

# Psychology of Data Visualization: Course Overview



Michael Friendly  
Psych 6135



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

@datavisFriendly

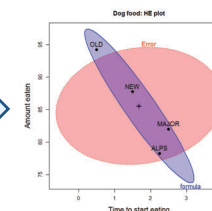
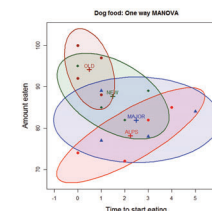
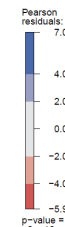
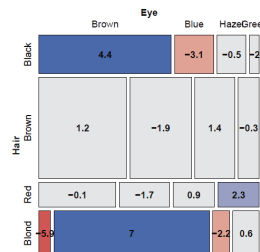
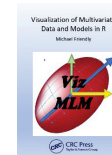
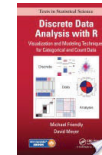
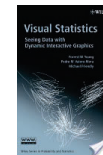
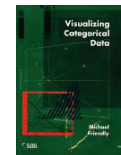


## Introducing: me

I wear two hats, both reflected on my license plate:



Statistical graphics developer (categorical & multivariate data analysis)



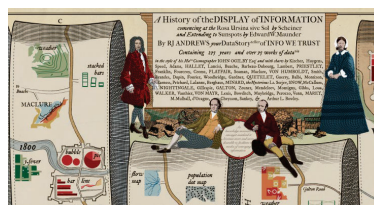
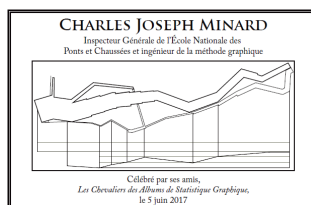
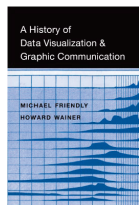
mosaic plots for frequency tables

HE plots for MANOVA

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## Introducing: me

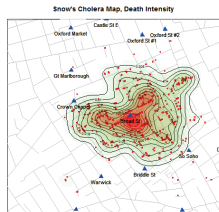
History of data visualization: *Les Chevaliers*; Friendly & Wainer (2021)



John Snow's map of cholera in London, 1854

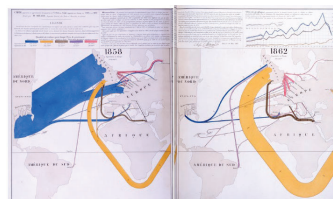


original



modern enhancement

C. J. Minard: Flow maps of cotton trade



Visual explanation: What happened in the US Civil War?

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## Why taking this course? Wordcloud

Just for fun, I made a wordcloud of words you mentioned in “Why taking this course?”



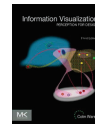
## Your role

- Weekly readings – see the course [web](#) site for updates
  - Please read the lecture slides in advance
- Discussion – no formal grade, but please contribute
  - **Show & tell:** Tell us something you found interesting somewhere
- Discussion leader (20%)
  - Each week 1-2 of you will lead a brief discussion on one of the readings or sub-topics (~ 5-8 min.)
  - Please [sign up on the Google sheet](#) (Schedule)
- Class presentation (40%) – see [About](#) page
  - In the last 2 weeks, each person will give a ~ 20 min presentation on a topic of research, application or software related to data visualization
- Research proposal (40%)
  - Prepare a brief research proposal on a data visualization topic

## Course Topics

- Varieties of information visualization
  - Goals of visualization
  - Survey of graphic forms
- History of information visualization
  - “Those who don’t know history are doomed to plagiarize it”
- Psychological models, theories and results
  - What can people see, **understand** and **remember** from data displays?
  - Perceptual aspects, cognitive aspects
- Human factors research
  - How to tell what works for different tasks?
  - Graphical communication
- Software tools for information visualization (mainly R)
  - ggplot2; tidyverse
- Special topics
  - Visualizing uncertainty; Data journalism
  - Categorical data; High-D data; Dynamic and interactive methods

## Books & Readings

Colin Ware, *Information Visualization*, 3<sup>rd</sup> Ed.

## What perceptual science has to say about data visualization, from a bottom-up perspective

Course notes at: <http://ccom.unh.edu/vislab/VisCourse/index.html>

Alberto Cairo, *The Truthful Art*

### Information graphics from a communication perspective

Blog: <http://www.thefunctionalart.com/>

Claus Wilke, *Fundamentals of Data Visualization*

Well thought out, a wide range of topics, good practical advice, lots of examples.

Online version: <https://clauswilke.com/dataviz/>

Course notes: <https://wilkelab.org/SDS375/>

Hadley Wickham, *ggplot2: Elegant graphics for data analysis*, 2nd Ed.1st Ed: Online, <http://ggplot2.org/book/>

ggplot2 Quick Reference: <http://sape.inf.usi.ch/quick-reference/ggplot2/>

Complete ggplot2 documentation: <http://docs.ggplot2.org/current/>



## More books I like



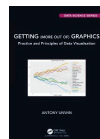
Tamara Munzner (2014), *Visualization Analysis & Design*  
An attractive new book combining computer science and design perspectives  
Web page: <http://www.cs.ubc.ca/~tmm/vadbook/> with lots of illustrations & lectures



Manuel Lima, *The Book of Trees: Visualizing branches of knowledge*  
A visual delight; an entire history of tree-type diagrams  
Blog: <http://www.visualcomplexity.com/vc/blog/>



Keiran Healy, *Data Visualization: A Practical Introduction*  
An accessible primer on how to create effective graphics from data using ggplot2  
Online: <http://socvis.co>



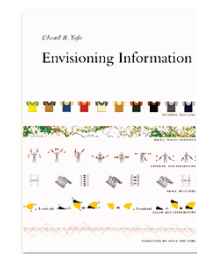
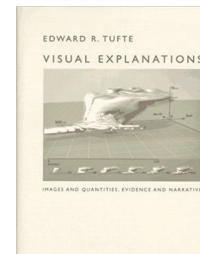
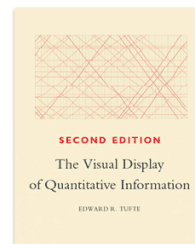
Antony Unwin, *Getting (more out of) Graphics*  
A collection of 25 case studies of interesting datasets, with ggplot2 graphics  
Online R code: <https://github.com/antonr4/GmooGkodes>

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## Tufte Stufe

Four books by Edward Tufte largely defined the landscape for data visualization and information design



Concepts introduced:

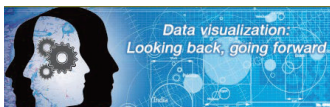
- chart junk,
- data-ink ratio,
- small multiples,
- substance takes precedence over visual design

Web site:  
<https://www.edwardtufte.com>

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## Blogs & Web resources



My web site, <http://datavis.ca>. Contains the [Milestone Project](#) on the history of data vis, [Data Visualization gallery](#), links to books, papers and courses.



Kaiser Fung, <http://junkcharts.typepad.com/>. Fung discusses a variety of data displays and discusses how they can be improved.



Nathan Yau's blog, <http://flowingdata.com>. A large number of blog posts illustrating data visualization methods with tutorials on how to do these with R and other software.



<http://visiphilia.org/>. Statisticians Di Cook and Heike Hofmann from Iowa State University blog about data visualization topics, using R

visual  
complexity

Manuel Lima's blog, <http://www.visualcomplexity.com/vc/blog/>, with hundreds of projects on all types of visualizations

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## Blogs & Web resources

# DATA STORIES

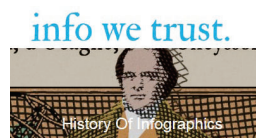
<http://datastori.es/>. A podcast on data visualization with Enrico Bertini and Moritz Stefaner; interviews with over 100 graphic designers & developers.



Annual awards celebrate excellence and beauty in data visualizations, infographics, interactives & information art.  
<https://www.informationisbeautifulawards.com>



<https://www.r-bloggers.com/>. A large collection of posts on R news and tutorials by over 750 R bloggers.

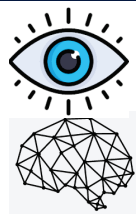


Raymond Andrews, <http://infowetrust.com/>. A visual storyteller delights with graphic stories from the history of data visualization

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# Psychology facts: Why visualization?

- ~90% of information about the environment is received through the eyes.
- ~50% of our brain neurons are involved in the processing of visual information.
- Pictures increase desire to read the text by ~80%.
- We remember 10% of what we heard, 20% of what's read, and 80% of what's seen!
- People perceive 70% of the information if there are no illustrations. Add pictures there — the figure will increase up to 95%.

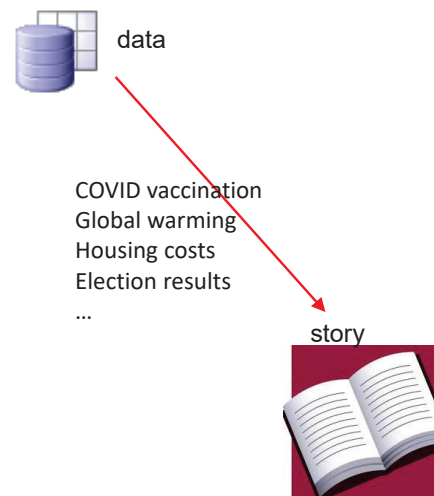


McLeod, S. A. (2018). Visual perception theory. Simply Psychology. [www.simplypsychology.org/perception-theories.html](http://www.simplypsychology.org/perception-theories.html)

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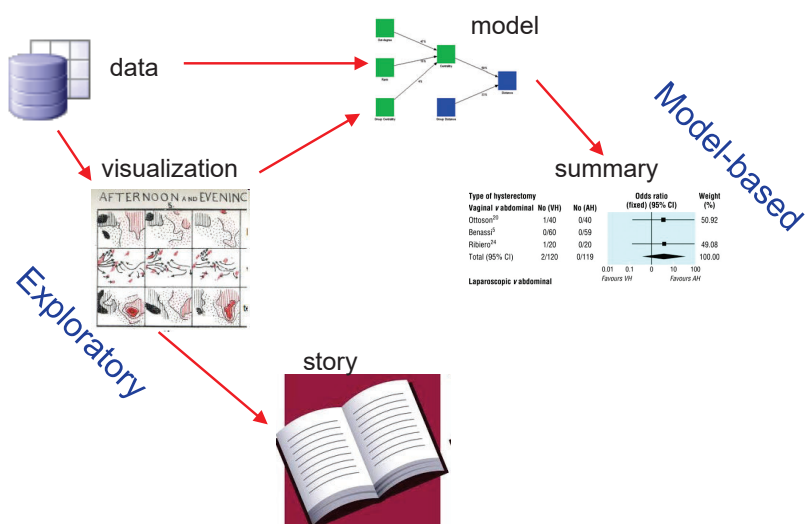
# Data, pictures, models & stories

Goal: Tell a **credible story** about some **real** data problem



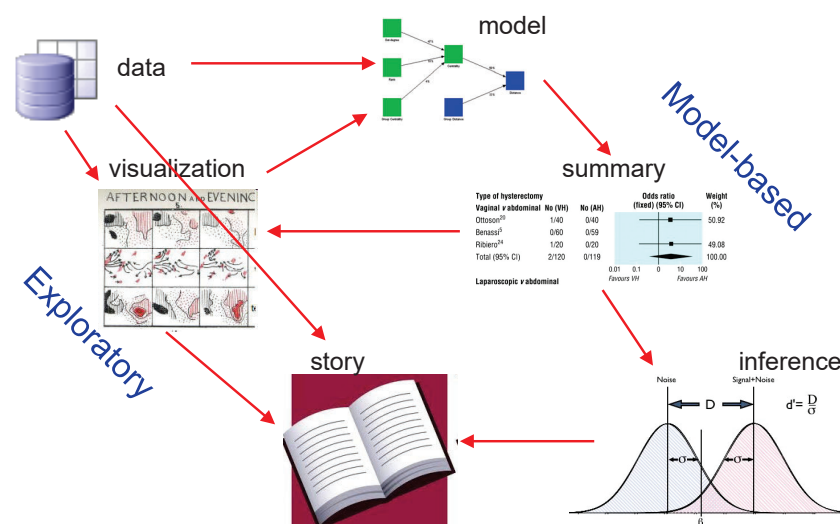
# Data, pictures, models & stories

Two paths to enlightenment



# Data, pictures, models & stories

Now, tell the story!

