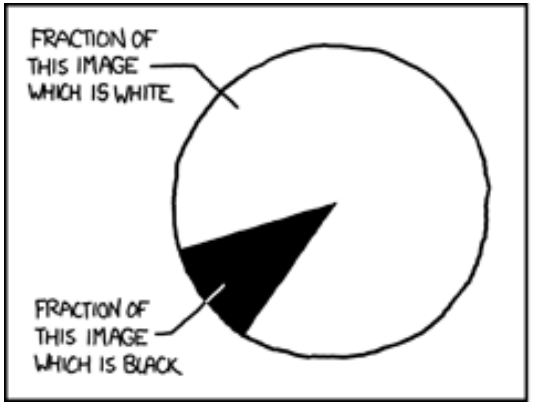
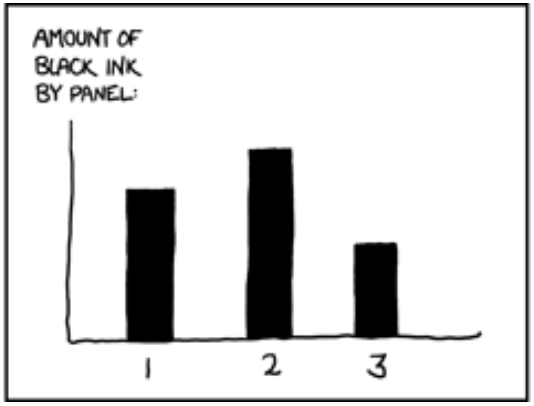
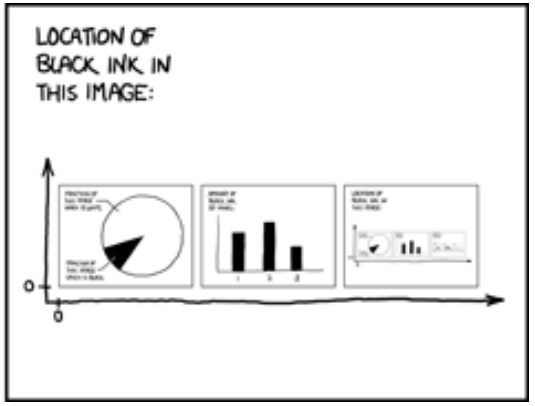
Communicating through infographics: visualizing scientific and engineering information



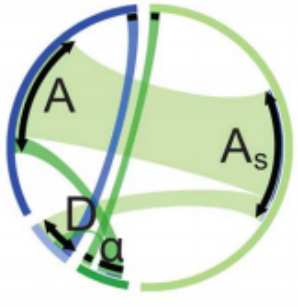


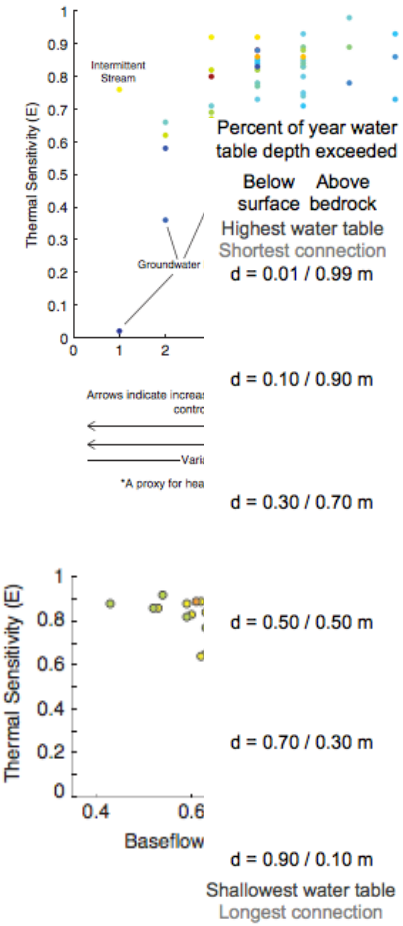


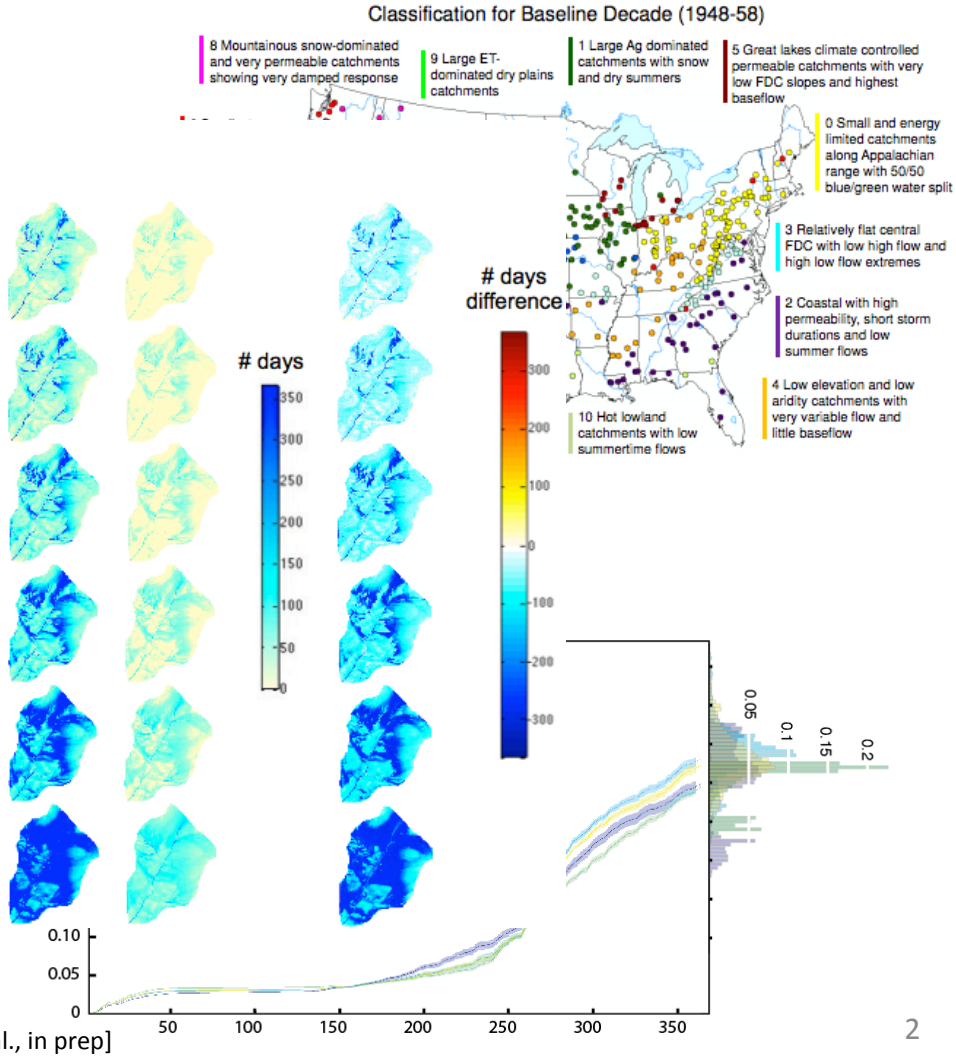
Christa Kelleher
Nicholas School of the Environment
Duke University

http://xkcd.com/688/

Model diagnostics, catchment modeling, and visualization of large environmental datasets



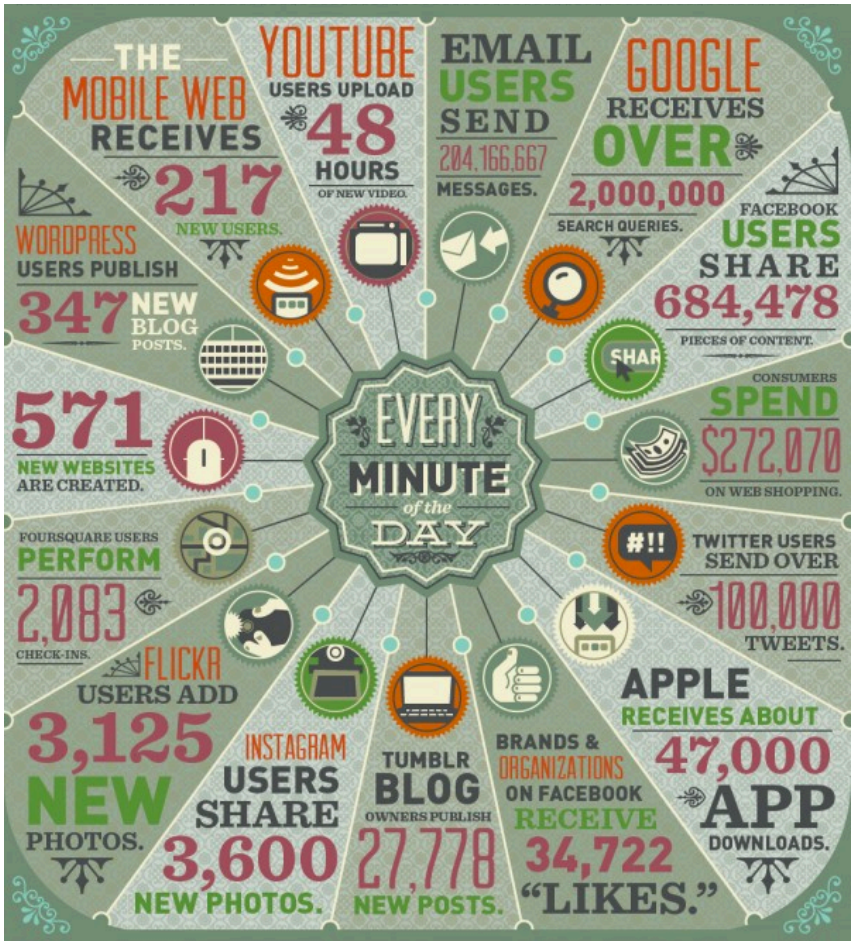




[Kelleher et al., 2012; Kelleher et al., 2013; Sawicz et al., 2013; Kelleher et al., in prep]

The importance of visualization

How much data is created every minute?



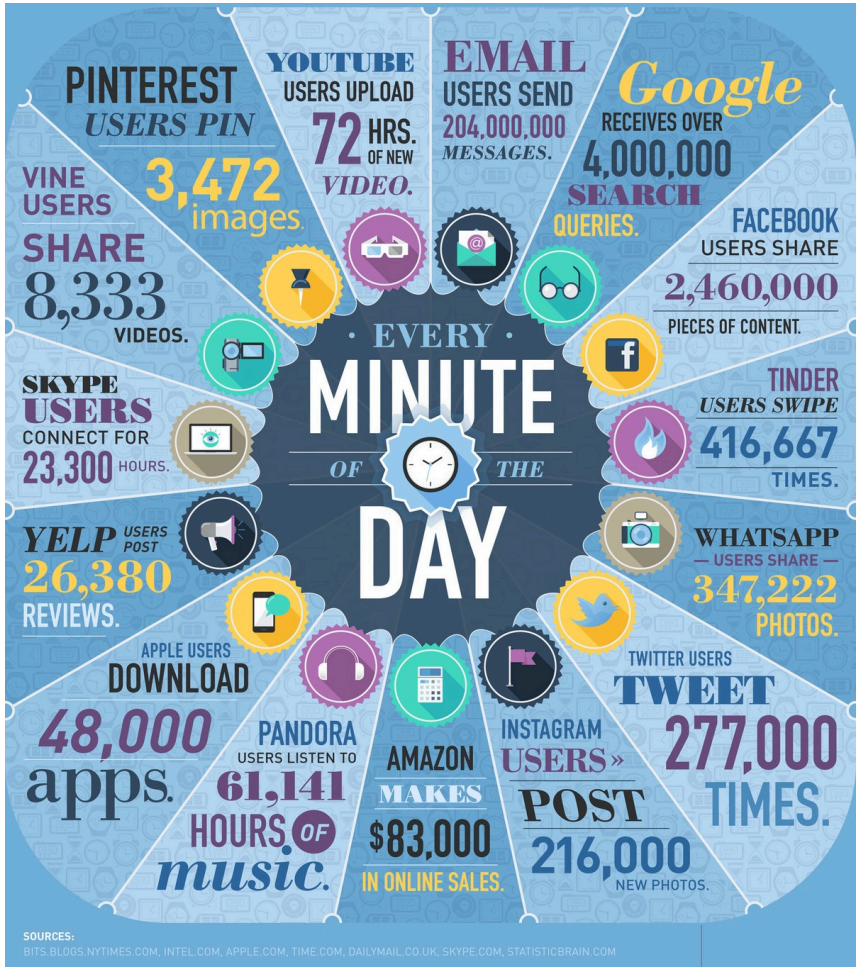
As of 2012 ….

- 100,000 tweets
- 2,000,000 google search queries
- 47,000 app downloads
- 571 new websites
- 217 new mobile web users

Source: [Visual News, http://www.visualnews.com/2012/06/19/how-much-data-created-every-minute/?view=infographic]

The importance of visualization

How much data is created every minute?



Source: [Mashable, http://mashable.com/2014/04/23/data-online-every-minute/?]

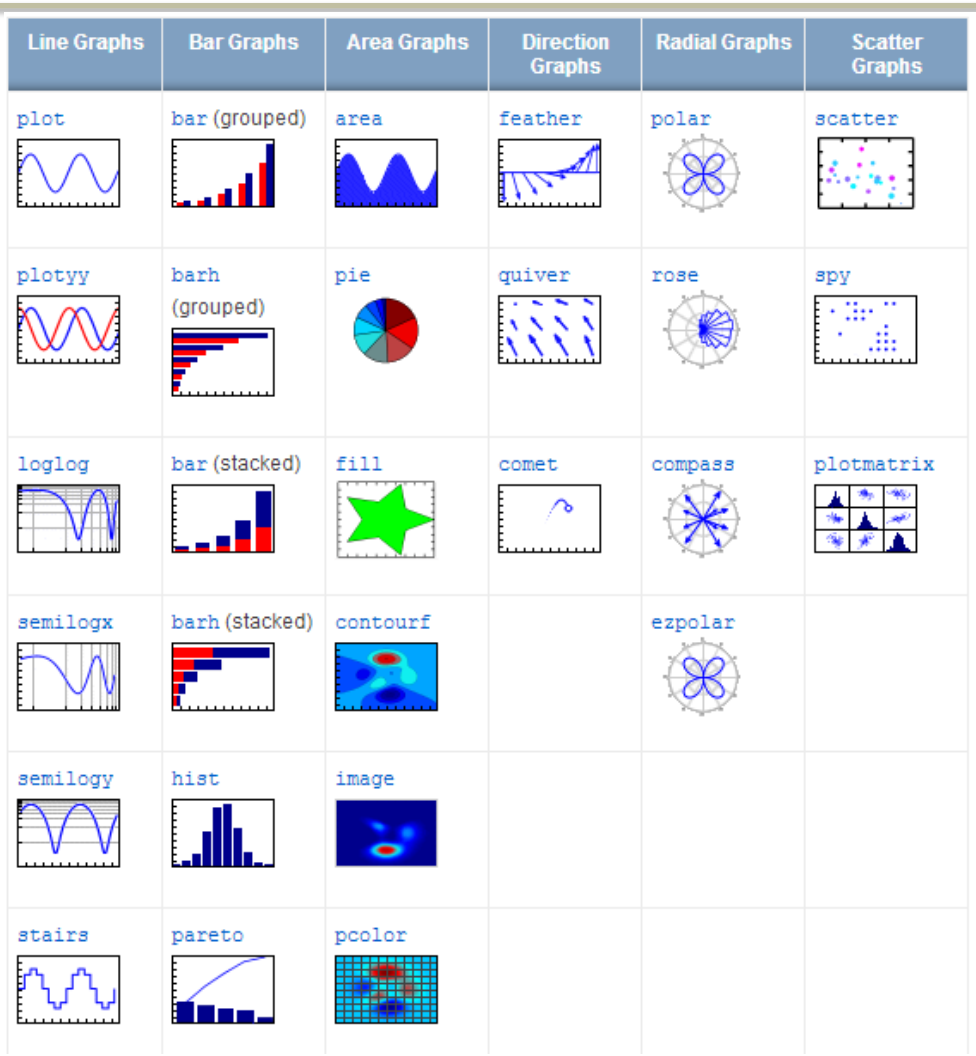
Resources

Data analysis:	Matlab	→	R, Python
Spatial analysis:	ArcGIS	→	R Mapping packages, qGIS, GRASS GIS, SAGA
Fine tuning:	Illustrator	→	Inkscape, CorelDRAW

HOW DO WE CREATE EFFECTIVE VISUALIZATIONS?

Rule 1 Choose an effective plot type

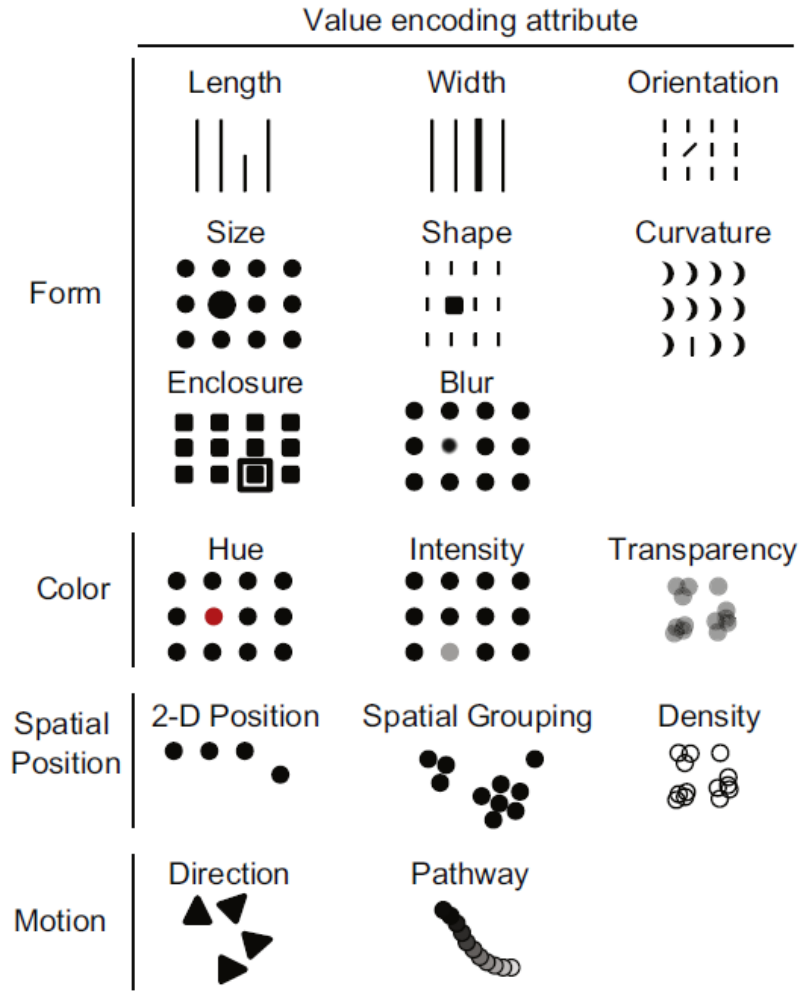
The type of plot you use should compliment the type of data you have (and the message you are conveying)



[Source: Matlab, http://www.mathworks.com/help/matlab/creating_plots/figures-plots-and-graphs.html]

Rule 1

Choose an effective plot type

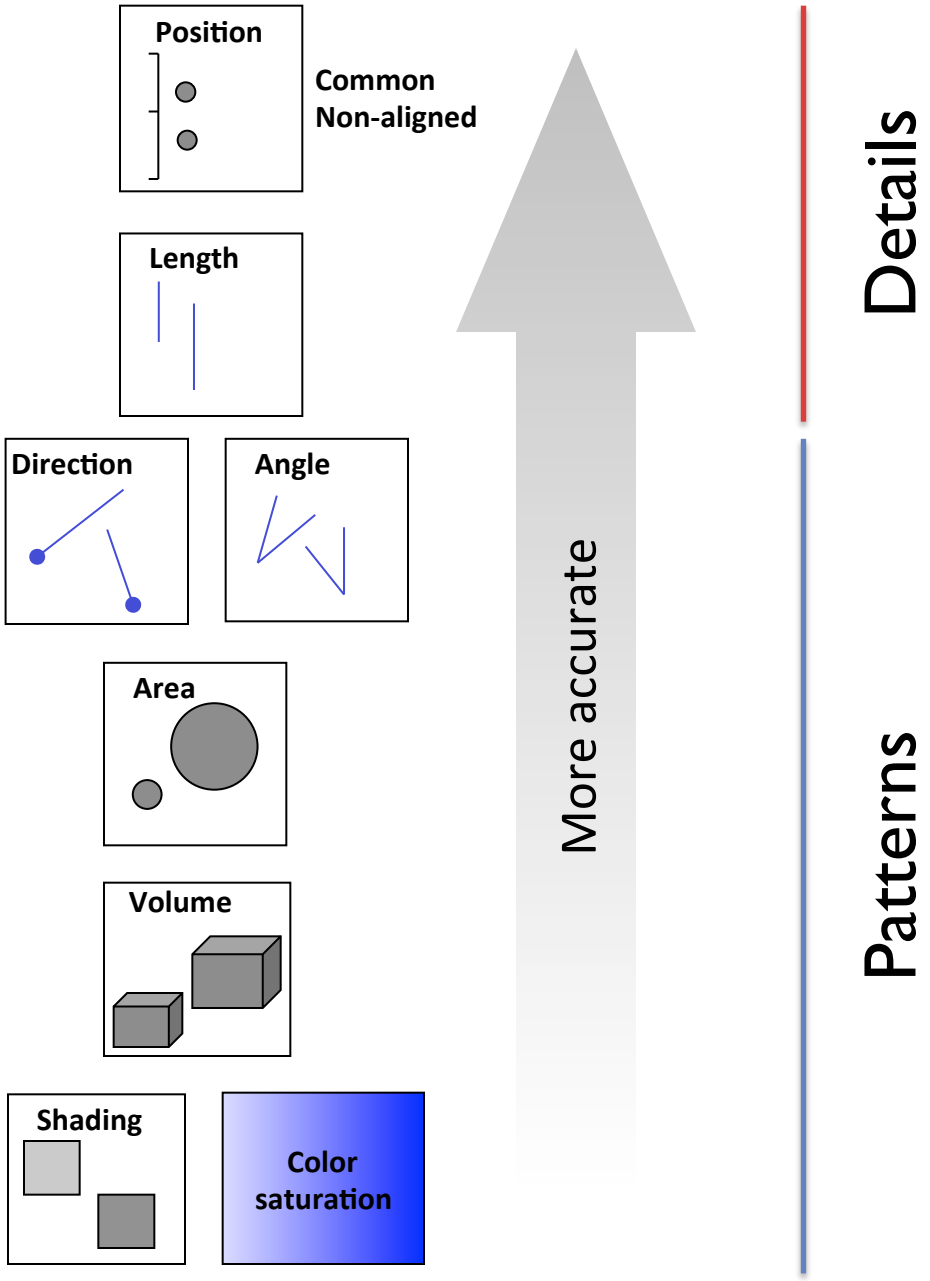


Plots use attributes to 'encode' information…

…BUT our ability to quantitatively perceive these attributes differs!

