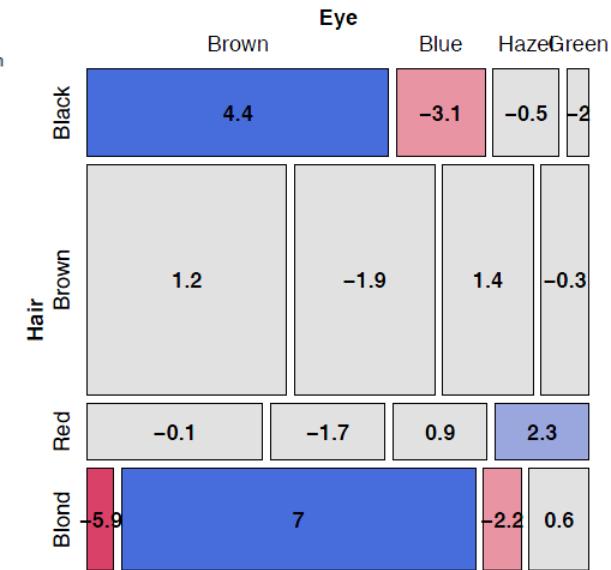
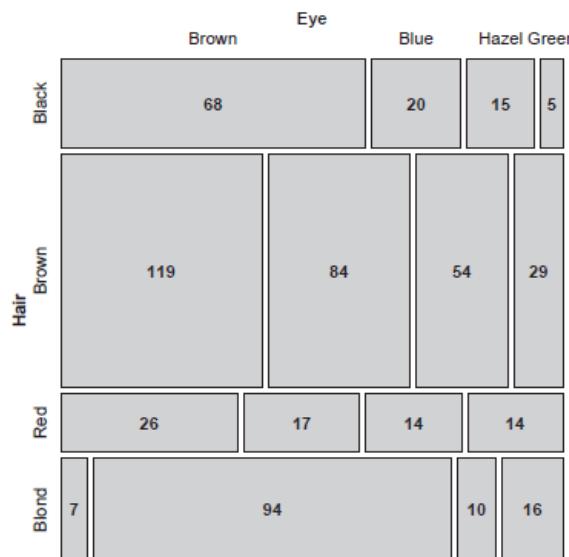
```
data: HEC
X-squared = 140, df = 9, p-value <2e-16
```



How to understand the association
between hair color and eye color?

Mosaic plots

Area proportional display of frequencies in n -way table
 Shaded according to deviation (residual) from independence



Divide unit square $\sim V1$
 marginal frequencies

Subdivide each $\sim V2|V1$
 conditional frequencies

Shade \sim residual (d_{ij})
positive: $O > E$
negative: $O < E$

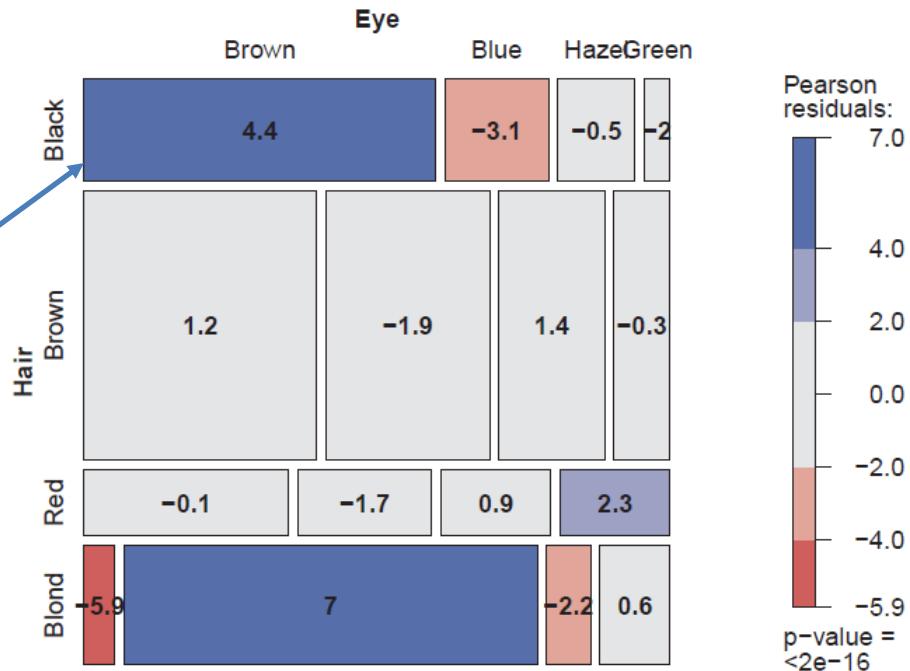
$$d_{ij} = \frac{(O_{ij} - E_{ij})}{\sqrt{E_{ij}}} \quad \chi^2 = \sum d_{ij}^2$$

Mosaic plots

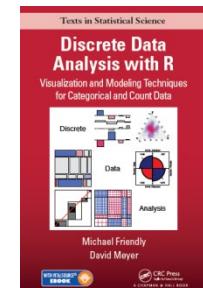
Shade each tile in relation to the contribution to the Pearson χ^2 statistic

$$\chi^2 = \sum d_{ij}^2 = \sum \frac{(o_{ij} - e_{ij})^2}{e_{ij}}$$

```
> round(residuals(chisq.test(HEC)), 2)
   Eye
Hair  Brown  Blue Hazel Green
Black  4.40 -3.07 -0.48 -1.95
Brown  1.23 -1.95  1.35 -0.35
Red    -0.07 -1.73  0.85  2.28
Blond -5.85  7.05 -2.23  0.61
```



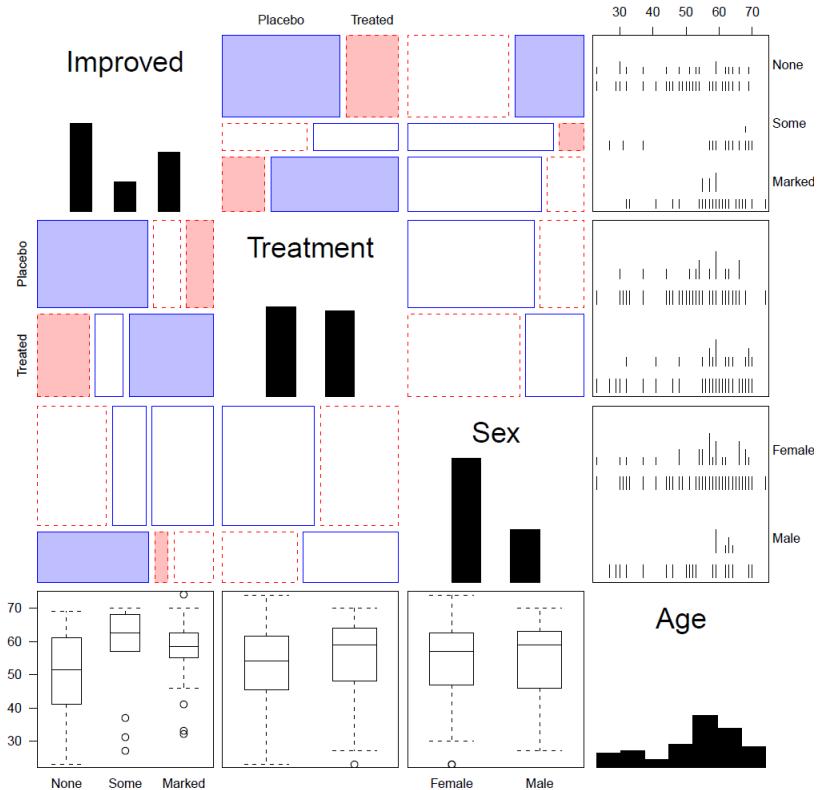
Mosaic plots extend readily to 3-way + tables
They are intimately connected with loglinear models
See: Friendly & Meyer (2016), Discrete Data Analysis with R, <http://ddar.datavis.ca/>



Generalized pairs plots

Generalized pairs plots from the [gpairs](#) package handle both categorical (**C**) and quantitative (**Q**) variables in sensible ways

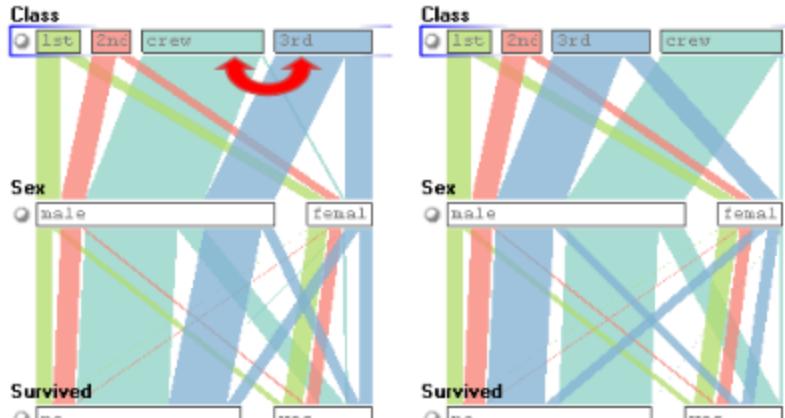
x	y	plot
Q	Q	scatterplot
C	Q	boxplot
Q	C	barcode
C	C	mosaic



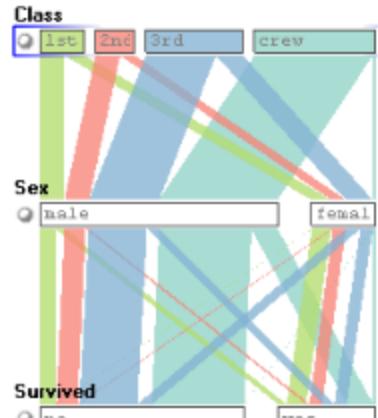
```
library(gpairs)
data(Arthritis)
gpairs(Arthritis[, c(5, 2:5)], ...)
```

Parallel Sets

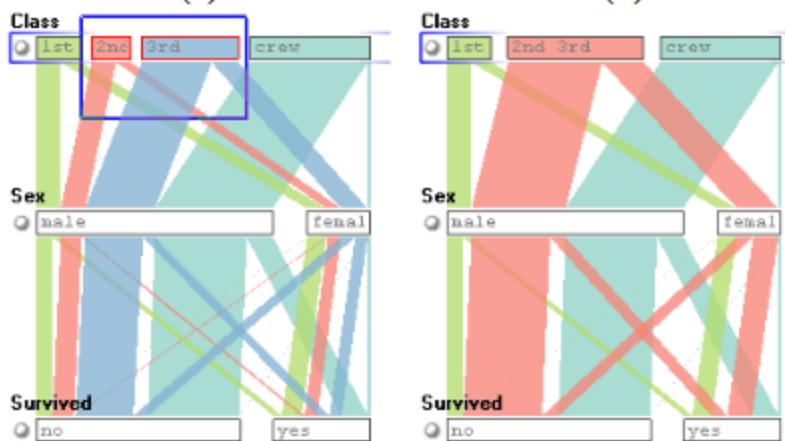
Titanic data: Who survived?



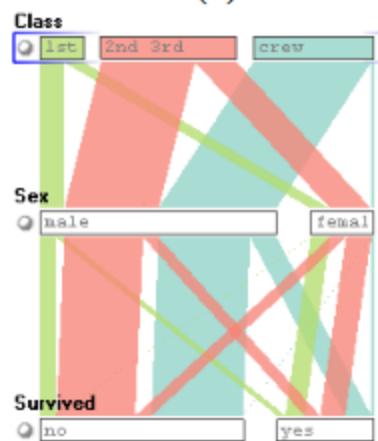
(a)



(b)



(c)



(d)

Parallel sets use **parallel coordinate** axes to show the relations among categorical variables.

The frequencies of one variable (Class) are sub-divided according to the joint frequencies in the next (Sex) and shown by the width of the connecting line.

The ParSets application is interactive:

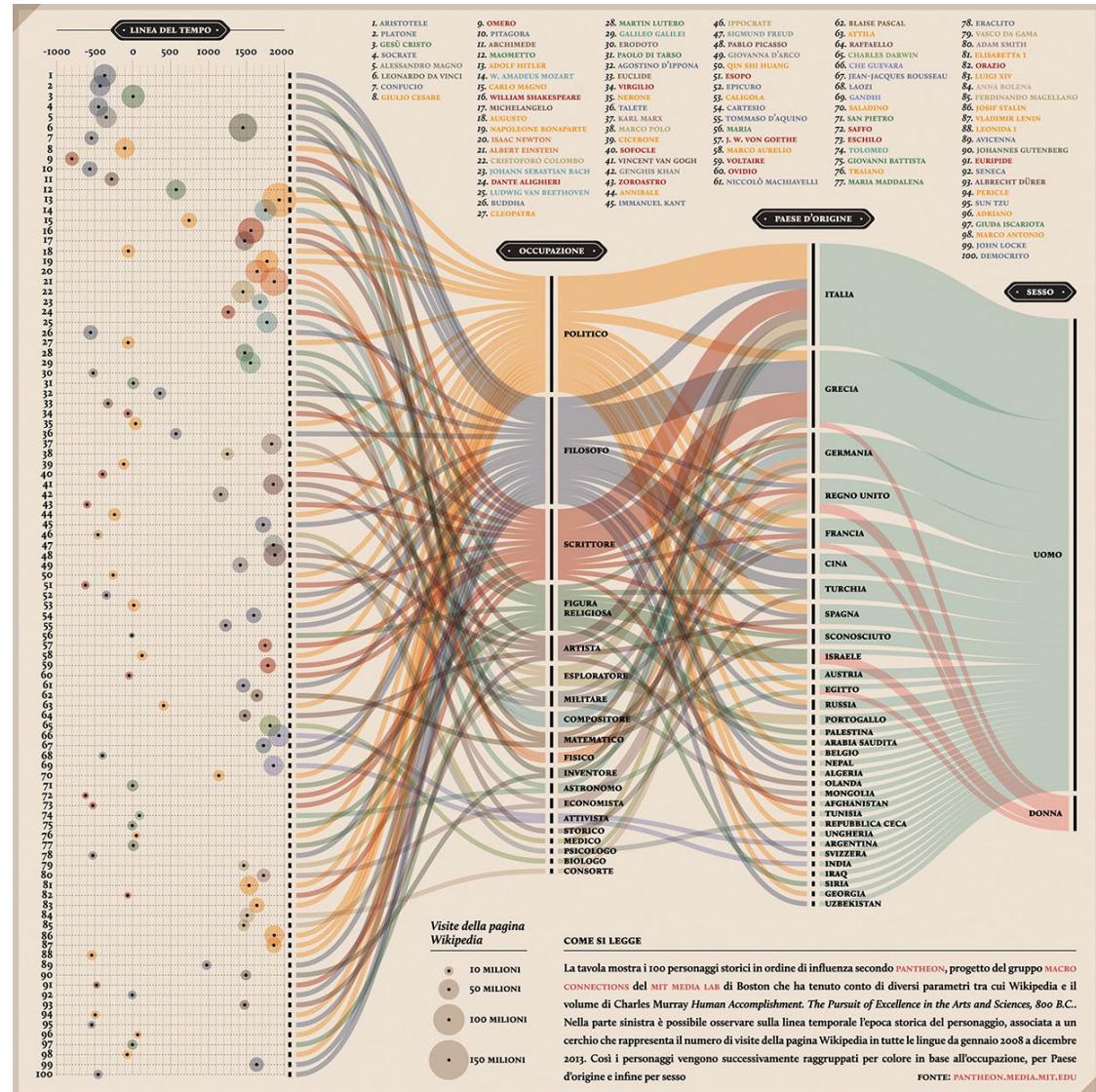
- categories can be reordered (a, b)
- categories can be grouped (c, d)

Sankey diagram

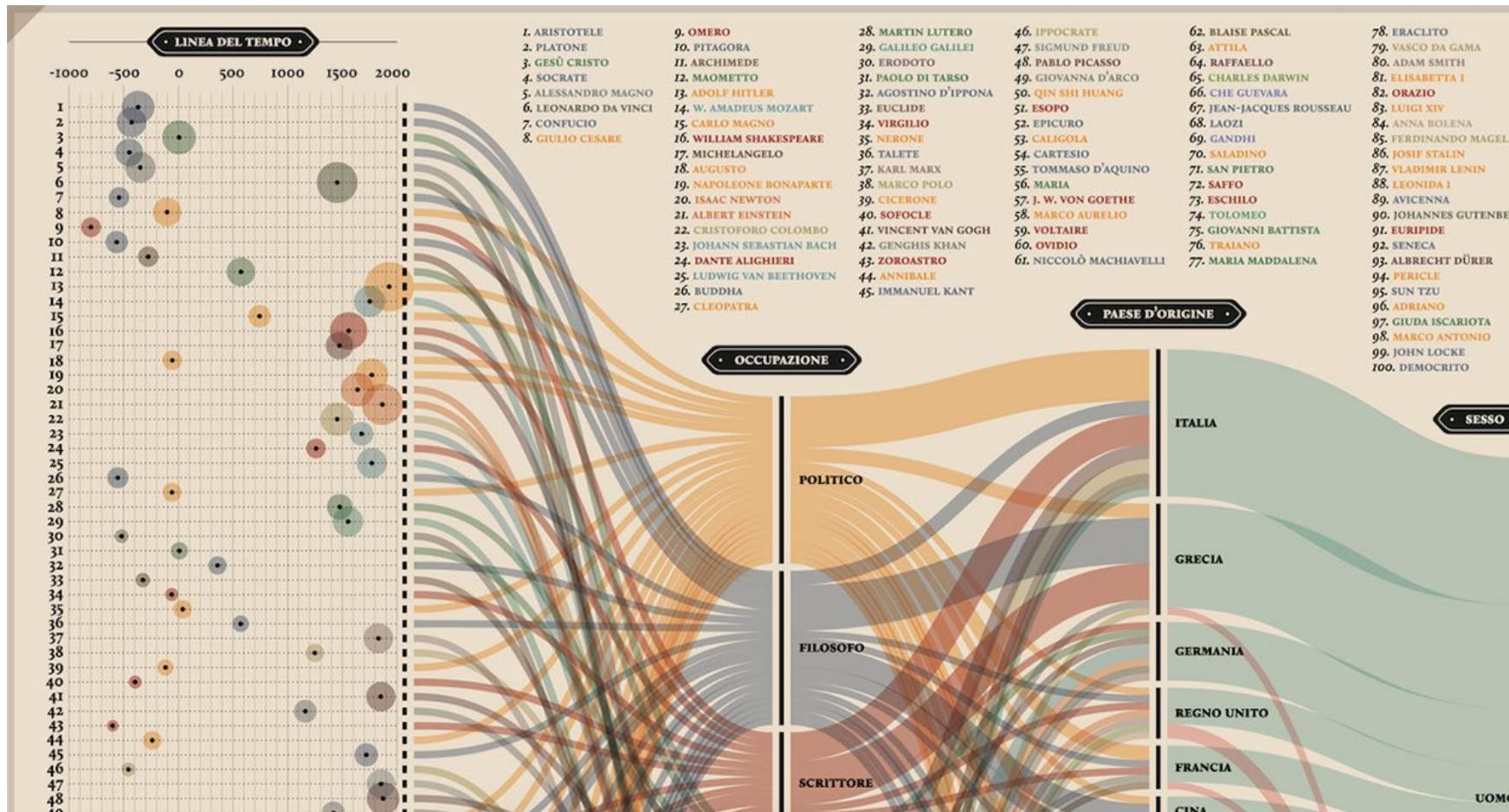
Pantheon, by Valerio Pellegrini
 Visualizing the 100 most
 influential figures in History
 (Wikipedia visits)

Columns show **occupation**,
country of origin and
gender

Flow lines link individuals to
 the column variables, width
 ~ influence



Sankey diagram

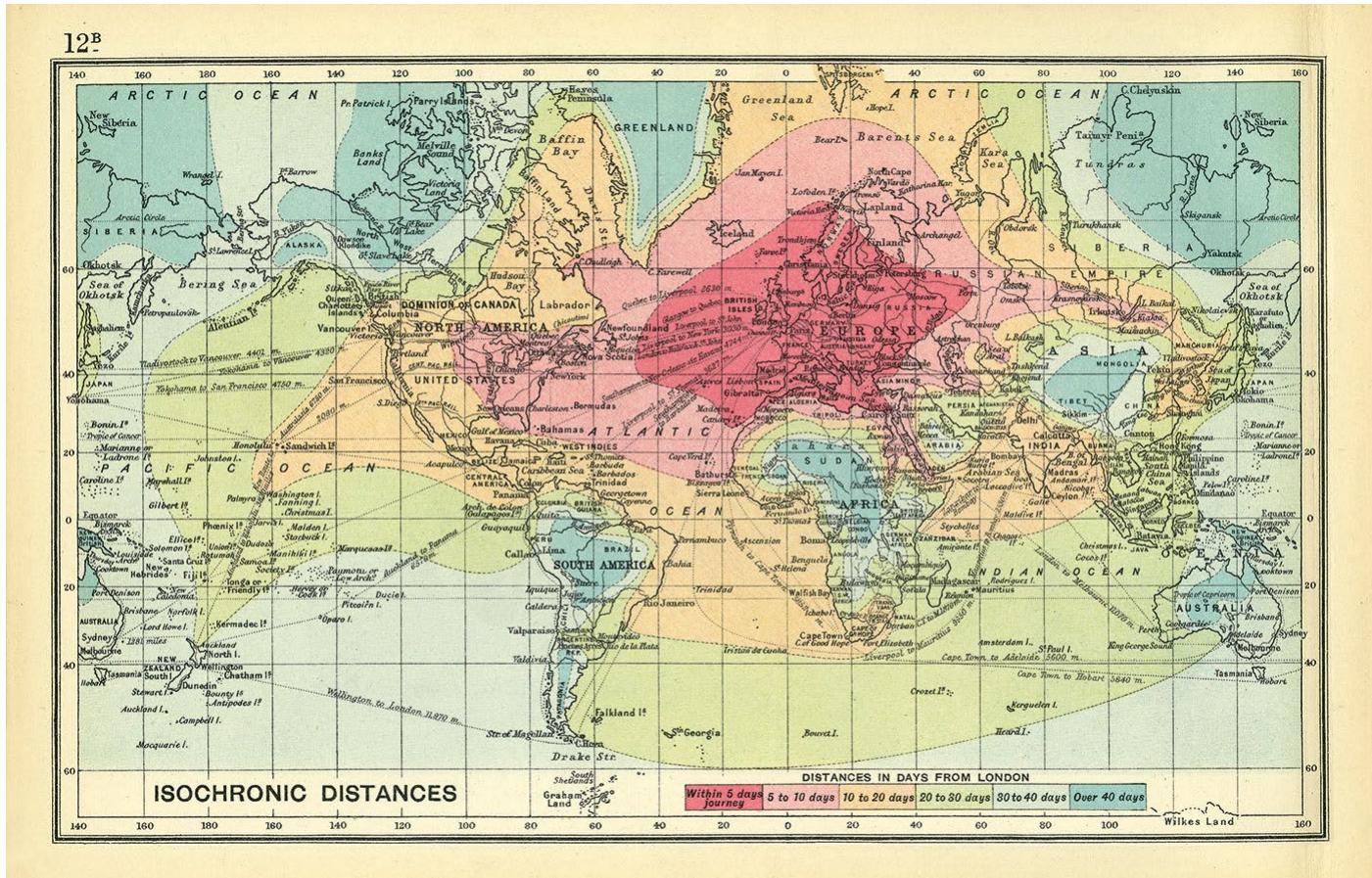


Multiple dimensions of the most influential people in history

From: <http://visualoop.com/blog/83382/pantheon-by-valerio-pellegrini>

3D: Iso-contour maps

Early attempts to show 3D data used **contours of equal value** on a map
The data was actually very thin; the contours the result of imaginative smoothing



Francis Galton, *Isochronic chart of travel time, 1881*

3D: Bivariate density estimation

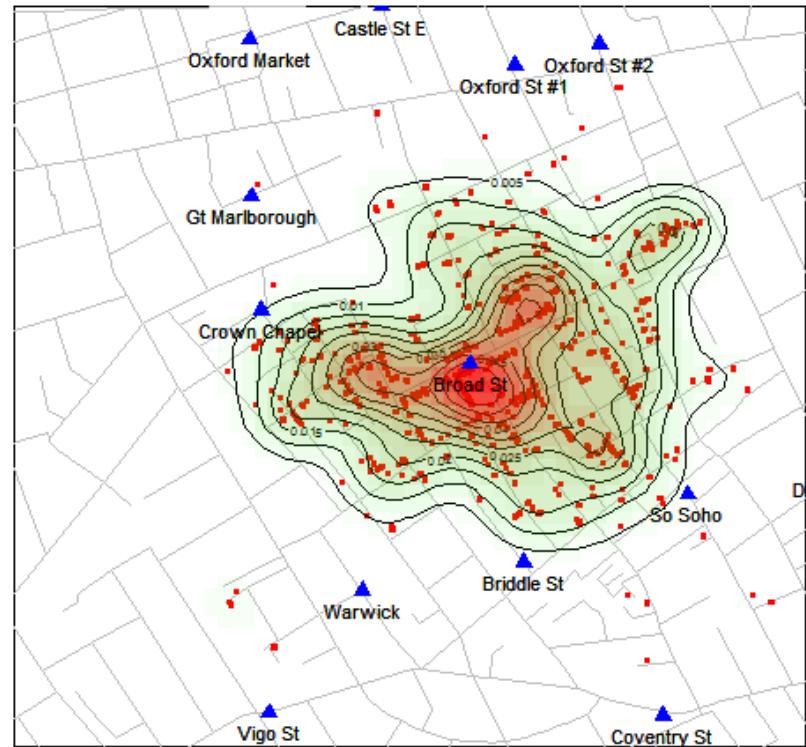
John Snow's map of cholera deaths in London, 1854