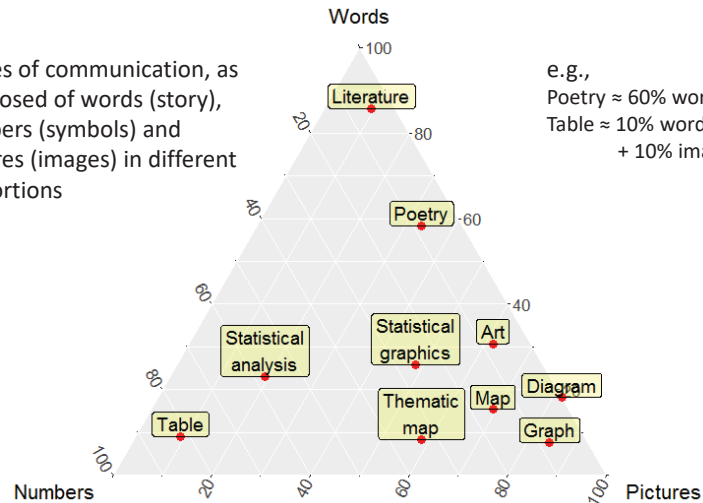




# Words, numbers and pictures

## Pictures and images in a wider context

Modes of communication, as composed of words (story), numbers (symbols) and pictures (images) in different proportions



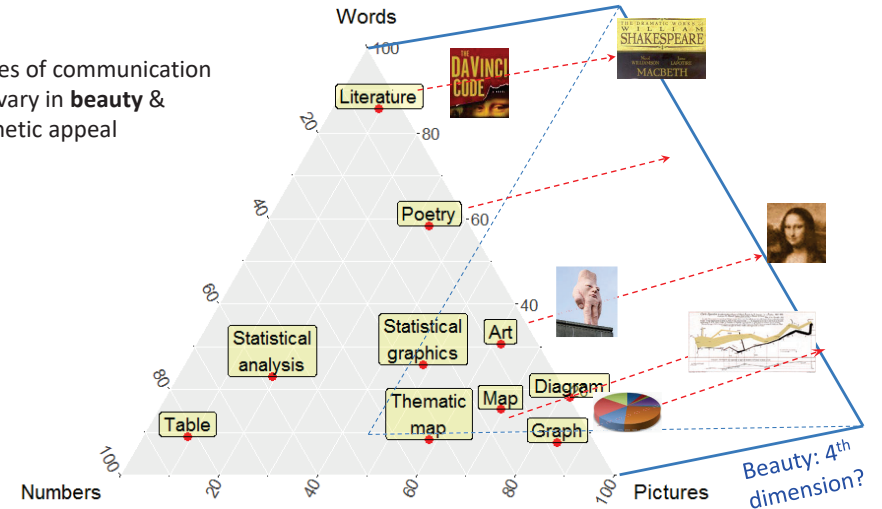
e.g.,  
Poetry  $\approx$  60% words + 40% images  
Table  $\approx$  10% words + 80% numbers + 10% images

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# Words, numbers and pictures

## Beauty: The 4<sup>th</sup> dimension

Modes of communication also vary in **beauty** & aesthetic appeal



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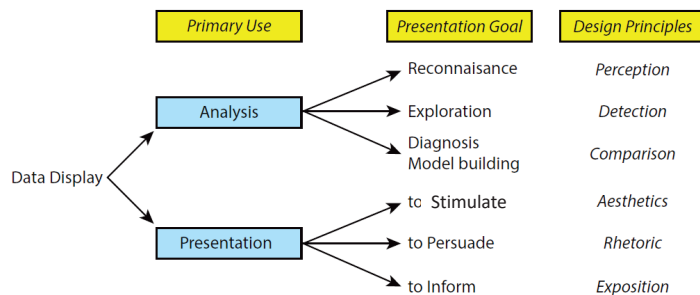
## Roles of graphics in communication

- Graphs (& tables) are forms of communication:
  - What is the audience?
  - What is the message?

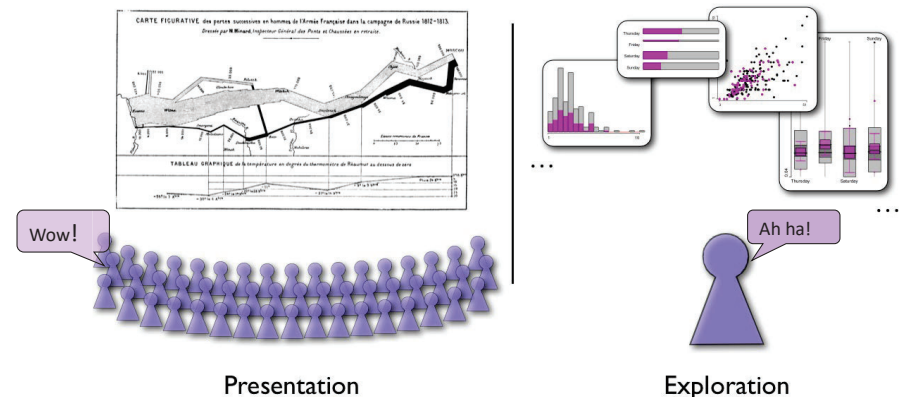
**Analysis graphs:** design to see patterns, trends, aid the process of data description, interpretation

**Presentation graphs:** design to attract attention, make a point, illustrate a conclusion

### Basic functions of data display



## Different graphs for different purposes



Goal: the Wow! experience  
Single image for a large audience  
Tells a clear story!

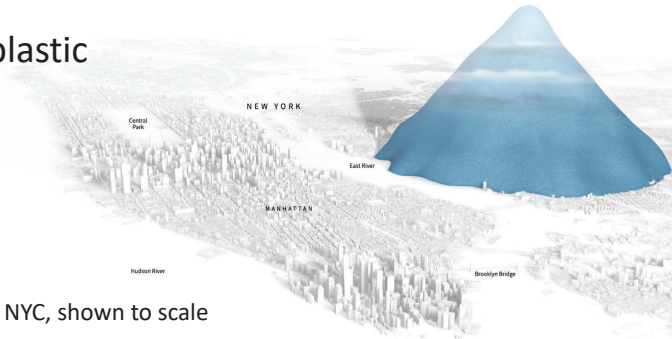
Goal: the Ah ha! Experience  
Many images, for a narrow audience (you!), linked to analysis

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# Infographics

The best infographics tell a story, using numbers, but shown visually

## Drowning in plastic



Plastic bottles sold in NYC, shown to scale

From: <https://graphics.reuters.com/ENVIRONMENT-PLASTIC/0100B275155/index.html>

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# Powerful graphs: Measles and vaccines

## Visualizing the impact of health policy interventions

In 2015 Tynan DeBold & Dov Friedman in the *Wall Street Journal* show the effect of the introduction of vaccination programs in the US states on disease incidence, using color-coded heat maps for a variety of diseases

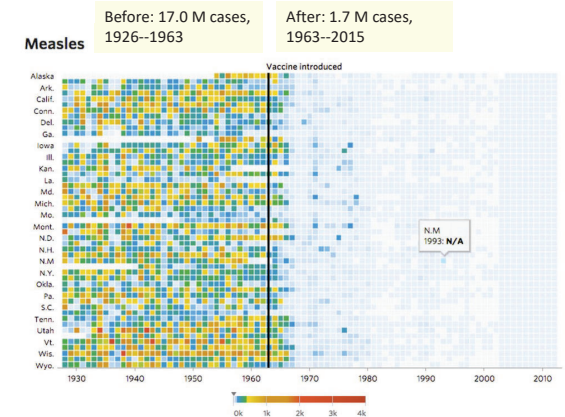
Measles was decimated!

The message hits you between the eyes!

Powerful graphs make comparison easy

In 2014, vaccination rates declined and measles re-emerged in those areas

Effective graphs can cure ignorance, but not stupidity.



Source: <http://graphics.wsj.com/infectious-diseases-and-vaccines/>

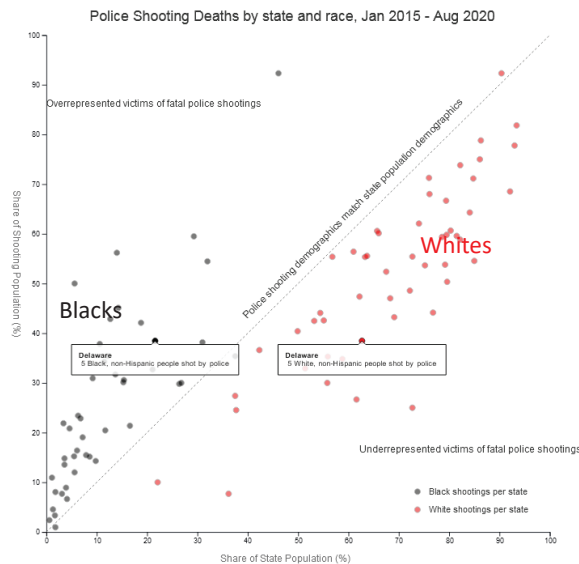
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# Police shooting deaths

Analysis of Washington Post database on 5500 police shooting deaths for Blacks vs. Whites

Plotting % of shooting vs. % of pop shows a clear & disturbing pattern

Annotations help to tell the story



From: <https://medium.com/two-n/visualizing-wapos-police-shooting-dataset-3792593f6be>

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# Presentation graph: Nightingale (1857)

After reform

APRIL 1855 TO MARCH 1856

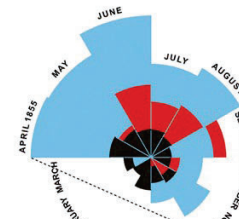
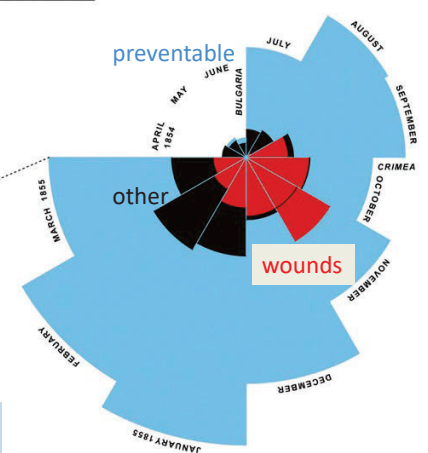


DIAGRAM OF THE CAUSES OF MORTALITY IN THE ARMY IN THE EAST

Before reform

APRIL 1854 TO MARCH 1855



The Areas of the blue, red, & black wedges are each measured from the centre as the common vertex  
The blue wedges measured from the centre of the circle represent area for area the deaths from Preventable or Mitigable Zymotic Diseases, the red wedges measured from the centre the deaths from wounds, & the black wedges measured from the centre the deaths from all other causes

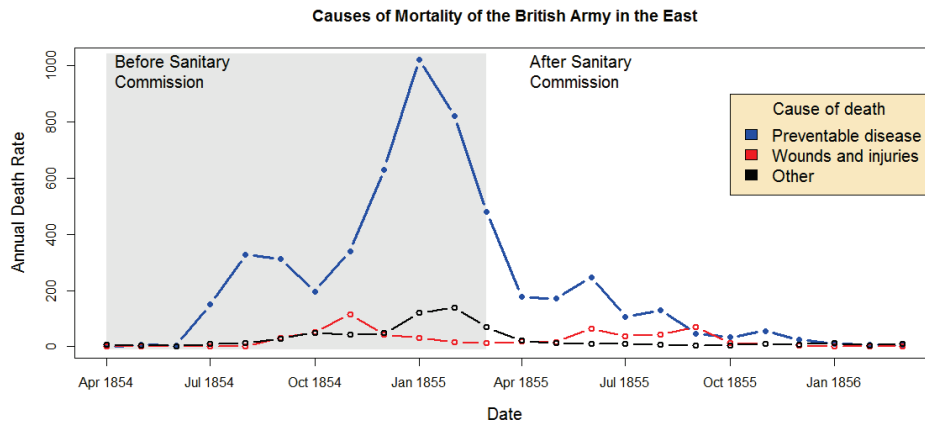
The best graphs pass the **Interocular Traumatic Test**: the message hits you between the eyes!

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## Data graph: Nightingale (1857)

The same, as a data graph, using time-series line plots

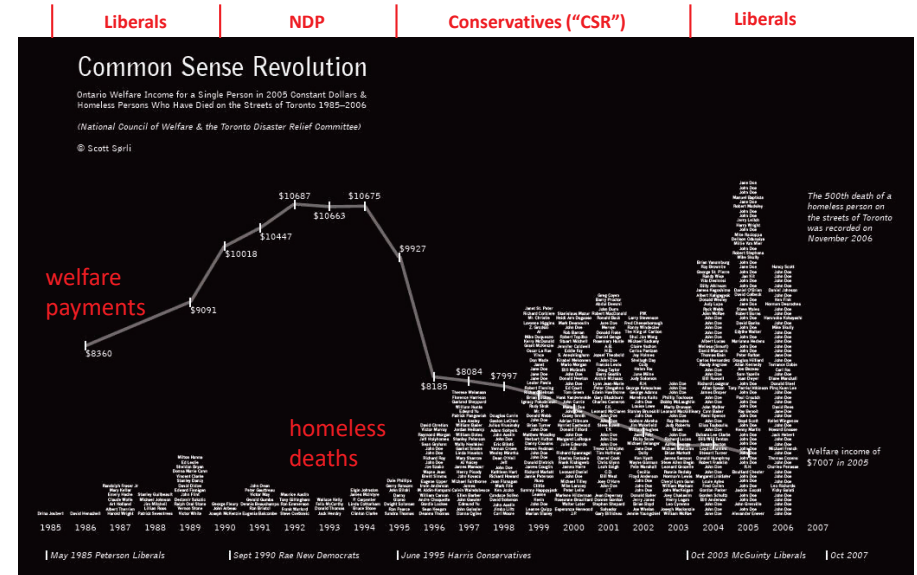
Some statisticians might prefer this today, but it doesn't draw attention or interest as Flo's original did. **It likely would not have roused British Parliament to act!**



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## Rhetorical graph: Welfare income and Homeless deaths after the "Common Sense Revolution"

Scott Sorli (2007)



## Analysis graph: Deaths vs. Income

Scatterplot of deaths vs. income

- Loess smooth + CI band
- Labels: year
- Color: party in power

The message here is interesting, but it lacks the power and eloquence of the original graph

As well, the relationship of deaths to time & party is lost

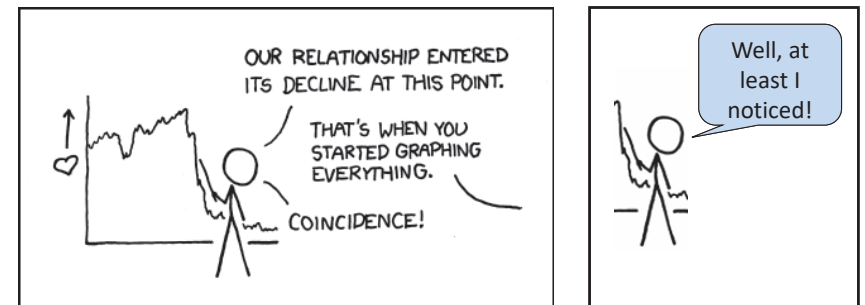


## Why plot your data?

Graphs help us to see

**patterns, trends, anomalies and other features**

not otherwise easily apparent from numerical summaries.

