Best practices in data visualization

Guillermo Aguilar & Verjinia Metodieva

With material from Aina Frau-Pascual & Nicolas P. Rougier

Heraklion, Crete, ASPP 2023

Course: 2.5h, easy to follow, nice pics and concepts, given in pairs

Structure: exercise + explanation. Let them work on it first and then show them the answer. Involve git: either notebook in repo to clone, or exercises as github issues and doing a PR to submit an exercise.

My Ideas:
- 10 rules for data viz
- Overview of libraries on top of Matplotlib (slide 26 N. Rougier)
- Maybe also tools dedicated for each domain: biology, brains, fMRI...
- Present all types of graphics, and which tools are better for which type of data structure
- Format of a figure: lossy/lossless compression, what is DPI, how to create a figure with text of same size as paper text...
- Use real data examples
- Script to modify a figure that was already done (after review), generic label
- How plotting can mislead: Datasaurus
https://cran.r-project.org/web/packages/datasauRus/vignettes/Datasaurus.html,
https://www.autodesk.com/research/publications/same-stats-different-graphs
- Some visualization related to the pelita tournament (e.g. update plot maze when adding a new value to a square). They will not know yet about the tournament so it has to be sufficiently vague

Design can decrease the effort to understand.

– Make text a priority.

– Decide what readers should see first. Grey everything else out.

Design can make things beautiful.

Beauty can make things:

– more interesting
– more engaging
– more memorable

Beauty is transferable.

Beautiful things seem simpler.

@lisacrost

Plan

17:00 Principles of data visualization

Hands-on Exercise 1: **mastering matplotlib**

Types of visualizations - Use of color - Common pitfalls

Hands-on Exercise 2: which visualization should I use?

Review of your solutions as PR

19:30 **END**

Visualization is a method of computing. It transforms the symbolic into geometric, **enabling researchers to observe** their simulations and computations. Visualization offers **a method for seeing the unseen.** It **enriches** the process of scientific discovery and fosters profound and unexpected insights.

Visualization in Scientific Computing, NSF report, 1987

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Often the most effective way to describe, explore, and summarize a set of numbers - even a very large set - is to look at pictures of those numbers.

The Visual Display of Quantitative Information, Edward Tufte, 1983

Excellence in statistical graphics consists of complex ideas communicated with clarity, precision, and efficiency. Graphical displays should

- show the data
- induce the viewer to think about the substance rather than about methodology, graphic design, the technology of graphic production, or something else
- avoid distorting what the data have to say
- present many numbers in a small space
- make large data sets coherent
- encourage the eye to compare different pieces of data
- reveal the data at several levels of detail, from a broad overview to the fine structure
- serve a reasonably clear purpose: description, exploration, tabulation, or decoration
- be closely integrated with the statistical and verbal descriptions of a data set.

Classical example: Anscombe's quartet

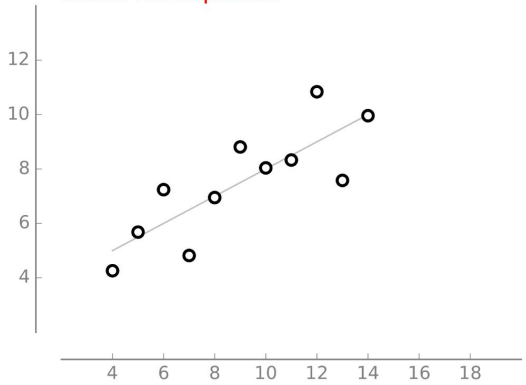
I		II		III		IV	
x	y	x	y	x	y	x	y
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56
7.0	4.82	7.0	7.26	7.0	6.42	8.0	7.91
5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89

statistic	value
mean of x	9
sample variance of x	11
mean of y	7.50
sample variance of y	4.125
correlation coefficient	0.816
linear regression line	y = 3.00 + 0.500x
coefficient of determination	0.67

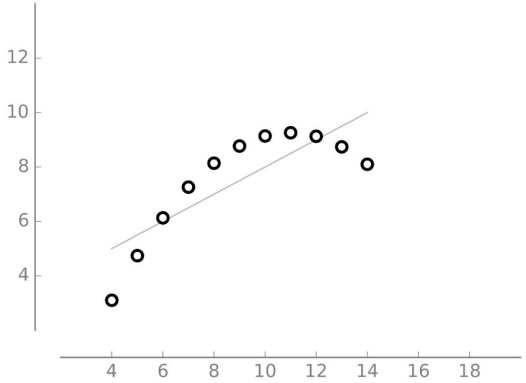
Anscombe (1973)

Classical example: Anscombe’s quartet

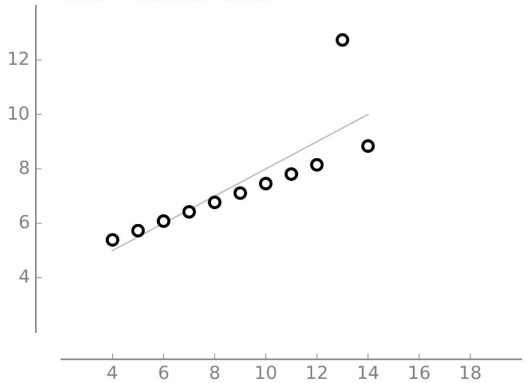
What we expect...



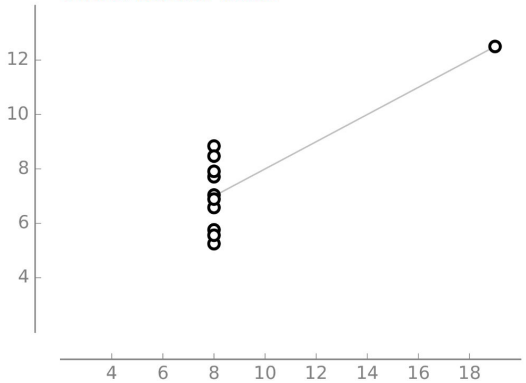
The non-linear case



The Y outlier case



The X outlier case



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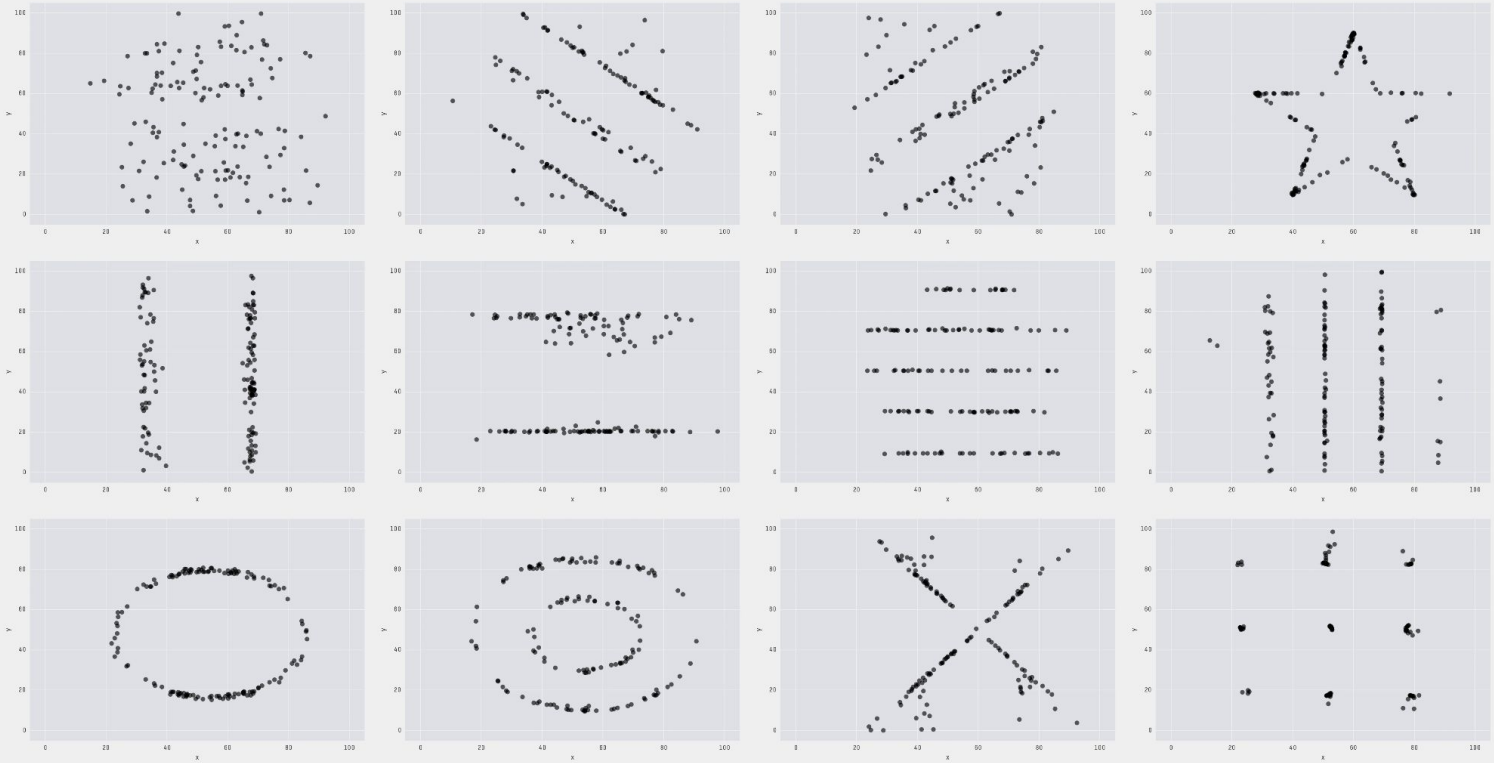
Datasaurus

X Mean: 54.26
Y Mean: 47.83
X SD : 16.76
Y SD : 26.93
Corr. : -0.06



And you will read this last

You will read this first

And you will read this

Then this one

Source: UX design

Main challenge: **mapping from data info to visual info**

Claus O. Wilke (2019)

Main challenge: **mapping from data info to visual info**

Data → **Graphical elements**

Type of variable	Examples	Appropriate scale
quantitative/numerical continuous	1.3, 5.7, 83, $1.5x10^{-2}$	continuous
quantitative/numerical discrete	1, 2, 3, 4	discrete
qualitative/categorical unordered	dog, cat, fish	discrete
qualitative/categorical ordered	good, fair, poor	discrete
date or time	Jan. 5 2018, 8:03am	continuous or discrete

Claus O. Wilke (2019)

Main challenge: **mapping from data info to visual info**

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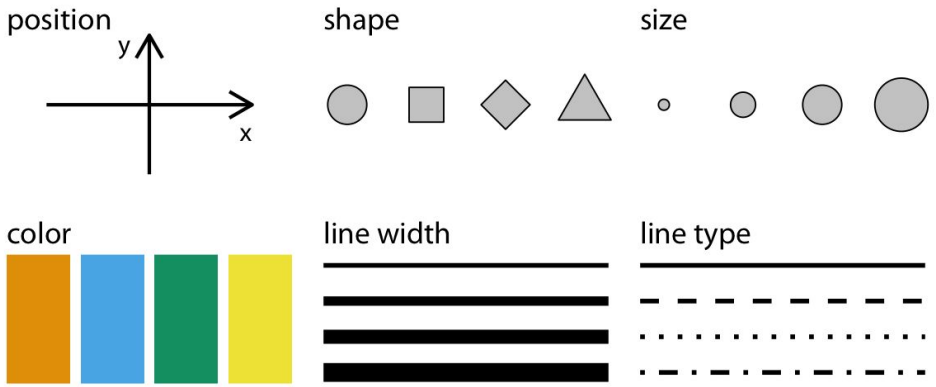


Claus O. Wilke (2019)

OPEN ACCESS Freely available online

PLOS | COMPUTATIONAL BIOLOGY

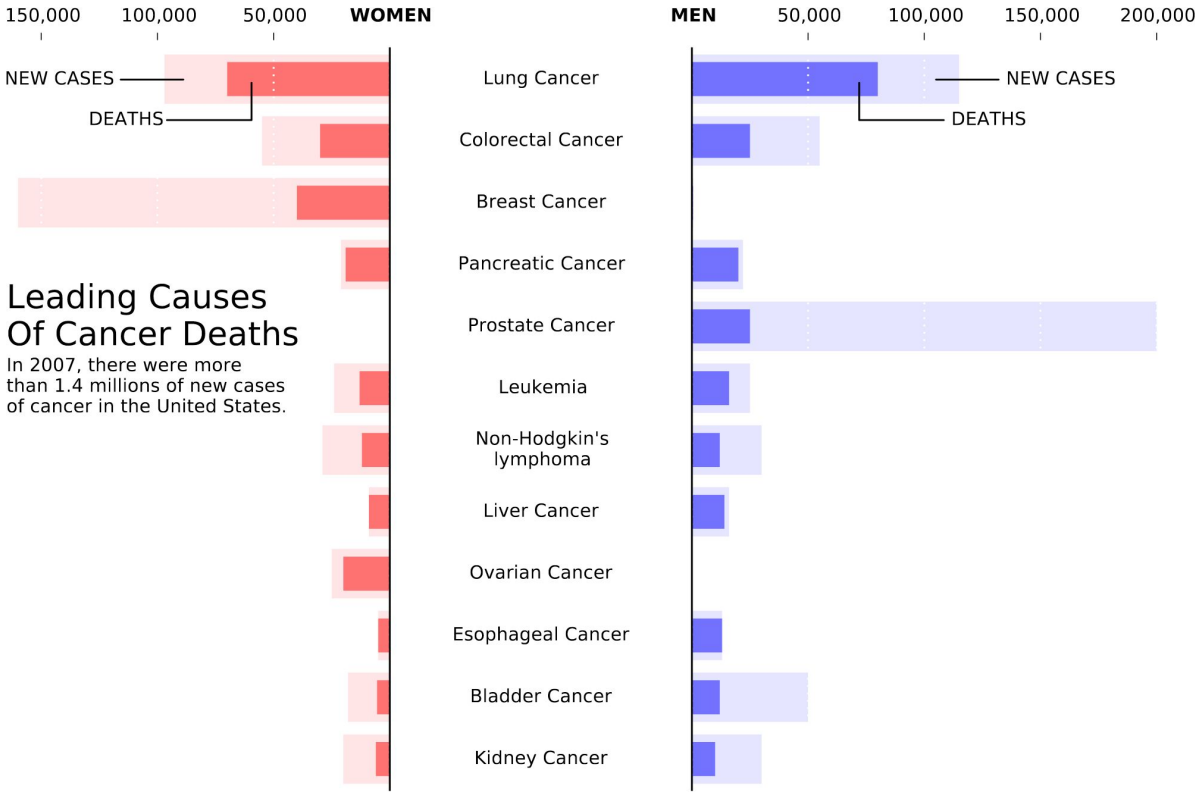
Editorial

Ten Simple Rules for Better Figures

Nicolas P. Rougier[1,2,3]*, Michael Droettboom[4], Philip E. Bourne[5]

1 INRIA Bordeaux Sud-Ouest, Talence, France, **2** LaBRI, UMR 5800 CNRS, Talence, France, **3** Institute of Neurodegenerative Diseases, UMR 5293 CNRS, Bordeaux, France, **4** Space Telescope Science Institute, Baltimore, Maryland, United States of America, **5** Office of the Director, The National Institutes of Health, Bethesda, Maryland, United States of America

Where was this published?