Broad St. pump

Modern statistical techniques can compute contours of constant density

Snow's Cholera Map, Death Intensity



Data: [HistData](#) package for R



3D: population pyramid

Italian demographer Luigi Perozzo (1880) developed the first true 3D diagram showing the population of Sweden over years and age groups as a 3D surface

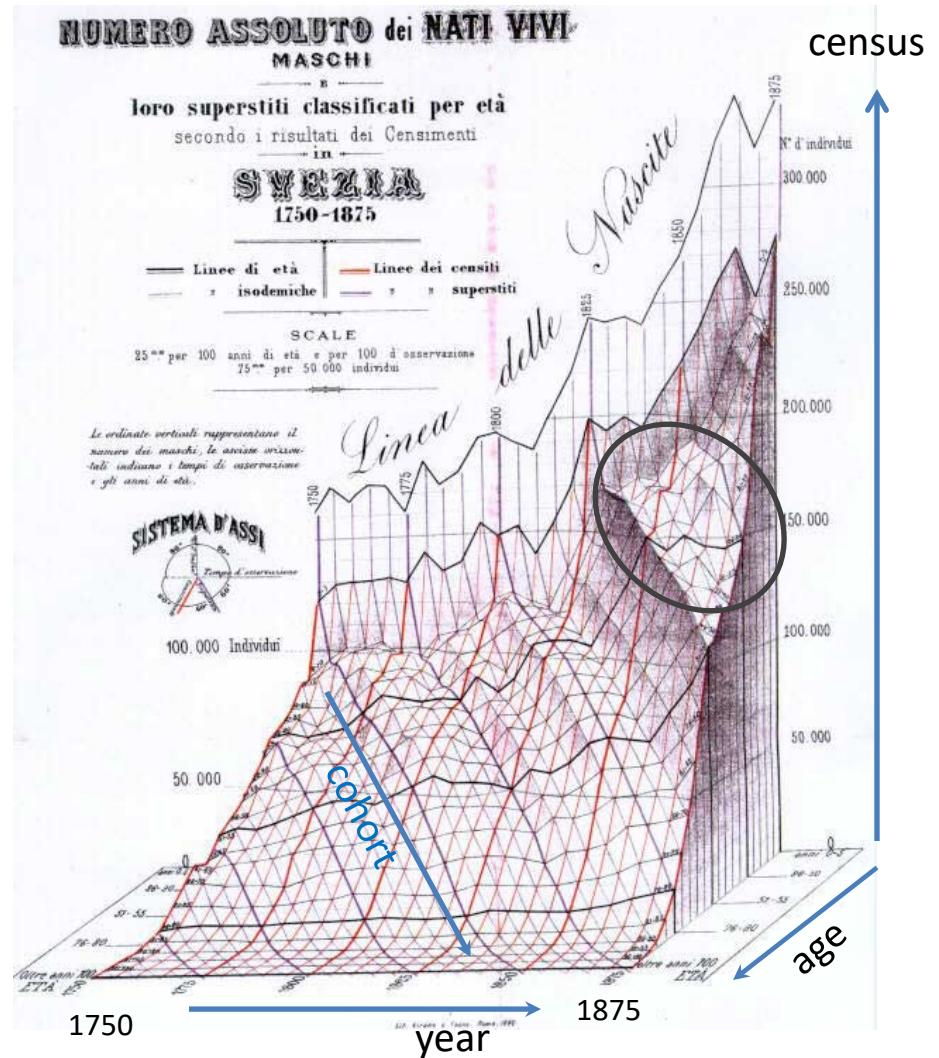
Census counts for a given **year** are shown by the **red** lines

Survival of a given **age** are shown by **black** lines

Cohorts are shown by diagonal lines down & to the right

These 3 variables are primary in demography.

A mystery here: what caused the decline at the upper right?

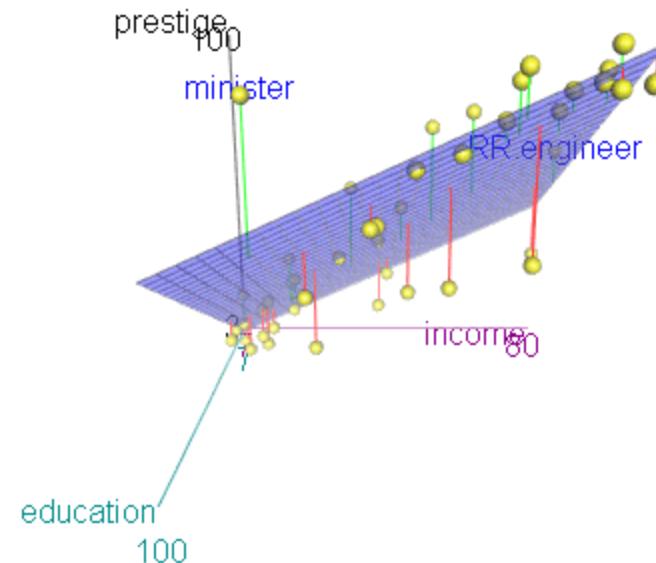


3D: scatterplot & regression surface

How does occupational prestige depend on income & education?

This plot shows the data and a fitted multiple regression surface, connecting the points to the regression plane

It is hard to see in a static view, but easier when the plot is rotated dynamically

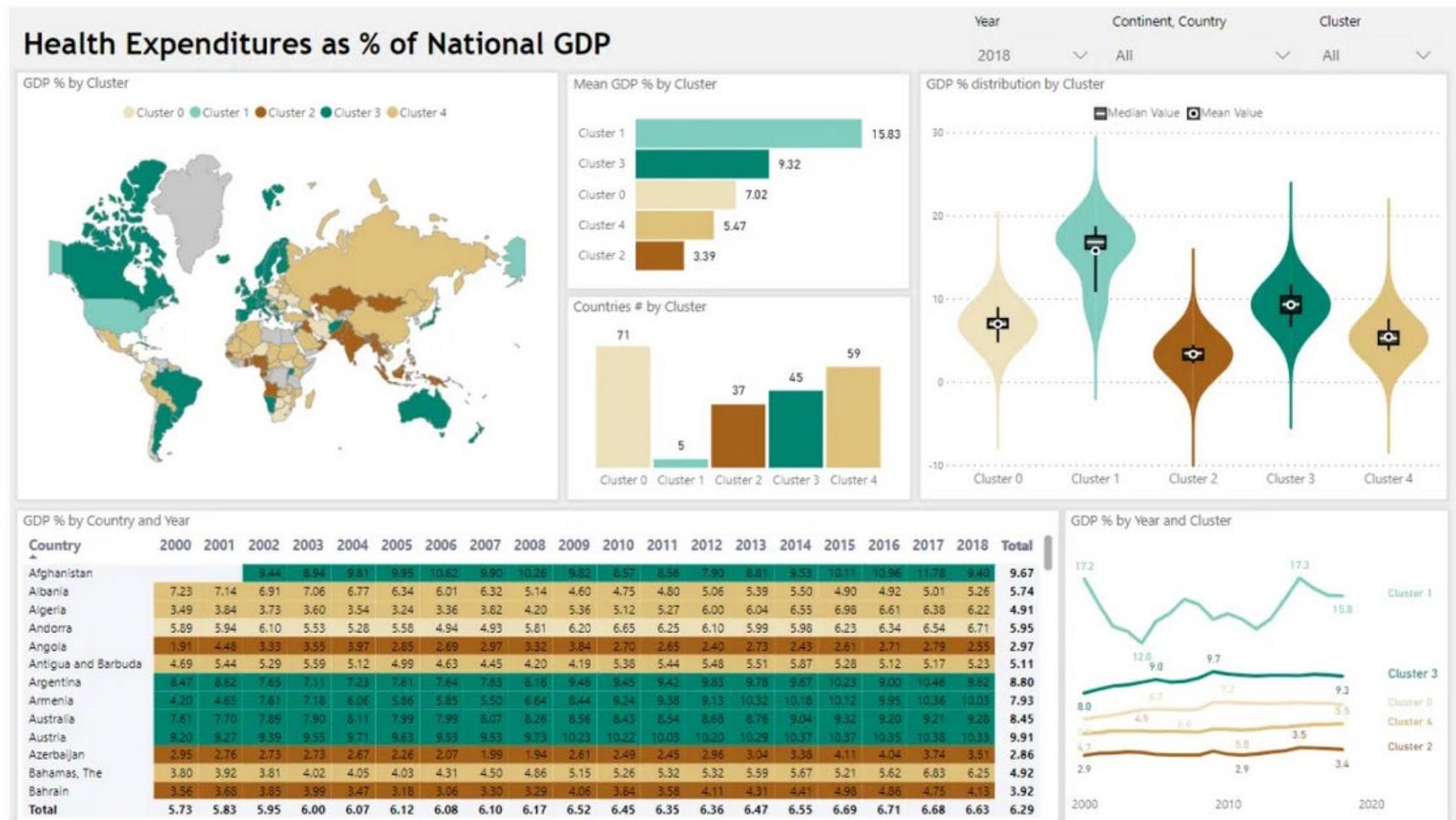


This plot is produced in R, using the [car](#) and [rgl](#) packages

```
data("Duncan", package="car")
scatter3d(prestige ~ income + education, data=Duncan, id.n=2)
movie3d(spin3d(c(0,1,0), rpm=6), duration=6, movie="duncan-reg3d")
```

Dashboards

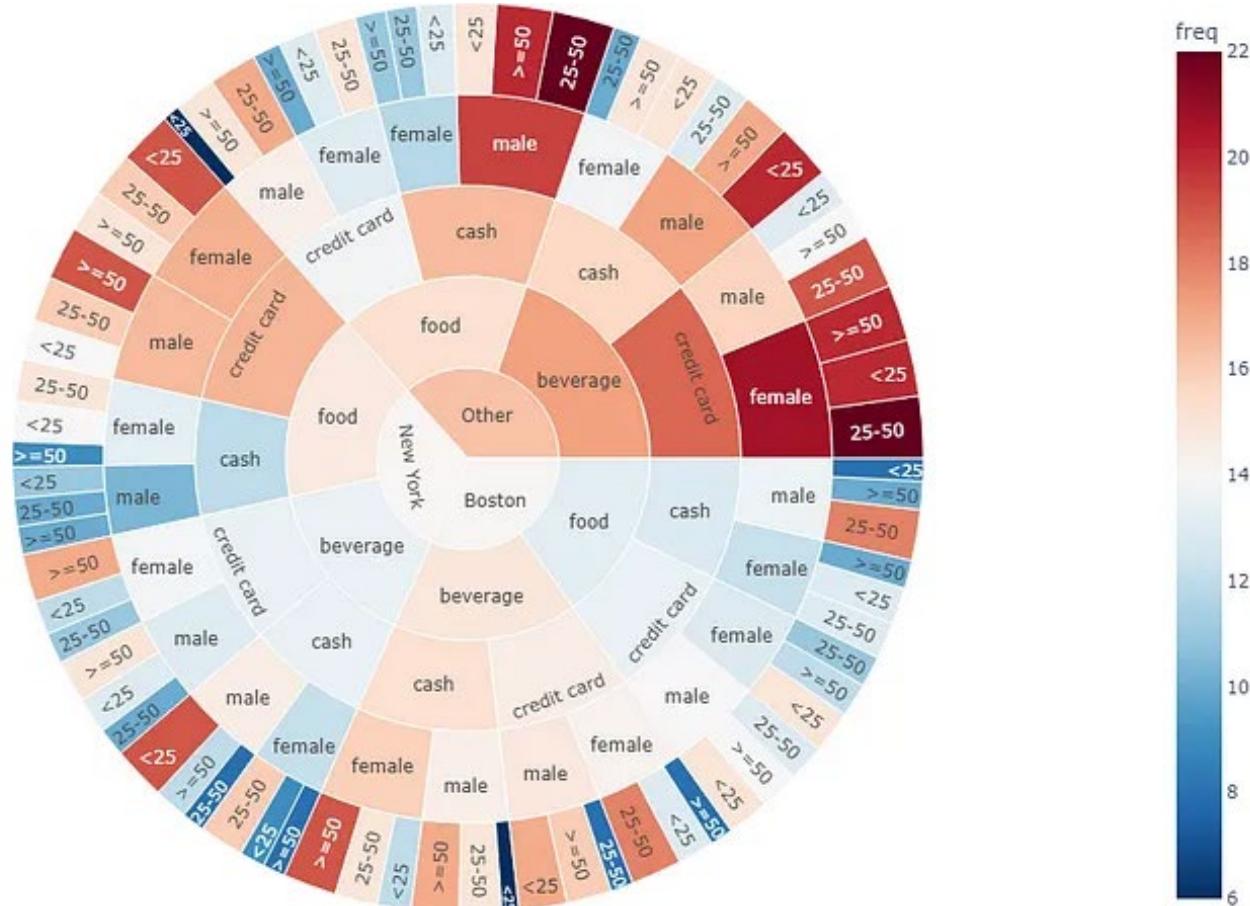
Dashboards provide multiple images of different aspects, often linked interactively

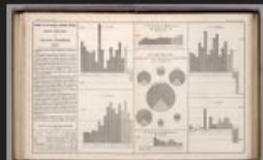


Exercise

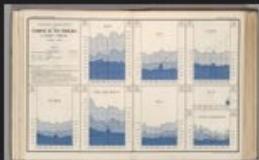
What is this SUNBURST chart trying to show?

- How many dimensions of data?
- What do the colors mean?





Ministere des T...
Statistique
1882
12513.
▼ Related (34)



Thematic (statistical) maps



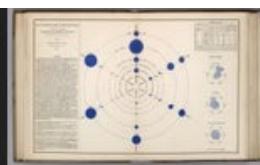
Ministere des T...
Statistical Dia...
1883
12514.021
▼ Related (34)



Ministere des T...
Statistical Dia...
1883
12514.022
▼ Related (34)



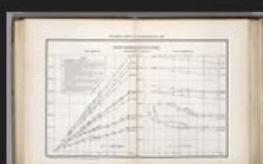
Ministere des T...
Statistical Dia...
1885
12515.011
▼ Related (31)



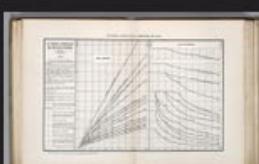
Ministere des T...
Statistical Dia...
1884
12515.012
▼ Related (31)



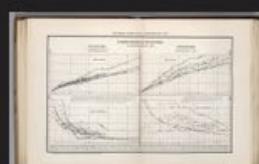
Ministere des T...
Statistical Dia...
1885
12515.013
▼ Related (31)



Ministere des T...
Statistical Dia...
1885
12515.014
▼ Related (31)



Ministere des T...
Statistical Dia...
1885
12515.015
▼ Related (31)



Ministere des T...
Statistical Dia...
1885
12515.016
▼ Related (31)



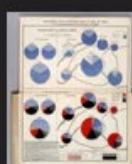
Ministere des T...
Statistical Dia...
1884
12515.029
▼ Related (31)



Ministere des T...
Statistical Dia...
1884
12515.030
▼ Related (31)



Ministere des T...
Statistical Dia...
1886
12516.015
▼ Related (28)



Ministere des T...
Statistical Dia...
1886
12516.024
▼ Related (28)



Active Media Group:

Thematic maps & Spatial visualization

Thematic maps use a wide variety of techniques to display quantitative or qualitative variables on the geographic framework of a map

Once the domain of cartographers, these ideas are now being developed as an area of **geospatial visualization** and geospatial statistical methods

	Point	Linear	Areal	2½-D	True 3-D
Spacing					
Size					
Perspective Height					None Possible
Orientation				None Recommended	
Shape				None Recommended	
Arrangement				None Recommended	
Lightness					

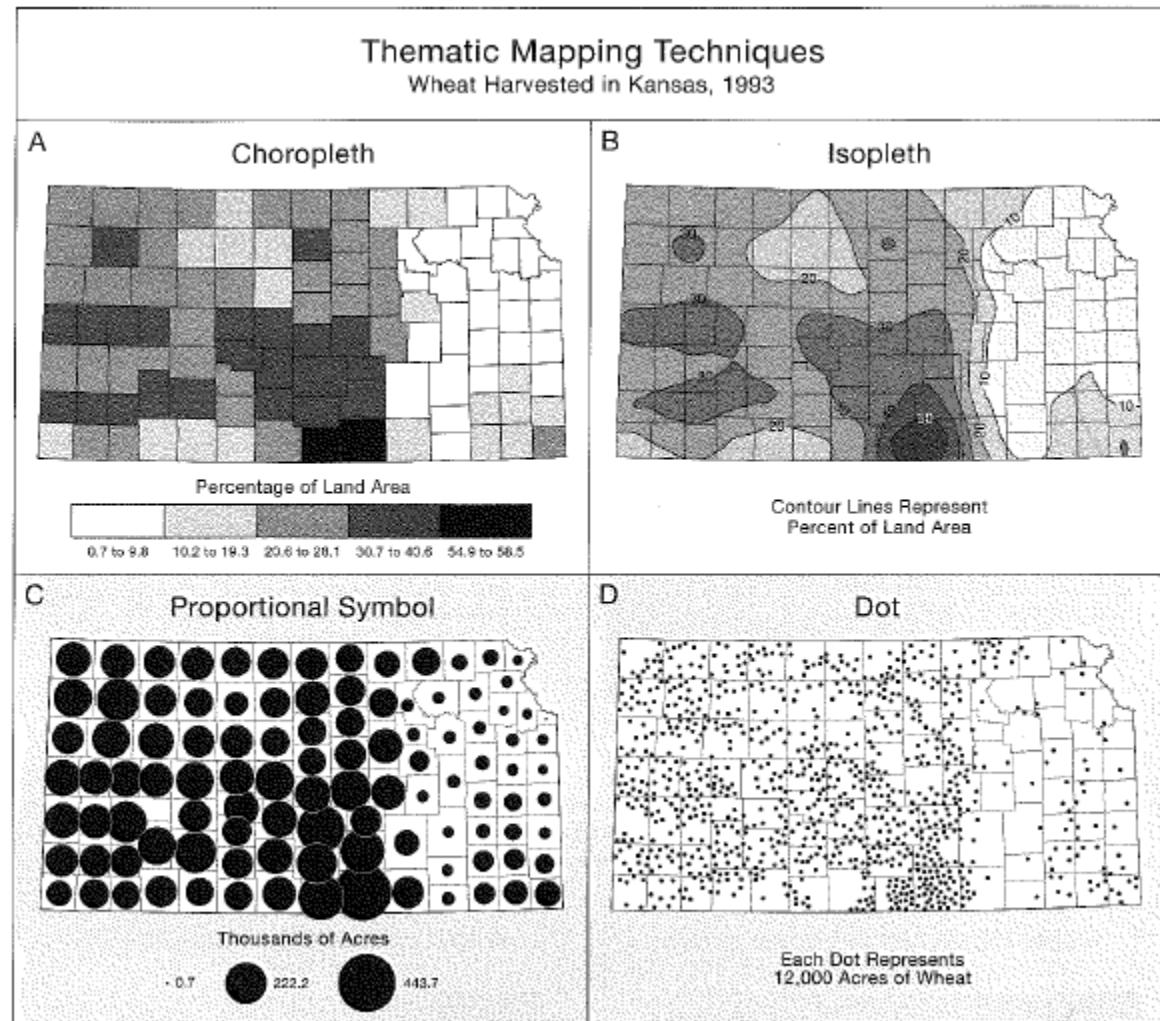
From: Slocum et al., *Thematic cartography and geographical visualization*, Fig 4.3

Thematic maps: Types

Basic types of thematic maps

Most are **direct** mappings of numbers to visual variables

- **Choropleth** maps shade by geographic unit
- **Isopleth** maps use contours of equal value



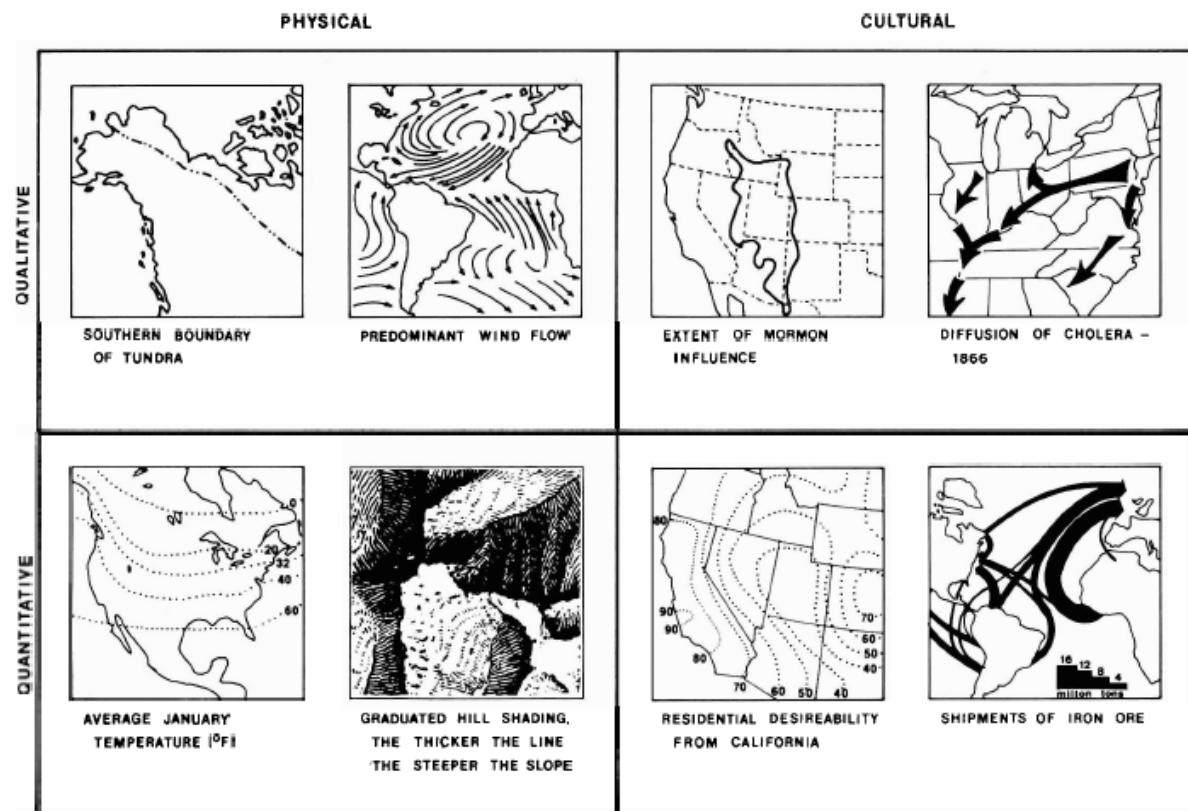
From: Slocum et al., *Thematic cartography and geographical visualization*, Fig 4.9

Thematic maps: Theory

Alan MacEachern (1979) classifies point, line and area symbols on thematic maps according to whether they depict **quantitative** or **qualitative** phenomena, in the **physical** or **cultural** domain.

This is a coarse classification.

Theories, ideas, and methods have advanced considerably since this time.