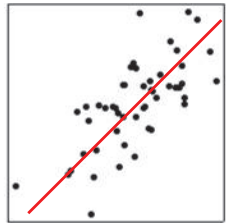


Source: <http://xkcd.com/523/>

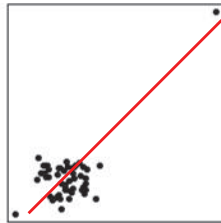
# Why plot your data?

Three data sets with exactly the same bivariate summary statistics:

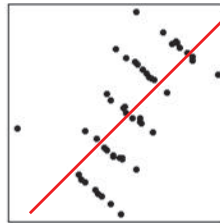
- Same correlations, linear regression lines, etc
- Indistinguishable from standard printed output
- Totally different interpretations!



Standard data



$r=0$  but + 2 outliers

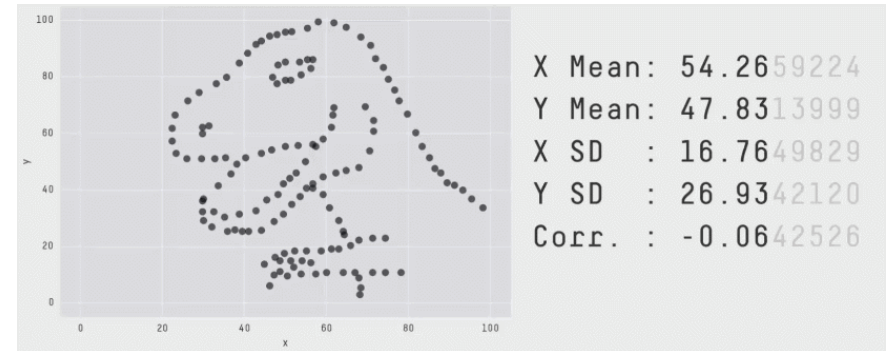


Lurking variable?

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# Datasaurus Dozen

As it happens, it is also possible to create any number of datasets with the same means, standard deviations and correlations with nearly any shape you like — even a dinosaur!



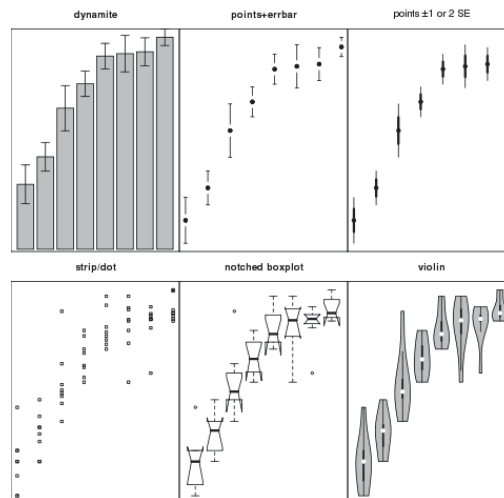
Method: Matejka & Fitzmaurice (2017). Same stats, different graphs. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. <https://doi.org/10.1145/3025453.3025912>  
Image source: [https://youtu.be/lt4UA75z\\_KQ](https://youtu.be/lt4UA75z_KQ)

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# Comparing groups: Analysis vs. Presentation graphs

Six different graphs for comparing groups in a one-way design

- which group means differ?
- equal variability?
- distribution shape?
- what do error bars mean?
- unusual observations?

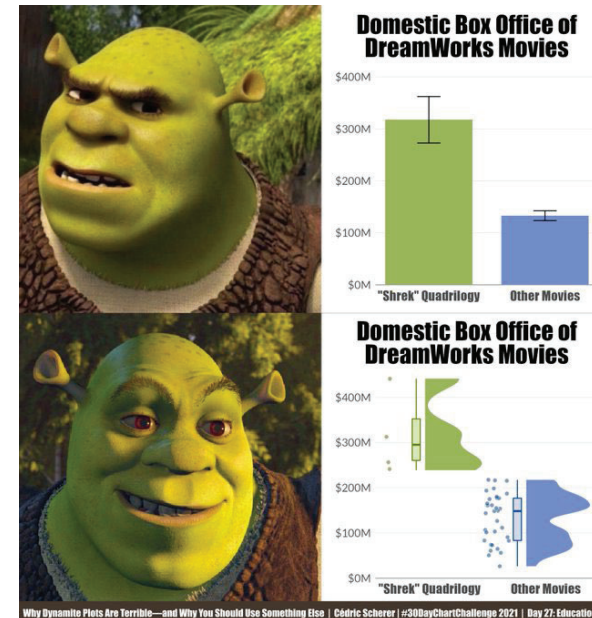


Never use dynamite plots

Always explain what error bars mean

Consider tradeoff between  
summarization & exposure

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## Presentation: Turning tables into graphs

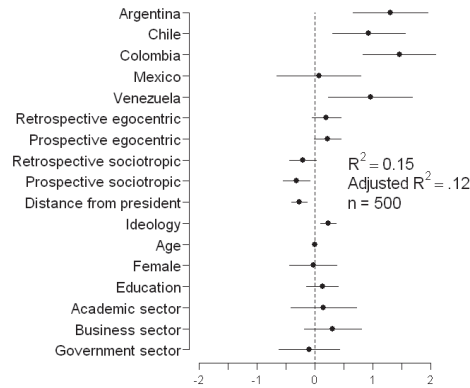
Table 2 from Stevens (2006): Determinants of Authoritarian Aggression

Variable	Coefficient (Standard Error)
Constant	.41 (.93)
<b>Countries</b>	
Argentina	1.31 (.33)*** B,M
Chile	.93 (.32)** B,M
Colombia	1.46 (.32)*** B,M
Mexico	.07 (.32) <sup>A,CH,CO,V</sup>
Venezuela	.96 (.37)** B,M
<b>Threat</b>	
Retrospective egocentric economic perceptions	.20 (.13)
Prospective egocentric economic perceptions	.22 (.12)*
Retrospective sociotropic economic perceptions	-.21 (.12)*
Prospective sociotropic economic perceptions	-.32 (.12)**
Ideological Distance from president	
<b>Ideology</b>	
Ideology	.23 (.07)***
<b>Individual Differences</b>	
Age	.00 (.01)
Female	-.03 (.21)
Education	.13 (.14)
Academic Sector	.15 (.29)
Business Sector	.31 (.25)
Government Sector	-.10 (.27)
R <sup>2</sup>	.15
Adjusted R <sup>2</sup>	.12
n	500

\*\*\*p < .01, \*\*p < .05, \*p < .10 (two-tailed)

<sup>A</sup> Coefficient is significantly different from Argentina's at p < .05;  
<sup>B</sup> Coefficient is significantly different from Brazil's at p < .05;  
<sup>CH</sup> Coefficient is significantly different from Chile's at p < .05;  
<sup>CO</sup> Coefficient is significantly different from Colombia's at p < .05;  
<sup>M</sup> Coefficient is significantly different from Mexico's at p < .05;  
<sup>V</sup> Coefficient is significantly different from Venezuela's at p < .05

Graphs of model coefficients are often clearer than tables



From: Kstellec & Leoni, 2007. "Using Graphs Instead of Tables in Political Science." *Perspectives on Politics* 5 (4): 755–71.  
See: The R dotwhisker pkg, <https://fsoit.org/dotwhisker/>

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## Semi-graphic tables

Tables can be made more visual by including **mini-graphs** in some table cells  
The original idea– **sparklines** (Tufte), is now more general

A good solution for the [Table 1 problem](#) – description of your sample

[13]:

index	id	name	line	bar	tristate	box
0	1	Oli Bob				
1	2	Mary May				
2	3	Christine Lobowski				
3	4	Brendon Philips				
4	5	Margret Marmajuke				
5	6	Frank Harbours				
6	7	Jamie Newhart				
7	8	Gemma Jane				
8	9	Emily Sykes				
9	10	James Newman				

Image from: <https://discourse.holoviz.org/t/add-sparkline-formatters-to-tabulator/3197>

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## Graphs & Information design

- Graphs & info displays should be viewed in relation to **communication goals** & **audience**
- Some criteria for assessing:
  - comprehensibility**: does it make information as easy to understand as possible?
  - attention**: does the audience take notice?
  - aesthetics**: is it visually appealing?
  - memorability**: will they remember it?
  - behavior**: does it result in some desired action?

From: Ben Jones, To Optimize or to Satisfice in Data Visualization? <https://dataremixed.com/2016/01/optimize-or-satisfice-in-dataviz/>

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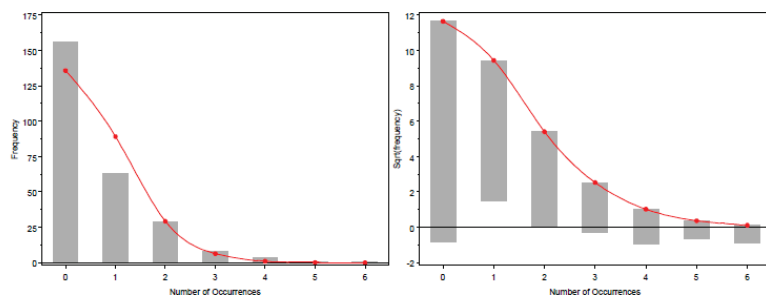
## Effective data display

- Make the **data** stand out
  - Fill the data region (axes, ranges)
  - Use visually distinct symbols (shape, color) for different groups
  - Avoid chart junk, heavy grid lines that detract from the data
- Facilitate **comparison**
  - Emphasize the important comparisons visually
  - Side-by-side easier than in separate panels
  - "data" vs. a "standard" easier against a horizontal line
  - Show uncertainty where possible
- Effect **ordering**
  - For variables and unordered factors, arrange them according to the **effects** to be seen

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# Make visual comparisons *easy*

- Visual grouping— connect with lines, make key comparisons contiguous
- Baselines— compare *data* to *model* against a line, preferably horizontal
- Frequencies often better plotted on a square-root scale



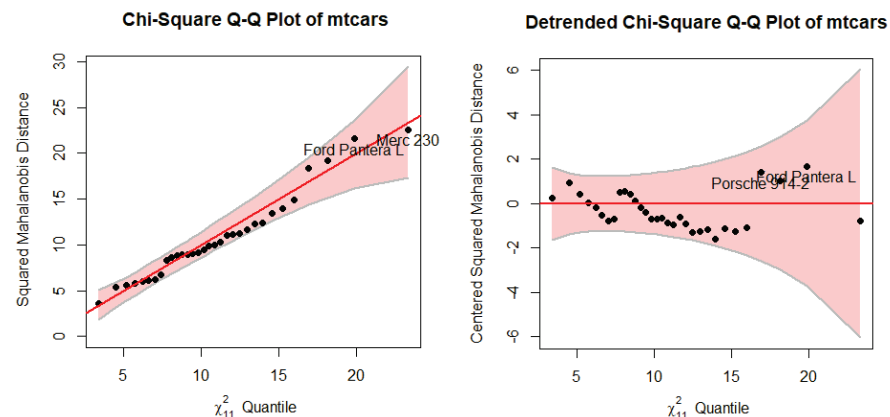
Standard histogram with fit

Suspended rootogram

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# Make visual comparisons *easy*

QQ plots assess the degree to which data follows a particular distribution (normal,  $\chi^2$ )  
 The reference line of equality is usually a 45° line  
 It is easier to see any departure in relation to a **horizontal line** at 0

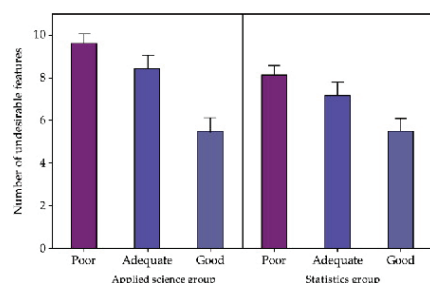


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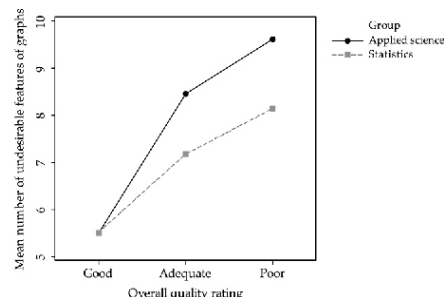
# Make comparisons *direct*

- Use **points** not bars
- Connect similar by **lines**
- **Same panel** rather than different panels

Is there evidence of an interaction here?



???



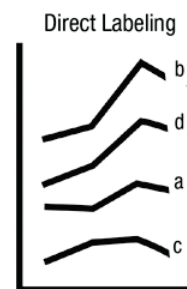
YES

45

# Direct labels vs. legends

**Direct labels** for points, lines and regions are usually easier and faster than **legends**

- Give the names of the four groups shown in the line graph at left in **top-to-bottom order**.  
 (Answer: b, d, a, c.)



