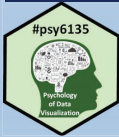
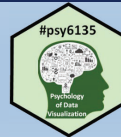


# Varieties of information visualization



Michael Friendly  
Psych 6135



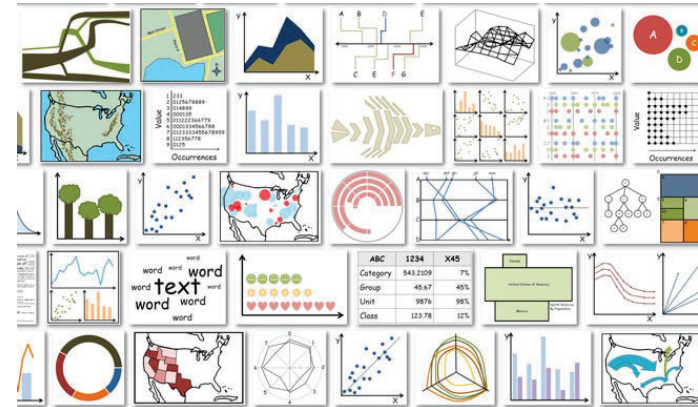
<https://friendly.github.io/6135>

@datvisFriendly

## So many types

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

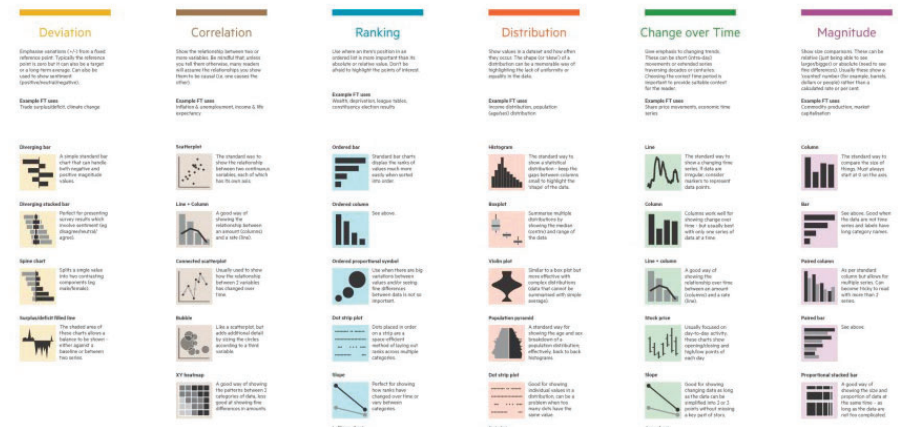
- What are their **features**?
- What **tasks** are they **good for**? – Accuracy or speed of judgment? Memorability?



## How to classify ???

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

**“What do I want to show?”**



## R Graph Gallery

OK: how do I actually DO these?



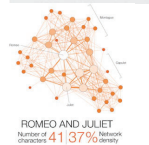
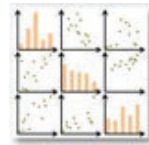
<https://r-graph-gallery.com/>  
uses a similar classification by  
**what to show**.

It shows exemplars of main  
types, with R code examples for  
each. Easy to copy/paste

There is a related online book,  
<https://www.kyle-w-brown.com/R-Gallery/>

# 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



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What are dimensions

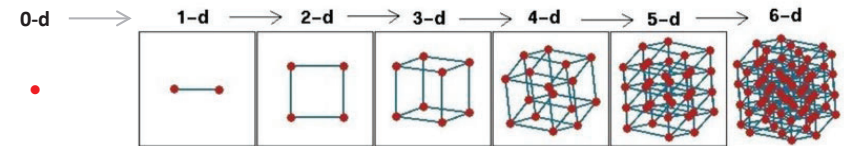


Fig credit: Di Cook @visnut

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

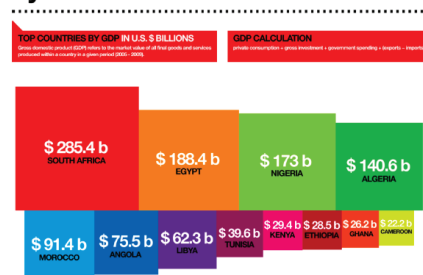
## Data graphs

6

## 1D: Infographic vs. Data graphic

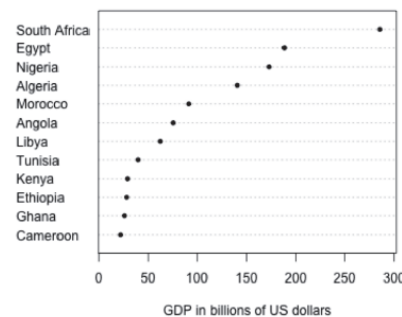
The same data can be shown in different forms, for different purposes

### African Countries by GDP



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

### African Countries by GDP



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

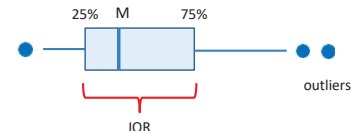
7

## 1.5D: Dotplots & boxplots

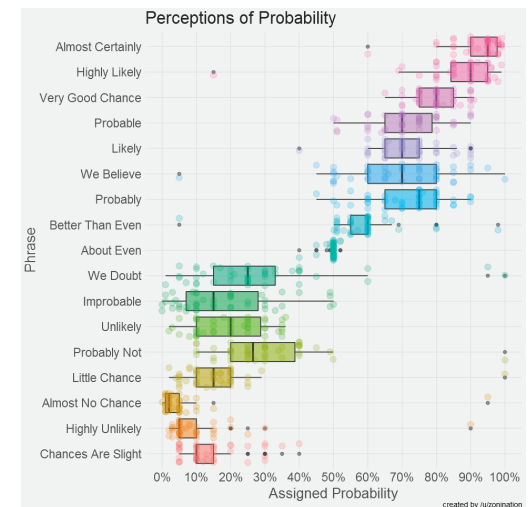
What number do you give to a probability phrase?

Boxplots summarize the important characteristics of a univariate data distribution:

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



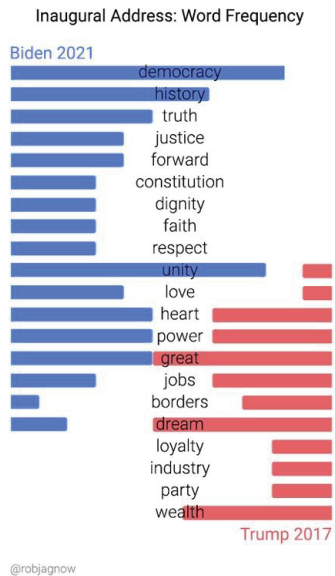
This example overlays the boxplot with a jittered dotplot, so we can also see the individual observations



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

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## 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

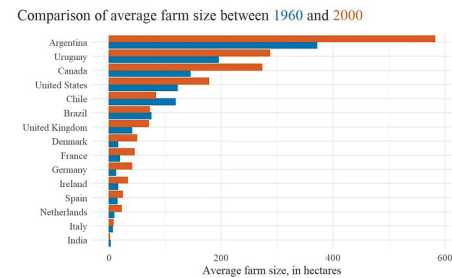
From: [https://www.reddit.com/r/dataisbeautiful/comments/17k0f0/us\\_inauguration\\_address\\_word\\_frequency\\_biden\\_vs/](https://www.reddit.com/r/dataisbeautiful/comments/17k0f0/us_inauguration_address_word_frequency_biden_vs/)

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## Bar chart variations

Bar charts are often used to make comparisons between two series

But your eyes must move around to compare

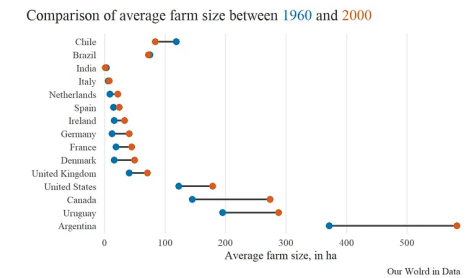


Which countries gained the most from 1960 – 2000?

From: <https://medium.com/@amorimfranchi/an-easier-to-interpret-alternative-to-paired-barplots-in-r-490d4472e8cd>

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



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## 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

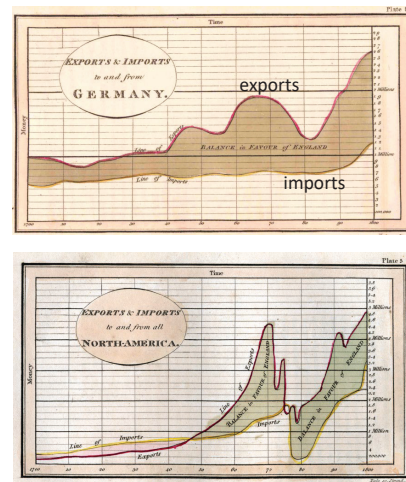
One curve for **imports**, one for **exports**

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

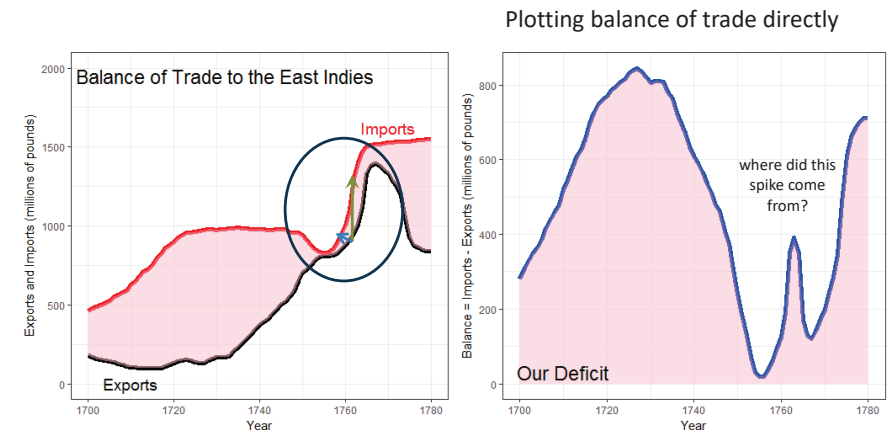
Economic 'history' could now be visualized and explained



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## Psychology: Distances between curves

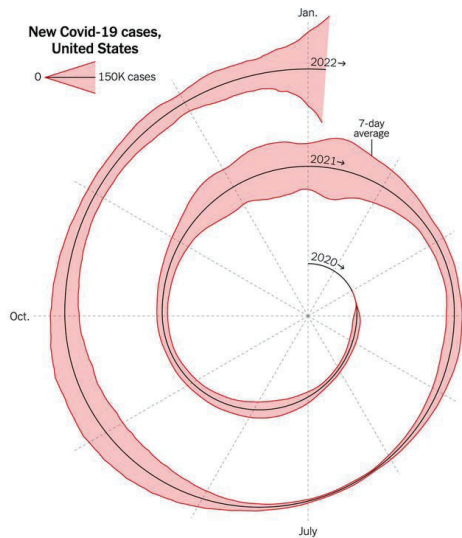
What Playfair didn't know is that judgments of **distance** between curves are **biased**. We tend to see the **perpendicular** distance rather than the **vertical** distance



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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>

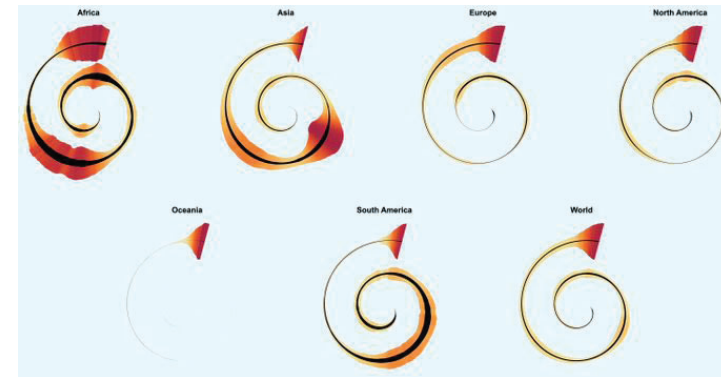
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## Multi-spirals

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

- Overlaid time-series probably would not work here
- What do you notice here?