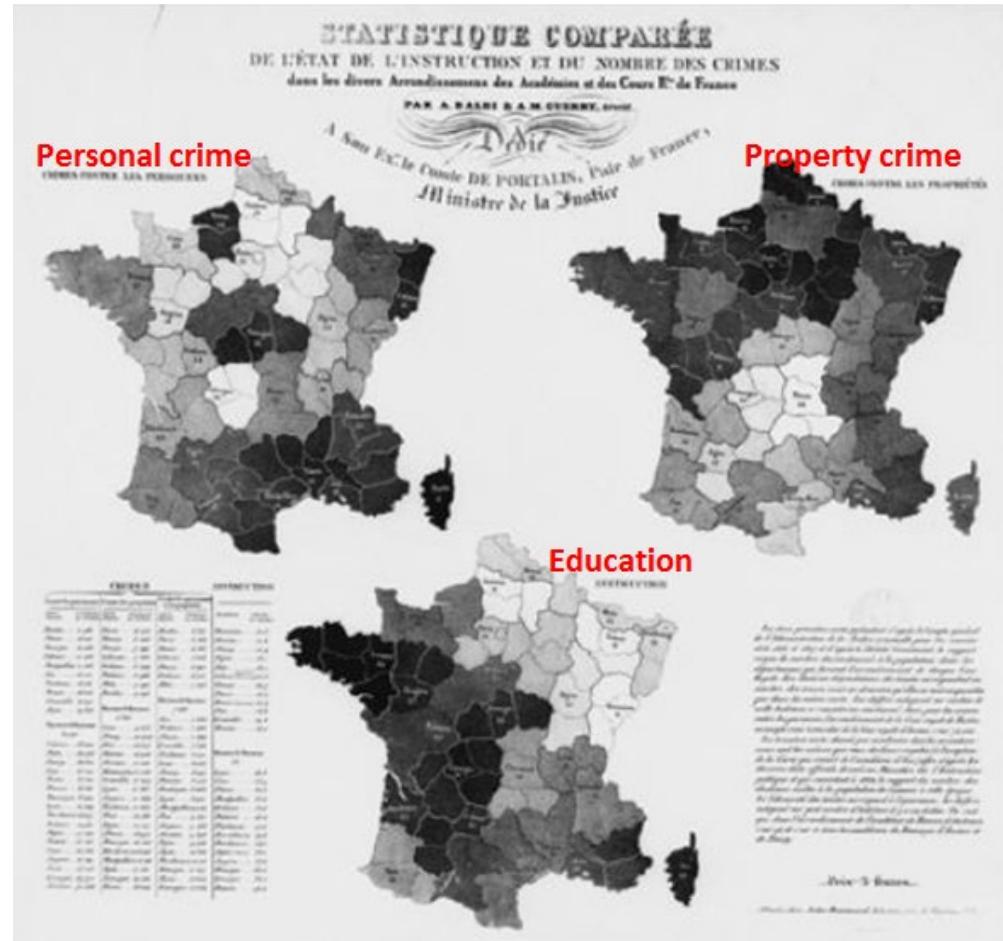
MacEachern, A. (1979). The Evolution Of Thematic Cartography / A Research Methodology and Historical Review, *The Canadian Cartographer* 16(1) June 1979, p. 17-33

Choropleth maps

Balbi & Guerry (1829)

- First thematic maps of crime data
 - First comparative maps (“small multiples”)
 - → Crime against persons inversely related to crime against property
 - → Education: *France obscure* & *France éclairée*
 - → N. of France highest in education & also property crime

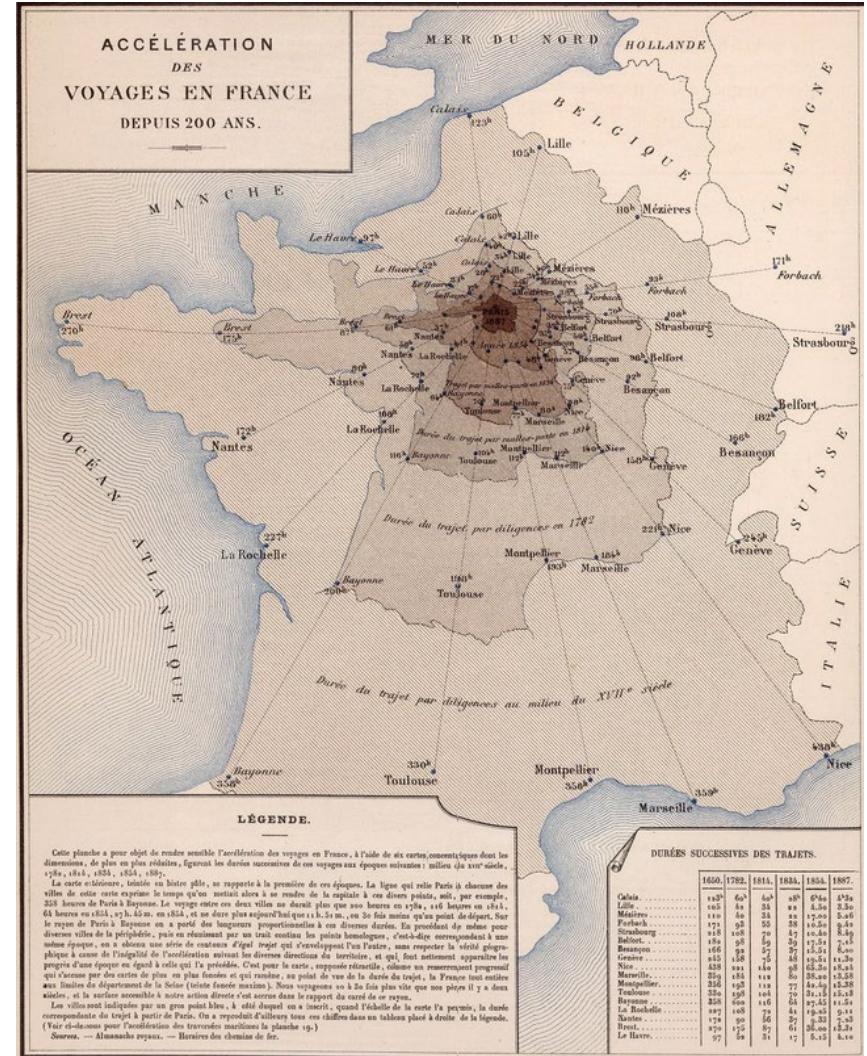
This was the beginning of modern criminology & social science --- relations among social variables made visible



See: Friendly, M. (2022). [The life and works of André-Michel Guerry, revisited](#). *Sociological Spectrum*, 42, 233–259

Anamorphic maps

- *Anamorph*: Deforming a spatial size or shape to show a quantitative variable
- Émile Cheysson used this to show the decrease in travel time from Paris to anywhere in France over 200 years



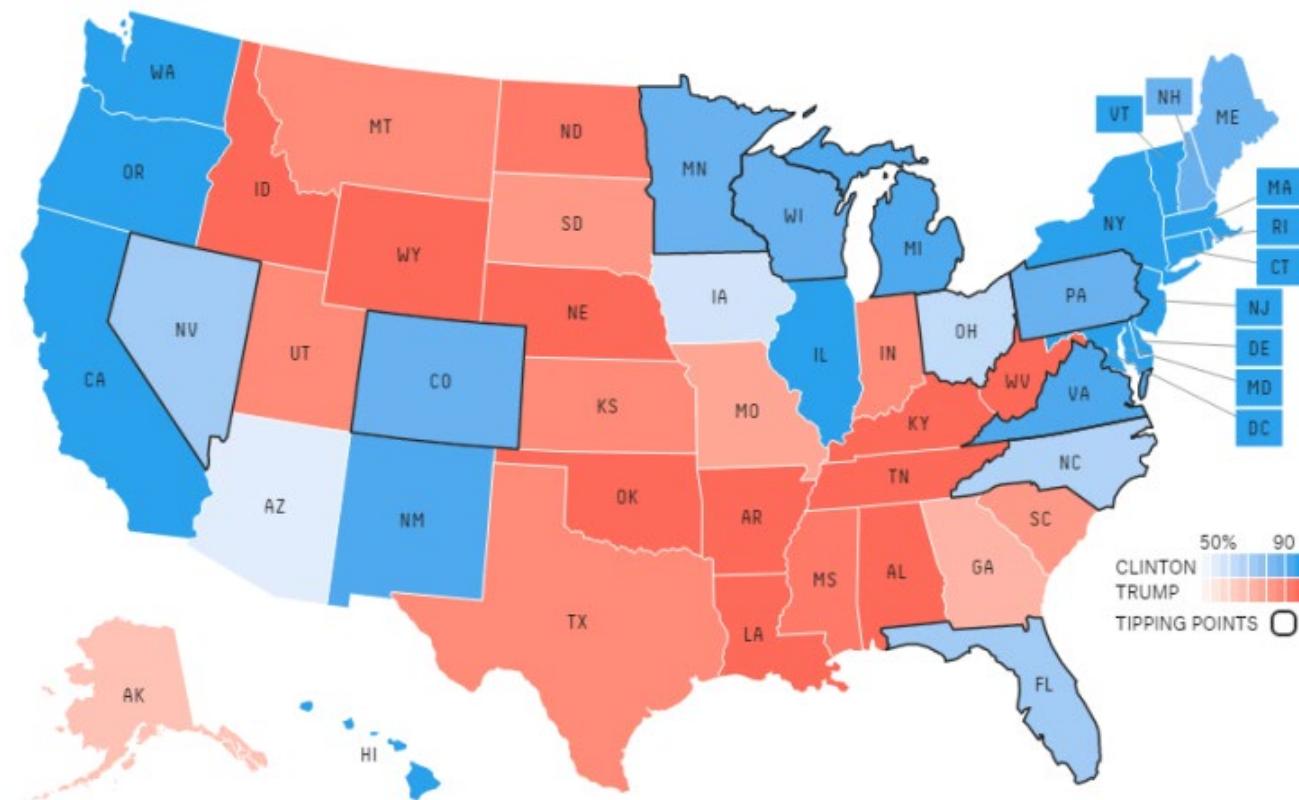
Album de Statistique Graphique, 1888, plate 8

What's wrong with choropleth maps?

Choropleth maps are misleading because size (area) of units dominates perception. This is particularly true for maps of the US & Canada. Not so for France (why?)

Montana looks
bigger than
Washington

Note use of labels
for small NE states



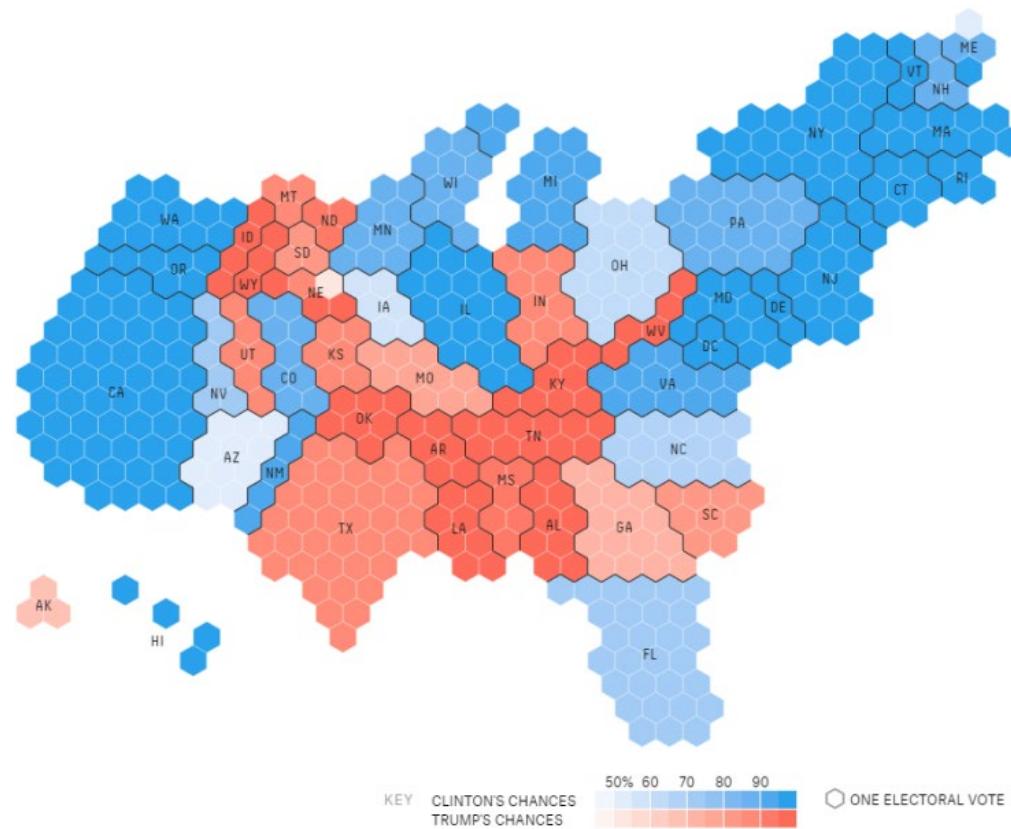
Cartogram (tilegrams)

A **tilegram** uses hexagonal tiles to make area proportional to a given variable

Here, the size of each state is made \sim number of electoral college votes

Now, it is easy to see the impact of states

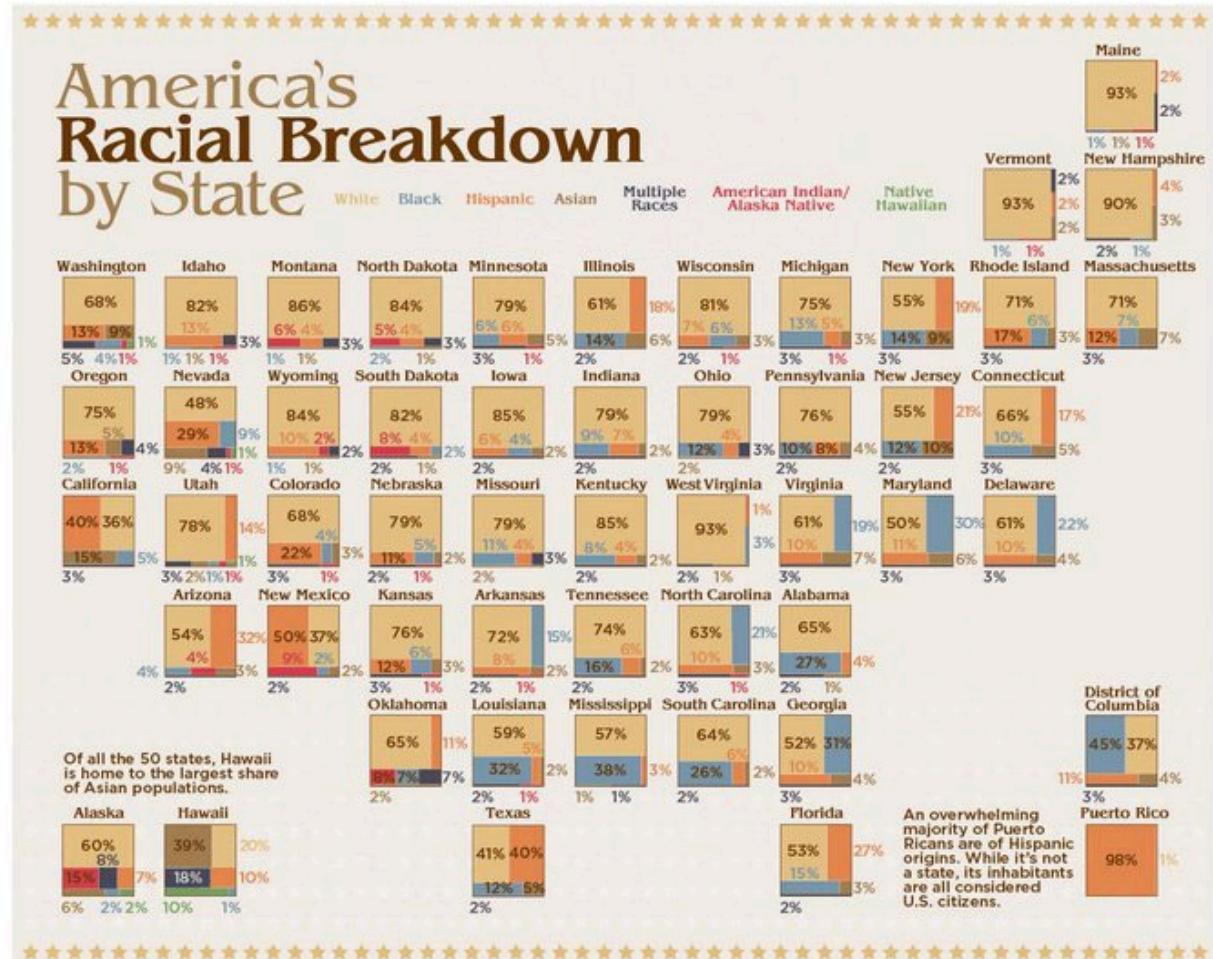
Take-away: Area doesn't vote; People do!



Mosaic cartograms

US map provides a spatial framework for showing the distribution of categorical data

Each tile is positioned as in a schematic US map



Sources: Kaiser Family Foundation, U.S. Census Bureau

[/visualcapitalist](#)

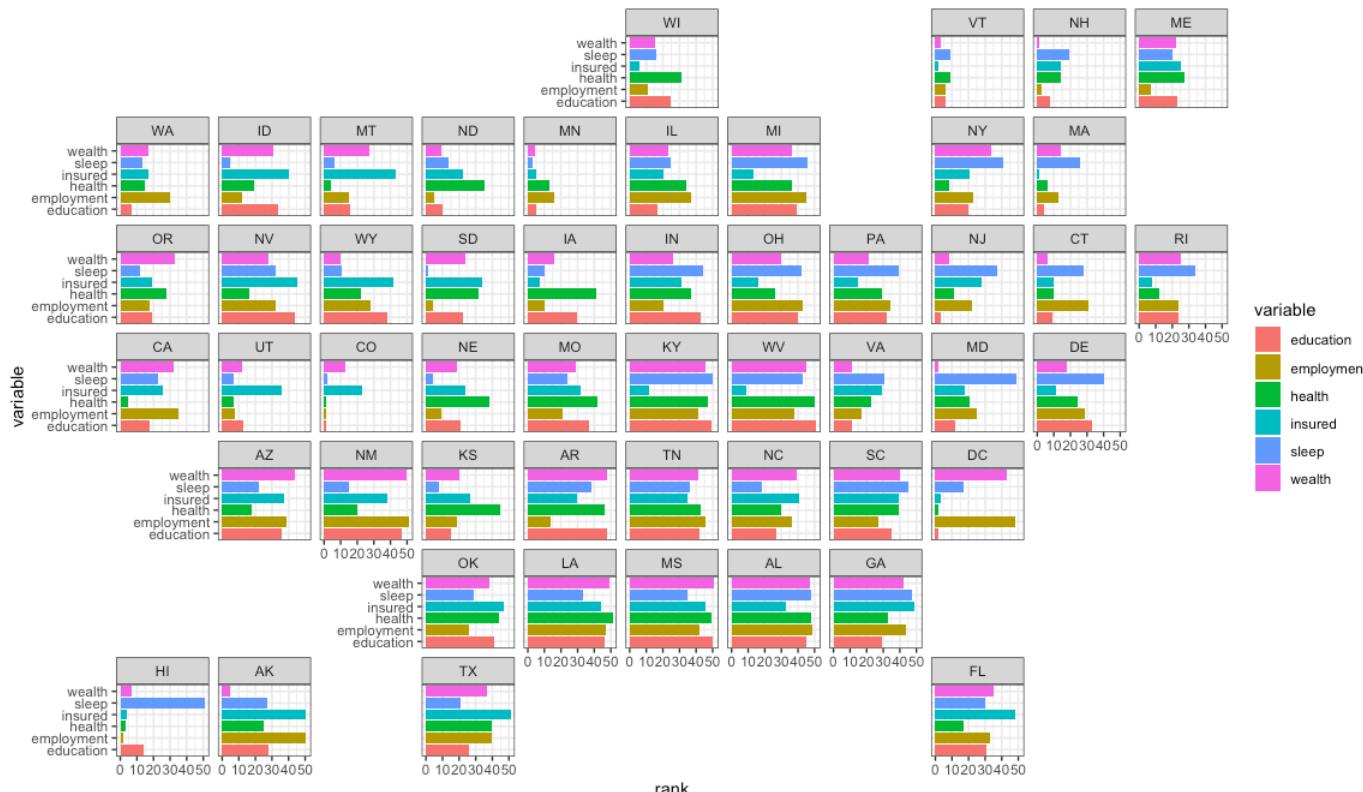
[@visualcap](#)

[visualcapitalist.com](#)

Geo-faceting

More general idea:

- A grid of (x, y) locations defines geographic units
- Each grid cell can be composed of any kind of plot conceivable with ggplot2



From: <https://cran.r-project.org/web/packages/geofacet/vignettes/geofacet.html>

Worldmapper: The world in cartograms

How to visualize social, economic, disease, ... data for geographic units?

worldmapper.org : cartograms: area ~ variable of interest (700+ maps)

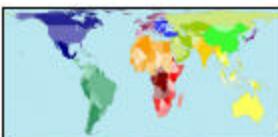
WORLD MAPPER *The world as you've never seen it before*

Search for a map: Go

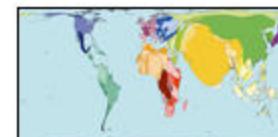
Home Map Categories Thumbnail Index A-Z Map Index About Worldmapper Help

Worldmapper is a collection of world maps, where territories are re-sized on each map according to the subject of interest. There are 366 maps, also available as PDF posters. Use the menu above or click on a thumbnail image below to view a map.

Reference maps ...

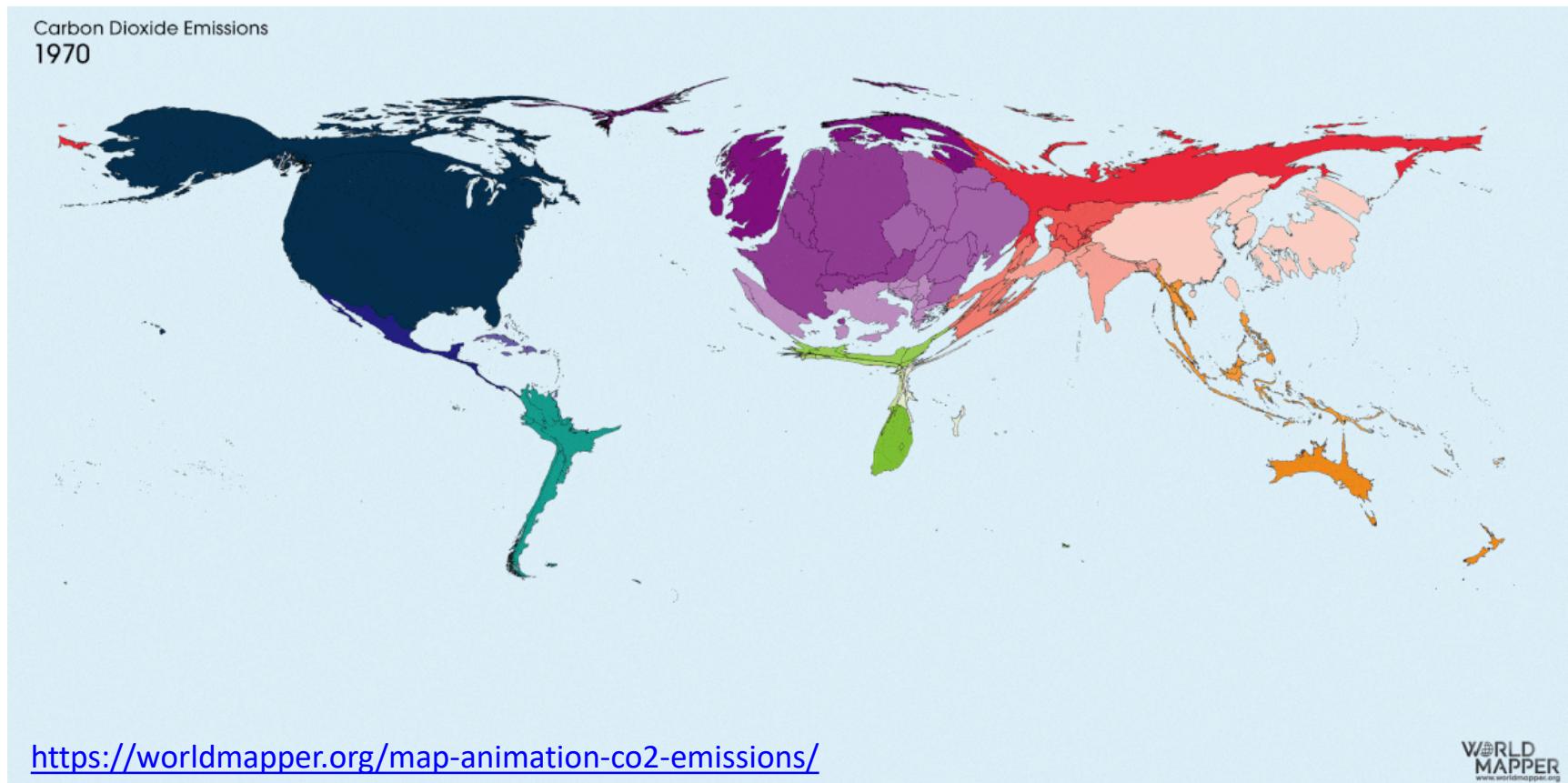
- 
Total Population
- 
Land Area
- 
Labelled Map
- 
Appendix A (Areas included)

Newest maps ...