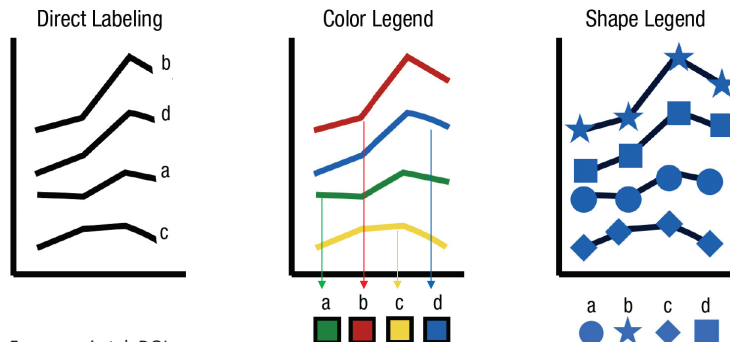
Source: Franconeri et al. DOI:  
[10.1177/15291006211051956](https://doi.org/10.1177/15291006211051956)

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# Direct labels vs. legends

Direct labels for points, lines and regions are usually easier and faster than legends

- Give the names of the four groups shown in the line graph at left in top-to-bottom order. (Answer: b, d, a, c.)
- Now do the same for the graphs using **color** or **shape** legends
- You need to look back and forth between the graph and legend



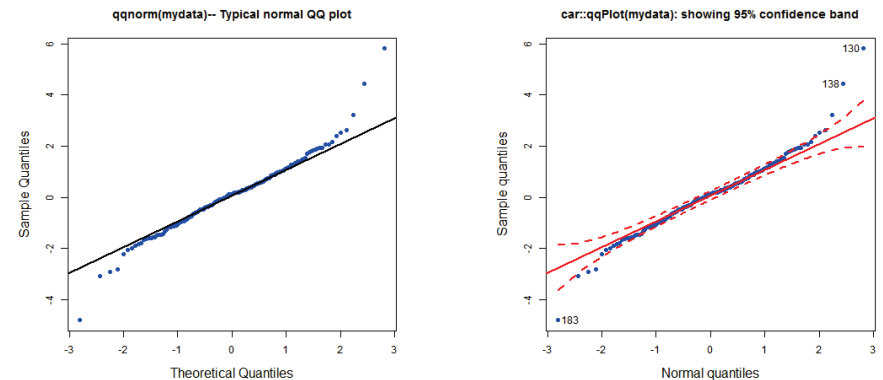
Source: Franconeri et al. DOI: [10.1177/15291006211051956](https://doi.org/10.1177/15291006211051956)

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# Visualizing uncertainty

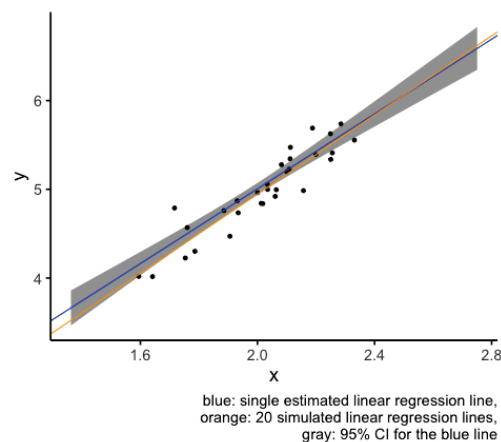
- Standard plots of observed vs. predicted lack a basis for assessment of **uncertainty**
- **Confidence envelopes** indicate extent of deviation wrt a standard
- Identify **"noteworthy"** observations to track them down

Example: Normal QQ plots used to assess normality of data



# Uncertainty: Theory & simulation

Effect of CI under simulations  
Simulation 1



In most cases, standard theory allows calculations of uncertainty intervals (confidence bands)

Simulation provides a theory-free alternative

Viewed as an animation gives a better sense of variation from sample to sample

49

# Effect ordering

- Information presentation is always **ordered**
  - in **time** or sequence (a talk or written paper)
  - in **space** (table or graph)
  - Constraints of time & space are dominant– can conceal or reveal the important message
- Effect ordering for data display
  - Sort the data by the **effects to be seen**
  - Order the data to **facilitate the task** at hand
    - lookup – find a value
    - comparison – which is greater?
    - detection – find patterns, trends, anomalies


Friendly & Kwan (2003). Effect Ordering for Data Displays. *Computational Statistics and Data Analysis*, 43, 509–539. DOI: [10.1016/S0167-9473\(02\)00290-6](https://doi.org/10.1016/S0167-9473(02)00290-6)

50

## Effect order failure: the *Challenger* disaster

- Few events in history provide as compelling illustration of importance of appropriate ordering and display of information
  - On January 28, 1986, the space shuttle *Challenger* exploded on take-off.
  - The cause was later determined to be that rubber O-rings failed due to cold weather
- Tables and charts presented to NASA by Thiokol engineers showed data from prior launches ordered by **time** (launch number), rather than by **temperature**—the crucial factor.
- The engineers' charts were also remarkable for **information obfuscation**: "erosion depth" (O-ring damage), "blow-by" (soot on O-rings), ...

HISTORY OF O-RING DAMAGE ON SRM FIELD JOINTS

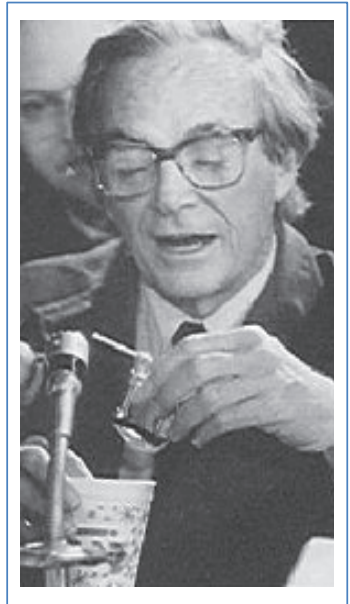


SRM No.	Cross Sectional View			Top View		Checking Location (deg)
	Erosion Depth (in.)	Perimeter Affected (deg)	Radial Dia. (in.)	Length of Max. Erosion (in.)	Total Heat Affected Length (in.)	
31A LH Center Field**	22A	None	None	0.100	None	35° - 56°
31A LH Outer Field**	22A	None	None	0.200	None	35° - 56°
31C LH Forward Field**	15A	0.010	154.0	0.250	4.25	163
31C RH Center Field (prim)**	15B	0.038	130.0	0.280	12.50	254
31C RH Center Field (sec)**	15B	None	45.0	0.280	29.50	354
41B RH Forward Field	13B	0.026	110.0	0.200	3.00	275
41C LH Aft Field*	11A	None	None	0.200	None	--
41B LH Forward Field	10A	0.040	217.0	0.280	3.00	351
STS-2 RH Aft Field	2B	0.053	116.0	0.280	--	90

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## Visual explanation: Physics

- NASA appointed members of the Rogers Commission to investigate the cause of the disaster
- the noted physicist Richard Feynman discovered the cause: at low temperature, O-rings became brittle and were subject to failure
- in his testimony, he demonstrated the effect by plunging a rubber O-ring into a cup of ice water



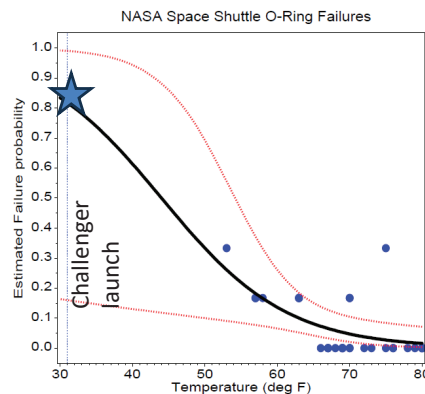
52

## Visual explanation: Graphics

- Subsequent statistical analysis showed the relationship between launch temperature and O-ring failures
- As Tufte (1997) notes: the fatal flaw was in the **ordering** of the data.

The graph shown here is the result of a statistical model fit to the data

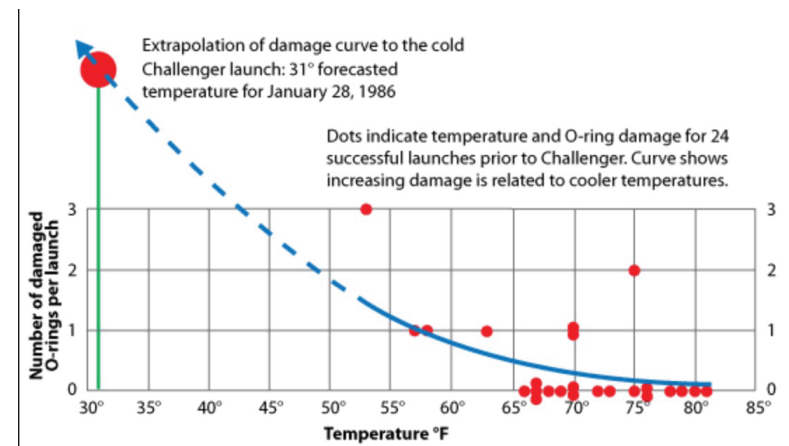
- The **thick** line shows the predicted value of failure vs. temperature
- The **red** dotted lines show uncertainty of the predicted values



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## Presentation graphic

A presentation version of the previous graph alters the scales and describes the story in text annotations



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## Graphic displays: Main effect ordering

- To see trends, patterns, anomalies: **Sort unordered factors by means or medians**



Data on barley yields  
10 varieties x 6 sites x 2 years

3-way dot plot, **sorted by main effect means**

- Which site has the highest yield?
- Which variety is highest on average?
- Which site stands out in pattern over year?

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## Tabular displays: Main effect ordering

- Tables are often presented with rows/cols ordered **alphabetically**
  - good for lookup
  - bad for seeing patterns, trends, anomalies

Table 1: Average Barley Yields (rounded), Means by Site and Variety

Variety	Site						Mean
	Crookston	Duluth	Grand Rapids	Morris	University Farm	Waseca	
Glabron	32	28	22	32	40	46	33.3
Manchuria	36	26	28	31	27	41	31.5
No. 457	40	28	26	36	35	50	35.8
No. 462	40	25	22	39	31	55	35.4
No. 475	38	30	17	33	27	44	31.8
Peatland	33	32	31	37	30	42	34.2
Svansota	31	24	23	30	31	43	30.4
Trebi	44	32	25	45	33	57	39.4
Velvet	37	24	28	32	33	44	33.1
Wisconsin No. 38	43	30	28	38	39	58	39.4
Mean	37.4	28.0	24.9	35.4	32.7	48.1	34.4

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## Tabular displays: Main effect ordering

- Better: sort rows/cols by means/medians
- Shade cells according to residual from additive model

Table 2: Average Barley Yields, sorted by Mean, shaded by residual from the model  $Yield = Variety + Site$

Variety	Site						Mean
	Grand Rapids	Duluth	University Farm	Morris	Crookston	Waseca	
Svansota	23	24	31	30	31	43	30.4
Manchuria	28	26	27	31	36	41	31.5
No. 475	17	30	27	33	38	44	31.8
Velvet	28	24	33	32	37	44	33.1
Glabron	22	28	40	32	32	46	33.3
Peatland	31	32	30	37	33	42	34.2
No. 462	22	25	31	39	40	55	35.4
No. 457	26	28	35	36	40	50	35.8
Wisconsin No. 38	28	30	39	38	43	58	39.4
Trebi	25	32	33	45	44	57	39.4
Mean	24.9	28.0	32.7	35.4	37.4	48.1	34.4

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## Tabular displays: Main effect ordering

Yield difference,  $\Delta y_{ij} = 1931 - 1932$  by Variety & Site

**Ordered:** by row and column means; **shaded:** by value ( $|\Delta y_{ij}| > \{2,3\} \times \sigma(\Delta y_{ij})$ )

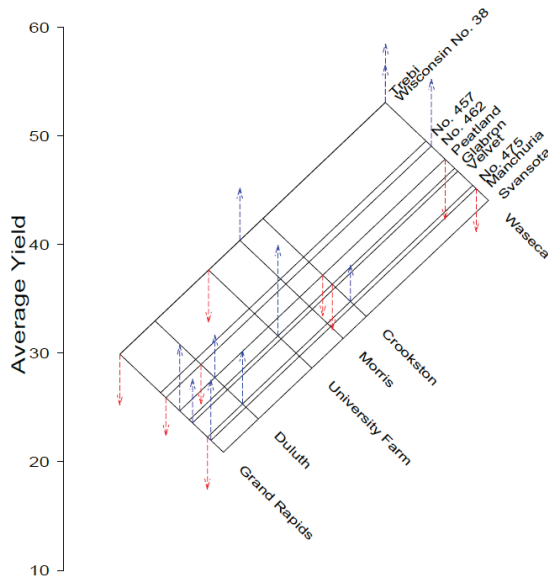
What features stand out?

