ScaDS.AI
DRESDEN LEIPZIG

CENTER FOR SCALABLE DATA ANALYTICS AND ARTIFICIAL INTELLIGENCE

TOPIC: Data Visualization – some theory

SPEAKER: Jan Ewald, Laura Žigutytė

Thanks to Mara Lampert for the support in creating visuals for the slides.

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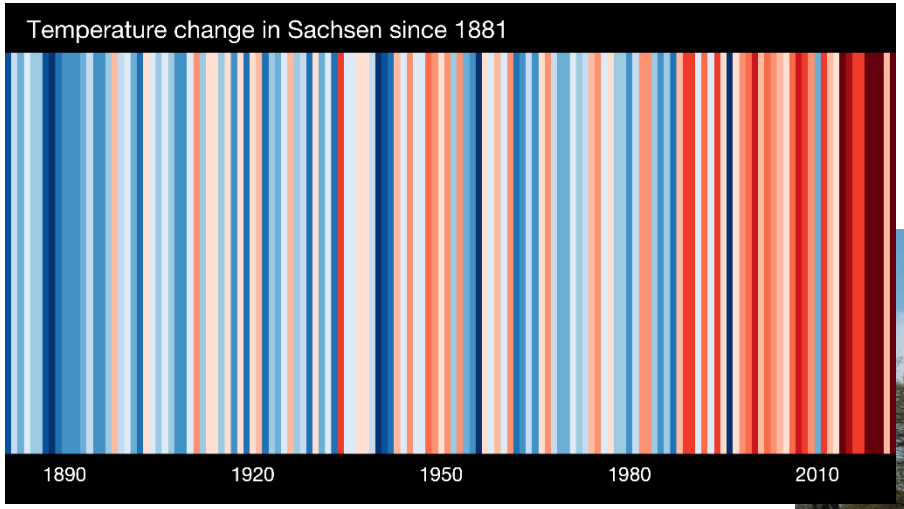
SACHSEN
Diese Maßnahme wird gefördert durch die Bundesregierung aufgrund eines Beschlusses des Deutschen Bundestages.
Diese Maßnahme wird mitfinanziert durch Steuermittel auf der Grundlage des von den Abgeordneten des Sächsischen Landtags beschlossenen Haushaltes.

Motivation – Example “warming stripes”