[Kelleher and Wagner (2011); Few (2009)]

Our accuracy to rank quantitative perceptual tasks varies across different encoding objects and graphs

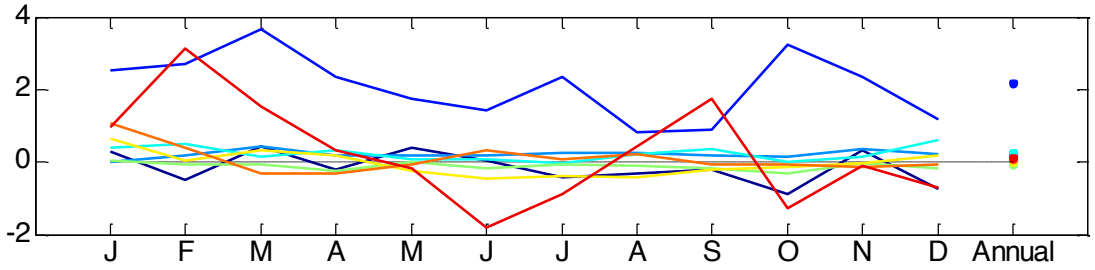


[Mackinlay (1986), *ACM Transactions on Graphics*]

Rule 1

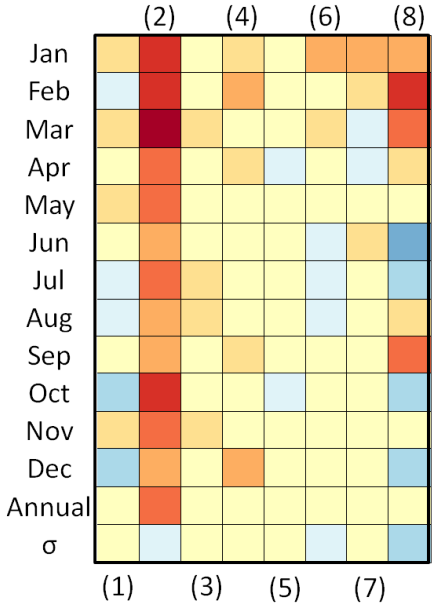
Choose an effective plot type

DETAILS
Line graph



VS

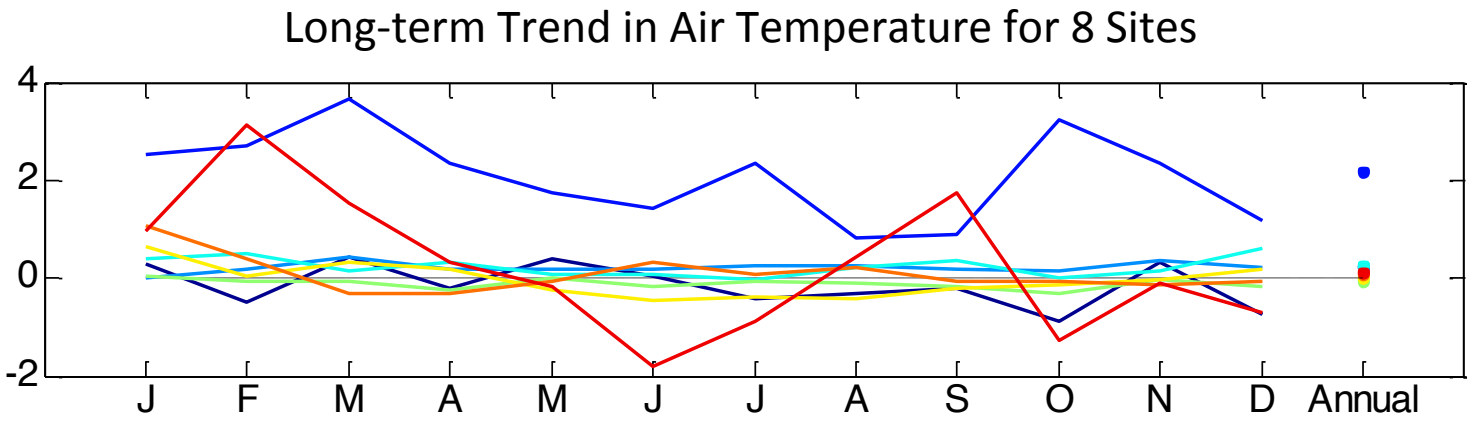
PATTERNS
Heat map
(Pattern plot)



[Kelleher and Wagner (2011); Few (2009)]

Rule 1 Choose an effective plot type

Line plots highlight details in the timeseries – high values, low values, and value comparisons

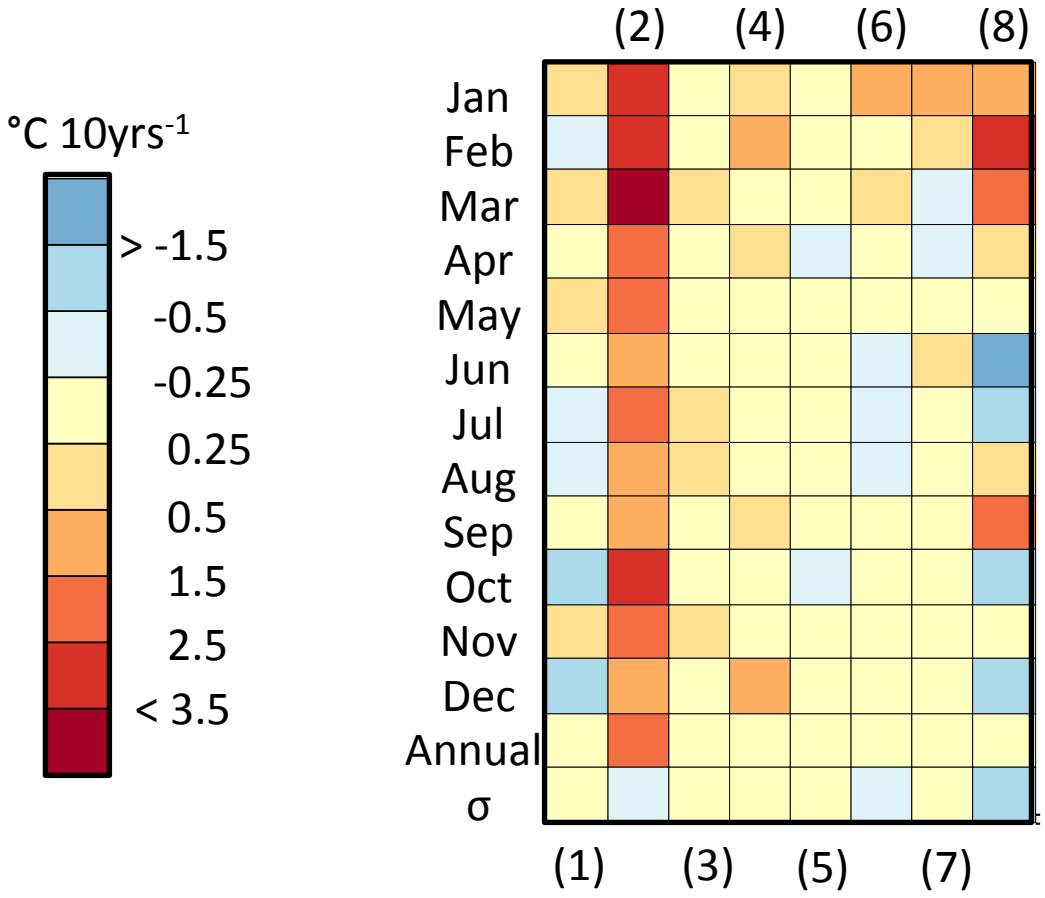


[Kelleher and Wagner (2011); Few (2009)]

Rule 1

Choose an effective plot type

Heat maps (pattern plots) highlight patterns in the data, and allow easy comparison

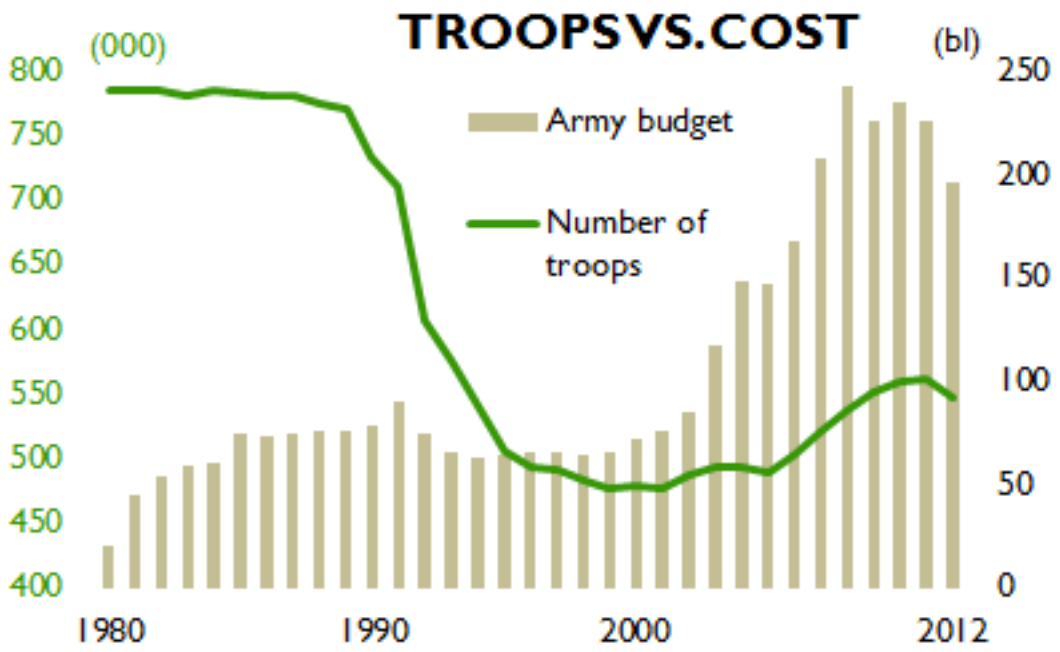


[Kelleher and Wagner (2011); Few (2009)]

Rule 1

Choose an effective plot type

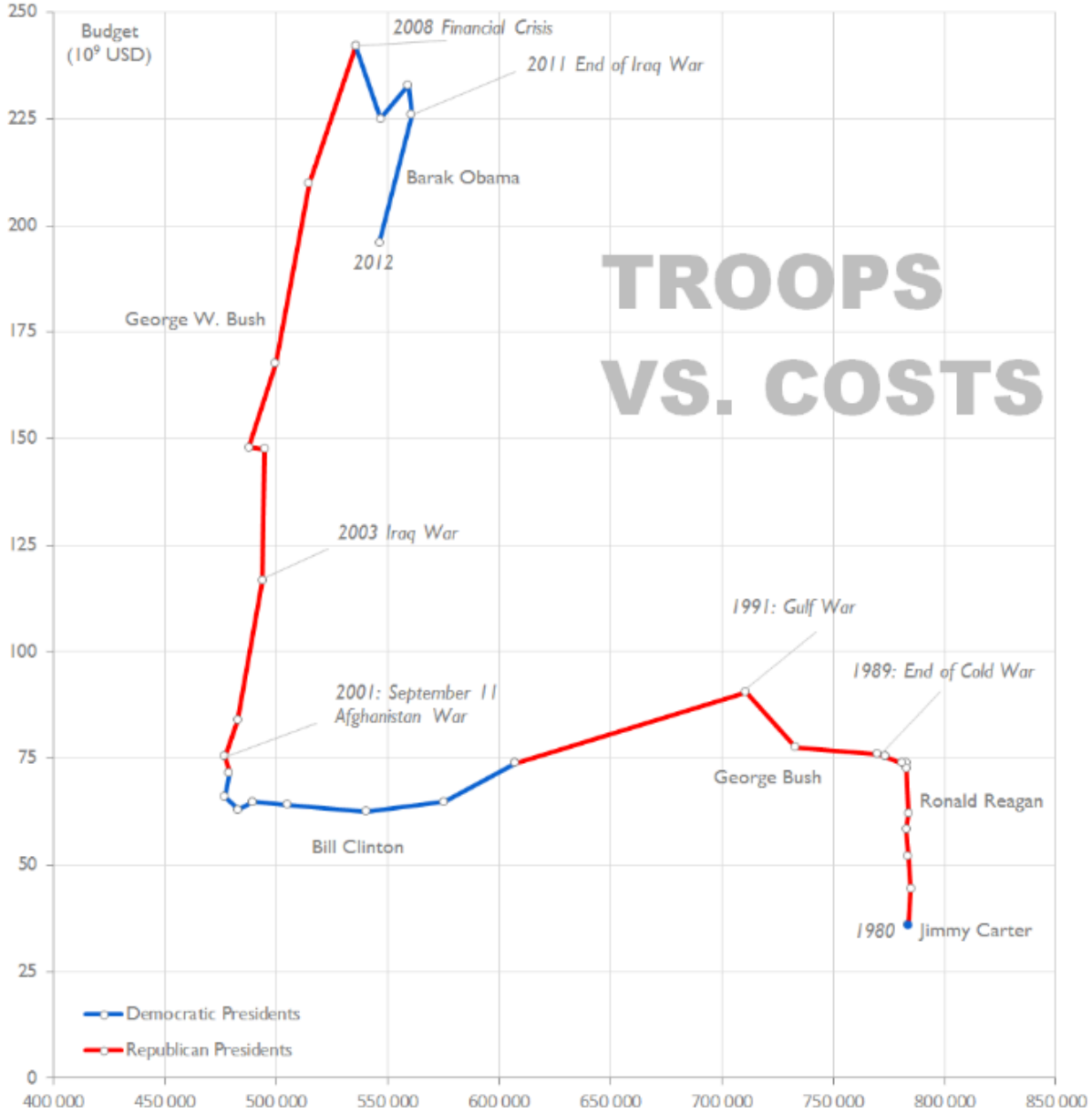
Aggregating data, troops versus cost, 1980 - 2012



Overall trends ….

Data source: Time Magazine
Creator: Jorge Camoes
Chart: http://www.excelcharts.com/blog/redraw-troops-vs-cost-time-magazine/

… vs details

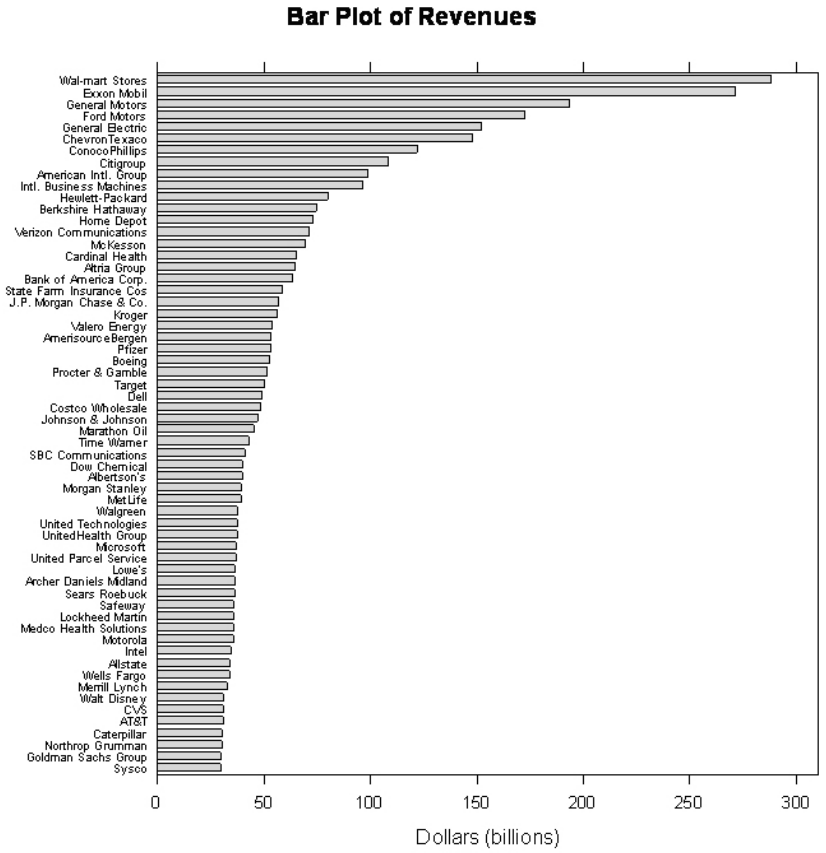


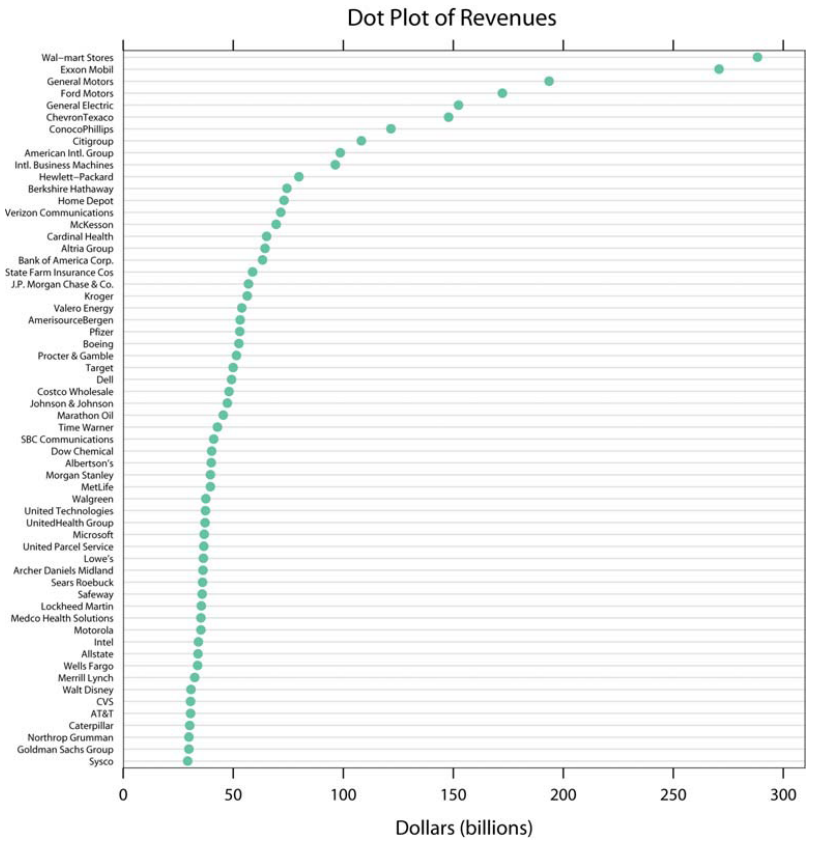
Data source: Time Magazine
Creator: Jorge Camoes
Chart: http://www.excelcharts.com/blog/redraw-troops-vs-cost-time-magazine/

Rule 1

Choose an effective plot type

Select attributes which can be easily perceived depending on your graph's message



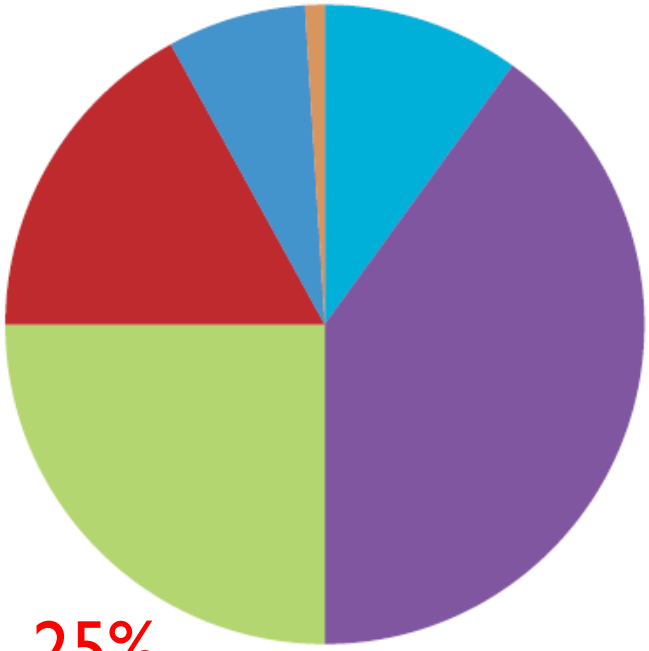


[Robbins (2006), accessed at: http://www.perceptualedge.com/articles/b-eye/dot_plots.pdf]

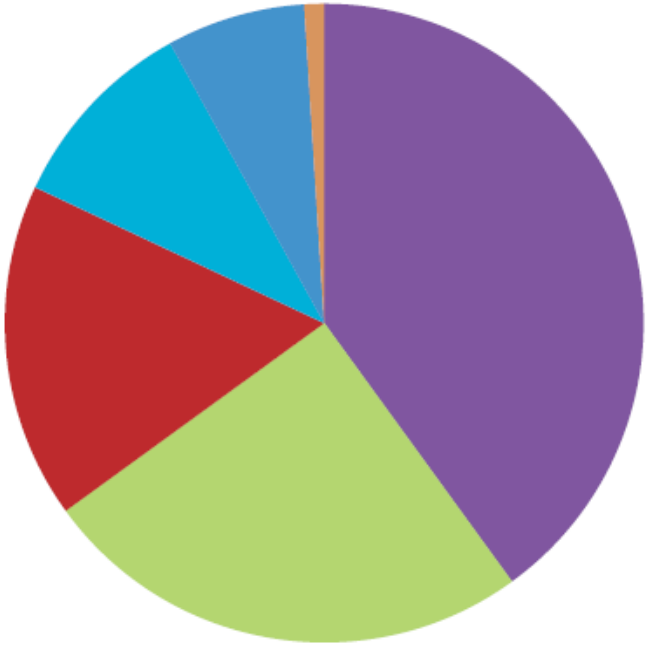
Rule 1

Choose an effective plot type

Pie charts are usually considered ineffective



25%



25% ??

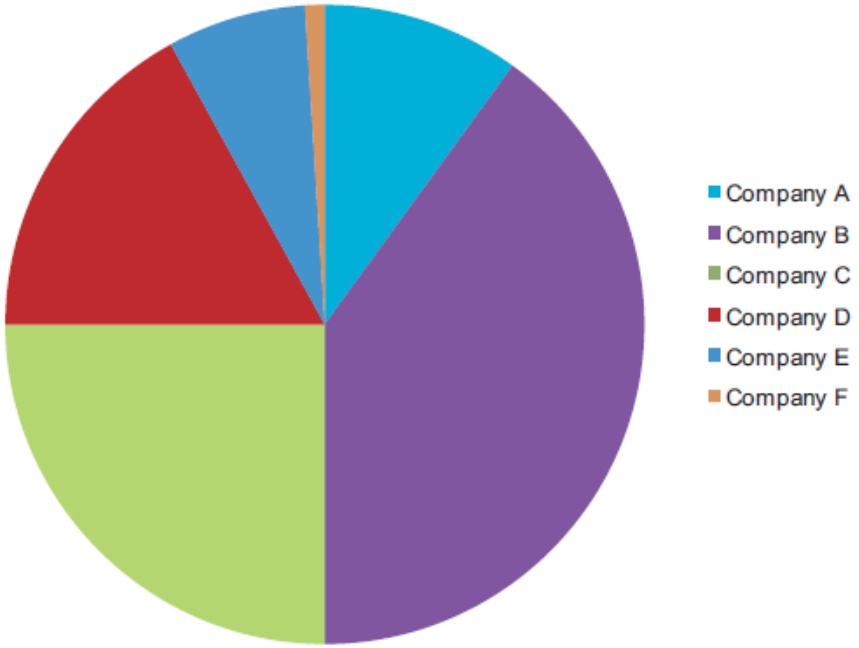
This one is up to you!

[Few (2007), accessed at: http://www.perceptualedge.com/articles/visual_business_intelligence/save_the_pies_for_dessert.pdf]

Rule 1

Choose an effective plot type

Tables are a good alternative



Companies	Percentage
Company B	40%
Company C	25%
Company D	17%
Company A	10%
Company E	7%
Company F	1%
Total	100%

[Few (2007), accessed at: http://www.perceptualedge.com/articles/visual_business_intelligence/save_the_pies_for_dessert.pdf]

Rule 2

Remove chart junk (Tufte, 1983)

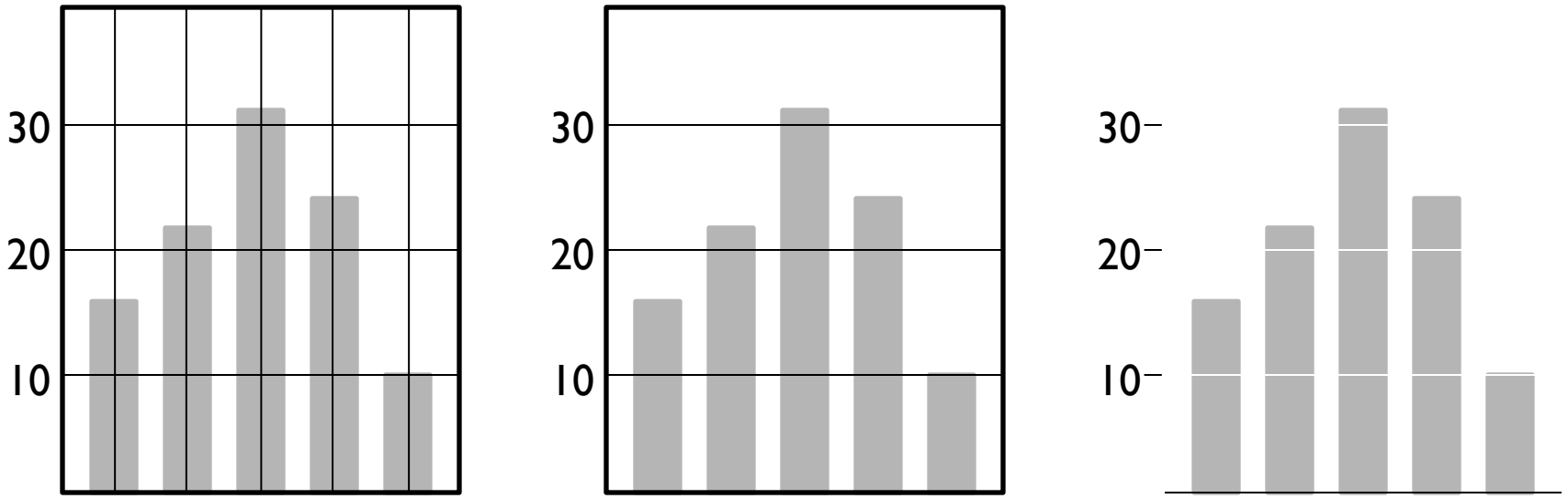
[S. Khosla, Global Post, http://www.globalpost.com/dispatch/news/regions/americas/brazil/140702/graphic-brazil-red-yellow-cards]

Rule 2

Remove chart junk (Tufte, 1983)

Chartjunk represents any ink on a given graph which displays redundant or non-data information

Reduction in chartjunk

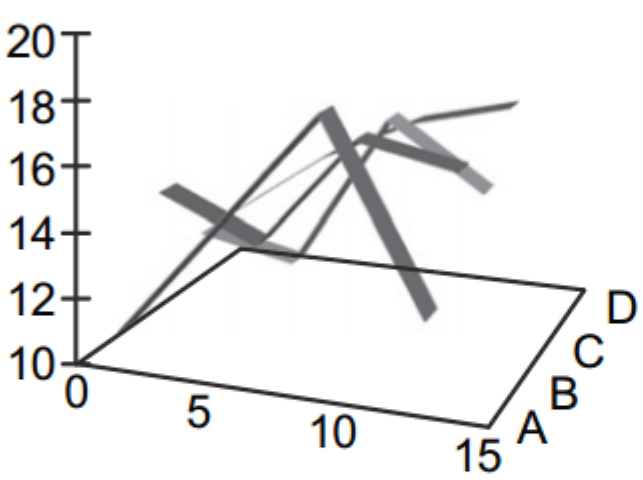


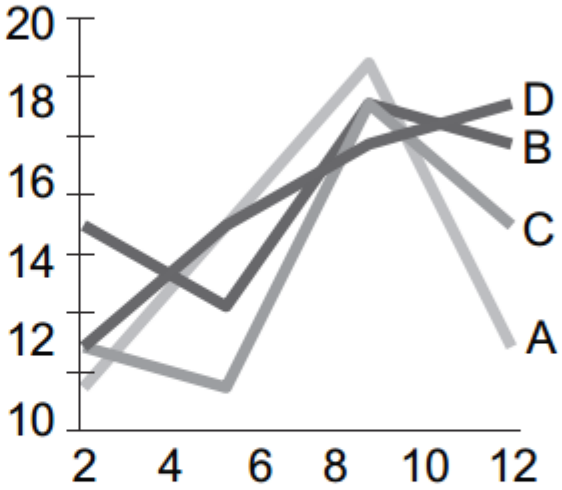
[Tufte (1983); Bray, Data-Ink Ratio Example 1, accessed at: http://www.tbray.org/ongoing/data-ink/di1]

Rule 2

Remove chart junk (Tufte, 1983)

This includes 3D graphics



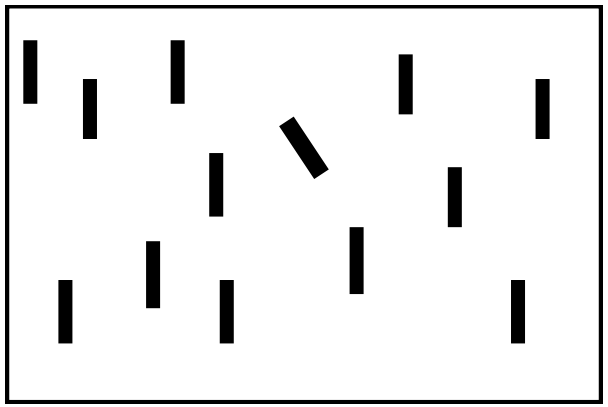


[Kelleher and Wagner (2011), *Environmental Modelling and Software*]

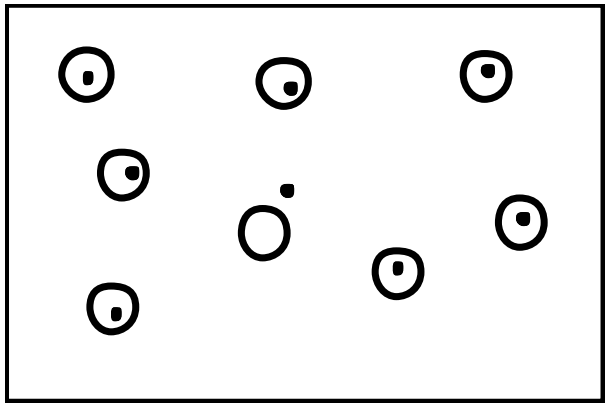
Rule 3

Display the same number of dimensions as the dataset

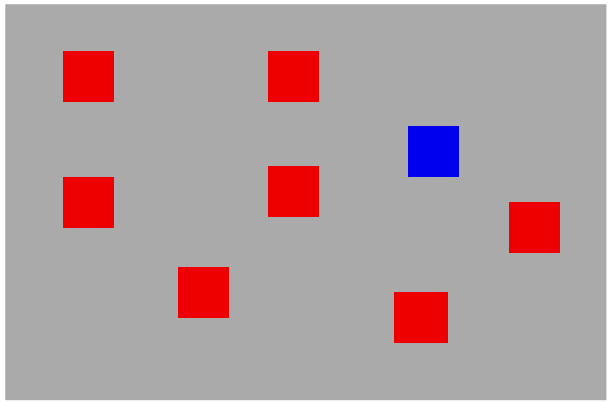
With a single encoding attribute, we can easily identify the object that doesn't follow the pattern



Orientation



Enclosure



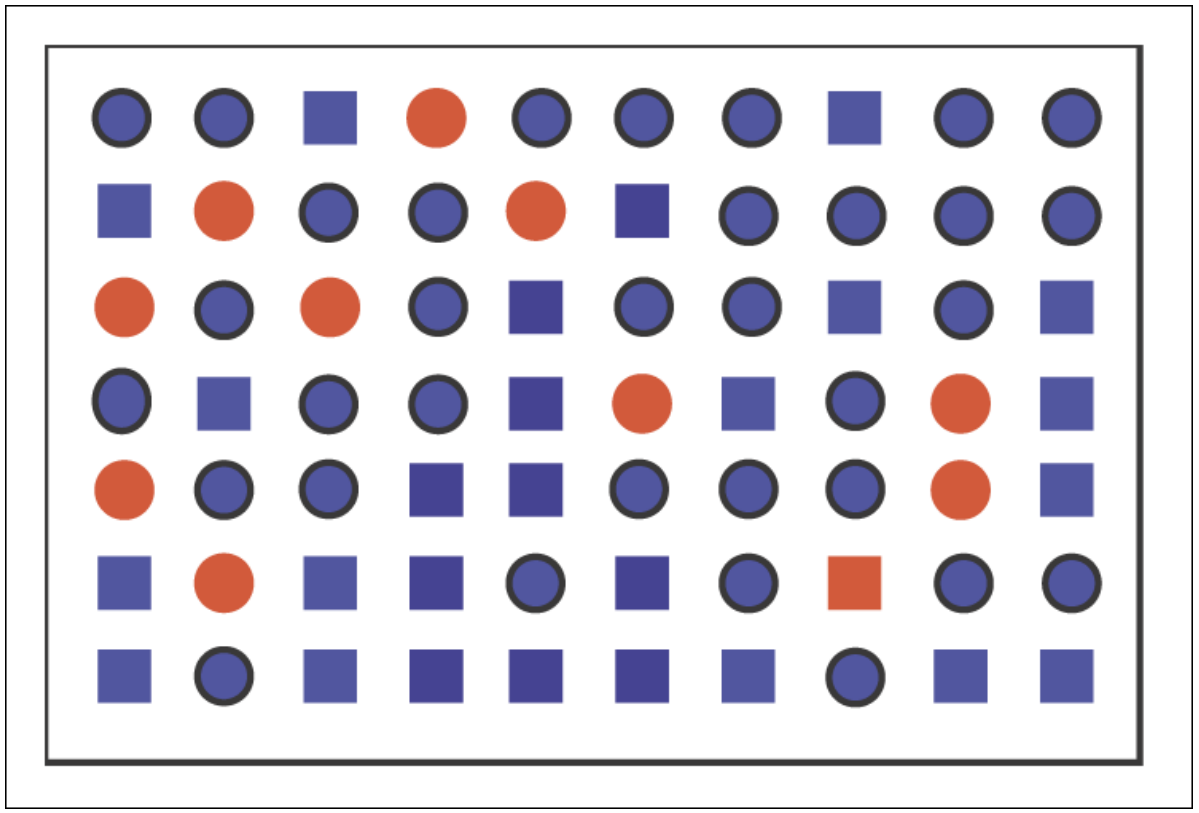
Color

[Spence (2007), *Information Visualization*]

Rule 3

Display the same number of dimensions as the dataset

FIND THE RED SQUARE!