1) Know your audience

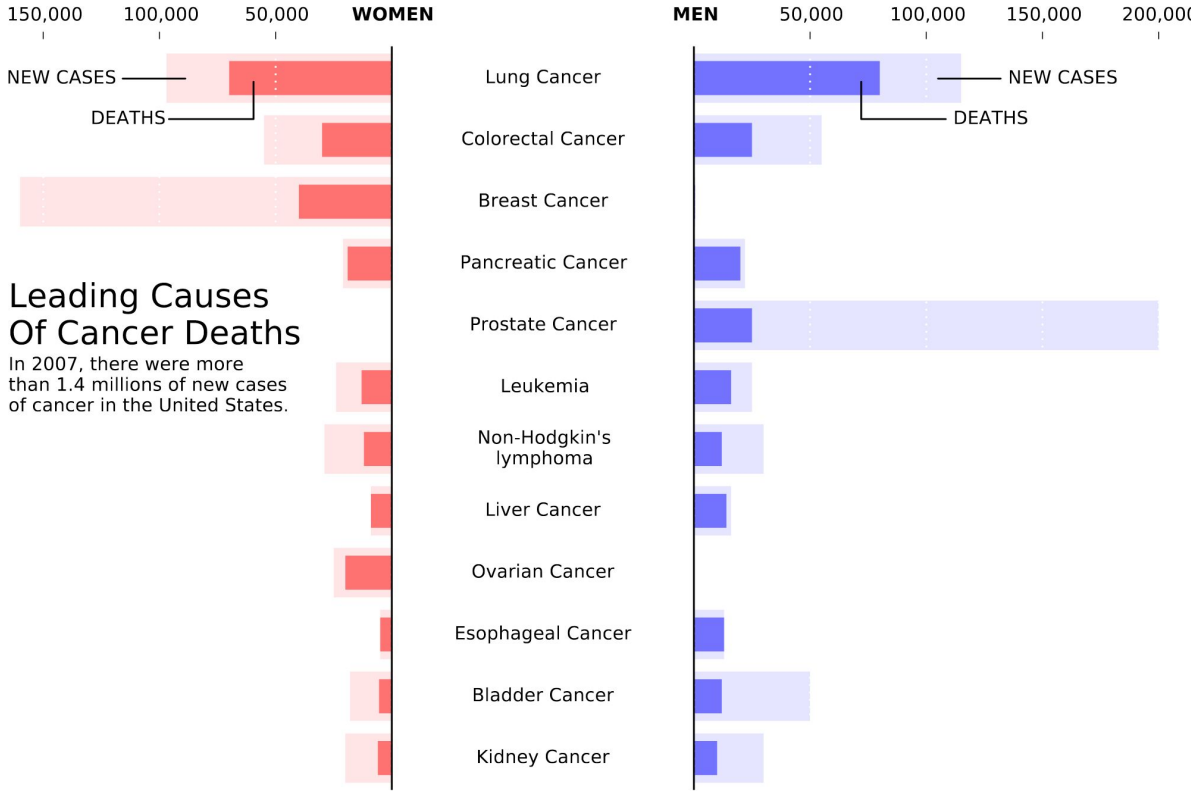
- Complexity +

My colleagues

Scientific community

Student audience

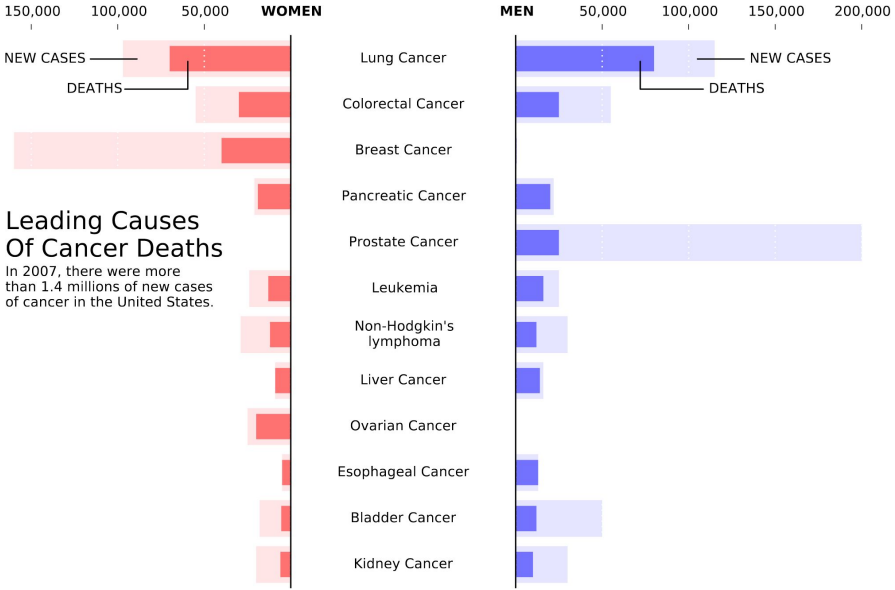
General public

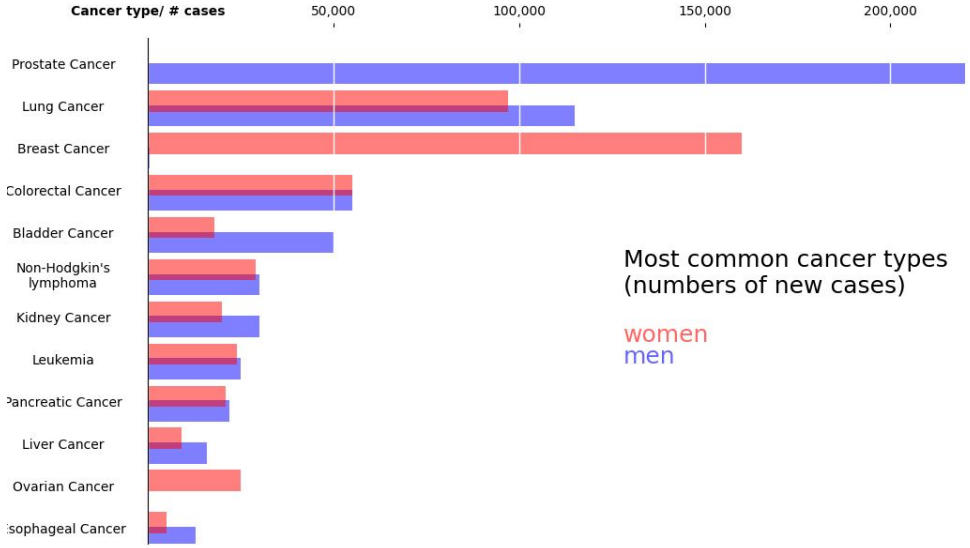


Audience: general public

Separated in sex groups: Women / Men

Same data. What's different?



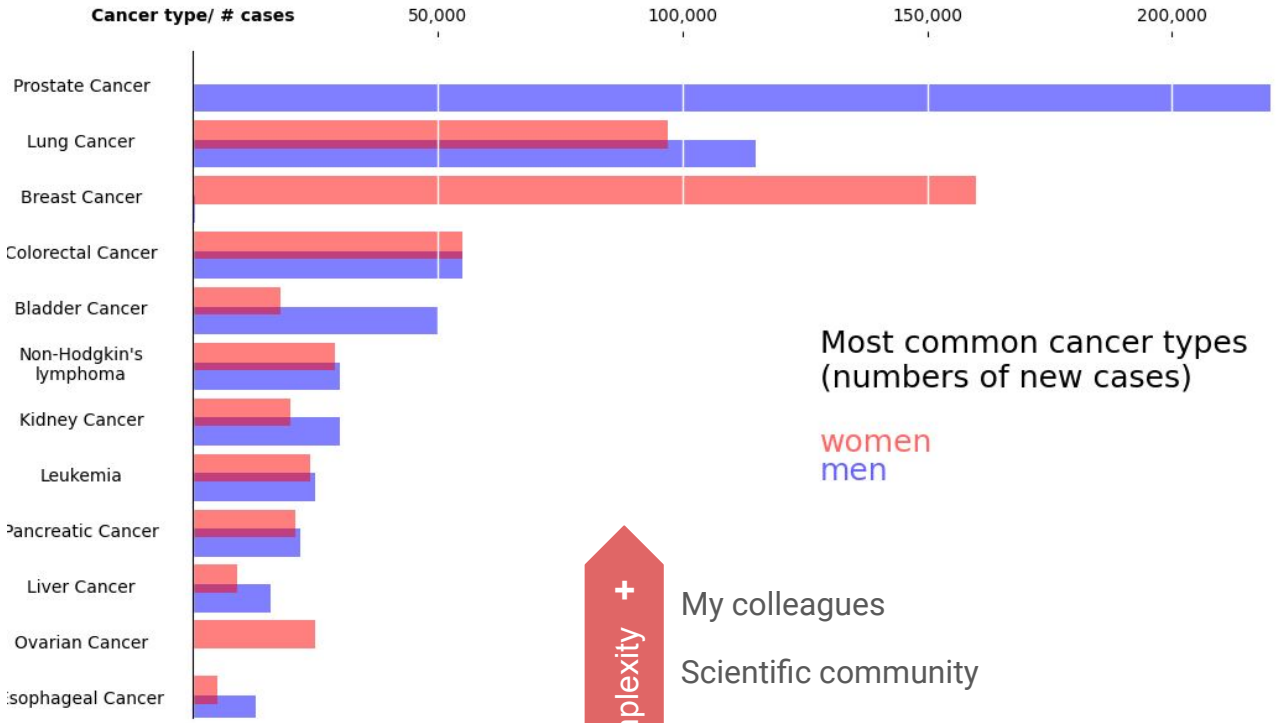


2) Identify your message

Main message: Men are mostly affected by prostate cancer, while the most common cancer type by women is breast cancer

Audience: general public

Focus on comparison between the sexes



My colleagues

Scientific community

Student audience

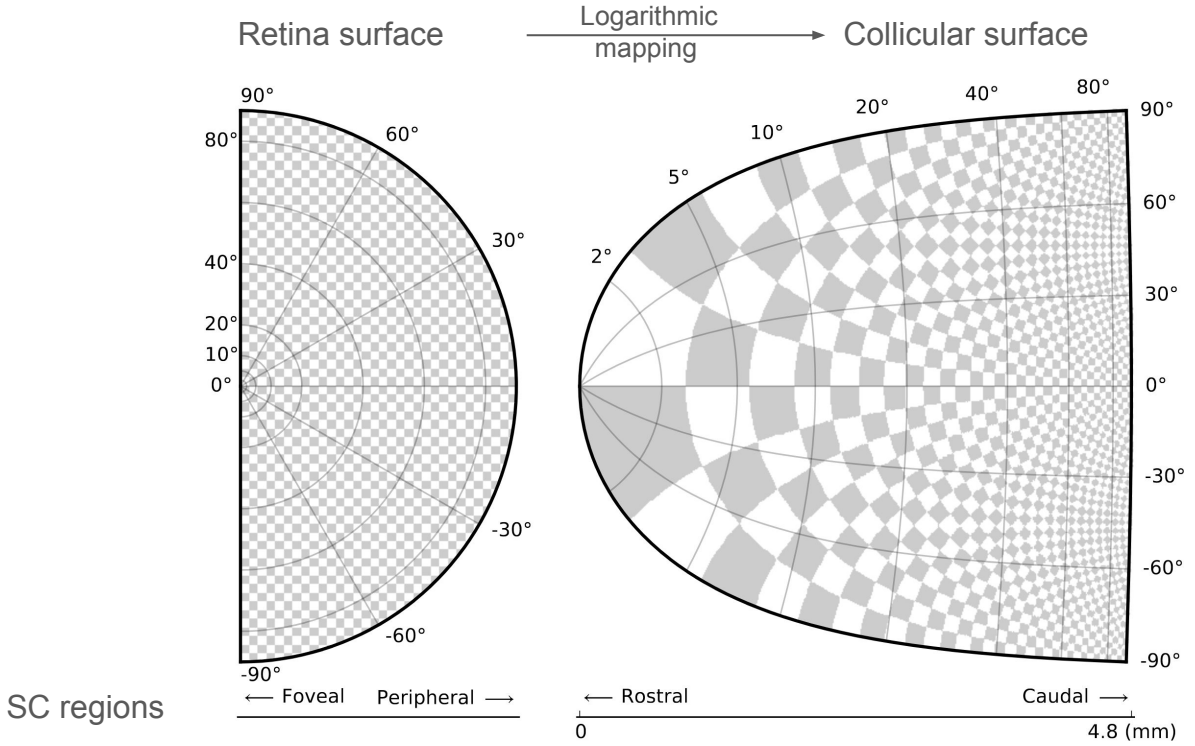
General public

2) Identify your message

Audience:

neuroscience scientific community

Superior Colliculus



SC regions

Main message: Artificial checkerboard pattern demonstrates the magnification of the foveal region in the superior colliculus (brainstem structure). This has to do with the induction of saccadic eye movement that the SC plays a role in.

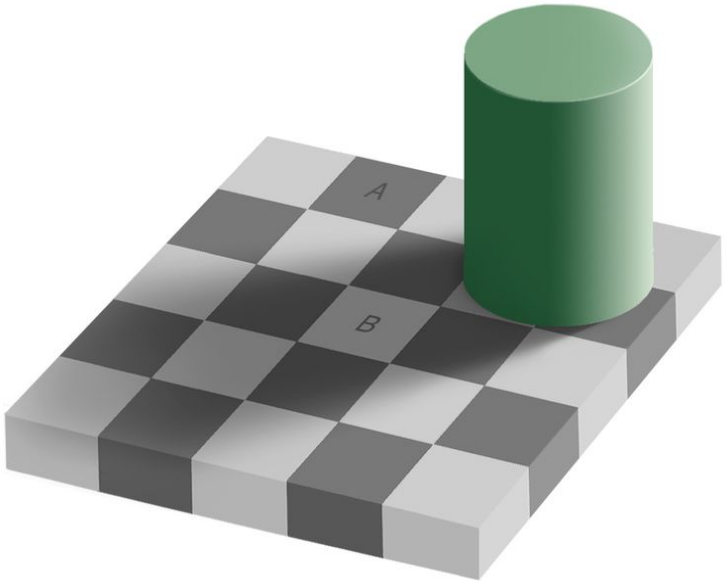


Figure 1. Optical illusion

3) Captions are not optional. Neither x and y-labels

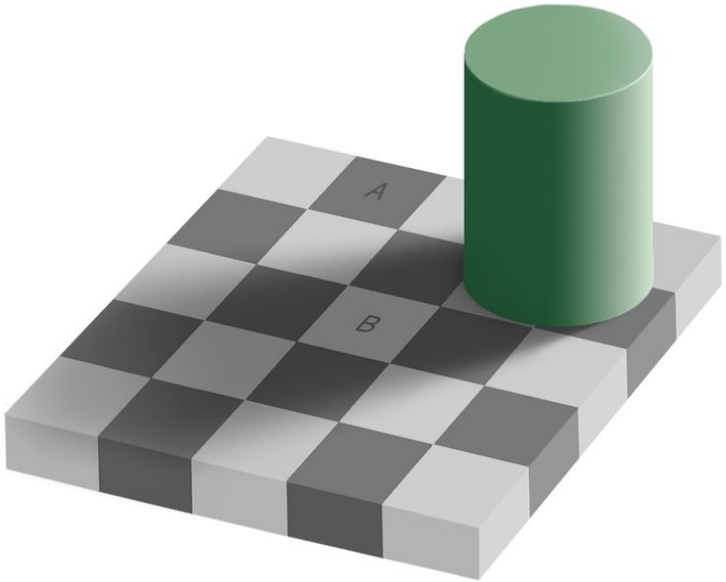


Figure 1. Optical illusion

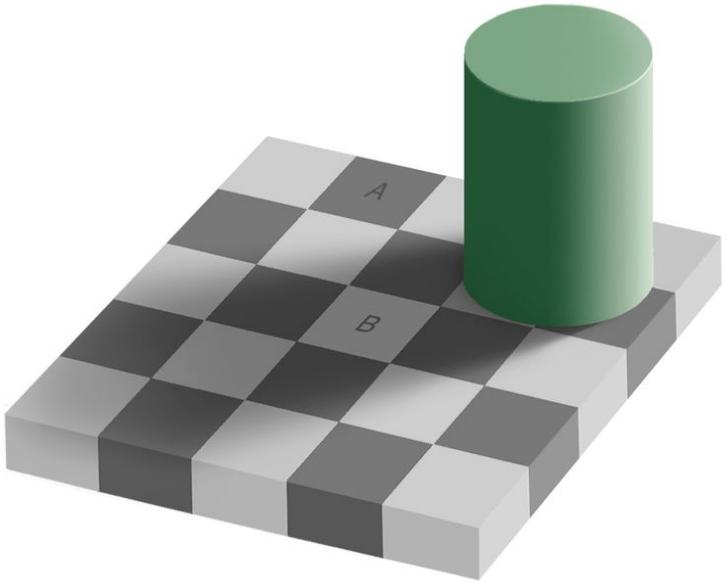


Figure 1. Optical illusion - A and B patches are the same color even though we perceive them as being different colors