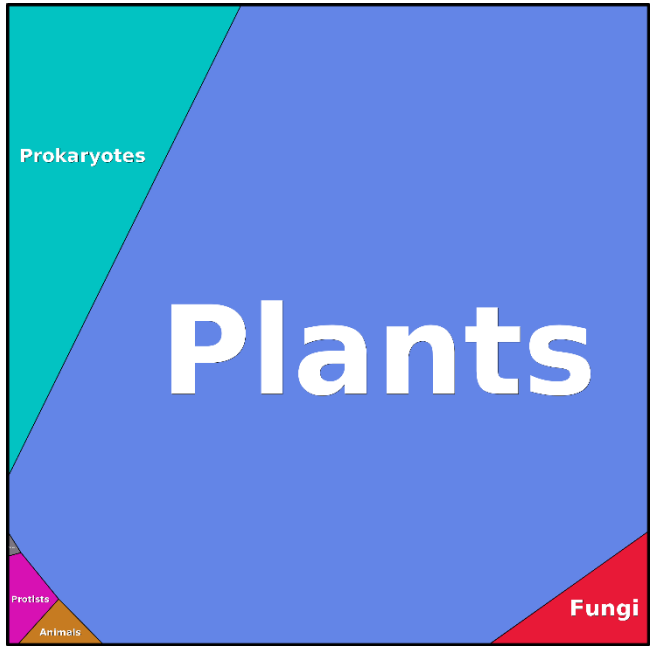


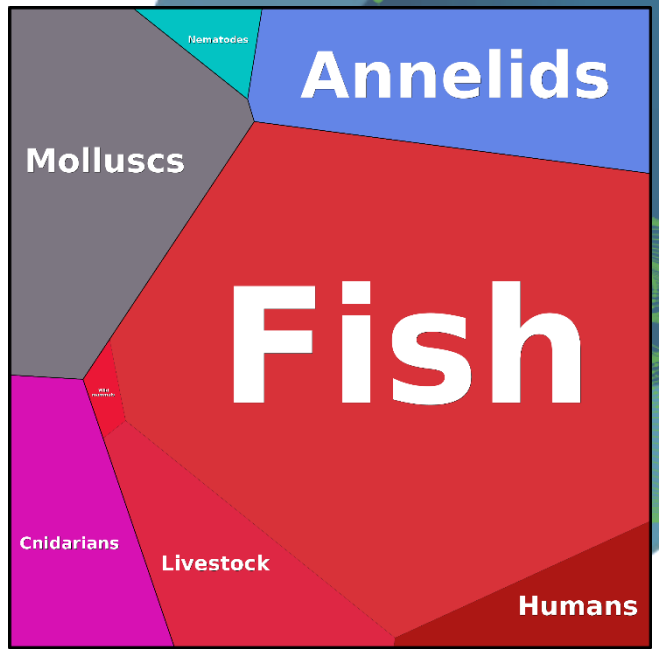
Ed Hawkins, University of Reading
https://showyourstripes.info/l/europe/germany/sachsen

Steffenster,licensed under CC-BY-SA https://commons.wikimedia.org/wiki/File:Warming_Stripes_on_the_Sachsenbr%C3%BCcke_Leipzig.jpg

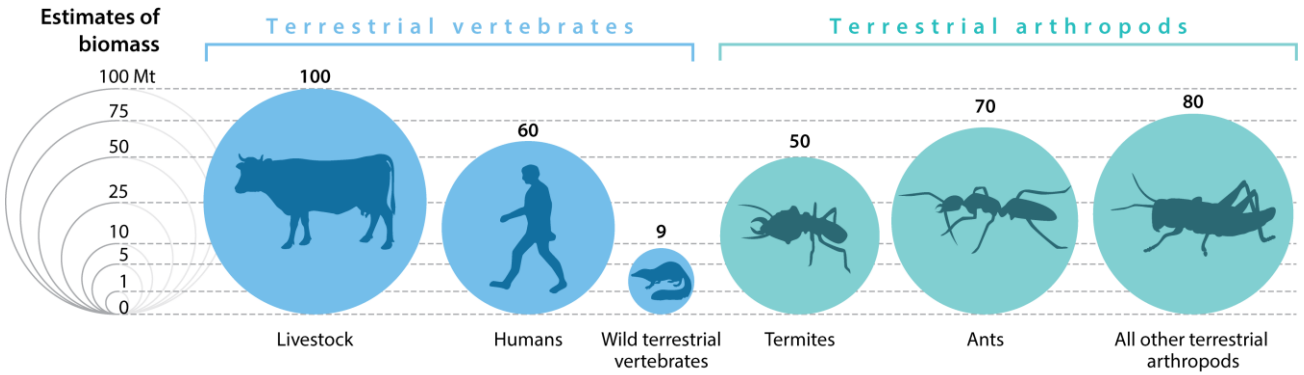
Motivation – biomass (1)

- Irregular shapes vs. quantification of areas
  - Voronoi-maps
  - Circles
- Color choices for species:
  - Plants are green
  - Fish -> ocean -> blue
  - Animal -> blood -> red