Table 3: Yield Differences, 1931-1932, sorted by mean difference, and shaded by value

Variety	Site						Mean
	Morris	Duluth	University Farm	Grand Rapids	Waseca	Crookston	
No. 475	-22	6	-5	4	6	12	0.1
Wisconsin No. 38	-18	2	1	14	1	14	2.4
Velvet	-13	4	13	-9	13	9	2.9
Peatland	-13	1	5	8	13	16	4.8
Manchuria	-7	6	0	11	15	7	5.5
Trebi	-3	3	7	9	15	5	6.1
Svansota	-9	3	8	13	9	20	7.3
No. 462	-17	6	11	5	21	18	7.4
Glabron	-6	4	6	15	17	12	8.0
No. 457	-15	11	17	13	16	11	8.8
Mean	-12.2	4.6	6.3	8.2	12.5	12.5	5.3

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## Graphical display: Two-way tables



Tukey two-way plot of average barley yield

If there is no interaction,  

$$y_{ij} = \mu + \alpha_{\text{site}} + \beta_{\text{variety}}$$

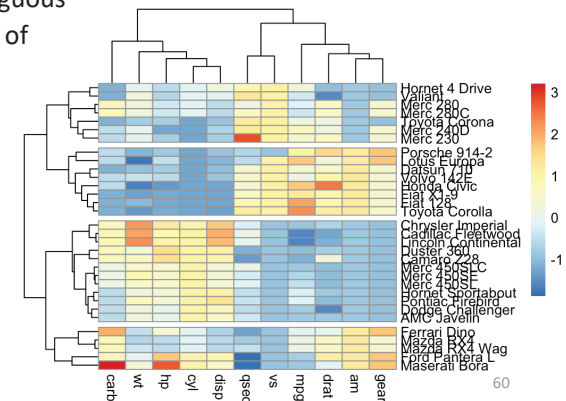
Site & variety effects sorted automatically  
 Effects are spaced by fitted values

More variation among sites than varieties  
 Waseca best, by a wide margin

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## Multivariate data: correlation ordering

- Arrange **variables** so that:
  - Similar variables are contiguous
  - Ordered to show patterns of relations
- Arrange **observations** so that:
  - Similar variables are contiguous
  - Ordered to show patterns of relations



## Correlation matrices: mtcars data

Correlations among 11 measures of size & performance of motor cars

- What can you see?
- Always round a lot!

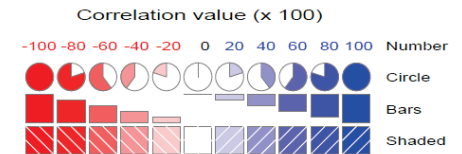
```
data(mtcars)
R <- cor(mtcars)
print(floor(100*R))
```

	mpg	cyl	disp	hp	drat	wt	qsec	vs	am	gear	carb
mpg	100	-86	-85	-78	68	-87	41	66	59	48	-56
cyl	-86	100	90	83	-70	78	-60	-82	-53	-50	52
disp	-85	90	100	79	-72	88	-44	-72	-60	-56	39
hp	-78	83	79	100	-45	65	-71	-73	-25	-13	74
drat	68	-70	-72	-45	100	-72	9	44	71	69	-10
wt	-87	78	88	65	-72	100	-18	-56	-70	-59	42
qsec	41	-60	-44	-71	9	-18	100	74	-23	-22	-66
vs	66	-82	-72	-73	44	-56	74	100	16	20	-57
am	59	-53	-60	-25	71	-70	-23	16	100	79	5
gear	48	-50	-56	-13	69	-59	-22	20	79	100	27
carb	-56	52	39	74	-10	42	-66	-57	5	27	100

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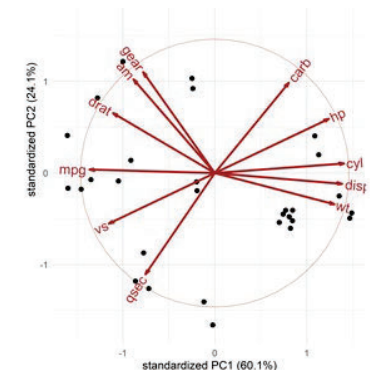
## Correlation ordering: corrgrams

**Rendering:** a correlation value can be displayed in different ways, for different tasks



**Correlation ordering:**

- A PCA finds weighted sums of variable to maximize variance accounted for
- Angles between vectors reflect the correlations
- Arrange variables in the order of their angles



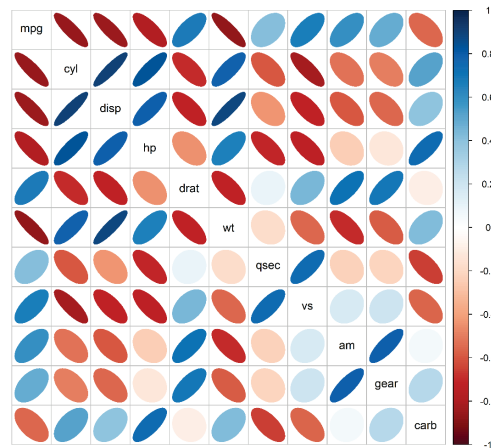
Friendly (2002), [Corrgrams: Exploratory displays for correlation matrices](#), American Statistician.

62

## mtcars data: dataset variable order

```
library(corrplot)  
corrplot(R, method = 'ellipse')
```

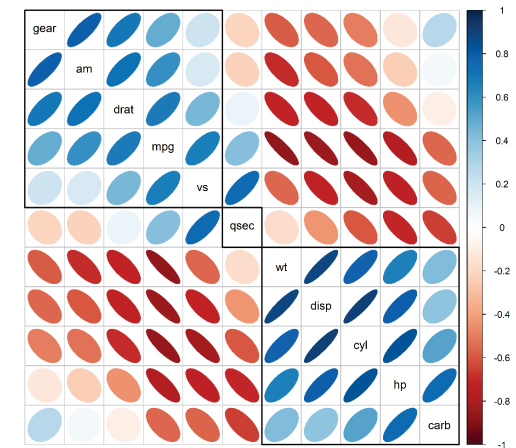
Dataset variable order



## mtcars data: PCA variable order

```
corrplot(R, method = 'ellipse',  
order = "AOE")
```

PCA variable order



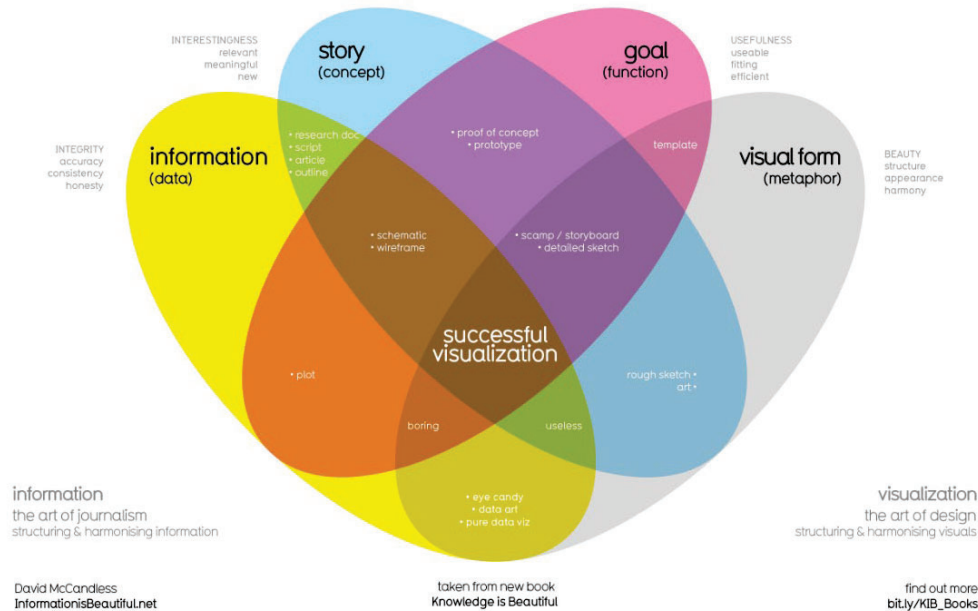
## Good/excellent graphs



- Like good writing, good graphical displays of data communicate ideas with:
  - clarity,
  - precision, and
  - efficiency— avoids graphic clutter
  - Even better: excellent graphs **make the message obvious**
- What makes a good graph?
  - Integrity (quality of information)
  - Story (interesting, meaningful)
  - Goal (usefulness)
  - Visual form (beauty)

## What Makes a Good Visualization?

explicit (implicit)



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## Bad/evil graphs

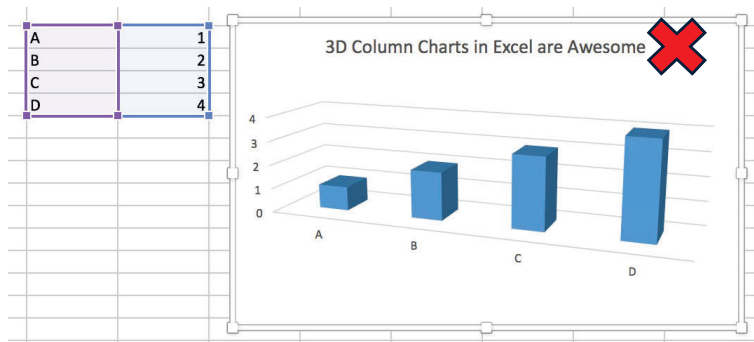


- Like poor writing, bad graphical displays:
  - distort or obscure the data,
  - make it harder to understand or compare, or
  - thwart the communicative effect the graph should convey.
  - Even worse: **evil graphs distort, or mislead.**

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## Bad graphs are easy in Excel

Friends don't let friends use Excel for data visualization or statistics

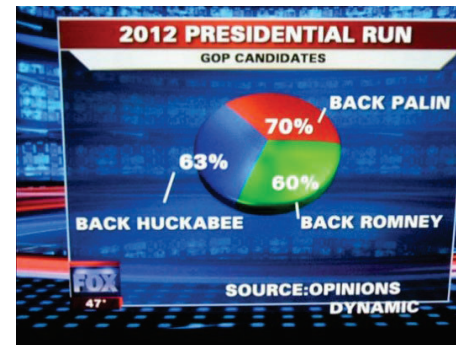


How many things are wrong with this graph?

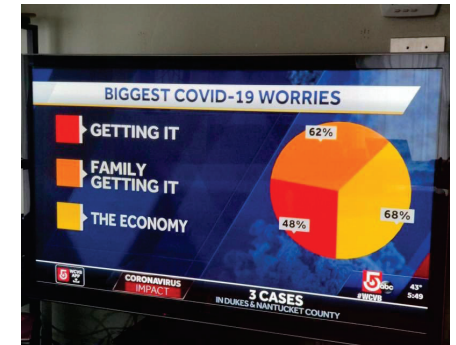
69

## Pie charts are easy to abuse

What's wrong with these pictures?



$1 \pi = 193\%$



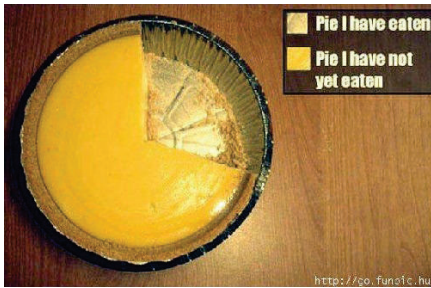
$1 \pi = 178\%$

Why do graphic designers so often get this wrong?

70

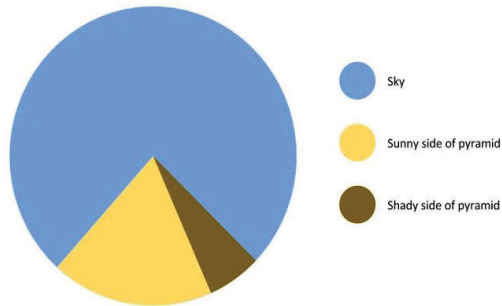


## Pie chart merriment



On the other hand, pie charts are a great source of merriment for people interested in graphics

But: how much  $\pi$  have I eaten?

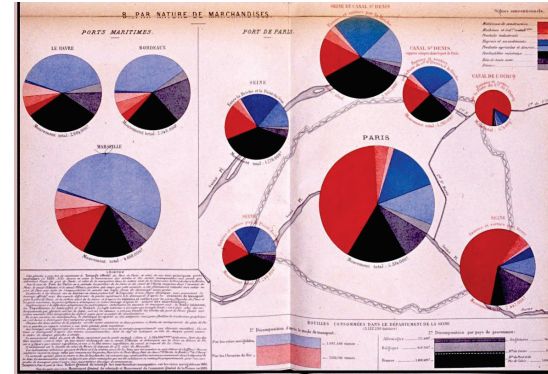


What perceptual ideas make this a great joke and lesson?

Once you see the pyramid, it's hard to see the pie.

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## But, can be used to great effect



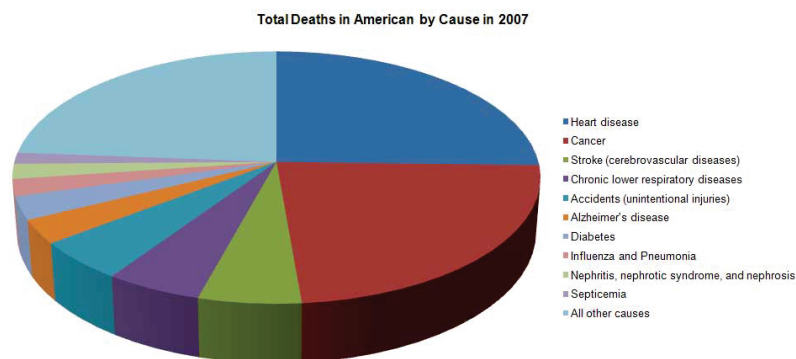
This graphic uses pie charts to show the transport of different kinds of goods to the ports of Paris and the principal maritime ports

- size of each pie reflects **total**
- sectors reflect **relative %**
- **location** places them in geo context

Émile Cheysson, Mouvement de la Navigation Dans le Port de Paris et les Principaux Ports Français en 1883. *Album de Statistique Graphique*, 1885, plate 17. <https://bit.ly/47DwnKU>

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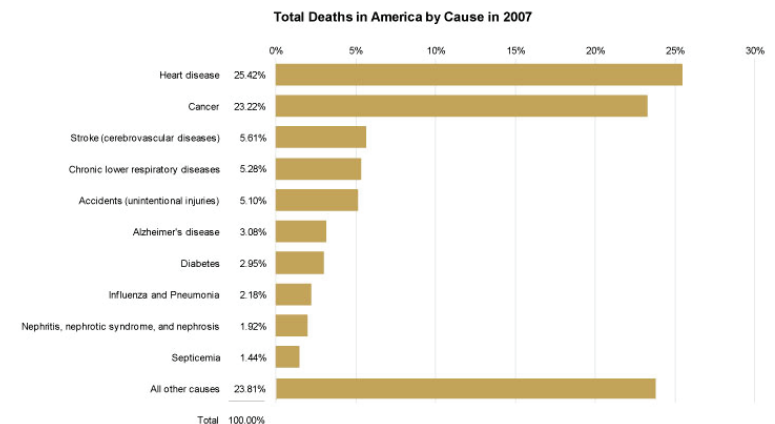
## 3D pie charts are usually evil



What was the intent of the designer of this graphic?  
Which category led to the greatest total deaths?  
What was the proportion of deaths due to strokes?  
Did more people die from strokes vs. accidents?