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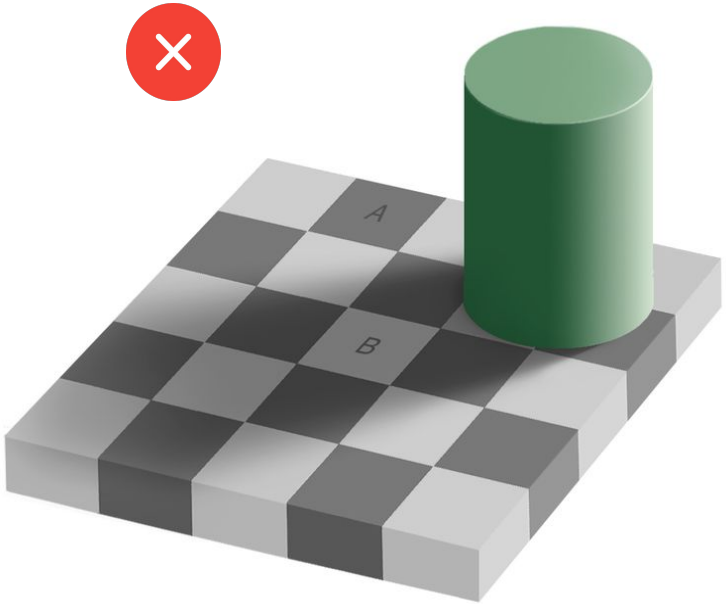


Figure 1. Optical illusion

Caption helps you understand the image

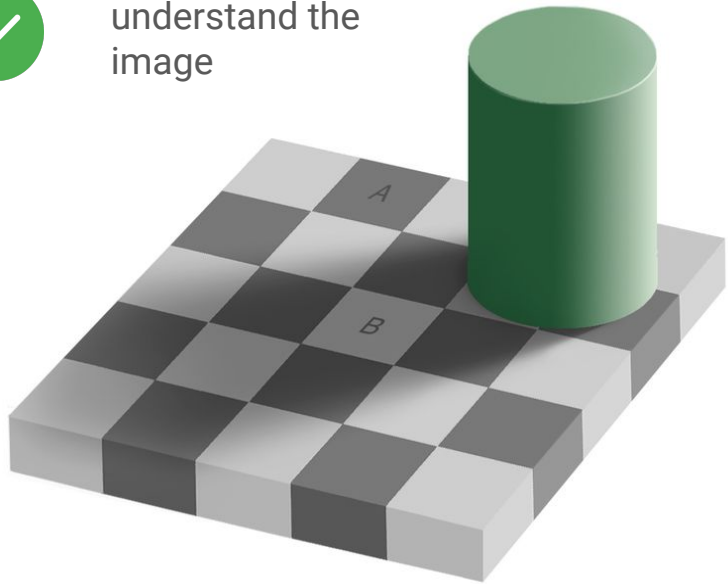
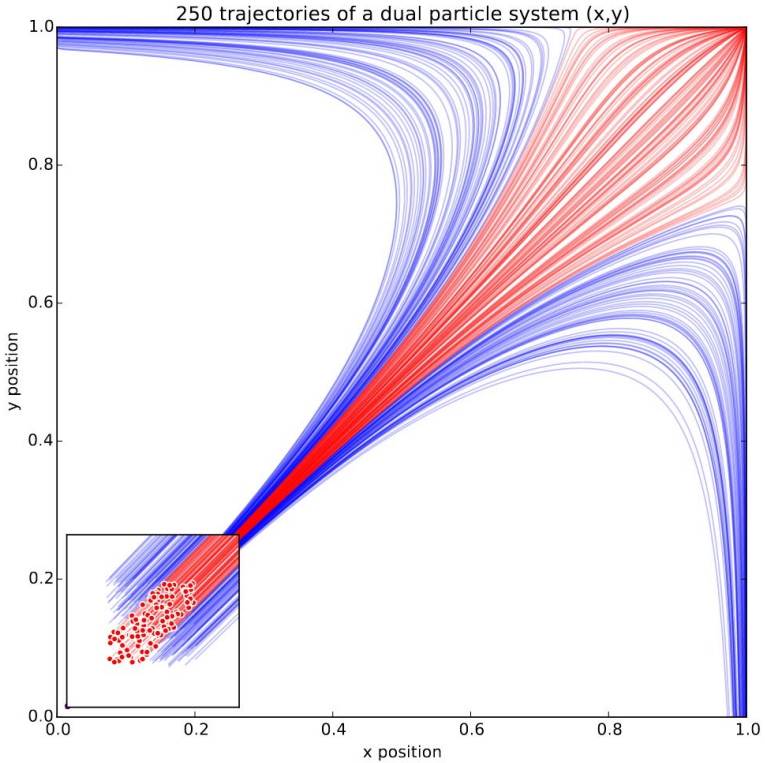
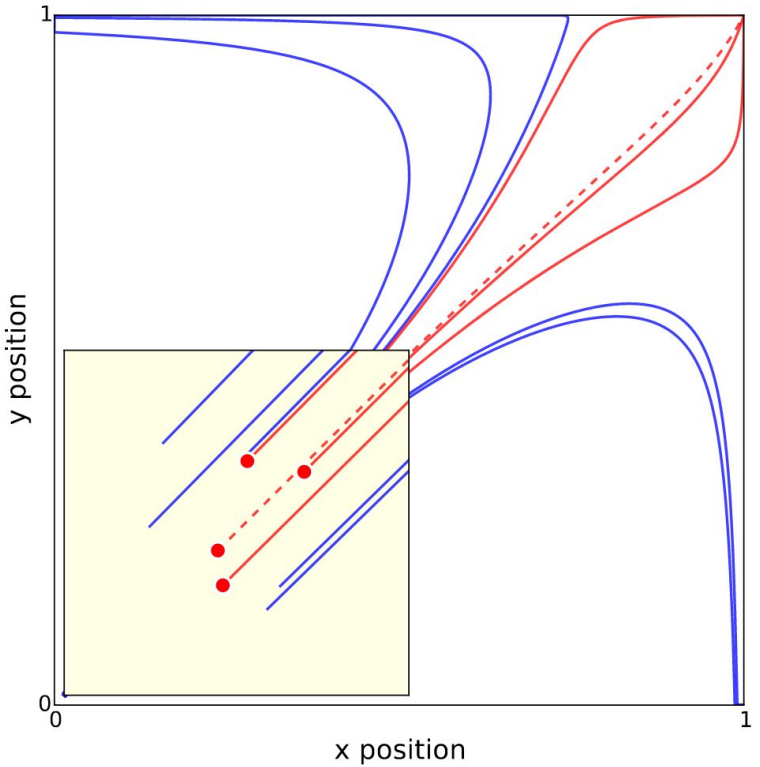


Figure 1. A and B patches are actually the same color even though we perceive them at being different color

Which figure is better? Why?





4) Adapt the figure to support the medium

Figure for a Paper

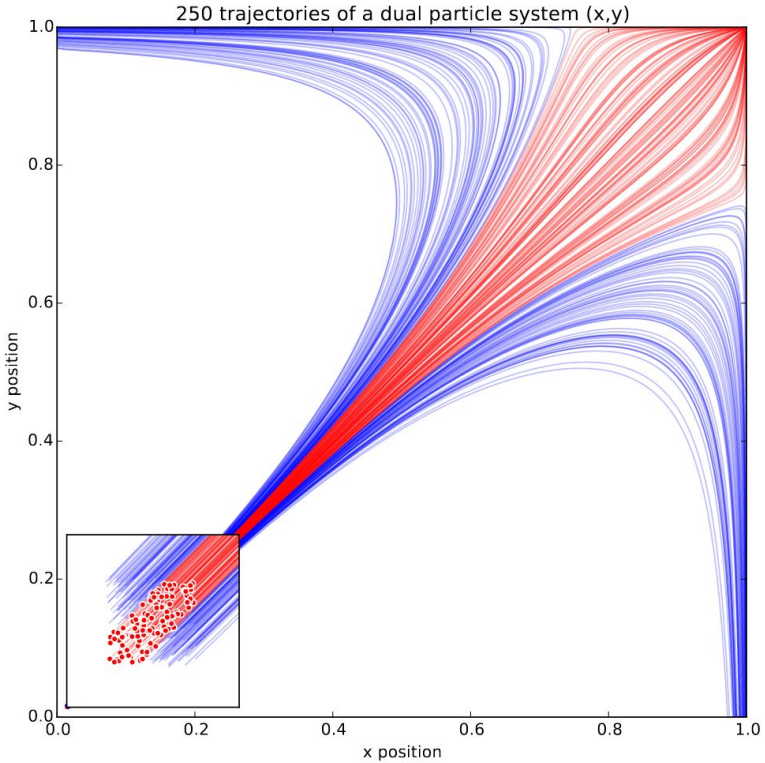
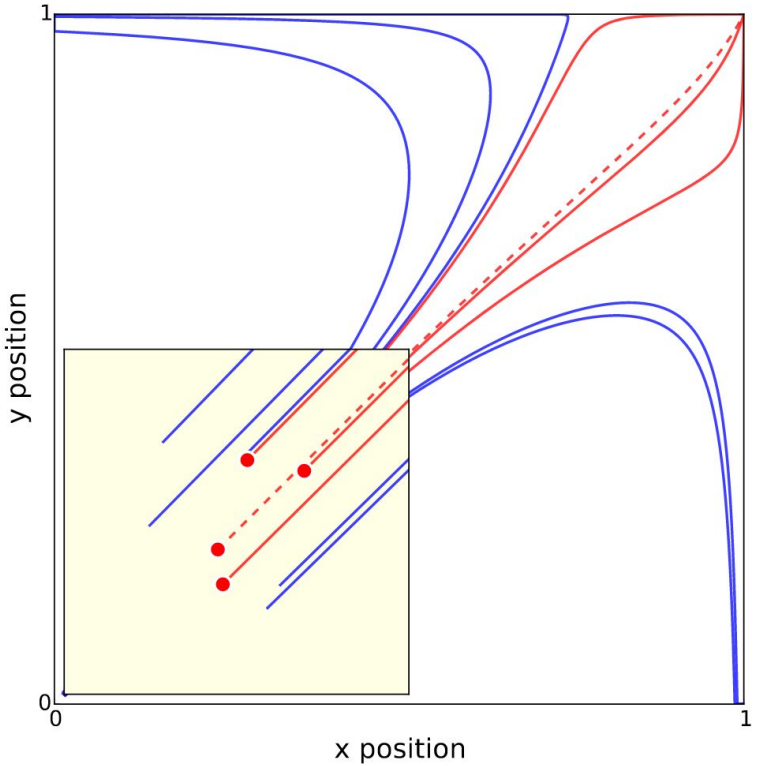
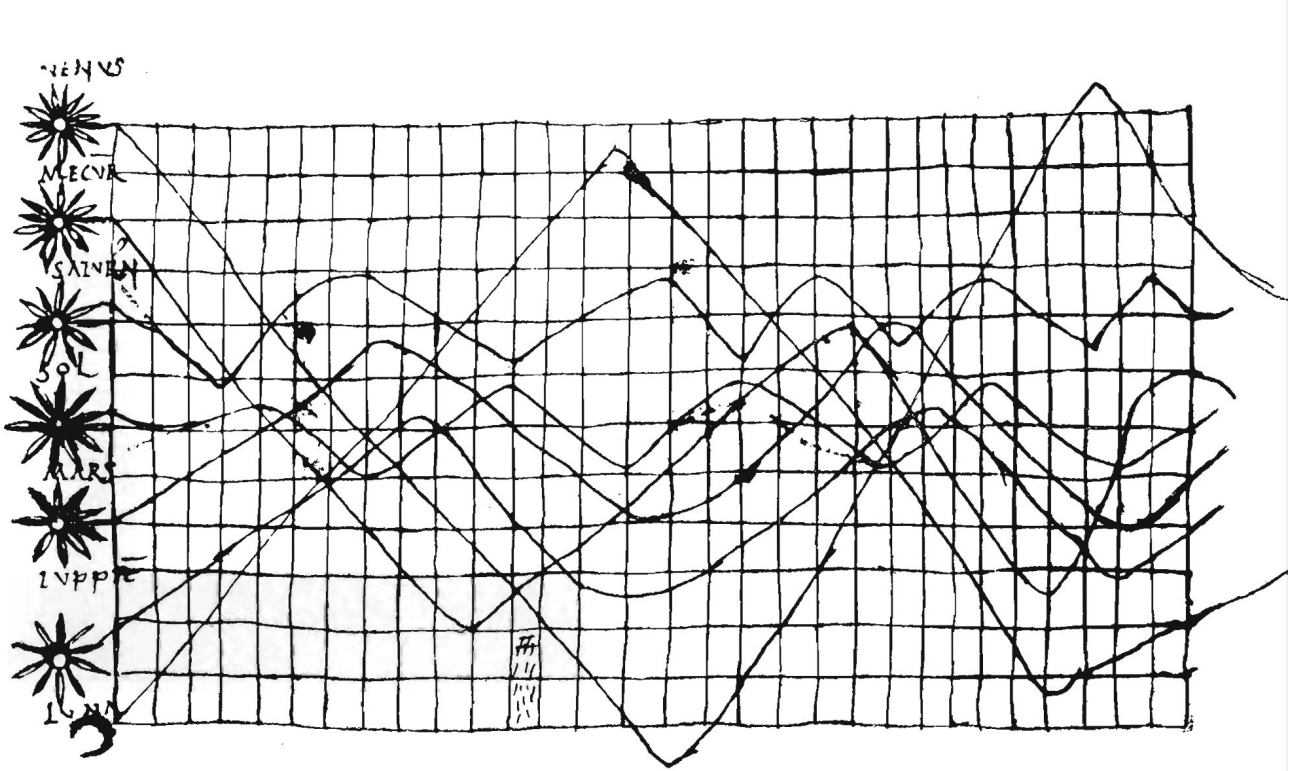