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



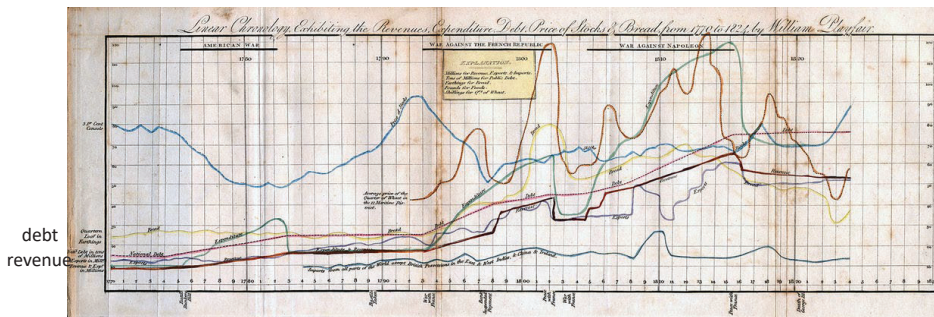
[https://twitter.com/h\\_i\\_g\\_s\\_c/status/1483195230404947968](https://twitter.com/h_i_g_s_c/status/1483195230404947968)

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## 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**

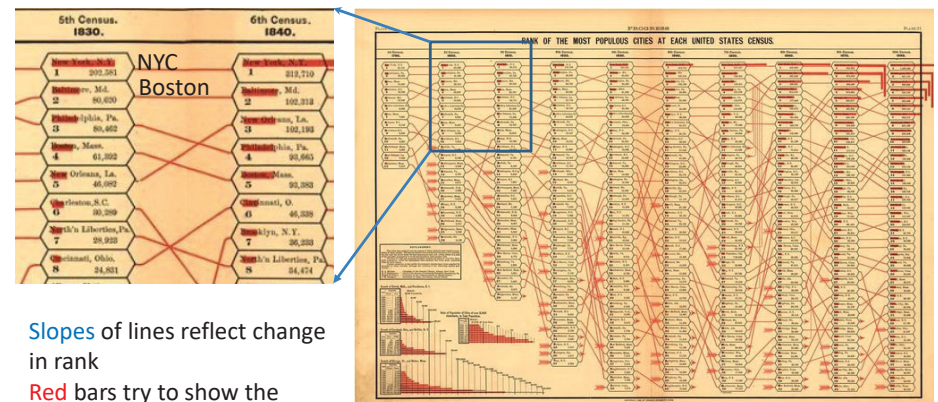


Playfair, W. (1824) Chronology of Public Events and Remarkable Occurrences.

15

## 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)

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# 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 (dirty old men?)
- parricide** relatively low until a spike at 60-70 (waited long enough!)

INFLUENCE DE L'AGE.  
DISTRIBUTION DES CRIMES AUX DIFFÉRENTS ÂGES, PAR PÉRIODE DE DIX ANNÉES.

IV.

A. CRIMES CONTRE LES PERSONNES.

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. Meurtres et coups.	181	Meurtres et coups.	218	Meurtres et coups.	179	Assassinats.	494	Meurtres.	165	Meurtres.	173	Viol sur des enfants.	318
2. Viol sur des enfants.	159	Meurtres.	157	Meurtres et coups.	157	Assassinats.	185	Meurtres.	165	Assassinats.	166	Meurtres et coups.	157
3. Meurtres.	147	Assassinats.	147	Meurtres.	153	Meurtres.	153	Meurtres et coups.	153	Meurtres et coups.	153	Meurtres.	155
4. Viol sur des adultes.	141	Meurtres et coups.	141	Meurtres et coups.	150	Meurtres et coups.	150	Meurtres et coups.	150	Meurtres et coups.	150	Meurtres et coups.	150
5. Assassinats.	101	Viol sur des adultes.	105	Viol sur des adultes.	73	Viol sur des enfants.	61	Viol sur des enfants.	61	Viol sur des enfants.	61	Viol sur des enfants.	61
6. Meurtres et coups.	76	Meurtres et coups.	76	Meurtres et coups.	76	Meurtres et coups.	76	Meurtres et coups.	76	Meurtres et coups.	76	Meurtres et coups.	76
7. Meurtres et coups.	48	Viol sur des enfants.	58	Viol sur des enfants.	58	Viol sur des enfants.	58	Viol sur des enfants.	58	Viol sur des enfants.	58	Viol sur des enfants.	58
8. Bles. env. accid.	47	Bles. env. accid.	50	Bles. env. accid.	50	Bles. env. accid.	50	Bles. env. accid.	50	Bles. env. accid.	50	Bles. env. accid.	50
9. Associat. de malit.	39	Paux témoignage.	39	Paux témoignage.	39	Paux témoignage.	39	Paux témoignage.	39	Paux témoignage.	39	Paux témoignage.	39
10. Paux témoignage.	29	Empoisonnement.	29	Empoisonnement.	29	Empoisonnement.	29	Empoisonnement.	29	Empoisonnement.	29	Empoisonnement.	29
11. Empoisonnement.	21	Crim. env. des enf.	21	Crim. env. des enf.	21	Crim. env. des enf.	21	Crim. env. des enf.	21	Crim. env. des enf.	21	Crim. env. des enf.	21
12. Yone de fait, etc.	11	Associat. de malit.	11	Associat. de malit.	11	Associat. de malit.	11	Associat. de malit.	11	Associat. de malit.	11	Associat. de malit.	11
13. Meud. av. violence.	6	Parricide.	6	Parricide.	6	Parricide.	6	Parricide.	6	Parricide.	6	Parricide.	6
14. Crim. env. des enf.	5	Meurtres et coups.	5	Meurtres et coups.	5	Meurtres et coups.	5	Meurtres et coups.	5	Meurtres et coups.	5	Meurtres et coups.	5
15. Parricide.	5	Associat. de malit.	5	Associat. de malit.	5	Associat. de malit.	5	Associat. de malit.	5	Associat. de malit.	5	Associat. de malit.	5
16. Avortement.	4	Bles. env. violence.	4	Bles. env. violence.	4	Bles. env. violence.	4	Bles. env. violence.	4	Bles. env. violence.	4	Bles. env. violence.	4
17. Bagnes.	4	Yone de fait, etc.	4	Yone de fait, etc.	4	Yone de fait, etc.	4	Yone de fait, etc.	4	Yone de fait, etc.	4	Yone de fait, etc.	4
Autres crimes.	4	Autres crimes.	4	Autres crimes.	4	Autres crimes.	4	Autres crimes.	4	Autres crimes.	4	Autres crimes.	4
Totaux.	1,000	Totaux.	1,000	Totaux.	1,000	Totaux.	1,000	Totaux.	1,000	Totaux.	1,000	Totaux.	1,000

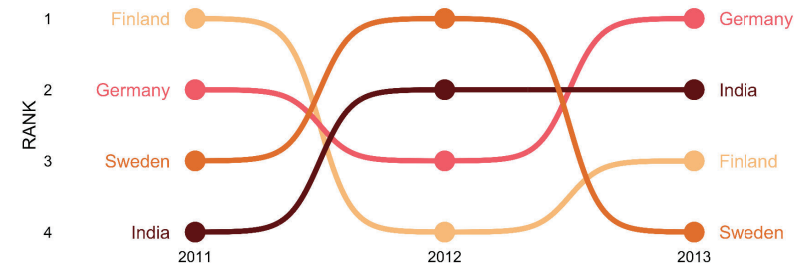
Friendly, (2007). "A.-M. Guerry's Moral Statistics of France: Challenges for Multivariable Spatial Analysis," *Statistical Science*, vol. 22, no. 3. <https://www.dataavis.ca/papers/guerry-ST5241.pdf>

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# Bump chart



This idea now called a bump chart. Implemented in the {ggbump} package



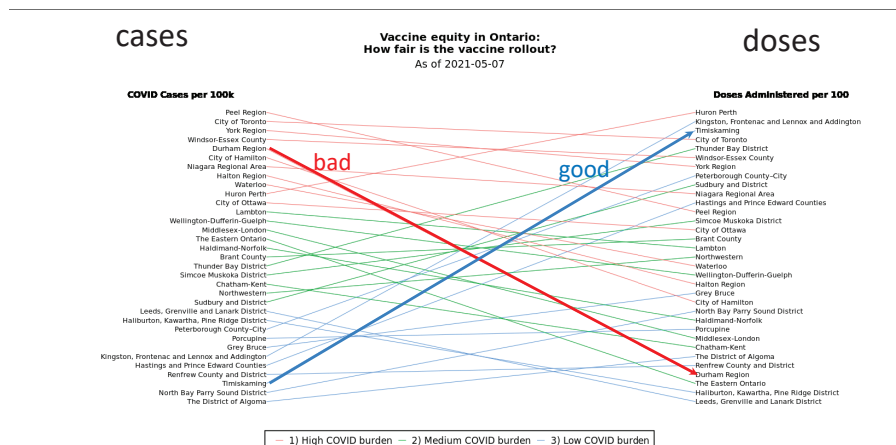
```
ggplot(df, aes(year, rank, color = country)) +  
  geom_point() +  
  geom_bump()
```

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# 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?



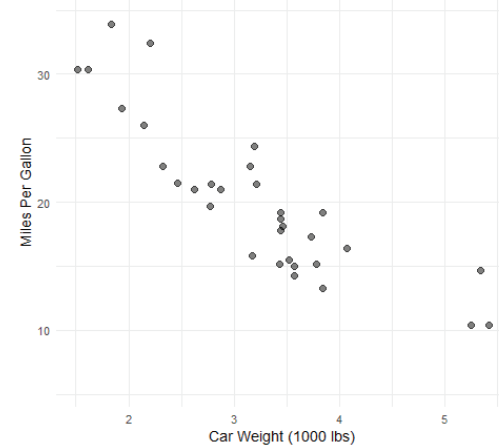
Graphic by Matthew Dubins, @MDubins

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# 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:

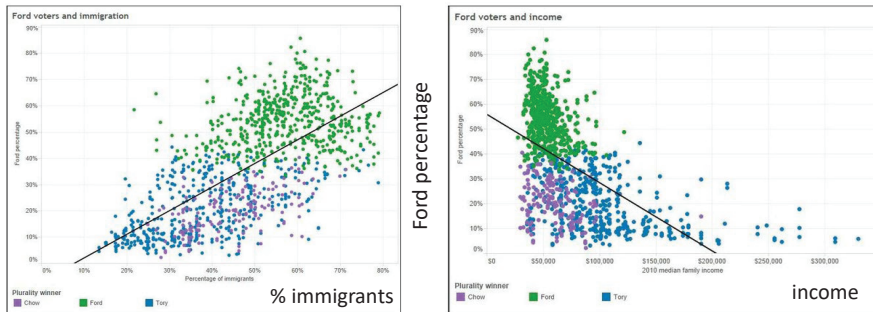
- regression line
- confidence band
- smoothed curve (nonlinear?)
- residuals

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## 2D: Scatterplots: Ford Nation



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



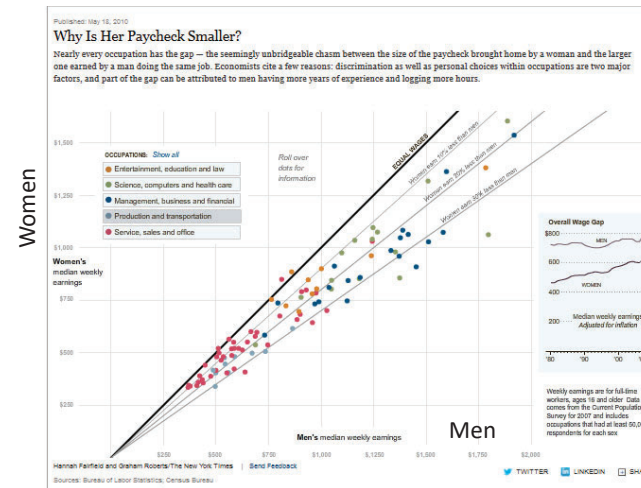
These simple scatterplots by data journalist Patrick Cain use simple enhancements:

- 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/>

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## Scatterplots: Wage gap



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

22

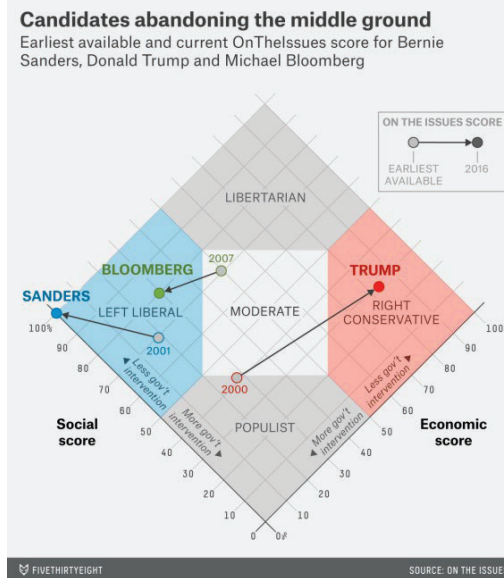
## Scatterplots: InfoVis

This graph, from [fivethirtyeight.com](http://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



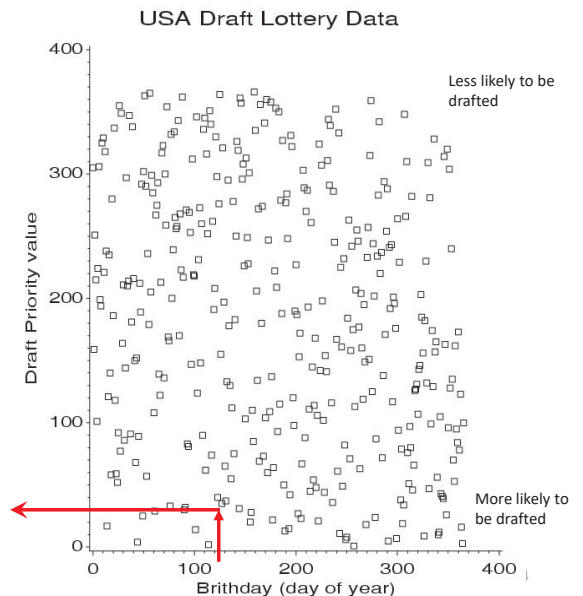
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## Scatterplots: Annotations enhance perception