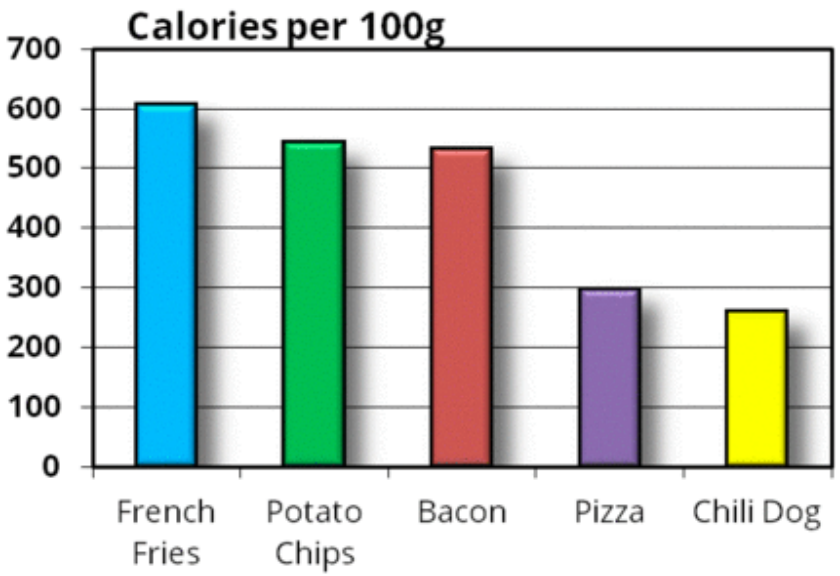


When we mix too many attributes, we make it harder to detect patterns

[Spence (2007), *Information Visualization*]

Rule 3

Display the same number of dimensions as the dataset



Biggest bank settlements with US authorities

	Bank	Settlement, $bn	Date	Cause
1	JPMorgan Chase	13.0	Oct 2013	MBS*
2	Bank of America	11.8	Feb 2012	Foreclosures†
3	Bank of America	11.6	Jan 2013	Mortgage repurchases
4	Bank of America	9.3	Mar 2014	MBS*
5	BNP Paribas	8.97	Jun 2014	Violating sanctions
6	Wells Fargo	5.3	Feb 2012	Foreclosures†
7	JPMorgan Chase	5.3	Feb 2012	Foreclosures†
8	JPMorgan Chase	5.1	Oct 2013	MBS*/mortgage repurchases
9	Bank of America	2.9	Jan 2013	Foreclosures‡
10	Credit Suisse	2.6	May 2014	Aiding tax evasion

Sources: Company reports; national sources; *Financial Times*

*Mortgage-backed securities †Part of $25bn National Mortgage Settlement ‡Part of $8.5bn settlement

[DarkHorse Analytics, http://darkhorseanalytics.com/blog/data-looks-better-naked/]

[The Economist, http://www.economist.com/blogs/graphicdetail/2014/07/daily-chart-3]

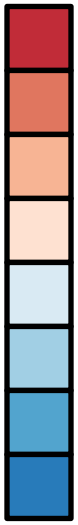
Rule 4

Consider the use of color to fit your chart and the type of data you're displaying

Sequential

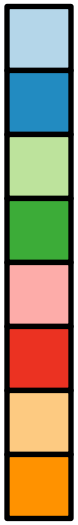
Example: air temperature, traffic counts

Diverging



Example: anomalies

Categorical



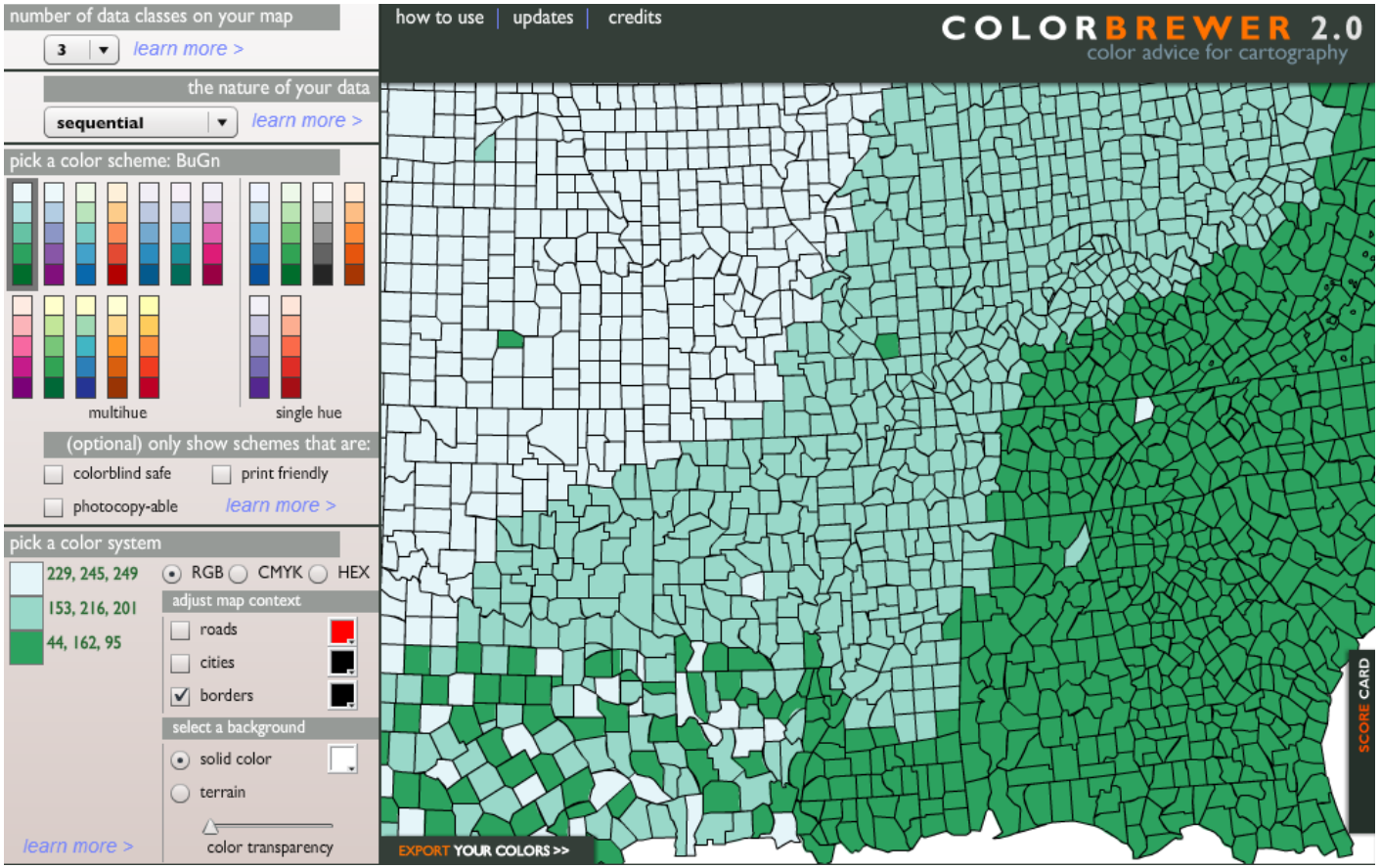
Example: colors, political parties, car types/ manufacturors

[ColorBrewer2, online at http://colorbrewer2.org/]

Rule 4

Consider the use of color to fit your chart and the type of data you're displaying

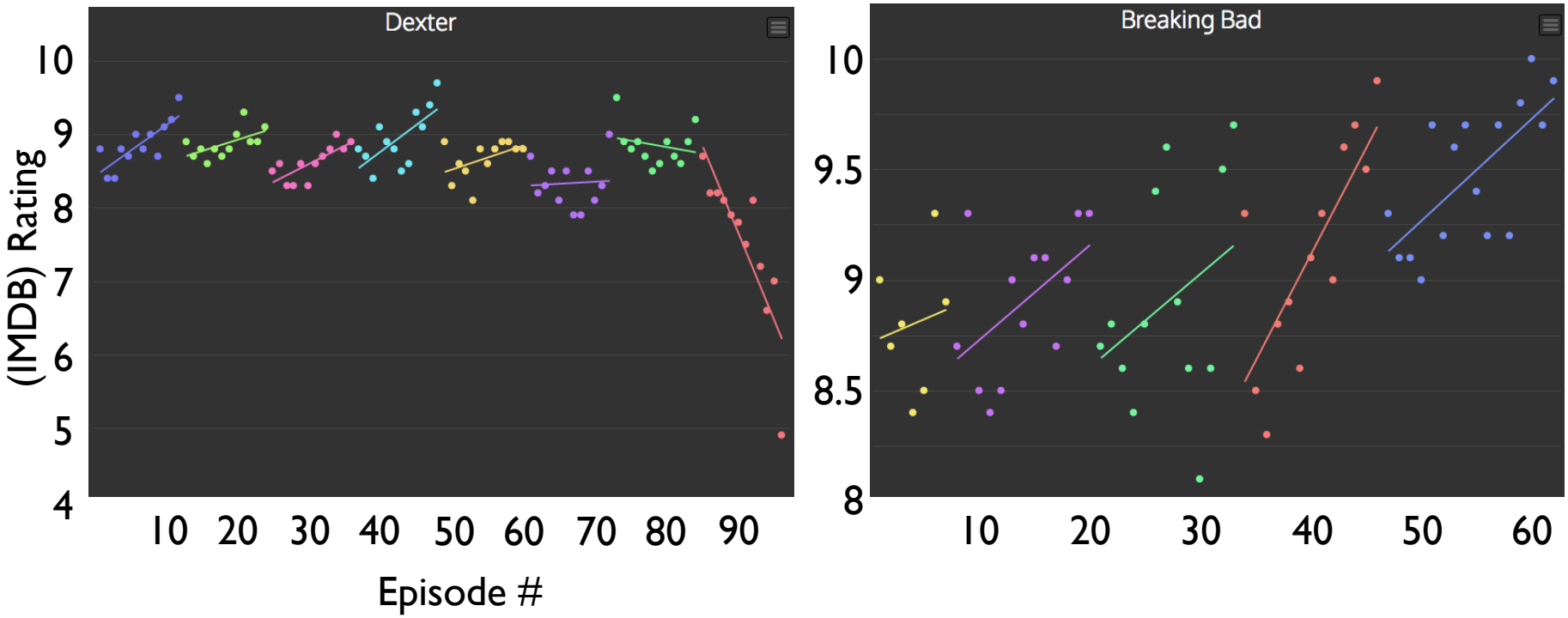
Colorbrewer2 (colorbrewer2.org/), developed by Cynthia Brewer (Penn State)



[ColorBrewer2, online at http://colorbrewer2.org/]

Rule 5

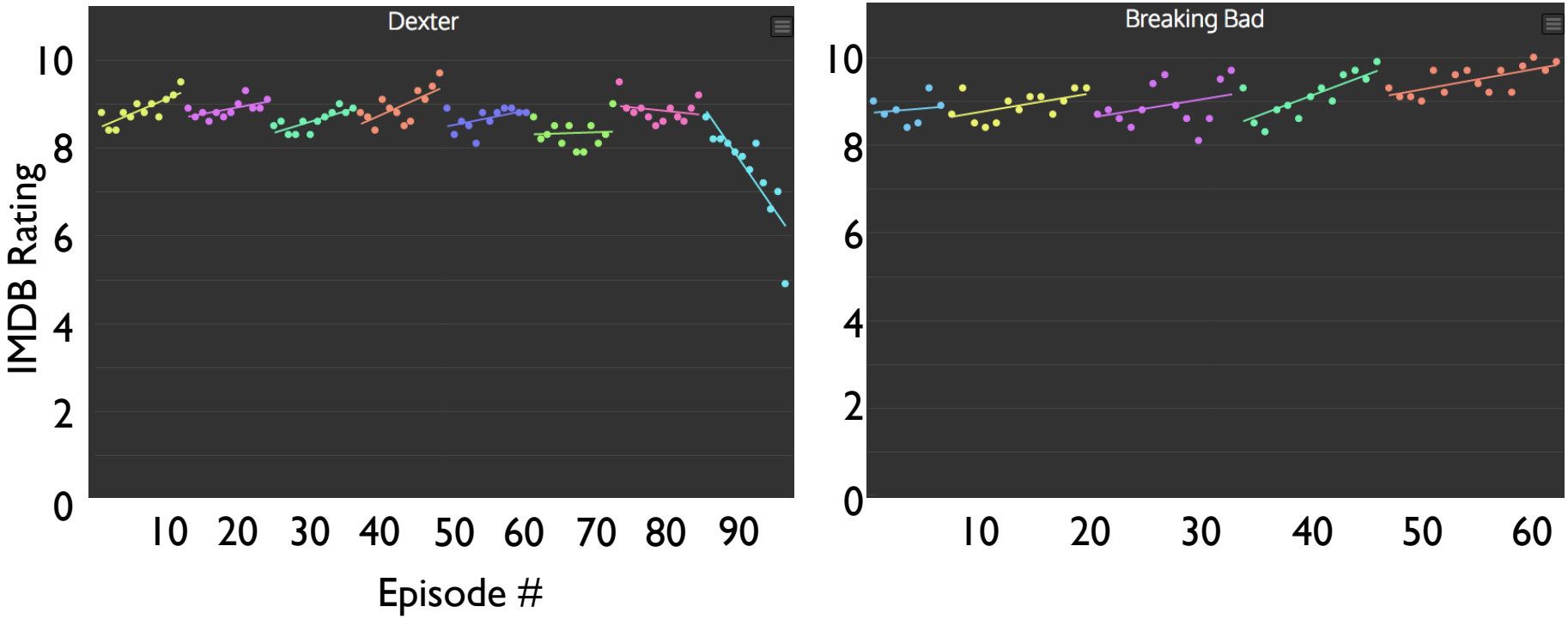
Maintain axes when comparing subplots



Data source: IMDB
Location: http://graphtv.kevinformatics.com/

Rule 5

Maintain axes when comparing subplots



Data source: IMDB
Location: http://graphtv.kevinformatics.com/

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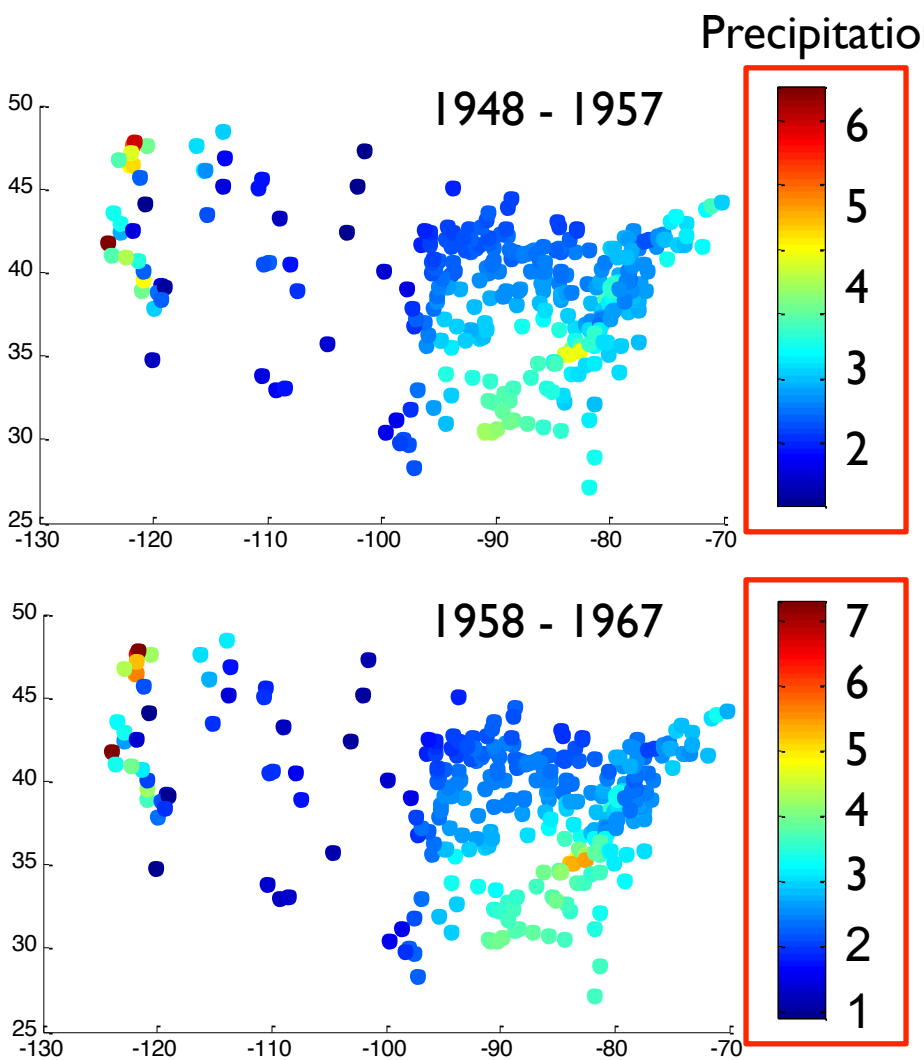
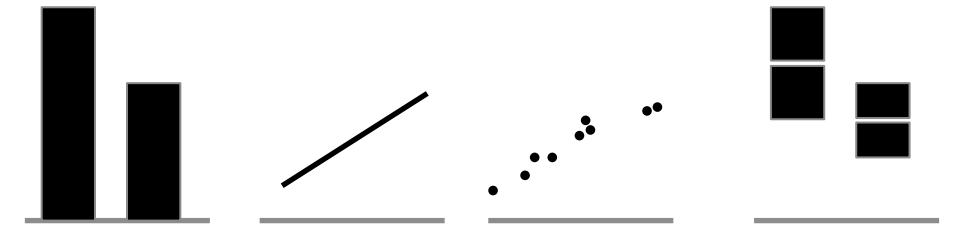


Visualization programs usually require that you manually set the axes and ranges between plots

[C. Kelleher, K. Sawicz]

Rules for specific plot types



Magnitude Change Correlation Distribution

Bar Charts: Rules for effective use

Reference to zero

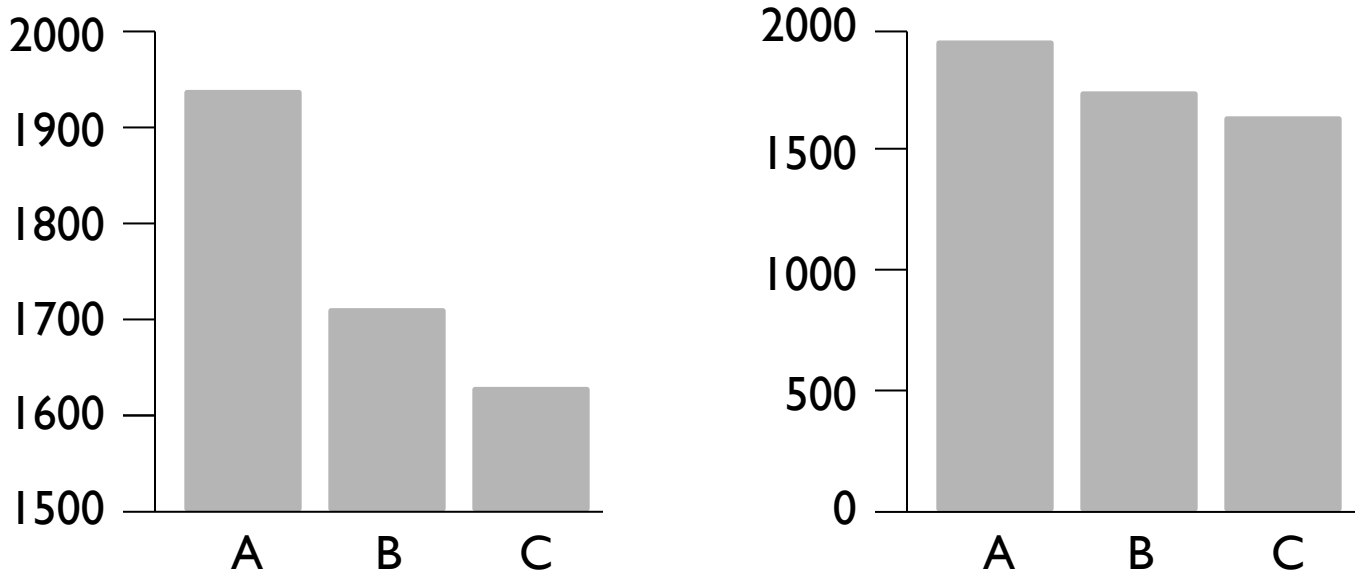
Use rotated bar charts if there are more than 8-10 categories

Include a legend

Be aware of scaling issues (important if you're showing more than one data series)

[Few, 2009; Gary Klass, Illinois State, http://lilt.ilstu.edu/gmklass/pos138/datadisplay/sections/goodcharts.htm]

Bar Charts: Reference the y-axis to zero on bar charts



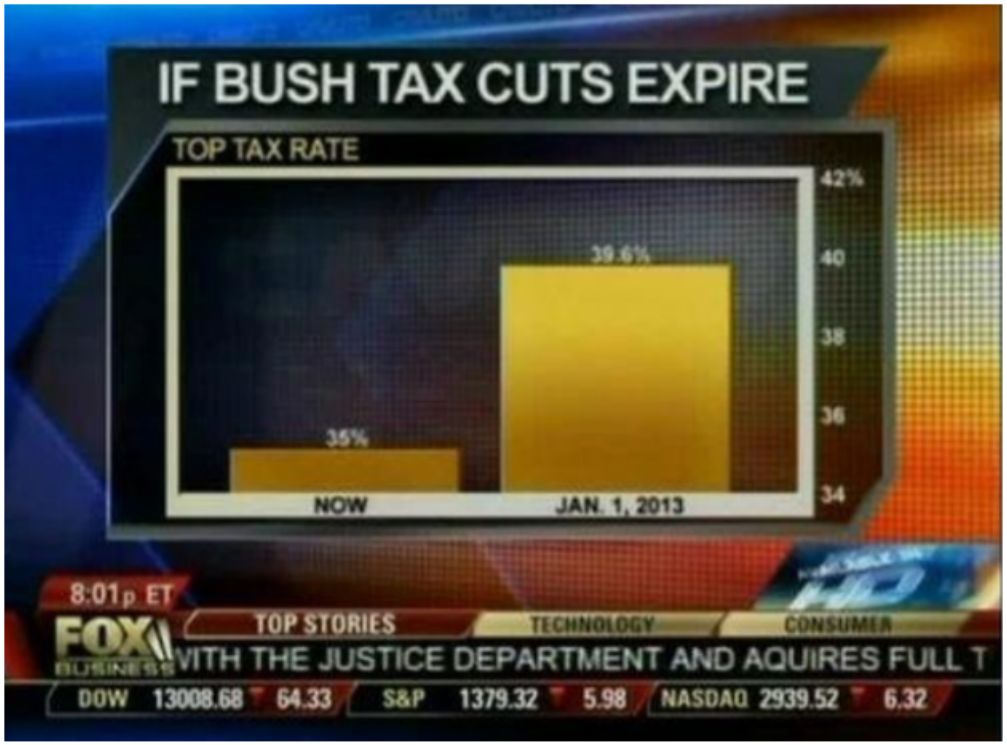
This accentuates the perceived differences between graphed entities