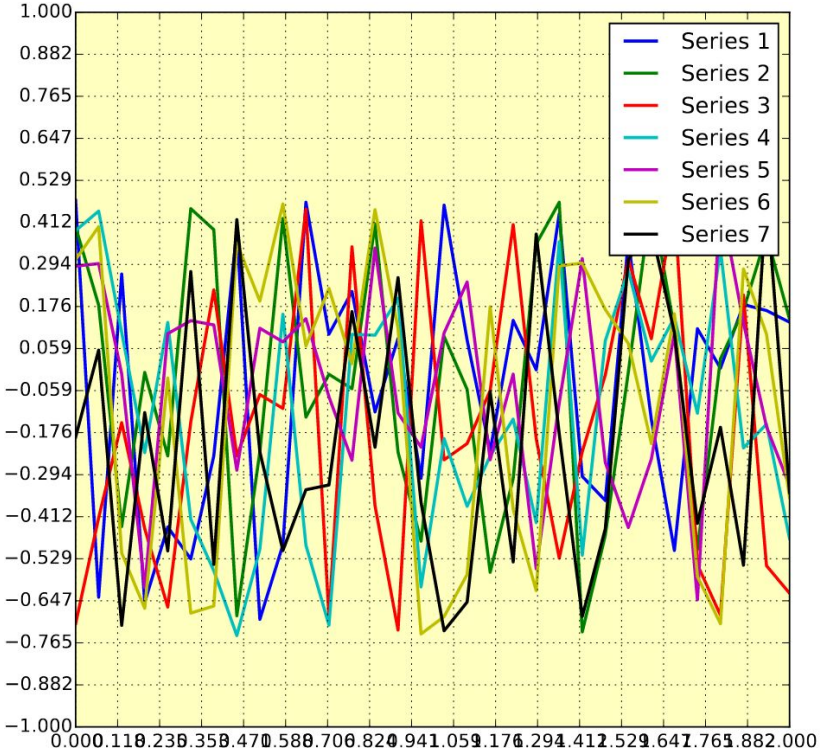
Figure for a Talk



Showing changing values graphically - 10th century

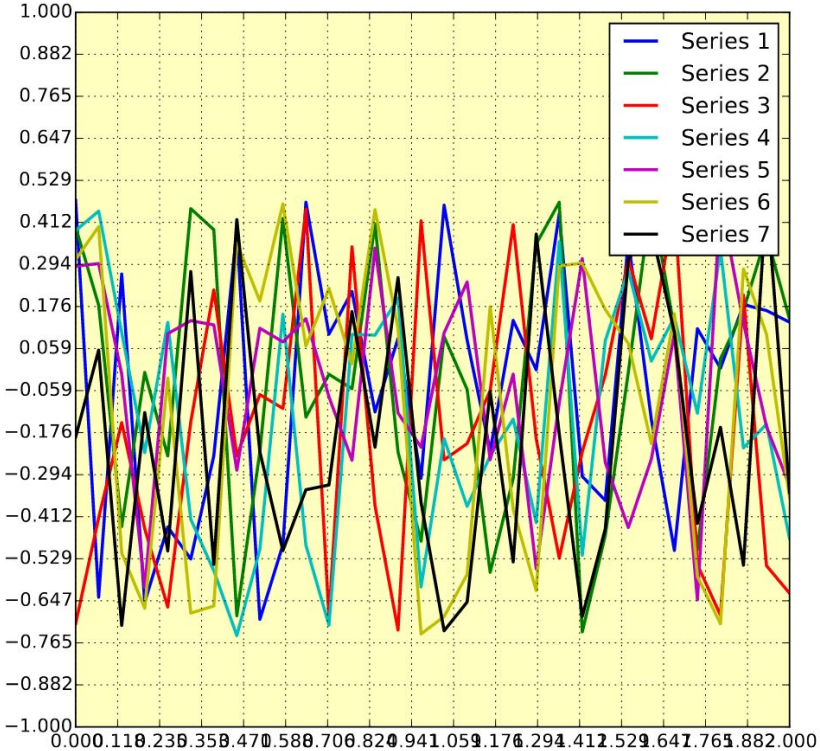


Tenth Century Graph," Osiris, 1 (January 1936), 260-262.



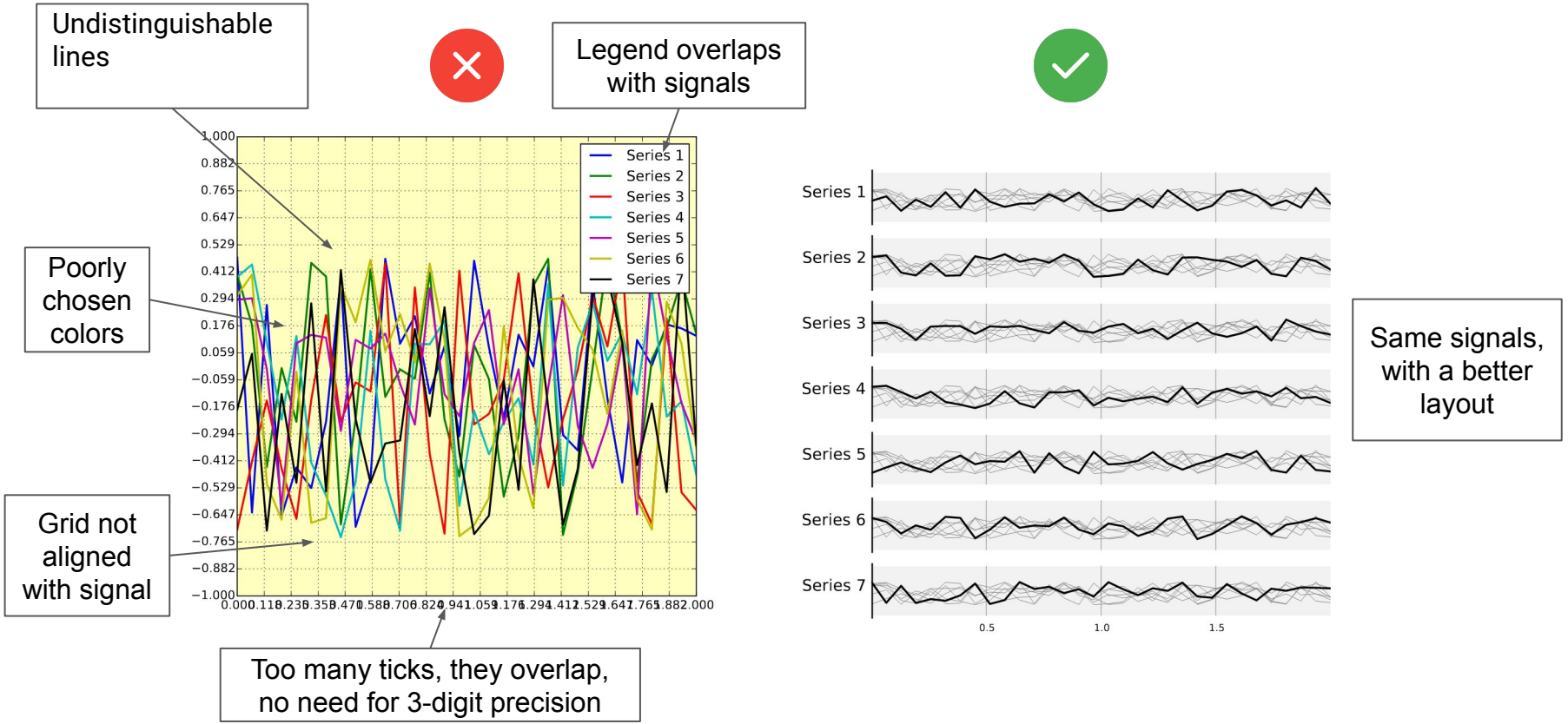
The purpose of figure is to visually compare signal series

What could be improved in this plot? Discuss with your partner.



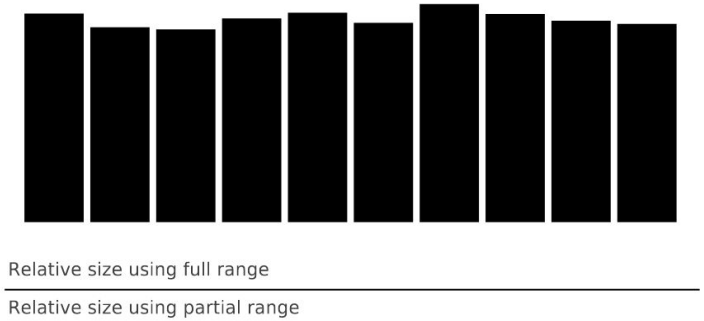
The purpose of figure is to visually compare signal series

5) Avoid **chartjunk**



6) Do not mislead the reader

Using full range bars shows a more realistic comparison among them



Relative size using full range

Relative size using partial range

Using **partial range bars misleads the reader** to think the difference is bigger

6) Do not mislead the reader

Using full range bars shows a more realistic comparison among them

Relative size using full range

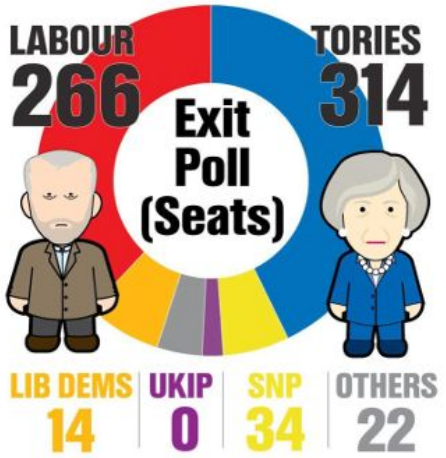
Relative size using partial range

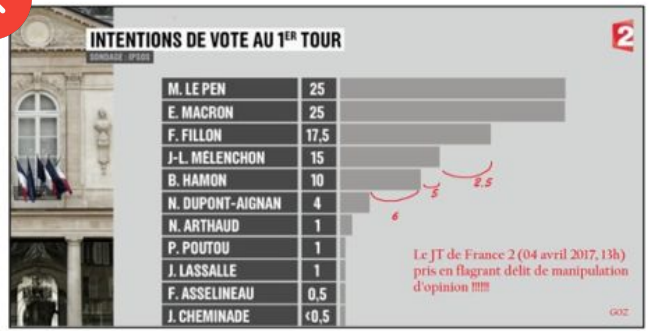
$$\text{Lie Factor} = \frac{\text{size of effect shown in graphic}}{\text{size of effect in data}}$$

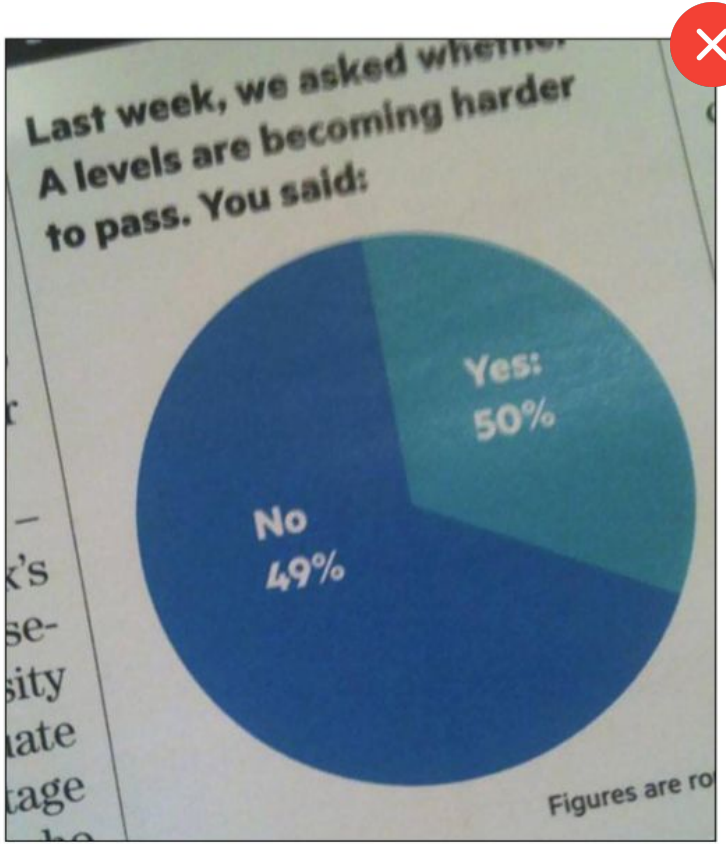
Optimal Lie Factor = [0.95, 1.05]

Using **partial range bars misleads the reader** to think the difference is bigger

6) Do not mislead the reader. Really.

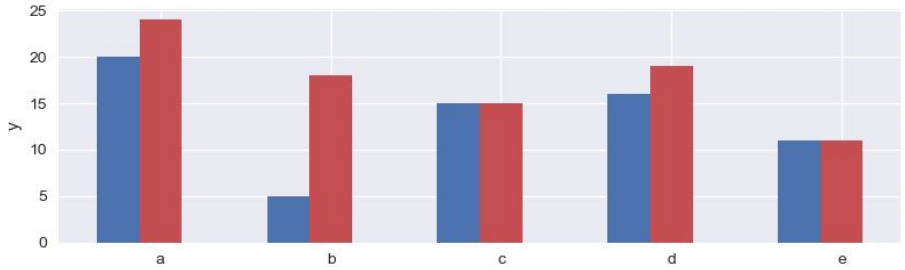


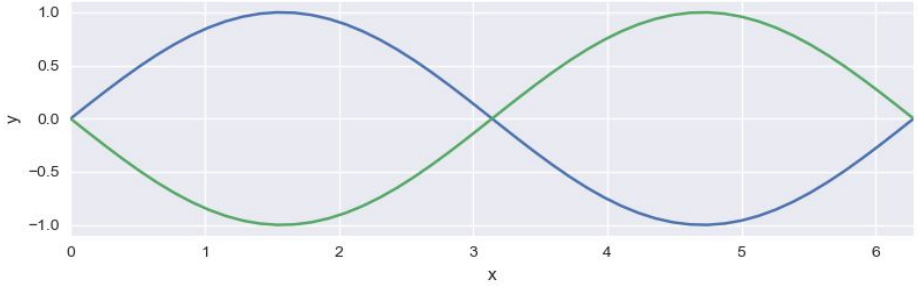


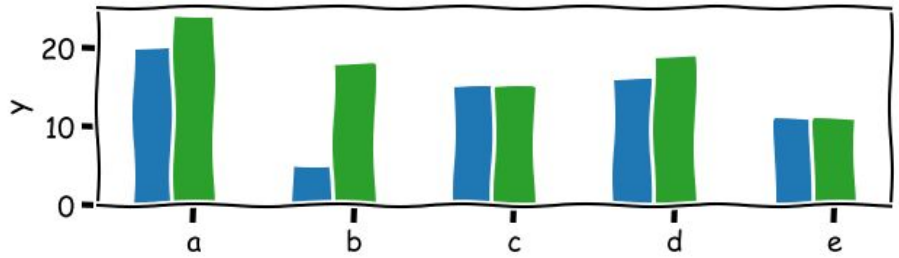


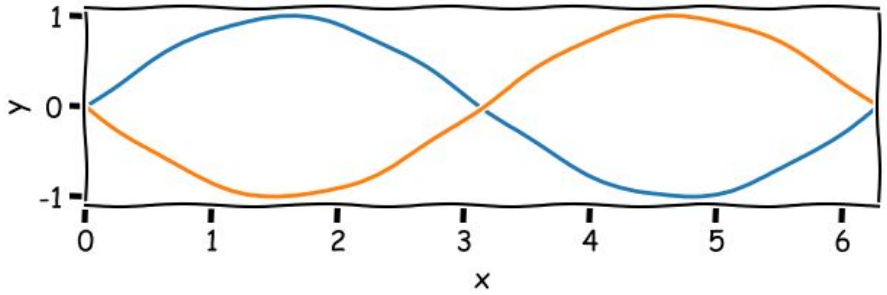
7) Message trumps beauty:

To convey an idea, sometimes an sketch suffices









8) Get the right tool

PDFCrop to remove white borders

GraphViz for creating easy graphs

ImageMagick for scripted image processing

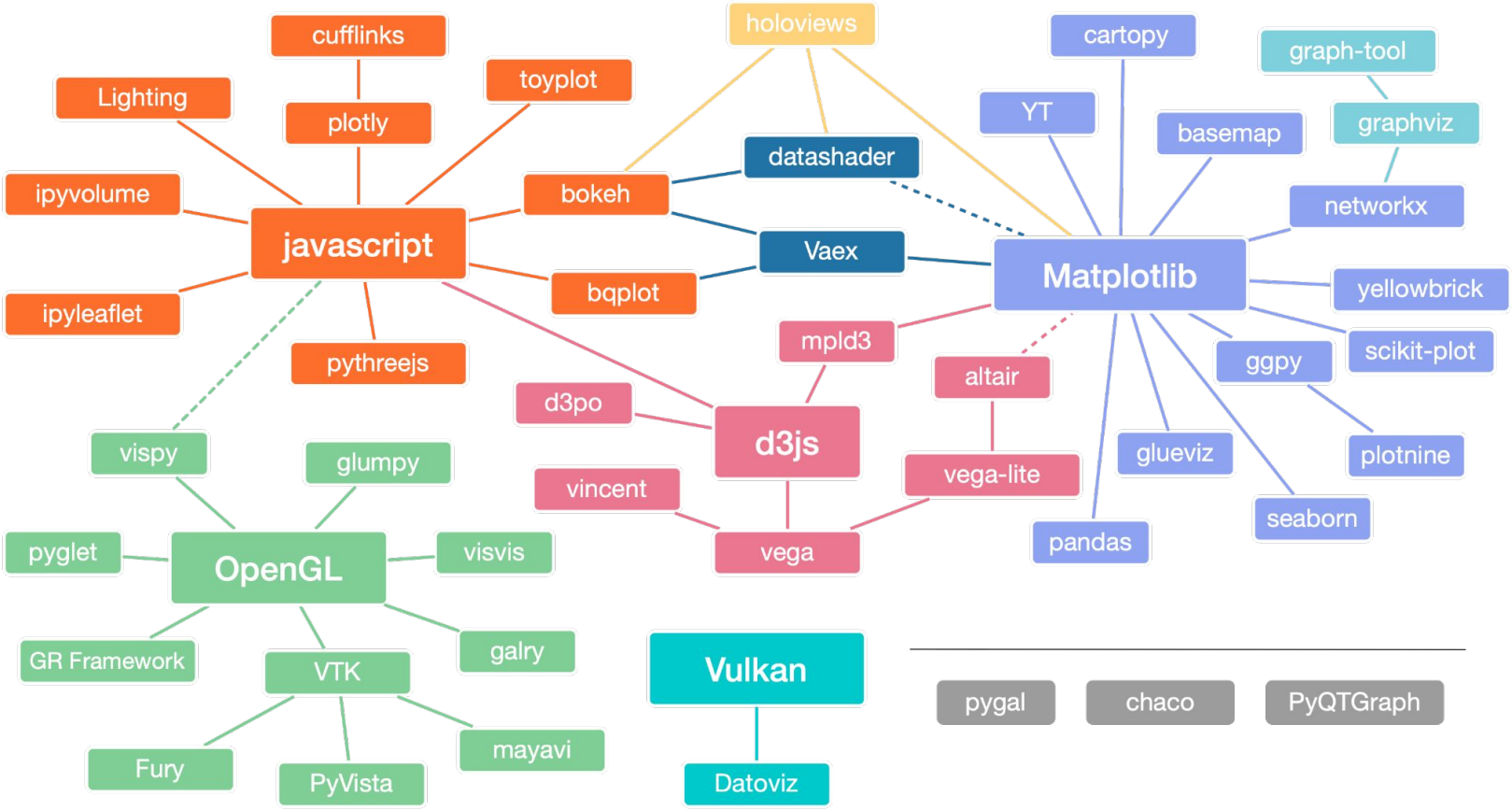
Gimp for bitmap image manipulation

Inkscape for vector image manipulation

Tikz for scripted vector art

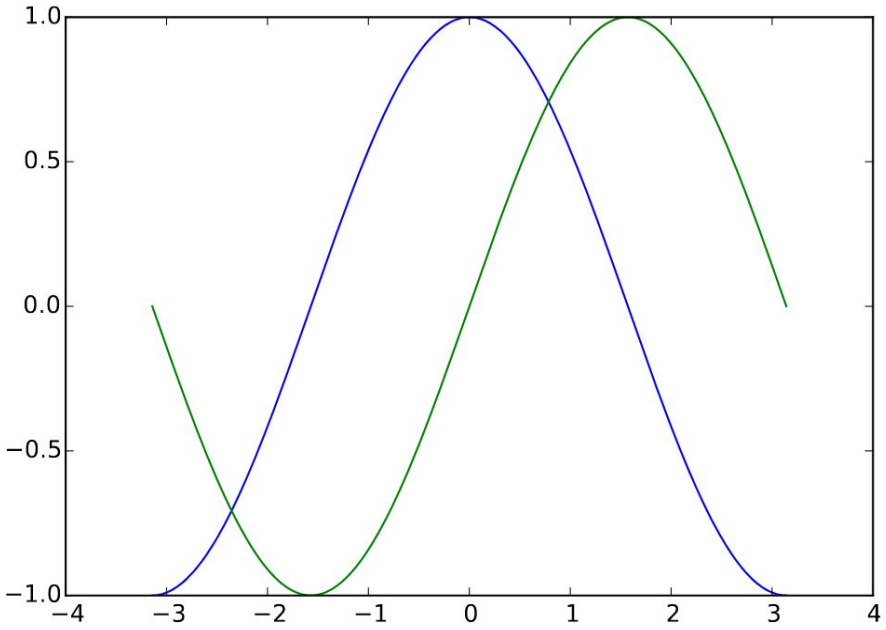
And many, many, many others…

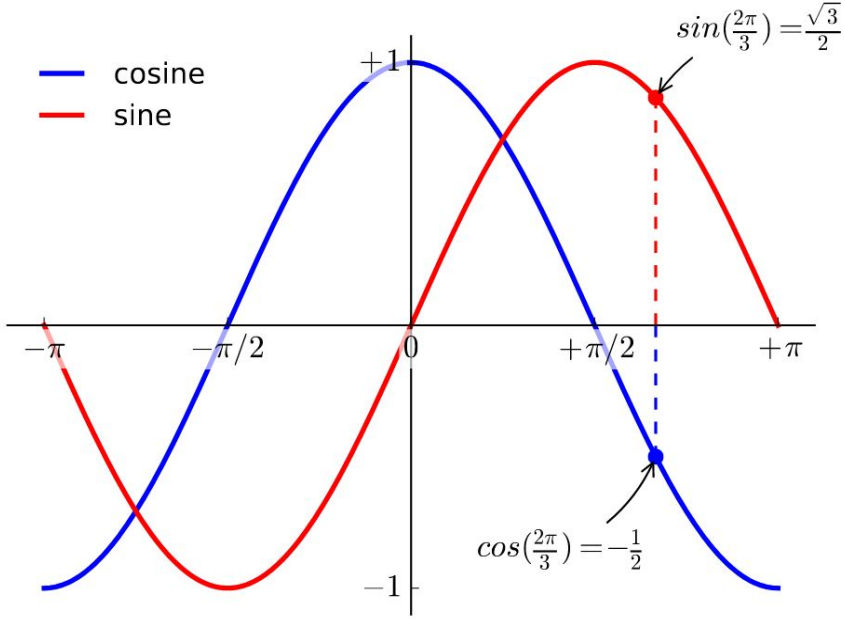
Overview of visualization libraries



9) Do not trust the defaults

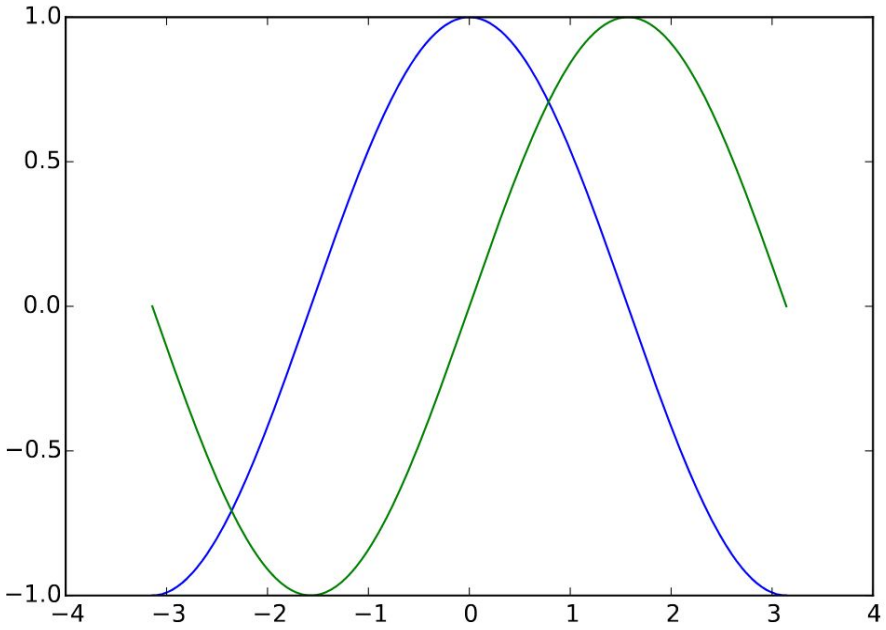
Matplotlib defaults



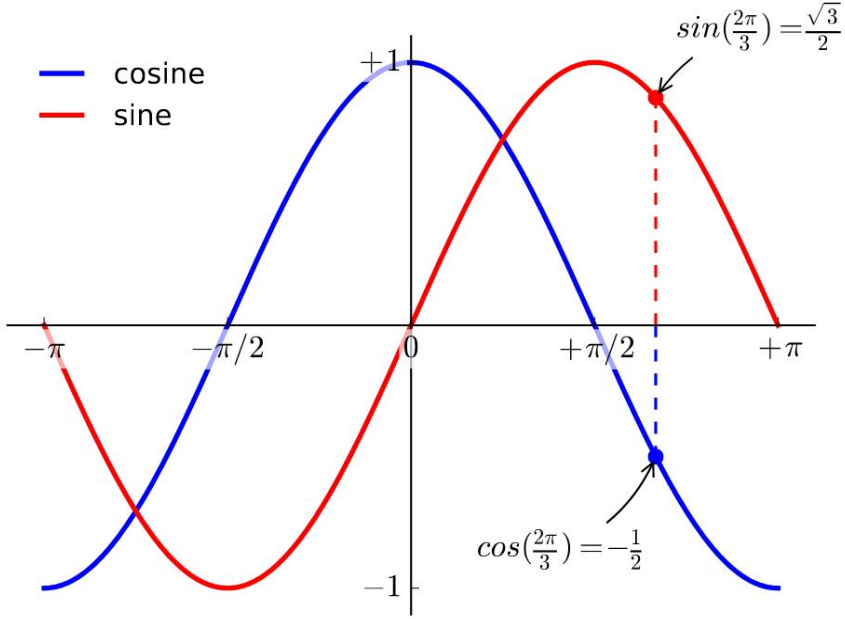


9) Do not trust the defaults

Matplotlib defaults



With a bit of work….
(Exercise 1 today)



10) Use color effectively → more on this later

Graphical excellence:

- is the well-designed presentation of data – a matter of substance, of statistics, and of design
- consists of complex ideas communicated with clarity, precision, and efficiency

- gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space

- is nearly always multivariate
- requires telling the truth about the data

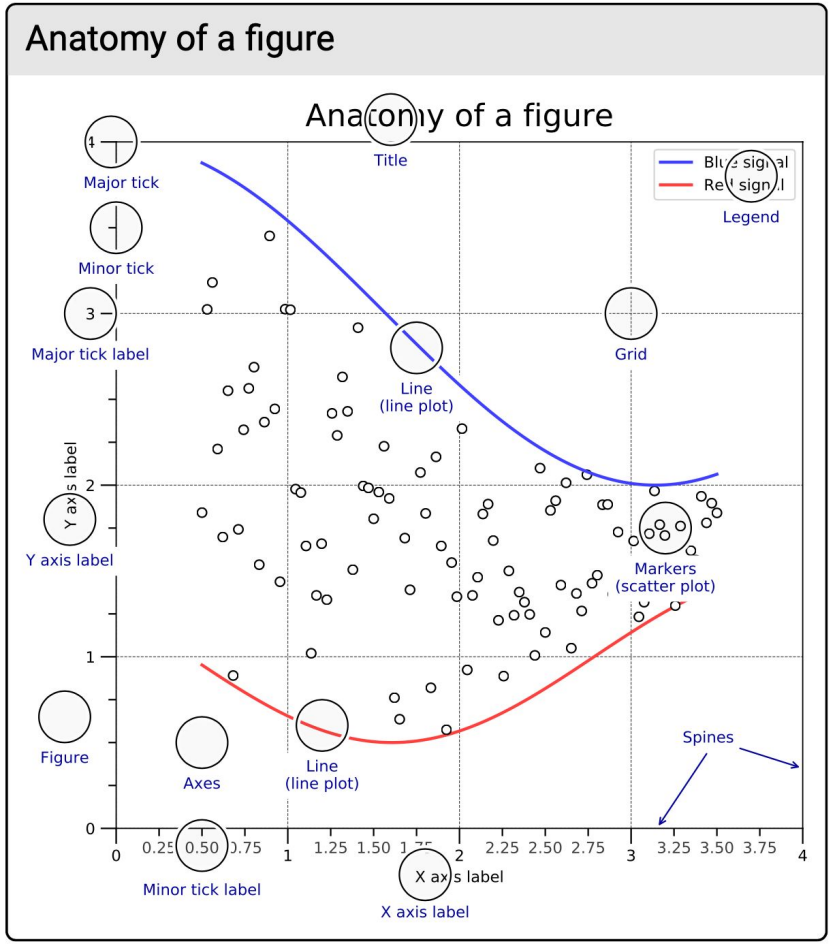
adapted from *The Visual Display of Quantitative Information,* Edward Tufte

Time for hands-on exercises!

Notebook 1: Mastering matplotlib

Have your cheatsheet at hand!:

https://matplotlib.org/cheatsheets/



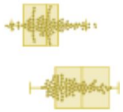
An useful tool:

datavizcatalogue.com

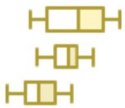
Distributions: one continuous variable

Barcode Plot

Bean Plot

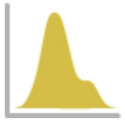


Bee Swarm Box Plot



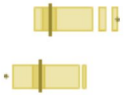
Box Plot

Box-Percentile Plot



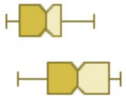
Density Plot

Dot Distribution Plot



HDR Box Plot

Histogram



Notched Box Plot

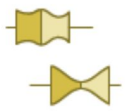
Population Pyramid

Q-Q Plot

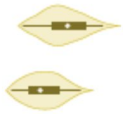
Ridgeline Plot

Sina Plots

Stem & Leaf Plot



Vase Plot



Violin Plot

Proportions, parts-to-a-whole and Flow

Bubble Chart

Bubble Map

Circle Packing

Demers Cartogram

Dorling Map

Marimekko Chart

100% Stacked Bar Chart

Donut Chart

Waffle Chart

Parallel Sets

Pie Chart

Proportional Area Chart

Sankey Diagram

Treemap

Unit Chart (Area)