- 
Often Preventable Deaths
- 
Morphing animation
- 
Deaths from Non-Communicable Illnesses
- 
All Injury Deaths

Worldmapper: Carbon emissions

This map animation shows the growth in CO₂ emissions globally: the map keeps growing in size from 1970 - 2016
also shows the changing shares of countries contributing to the increase in emissions



<https://worldmapper.org/map-animation-co2-emissions/>

Worldmapper: Cholera deaths

Deaths from cholera in 2004. Territory size ~ proportion of worldwide deaths

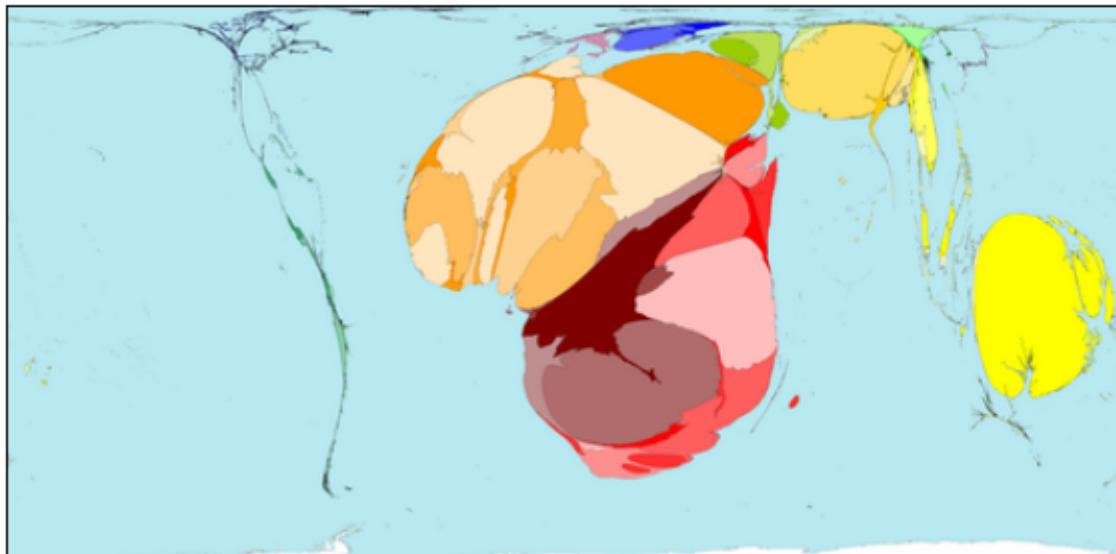
[< Previous Map](#)

Cholera Deaths

Map No. 232

[Open PDF poster](#)

[Next Map >](#)



'The cholera outbreak has continued ... water provided by the tankers is not enough and they try to boost their supply from the wells, which are not covered. The rain washes faeces and other pollutants into the wells ...' Pierre Kahozzi, 2004

Cholera deaths result from severe dehydration caused by diarrhoea. This is treatable: in 2004 the number of cholera deaths was only 2.5% of the number of cholera cases that year. Distributions of cholera cases and deaths differ due to differing availability of treatments.

In 1962, in Papua New Guinea, 36% of cholera cases, which was 464 people, died. In 2004, in the Central African Republic, 15% of cholera cases, which was 48 people, died.

In contrast, there were 73 territories where nobody died from cholera, because of good sanitation, clean water and available treatment. These territories have no area on this map.

Territory size shows the proportion of worldwide deaths from cholera that occurred there in 2004 or most recent year available.

Bivariate maps

How to show relation between two variables on a map?

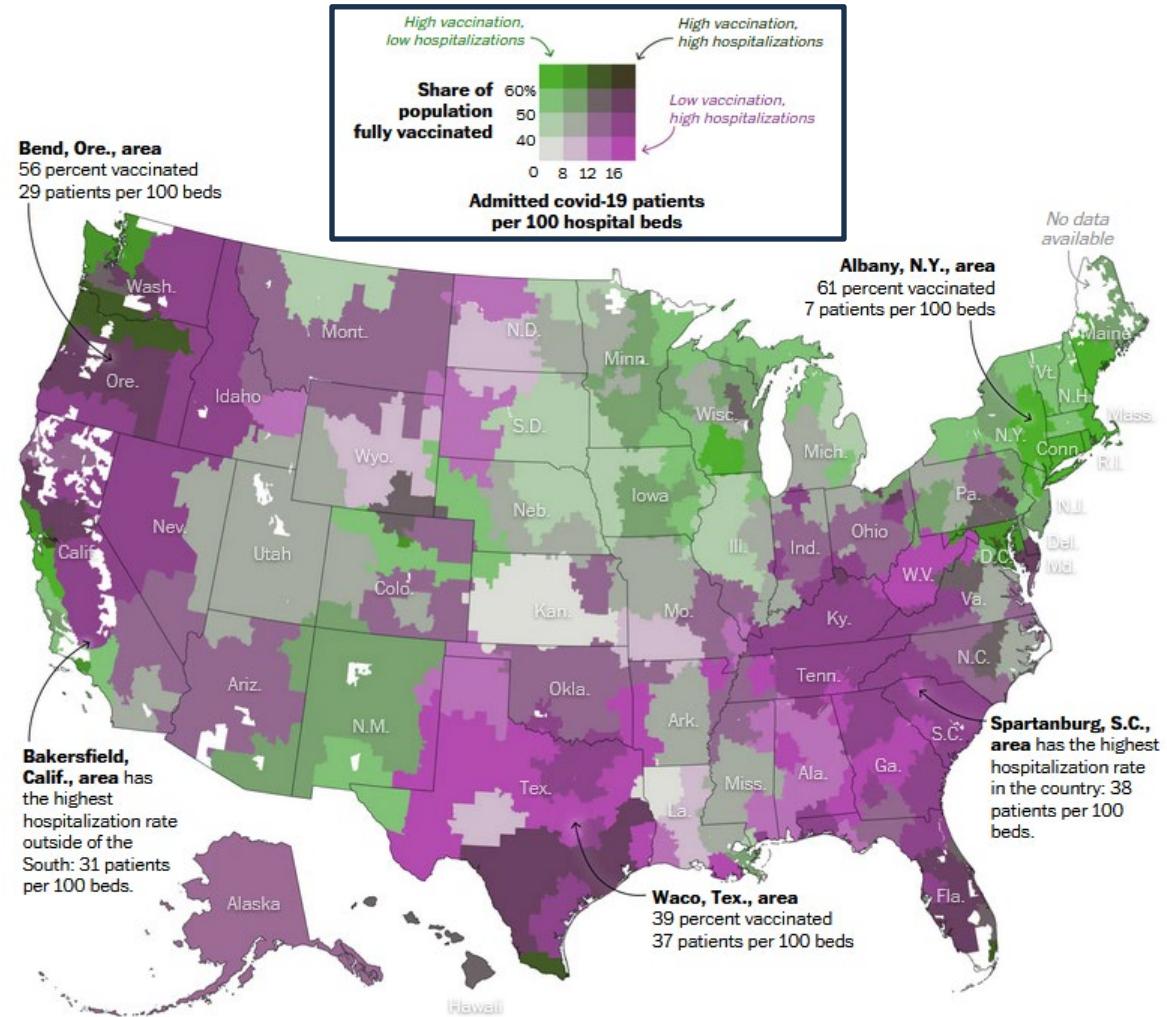
Bivariate maps combine two colors with degrees of saturation

Claim:

Regions with more vaccinations have fewer hospitalizations

Can you see this?

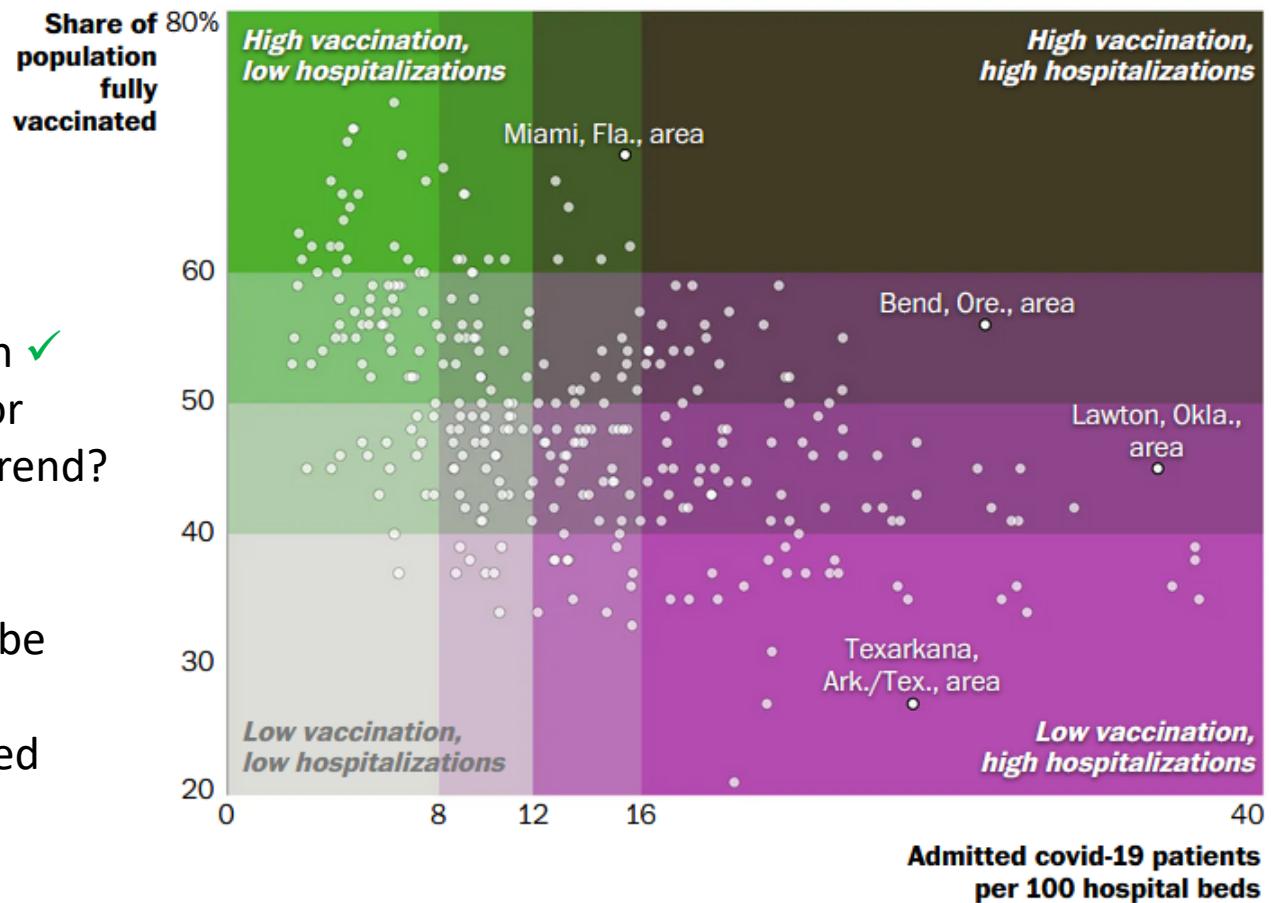
Vaccination rates and COVID hospitalizations



Scatterplot to the rescue

Distribution of vaccination and hospitalization rates

Most hospital regions with high vaccination rates have lower hospitalization rates – and places with lower vaccination rates tend to see higher rates of admitted patients.



This lovely scatterplot shows:

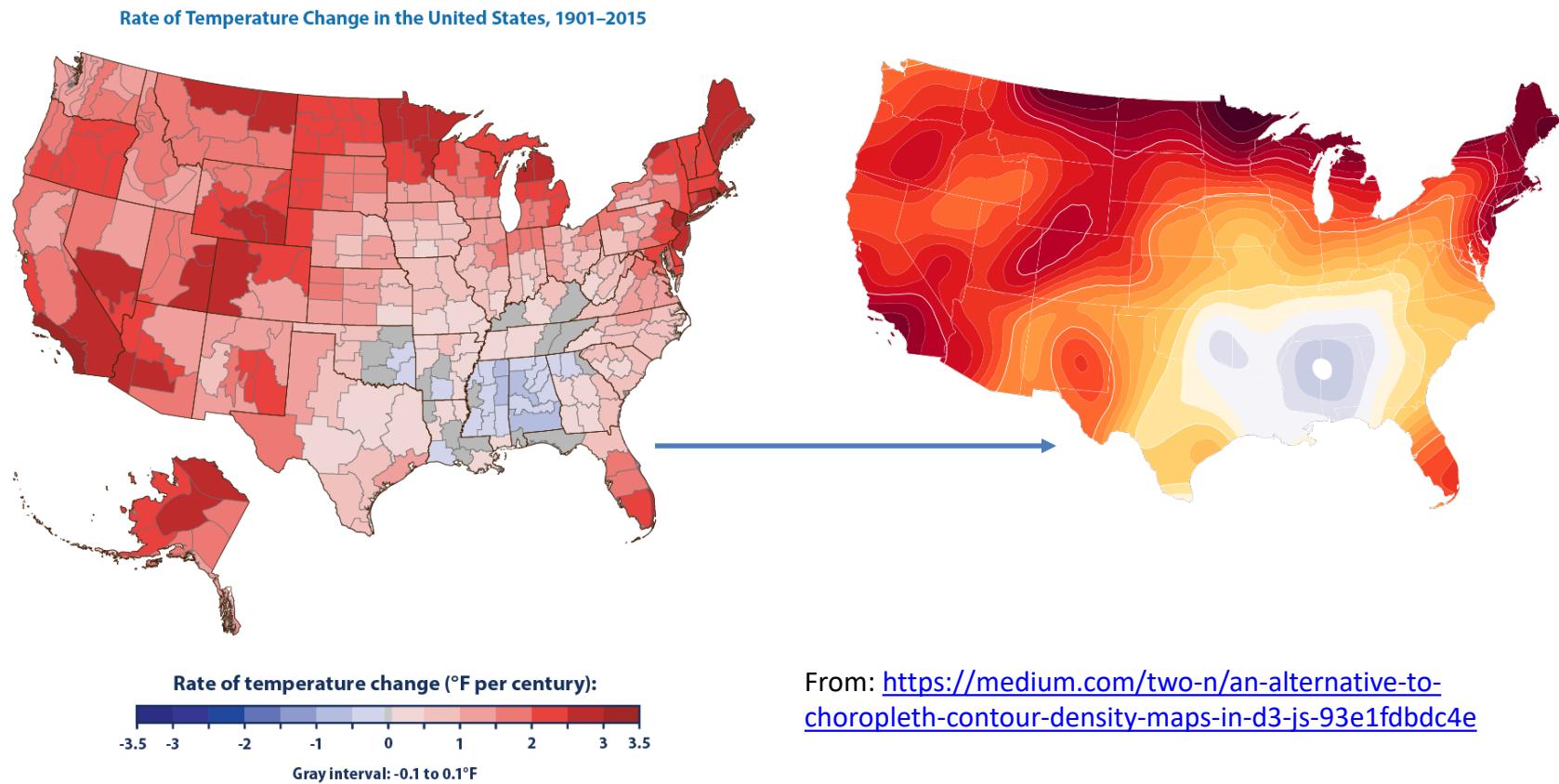
- Yes, inverse relation ✓
- NB: Classing of color
- Whoa: non-linear trend?

But:

- Shouldn't the axes be reversed?
- Geography is ignored

Contour maps

Contour maps ignore region boundaries and estimate constant contours of a phenomenon over geographical space. This is a form of **geo-smoothing**.



Spatial visualization: Analysis + maps

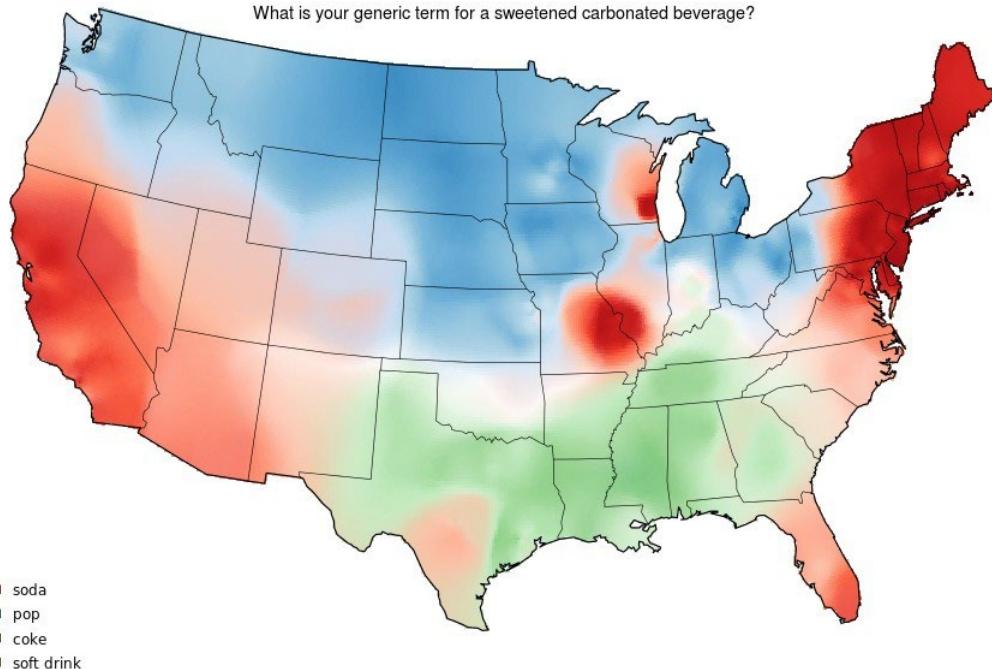
Linguistics: Food dialect maps— visualizing how people speak

In the *Cambridge Online Survey of World Englishes*, Bert Vaux and Marius L. Jøhndal surveyed 11,500 people to study the ways people use English words.

NC State Univ. student Joshua Katz turned the US data into shaded **kernel density maps**.

soda vs. pop?

What is your generic term for a sweetened carbonated beverage?



Take the survey: http://www.tekstlab.uio.no/cambridge_survey

Programming in R: <http://blog.revolutionanalytics.com/2013/06/r-and-language.html>

Spatial visualization: Analysis + maps

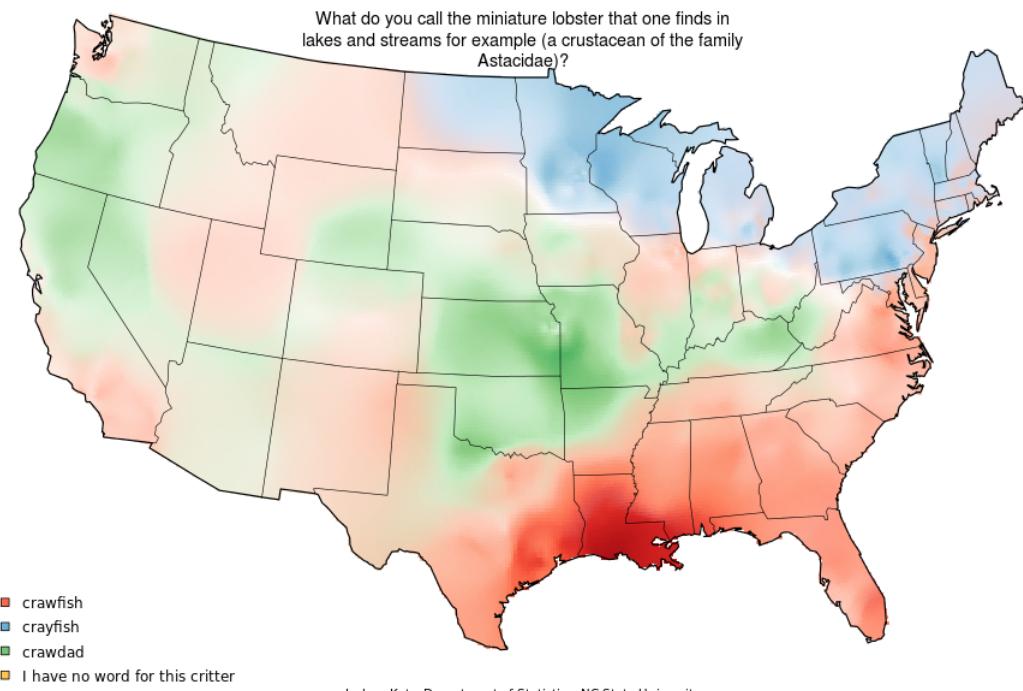
Linguistics: Food dialect maps— visualizing how people speak

A k -nearest neighbor **kernel density estimate** over (x,y) locations gives a smoothed & interpretable display of the choice probabilities.

Regional differences are quite apparent.

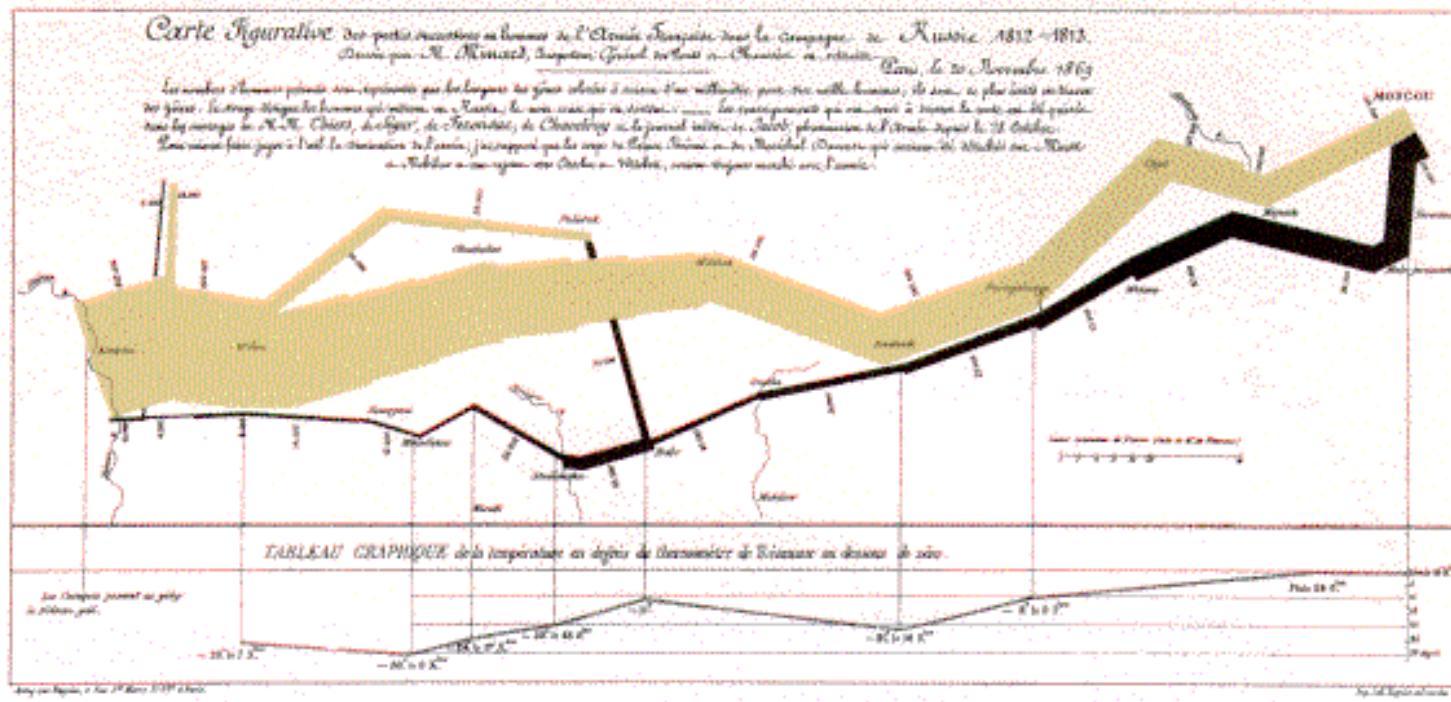
The use of **color** combines discrete categories with intensity to give a meaningful display

crawfish, crawfish, crawdad?