Data from the US Vietnam 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

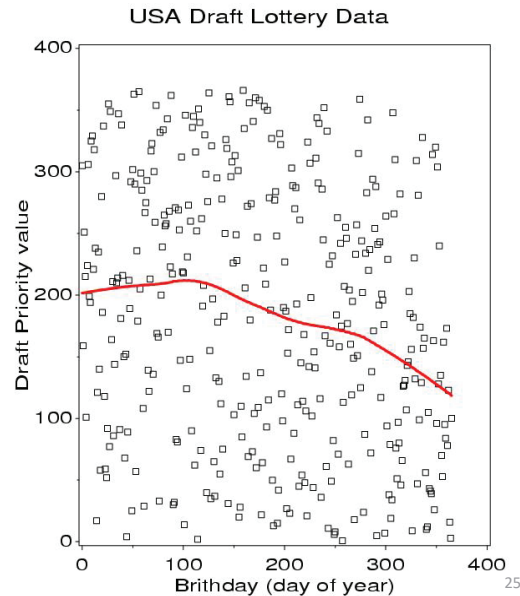


## Scatterplots: Smoothing enhances perception

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:

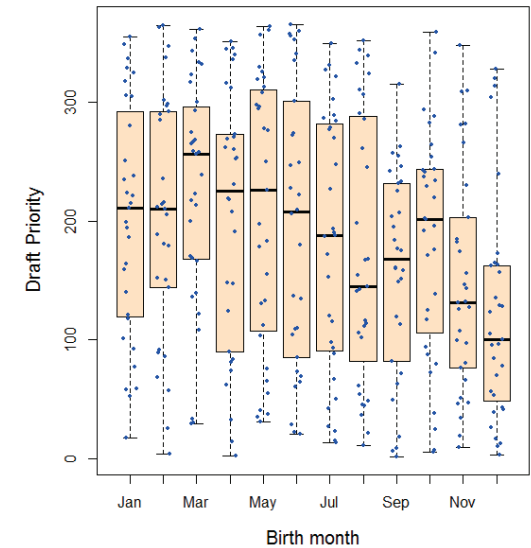


## Smoothing by grouping and summarization

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

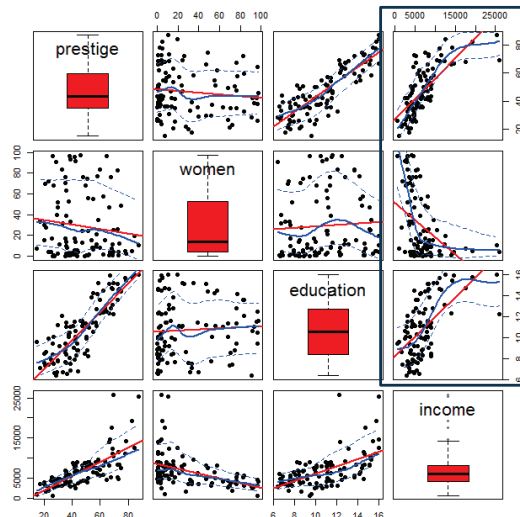
A scatterplot matrix shows the bivariate relation between all **pairs** of variables. Seeing these all together is more useful than a collection of separate plots.

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

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

Some plots are highly non-linear

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



## Scatterplot matrices

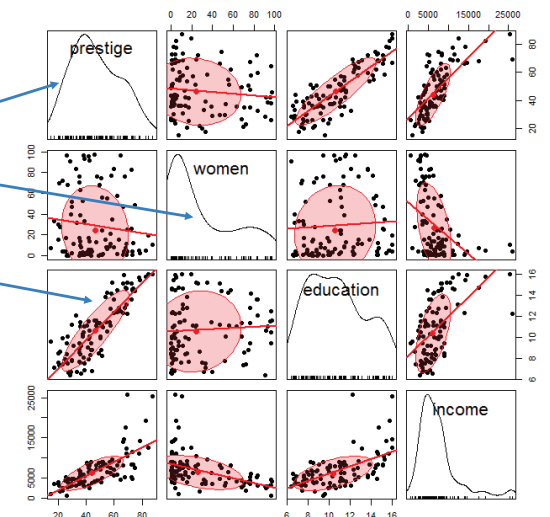
Essential idea: You can choose different methods to render the diagonal & off-diagonal panels

**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

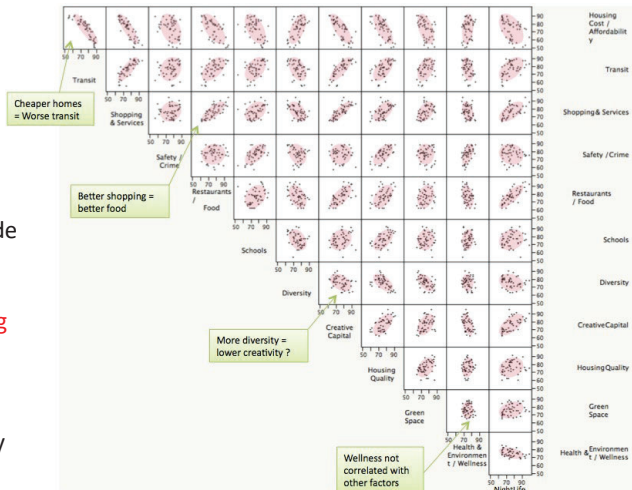
Where to live in NYC?

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



From: [http://junkcharts.typepad.com/junk\\_charts/2010/06/the-scatterplot-matrix-a-great-tool.html](http://junkcharts.typepad.com/junk_charts/2010/06/the-scatterplot-matrix-a-great-tool.html)

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# Categorical data

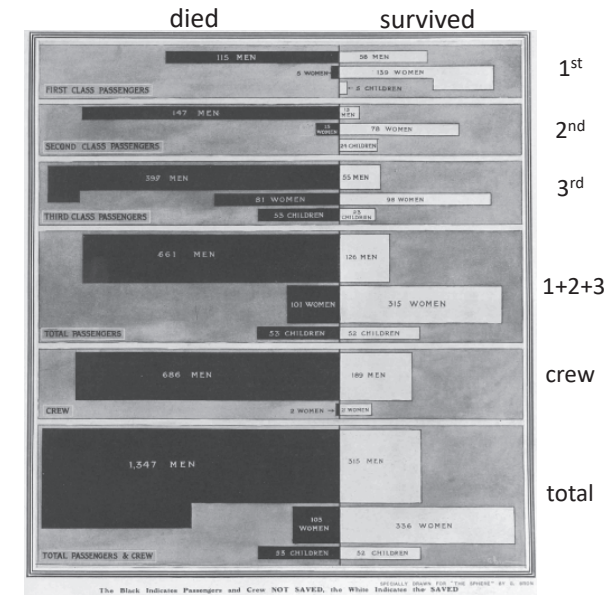
This remarkable chart shows survival on the *Titanic*, by Class for passengers and Gender and Age.

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/>



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# Categorical data: Mosaic plots

Similar to a grouped bar chart  
Shows a frequency table with tiles,  
**area ~ frequency**

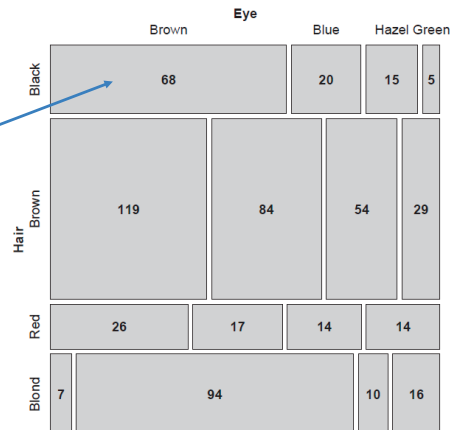
```
> data(HairEyeColor)
> HEC <- margin.table(HairEyeColor, 1:2)
> HEC
```

Hair	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

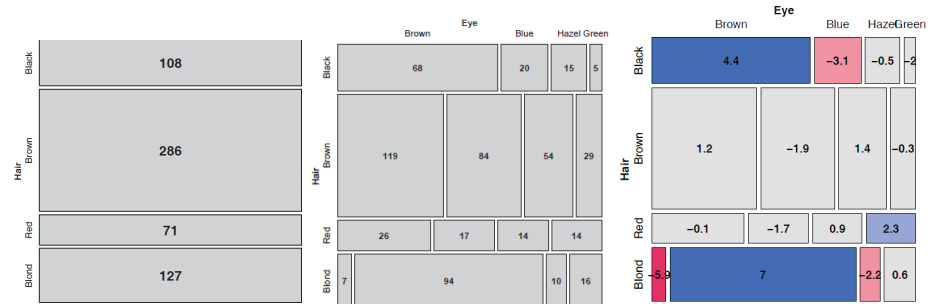


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How to understand the association between hair color and eye color?

# Mosaic plots

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



Divide unit square ~ V1  
marginal frequencies

Subdivide each ~ V2|V1  
conditional frequencies

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

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

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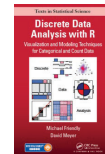
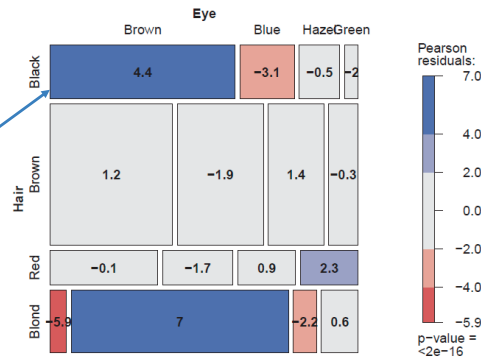
# Mosaic plots

Shade each tile in relation to the contribution to the Pearson  $\chi^2$  statistic

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

```
> round(residuals(chisq.test(HEC)), 2)
```

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

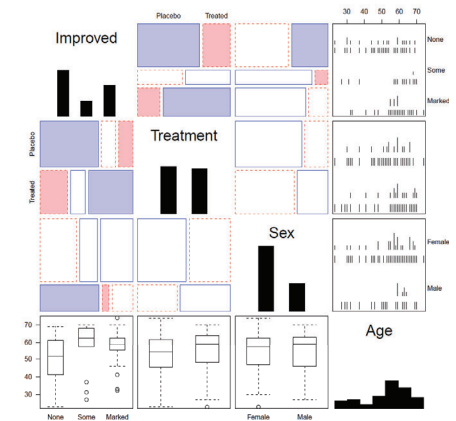
See: Friendly & Meyer (2016), Discrete Data Analysis with R, <http://ddar.datavis.ca/>

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# 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

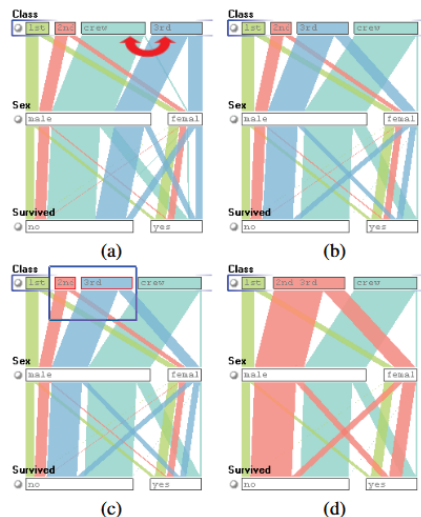


```
library(gpairs)
data(Arthritis)
gpairs(Arthritis[, c(5, 2:5)], ...)
```

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# Parallel Sets

Titanic data: Who survived?