Alluvial Diagram

Flow Diagram

Comparisons: more than one variable

Bar Chart

Bullet Graph

Column Chart

Dot Graph

Grouped Bar Chart

Lollipop Chart

Pictogram Chart

Radial Column Chart

Side by Side Bar Chart

Slopegraph

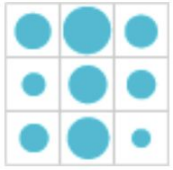
Stacked Bar Chart

Unit Chart

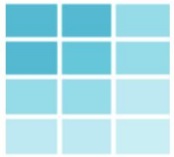
Radar Chart

Correlations and Uncertainty/Error

Bubble Chart



Correlation Matrix

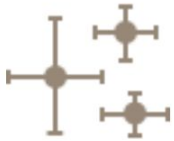


Heatmap

Scatterplot

Area Bands

Confidence Strips



Error Bars

Graded Error Bars

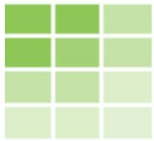
Data over time: timeseries

Area Graph

Connected Scatterplot

Control Chart

Gantt Chart



Heatmap

Horizon Plot

Line Graph

Run Chart

Spiral Plot

Stacked Area Graph

Streamgraph

Timeline

Connections and Hierarchy

Arc Diagram

Circular Tree Diagram

Connection Map

Hive Plot

Network Diagram

Non-ribbon Chord Diagram

Circular Tree Diagram

Circular Treemap

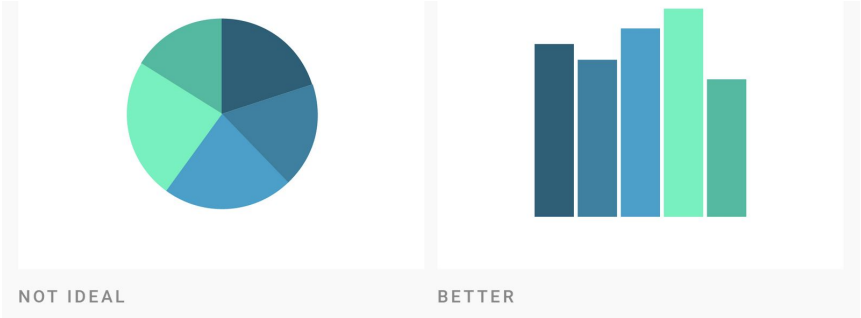
Icicle Chart

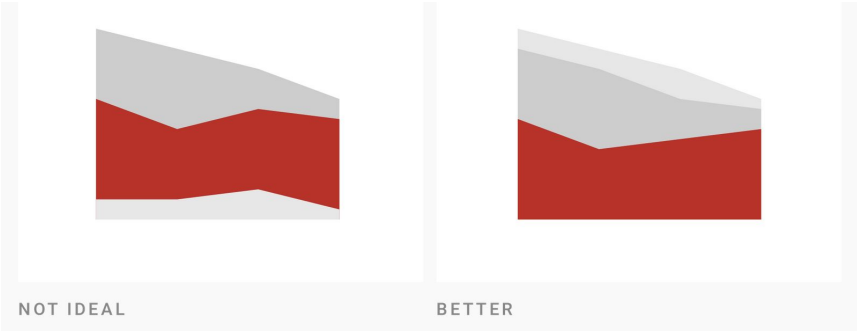
Sunburst Diagram

Tree Diagram

Treemap

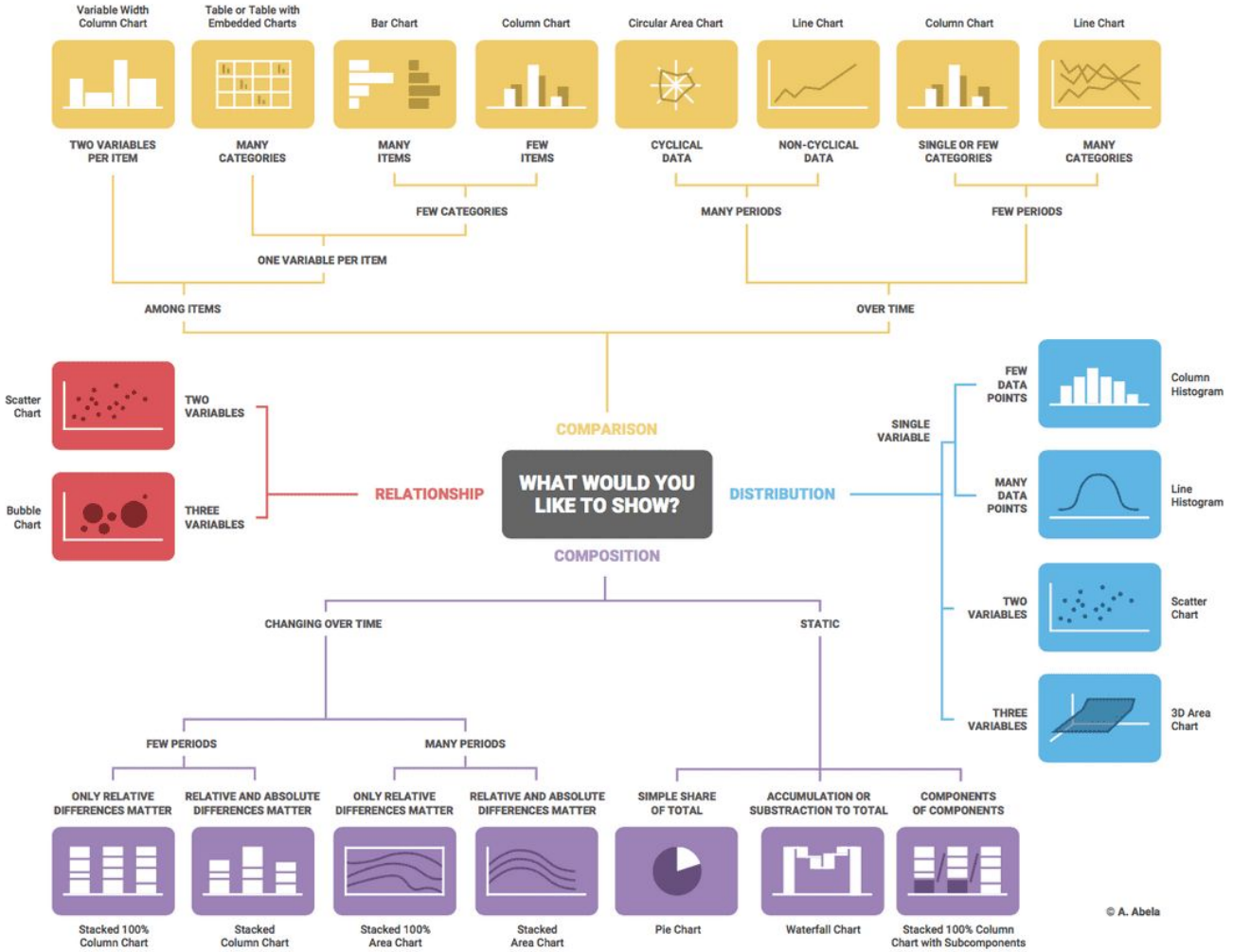
Each data structure has a better graphic type to represent it





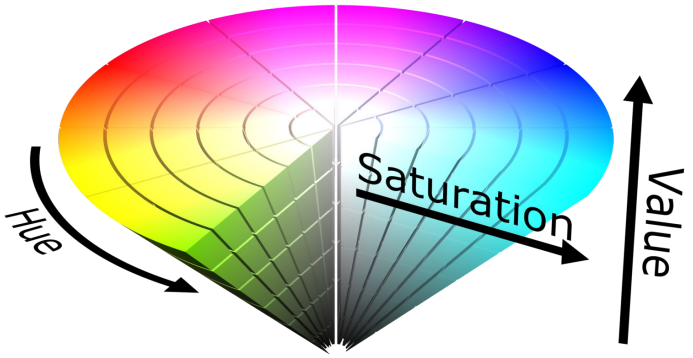
Another,
older tool

Chart
suggestions
by Abela



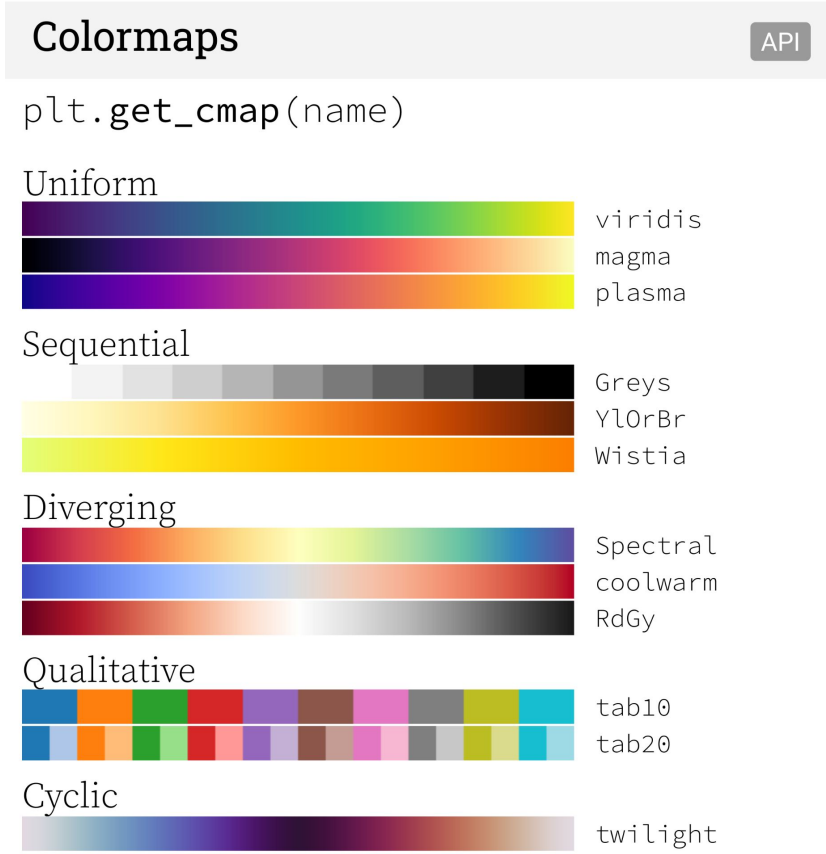
6) Use color effectively

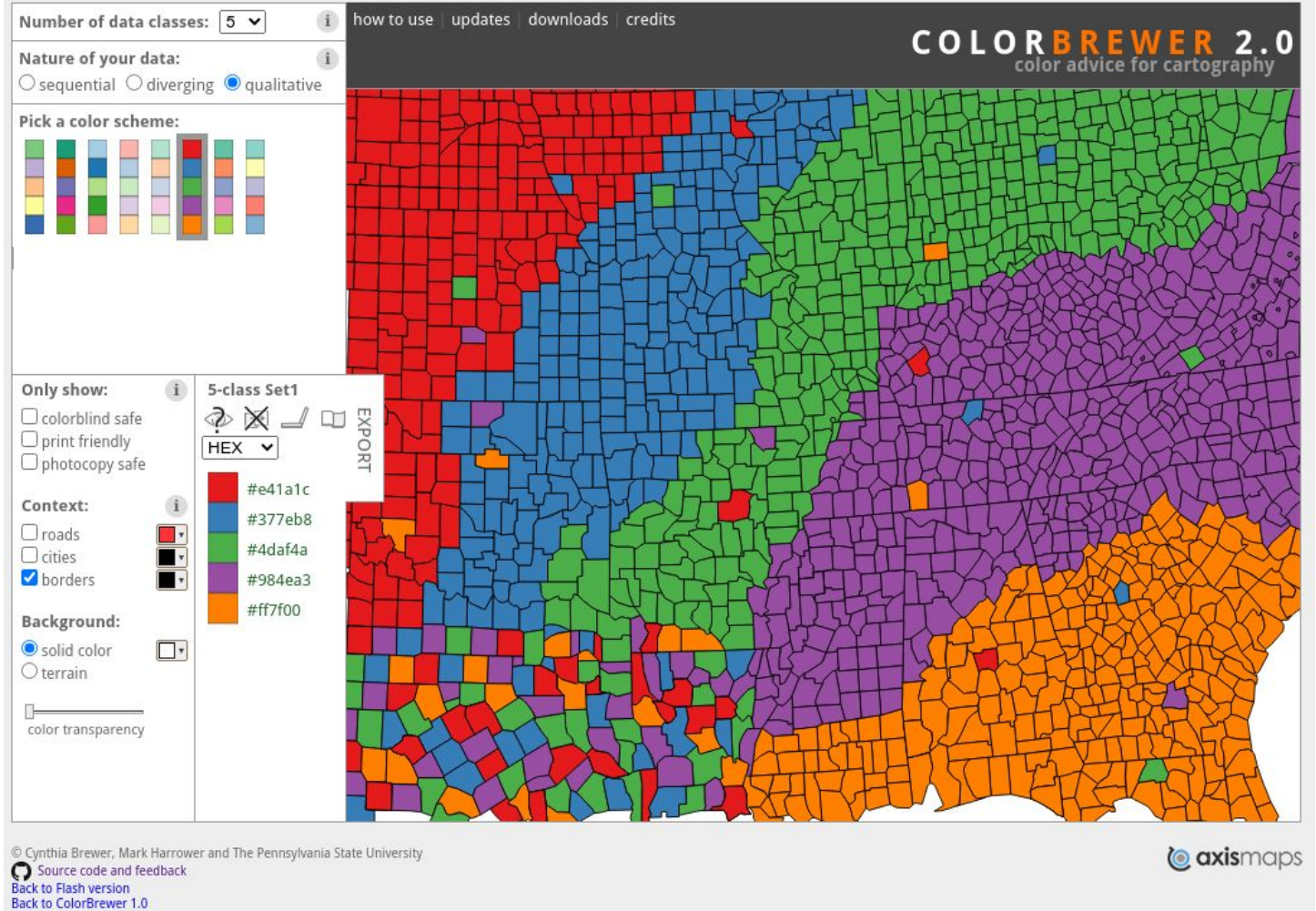
Three dimensions of color: Hue, saturation and brightness



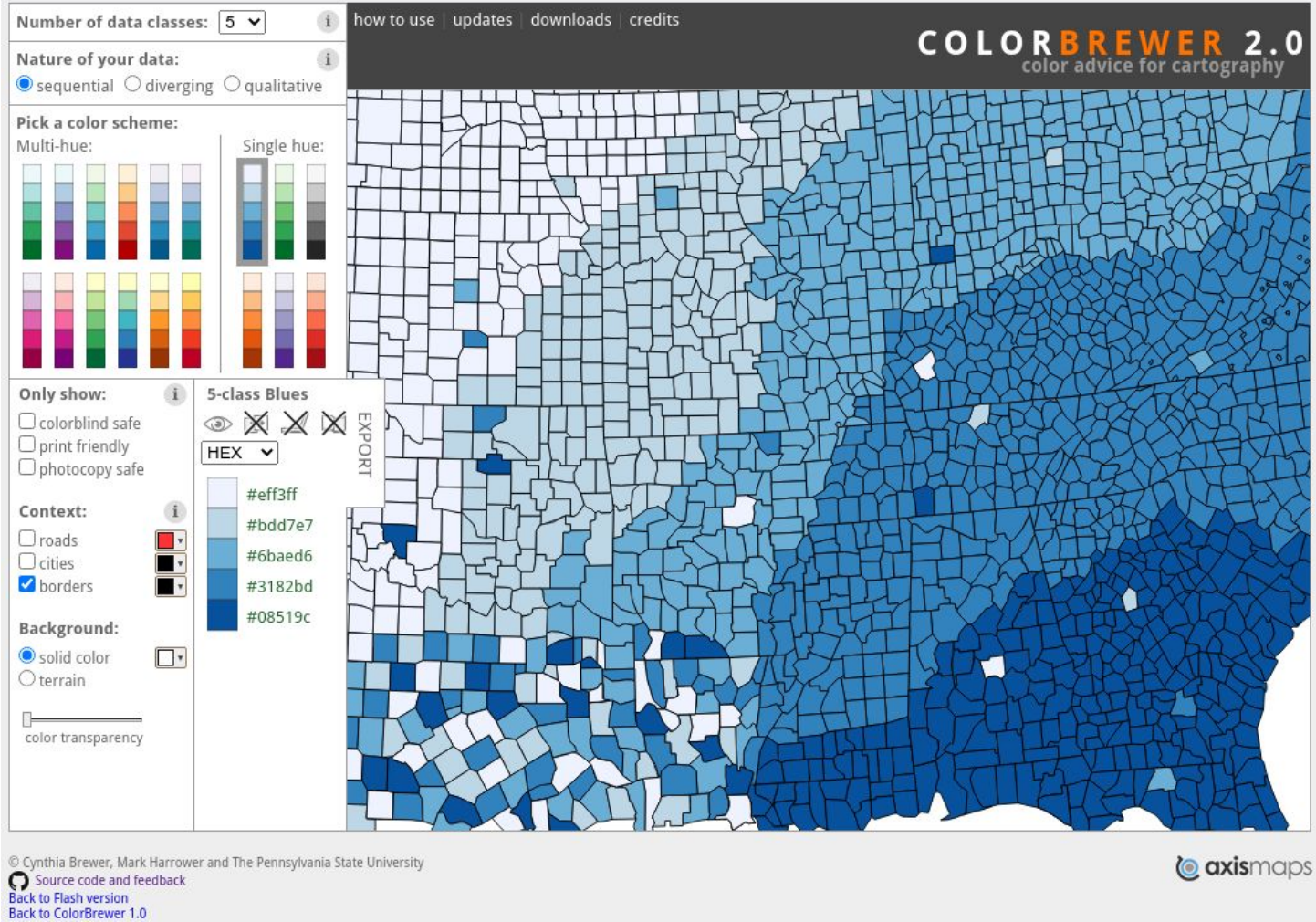
Types of color scales

- **Qualitative/categorical**: data with no order
  - e.g. cities, countries
- **Sequential**: increasing or decreasing data
  - e.g. year
- **Diverging**: data with a natural zero
  - e.g. % change, temperature
- **Circular**
  - e.g. orientation, direction