Flow maps

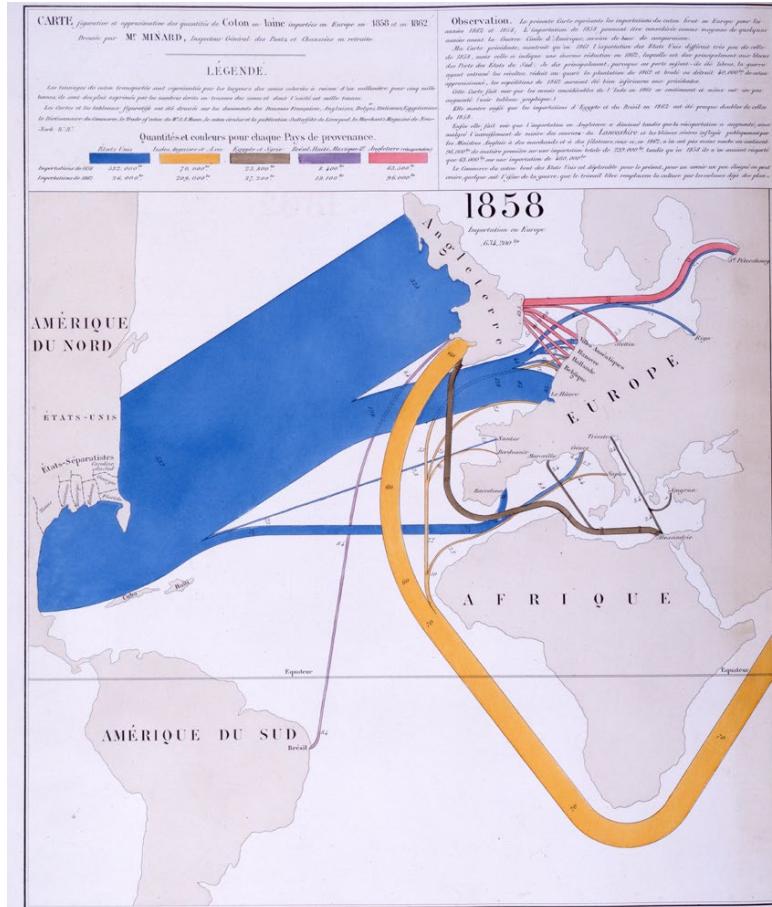
Flow maps show **movement** or **change** in a geographic framework
The master work is this image by Charles-Joseph Minard (1869)



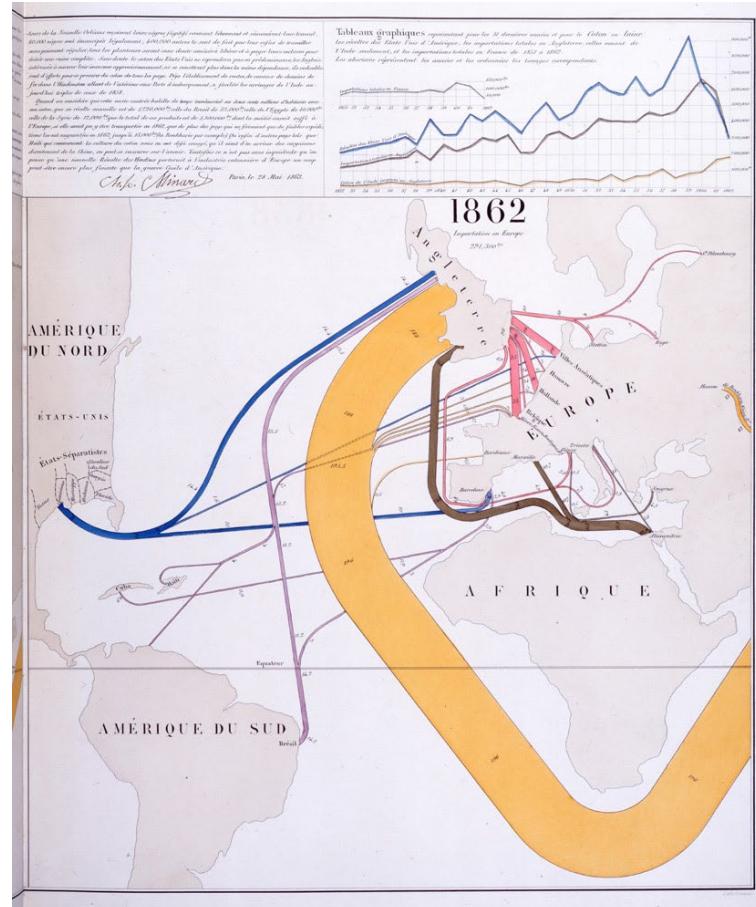
- Marey (1878): “*defies the pen of the historian in its brutal eloquence*”
 - Tufte (1983): “*the best statistical graphic ever produced*”

Effect of US civil war on cotton trade

Before



After

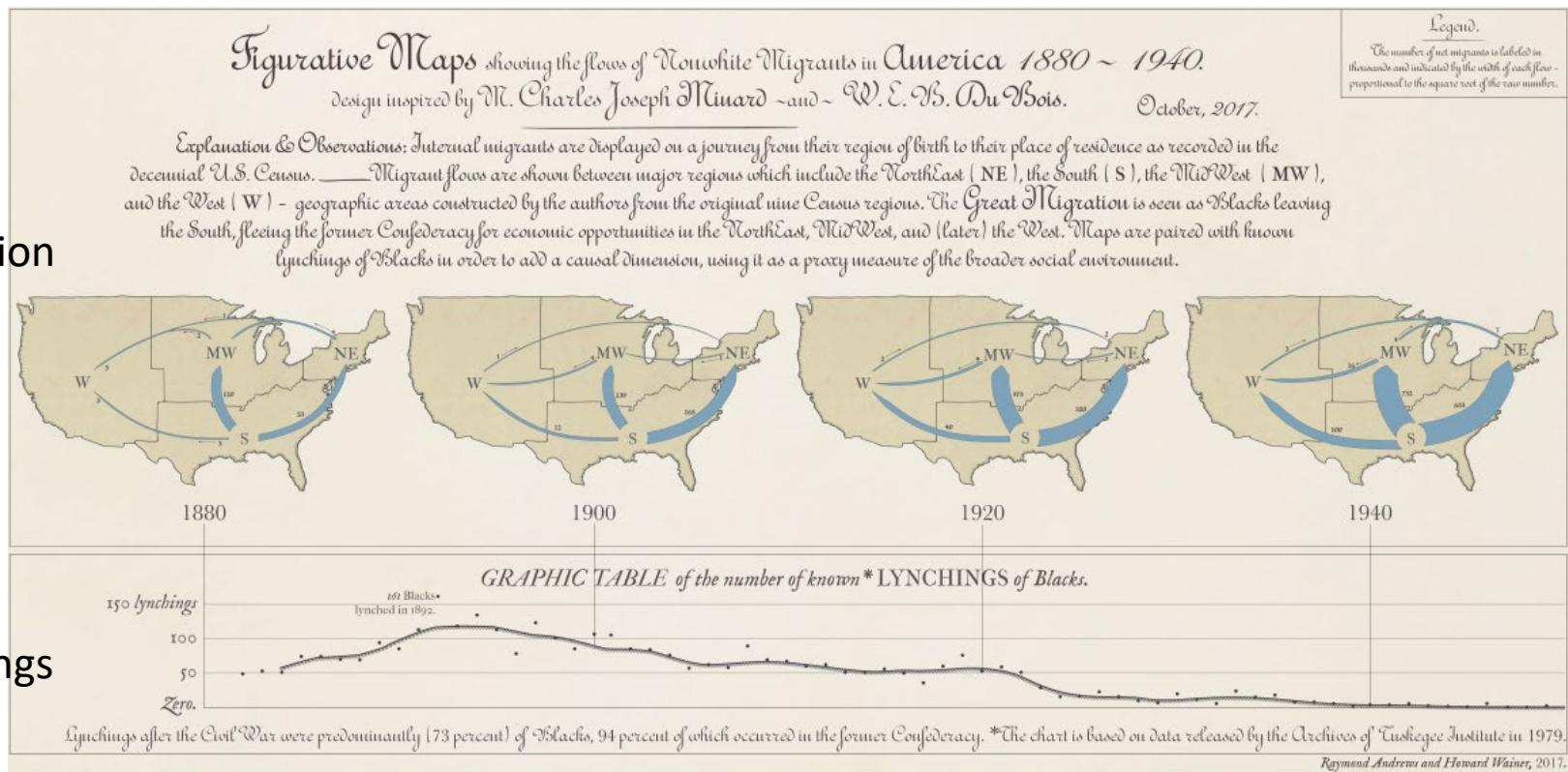


Note the deformation of the map to accommodate the data

The Great Migration

In a graphic tribute to C.-J. Minard and W. E. B. Du Bois, RJ Andrews & Howard Wainer tell the story of the migration of blacks from the southern US after freedom from slavery.

Migration



Andrews, R. J. & Wainer, H. The Great Migration: A Graphics Novel Featuring the Contributions of W. E. B. Du Bois and C. J. Minard. *Significance*, 2017, 14, 14-19. See also: <http://infowetrust.com/picturing-the-great-migration/> for the story of this graphic

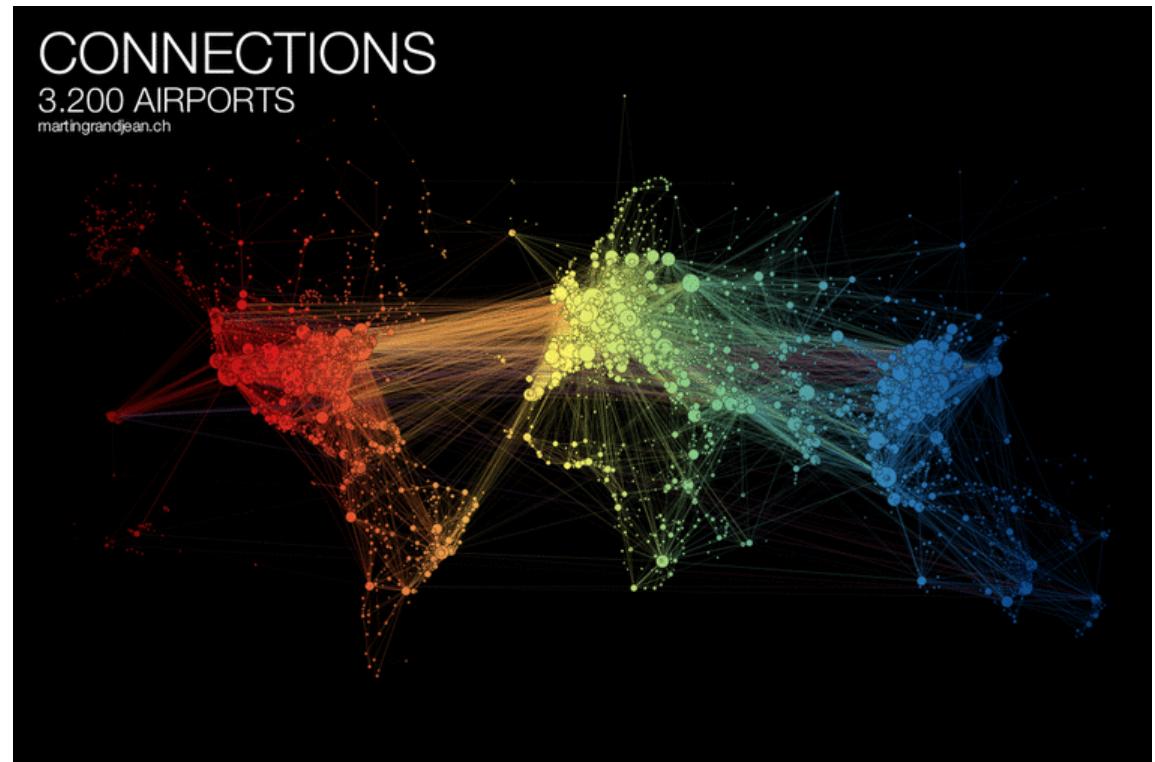
Network visualization



Once the domain of mathematicians & computer scientists, graph theory and network visualization turn out to have surprising & interesting applications.

Animated demo by Martin Granjean showing transport of passengers from/to world airports.

It illustrates the difference between geography & **force-directed layout** to focus on volume & connections



From: <http://www.martingrandjean.ch/connected-world-air-traffic-network/>
See more: <https://flowingdata.com/2016/05/31/air-transportation-network/>

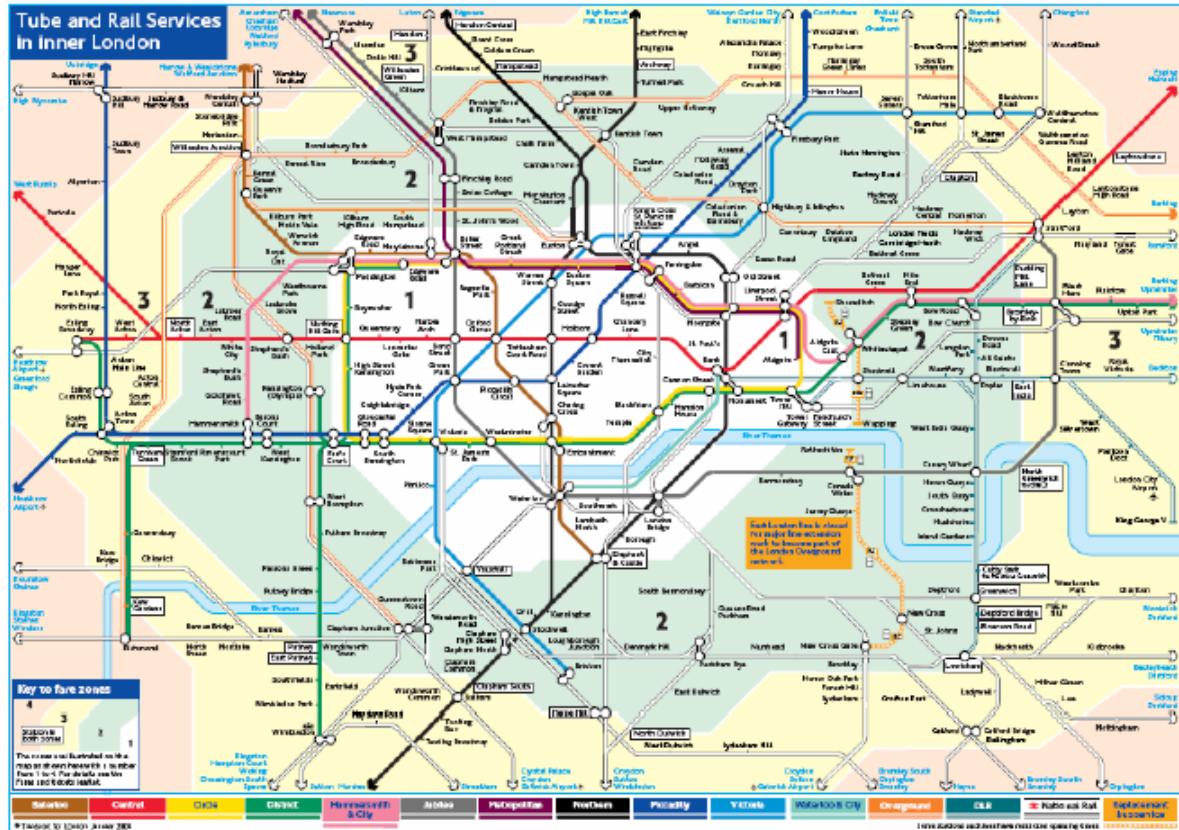
Network visualization: Transport maps

How do I get from Chigwell to Charing Cross?
How much will it cost?

This route map shows the connections and fare zones

The first one was designed by Henry Beck in 1931.

The modern version is zoomable and available on your phone.



See: <https://tfl.gov.uk/maps/track>

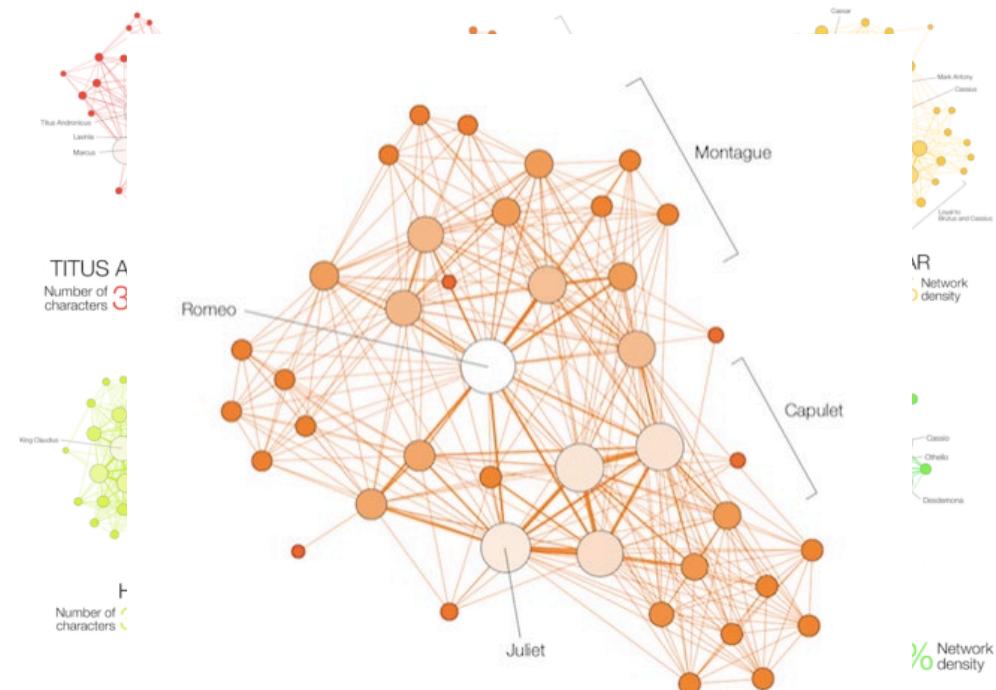
Network visualization: Shakespeare tragedies

A new form of literary criticism?

Martin Grandjean looked at the structure of Shakespeare tragedies through character interactions.

Each circle (node) represents a character, and an edge represents two characters who appeared in the same scene.

The structural characteristics of the graphs have meaningful interpretations.



ROMEO AND JULIET

Number of characters **41** | Network density **37%**

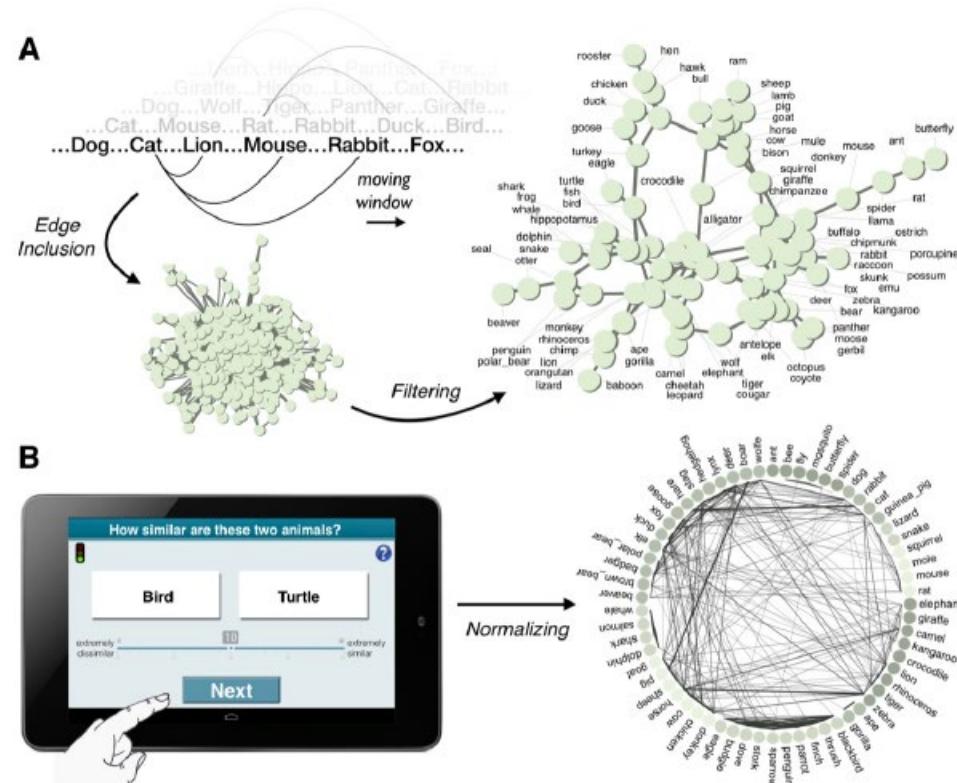
From: <https://flowingdata.com/2015/12/30/shakespeare-tragedies-as-network-graphs/>

Semantic memory: Cognitive structure

Various tasks can be used to assess the relations among words/concepts in our semantic memory

The data can be used to calculate measures of **similarity**, and be shown in network or other diagrams

Verbal fluency task: Say/write all the names of [animals, countries, ...] you can in 1 minute.



Similarity ratings: For each pair, indicate how similar they are

From: Wulff et al. (2018), Structural differences in the semantic networks of younger and older adults,
<https://www.nature.com/articles/s41598-022-11698-4>

Semantic memory: Cognitive structure

Do younger and older adults differ on measures calculated from their network diagrams?

$\langle k \rangle$: Average “degree” # of connections

C : average local clustering

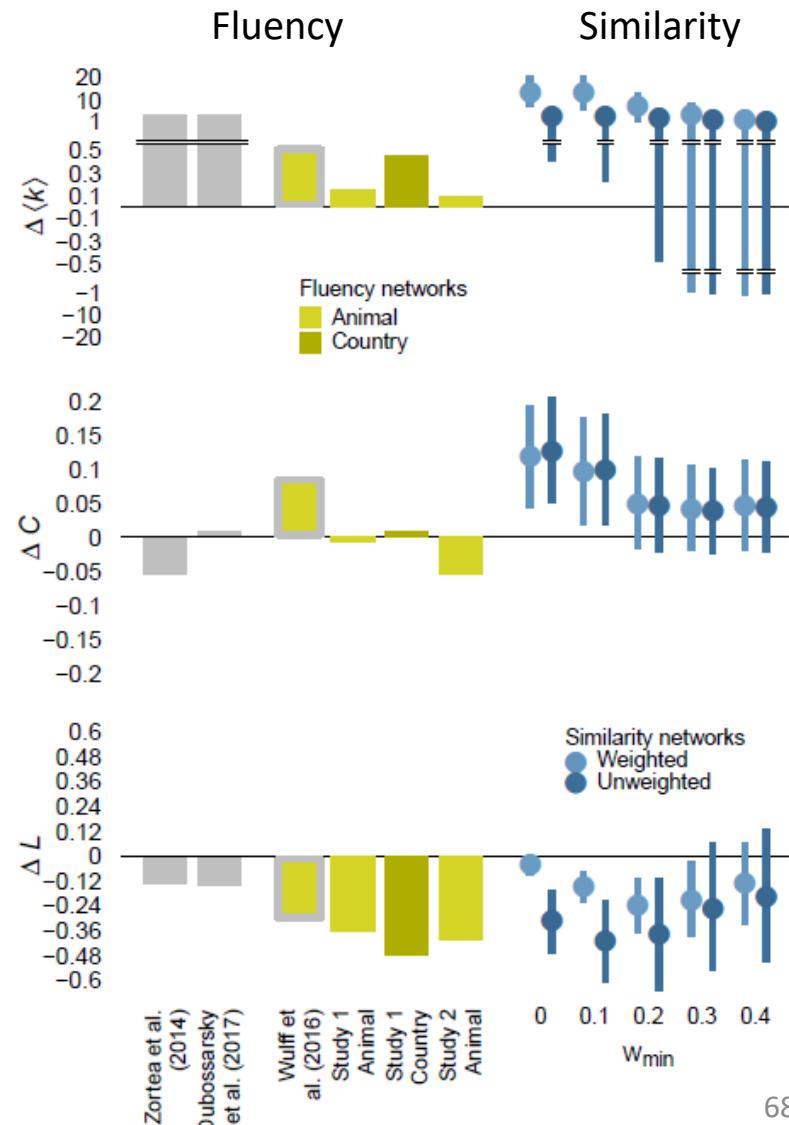
L : average path length in network

$\Delta()$: young – old difference

IMHO, this graph tries to do too much.

The fluency data is most important to their argument.

ΔL & $\Delta \langle k \rangle$ show consistent differences between young & old



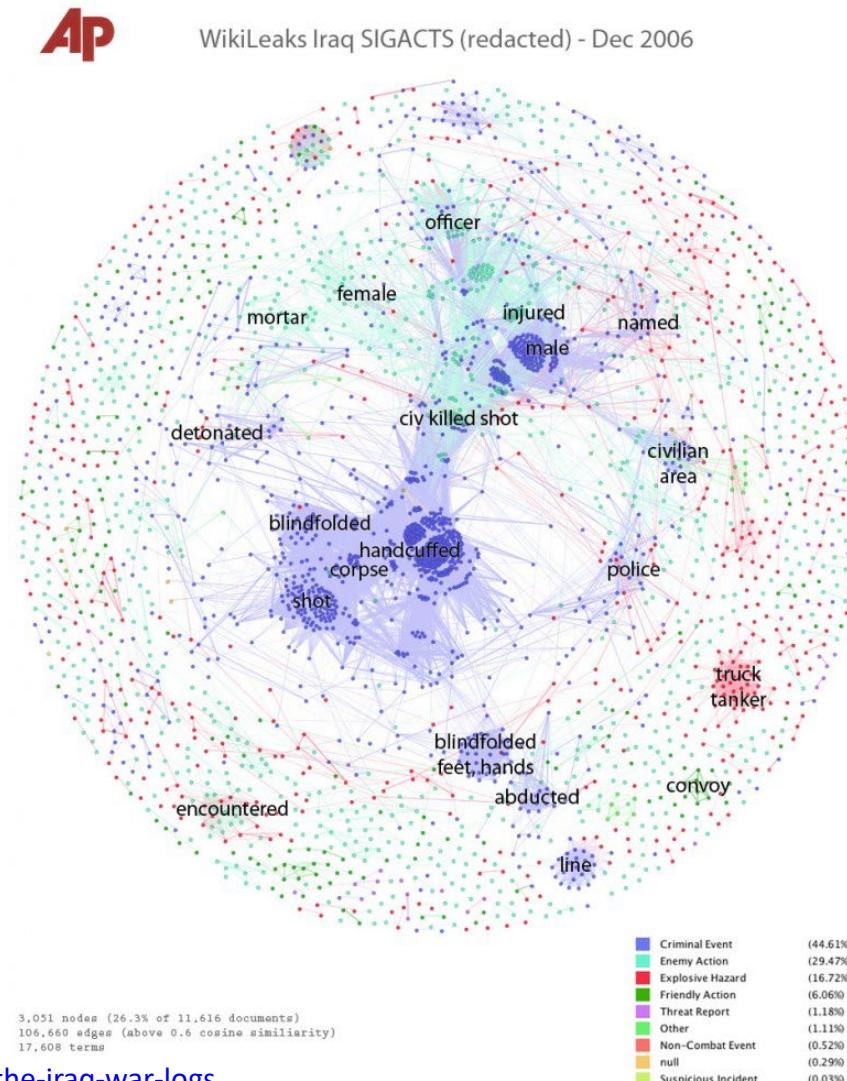
WikiLeaks Iraq war logs

Johnathan Stray & Julian Burgess analyzed > 11,000 documents for SIGACT (“significant action”) reports from the 2006 Iraqi civil war made available by WikiLeaks.