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)

From: Kosera et al. (2006), [https://kosera.net/papers/2006/Kosara\\_TVCG\\_2006.pdf](https://kosera.net/papers/2006/Kosara_TVCG_2006.pdf)

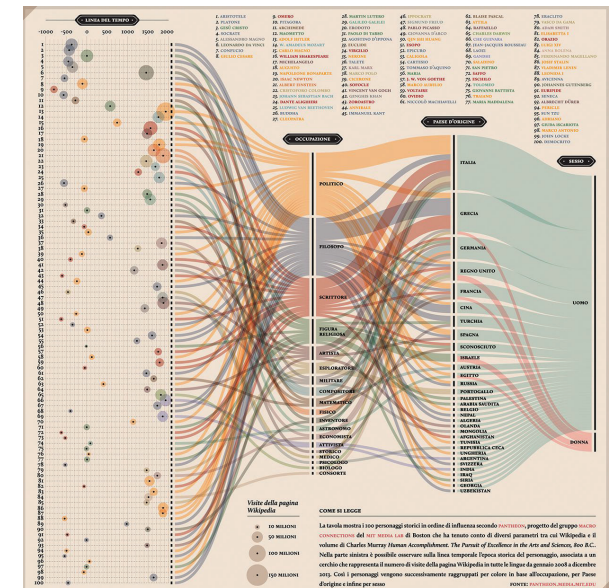
35

# Sankey diagram

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

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

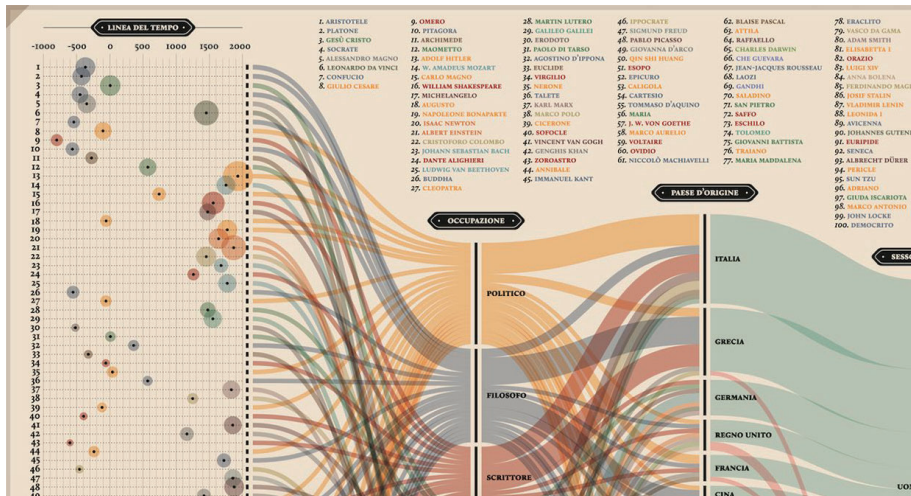
Flow lines link individuals to the column variables, width ~ influence



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## Sankey diagram



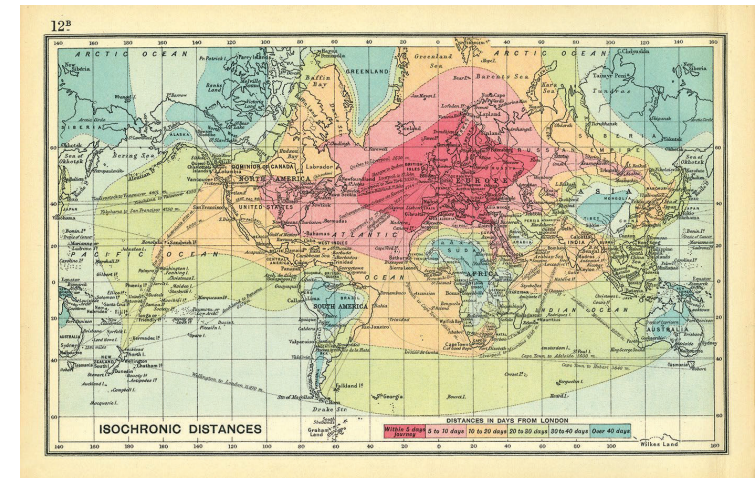
Multiple dimensions of the most influential people in history

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

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## 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

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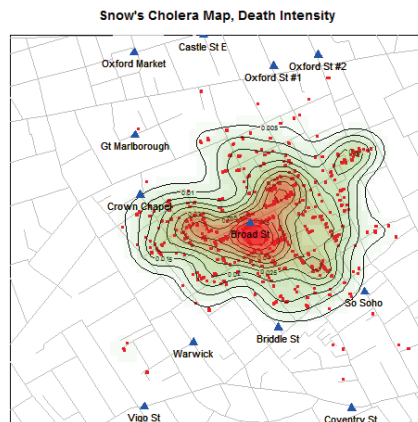
## 3D: Bivariate density estimation

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



Broad St. pump

Modern statistical techniques can compute contours of constant density



Data: [HistData](#) package for R



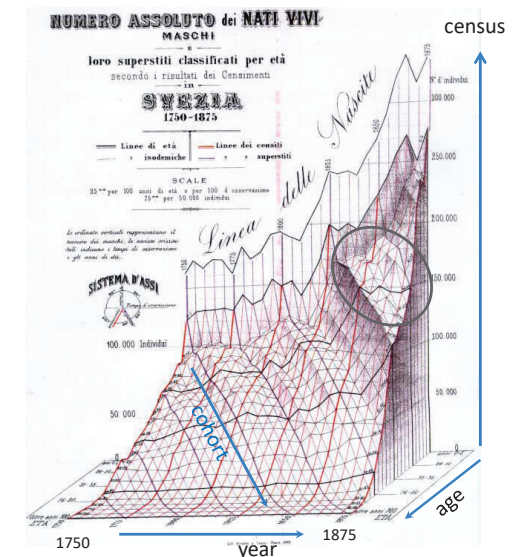
39

## 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?



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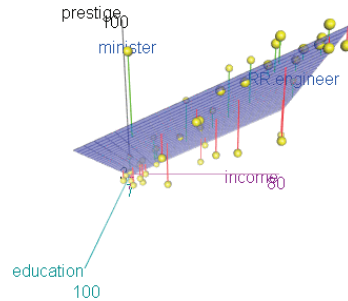
# 3D: scatterplot & regression surface

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

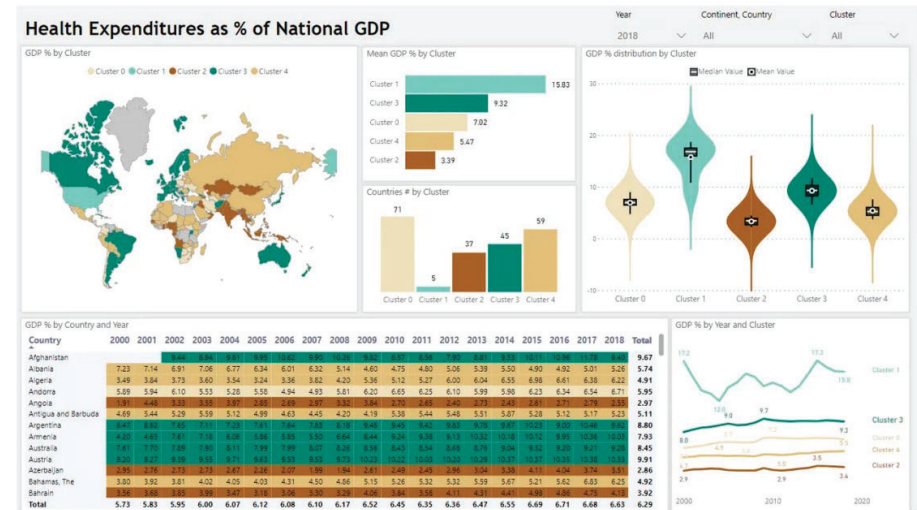


```
data("Duncan", package="car")
scatter3d(prestige ~ income + education, data=Duncan, id.n=2)
movie3d(spin3d(c(0,1,0), rpm=6), duration=6, movie="duncan-reg3d")
```

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# Dashboards

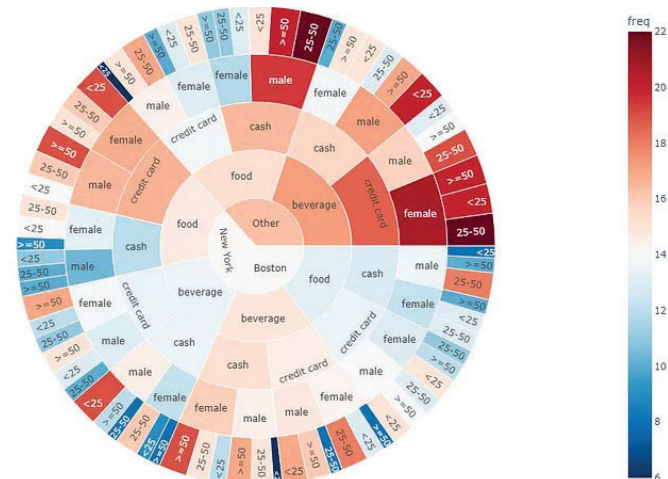
Dashboards provide multiple images of different aspects, often **linked interactively**. Designed to give a high-level overview of multiple aspects



# Exercise

What is this SUNBURST chart trying to show?

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



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# Thematic (statistical) maps

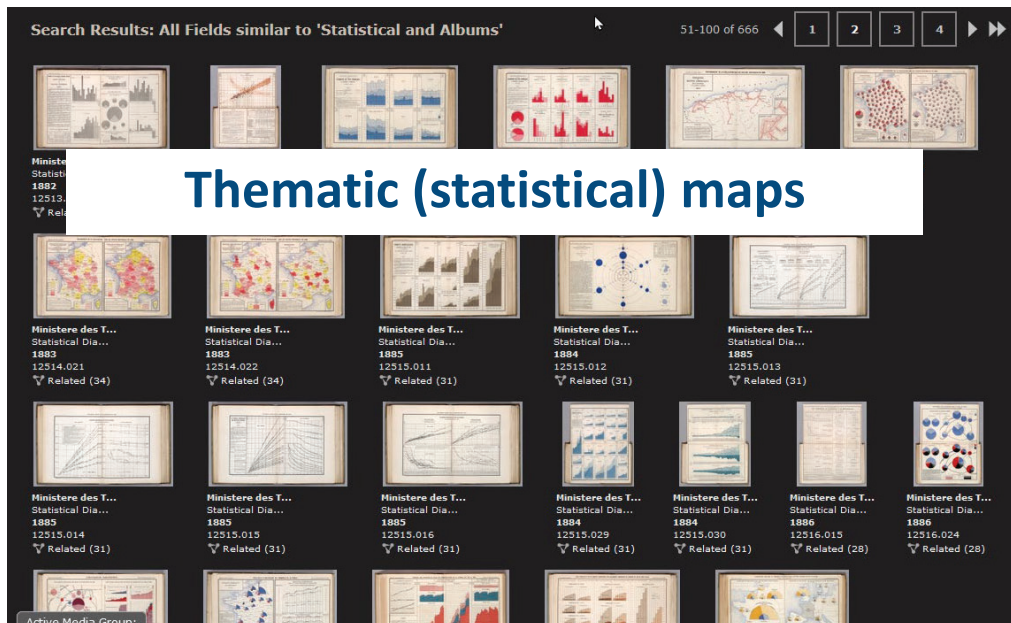


Image from: David Rumsey Map Collection, <https://www.davidrumsey.com/>

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# Thematic maps & Spatial visualization

Data often has a spatial context

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**

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

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

----- # dimensions -----

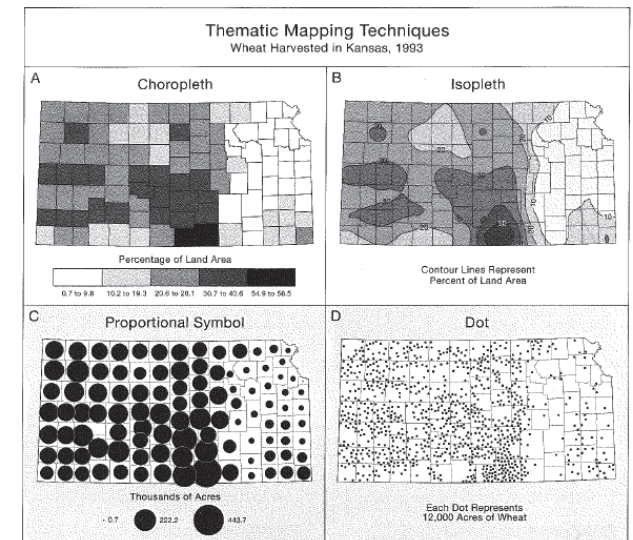
45

# 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

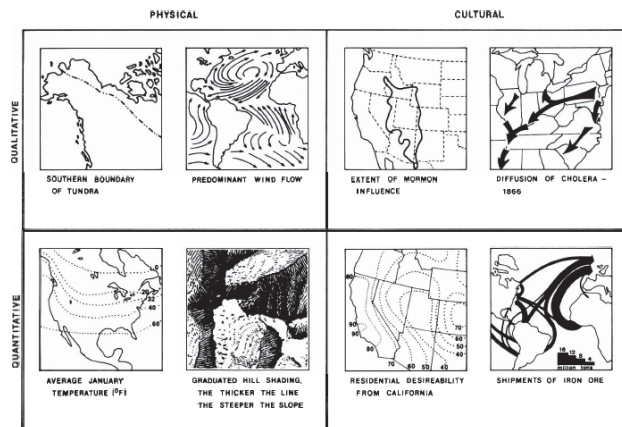
46

## 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

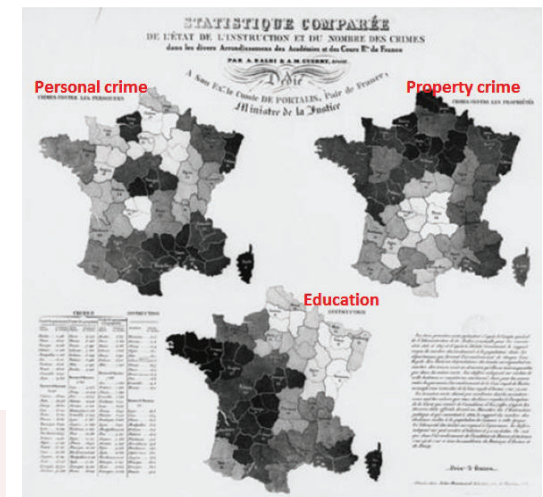
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## Choropleth maps

### 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



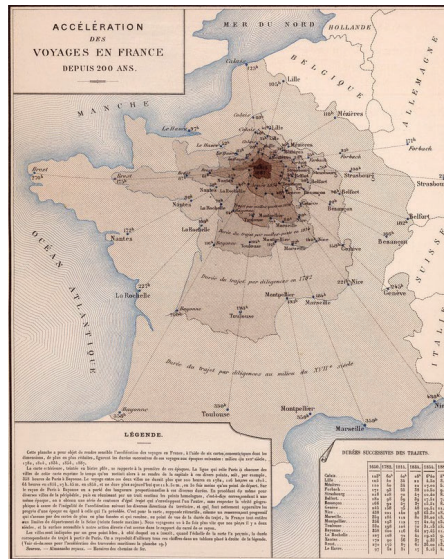
See: Friendly, M. (2022). *The life and works of André-Michel Guerry*, *Sociological Spectrum*, 42, 233-259

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# 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

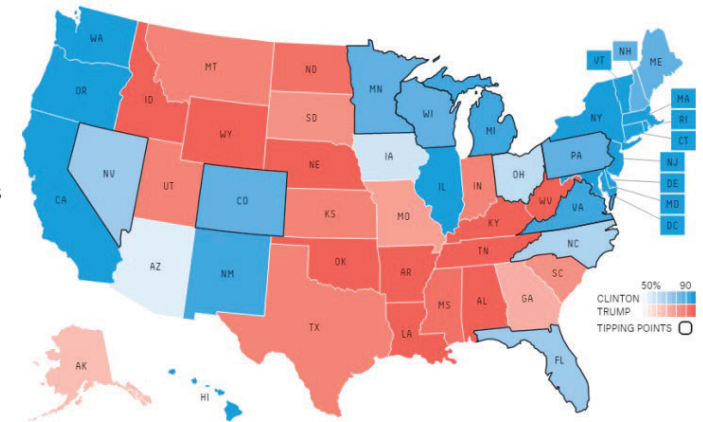
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# What's wrong with choropleth maps?