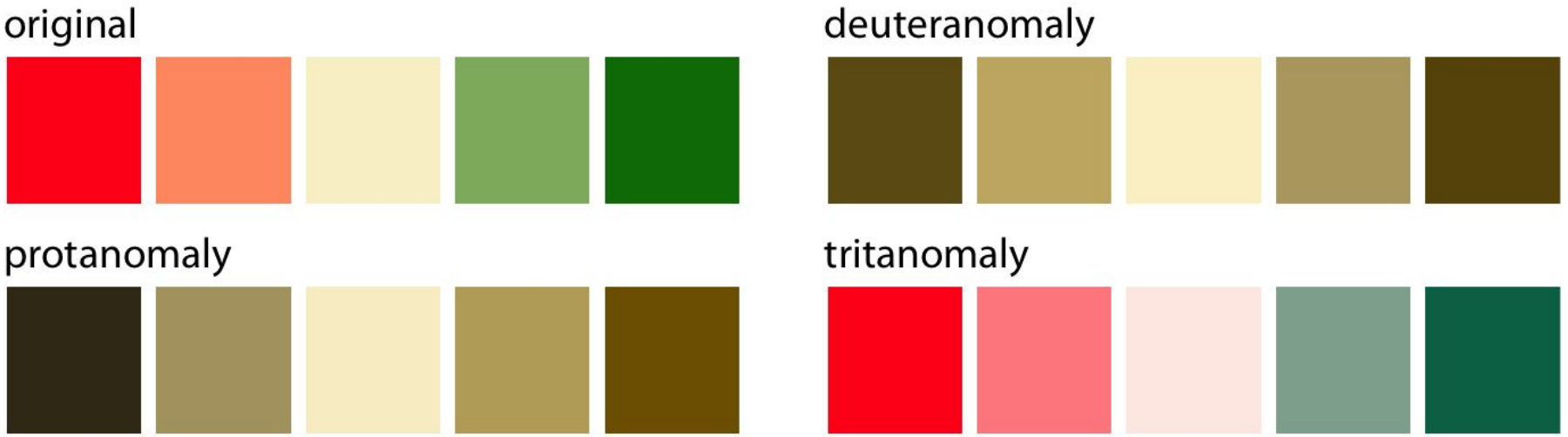


https://colorbrewer2.org



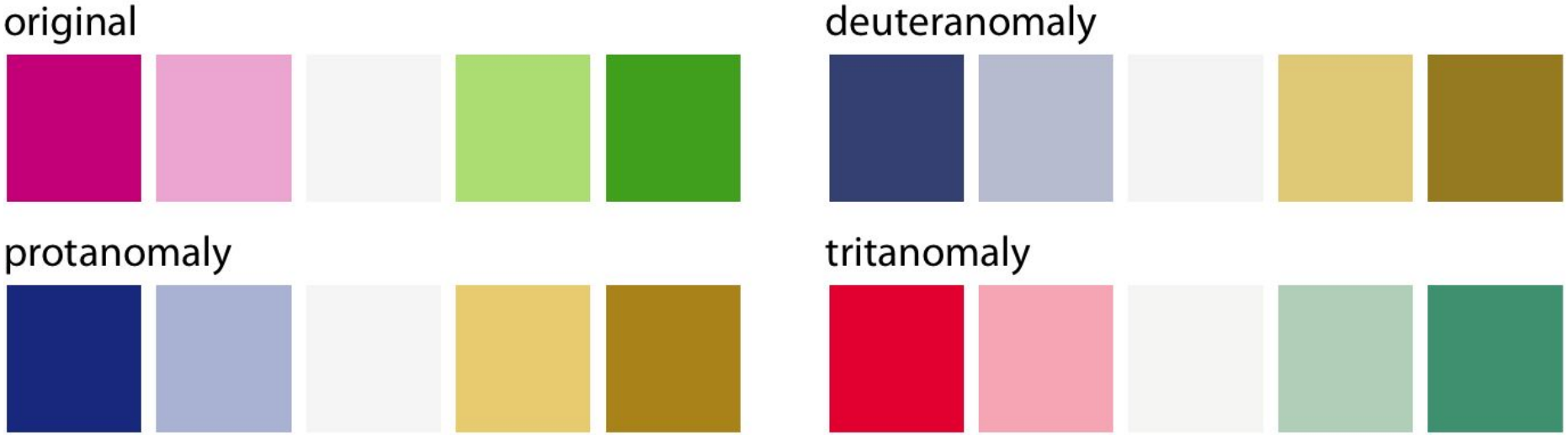
https://colorbrewer2.org

Consider colorblindness



A red–green contrast becomes indistinguishable under red–green color vision deficiency (deuteranomaly or protanomaly) From Wilke (2019)

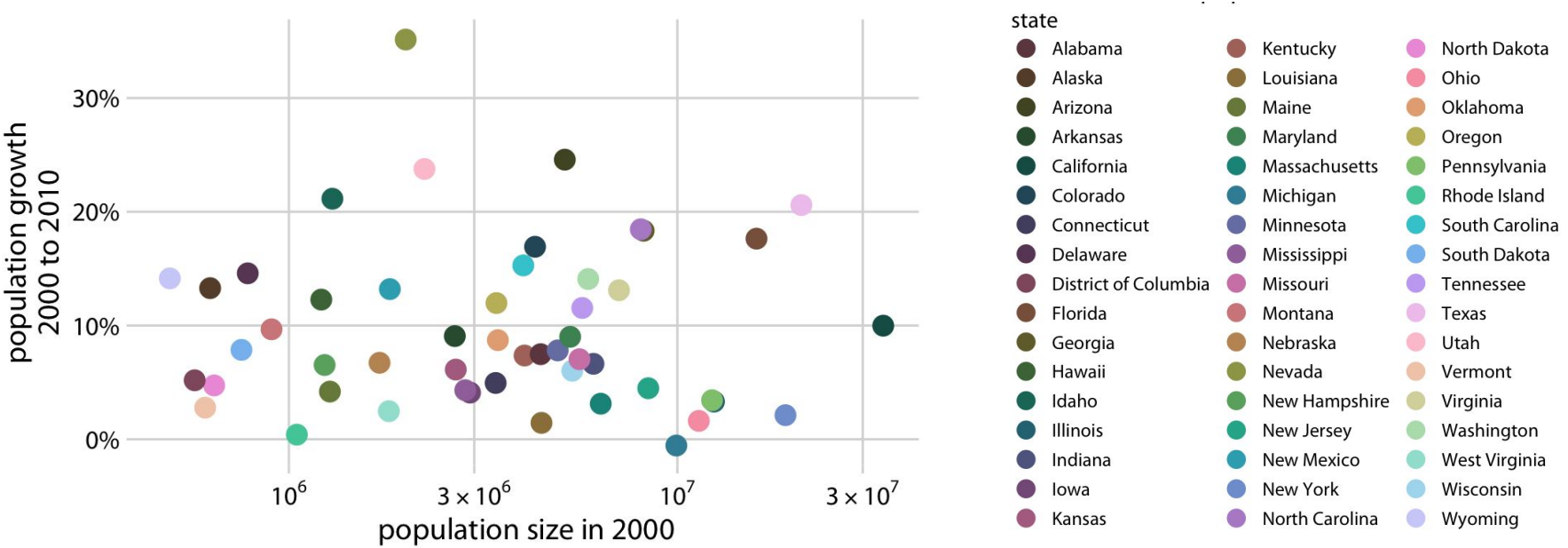
Consider colorblindness



The ColorBrewer PiYG (pink to yellow-green) scale looks like a red–green contrast to people with regular color vision but works for all forms of color-vision deficiency.

From Wilke (2019)

Common pitfall: encoding too much information



Claus O. Wilke (2019)

Common pitfall: using the wrong color scale

rainbow scale

rainbow converted to grayscale

The jet/rainbow color scale is **NOT a sequential** colormap,

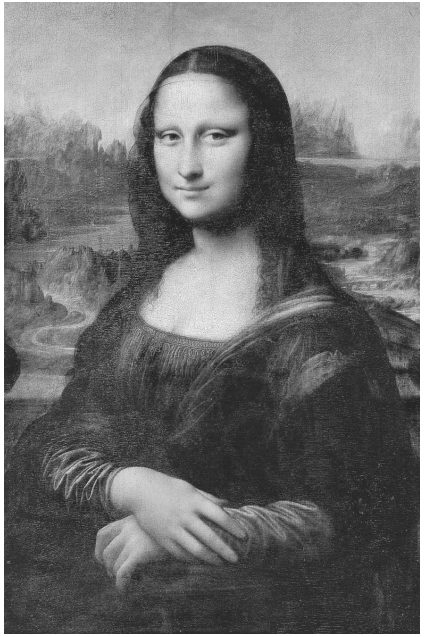
→ our perception of it is NOT linear but **circular!**

So do not use it for data that is not circular.

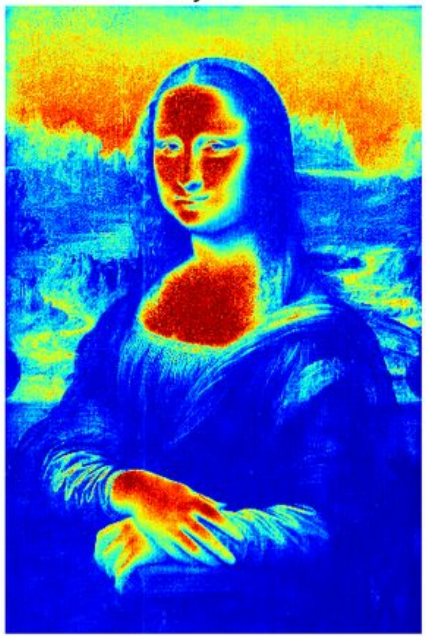
Common pitfall: using the wrong color scale

Colour

Grey

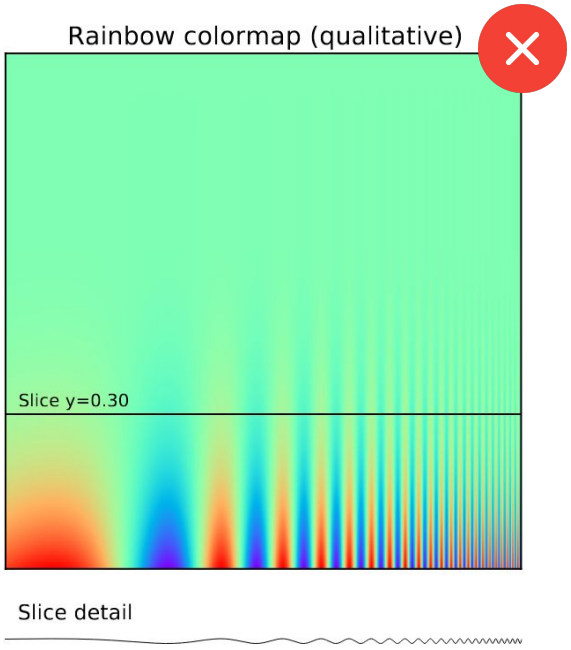


Jet

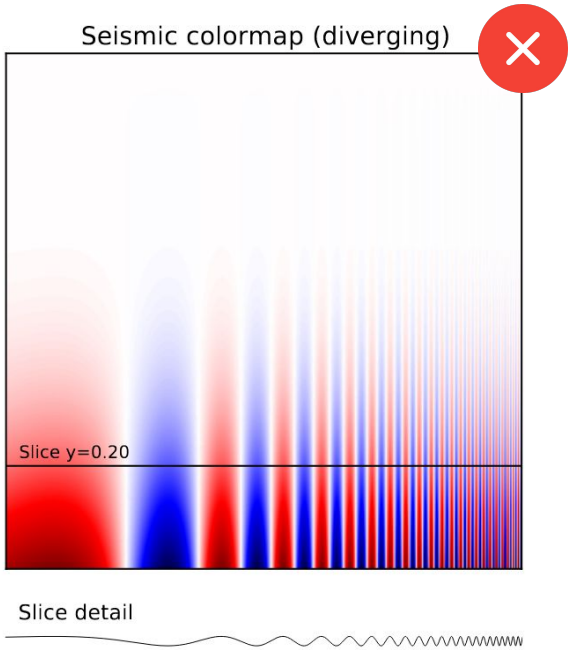


Viridis

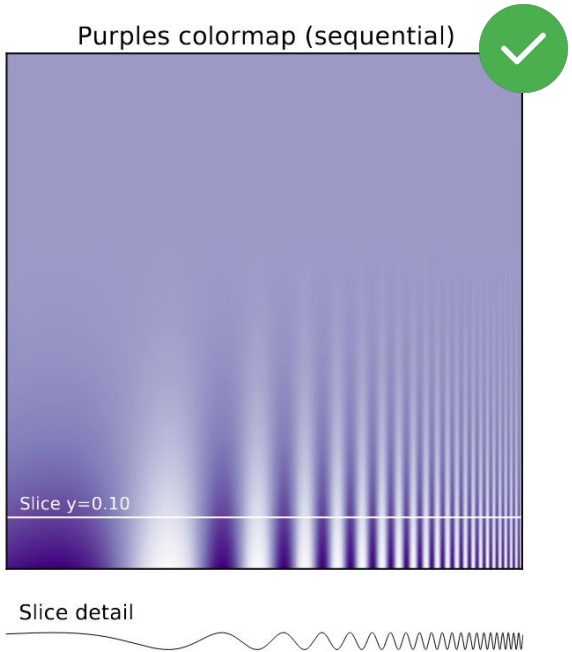
Common pitfall: using the wrong color scale



Qualitative: rapid variation of colors, used mainly for discrete/categorical data.



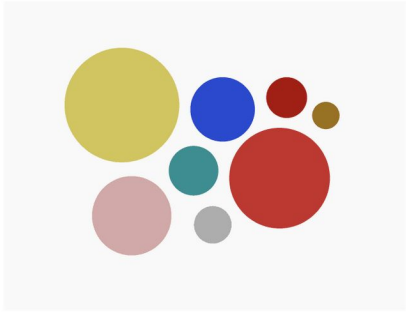
Diverging: variation between colors used to highlight deviation from a median value



Sequential: variation of a unique color, used for quantitative data varying low to high.