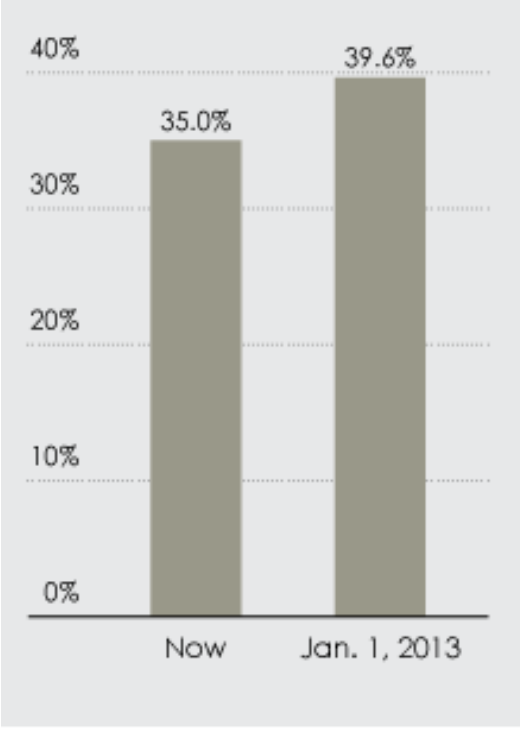
[Kelleher and Wagener (2011), *Environmental Modelling and Software*; Wainer (1984) *The Am statistician*]

Bar Charts: Reference the y-axis to zero on bar charts

Fox News continues charting excellence

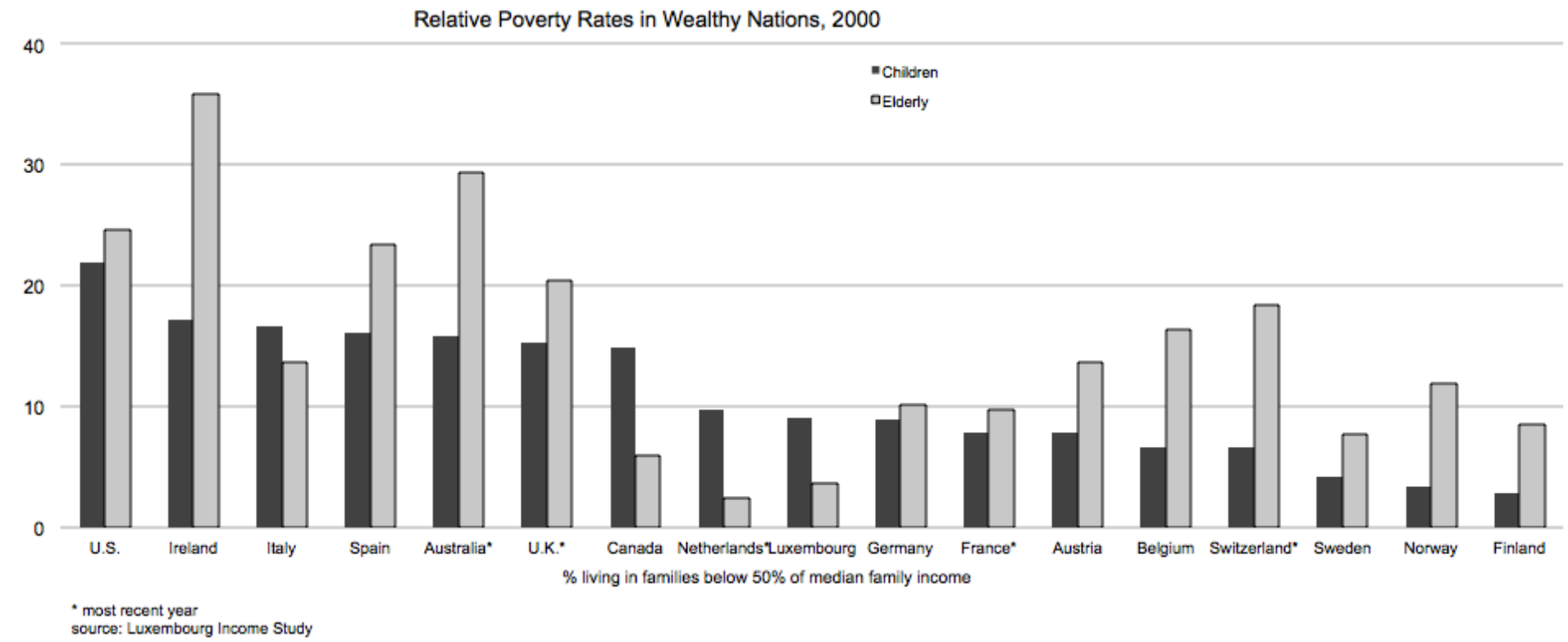
August 6, 2012 to Mistaken Data by Nathan Yau





[Yau (2012), FlowingData.com, accessed at: http://flowingdata.com/2012/08/06/fox-news-continues-charting-excellence/]

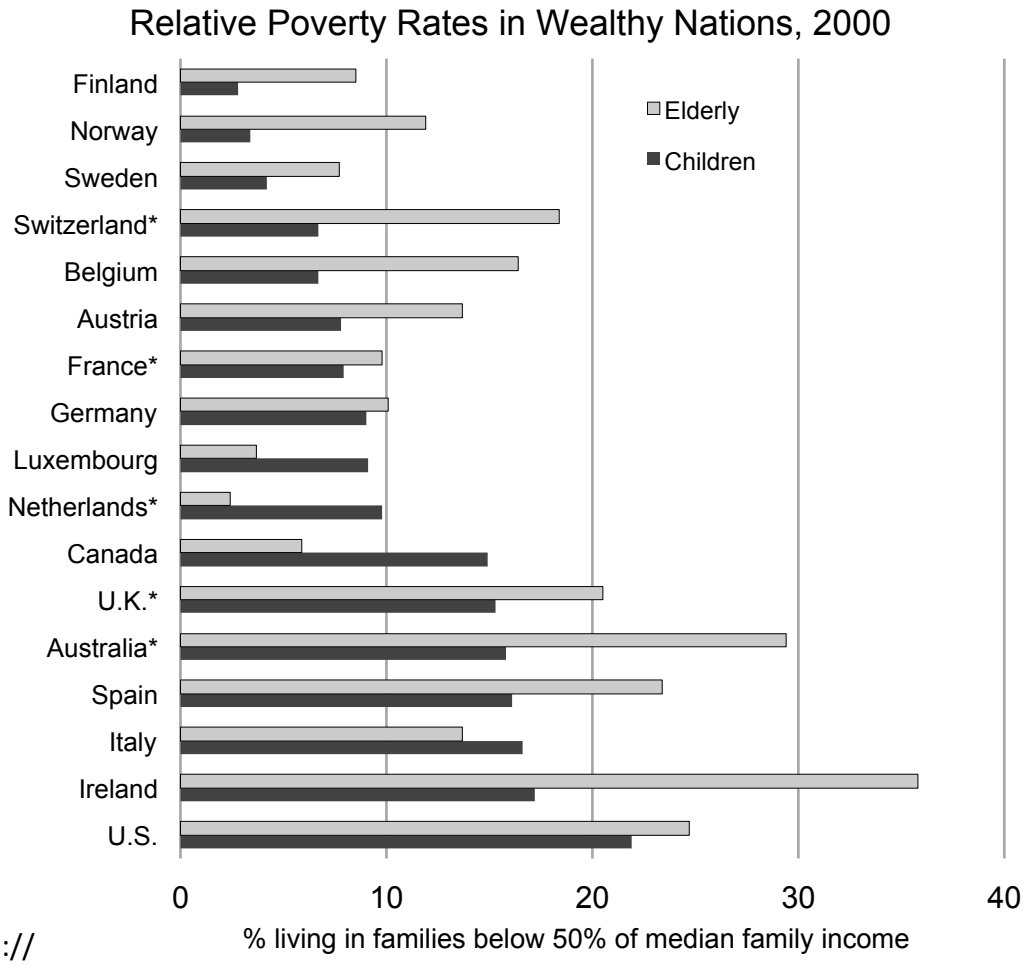
Bar Charts: Rotate your chart if displaying more than 8-10 categories



[Gary Klass, Illinois State, http://lilt.ilstu.edu/gmklass/pos138/datadisplay/sections/goodcharts.htm]

Bar Charts:

Rotate your chart if displaying more than 8-10 categories

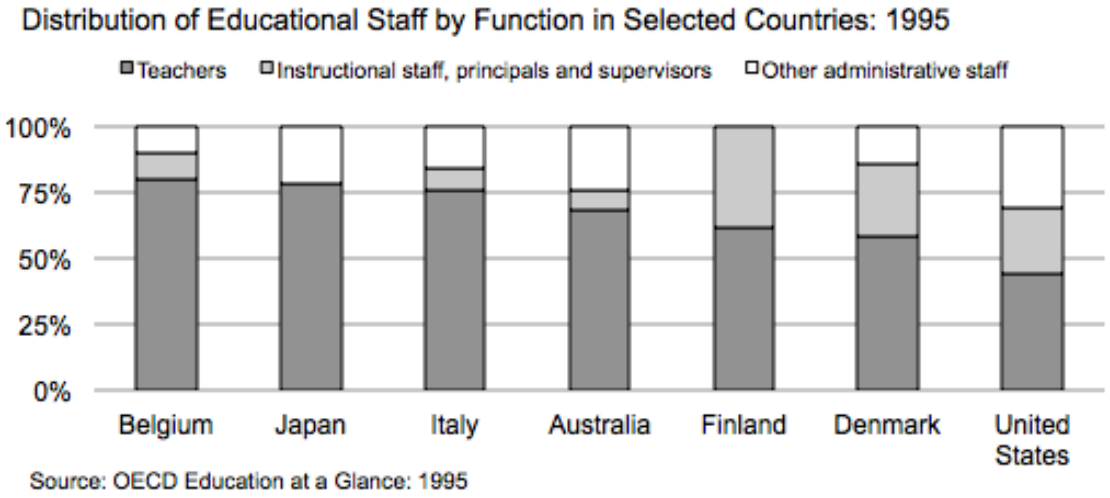


[Gary Klass, Illinois State, http://lilt.ilstu.edu/gmklass/pos138/datadisplay/sections/goodcharts.htm]

* most recent year
source: Luxembourg Income Study

Bar Charts:

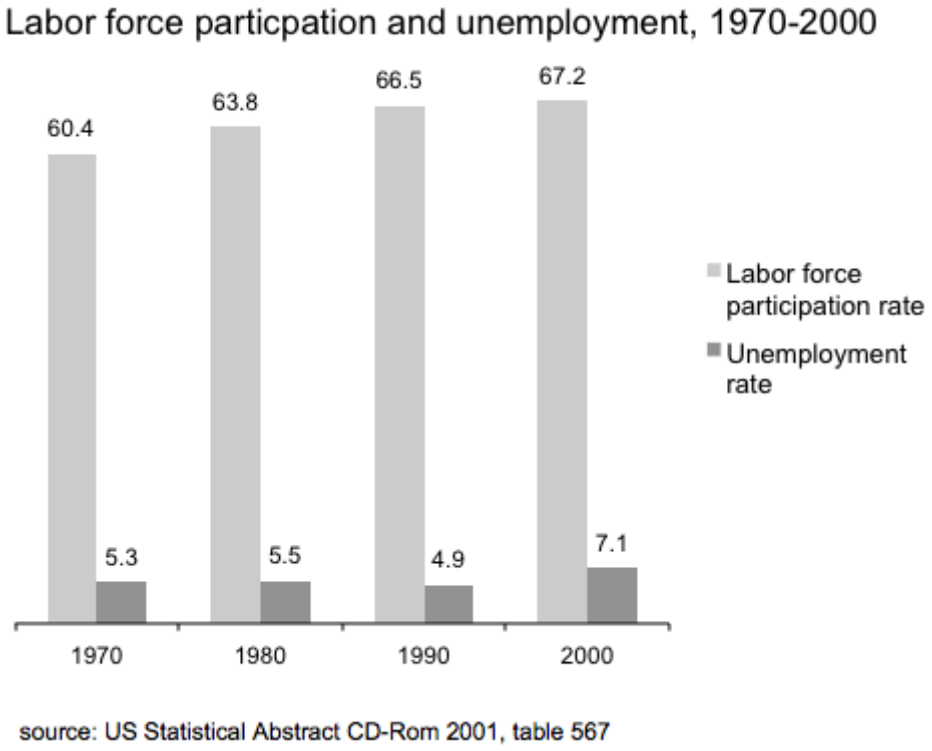
Stacked bar charts make sense when comparing the bottom series



[Gary Klass, Illinois State, http://lilt.ilstu.edu/gmklass/pos138/datadisplay/sections/goodcharts.htm]

Bar Charts: Bar charts and scaling issues

… especially important when displaying two data series with very different magnitudes



[Gary Klass, Illinois State, http://lilt.ilstu.edu/gmklass/pos138/datadisplay/sections/goodcharts.htm]

Bar Charts: Bar charts and scaling issues

… especially important when displaying two data series with very different magnitudes

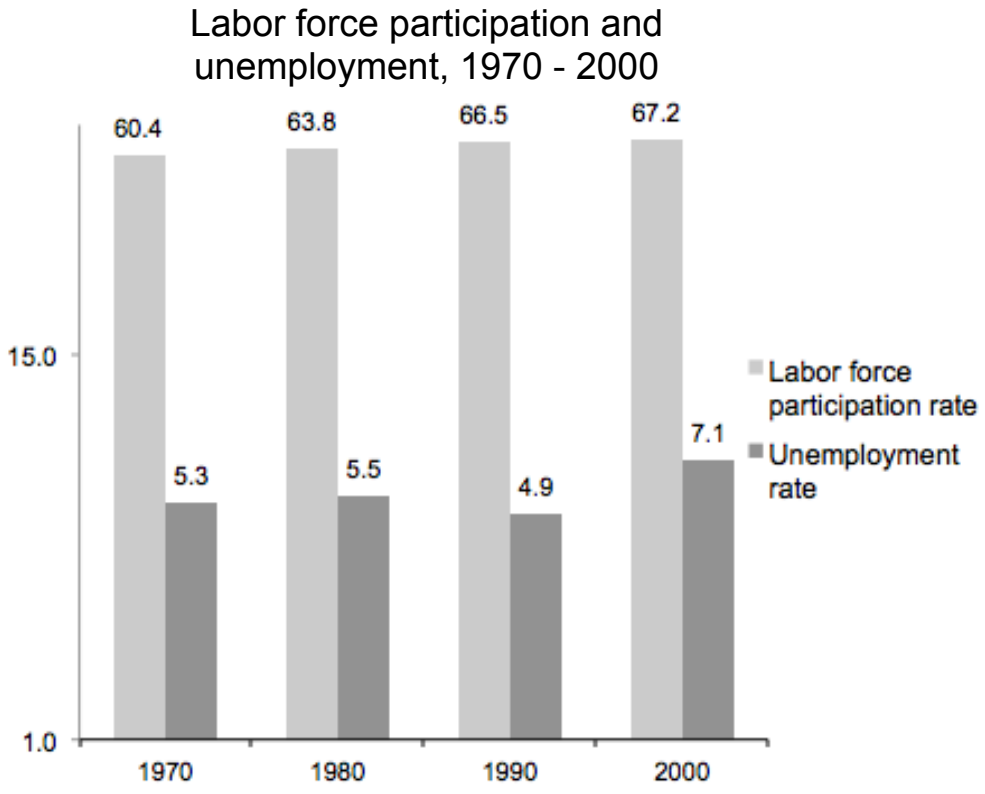
Highlights the fact that labor participation is large across all years

Misses that the unemployment rate increases by a factor of 30%

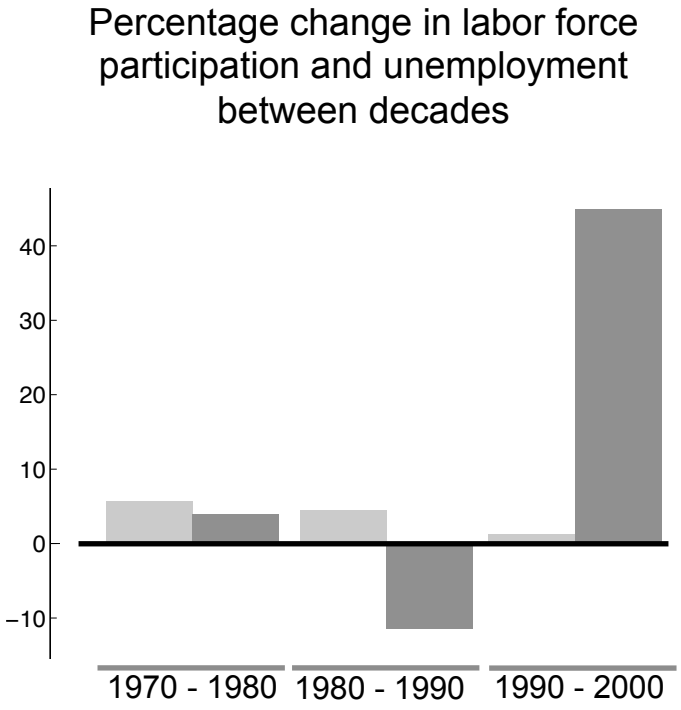
[Gary Klass, Illinois State, http://lilt.ilstu.edu/gmklass/pos138/datadisplay/sections/goodcharts.htm]

Bar Charts: Bar charts and scaling issues

Displaying the y-axis on a log scale can help to highlight the rate of change

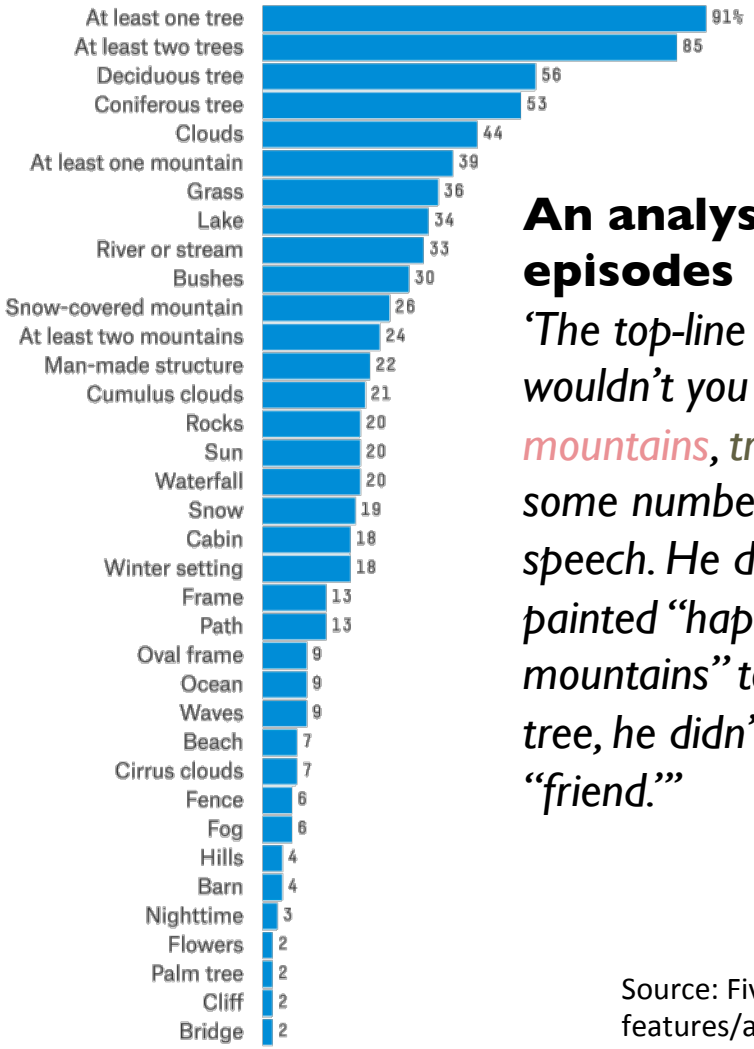


source: US Statistical Abstract CD-Rom 2001, table 567



[Gary Klass, Illinois State, http://lilt.ilstu.edu/gmklass/pos138/datadisplay/sections/goodcharts.htm]

Bar Charts: Example – the paintings of Bob Ross



An analysis of 381 Bob Ross episodes

'The top-line results are to be expected — wouldn't you know, he did paint a bunch of mountains, trees and lakes! — but then I put some numbers to Ross's classic figures of speech. He didn't paint oaks or spruces, he painted "happy trees." He favored "almighty mountains" to peaks. Once he'd painted one tree, he didn't paint another — he painted a "friend.""

Source: FiveThirtyEight, <http://fivethirtyeight.com/features/a-statistical-analysis-of-the-work-of-bob-ross/>

Line Charts: Rules for effective use

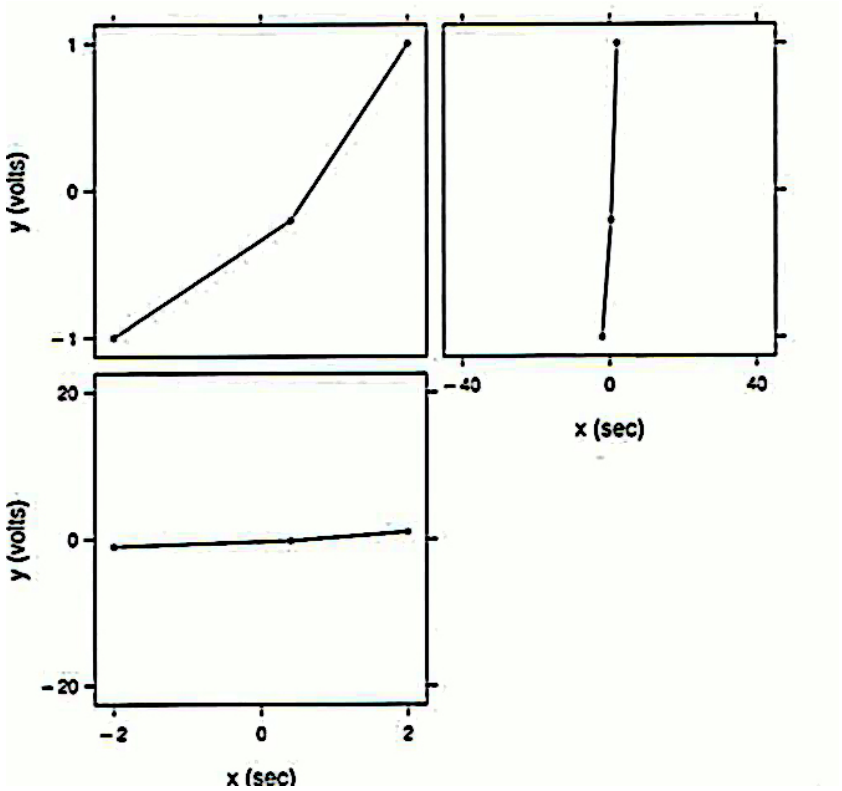
Be aware of scaling issues

Distinguish between different series of data

[Few, 2009; Gary Klass, Illinois State, http://lilt.ilstu.edu/gmklass/pos138/datadisplay/sections/goodcharts.htm]

Line Charts: Select an aspect ratio that banks to 45 degrees

ASPECT RATIO! Or Banking to 45° (Cleveland, 1995)



WHY?

"…a viewer's ability to judge the relative slopes of line segments on a graph is maximized when the absolute values of the orientations of the segments are centered on 45 degrees."