Each report is a dot. Each dot is labelled by the three most “characteristic” words in that report.

Documents that are “similar” have edges drawn between them, width ~ similarity

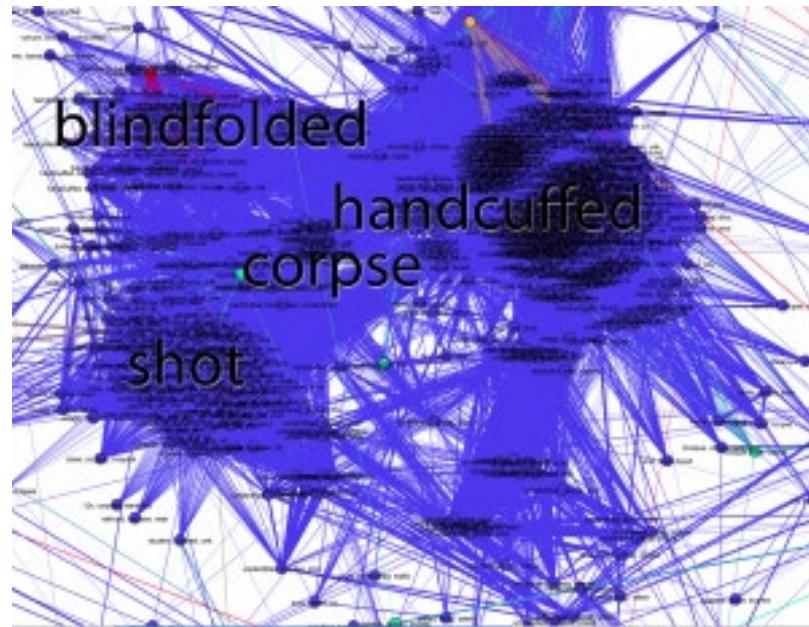
The graph-drawing algorithm placed similar nodes together



WikiLeaks Iraq war logs

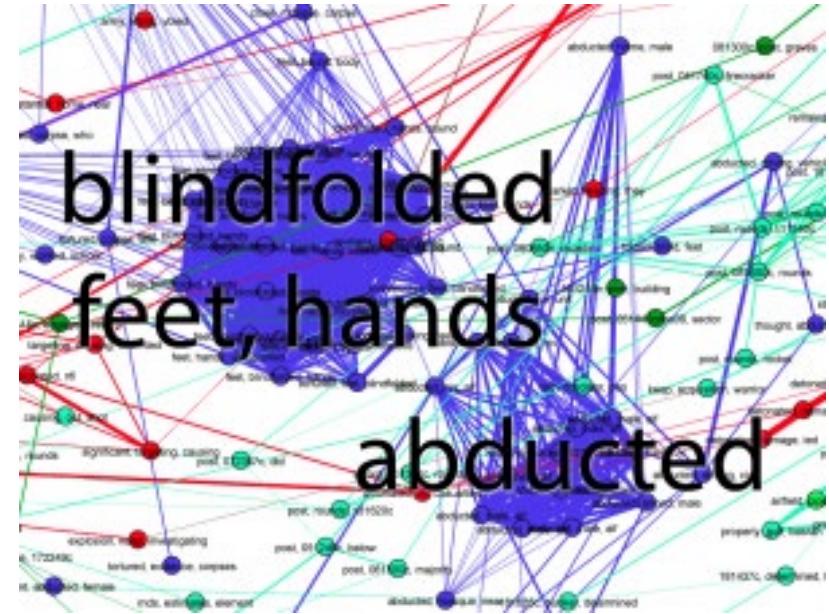
Certain themes became clear, and could be studied in rich detail
The underlying methods use “term frequency–inverse document frequency”
measures of **text-mining**.

Murder cluster. All contain the word
“corpse”



<http://jonathanstray.com/wp-content/uploads/2010/12/Murders.png>

Torture-abduction cluster



<http://jonathanstray.com/wp-content/uploads/2010/12/Torture-abduction.png>

Twitter network of R users

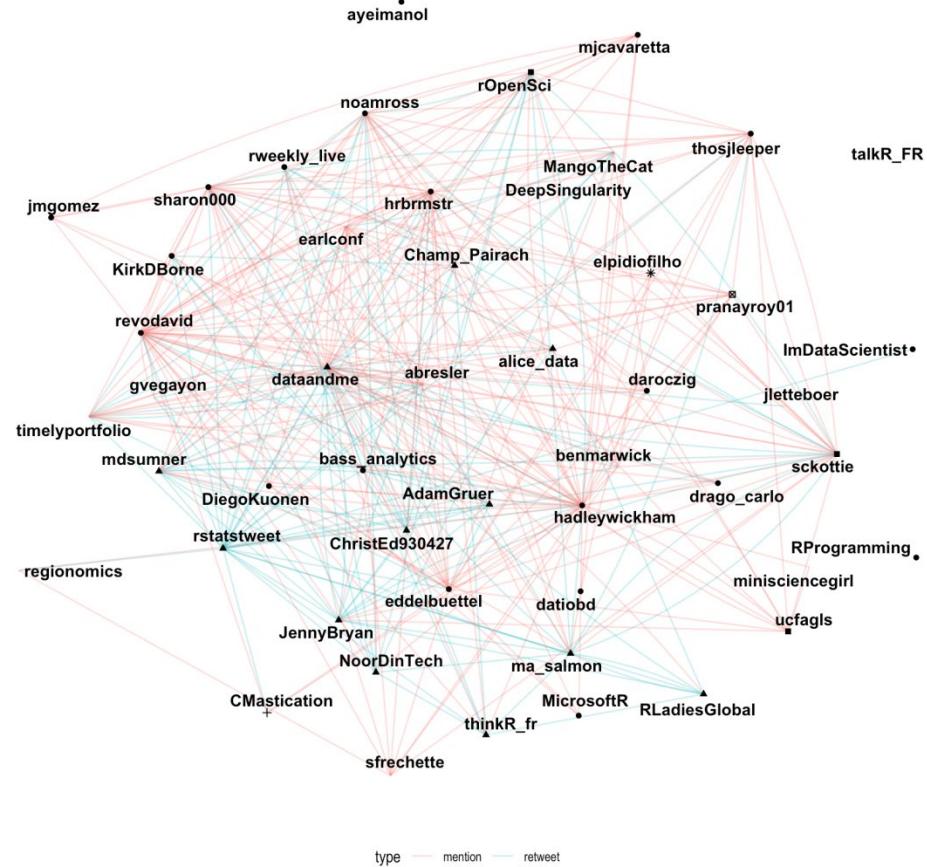
Perry Stephenson explores the connections among the top 50 R users on Twitter

The [rtweet](#) package provides access to Twitter info

```
library(rtweet)
followers <-
get_followers("datavisFriendly")
```

R Twitter Activity Network

Top 50 users (by centrality) - July 2018



From: <https://perrystephenson.me/2018/09/29/the-r-twitter-network/>

Twitter circles

Who do I most often interact with?

Three rings to show my twitter world

One ring to rule them all:
@datavisFriendly

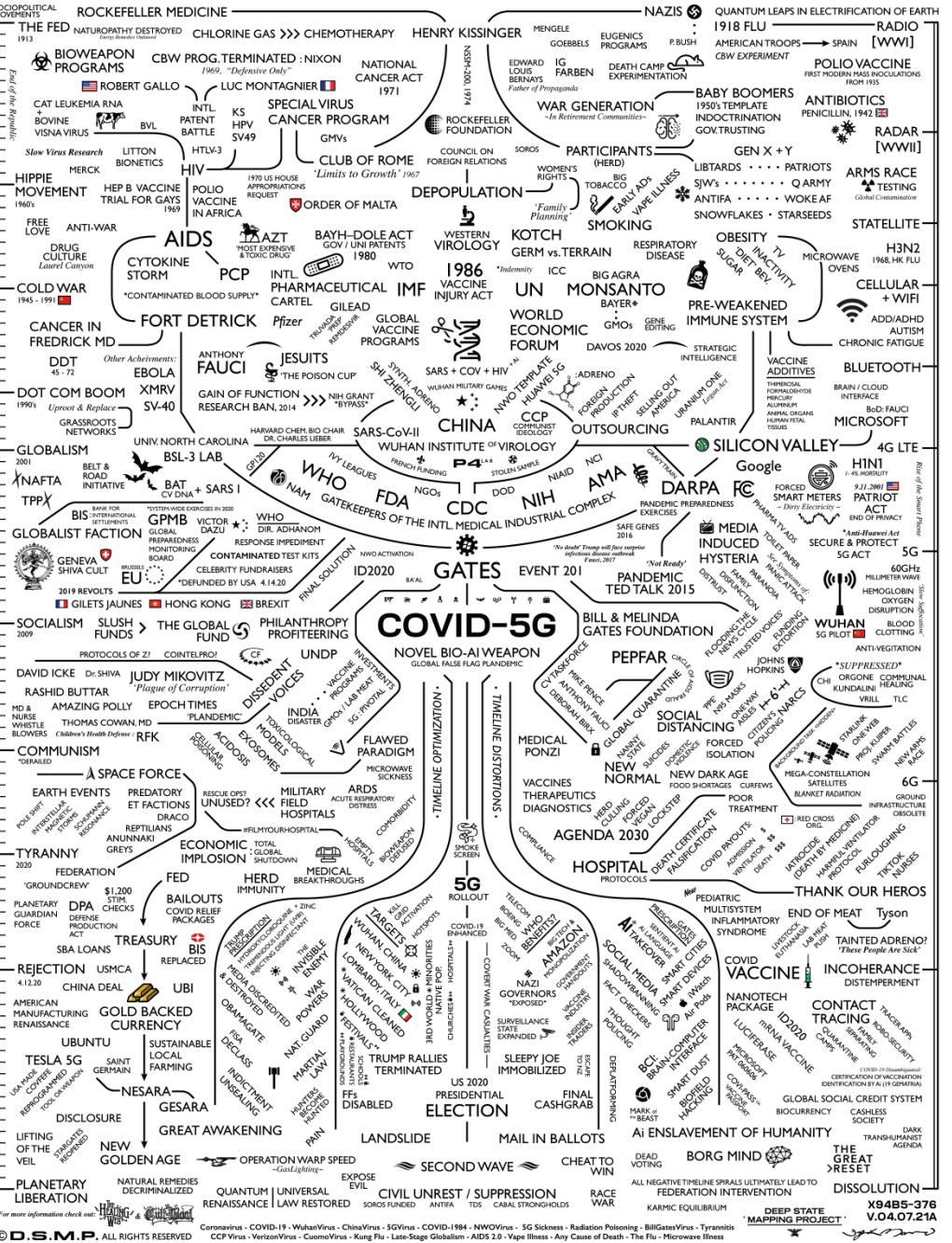
Other rings: #datavis,
#maps, #rstats, #psy6135



Pathological networks

Conspiracy theories (QANON) are aided by diagrams like this suggesting that everything is connected to everything else

- “labyrinthic chartjunk”
- Information overload
- The world is chaotic
- Something MUST BE DONE!

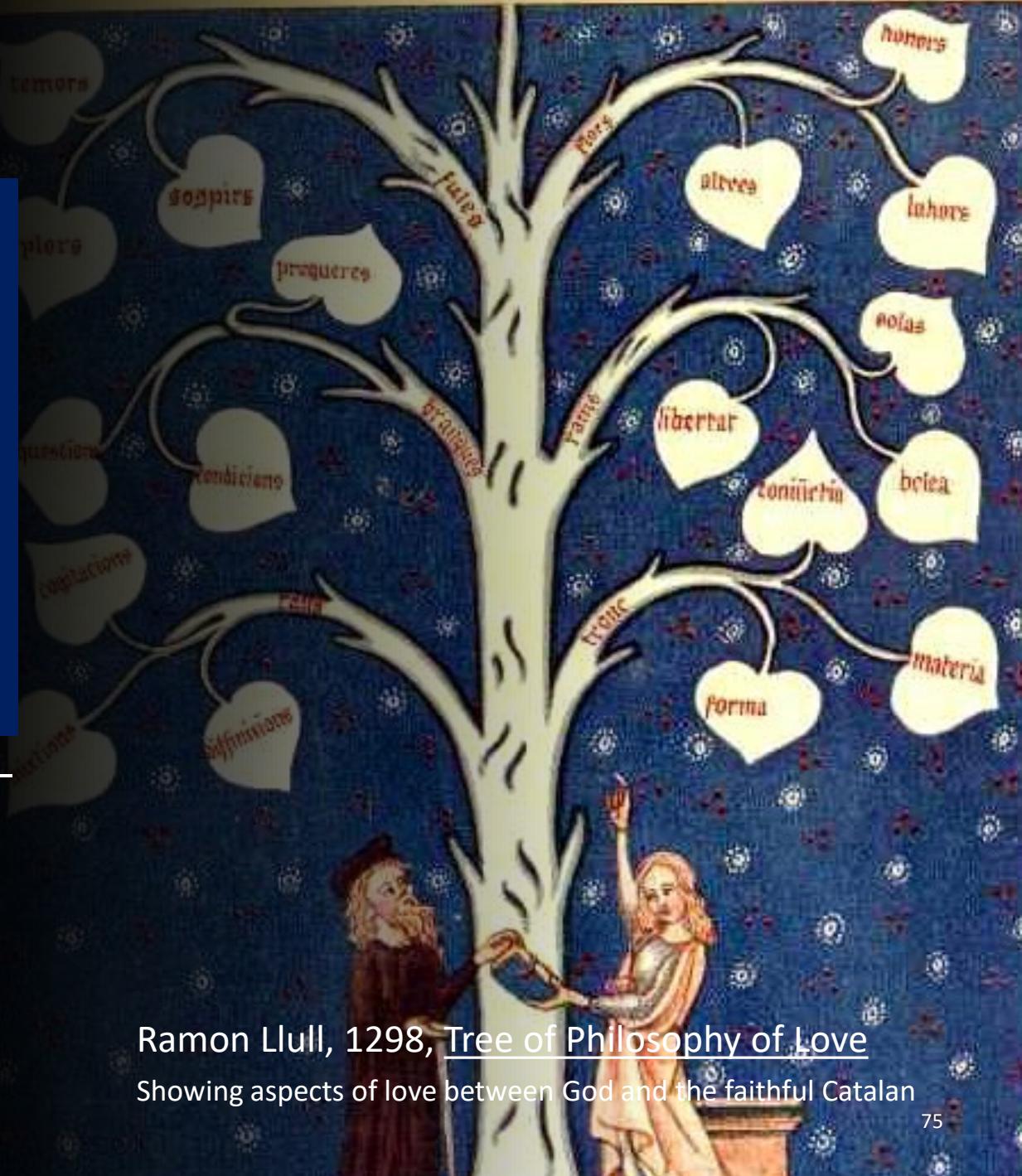


Tree-based Visualization

Branching patterns

History as a tree

Treemaps

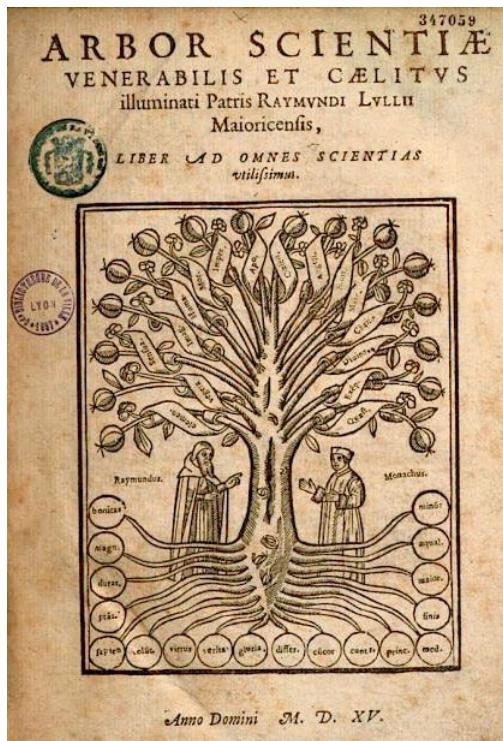


Ramon Llull, 1298, Tree of Philosophy of Love

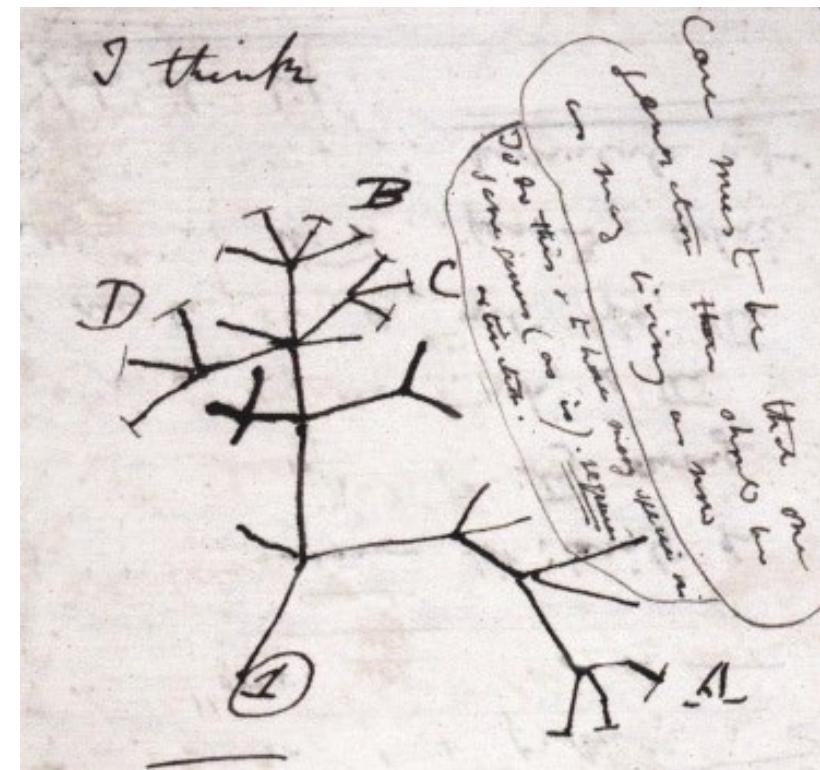
Showing aspects of love between God and the faithful Catalan

Tree diagrams

Trees are natural, organic visual metaphors for **branching processes** and **space-filling designs**.



[Ramon Llull's tree of science](#), showing roots and branches of knowledge

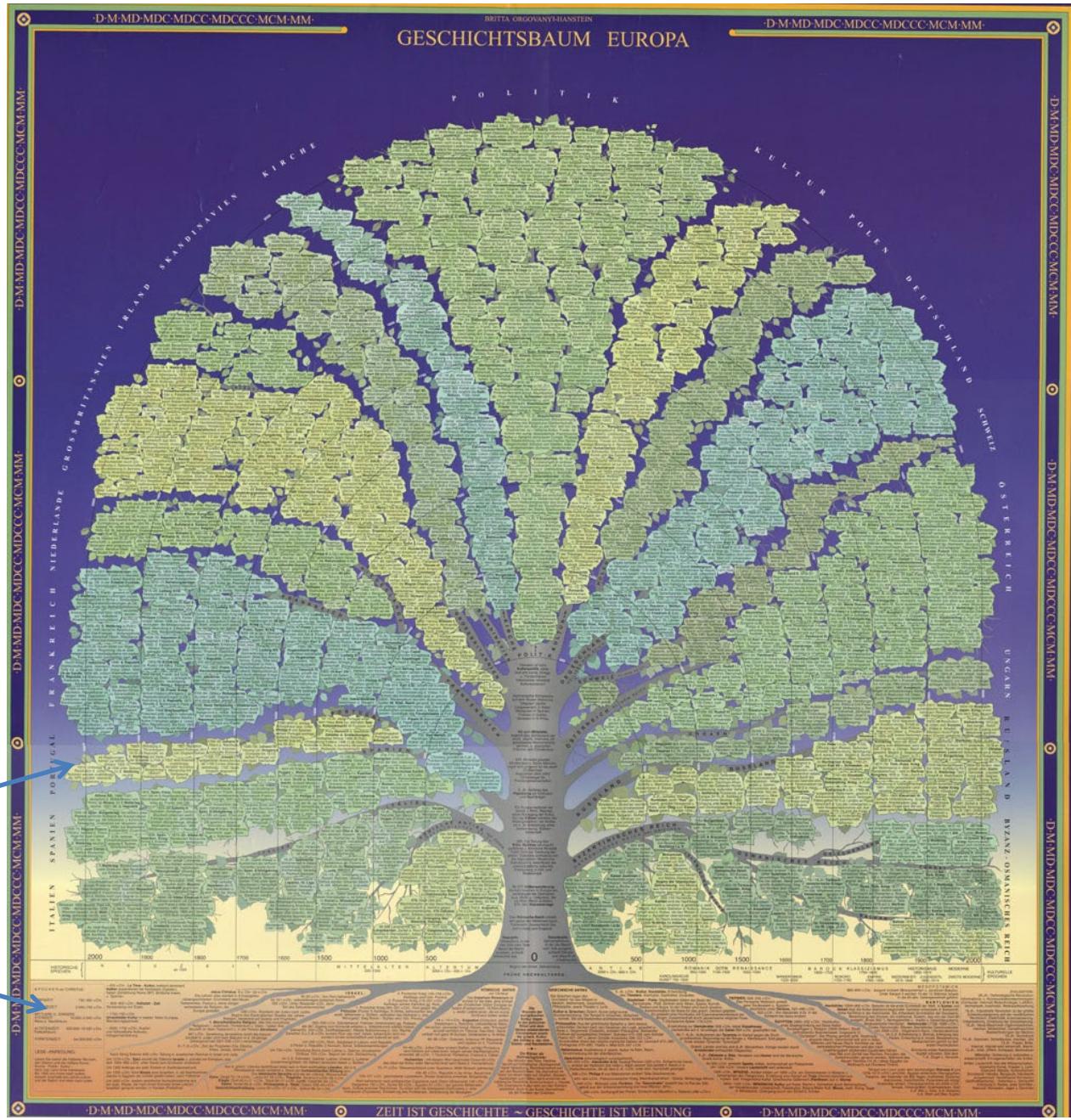


Charles Darwin's first visual sketch of [the evolution of species](#)

History as a Tree: *Geschichtsbaum Europa* (2003)

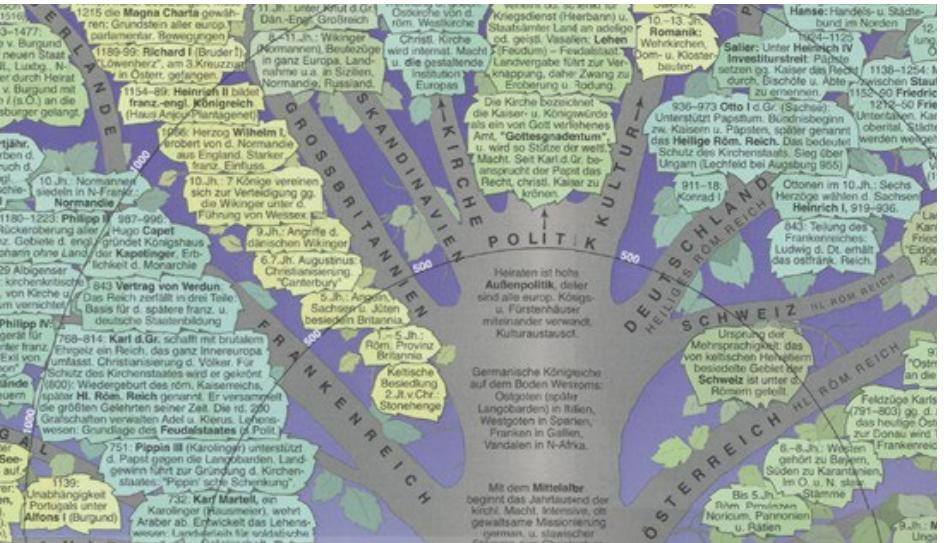
The entire history of Europe in one diagram

- space-filling design:
resolution \sim time²
- natural metaphors for roots, branches

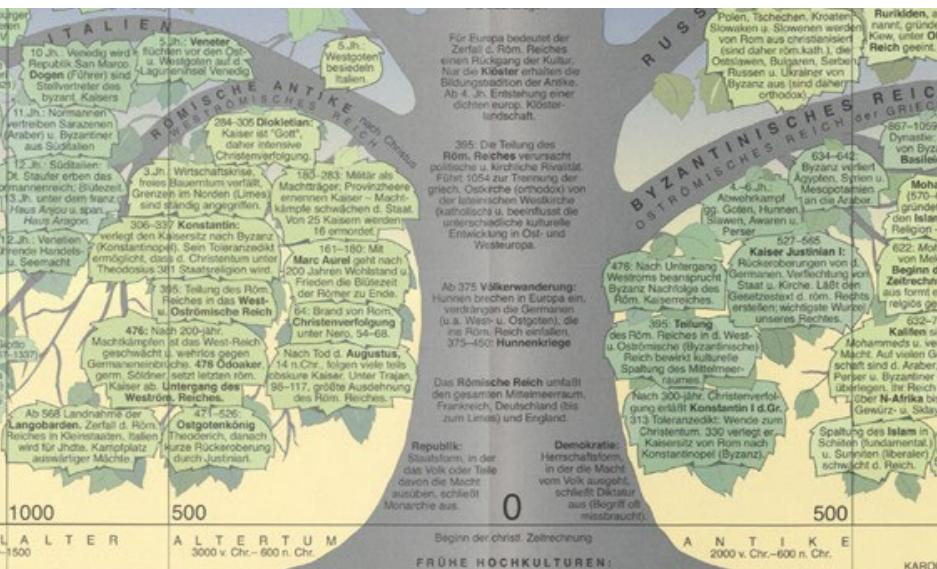


History as a Tree

- Branches for countries & domains of thought
- Leaves for all the details



- linear horizontal scale → area ~ time²



Treemaps

Treemaps display [hierarchical data](#) as a set of nested rectangles.
Each node (leaf) has an area \sim size (CO_2)

Who emits the most CO_2 ?