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



fivethirtyeight.com election predictions, Oct. 13, 2017

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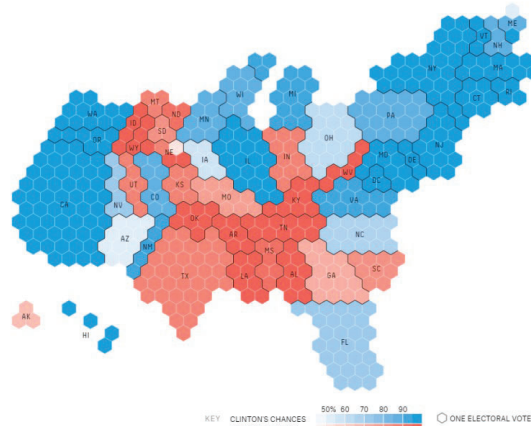
# Cartogram (tilegrams)

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

Here, the size of each state is made ~ number of **electoral college votes**

Now, it is easy to see the impact of states

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



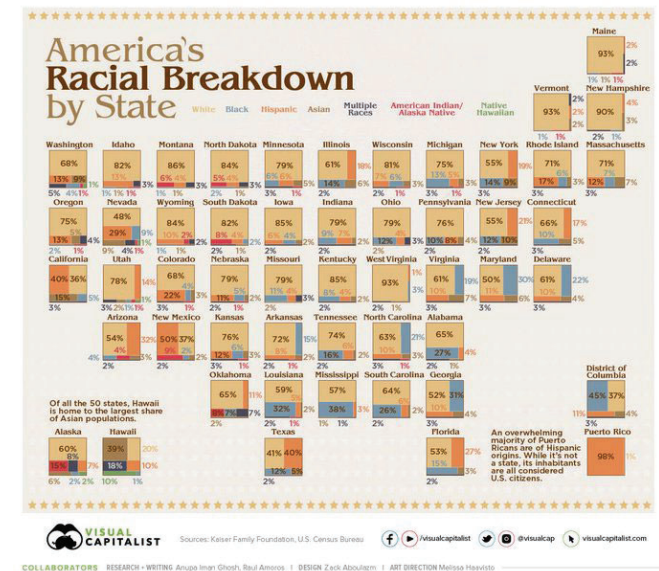
fivethirtyeight.com election predictions, Oct. 13, 2017

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# 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



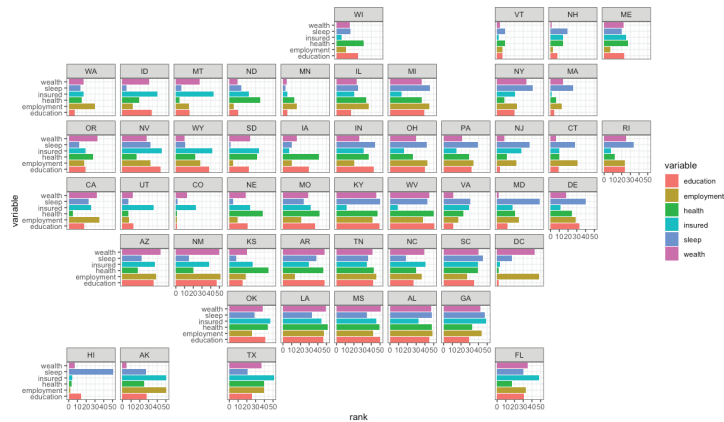
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# Geo-faceting

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



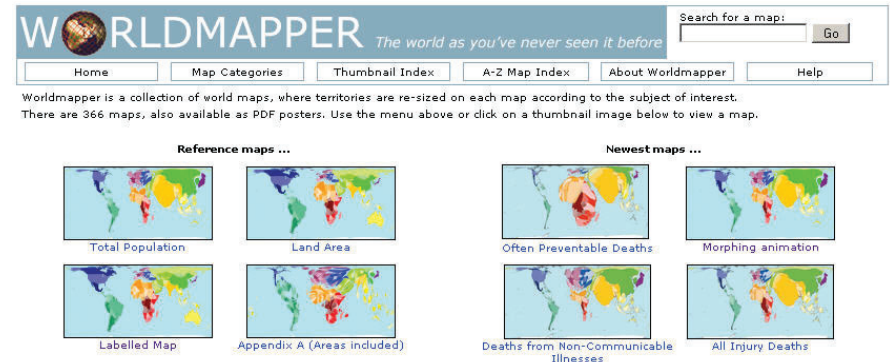
From: <https://cran.r-project.org/web/packages/geofacet/vignettes/geofacet.html>

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# Worldmapper: The world in cartograms

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

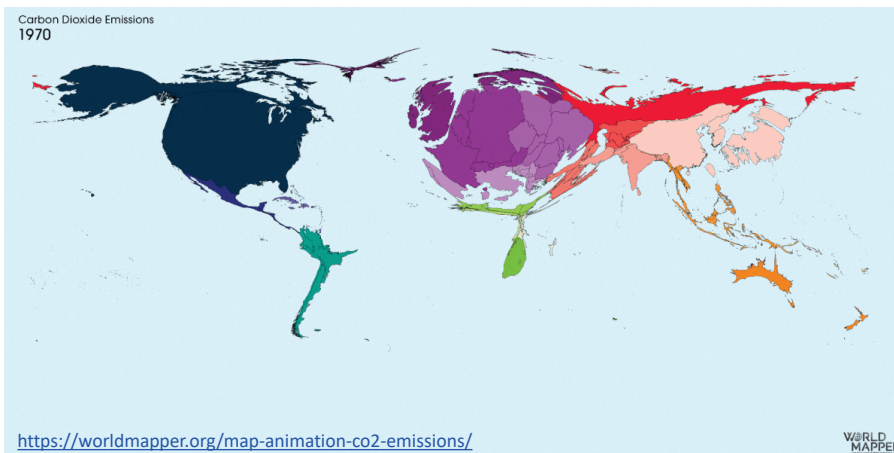
[worldmapper.org](http://worldmapper.org) : cartograms: area ~ variable of interest (700+ maps)



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# Worldmapper: Carbon emissions

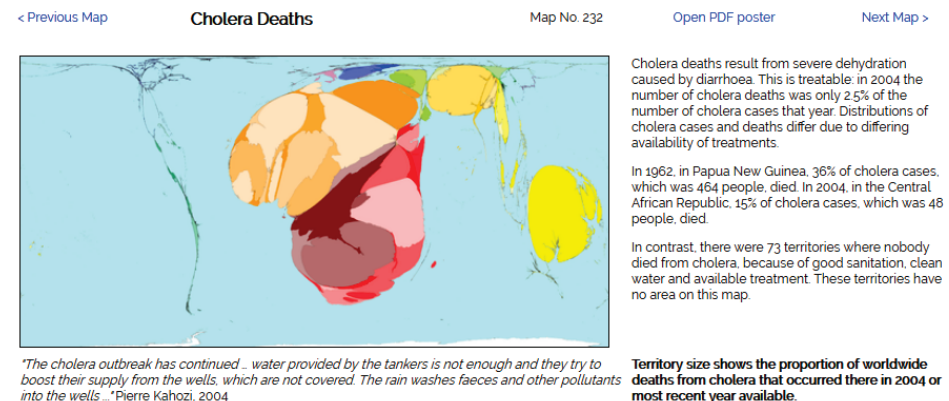
This map animation shows the growth in CO2 emissions globally: the map keeps growing in size from 1970 - 2016  
Also shows the changing shares of countries contributing to the increase in emissions



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# Worldmapper: Cholera deaths

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



<http://www.worldmapper.org/display.php?selected=232>

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## Bivariate maps

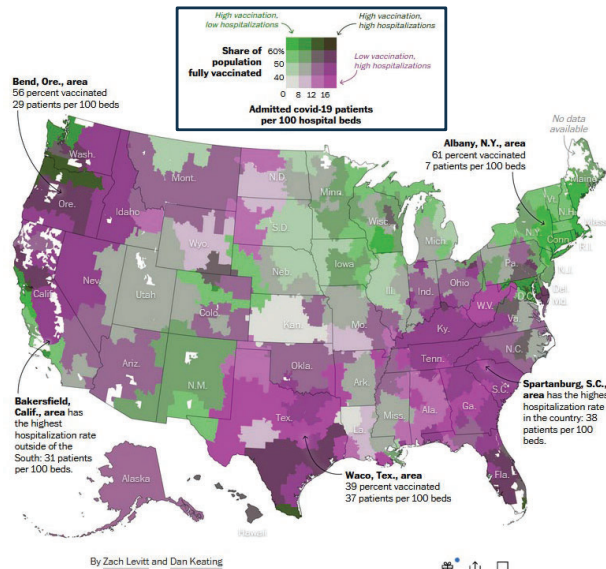
How to show relation between two variables on a map?

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



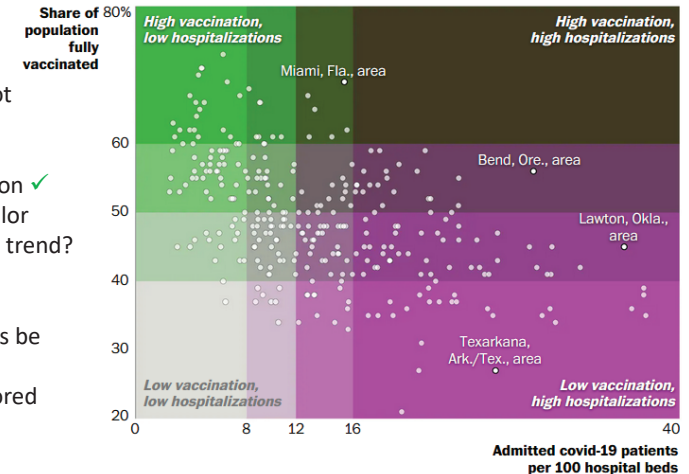
<https://www.washingtonpost.com/health/2021/09/23/covid-vaccination-hospitalization-map/>

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## 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?

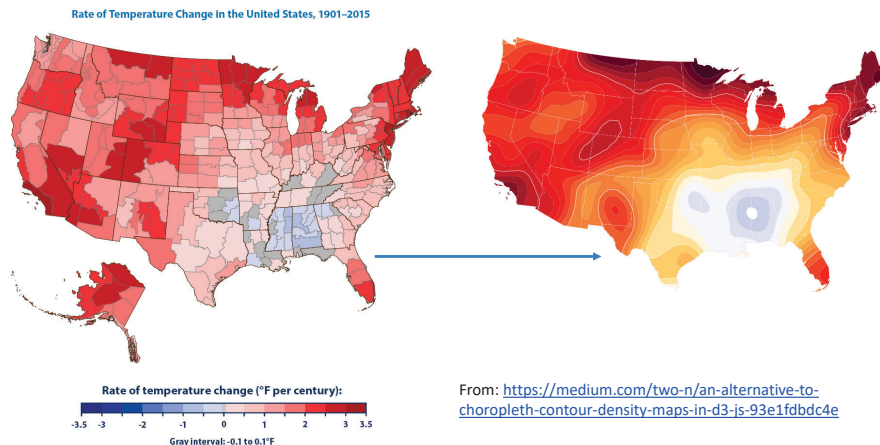
But:

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

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## Contour maps

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



From: <https://medium.com/two-n/an-alternative-to-choropleth-contour-density-maps-in-d3-js-93e1fdbdc4e>

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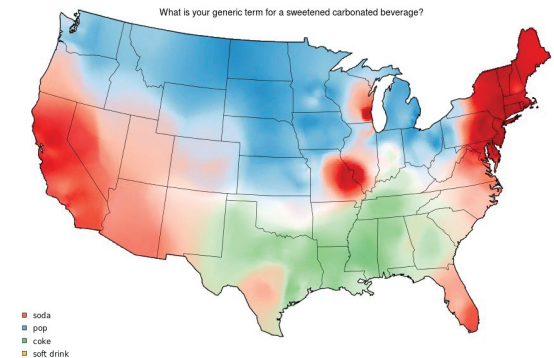
## Spatial visualization: Analysis + maps

Linguistics: Food dialect maps— visualizing how people speak

### soda vs. pop?

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**.