Source: Nina Zumel, 2009, Win-Vector Blog, Accessed at: http://www.win-vector.com/blog/2009/08/good-graphs-graphical-perception-and-data-visualization/

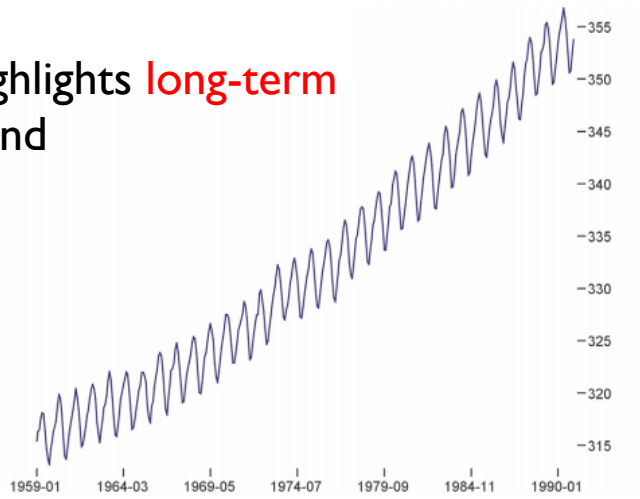
Aspect ratio: Width/Height

[Cleveland (1995), *Visualizing Data*]

Line Charts: Select an aspect ratio that banks to 45 degrees

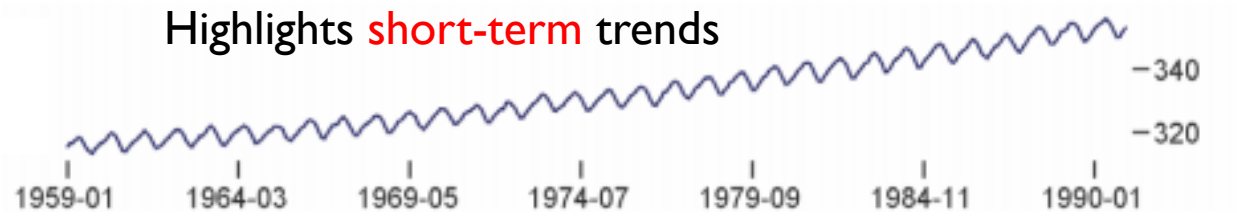
Aspect ratio = 1.17

Highlights long-term trend



Aspect ratio = 7.87

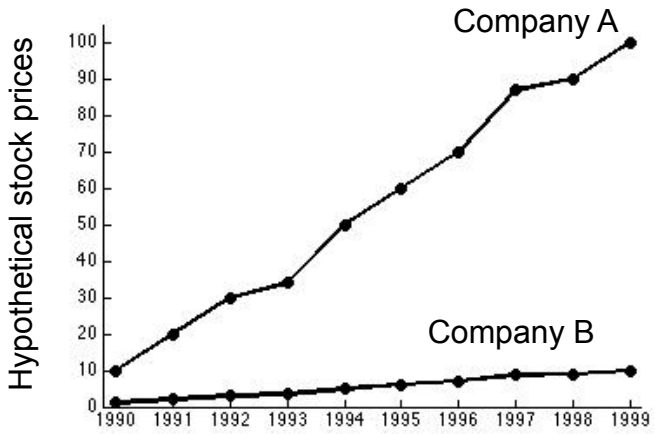
Highlights short-term trends



[Heer and Agrawala (2006), *IEEE Transactions on Visualization and Computer Graphics*]

Line Charts: Distinguish between different data series

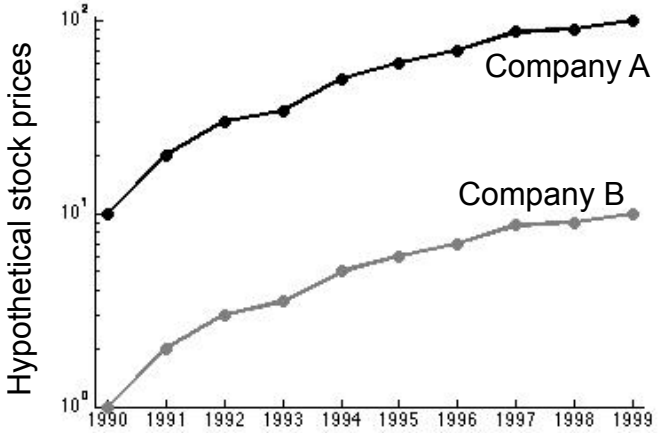
This includes both how the data is distinguished (color, line type) and considering the magnitudes of data

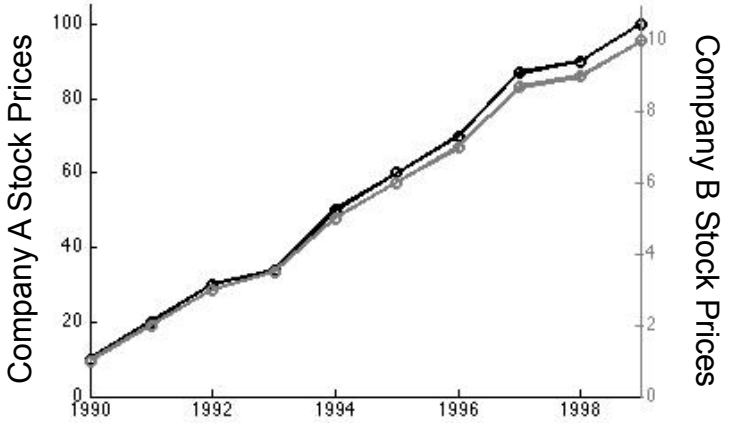


[Gary Klass, Illinois State, http://lilt.ilstu.edu/gmklass/pos138/datadisplay/sections/goodcharts.htm]

Line Charts: Distinguish between different data series

The y-axis can be transformed it is still difficult to see differences, you can use two scales



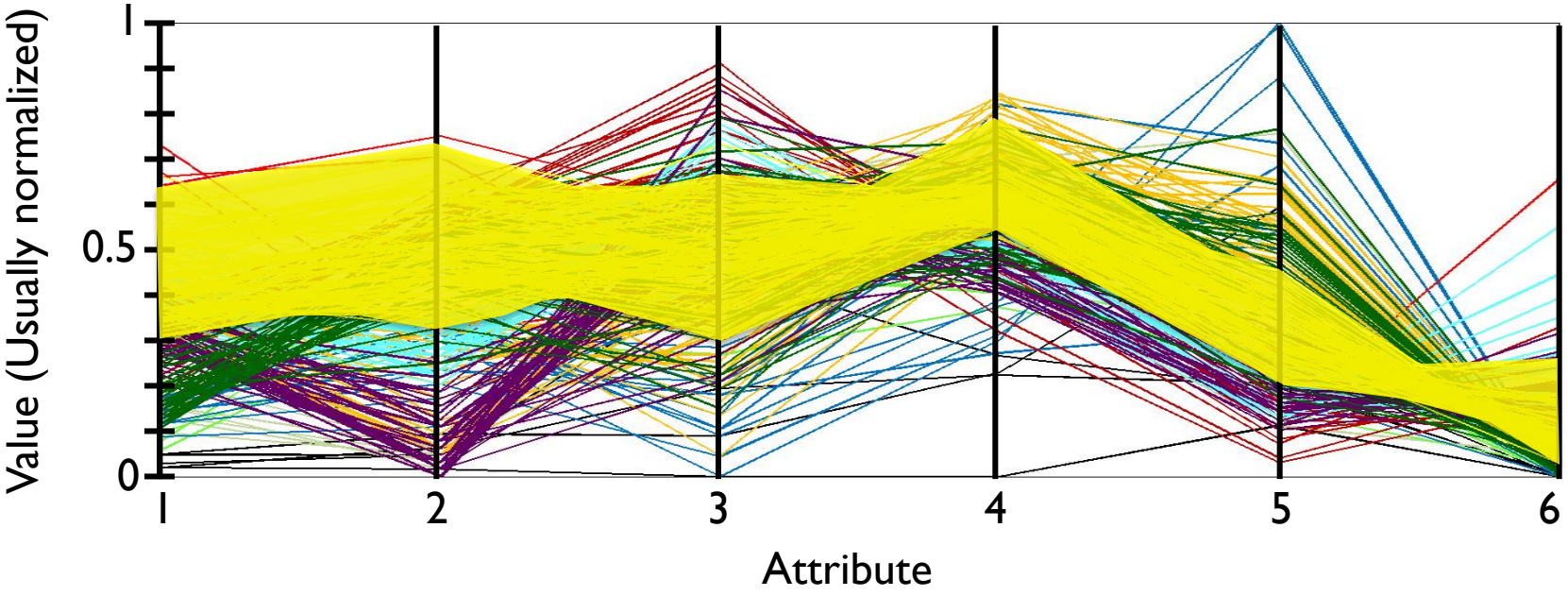


If it is still difficult to see differences, you can use two scales

[Gary Klass, Illinois State, http://lilt.ilstu.edu/gmklass/pos138/datadisplay/sections/goodcharts.htm]

Line Charts: Parallel coordinate plots

Parallel coordinate plots display attributes of a dataset across a range of entities

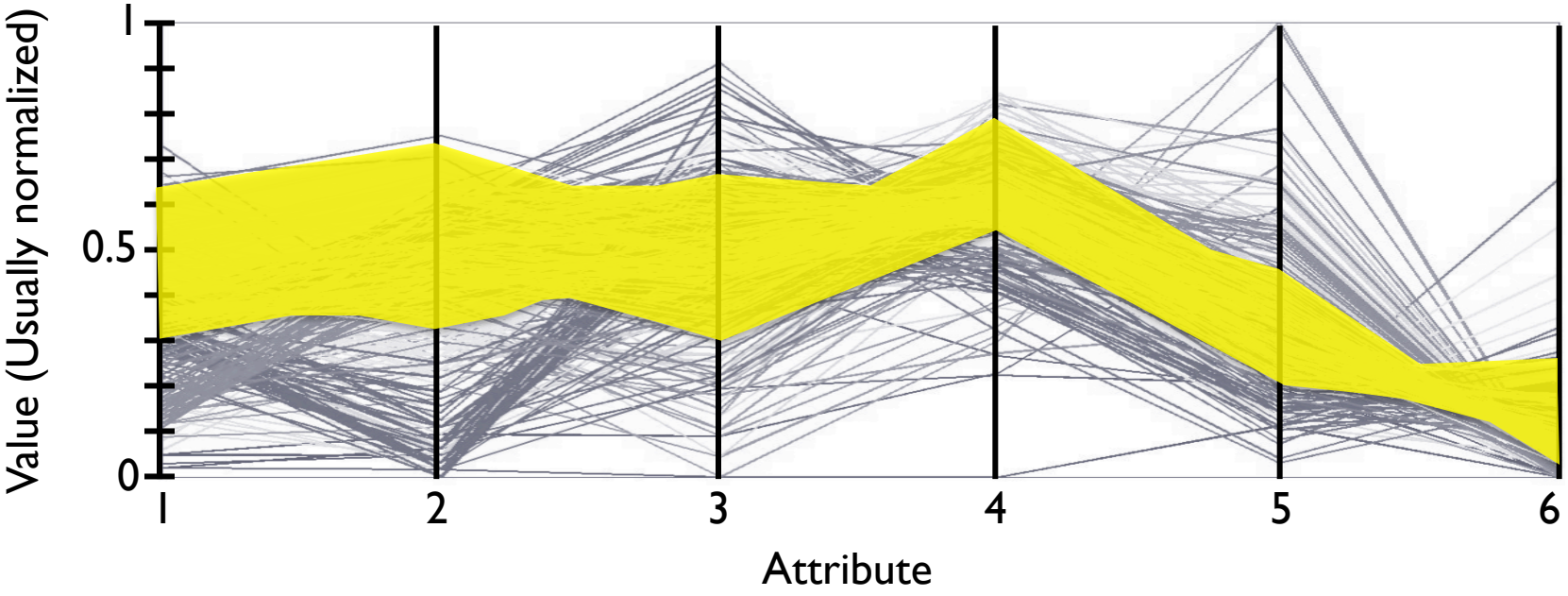


Each line represents an entity; color can be used to represent other information

[C. Kelleher and K. Sawicz]

Line Charts: Parallel coordinate plots

Parallel coordinate plots display attributes of a dataset across a range of entities

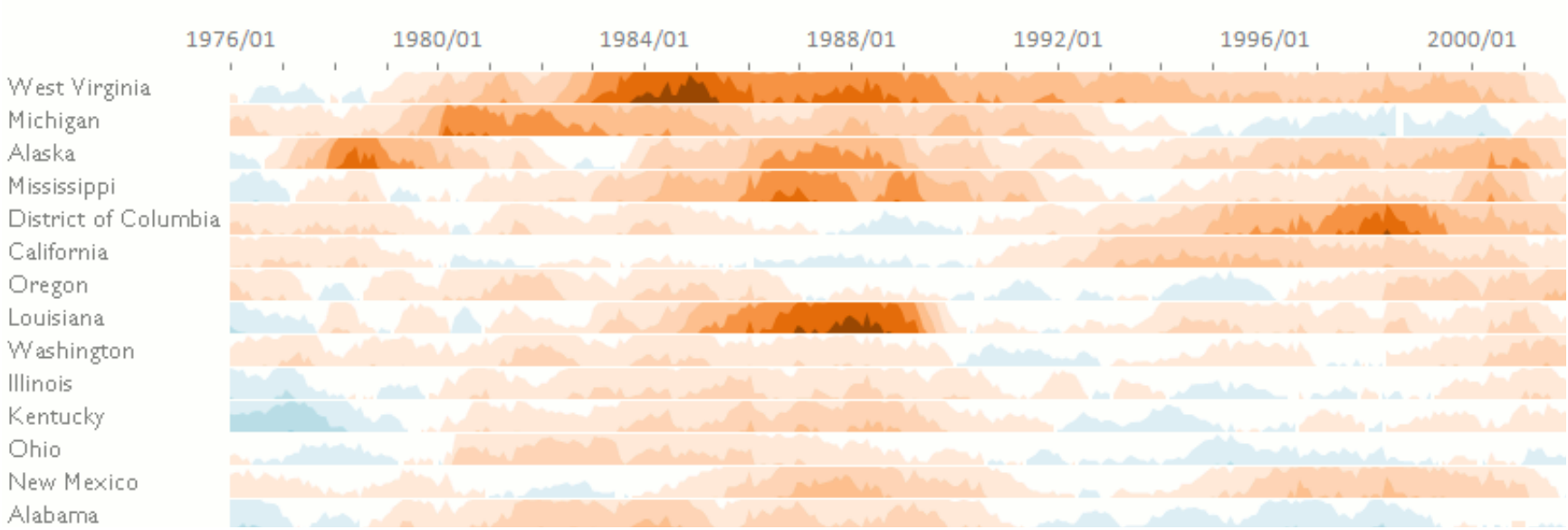


Each line represents an entity; color can be used to represent other information

[C. Kelleher and K. Sawicz]

Line Charts: Horizon graphs

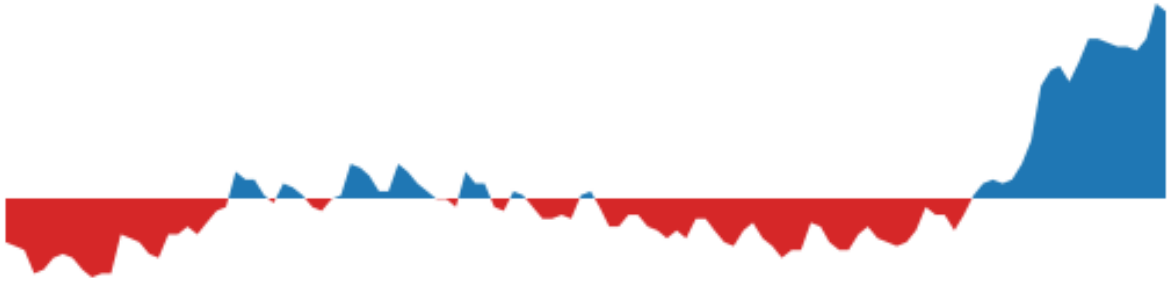
Horizon graphs display highs and lows across a large number of entities



Unemployment Rate: Differences to the National Average

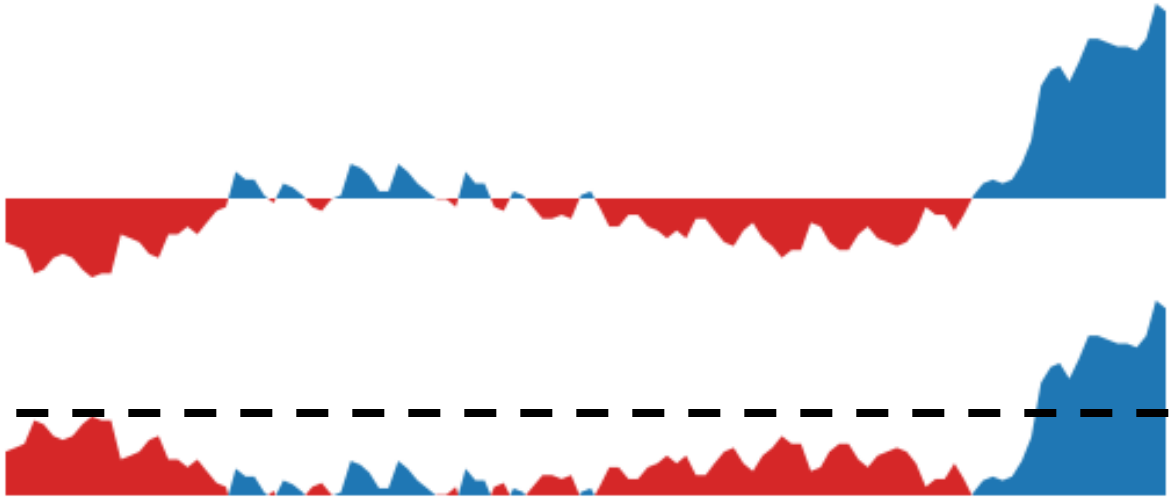
[ExcelCharts.com, accessed at http://charts4.excelcharts.com/blog/wp-content/uploads/2012/06/horizon-chart-unemployment-rate.png]

Line Charts: Horizon graphs



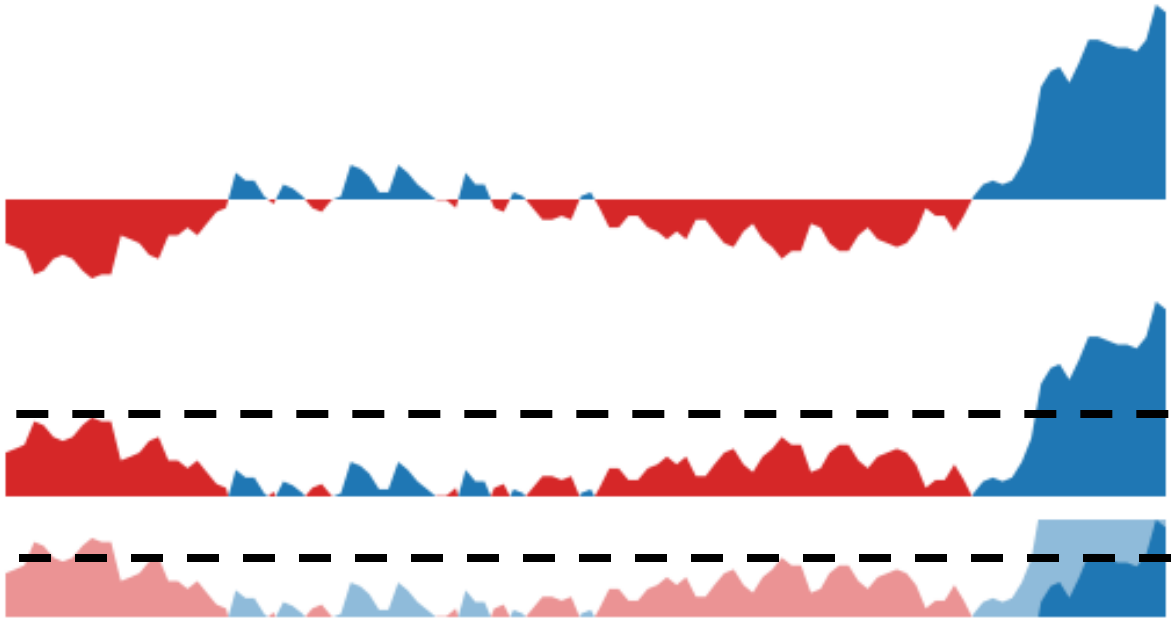
[Heer, Bostock, and Ogievetsky, A tour through the visualization zoo, accessed at: http://hci.stanford.edu/jheer/files/zoo/]

Line Charts: Horizon graphs



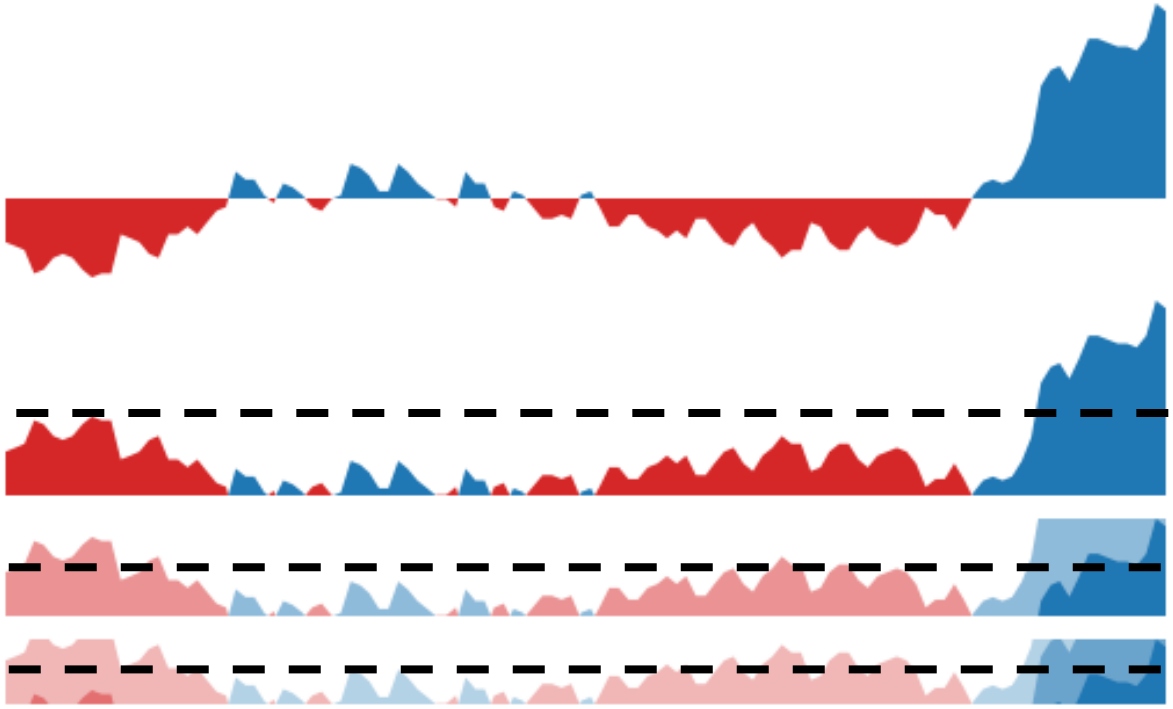
[Heer, Bostock, and Ogievetsky, A tour through the visualization zoo, accessed at: http://hci.stanford.edu/jheer/files/zoo/]

Line Charts: Horizon graphs



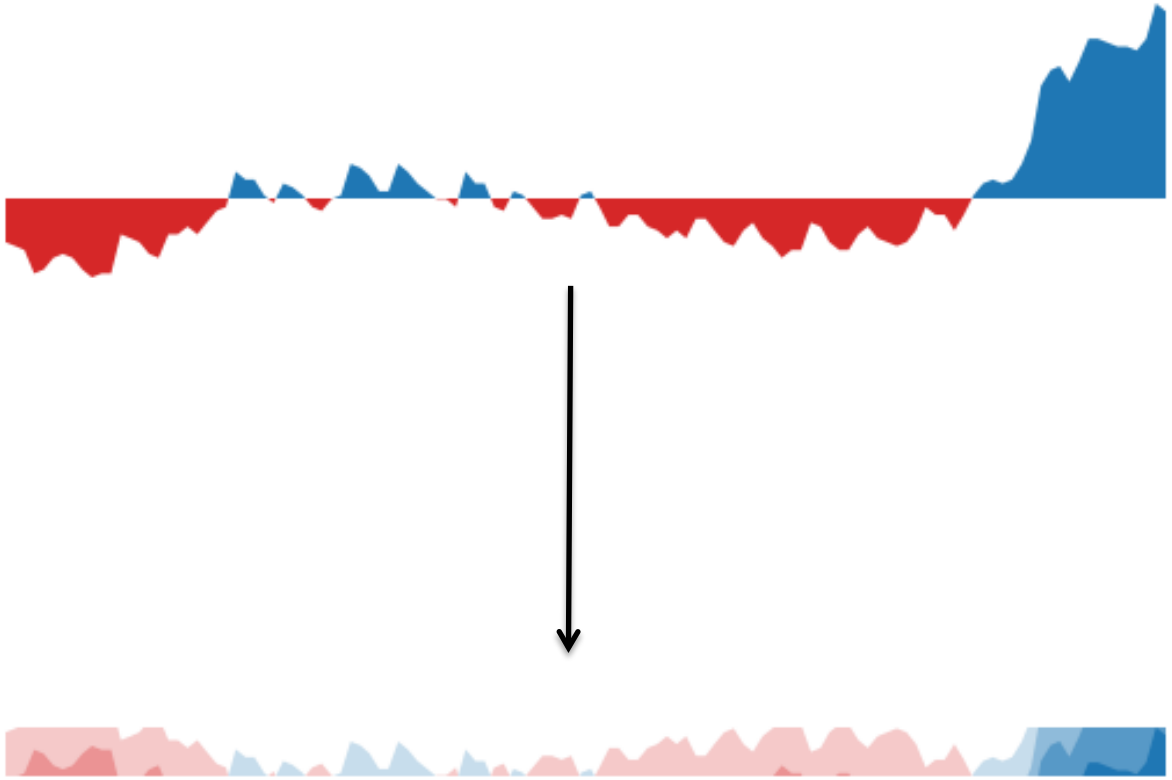
[Heer, Bostock, and Ogievetsky, A tour through the visualization zoo, accessed at: http://hci.stanford.edu/jheer/files/zoo/]

Line Charts: Horizon graphs



[Heer, Bostock, and Ogievetsky, A tour through the visualization zoo, accessed at: http://hci.stanford.edu/jheer/files/zoo/]

Line Charts: Horizon graphs



[Heer, Bostock, and Ogievetsky, A tour through the visualization zoo, accessed at: http://hci.stanford.edu/jheer/files/zoo/]

Scatterplots: Rules for effective use

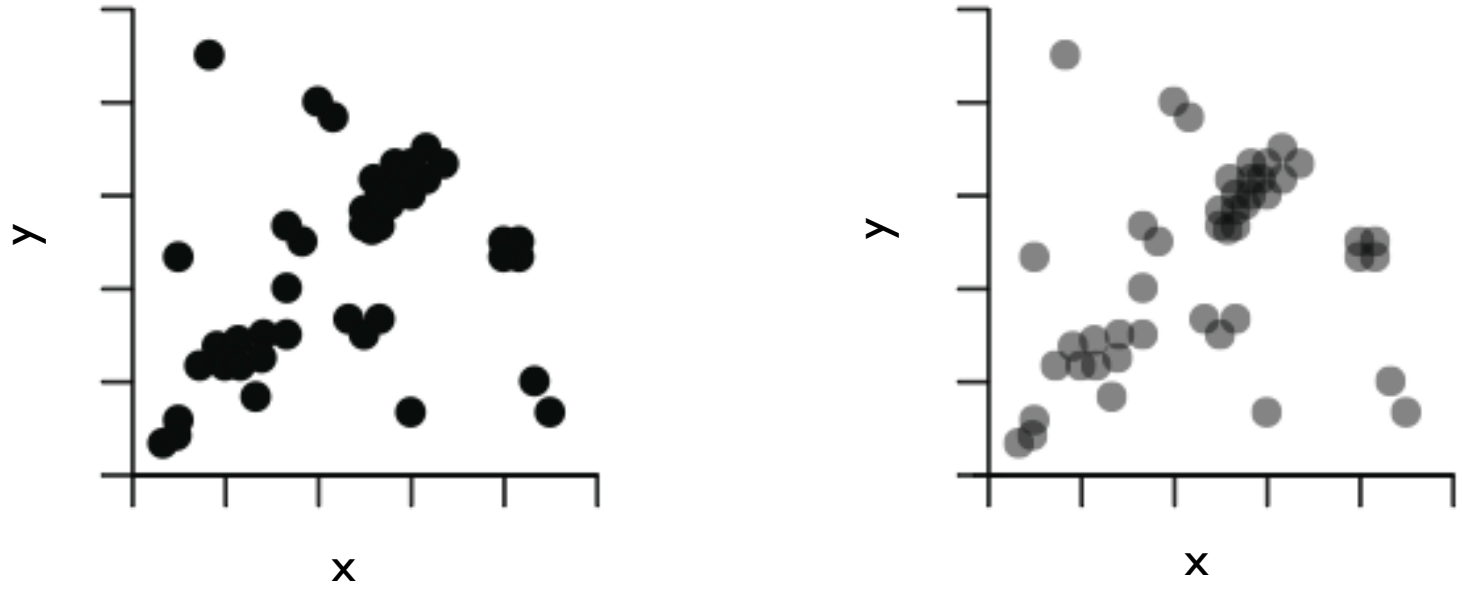
Use density to your advantage

If there is a causal relationship, the independent variable should be on the x-axis and the dependent variable should be on the y-axis