Global carbon dioxide (CO_2) emissions were 36.2 billion tonnes in 2017.

Asia

19 billion tonnes CO_2
53% global emissions

China

9.8 billion tonnes CO_2
27% global emissions

Japan
1.2 billion tonnes
3.3%

Saudi Arabia
635 million tonnes
1.8%

Thailand
331M tonnes
0.9%

UAE
232M tonnes
0.6%

Pakistan
199M tonnes
0.55%

Canada
573M tonnes
1.6%

Mexico
490M tonnes
1.4%

Brazil
476M tonnes
1.3%

Australia
414M t
1.1%

International aviation & shipping
1.15 billion tonnes
3.2%

South Korea
616 million tonnes
1.7%

Vietnam
293M tonnes
0.85%

Kazakhstan
199M tonnes
0.85%

Iraq
194M tonnes
0.54%

South Africa
456M tonnes
1.3%

Nigeria
107M tonnes
0.3%

Egypt
88M tonnes
0.6%

Argentina
204M tonnes (0.6%)

Venezuela
100M tonnes
4.4%

Taiwan
272M tonnes
0.8%

Philippines
128M tonnes
0.35%

Qatar
130M tonnes
0.4%

Bangladesh
128M tonnes
0.35%

Morocco
109M tonnes
0.31%

Chile
80M tonnes
0.2%

Colombia
102M tonnes
0.22%

Angola
102M tonnes
0.22%

Peru
69M tonnes
0.18%

Iran
672 million tonnes
1.9%

Indonesia
489 million tonnes
1.4%

Malaysia
255M tonnes
0.7%

Kuwait
200M tonnes
0.6%

Algeria
191M tonnes (0.4%)

Lebanon
160M tonnes
0.4%

Yemen
150M tonnes
0.4%

Honduras
122M tonnes
0.33%

Costa Rica
100M tonnes
0.27%

North America

6.5 billion tonnes CO_2
18% global emissions

USA

5.3 billion tonnes CO_2
15% global emissions

Mexico
490M tonnes
1.4%

Canada
573M tonnes
1.6%

USA
5.3 billion tonnes CO_2
15% global emissions

Our World in Data

Europe

6.1 billion tonnes CO_2
17% global emissions

EU-28

3.5 billion tonnes CO_2
9.8% global emissions

Russia
1.7 billion tonnes
4.7%

Turkey
443M tonnes
1.2%

Ukraine
212M tonnes
0.6%

Belarus (61M t)

Croatia (20M t)

Montenegro (10M t)

Norway (10M t)

San Marino (1M t)

Andorra (1M t)

Gibraltar (1M t)

Malta (1M t)

Luxembourg (1M t)

Albania (1M t)

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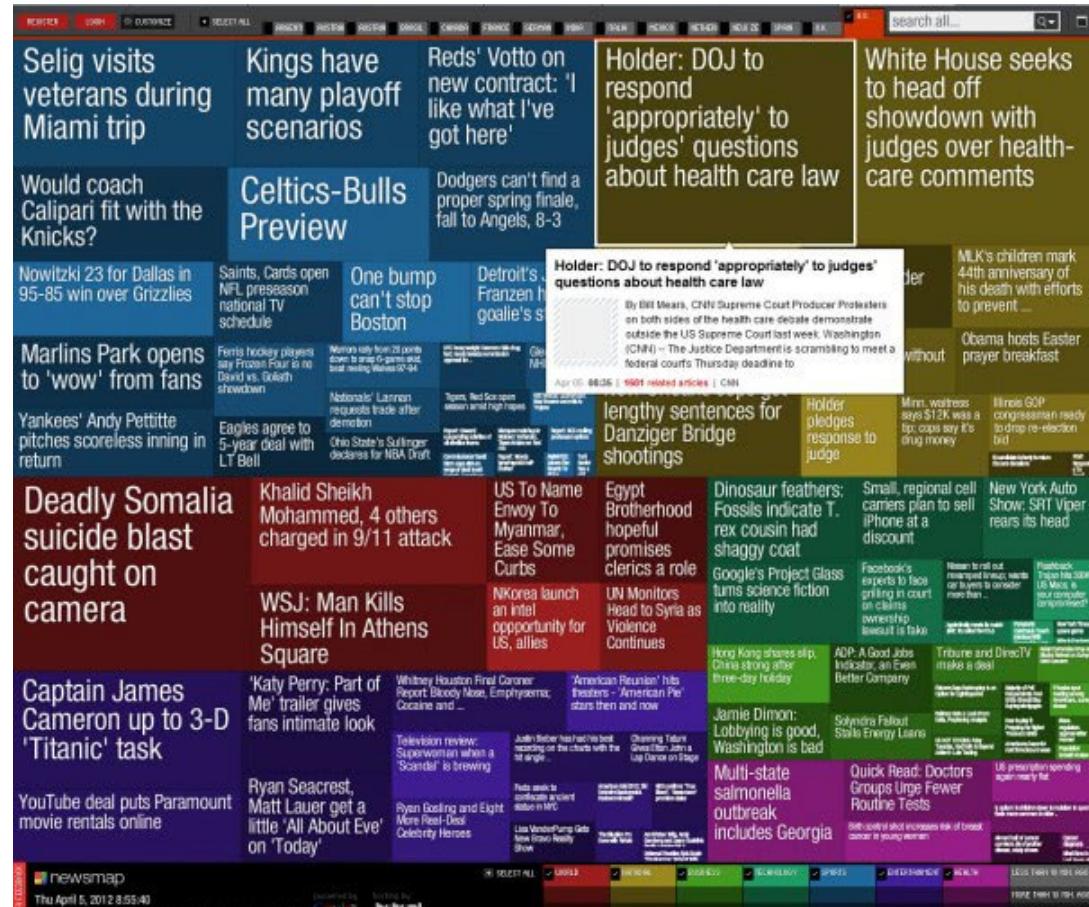
Treemaps: Google Newsmap

They turn out to be useful in a wide range of applications

Google NewsMap shows top news stories with

- Size ~ popularity
- Color: domain— **world news, sports, national, ...**
- Shades: recency

Interactivity: Hover, click to show details



See: <https://newsmap.ijmacd.com/>. This uses <https://github.com/ijmacd/newsmap-js>

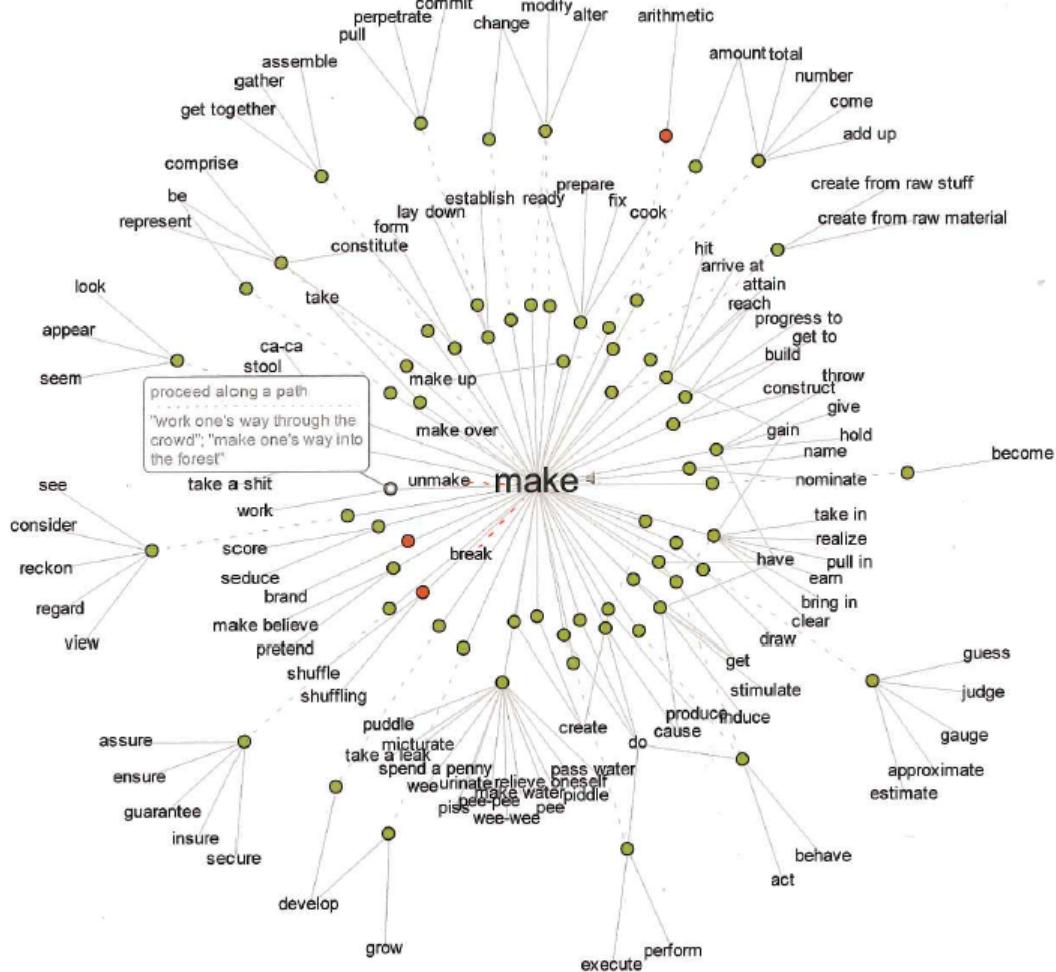
Radial trees: *Visual Thesaurus*

The *Visual Thesaurus*, from Thinkmap was the first application to make word meanings **visual** and **interactive**.

They used a radial layout to show the various related senses of given focus word.

This application was incisive in promoting ideas of interaction with tree-based data: query, zoom, tool-tips,

...



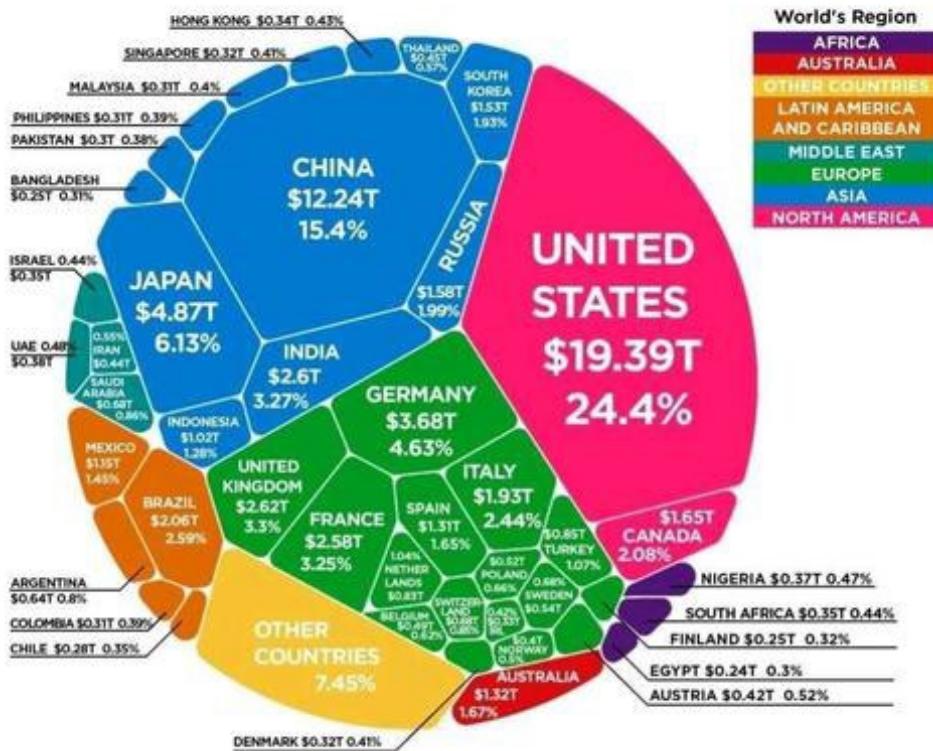
This fig from Manuel Lima, *The Book of Trees*, p. 127

Voroni treemaps

Le nouveau camembert?

80 Trillion Dollar \$ 😯

World Economy in a Single Chart ↗



A **voroni diagram** subdivides space into polygons.

As a **treemap**, this is done recursively in hierarchical categories.

The **circular form** makes it an easy replacement for a lowly π chart,

Animation & Interactive Graphics

Origins: Visualizing motion
Animated graphics
Dynamically updated
graphics
Linking views
Interactive application
development frameworks

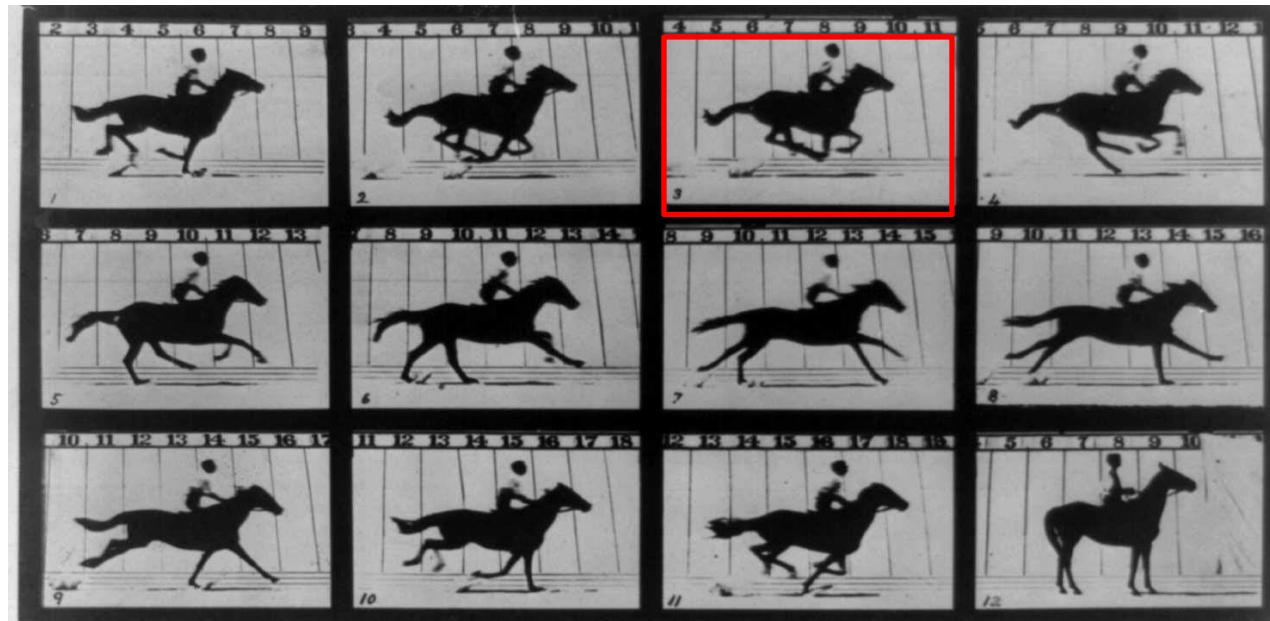


A wager about a horse in motion

In the late 1800s, a popular quasi-scientific question was: **Does a horse, in a trot, cantor or gallop ever have all four feet off the ground?**

This came to be called the **Hypothesis of Unsupported Transit**

Eadweard Muybridge solved the problem by automating multiple photographs



Copyright, 1878, by MUYSBRIDGE.

MORSE'S GALLERY, 417 Montgomery St., San Francisco

THE HORSE IN MOTION.

Illustrated by
MUYSBRIDGE.

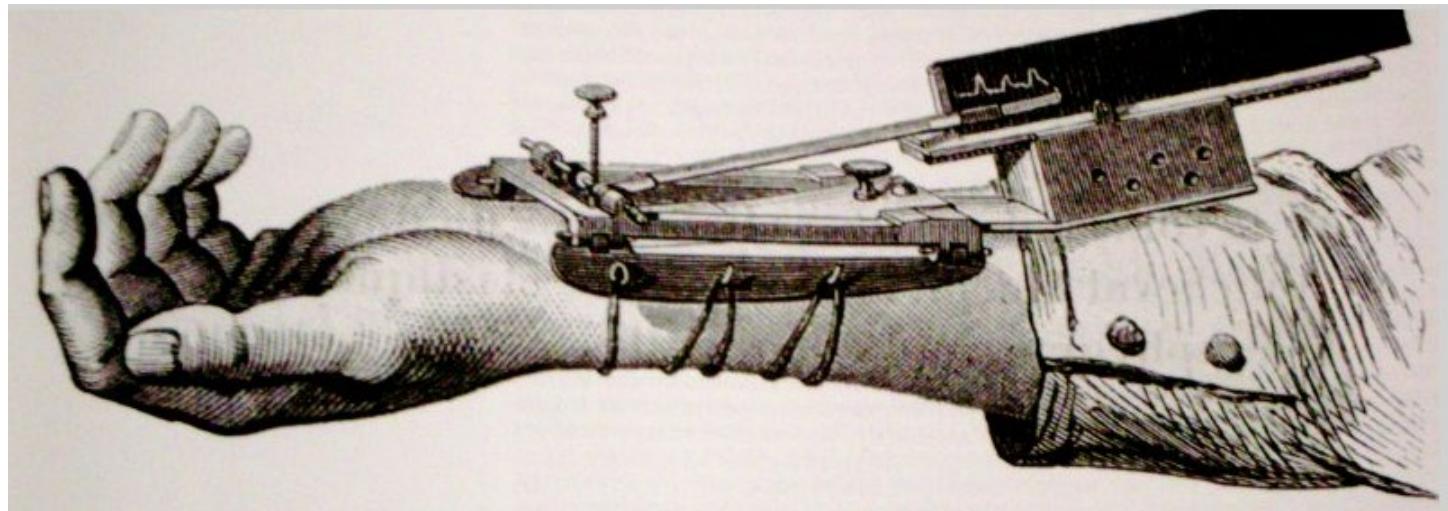
AUTOMATIC ELECTRO-PHOTOGRAPH.

"SALLIE GARDNER," owned by LELAND STANFORD; ridden by G. DOMM, running at a 1.40 gait over the Palo Alto track, 19th June, 1878.
The negatives of these photographs were made at intervals of twenty-seven inches of distance, and about the twenty-fifth part of a second of time; they illustrate consecutive positions assumed
during a single stride of the mare. The vertical lines were twenty-seven inches apart; the horizontal lines represent elevations of four inches each.
The negatives were each exposed during the two-thousandth part of a second, and are absolutely "untouched."

É.-J. Marey: A science of visualizing motion

- Physiology: How to make internal physiological processes subject to visual analysis?
 - Invented many graphic recording devices (heart rate, blood pressure, muscle contraction, etc.)
 - “Every kind of observation can be expressed by graphs”

Marey's sphygmograph, recording a visual trace of arterial blood pressure



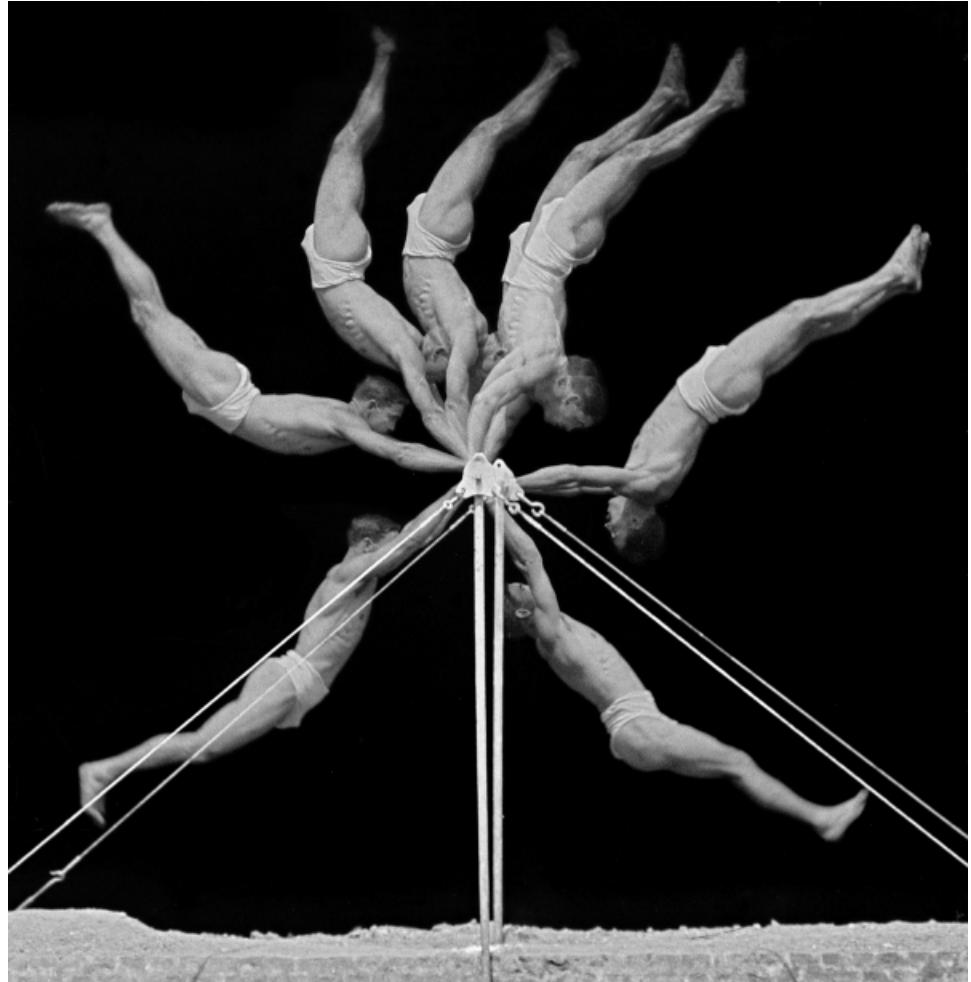
Animation: Chronophotography

Marey pioneered the study of human and animal motion photographically



Fig. 5. Mode d'emploi du fusil photographique.

The photographic gun, allowing recording of 12 frames/sec. at intervals of 1/720 of a second

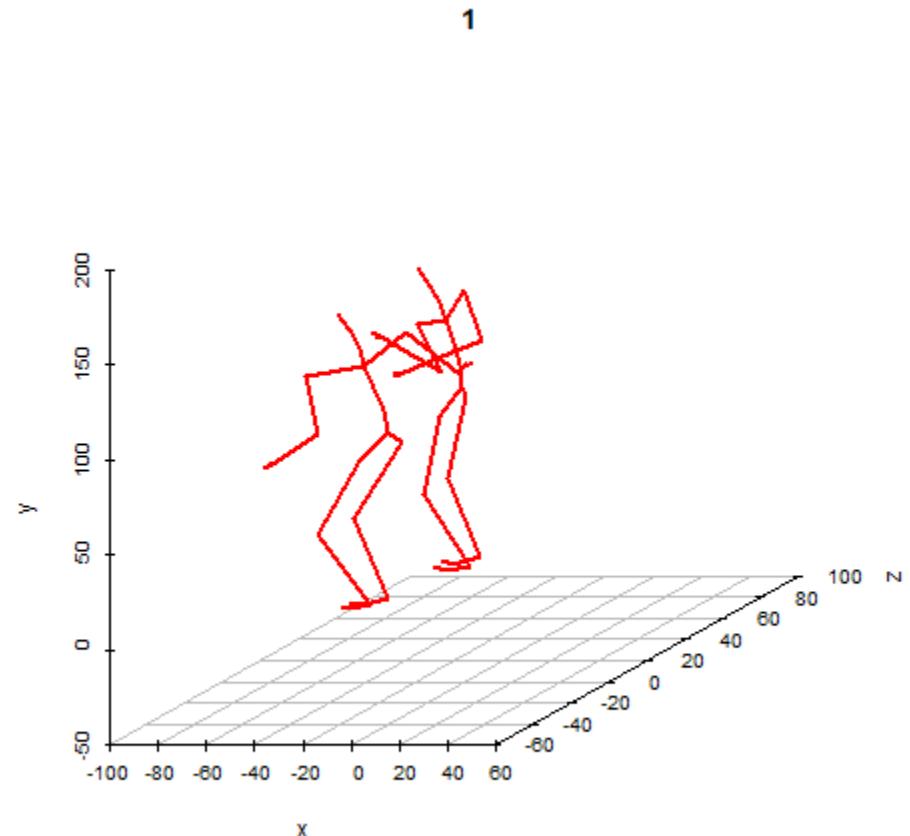


Animated graphics

Animated graphics, like movies
are just a series of frames strung
together in a sequence

The data for this animation come
from human figures in motion-
capture suits dancing the Charleston.