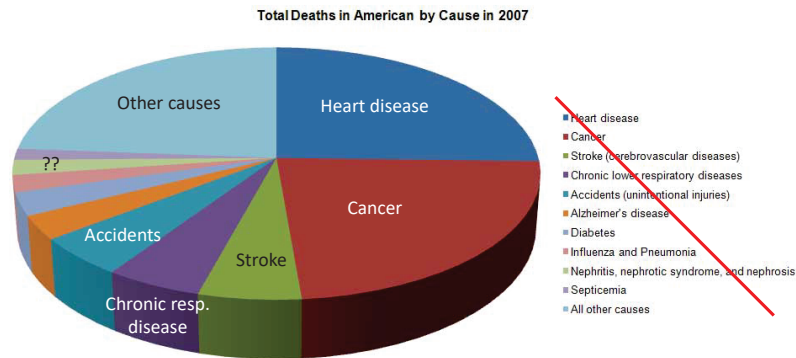
73

## Simple re-design makes it clearer



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## Or, try to use direct labels



As a rule of thumb, pie charts max out at ~ 5-7 sectors

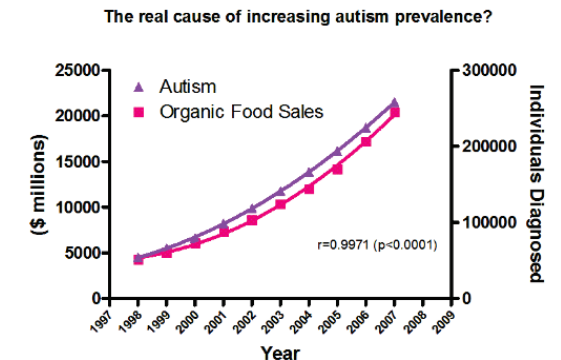
75

## Double Y-axis: Really evil graphs

After pie charts, double Y-axis graphs have caused more trouble than almost any other

OMG, **autism** has been increasing directly with sales of **organic** food!

**BAN  
ORGANIC  
FOOD!**



Sources: Organic Trade Association, 2011 Organic Industry Survey, U.S. Department of Education, Office of Special Education Programs, Data Analysis System (DANS), OMB# 1620-0043. \*Children with Disabilities Receiving Special Education Under Part B of the Individuals with Disabilities Education Act

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## But, can be used to great effect

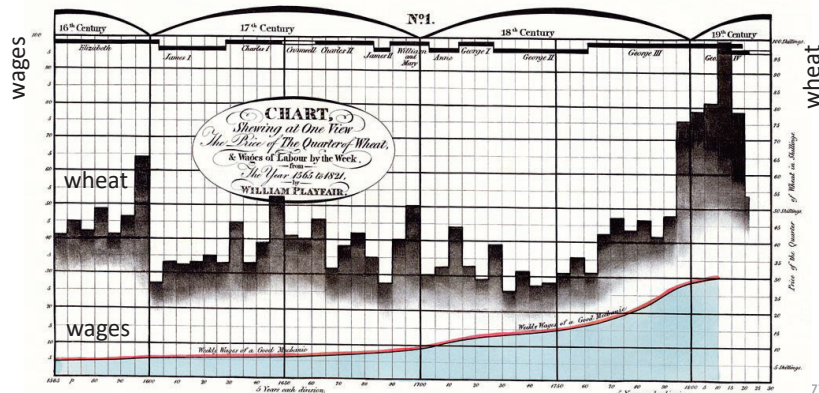
William Playfair invented the pie chart, line chart and bar chart.

In this figure, he shows 3 parallel time series over a 250-year period, 1560--1810

- weekly wages of a good mechanic
- price of wheat
- reigning monarch

**Goal:** show that workers were better off most recently (1810) than in the past.

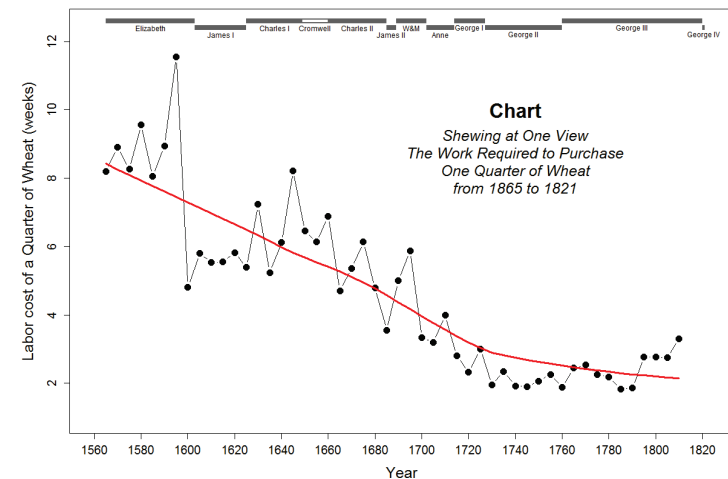
**Is this what you see?**



77

## Or, another graph would have been better

A modern **re-vision** plots the **ratio** of price of wheat to wages directly  
Makes Playfair's point more directly, but less beautifully



78

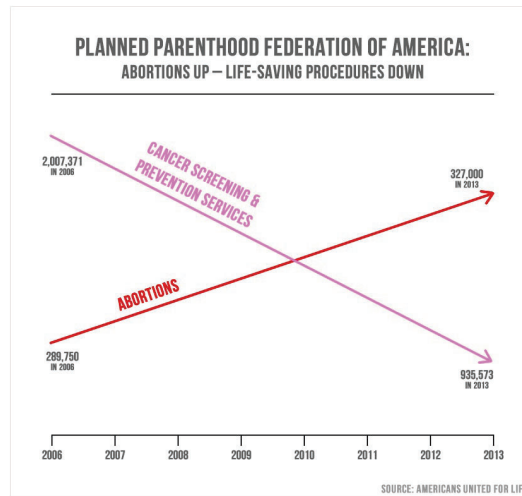
## Even more evil: No scales, no data

Rep. Jason Chaffetz, R-Utah, sparred with Planned Parenthood president Cecile Richards during a high-profile hearing on Sept. 29, 2015 and presented this graph.

"In pink, that's the reduction in the breast exams, and the red is the increase in the abortions. That's what's going on in your organization."

Created by an anti-abortion group it is a deliberate attempt to mislead.

Can you see why?



See: <http://www.politifact.com/truth-o-meter/statements/2015/oct/01/jason-chaffetz/chart-shown-planned-parenthood-hearing-misleading-/>

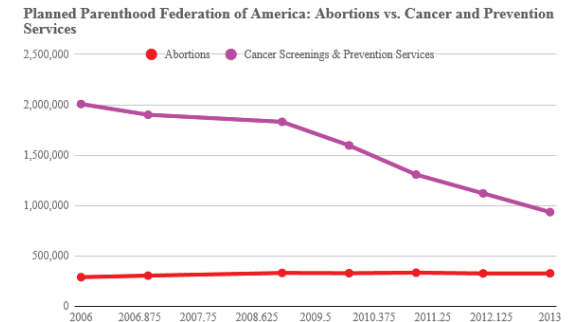
79

## Corrected graph

This graph shows the actual data from the Planned Parenthood reports used by Americans United for Life

The number of abortions was relatively steady.

Some services like pap smears, dropped due to changing medical standards about who should be screened and how often.



What improvements can be made to this graph?

- Fix formatting of axis labels
- Choose better colors
- Use direct labels

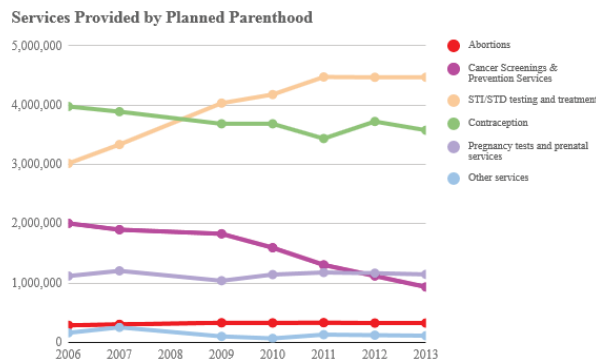
80

## Corrected graph, in context

Showing a wider range of PP activities puts these data in context

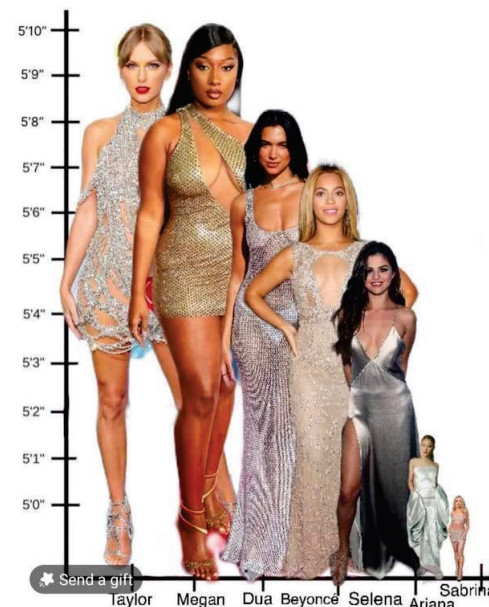
PP activities were far higher for contraception and STD testing

What is still WRONG with this graph?



81

Heights of female pop stars



## Exercise: What's wrong with this chart?

Truncation of Y axis

- Makes differences artificially large
- We tend to perceive **ratios**

Linear scaling of height

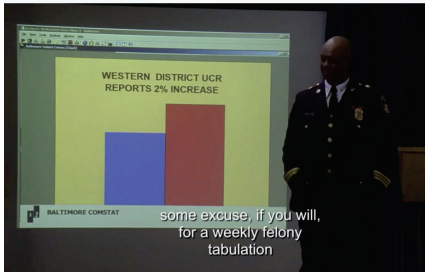
- Magnifies apparent "size"
- We tend to perceive **areas**

From <https://bsky.app/profile/peck.phd/post/3leg445f6ck2x>

82



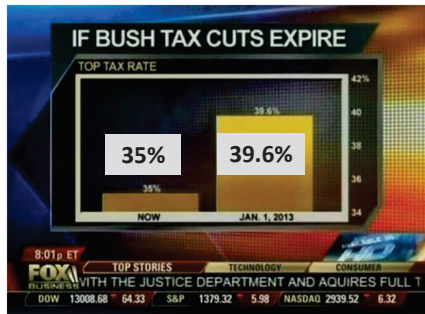
## Evil Bars



You can say anything you want if you don't show a scale for the vertical axis

Q: Do people judge the **difference** in heights or the **ratio** of heights?

A: It depends on the question



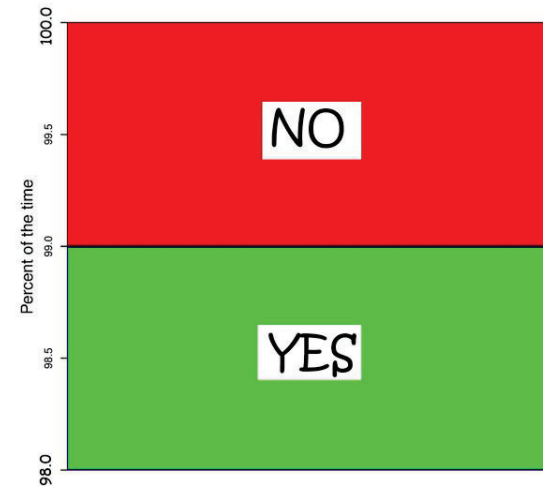
You can greatly distort the perception of difference or ratio by **truncating** the Y axis.

Y-axis truncation is/was the default in Excel!