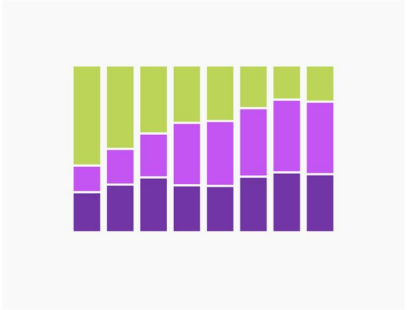
Broaden your understanding of colors

NOT IDEAL



BETTER

Use warm colors & blue

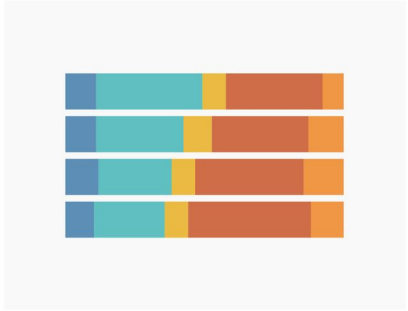


NOT IDEAL

BETTER

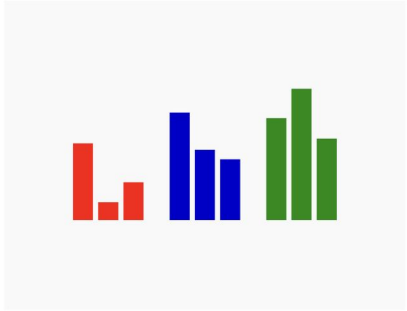
Don’t dance all over the color wheel

NOT IDEAL



BETTER

Avoid pure colors

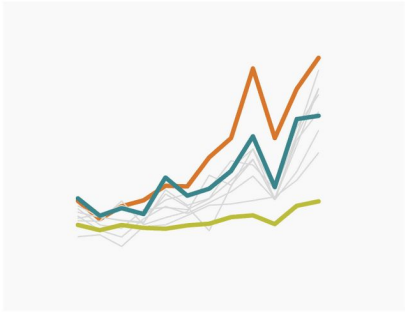


NOT IDEAL

BETTER

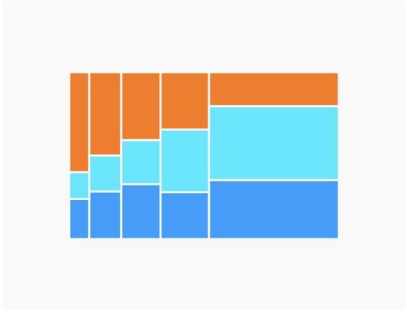
Make your colors similarly “colorful”

NOT IDEAL



BETTER

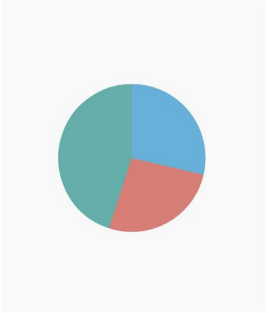
Use saturation and lightness to make your hues work



NOT IDEAL

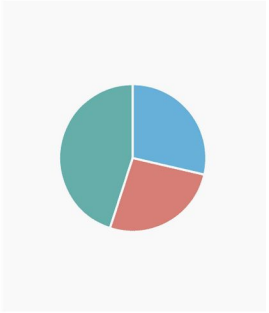
BETTER

Combine colors with different lightness



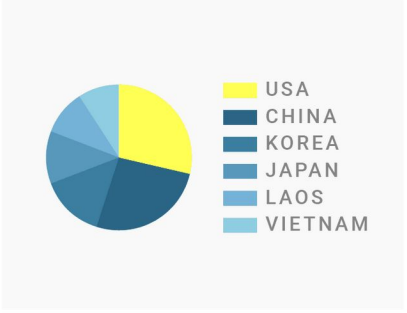
NOT IDEAL

BETTER

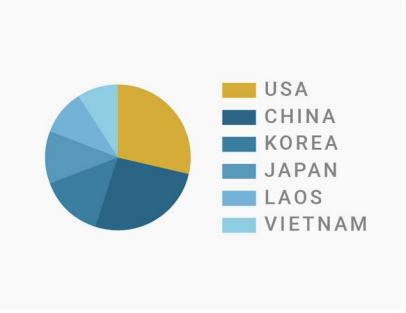


BETTER

Avoid bright, saturated colors



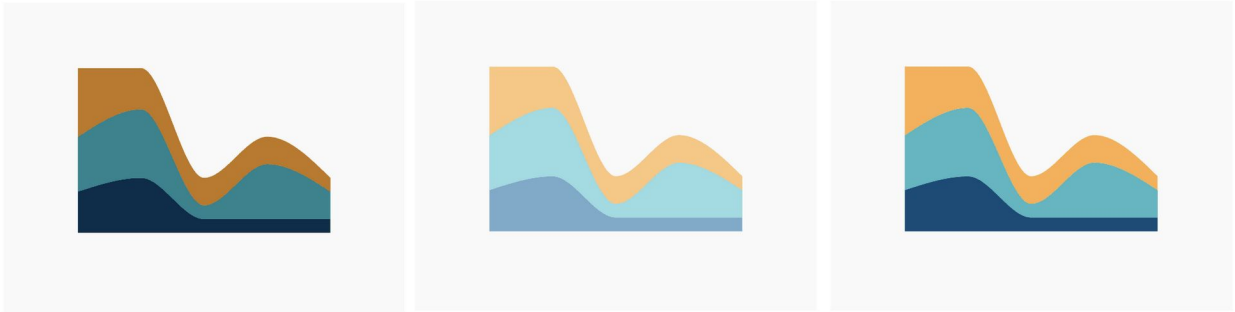
NOT IDEAL



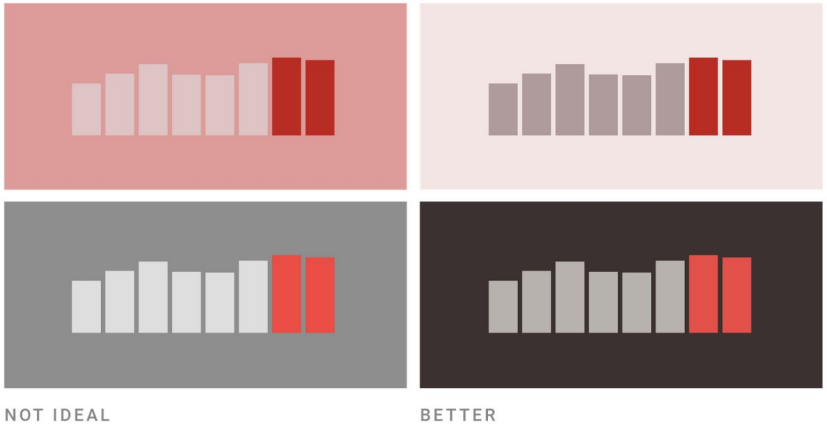
BETTER

Colors choice

Avoid too little/much contrast with the background



Choose a background that is desaturated enough



Exercise 2: which visualization should I use?

Goal: a visualization that is *publication-ready*

- Work in pairs, develop in your fork
- Do only 1 exercise (A - E)
- Do a Pull Request when ready.
- We'll review your visualizations and comment them together

Have your cheatsheet at hand!: https://matplotlib.org/cheatsheets/

Exercise:

Terrible figures are given with code.

Their task is to modify them to make them publication ready. That means to choose color appropriately, change type of plot, change fontsizes, remove spines, unnecessary lines, uncrowd the figure. Finally save it as vector graphics.

Learning goal: put into practice principles just discussed. Learn implementation level, how to do it in matplotlib.

Extra-Material (from ASPP-2021)

- **Scales & projections** (**notebook**). Tutorial on different type of scales (log scale, symlog scale, logit scale) and projections (polar, 3D, geographic).
- **Animation** (**notebook**). Animation with matplotlib can be created very easily using the animation framework. This notebook shows how to create an animation and save it as a movie.

Further Resources

At the implementation level (code, galleries and how-tos):

- **Seaborn library**, a library for statistical data visualization. Very recommended as a next step in your learning journey.
- **Matplotlib Cheatsheets**, Nicolas P. Rougier (2020)
- **Scientific Visualization – Python & Matplotlib**, open-source book from Nicolas P. Rougier (2021)
- **Python Graph Gallery**, Yan Holtz (2017)
- **Matplotlib Gallery**, Matplotlib team

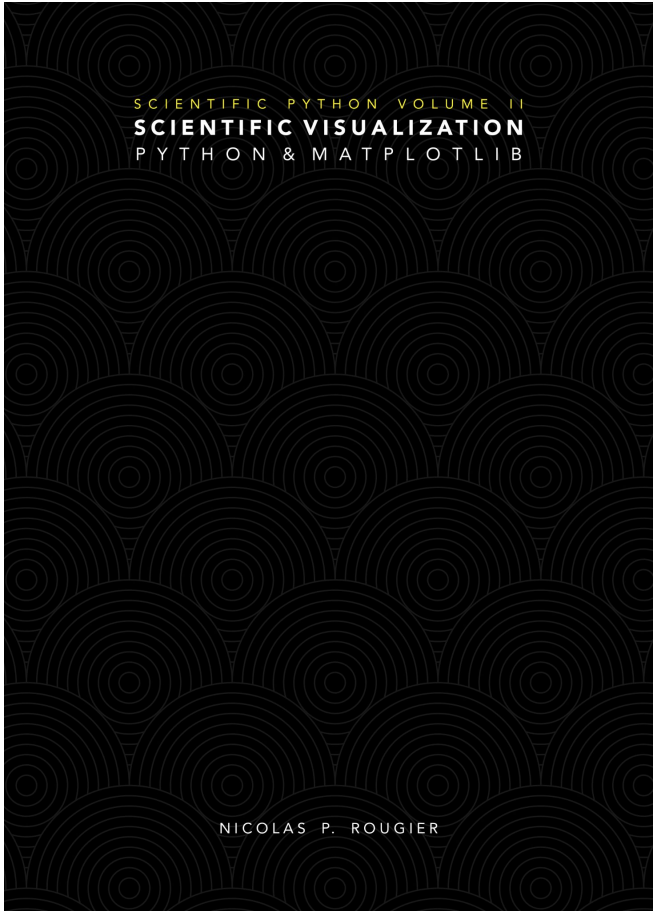
At the conceptual level :

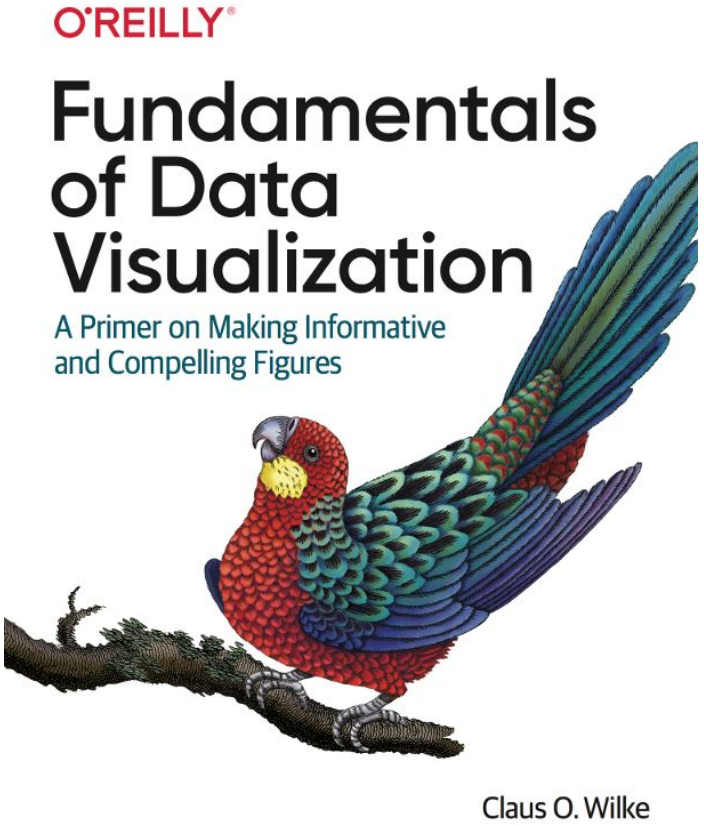
- **Ten simple rules for better figures**, Nicolas P. Rougier, Michael Droettboom, Philip E. Bourne (2014)
- **Fundamentals of Data Visualization**, book by Claus O. Wilke (2019)
- **Chart Suggestions - a though-starter** by A. Abelas.
- **Data Visualization Catalogue**
- **Edward Tufte**'s series of books: The Visual Display of Quantitative Information (1983), Envisioning Information (1990), Beautiful Evidence (2006), etc.

Interactive visualizations:

- **Widgets in Jupyter notebook**
- **Plotly**

Selected further resources

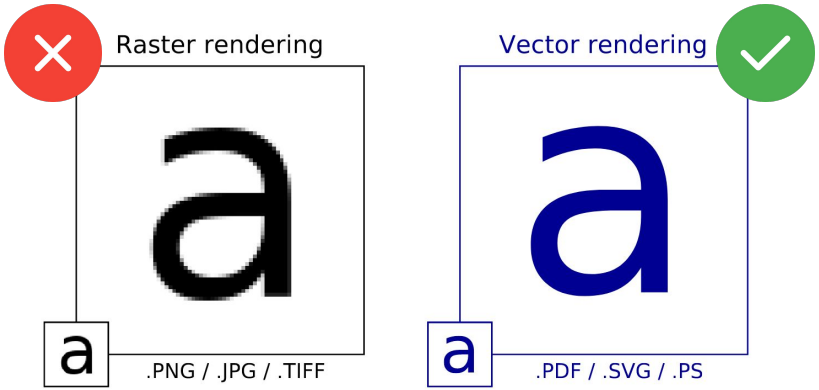


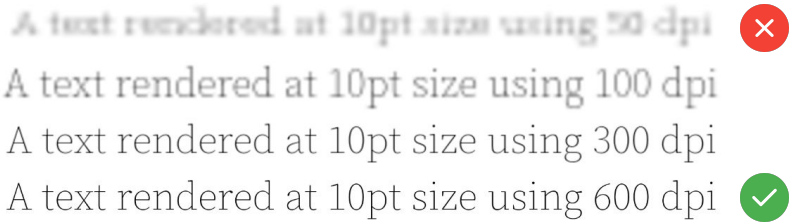


Some extra tips

Exporting a figure: vector format!

As a rule of thumb: Save in vector format and with enough DPI (dots per inch)





Bitmap formats

PNG: Portable Network Graphics (lossless)
JPG: Joint Photographic Experts Group (lossy)

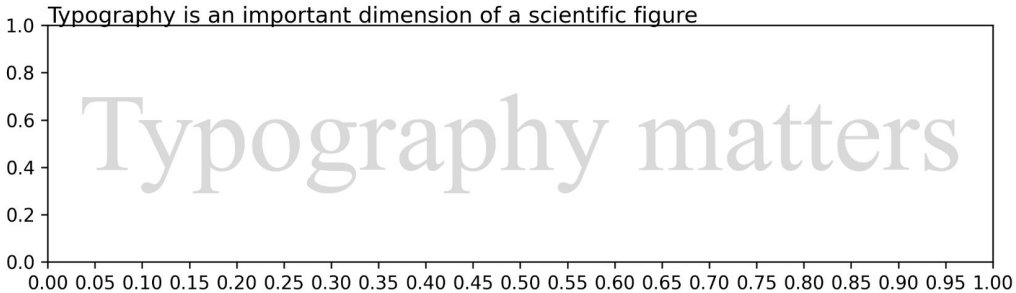
Vector formats

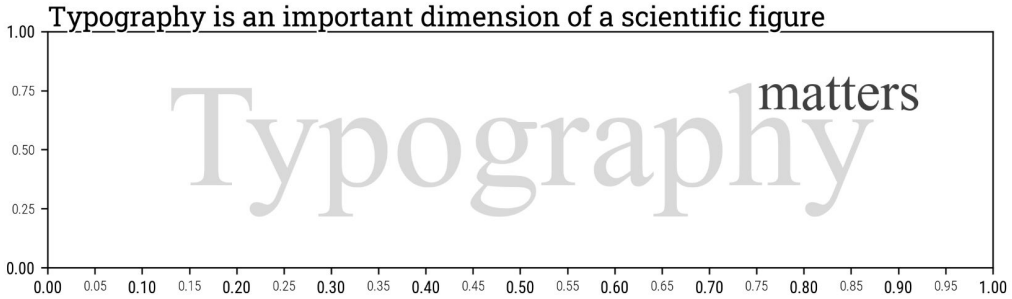
PDF: Portable Document Format
SVG: Scalable Vector Graphics

Text rendered in matplotlib and saved using different dpi

Font stack choice

Influence of typography on the perception of a figure. Choose the right font for you.





Serif
DejaVuSerif.ttf

Sans
DejaVuSans.ttf

Serif
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Sans
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Serif
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Sans
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Monospace
DejaVuSansMono.ttf

Cursive
Apple Chancery.ttf

Monospace
RobotoMono-Regular.ttf

Cursive
Merienda-Regular.ttf

Monospace
SourceCodePro-Regular.ttf

Cursive
ITC Zapf Chancery.ttf

TODO

To talk about - ask Tiziano about Pelita and visualization exercise. → juntarnos con TIZ