How to think about visualization

DAMON WISCHIK

Which of these plots is better, A or B? Why?

From a dataset of countries:

Mean GDP per capita [PPP USD], split by whether unemployment is <7%



From a dataset of monthly temperature readings: Average annual temperature [°C] in Cambridge



Which of these plots is better, A or B? Why?

Average daytime speeds in central London, major roads





PART I. Scales

Aesthetic mappings convert dataset feature scales to perceptual scales on a plot.

Sepal. Length	Sepal. Width	Petal. Length	Petal. Width	Species
5.0	3.4	1.6	0.4	setosa
6.5	3.0	5.5	1.8	virginica
5.0	3.5	1.3	0.3	setosa
6.7	2.5	5.8	1.8	virginica



EXERCISE: what are the data features and aesthetic scales?

Populists have gained ground across the political spectrum



EXERCISE: what are the data features and aesthetic scales?



Charles Minard's map of Napolean's 1812 Russia campaign

What perceptual scales are there? And how should we choose which to use?









According to *On the theory of scales of measurement* (Stevens 1946) there are four types of data scale. (This isn't really true but it's a good place to start.)



from The Grammar of Graphics (Wilkinson 2005)

Wilkinson, 2005.

The four data scales fit naturally with certain aesthetic scales.



shape colour choice

colour sequence

location extent colour gradient

area size divergent colours



Designing colour scales is hard!

Best to use a well-thought-out off-the-shelf colour scale.

Qualitative palette nominal scale



Sequential palette ordinal or interval scale



Divergent palette ratio scale



You should only use an aesthetic scale that *doesn't* match your data scale when you're making an artistic or rhetorical statement.







































Nominal: no comparison is meaningful

> Algeria Argentina Bolivia Brazil Canada Chile CostaRica Ecuador Ethiopia France Gambia Germany Guinea Haiti Hungary Iraq Italy Jamaica Libya Malaysia Mali Pakistan Somalia Spain Sweden Turkey Yemen

Country

This is dumb! How can we say "no comparison is meaningful" and at the same time render onto a y scale, inviting comparison?

Minimum and maximum February temperatures [°C] at weather stations around the UK





PART II. Argument

Why do we even use plots?

So that we can take advantage of the audience's perception, rather than just their cognition. (Don't make your audience do all the work!)



EXERCISE: what does this scientist want us to perceive?

DATASET: medical data for 10 patients was processed by 4 classification algorithms, and each algorithm was scored on a holdout dataset of size 30, to measure its prediction accuracy.

patient ID	classification algorithm	accuracy score
p2	lasso	0.228
р3	owl	0.279
р3	crl	0.197
:	:	÷



- Plots invite the viewer to make comparisons (how does feature A depend on B, C, or D?)
- So decide what comparisons you want your audience to make, and put your primary comparators on the best-perceived scales

EXERCISE: what comparisons does this scientist want us to make?

DATASET: medical data for 10 patients was processed by 4 classification algorithms, and each algorithm was scored on a holdout dataset of size 30, to measure its prediction accuracy.

patient ID	classification algorithm	accuracy score
p2	lasso	0.228
р3	owl	0.279
р3	crl	0.197
:	:	:



EXERCISE: what comparisons does this scientist want us to make?

DATASET: medical data for 10 patients was processed by 4 classification algorithms, and each algorithm was scored on a holdout dataset of size 30, to measure its prediction accuracy.

patient ID	classification algorithm	accuracy score
p2	lasso	0.228
р3	owl	0.279
р3	crl	0.197
:	:	:

- Probably "how does accuracy depend on algorithm?"
- So put this on x and y scales, which are easier to perceive!
- The lines group together the readings for a single patient, which helps with making between-patient comparisons.
- Between-patients is of secondary importance, so we'll use hue.



EXERCISE: what comparisons are we invited to make?



This plot shows signal strength from a pulsar. Each line spans a period in time, and the periods are arranged in order of time, with occlusion.

Joy Division's album Unknown Pleasures, 1979 https://blogs.scientificamerican.com/sa-visual/ pop-culture-pulsar-origin-story-of-joy-division-s-unknown-pleasures-album-cover-video/

EXERCISE: what comparisons are we invited to make?

An individual's monthly activity (3 categories) and sleep quality (1 category), normalized by the monthly maximum in each category.

All differences between means with p < 0.01 are indicated (within the same category and across categories). ^{##}, p < 0.01, for Sep–Dec 2016 and any time interval before May 2016; ***, p < 0.001; ****, p < 0.0001; two-tailed paired *t*-tests.



This plot is annotated with hypothesis tests.

If your plot does not depict the comparisons you want to make, find a better plot.

https://www.nature.com/articles/s41551-017-0079

EXERCISE: what comparisons are we invited to make?

Detected fires in the Amazon using data from NASA satellites Terra and Aqua (which can detect the infrared radiation emitted by fires)



This is a "small multiple" plot, useful for making comparisons between multidimensional outputs.

(The medical example was a badly-done small multiple plot.)

New York Times

https://www.nytimes.com/interactive/2019/08/24/world/americas/amazon-rain-forest-fire-maps.html

"Decide what comparisons you want your audience to make, and put your primary comparators on the best-perceived scales"

What does "best-perceived scale" mean?



Exercise: what is the data \rightleftharpoons aesthetic mapping?



What perceptual scales might I use to convey quantity?