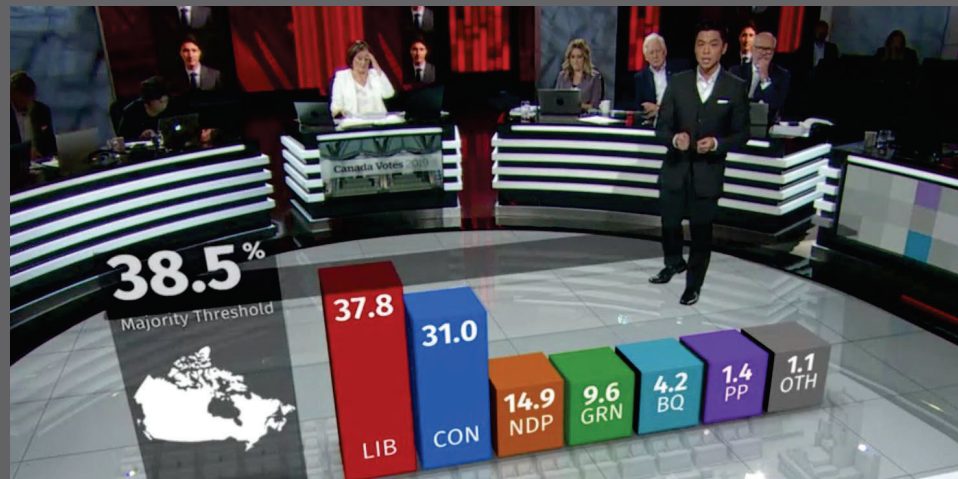
83

## Evil bars: A source of merriment?

Is truncating the y-axis misleading?



84



### More evil: 3D bars

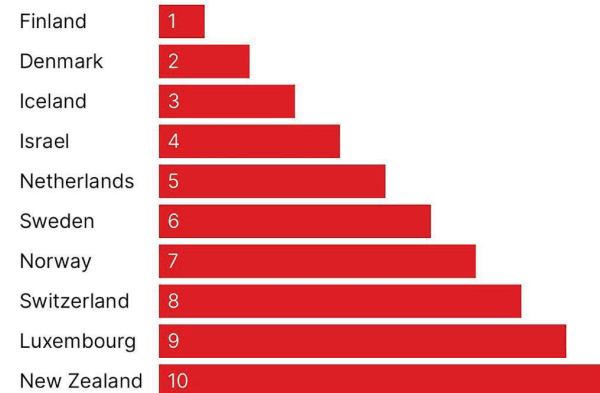
- CBC found it irresistible to make 3D bars to show the 2015 election projection.
- Why do you think the smallest 5 bars are all the same height?

85

## How to make a confusing bar chart

### Top 10 Happiest Countries in 2023

This chart shows the top 10 happiest countries according to the 2023 World Happiness Report.



Why did they make this a bar chart?

What re-design would avoid the confusion?

Kilde: [World Happiness Report](https://twitter.com/TheEditorDiary/status/1742939764003893567/photo/1)

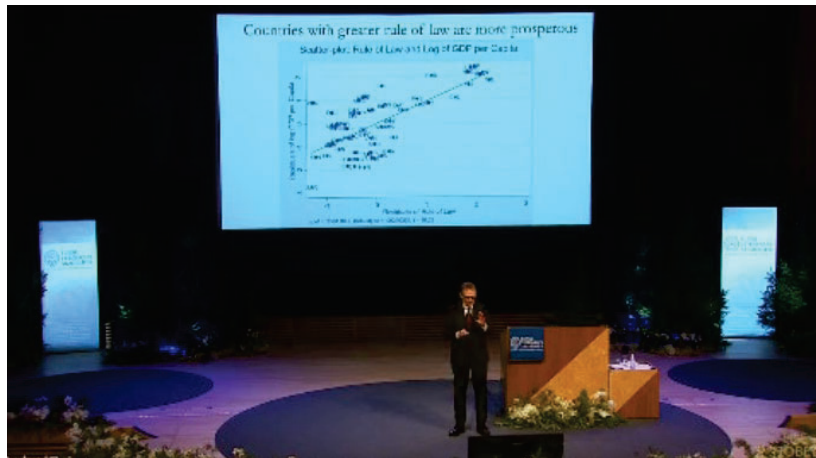
<https://twitter.com/TheEditorDiary/status/1742939764003893567/photo/1>

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## What not to do when you win a Nobel Prize

Daren Acemoglu accepts the 2024 Nobel Prize in Economics but gets an F for a spectacularly bad scatterplot.



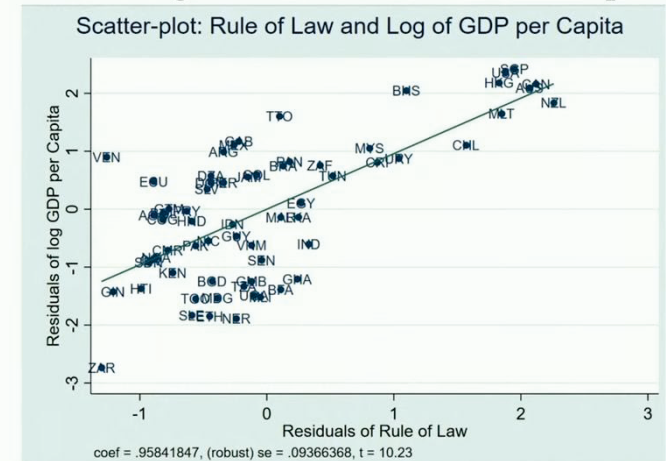
Video: <https://www.youtube.com/live/YcuxbYUW8R8?si=3M859wkuy1uQOKP9&t=4411>

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## What not to do when you win a Nobel Prize

What was the presentation goal?  
Why does this fail?

### Countries with greater rule of law are more prosperous



## Graphical Excellence: Tables

A study by Abigail Friendly (2017) wanted to show the use of benefits afforded to Toronto developers for their contributions of different types over time

Figure 9: Section 37 benefits by type (1998–2015)

	1998–2002	2003–2005	2006–2009	2010–2013	2014–2016	Scale
Roads, streetscapes	30	35	54	83	15	0 - 10
Culture, community, recreation	26	50	59	47	16	11 - 20
Parks	27	41	41	52	20	21 - 30
Affordable housing	17	26	38	56	11	31 - 40
Public art	26	25	41	32	4	41 - 50
Heritage	16	13	26	18	3	51 - 60
Transit	11	7	10	20	3	61 - 70
Libraries	6	2	5	11	1	71 - 80
Other	3	6	7	8	3	81 - 90

Color background scale from light to dark highlights the largest values

Most frequent benefits appear at the top

Can see overall trends and anomalies

What happened in 2014–2016?

Source: Friendly, A. R. (2017). *Land Value Capture and Social Benefits: Toronto and São Paulo Compared*. IMFG Papers on Municipal Finance and Governance, No 33, University of Toronto. <https://munkschool.utoronto.ca/imfg/>

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## Graphical failure

This graph reports the results of a survey by Sherman Kent for the CIA with the question:

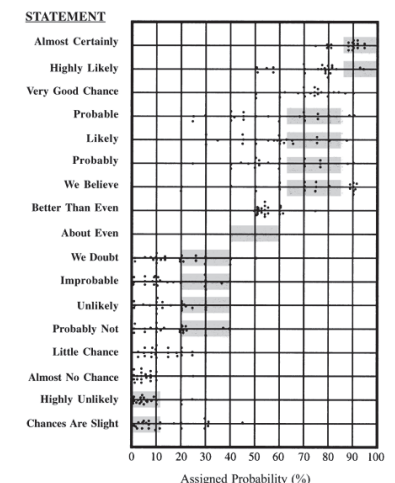
*What [probability/number] would you assign to the phrase "[phrase]"*

The goal was to contribute to an understanding of how intelligence analysts (& spies) use these terms

Why can this be considered a graphical failure?

- Grid lines obscure the data
- What do the grey bars mean?

Figure 18: Measuring Perceptions of Uncertainty



<https://www.cia.gov/library/center-for-the-study-of-intelligence/csi-publications/books-and-monographs/psychology-of-intelligence-analysis/fig18.gif/image.gif>

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# Graphical excellence

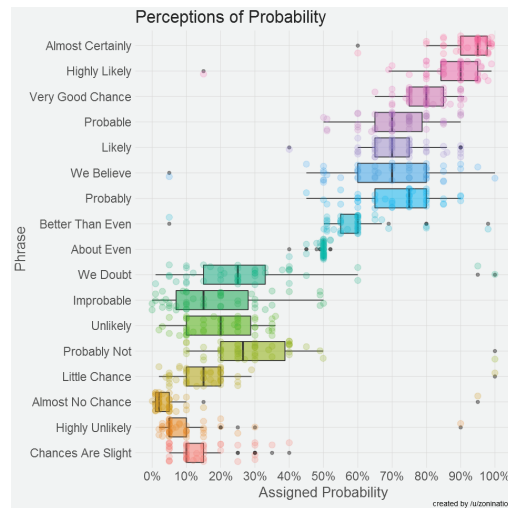
This graph shows the same data, as both dotplots & boxplots

We can see a lot more:

- “about even” has very low variability
- the bottom 3 categories are listed out of order
- the extreme outliers stand out
- skewness is – for high probability, + for low probability

Technical notes:

- software: ggplot2
- design: faint grid lines
- color: points use transparent color & jittering; outliers also shown in black



From: <https://github.com/zonination/perceptions>

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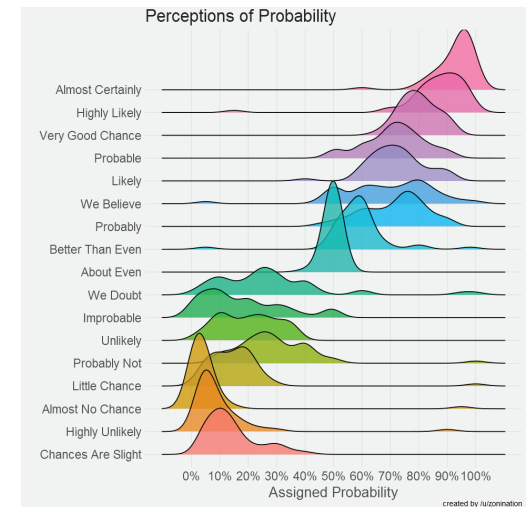
# Graphical excellence

This graph uses “ridgeline” plots to show the same data

Each one is a small version of a density plot showing a smoothed version of the distribution

Stacking them in this way allows center, variability, shape and other features to be readily compared.

Color & transparency are used effectively

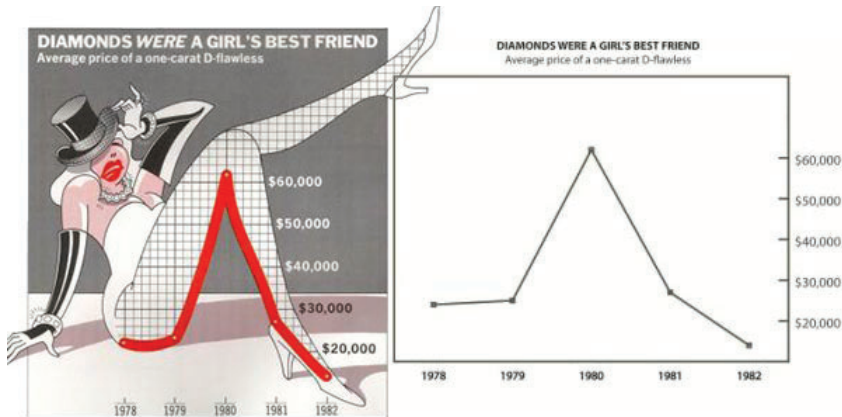


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## Chart junk or effective info vis?

Charts can be offensive and/or effective

What is the message?  
Who is the audience?



NB: Info designers now consider the term “chart junk” itself offensive

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## Chart junk or effective info vis?

Suzanaerculano-Houzel has a new method for determining counts of cortical neurons across different species. How to present this effectively?

Goal: compare mammal species brain size and cortical neuron count

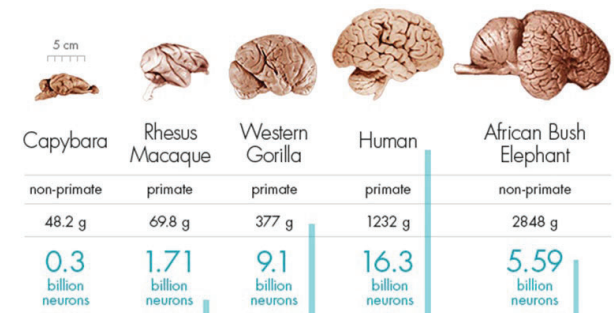
Neuron count is shown both as numbers and bars

**Claim:** Human brain is ~linear of primate brains

What do you think?

How could this be made better?

**BRAIN SIZE AND NEURON COUNT**  
Cerebral cortex mass and neuron count for various mammals.



From: Herculano-Houzel, “The human brain in numbers: a linearly scaled-up primate brain”  
<https://www.frontiersin.org/articles/10.3389/neuro.09.031.2009/full>

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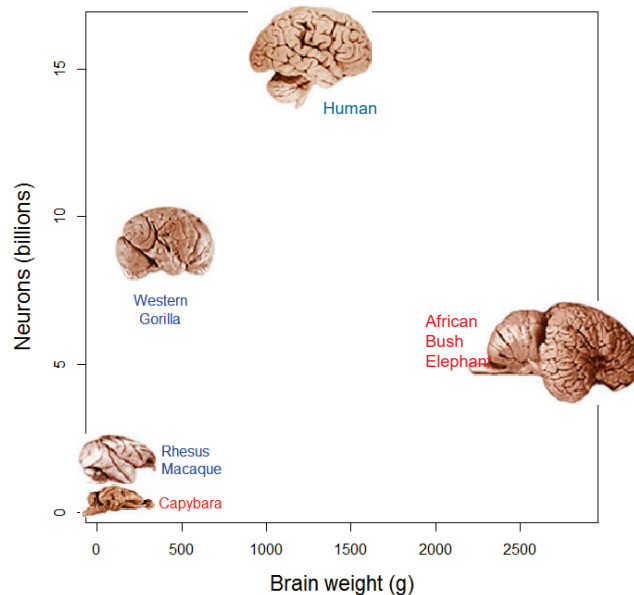
## As a scatterplot?