Take the survey: [http://www.tekstlab.uio.no/cambridge\\_survey](http://www.tekstlab.uio.no/cambridge_survey)

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

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# Spatial visualization: Analysis + maps

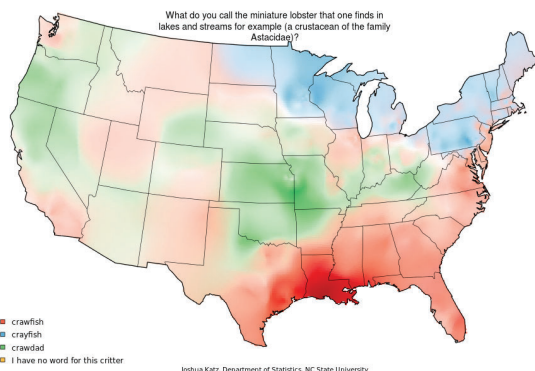
Linguistics: Food dialect maps– visualizing how people speak

crawfish, crayfish, crawdad?

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.

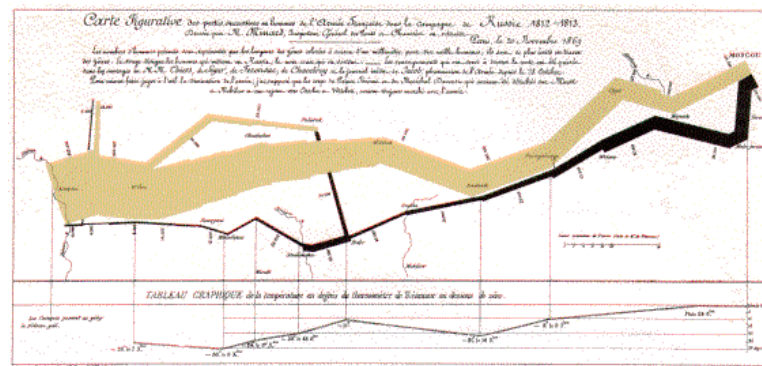
The use of **color** combines discrete categories with intensity to give a meaningful display



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# Flow maps

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



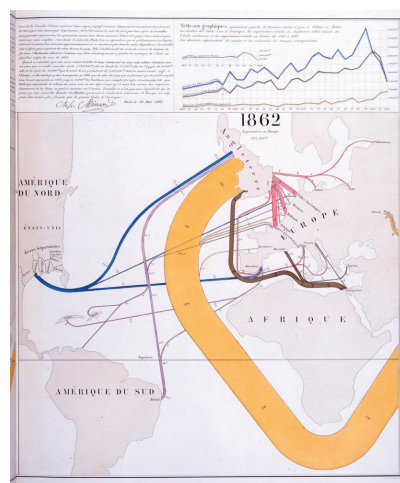
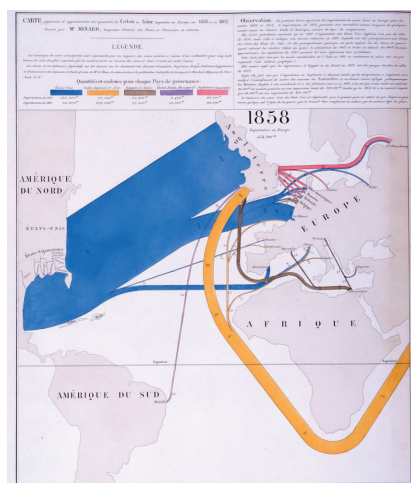
- Marey (1878): “defies the pen of the historian in its brutal eloquence”
- Tufte (1983): “the best statistical graphic ever produced”

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# Effect of US civil war on cotton trade

Before

After



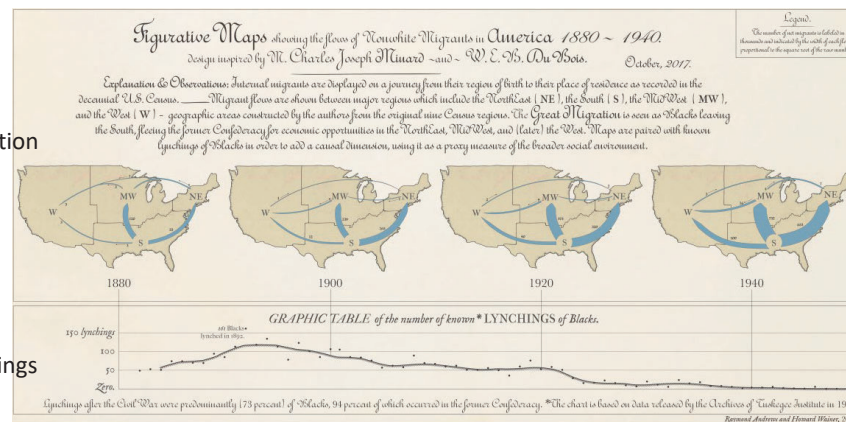
Note the deformation of the map to accommodate the data

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# 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



Lynchings

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

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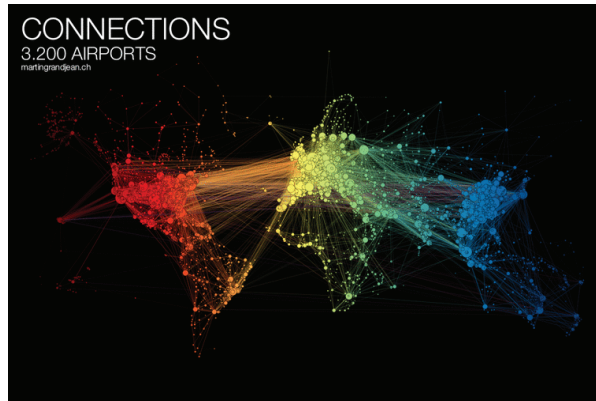
# Network visualization



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

Animated demo by Martin Grandjean 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/>

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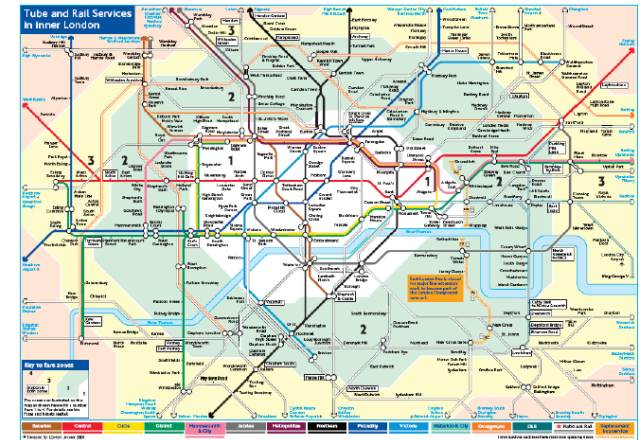
# Network visualization: Transport maps

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>

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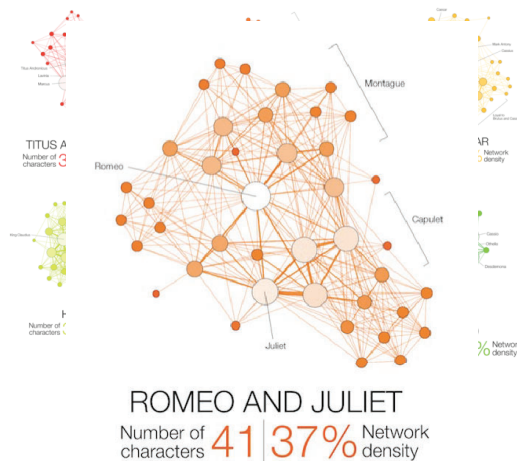
# Network visualization: Shakespeare tragedies

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 (# connections, centrality, ...)



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

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# Episodic memory: Free recall

Organization of words in memory can be inferred from their **order of recall** in multi-trial free recall task

Trial 2: urge quarrel assault captive decree execution mast professor inventor north  
 Trial 4: urge north quarrel assault captive execution highway professor inventor  
 Trial 5: highway structure decree mast north urge execution captive assault quarrel inventor professor  
 Trial 6: quarrel assault captive execution decree north structure mast highway inventor professor urge  
 Trial 7: quarrel assault captive execution decree north structure mast highway inventor professor urge  
 Trial 8: quarrel assault captive execution decree: urge structure north inventor professor highway mast

FIG. 1. Recall protocols for one subject in a free recall task.

TABLE 2  
MATRIX OF AVERAGE PROXIMITIES

	1	2	3	4	5	6	7	8	9	10	11	12
1. Inventor	100*											
2. Professor	79*	78										
3. Highway	77	77	94*									
4. Mast	76	70	79	86								
5. North	73	64	91*	85	95*							
6. Structure	55	52	47	52	67	57						
7. Assault	48	45	38	43	61	48						
8. Quarrel	64	61	60	61	76	70						
9. Captive	68	65	65	80	80	75	97*	88				
10. Execution	58	53	68	80	82	86*	82	73	87	95*		
11. Decree	64	64	69	68	79	82*	70	67	76	76	76	
12. Urge												

Proximity for each pair of words

MDS and cluster analysis used to infer **semantic structure**

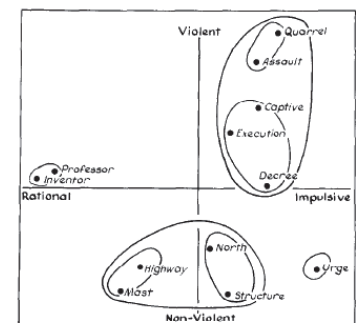


FIG. 2. Multidimensional scaling solution for the proximities in Table 2.

Friendly, M. (1977). In search of the M-Gram: The structure of organization in free recall. *Cognitive Psychology*, 9, 188–249. [https://doi.org/10.1016/0010-0285\(77\)90008-1](https://doi.org/10.1016/0010-0285(77)90008-1)

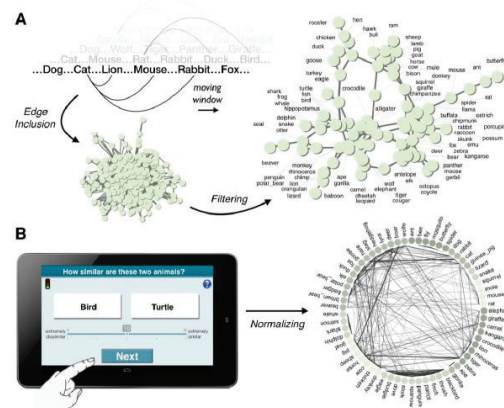
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# Semantic memory: Cognitive structure

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>

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# Semantic memory: Cognitive structure

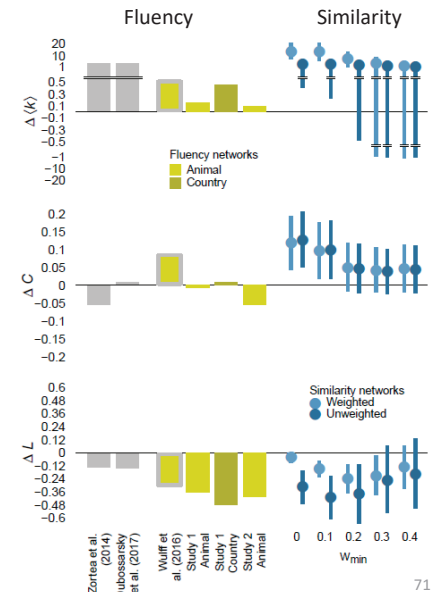
Do younger and older adults differ on measures calculated from their network diagrams?

$\langle k \rangle$  : 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.  
 $\Delta L$  &  $\Delta \langle k \rangle$  show consistent differences between young & old



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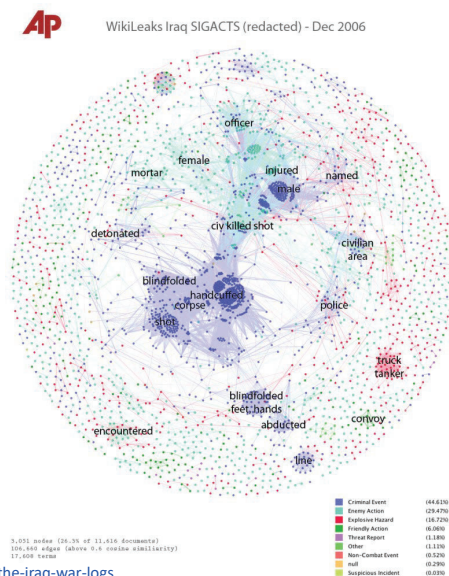
## WikiLeaks Iraq war logs

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



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From: <http://jonathanstray.com/a-full-text-visualization-of-the-iraq-war-logs>

## WikiLeaks Iraq war logs

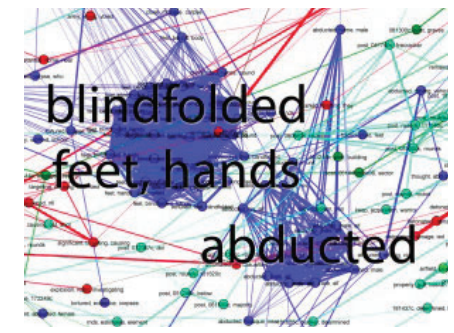
Certain themes became clear, and could be studied in rich detail  
The underlying methods use “term frequency–inverse document frequency” measures of **text-mining**.