Area is dangerous Stevens exponent: perceived area = (drawn area)^{0.8}





Information visualization: perception for design by Colin Ware Why scientists need to be better at data visualization https://www.knowablemagazine.org/article/mind/2019/science-data-visualization ³²

What colour scale might I use to convey quantity?



Hue (c) conveys broad differences, while brightness (b) conveys fine differences. They can be combined (d).

(Rainbow palettes (a) should only be used for drawing rainbows.)

Total column density of ozone above the southern hemisphere (Why Should Engineers and Scientists Be Worried About Color? Rogowitz and Trienish, 1998)

How are the different perceptual scales perceived?



Lines banked around 45° are easiest to read.

How are the different perceptual scales perceived?

Is there a red dot?



We can see colour differences more easily than shape differences.

How are the different perceptual scales perceived?

Where is the red dot?



We notice differences relative to the field

Fraction who survived, among people on the Titanic



PART III. The atomic theory of plotting

In the best plots, every dot of ink is a datapoint.



Our brains are wired to understand how datapoints look when they're aggregated

NASA earth observatory https://earthobservatory.nasa.gov/images/87551/london-at-night Our brains are wired to understand how datapoints look when they're aggregated

This is why histograms are so easy to understand





Iraq's bloody toll



South China Morning Post

https://www.scmp.com/infographics/article/1284683/iraqs-bloody-toll 41

In the best plots, every dot of ink is a datapoint with its own story.

The New York Times makes great use of interactive dotplots, to tell stories.



In the best plots, every dot of ink is a datapoint with its own story.

It's too easy to lie with aggregated data.



Beyond Bar and Line Graphs: Time for a New Data Presentation Paradigm

https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.1002128

Show the dots in plots

https://www.nature.com/articles/s41551-017-0079

Plot things, not numbers (if you can)

- All data starts with observable things
- Don't do too much computation (thresholding etc.) before showing the plot: let the computation be in the eye of the beholder



Why do we even use plots?

We use plots to take advantage of the audience's perception, rather than just their cognition.

So don't ask too much of the viewer's cognition.

Plot things, not numbers (if you can)

- All data starts with observable things
- Don't do too much computation (thresholding etc.) before showing the plot: let the computation be in the eye of the beholder
- Make up the underlying observable things, if it helps!



Origin-destination matrix for taxi trips in New York

https://blog.revolutionanalytics.com/2016/12/taxi-mrs-spark.html Ali Zaidi, data scientist at Microsoft



Imputed traffic flows based on shortest-path routing

Rules for atomic plots

- If our data scale is accumulative: show it with a histogram, and let the size be accumulated mass
- If our data is not accumulative: don't use bars, because they convey the impression of mass







From a dataset of monthly temperature readings:

Annual average temperature [°C] in Cambridge



Average daytime speeds in central London, major roads

PART IV. Presentation

Temperature distribution analysis

Distribution of monthly mean temperatures in Cambridge, split by season

temperature distribution (1960s)



"We looked at the distribution of monthly mean temperatures in Cambridge, split by season. These plots show that not only has it gotten hotter, but the distribution has also become more extreme."

Temperature distribution analysis

Distribution of monthly mean temperatures in Cambridge, split by season

temperature distribution (2010s)



"We looked at the distribution of monthly mean temperatures in Cambridge, split by season. These plots show that not only has it gotten hotter, but the distribution has also become more extreme."

EXERCISE: what's wrong with this visualization?



Slides as props. The speaker has the audience's attention. The audience only looks at the slides when prompted to.



Slides as docs. The audience focuses first on making sense of the slide, and only then pays attention to the speaker. (All Zoom talks work like this.)

Temperatures have become both hotter and more extreme



Method: analysis of monthly readings in Cambridge



- The slide title should be the full claim or hypothesis that this slide is about. (If an audience member already believes your claim, this leaves them free to take a quick break.)
- The title should not be a noun or noun-phrase. (Such titles are just notes from the speaker to themselves.)
- The audience's attention will drift between the slide and the speaker. As you speak, give 'hooks' so that the audience can re-attach to your speech.
- One slide takes 3–5 minutes

Temperatures have become both hotter and more extreme



N



Slides can take as little as 30sec, depending on content.

But do **dwell on plots**. Build up plots step by step; don't just state the conclusion you want to draw from them.

- What are the axes?
- What are the entities being plotted?
- What comparison are you interested in? What shape would we expect to see if there was nothing going on?
- What shape do we actually see? What does this tell you about the dataset?



What are the axes?

The x axis is season (winter, spring, summer, autumn), and the y axis is temperature. For each shape, the left hand side shows a histogram of temperatures in the 1960s, and the right hand side shows temperatures in the 2010s.

What are the entities being plotted?

These histograms are obtained by taking the average temperature at each month over the decade, and binning it.

What comparison are you interested in? What shape would we expect to see if there was nothing going on? We want to see how temperature distributions have changed from 1960s to 2010s. If there were no change, then the histograms on the left would be the same shape as on the right, for each season.

What shape do we actually see? What does this tell us about the dataset?

But we can see that the histograms have moved slightly higher up, in other words slightly higher temperatures, by about 1°C it looks like. And in winter and summer especially, there's a much more pronounced peak at the top of the distribution.

Visualizations are quantitative rhetoric



My Best Visualization

DAMON WISCHIK

Chicago toll-road toll plazas



For each vehicle passing under a detector, we are given

- plaza_id
- payment_tag_id
- vehicle_class (car, bus or 2-axle truck , freight)
- timestamp
- speed