You can add a third dimension using color, shape, etc

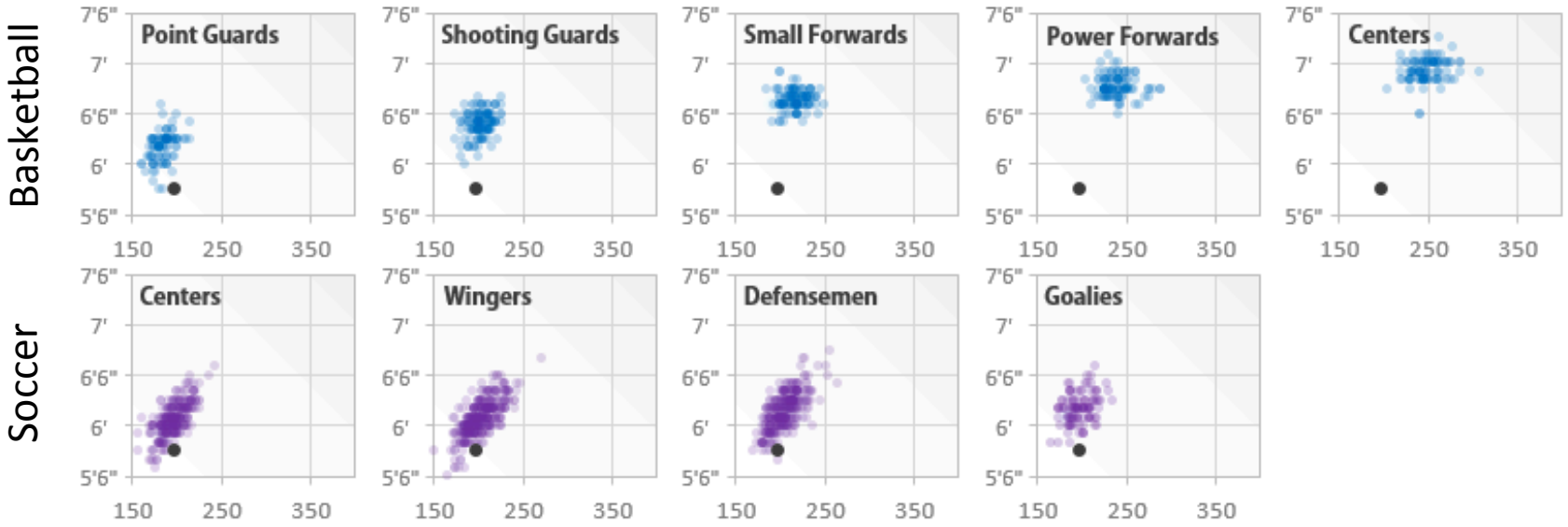
[Few, 2009; Gary Klass, Illinois State, http://lilt.ilstu.edu/gmklass/pos138/datadisplay/sections/goodcharts.htm]

Scatterplots: Use transparency to highlight density



Scatterplots: Use transparency to highlight density

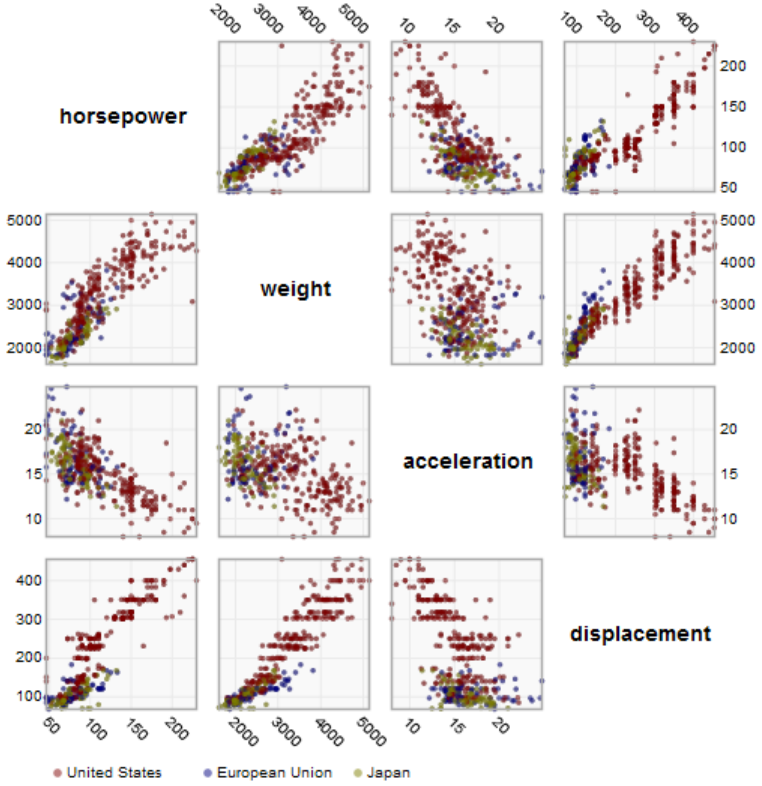
Height and weight distribution by position
(Grey dot represents average male)



Source: SportChart, http://sportchart.wordpress.com/2014/05/27/professional-athlete-size-comparison/

Scatterplots: Scatterplot matrices

Scatterplot matrices highlight relationships across data…

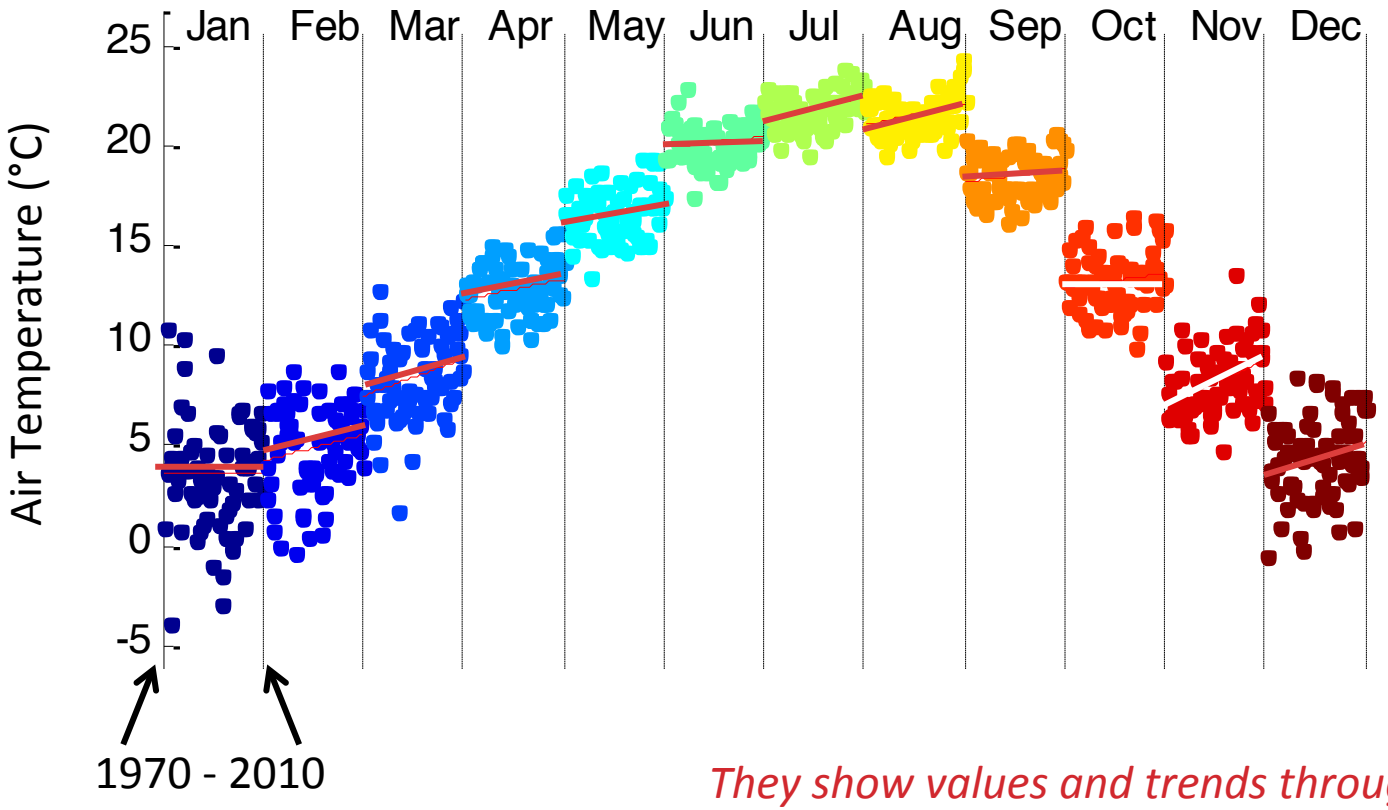


…color can be used to plot a third dimension

[Heer, Bostock, and Ogievetsky, A tour through the visualization zoo, accessed at: http://hci.stanford.edu/jheer/files/zoo/]

Scatterplots: Cycle plots

Cycle plots are a combination of points and line graph information

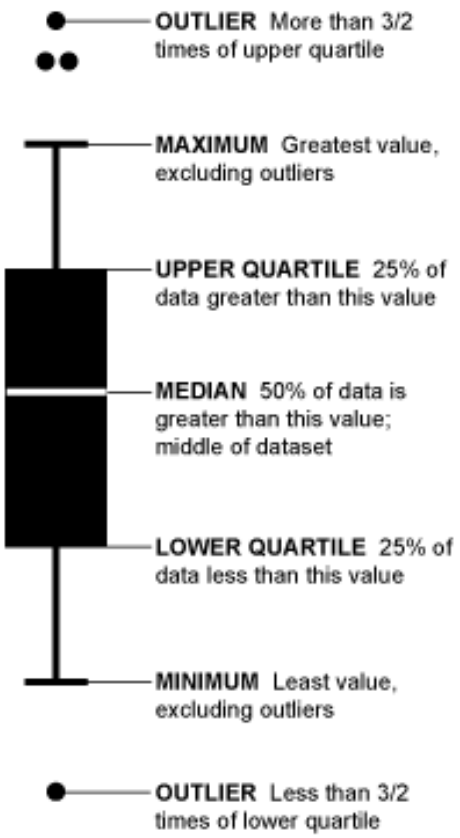


They show values and trends through time

[C. Kelleher]

Frequency plots:

Box-and-whisker plots



(1) Overall distribution

(2) Outliers

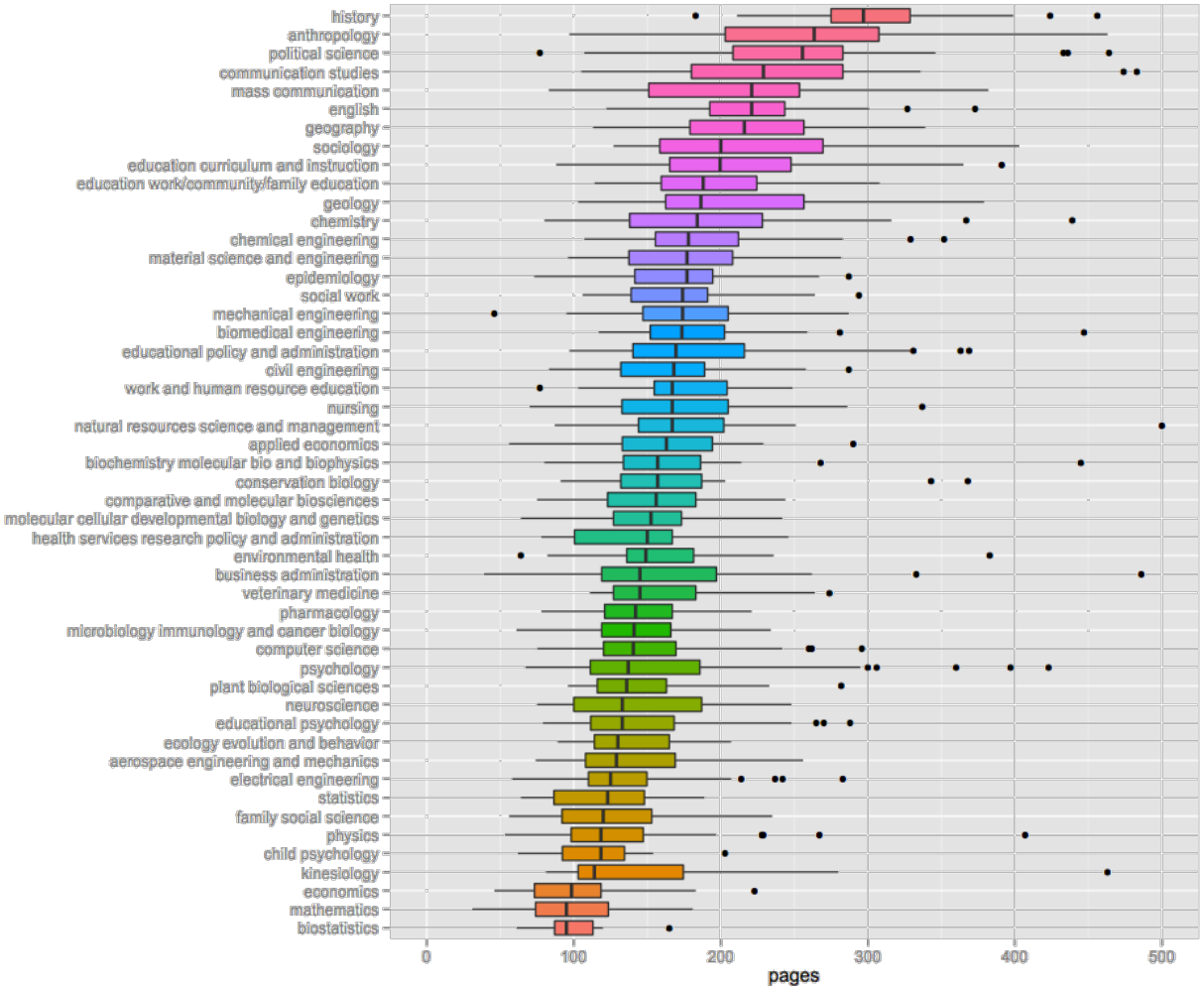
(3) Skew (difference between quartiles and median)

[Flowing data, http://flowingdata.com/2008/02/15/how-to-read-and-use-a-box-and-whisker-plot/]

Frequency plots:

Box-and-whisker plots

How long is the average dissertation?



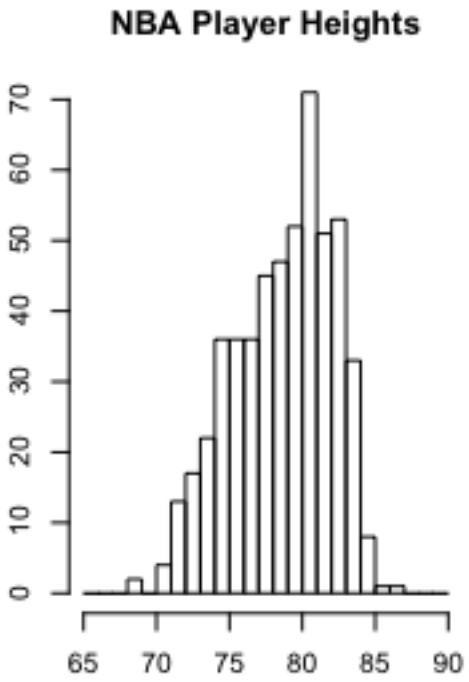
Source: http://beckmw.wordpress.com/2013/04/15/how-long-is-the-average-dissertation/

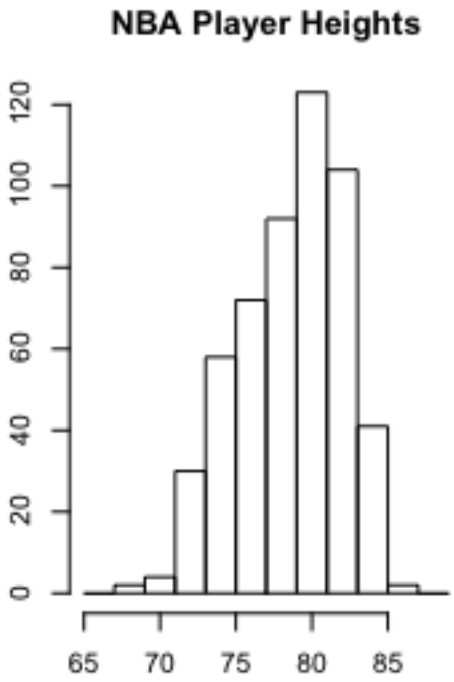
Frequency plots:

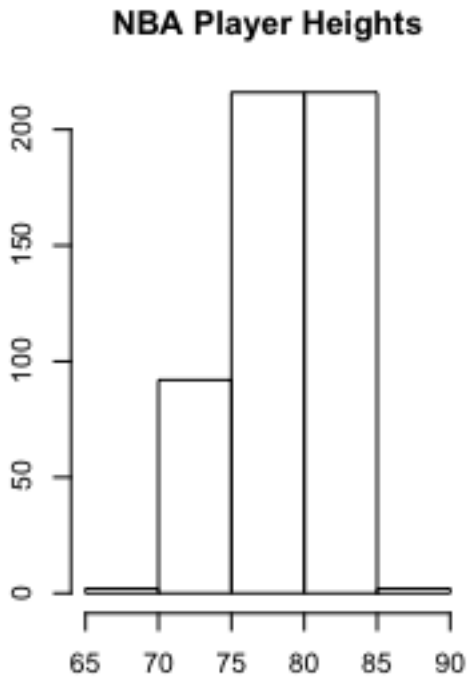
Histograms and kernel density estimators

Rule of thumb for the number of bins depends on number of data values, n:

bins = √n



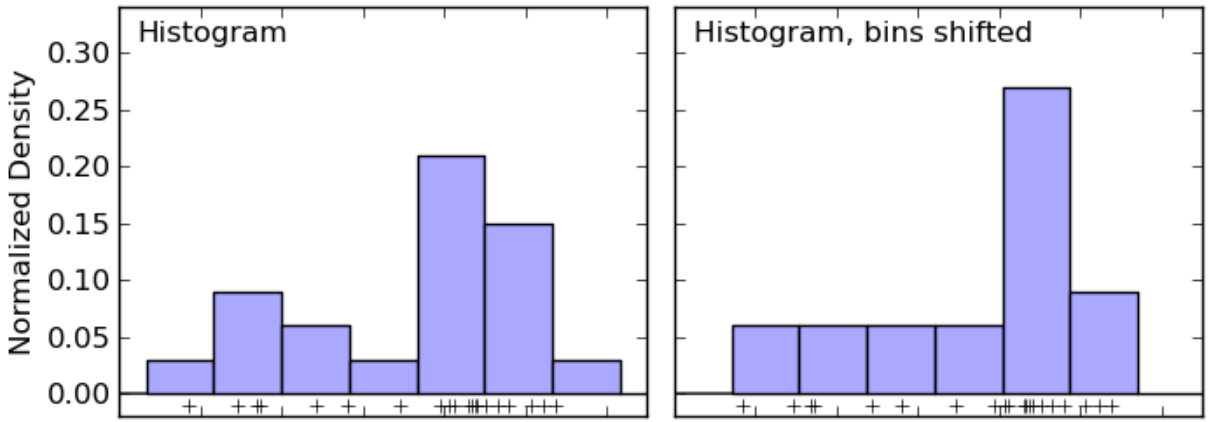




[Flowing data, http://flowingdata.com/2014/02/27/how-to-read-histograms-and-use-them-in-r/]

Frequency plots:

Histograms and kernel density estimators



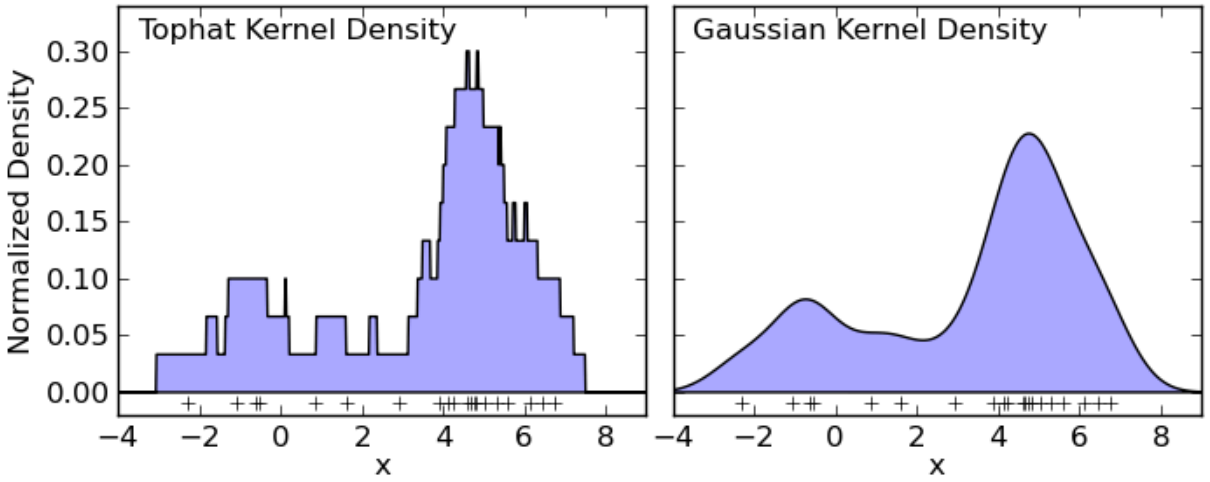
Histograms are very sensitive to how you define your bins (size and interval)

[SciKit, http://scikit-learn.org/stable/modules/density.html]

Frequency plots:

Histograms and kernel density estimators

Kernel density estimators produce a non-parametric probability density function of a random variable



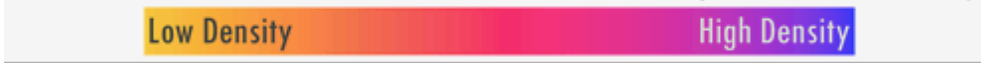
-Smooth
-Have no end points
-Depend on bandwidth and kernel

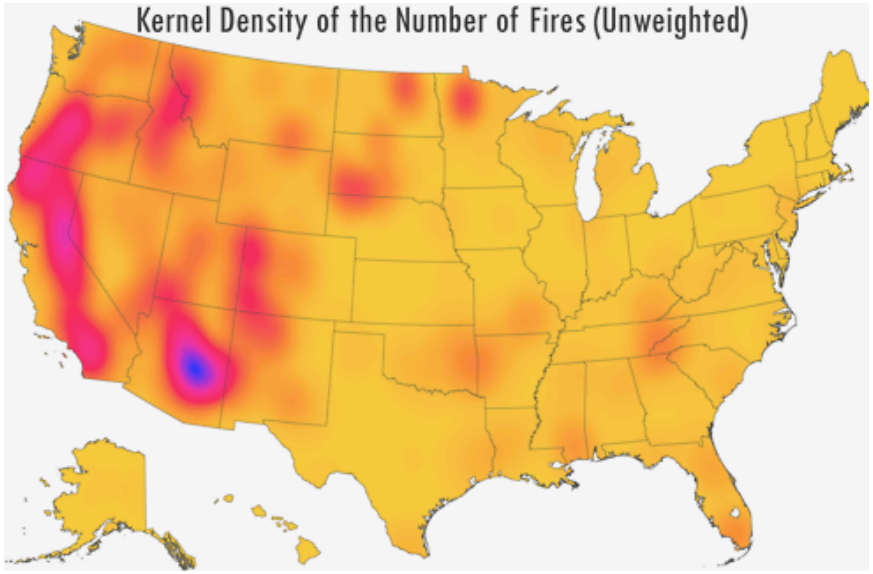
[SciKit, http://scikit-learn.org/stable/modules/density.html]

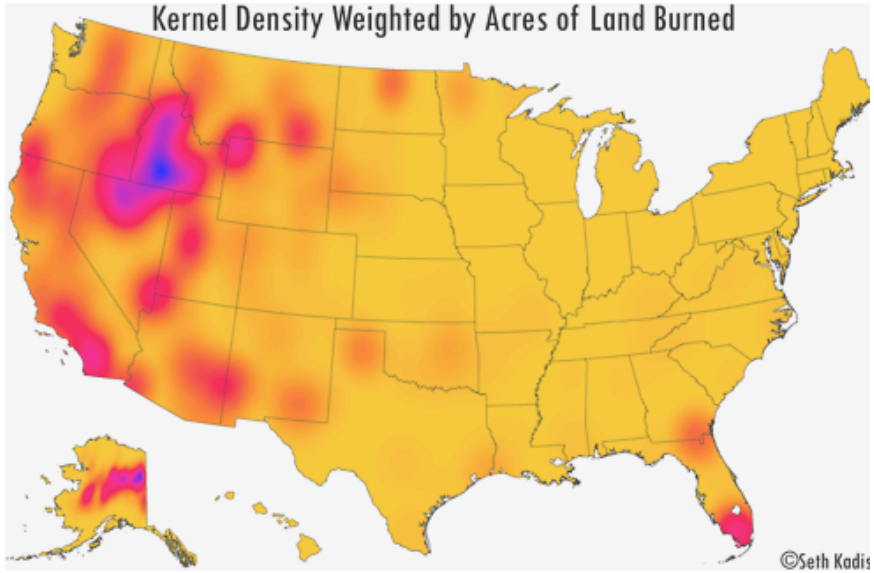
Frequency plots:

Histograms and kernel density estimators

Federal wildfire occurrences (1980-2012)







Unweighted: purple indicates more occurrences

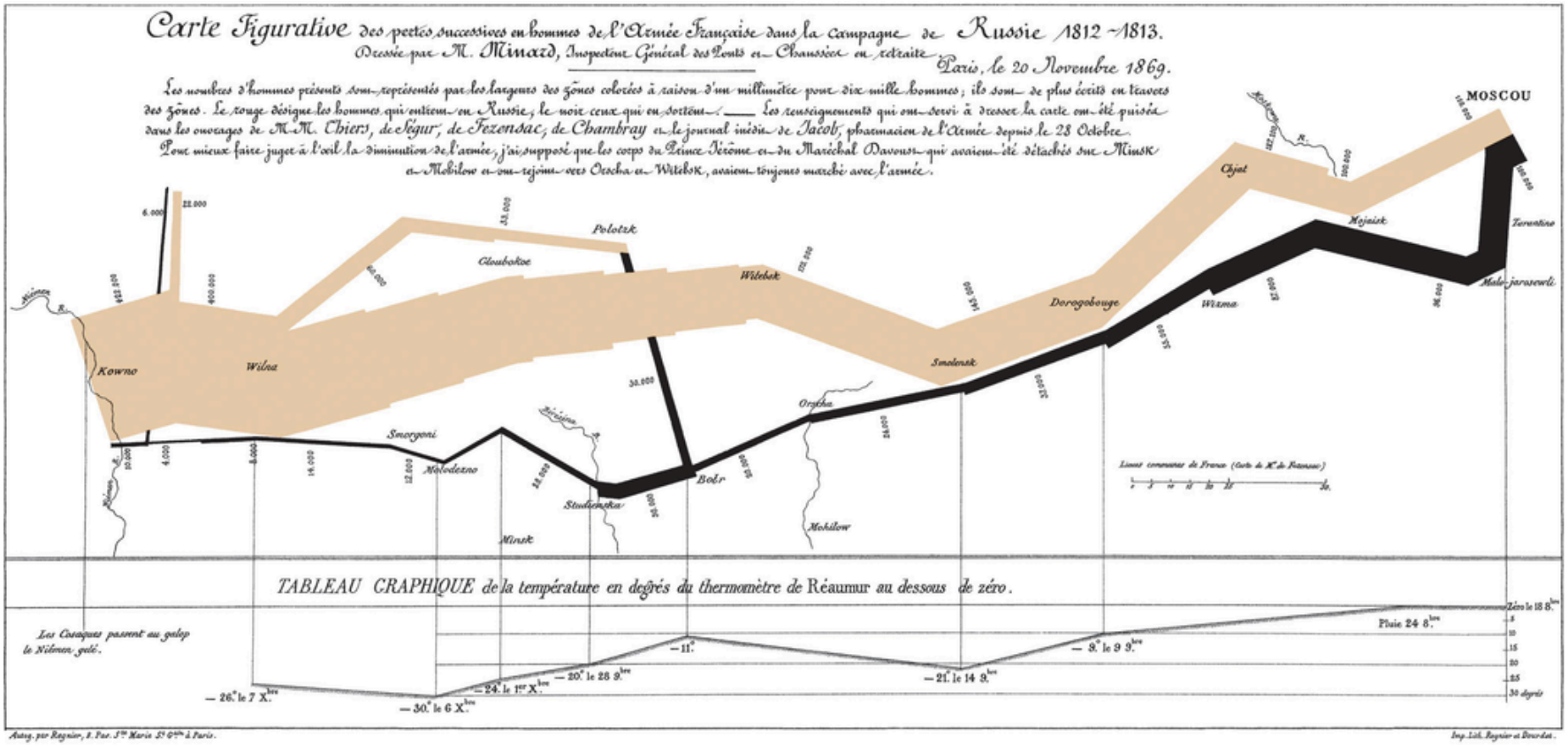
Weighted, number of acres burned for each fire: purple indicates geographically widespread fires