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>

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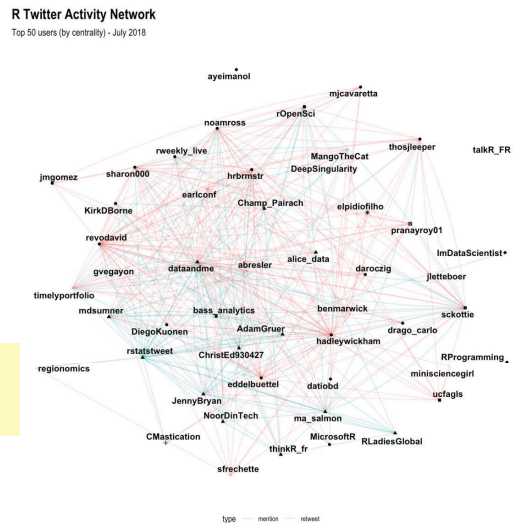


# Twitter network of R users

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")
```



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

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## 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



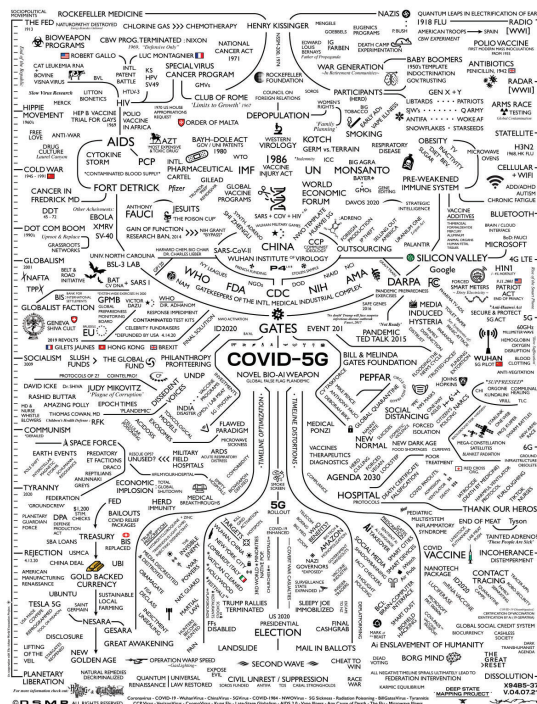
Generated by <http://chirpty.com>

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## Pathological networks

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

- "labyrinthine chartjunk"
- Information overload
- The world is chaotic
- Something MUST BE DONE!



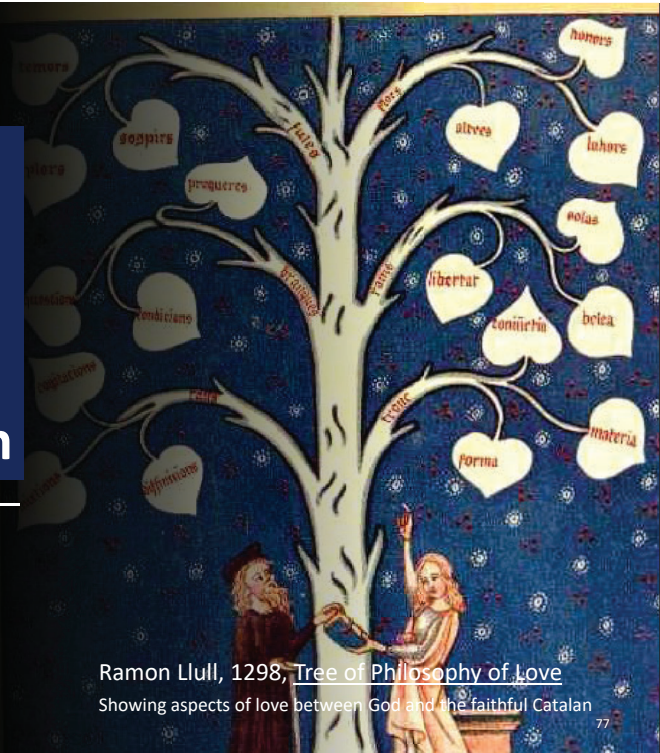
From: <https://deepstatemappingproject.com/>

## 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

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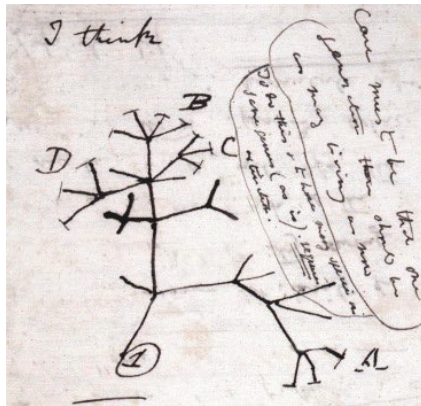


# Tree diagrams

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

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## History as a Tree:

*Geschichtesbaum Europa* (2003)

The entire history of Europe in one diagram

- space-filling design:
- resolution  $\sim \text{time}^2$
- natural metaphors for roots, branches

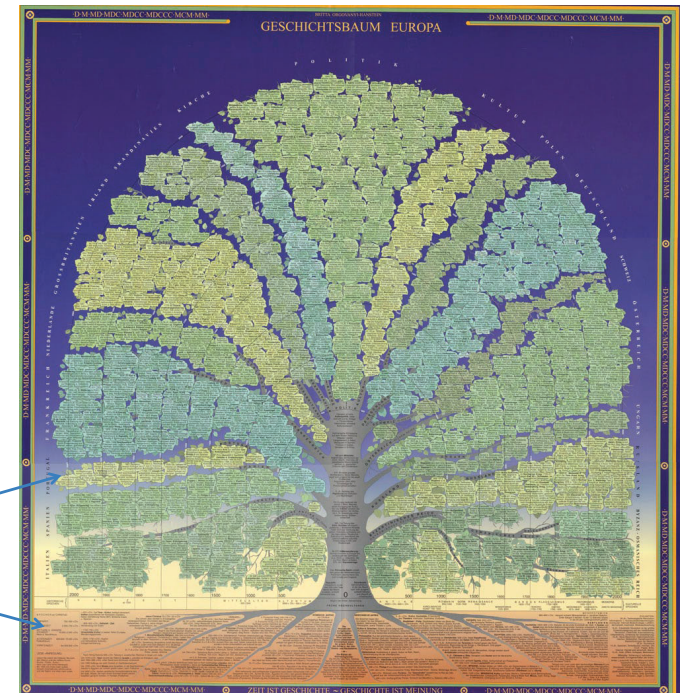
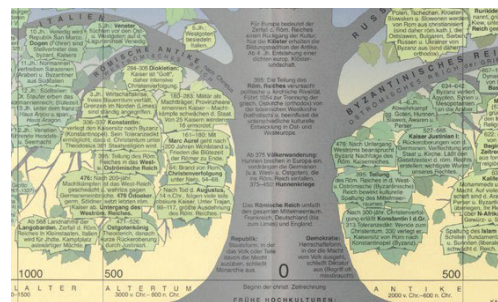
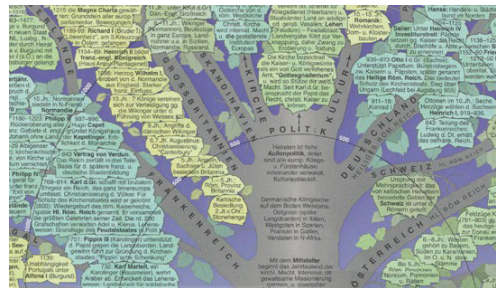


Image: David Rumsey map collection, <https://bit.ly/3GYZ2iw>

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## History as a Tree

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



- linear horizontal scale  $\rightarrow$  area  $\sim \text{time}^2$

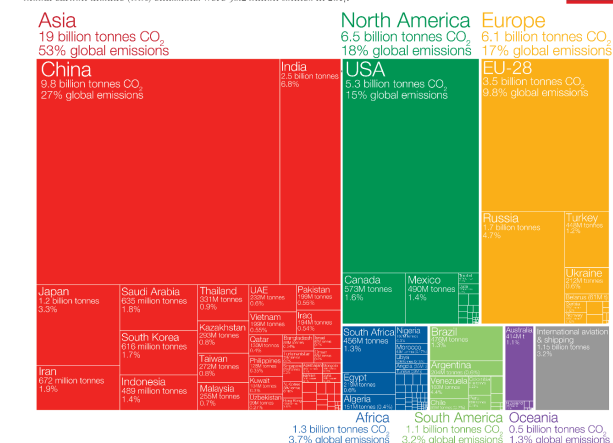
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## Treemaps

Treemaps display **hierarchical data** as a set of **nested rectangles**. Each node (leaf) has an area  $\sim \text{size}(\text{CO}_2)$

### Who emits the most CO<sub>2</sub>?

Global carbon dioxide (CO<sub>2</sub>) emissions were 36.2 billion tonnes in 2017.



The construction makes efficient use of space

**Nesting** shows relative size at multiple levels: continent  $\rightarrow$  country

No limit to the depth of the branches

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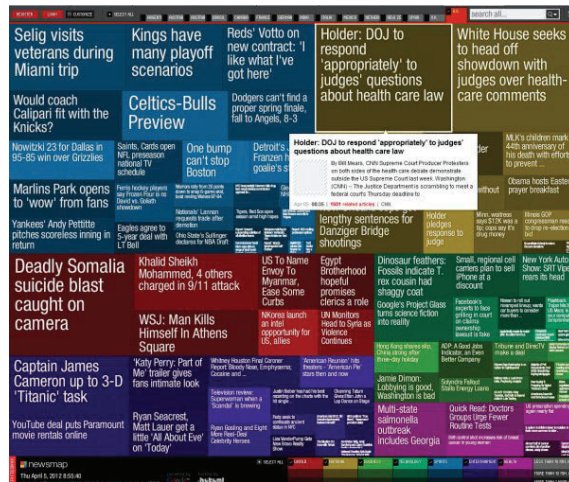
# Treemaps: Google Newsmap

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>

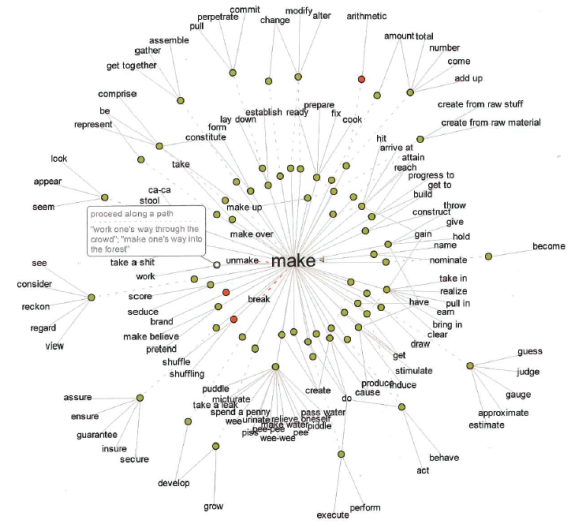
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# Radial trees: Visual Thesaurus

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

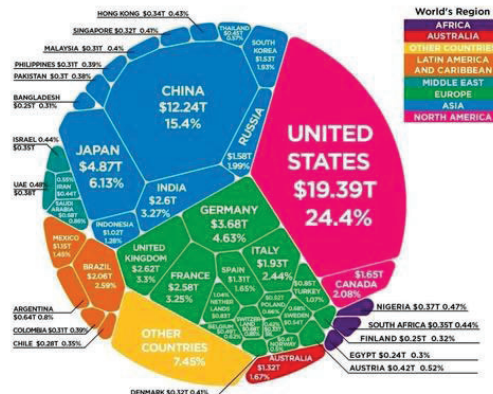
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# Voronoi treemaps

## Le nouveau camembert?

80 Trillion Dollar 💵

World Economy in a Single Chart 🗺️



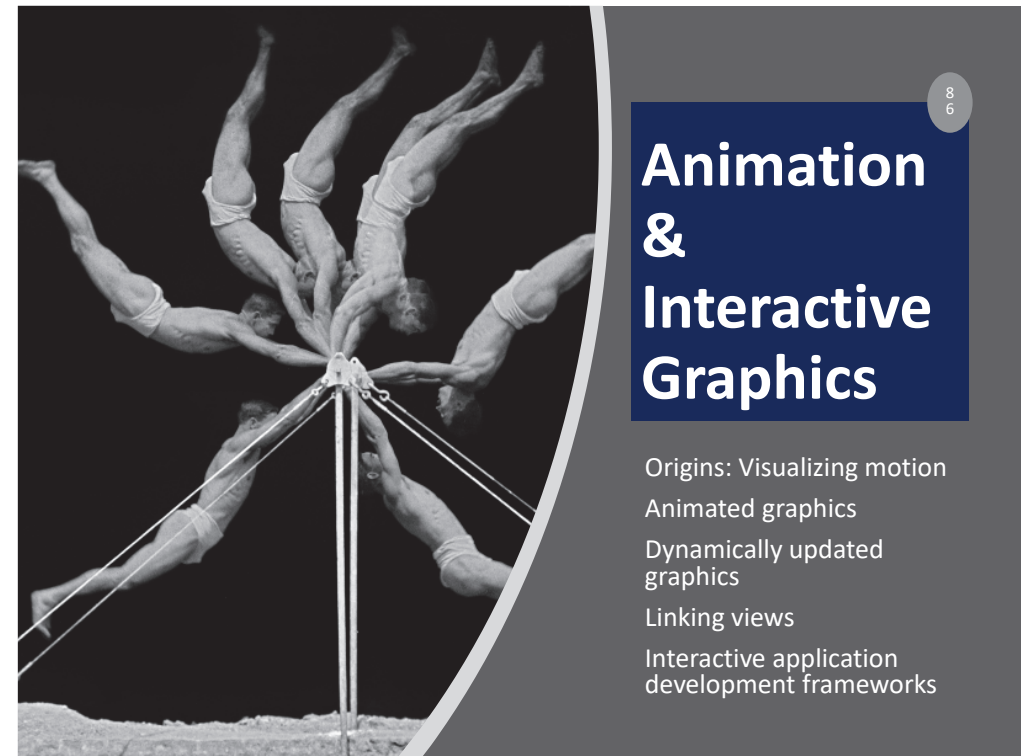
A **voroni diagram** subdivides space into polygons.

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

The **circular** form makes it an easy replacement for a lowly  $\pi$  chart,

Image from: <https://community.tableau.com/s/question/0D54T00000C6fMDSA/voronoi-diagram-and-other-charts>

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# Animation & Interactive Graphics

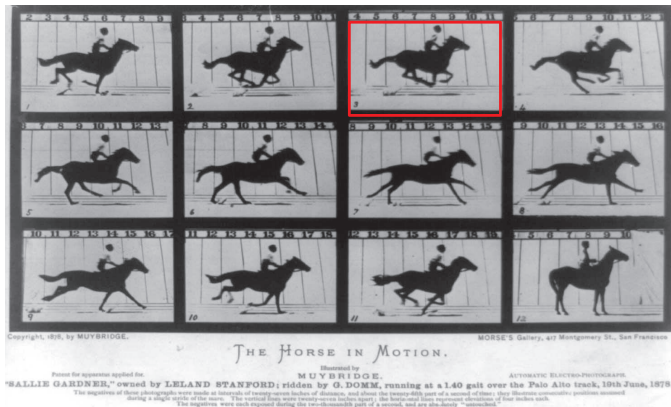
Origins: Visualizing motion  
Animated graphics  
Dynamically updated graphics  
Linking views  
Interactive application development frameworks