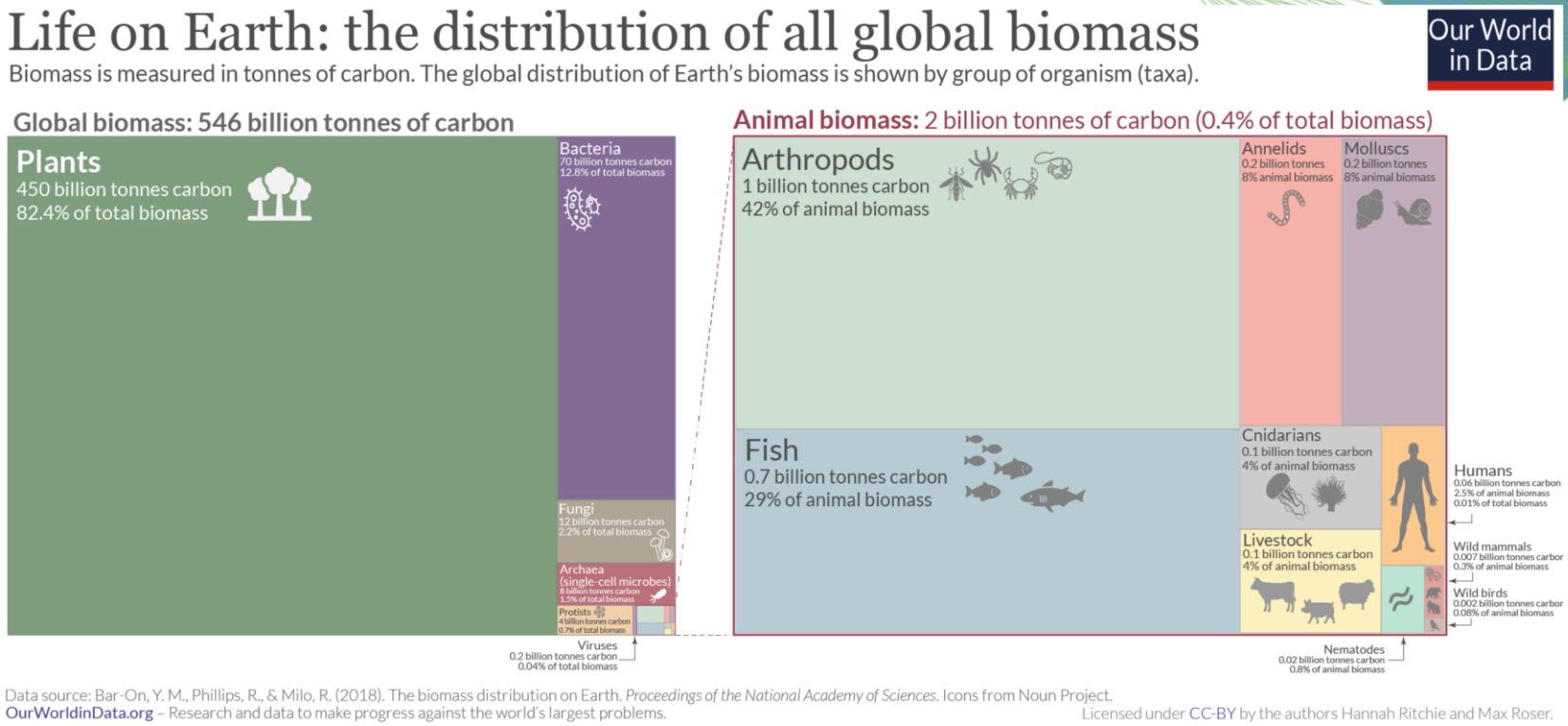
Self-created with http://bionic-vis.biologie.uni-greifswald.de/ based on:
Bar-On, Yinon M., Rob Phillips, and Ron Milo. "The biomass distribution on Earth." PNAS 115.25 (2018): 6506-6511.