Data source: USGS, http://wildfire.cr.usgs.gov/firehistory/data.html
Creator/author: Seth Kadish
Visualization: http://vizual-statistix.tumblr.com/post/85819638606/the-usgs-offers-data-on-more-than-20-years-of

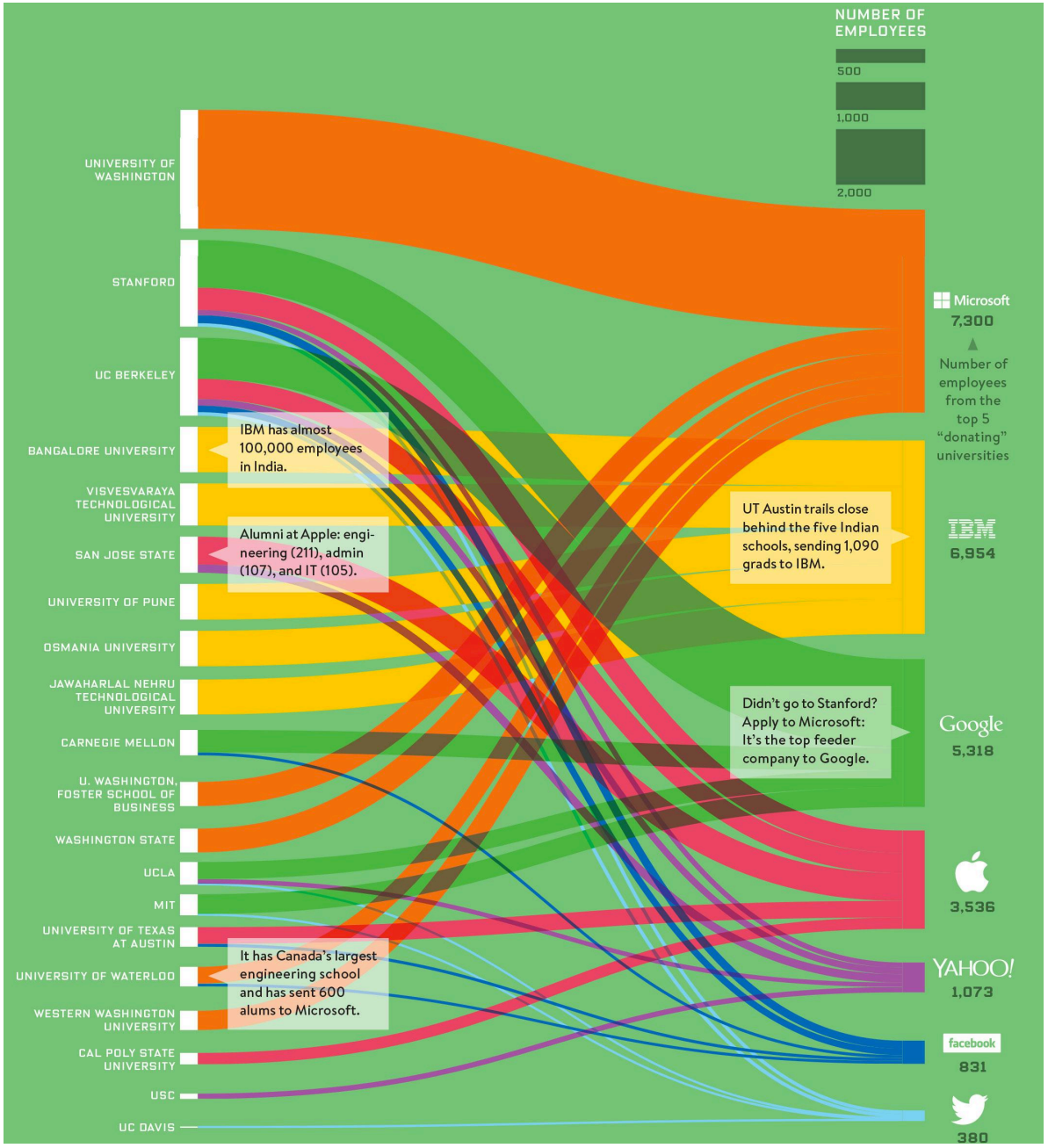
Cool graphics: Sankey diagrams

A flow diagram where arrow width is proportional to the quantity of material flow

A classic used by Edward Tufte: Minard's diagram of Napoleon's march on Moscow

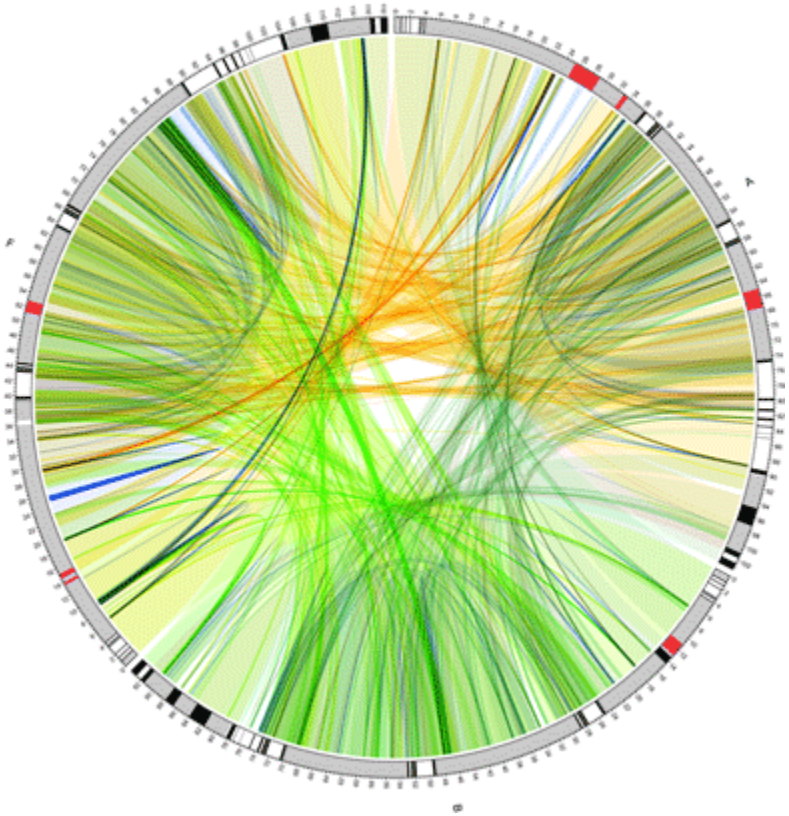


Source: http://en.wikipedia.org/wiki/Sankey_diagram



Source: Luca Masud and Brittney Everett, Wired, http://www.wired.com/2014/05/alumni-network-2/

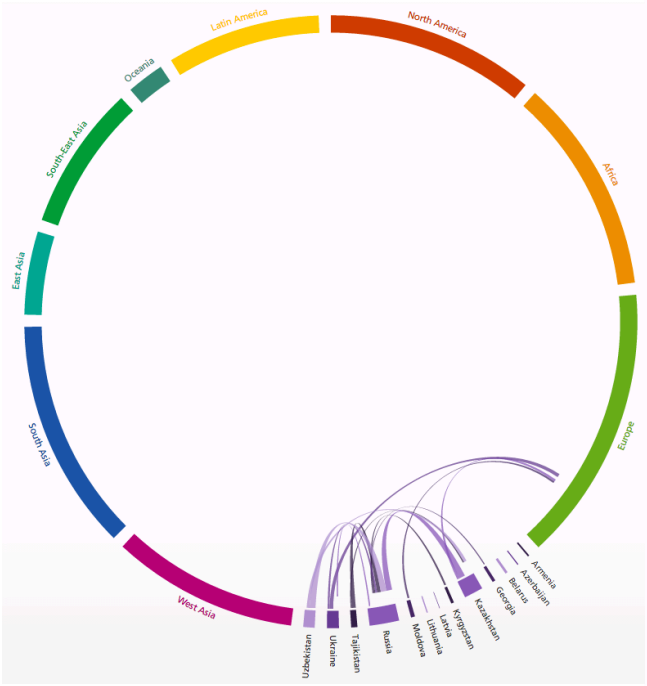
Circos plots



Circos Plots (http://circos.ca/)

http://circos.ca/intro/general_data/

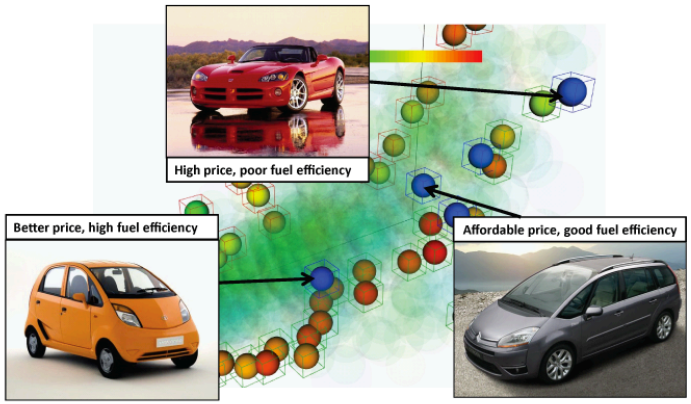
The global flow of people

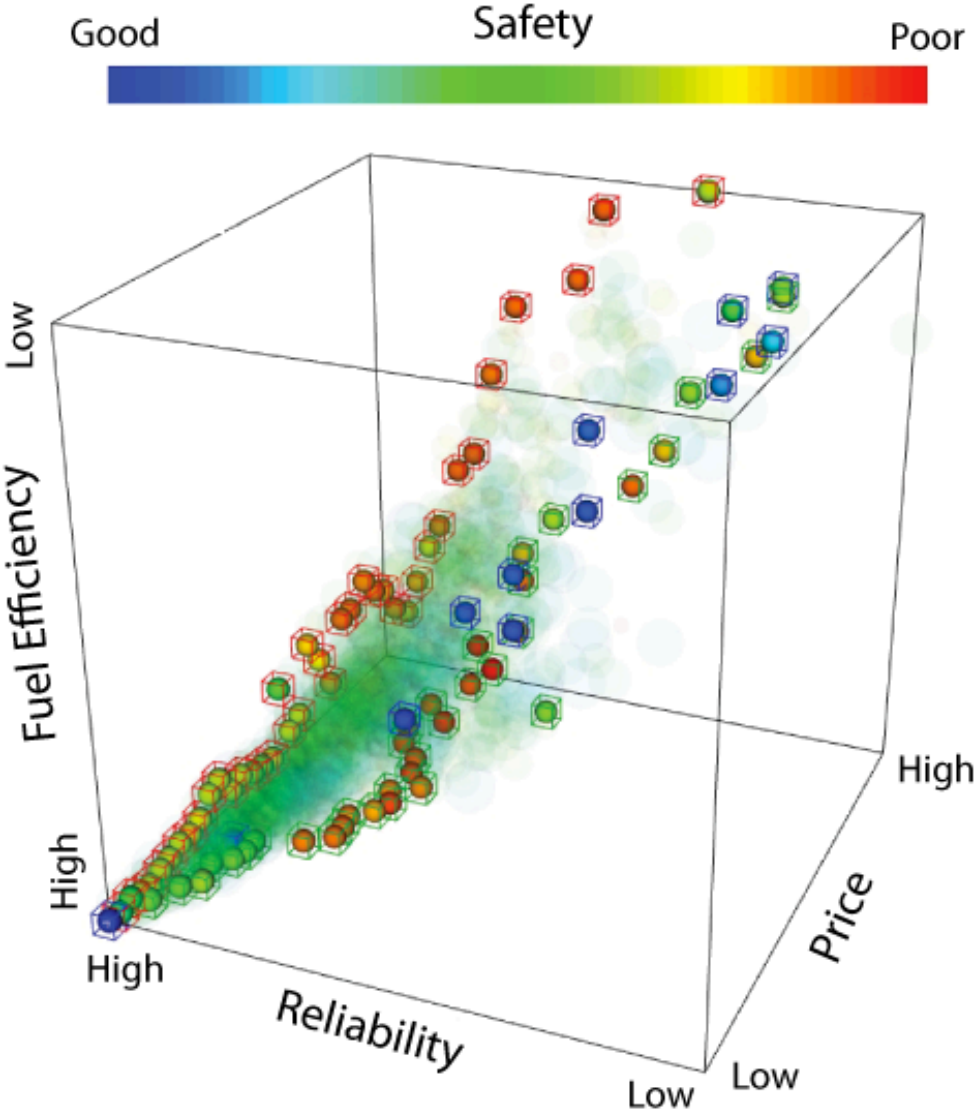


Souce: Circos, http://circos.ca/intro/general_data/; http://www.global-migration.info/

Cool graphics

AeroVis

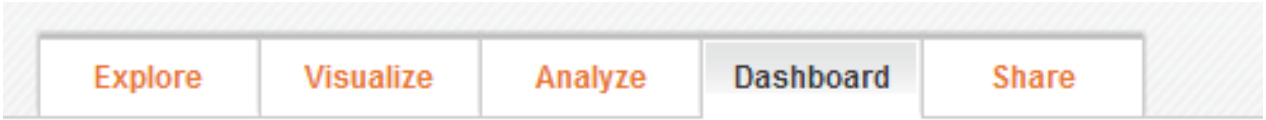


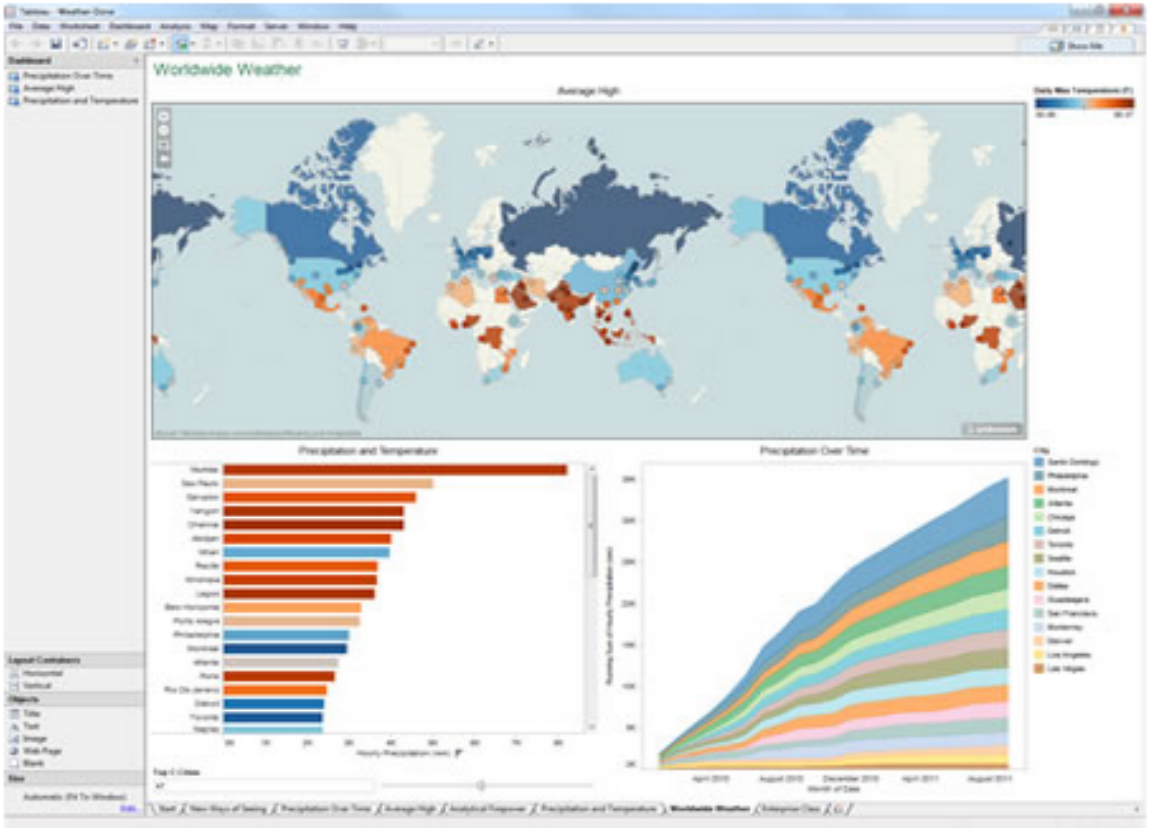


DecisionVis, https://www.decisionvis.com/;

Try it yourself!

Tableau, http://www.tableausoftware.com/



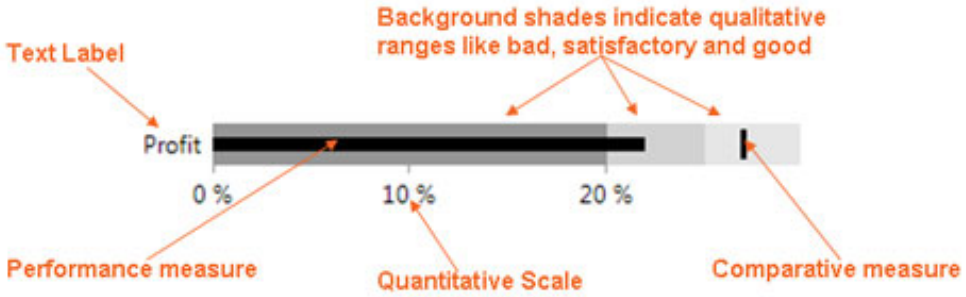


Try it yourself!

Panopticon, http://www.panopticon.com/

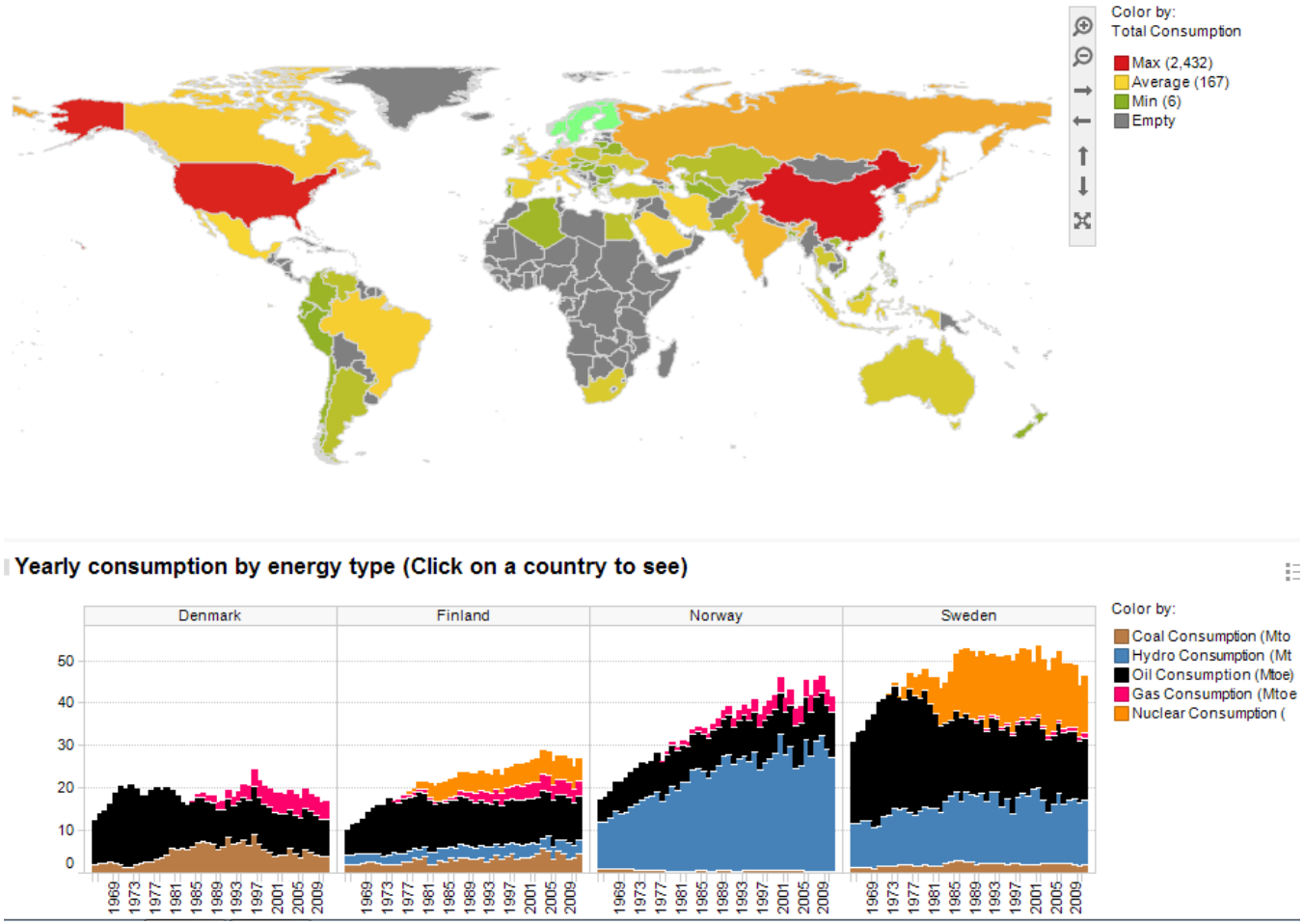
See your KPI's — updated in real time!

As with all of our information visualizations, our Bullet Graphs are real-time — they respond instantly to changes in the underlying data. You can feed them with any combination of historical data, calculated results and/or real-time data streams from message queues or other sources.



Try it yourself!

Spotfire, http://spotfire.tibco.com/



http://spotfire.tibco.com/en/demos/world-energy-survey.aspx

Resources

How can you develop your own visualization products?

Open Source:

R http://cran.r-project.org/
Help: http://rforcats.net/

Python https://www.python.org/
Help: http://learnpythonthehardway.org/

D3 JS http://d3js.org/
Help: https://www.dashingd3js.com/table-of-contents

Inkscape http://inkscape.org/en/

Academic resources:
http://colorbrewer2.org
http://reed.cee.cornell.edu/index.php/Resources
http://idl.cs.washington.edu/

Visualization fun: Tableau public, Gapminder desktop, Google public data, Stat silk

Resources

If you're interested in data visualization

FlowingData.com

reddit.com/r/dataisbeautiful

www.informationisbeautiful.net/

visual.ly/

www-958.ibm.com/software/analytics/manyeyes/

www.visualcomplexity.com/vc/

chartporn.org/

www.visualizing.org/

Edward Tufte

Hans Rossling

Stephen Few

Nathan Yau

References (this and more)

W. Cleveland (1995), *Visualizing Data*, Hobart Press, 360 pp.

T. Bray (2003), DI Ratio and the Ratio Family, Example 1, accessed at: http://www.tbray.org/ongoing/data-ink/di1.

ExcelCharts.com, The Horizon Graph Is a Reorderable Matrix Too: Unemployment Rate 1976-2012, accessed at: http://charts4.excelcharts.com/blog/wp-content/uploads/2012/06/horizon-chart-unemployment-rate.png.

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Software:

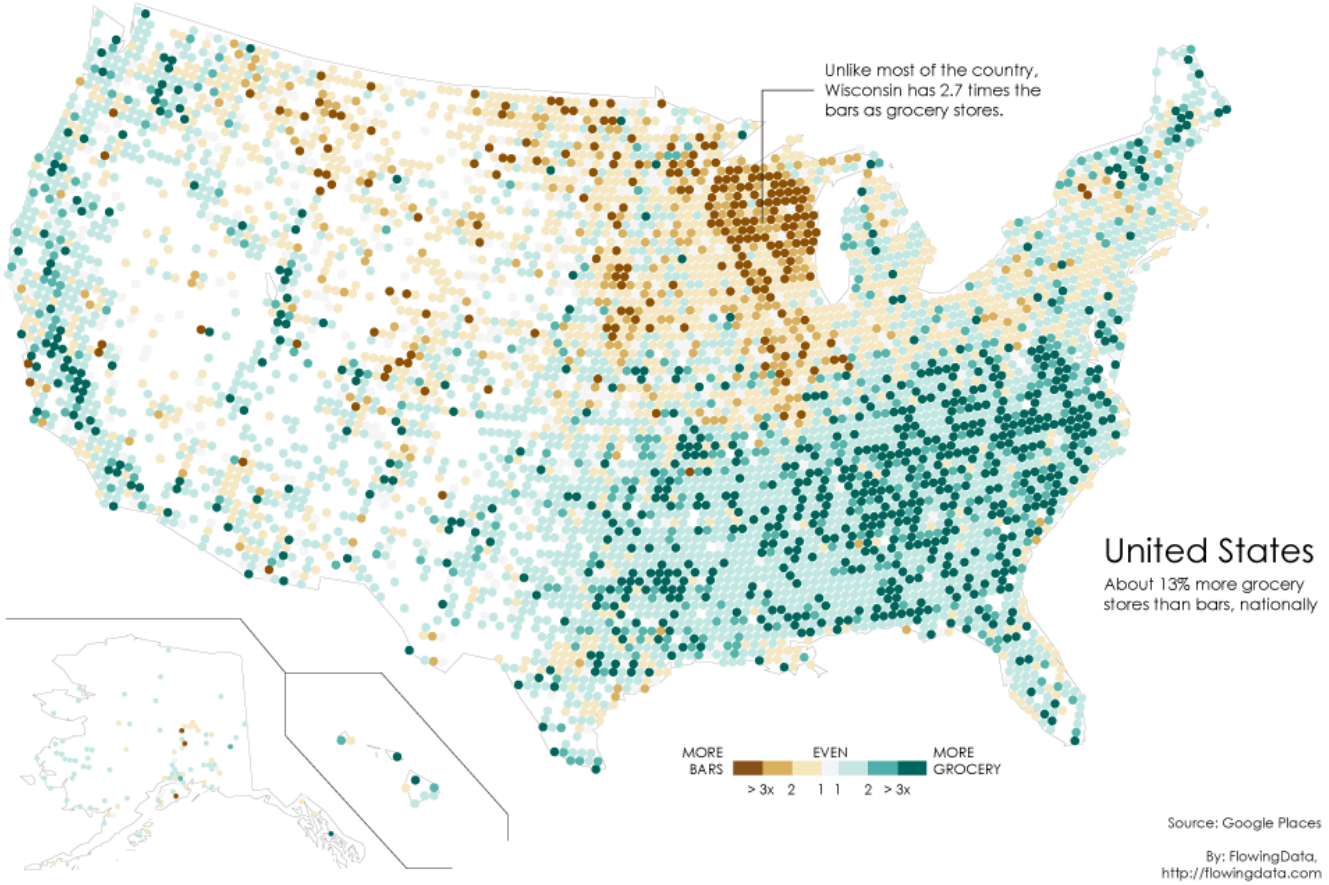
Circos, http://circos.ca/intro/general_data.