# 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? Leland Stanford made a bet. This came to be called the **Hypothesis of Unsupported Transit**

Eadweard Muybridge solved the problem by automating multiple photographs

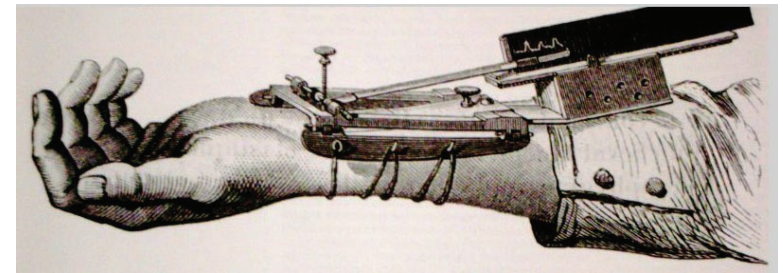


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# É.-J. Marey: A science of visualizing motion

- 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



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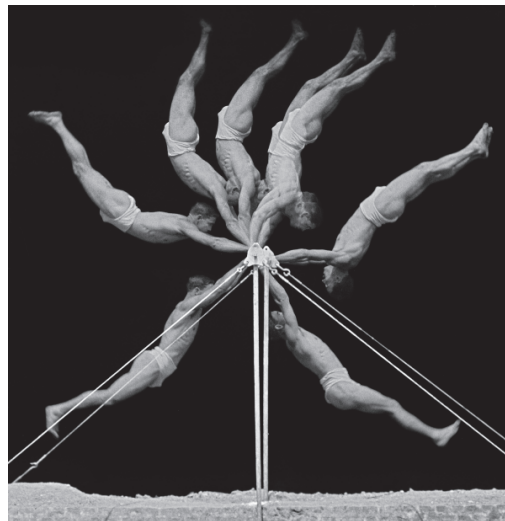
# Animation: Chronophotography

Marey pioneered the study of human and animal motion photographically



Fig. 1. Marey's chronophotographic gun.

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



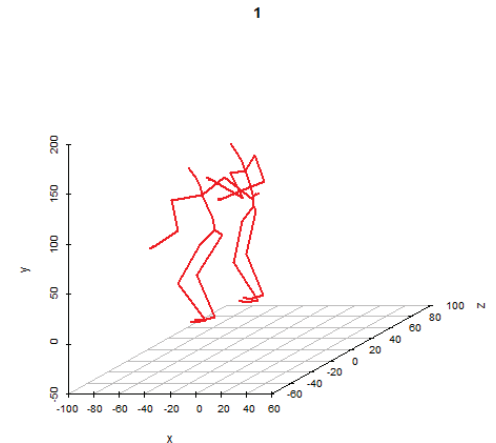
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# Animated graphics

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>

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## Animated line graph

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



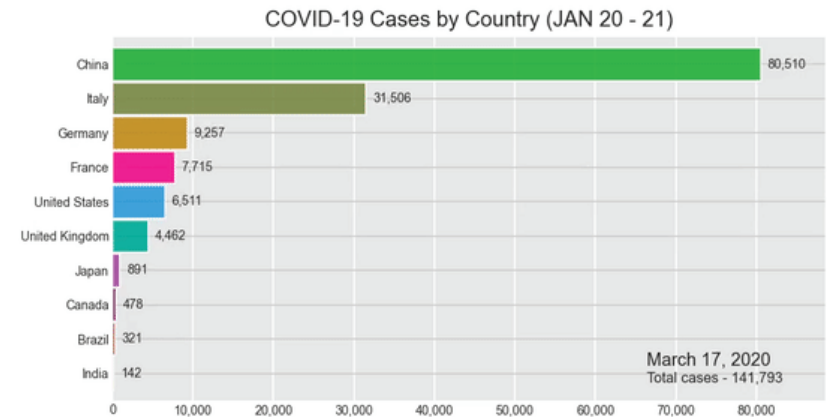
The [Data Visualization Catalog](#) shows page views of its top 10 charts  
Graphs like this can be done using the [gganimate](#) package

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## 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.



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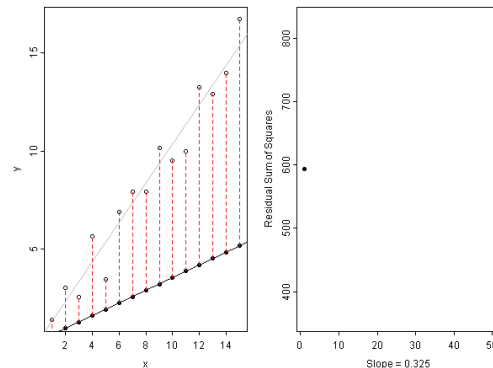
## Statistical animations

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.

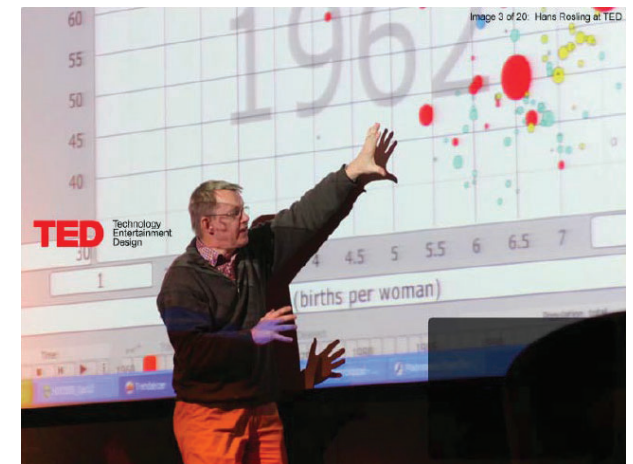
This plot was done using the [animate](#) package in R.



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## 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](https://www.ted.com/talks/hans_rosling_shows_the_best_stats_you_ve_ever_seen)

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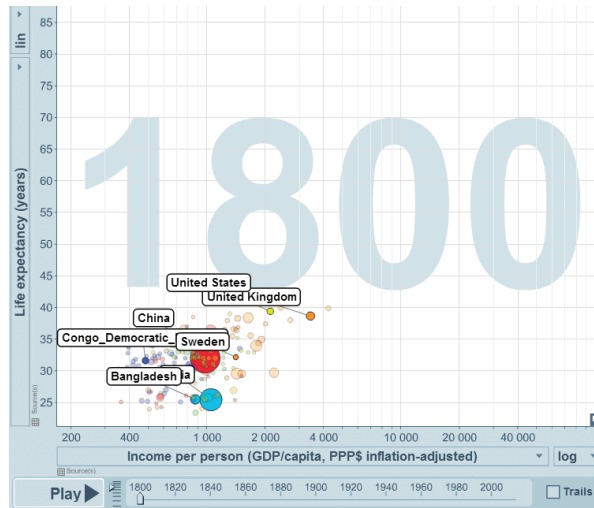
# Animation & Interactivity

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



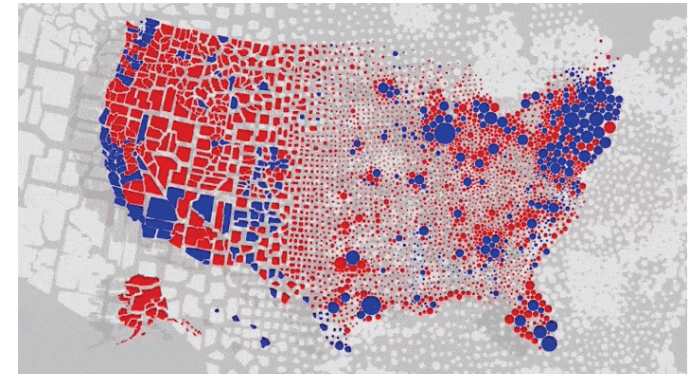
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# Animation: Interpolated views

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 Douieb/Jetpack.ai]

<https://www.fastcompany.com/90572489/u-s-election-maps-are-wildly-misleading-so-this-designer-fixed-them>

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# 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

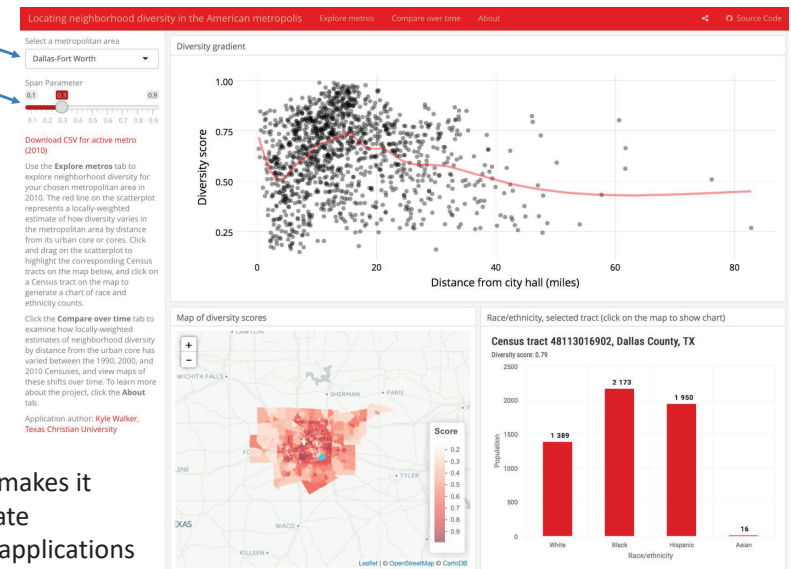


From: Carson Sievert, <https://plotly-book.cpsievert.me/linking-animted-views.html>

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# Interactive application frameworks

selectors  
inputs



shiny for R makes it easy to create interactive applications

[https://walkerke.shinyapps.io/neighborhood\\_diversity/](https://walkerke.shinyapps.io/neighborhood_diversity/)

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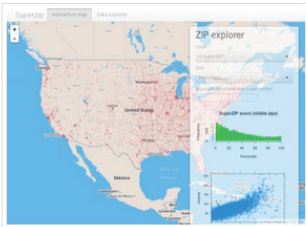


# shiny gallery

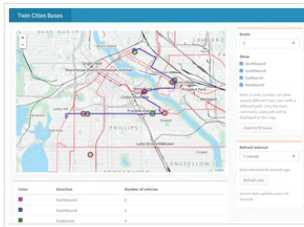
There is now a large collection of shiny applications, <https://shiny.rstudio.com/gallery/>  
These integrate other interactive web software: d3, Leaflet, Google Charts, ...

## Interactive visualizations

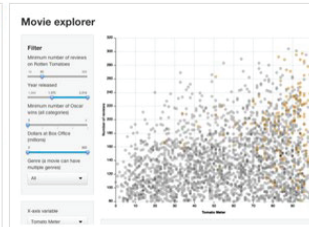
Shiny is designed for fully interactive visualization, using JavaScript libraries like d3, Leaflet, and Google Charts.



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