A scatterplot makes clear how humans differ from other species

- Using scaled images as point symbols also conveys brain size
- Primates are distinguished from non-primates by text color

This is arguably a more effective display.

What do you think?



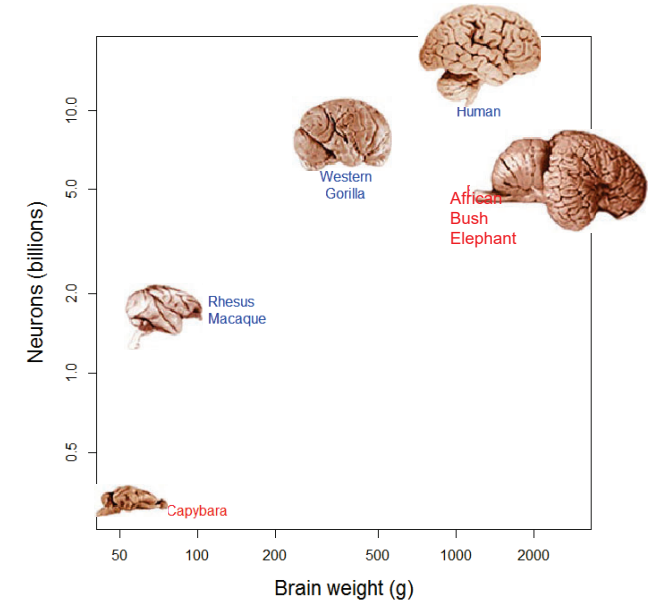
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## As a scatterplot – log scale

Perhaps even better is to make the plot using **log scales** for both axes

The relationship is now easier to see, but only approx. linear

The argument for neurons  $\sim$  brain weight needs more work.



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## Why graphs matter: Climate change

In the movie, *An Inconvenient Truth* (2006), Al Gore used the now-famous “**hockey stick**” graph to show that human activities had greatly increased the degree of global warming over the recent past

**Goal:** raise public awareness and call for action to curb environmental effects: CO<sub>2</sub> emissions as the main agent.



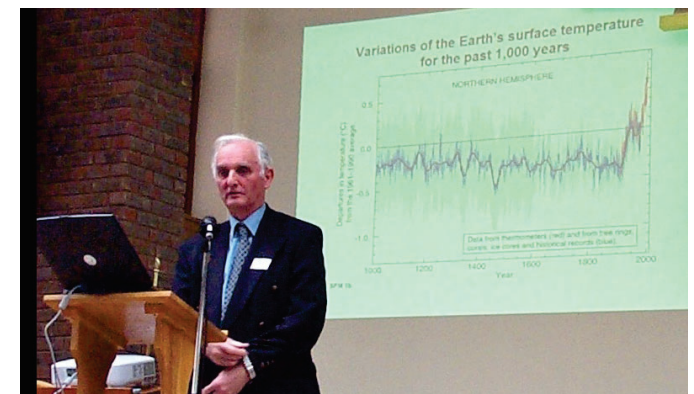
Movie: <https://www.youtube.com/watch?v=8ZUoYGA15i0>; <http://www.imdb.com/title/tt0497116/>

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## Climate change: Original graph

Sir John Houghton presents the original Northern Hemisphere hockey stick graph to the [Intergovernmental Panel on Climate Change](#) (IPCC) in 2005.

It is based on an analysis by Mann, Bradley & Hughes (1990), with a **smoothed** curve and **uncertainty** intervals.



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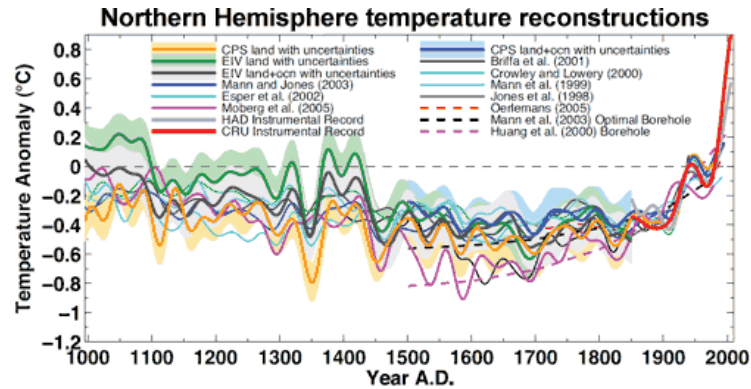


# Climate change: data sources

The MBH (1999) paper had used a wide variety of data sources. They were combined using a novel statistical technique, the **first eigenvector-based climate field reconstruction** (CFR). (WTF??)

Climate scientists understood this; the sceptics did not.

**TOO MUCH INFO??**



See: [https://en.wikipedia.org/wiki/Hockey\\_stick\\_controversy](https://en.wikipedia.org/wiki/Hockey_stick_controversy) for details

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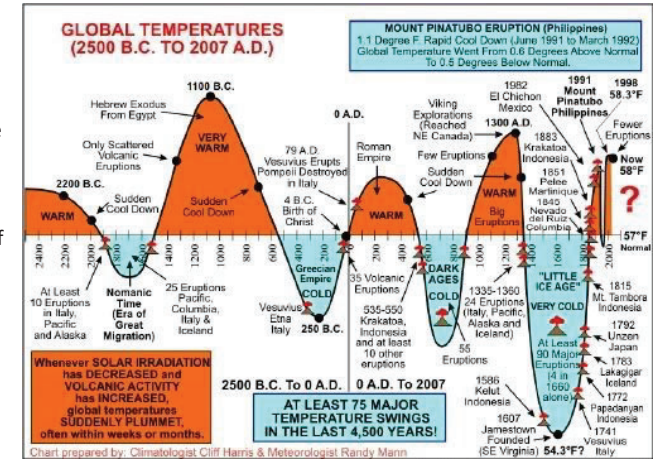
# Denying climate change

Taking a longer view, and adding a lot of extraneous historical details, climate sceptics were easily able to mount alternative explanations:

Solar radiation & volcanoes

How to mislead:

- Show no temp. scale
- Draw smoothed curve
- Suggest that all is due to "swings" in temp.
- Compress recent history into the end of the time scale



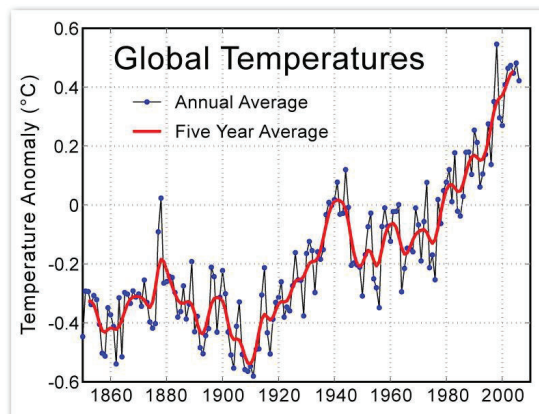
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# Time scale

Perhaps one fault with the original graphs was trying to show noisy data, from many sources, over too wide a time span.

What could you do to make this graph even more convincing?

- De-emphasize the annual data
- Add an overall smooth curve



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# Climate change: Infographic

A politically-incorrect graphic shows very clearly the effect of global warming on panty size



Source: <http://www.politically-incorrect-humor.com/2010/03/positive-proof-of-global-warming>

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# Climate change: animation

This NASA video by Ed Hawkins shows monthly global temperature anomalies, 1890-2021 as an increasing spiral whose color reflects temperature.

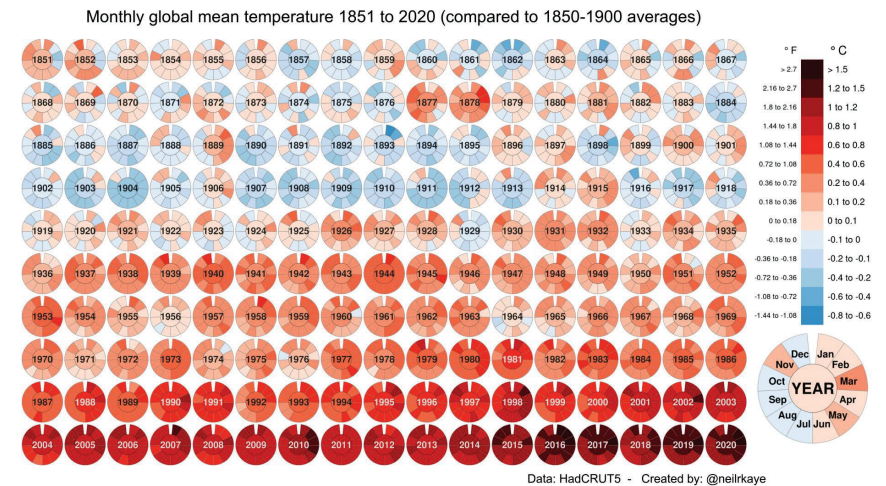


Video: <https://www.youtube.com/watch?v=jWoCXLuTIkI>  
See also: <https://www.climate-lab-book.ac.uk/spirals/>

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# Circle graphs

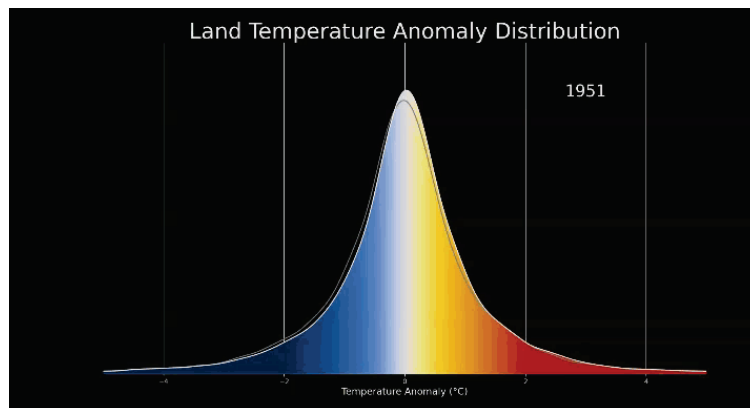
What features makes this graph effective?



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# Animation

Shifting Distribution of Land Temperature Anomalies, 1951-2020

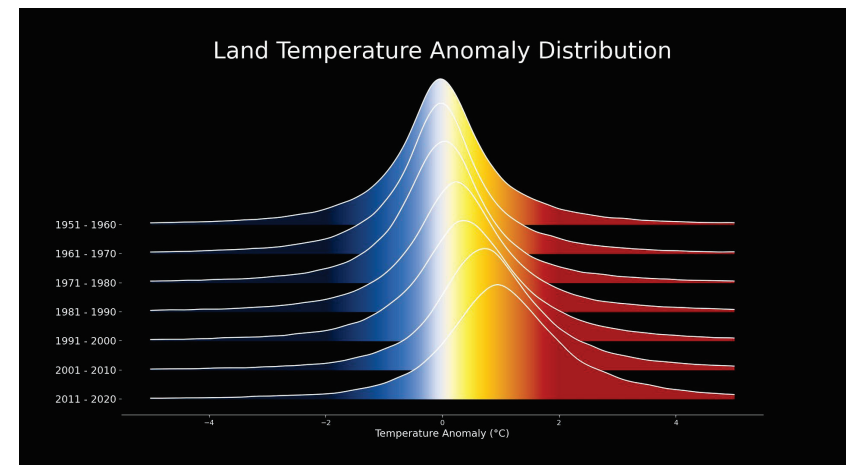


<https://svs.gsfc.nasa.gov/4891>

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# Animation -> Ridgeline plot

A ridgeline plot (stacking traces) turns the animation into a static graph



<https://svs.gsfc.nasa.gov/4891>

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## Some graphic rules

- Bars
  - Don't cut off their feet
  - Don't add dynamite fuses
- Pies
  - Generally, best preserved for dessert
  - Well used for part-whole relations with a small number of categories
  - Better used as a graphic form in larger displays
- Axes
  - Avoid double Y-axes
  - Don't truncate without considerable thought
- 3D
  - Avoid for useless "glitz"

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## Summary

Graphs as a form of communication

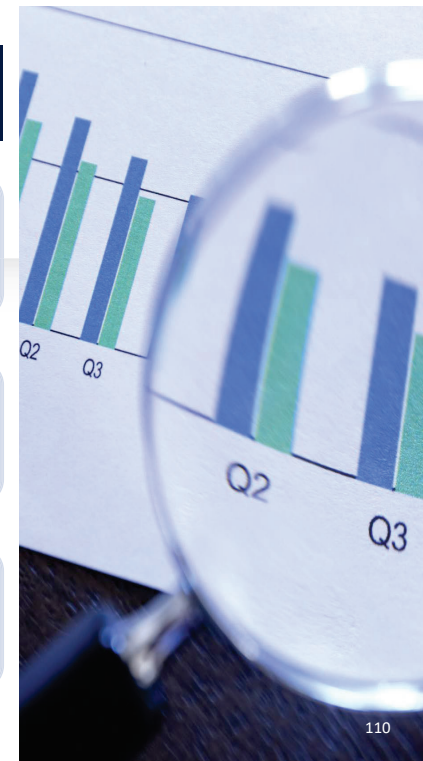
- Data (numbers), words, images → Stories
- Goal: tell a **credible** story

Analysis graphs vs. presentation graphs

- Know your audience
- Target info to your message
- Avoid doing evil

Some principles of effective data display

- Make the data stand out
- Facilitate comparisons
- Effect ordering
- Direct labeling



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