Tableau, http://www.tableausoftware.com/.

Panopticon, http://www.panopticon.com.

Spotfire, http://spotfire.tibco.com/.

Thanks to:



[Flowing Data, http://flowingdata.com/2014/05/29/bars-versus-grocery-stores-around-the-world/]

EXTRA SLIDES

Resources

How can you develop your own visualization products?

Proprietary:

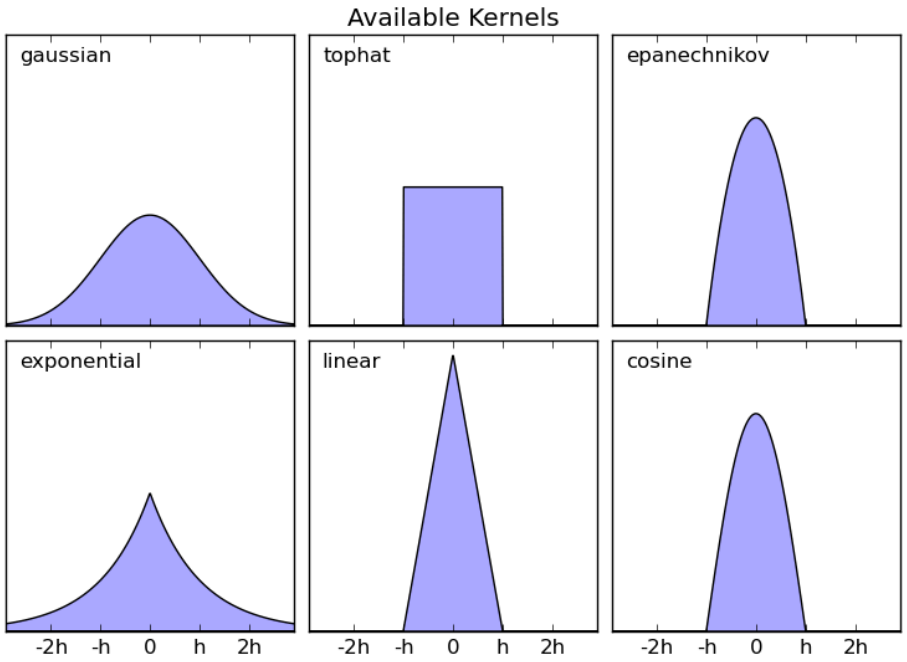
Statistical:
Minitab
Sigma plot
SAS
Matlab

Visualization only:
Spotfire
Tableau
Panopticon
ArcGIS (spatial)
JMP

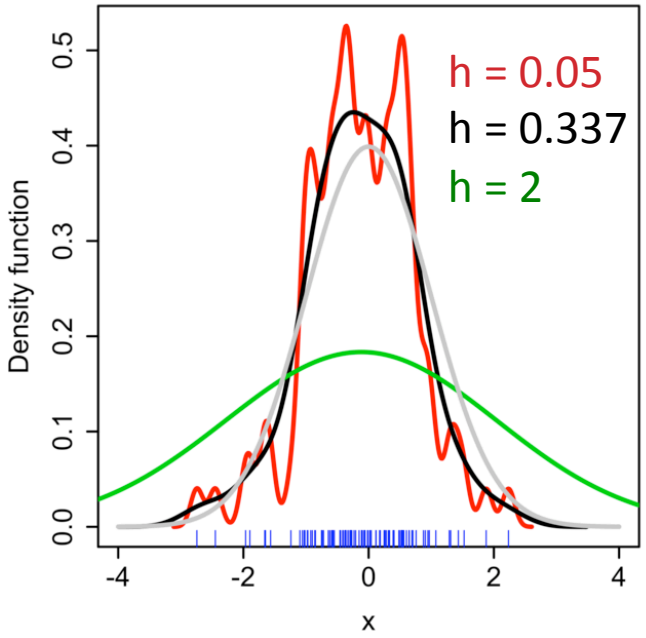
Frequency plots:

Histograms and kernel density estimators

The kernel is a symmetric function that integrates to one



The bandwidth is a free parameter and greatly controls the shape of the kernel density estimate



[SciKit, http://scikit-learn.org/stable/modules/density.html; Wikipedia, http://en.wikipedia.org/wiki/Kernel_density_estimation]

Rules for effective use

Use an accurate classification scheme for your data (don't lie!)

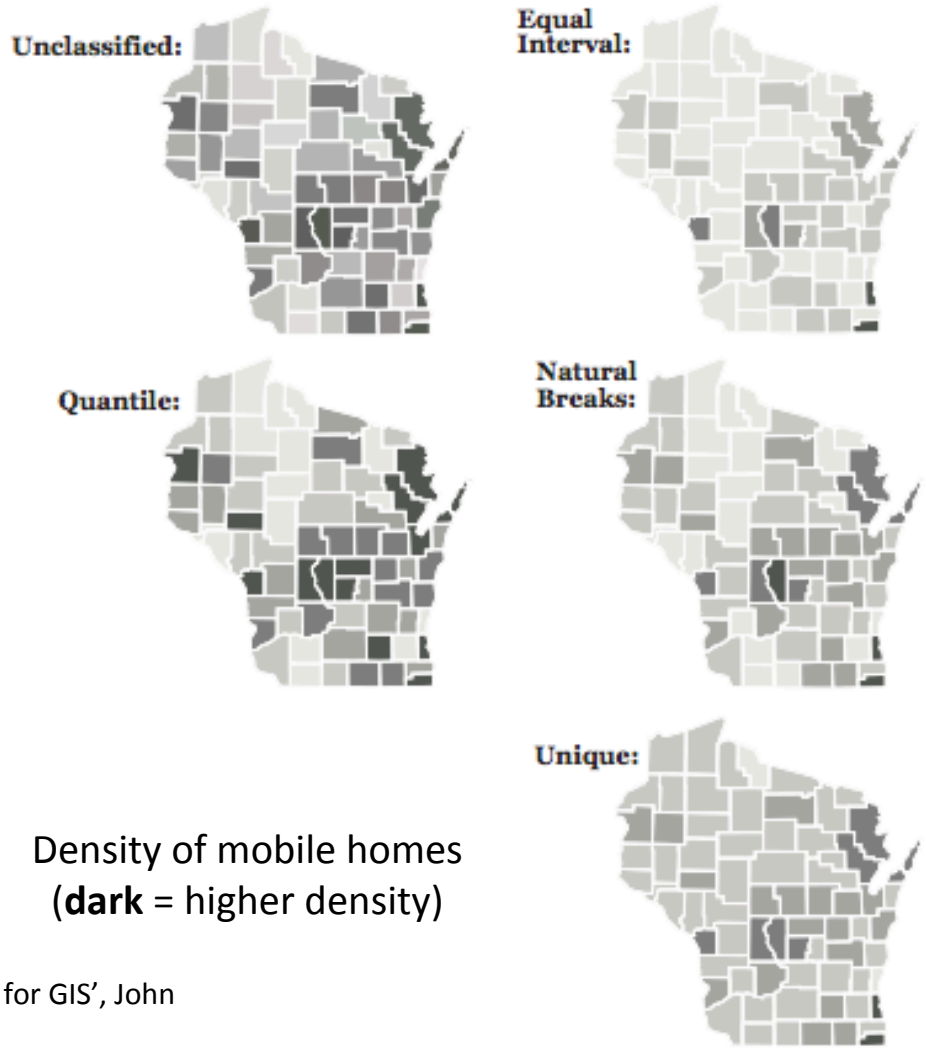
Use intuitive labeling

Map symbols should be intuitive and well distinguished

Highlight visual differences

Scale bars and data classification

Where boundaries are placed between classes can change the graph's meaning

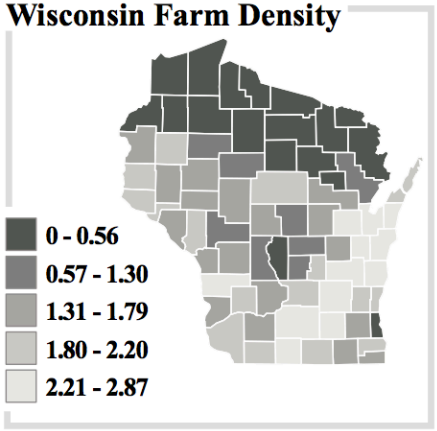


Density of mobile homes
(**dark** = higher density)

['Making Maps: A Visual Guide to Map Design for GIS', John Krygier and Denis Wood, 2005]

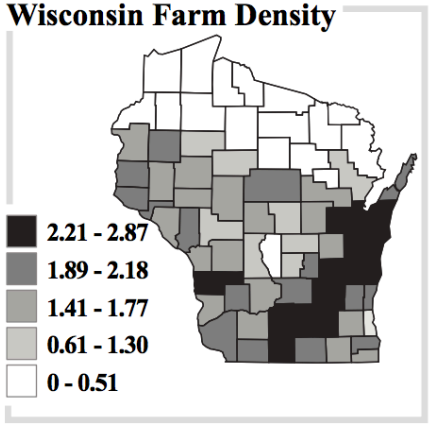
Use intuitive labeling

Poor value & legend:



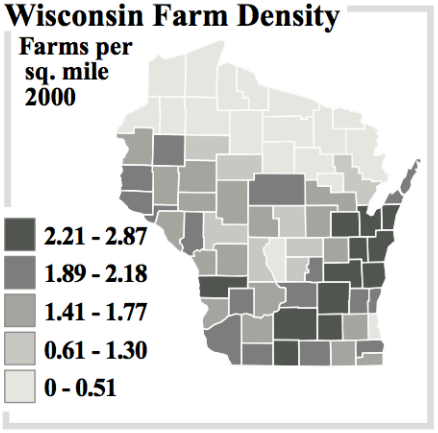
✓ dark means less is not intuitive.
✓ smaller values at *top* of legend are not intuitive.

Poor value & boundaries:



✓ black blends with boundaries.
✓ white suggests no data.
✓ boundaries stand out too much.

Good value & legend & boundaries:



✓ dark means more to most people.
✓ non-continuous legend, with larger values at the top and a title which explains the numbers in the legend.
✓ overall smoother feel without black and white in addition to removing the problems they cause.
✓ boundaries less dominant but distinct.

['Making Maps: A Visual Guide to Map Design for GIS', John Krygier and Denis Wood, 2005]

Map symbols should be intuitive and well distinguished

Feature Type	Visual Variable		
	Shape	Orientation	Color Hue
Point	Spring House Tower	Live Tree Dead Tree	Live Tree Dead Tree
Line	National Border Trail Section Line	Asphalt Road Concrete Road	National Border State Border
Area	Gravel Sand	Orchard Field Crop	Land Water

Hue, shape, orientation

Feature Type	Visual Variable			
	Size	Pattern Texture	Color Lightness	Color Saturation
Point	Small → Large Low → High	Coarse → Fine Low → High	Light → Dark Low → High	Pale → Intense Low → High
Line	Medium Low High	Medium Low High	Medium Low High	Medium Low High
Area	High Medium Low	Medium High Low	Medium High Low	Medium High Low

Shape, color, saturation

[ESRI, http://www.esri.com/news/arcuser/0911/making-a-map-meaningful.html]

Spatial graphics

Map symbols should be intuitive and well distinguished

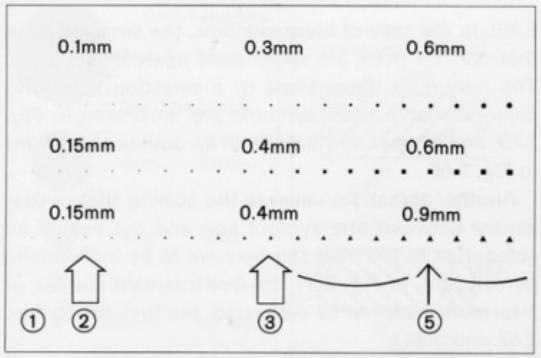


Fig. 2.40 The perception of point symbols (2), and the differentiation of their shapes (3)

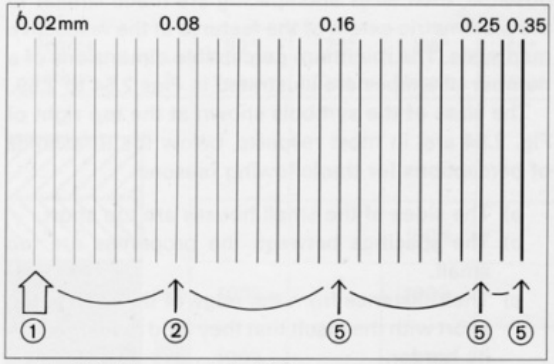


Fig. 2.42 Line symbols: (1) line perceptible, (5) widths sufficiently different to be distinguishable

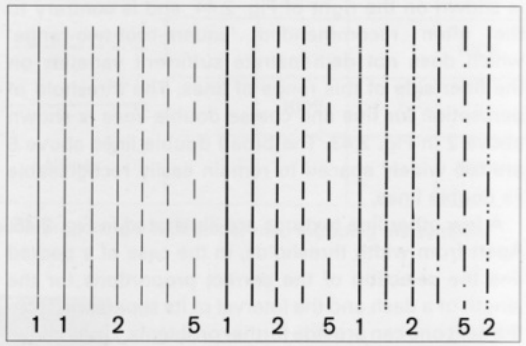


Fig. 2.45 Pecked lines with too small an interval between solid elements (1), recommended (2), too large an interval (5)

[MAKINGMAPS.NET, http://makingmaps.net/2007/09/07/map-symbols-thresholds-of-perception-part-1/]

Spatial graphics

Map symbols should be intuitive and well distinguished

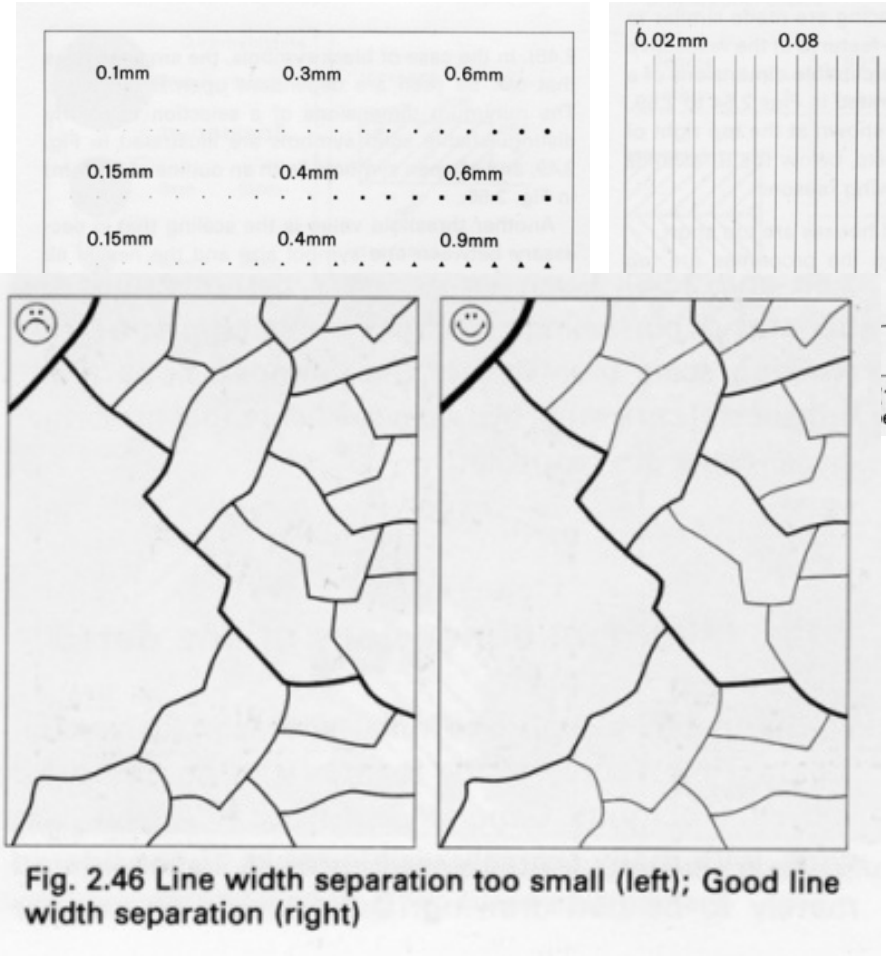


Fig. 2.46 Line width separation too small (left); Good line width separation (right)

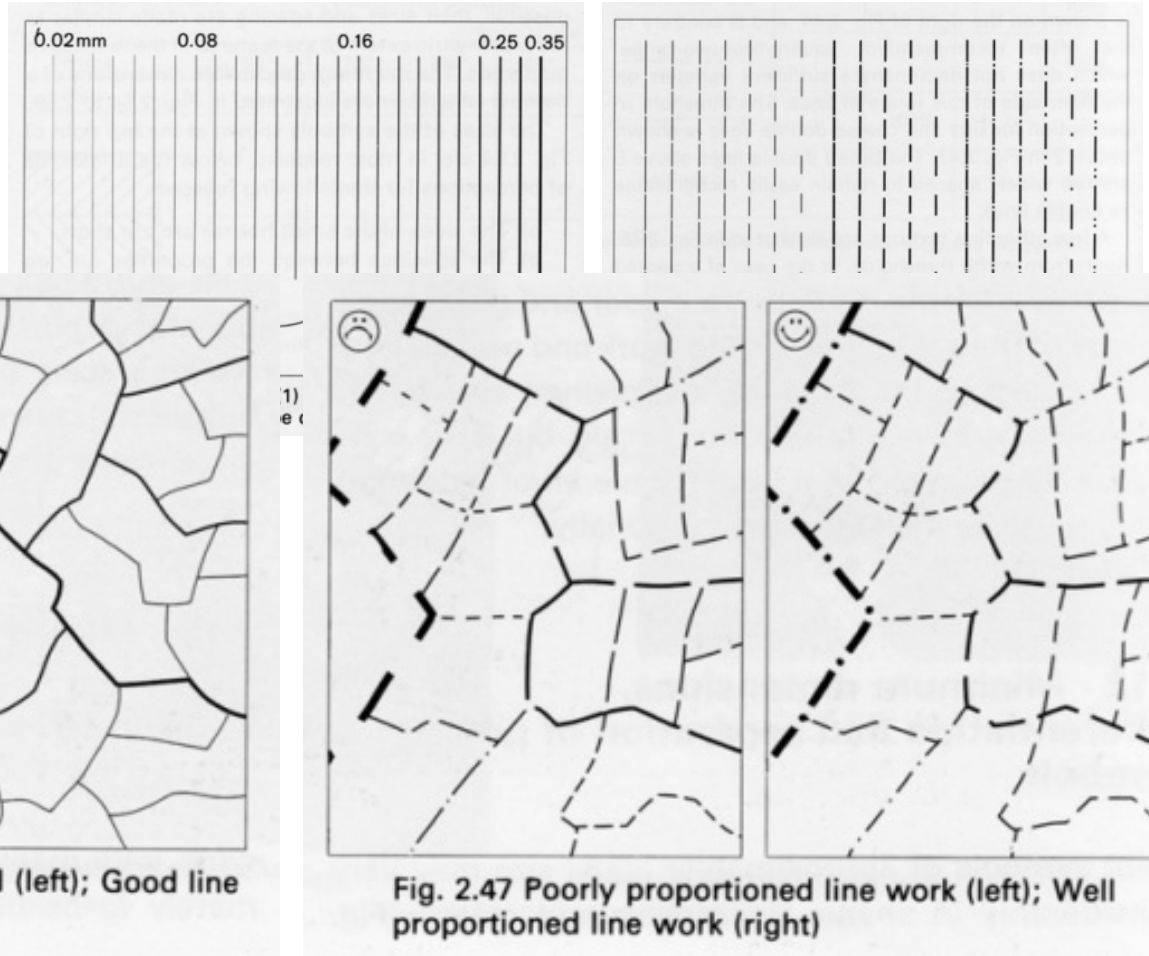
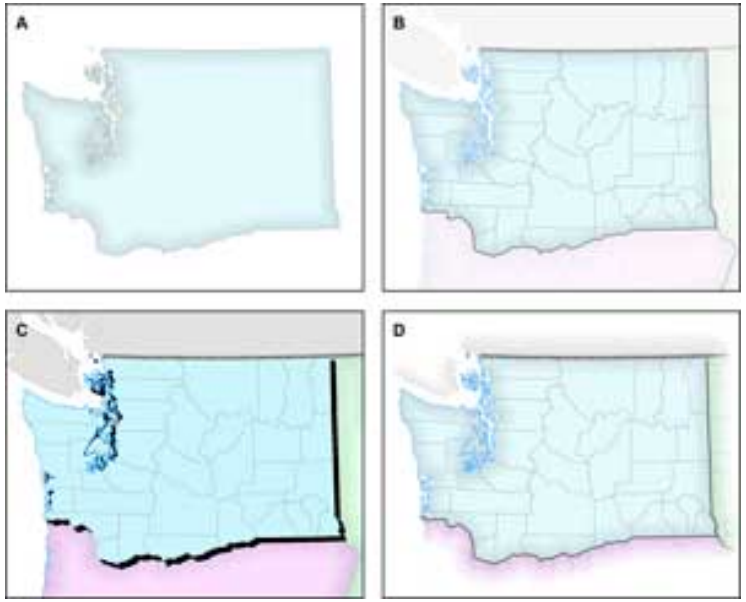


Fig. 2.47 Poorly proportioned line work (left); Well proportioned line work (right)

[MAKINGMAPS.NET, http://makingmaps.net/2007/09/07/map-symbols-thresholds-of-perception-part-1/]

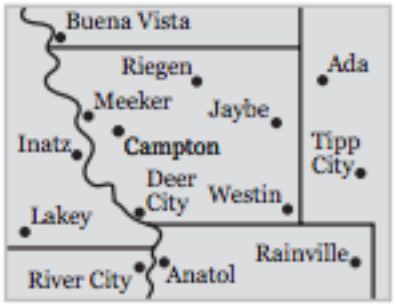
Highlight visual differences

Example 1:

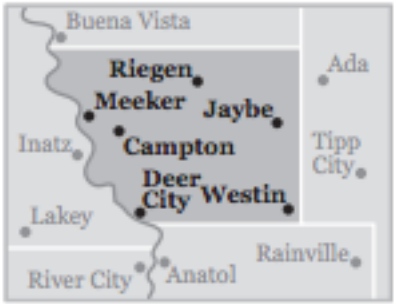


Example 2:

Poor visual difference:



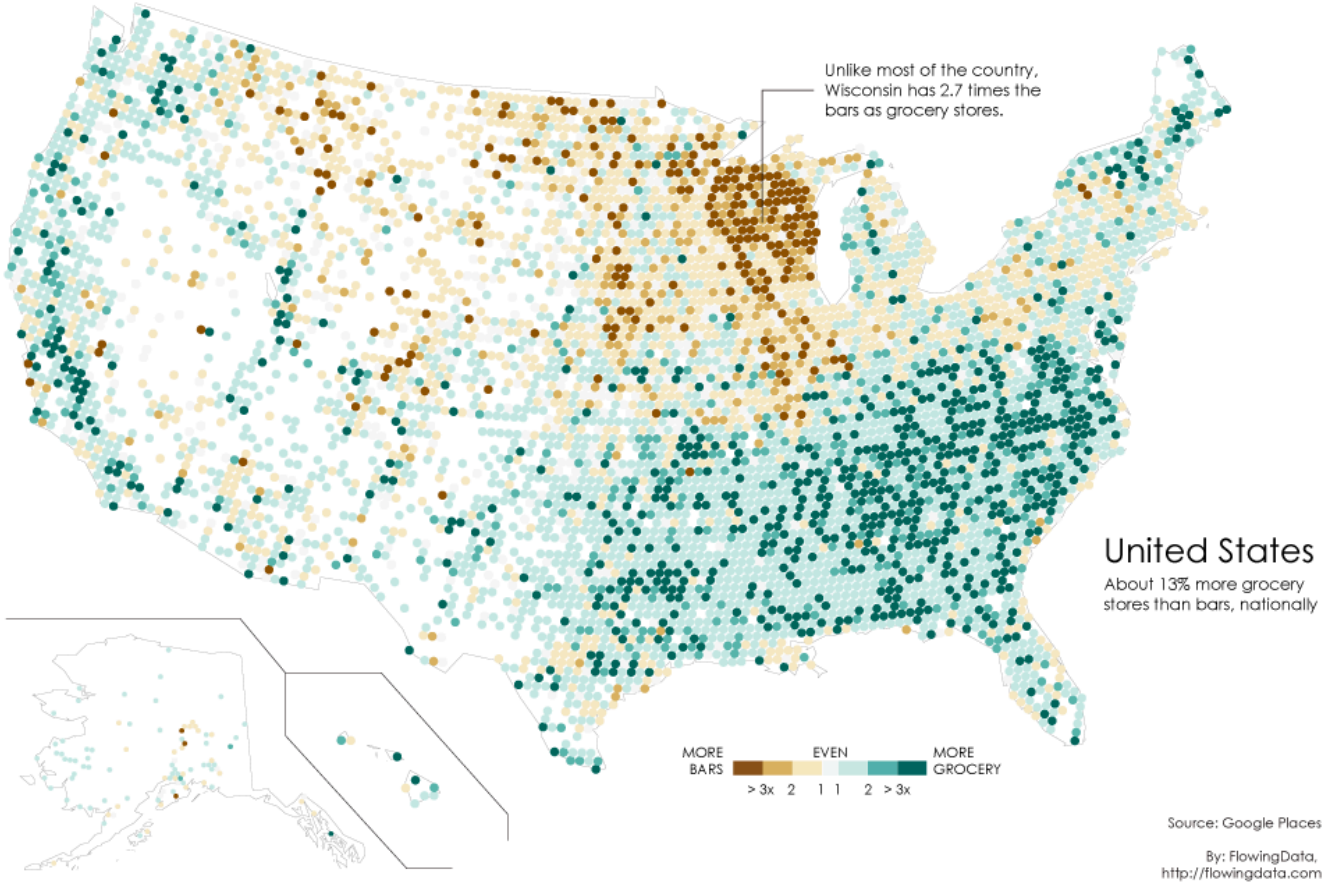
Good visual difference:



['Making Maps: A Visual Guide to Map Design for GIS', John Krygier and Denis Wood, 2005; ESRI, http://www.esri.com/news/arcuser/0911/making-a-map-meaningful.html]

Spatial graphics

Bars versus grocery stores across the US



[Flowing Data, http://flowingdata.com/2014/05/29/bars-versus-grocery-stores-around-the-world/]

The amount of available data is accelerating

Climate simulations:

'long running simulations typically require millions of core-hours to complete and usually produce many terabytes of model output'

– Climate Simulation Laboratory (https://www2.cisl.ucar.edu/csl)

A model of the universe:

'In order to capture the history of the universe in a box, you need a lot of computing power. Astronomers dedicated five years to programming Illustris, and it took 8000 CPUs running in unison three months to crunch all the numbers that the model is based on, according to the Illustris website. It would have taken an average desktop computer over 2000 years to complete the calculations.'

– Discovery Magazine Blogs, 'Evolution of the universe revealed in computer simulation' (http://blogs.discovermagazine.com/)