The Carnegie-Mellon Graphics Lab
maintains a Motion Capture
Database, <http://mocap.cs.cmu.edu/>



From: <http://blog.revolutionanalytics.com/2017/08/3-d-animations-with-r.html>

Animated line graph

To show the evolution of time series over time, you can use an animation line graph

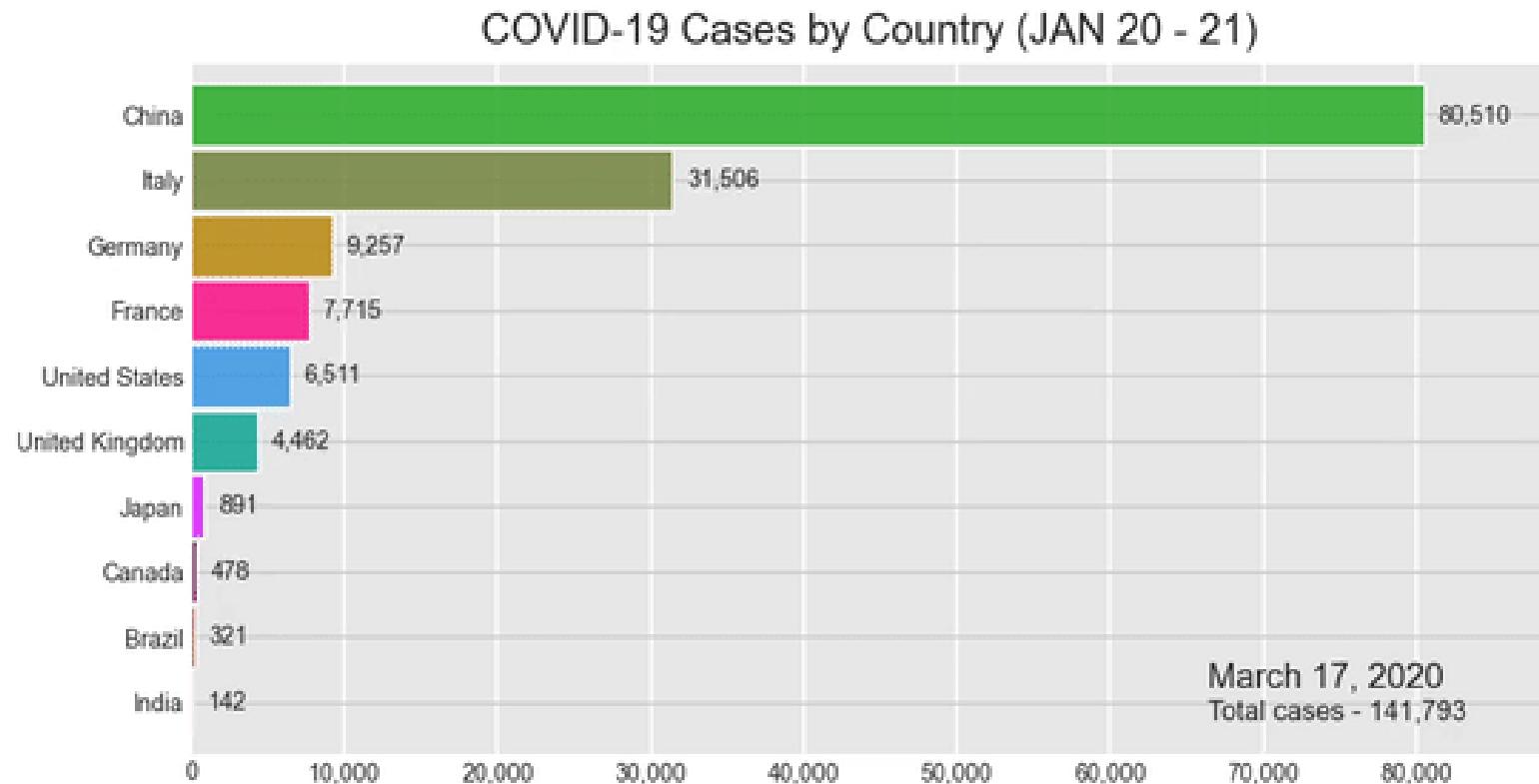


The [Data Visualization Catalog](#) shows page views of its top 10 charts
Graphs like this can be done using the [gganimate](#) package

Bar chart races

Data that changes over time can often be shown in a simpler animated graphic

This example of a **bar chart race** shows the strengths & weaknesses of this approach.



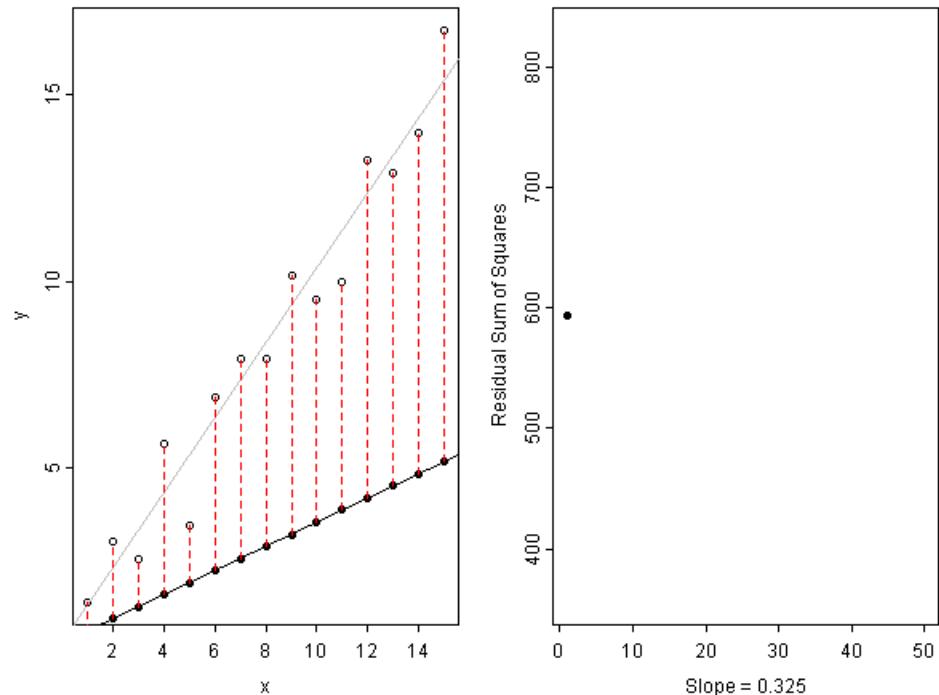
Statistical animations

Statistical concepts can often be illustrated in a dynamic plot of some process.

This example illustrates the idea of least squares fitting of a regression line.

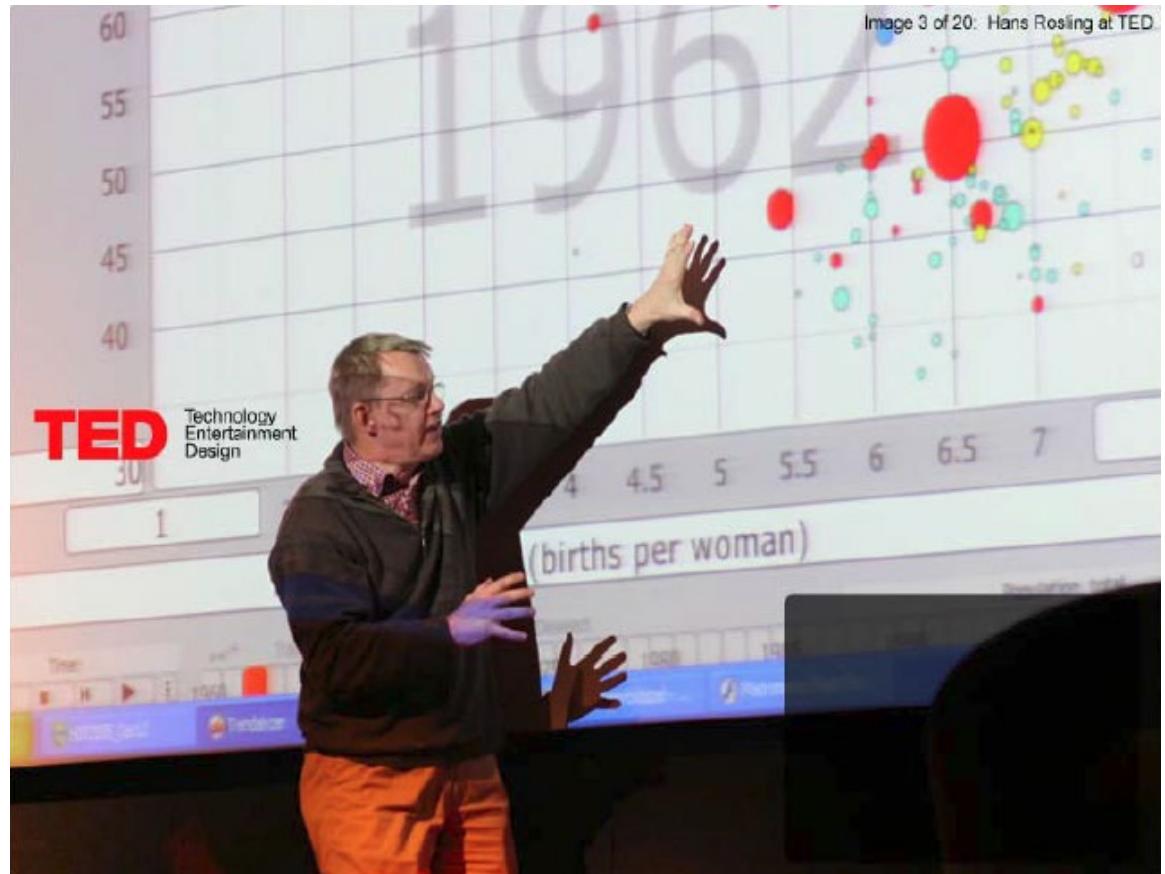
As the slope of the line is varied, the right panel shows the residual sum of squares.

This plot was done using the [animate](#) package in R.



Animated graphics

Hans Rosling captivated audiences with dynamic graphics showing changes over time in world health data



Video: Hans Rosling, “The best stats you’ve ever seen,”

https://www.ted.com/talks/hans_rosling_shows_the_best_stats_you_ve_ever_seen

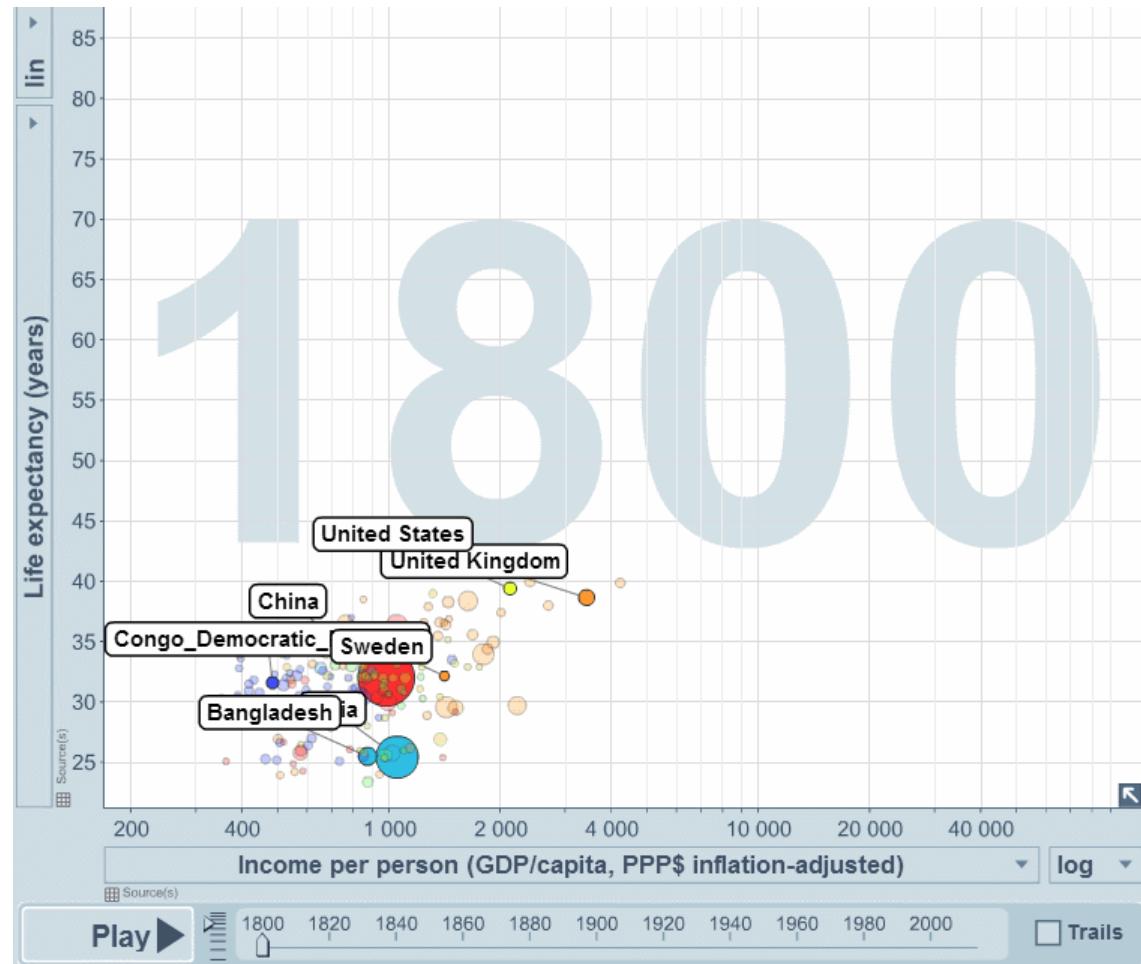
Animation & Interactivity

The Gapminder “moving bubble chart” was the vehicle.

- Choose (x, y) variables
- Choose bubble size variable
- Animate this over time

Liberating the X axis from time opened new vistas for data exploration

Software made this available as a general tool

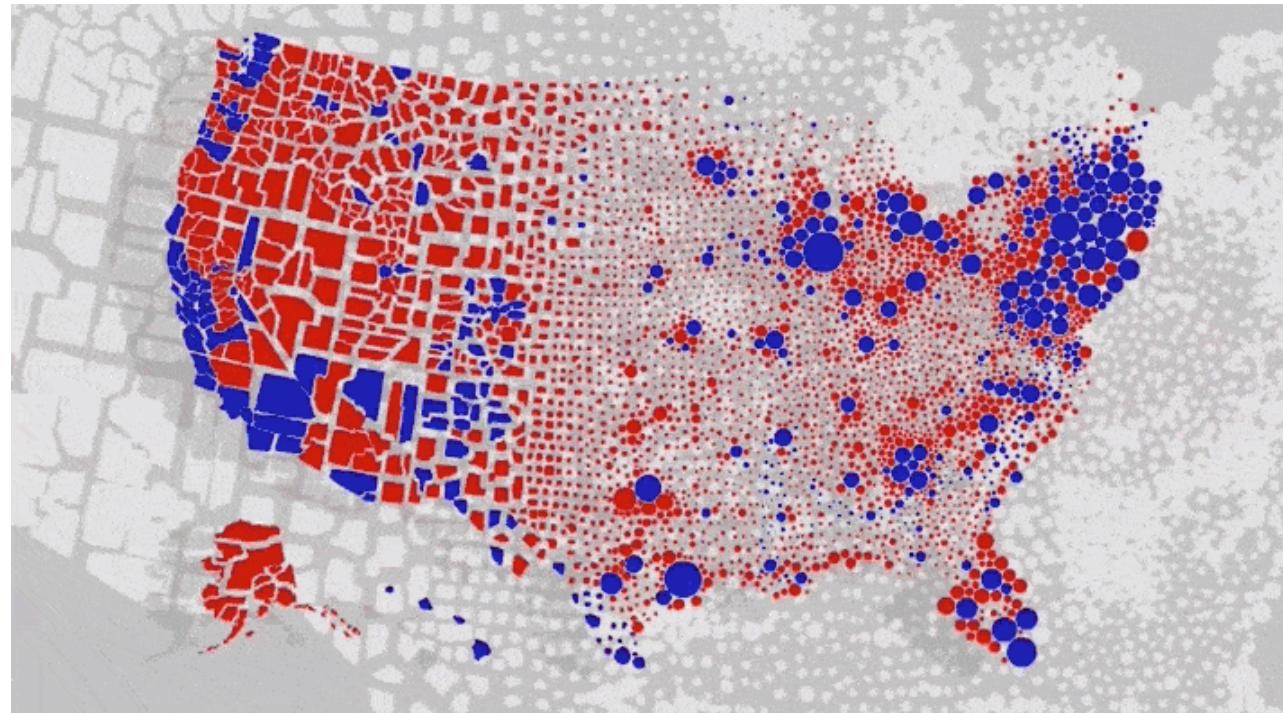


Animation: Interpolated views

Animation can also be used to show the difference between two views, using interpolated transitions: $\text{Current} = \alpha \text{ view}_1 + (1 - \alpha) \text{ view}_2$

This image showed Rep vs. Dem votes in the 2016 US election, contrasting shading by area vs. shading by population.

Land doesn't vote;
people do



[Image: Karim Douïeb/Jetpack.ai]

Linking animated views

This example links a **dendrogram** to a **grand tour** and **map** of the USArrests data to visualize a classification in 5 dimensions

The grand tour animates a series of 2D projections of the 5D data

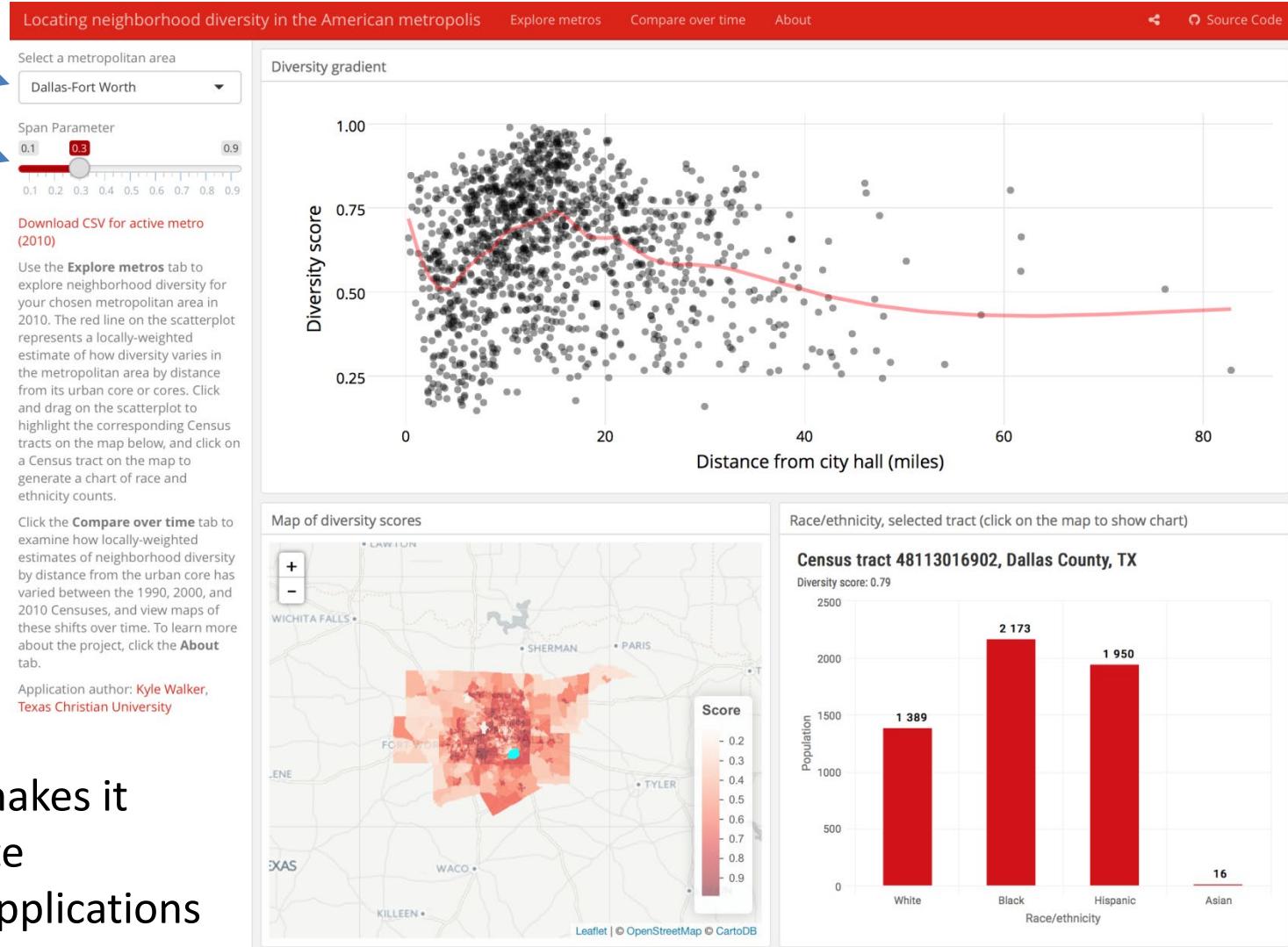
The image is recorded as a GIF

rgba(228)



Interactive application frameworks

selectors
inputs



shiny for R makes it
easy to create
interactive applications

https://walkerke.shinyapps.io/neighborhood_diversity/

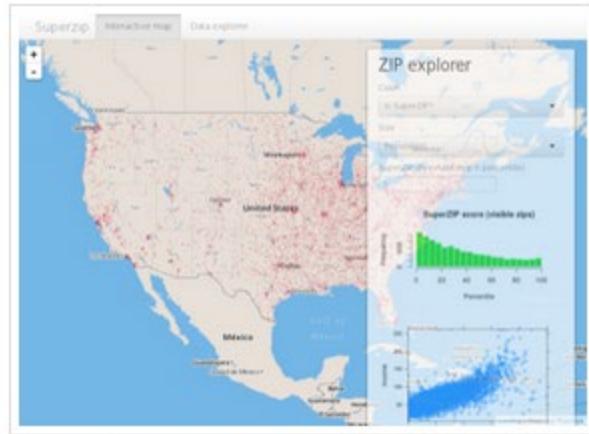
96

shiny gallery

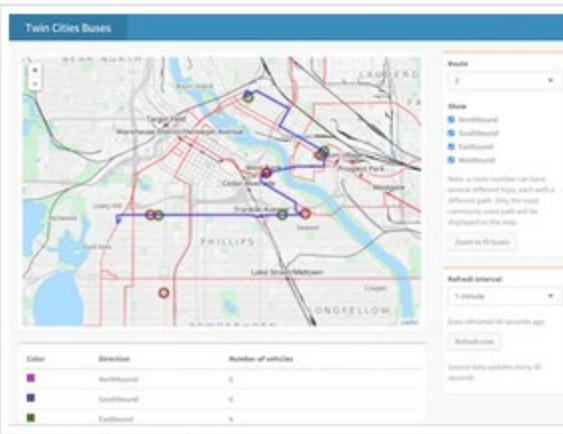
There is now a large collection of shiny applications, <https://shiny.rstudio.com/gallery/>
These integrate other interactive web software: d3, Leaflet, Google Charts, ...

Interactive visualizations

Shiny is designed for fully interactive visualization, using JavaScript libraries like d3, Leaflet, and Google Charts.



SuperZip example



Bus dashboard



Movie explorer

Summary

- The topics here were largely about data graphs, for analysis & presentation. Mainly not Info-graphics
 - Quantitative data: different forms for 1D, 1.5D, 2D, 3+D data
 - Categorical data: often best shown as areas ~ frequency (bar plots, mosaic plots)
- Thematic maps: visualizing spatially varying data
 - Raw data with different visual encodings
 - Spatial statistical models provide some smoothings
- Networks/trees: visualizing connections
- Animation: show changes over time or space
- Interaction: allow the viewer to explore the data