Eggleton P. 2020.
Annu. Rev. Environ. Resour. 45:61–82

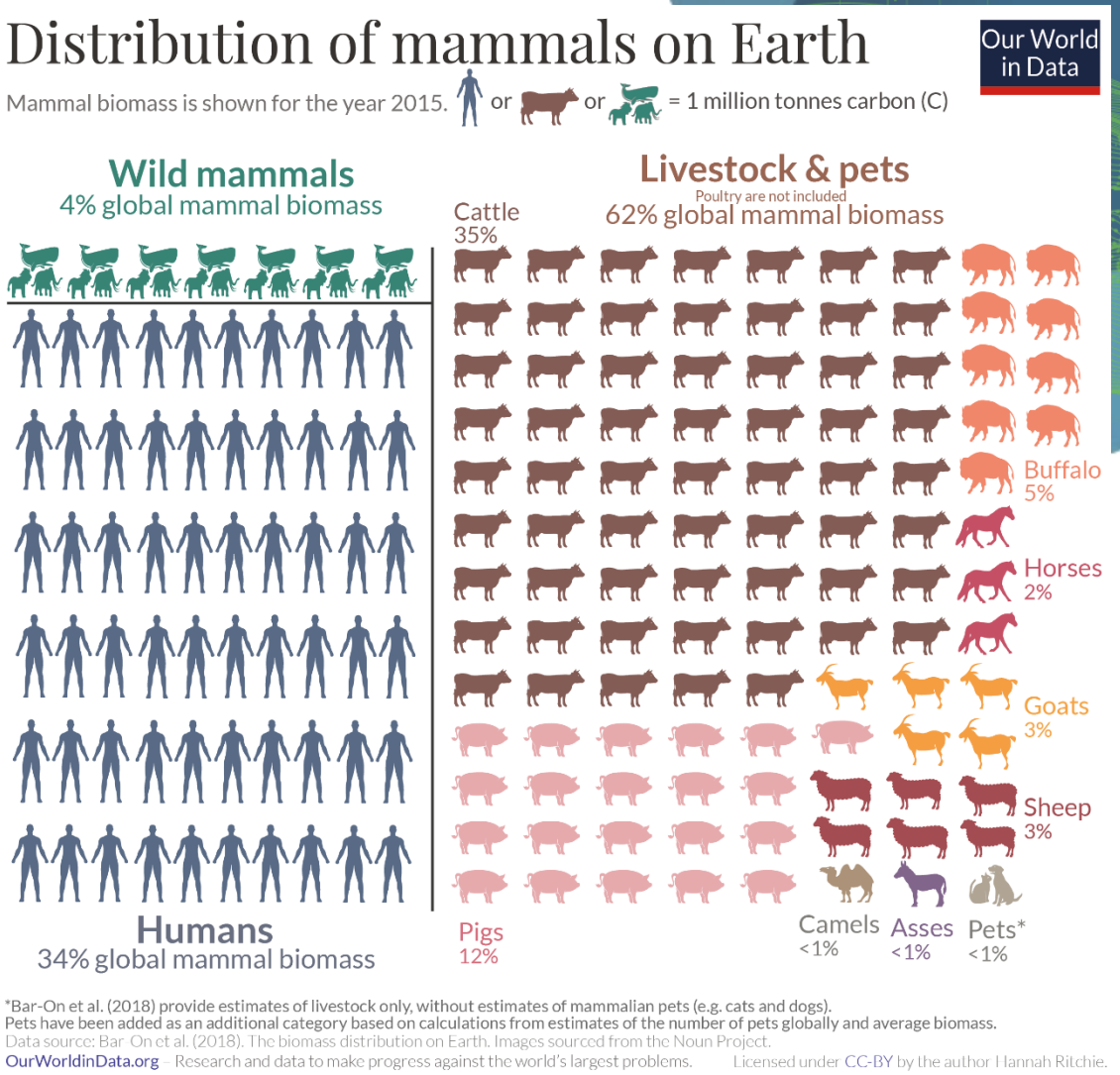
Motivation – biomass (2)

- Rectangles: quantification of areas
- Icons for species and annotation



Motivation – biomass (3)

- Fixed size of icons: make data countable!
- Intuitive icons and partially colors

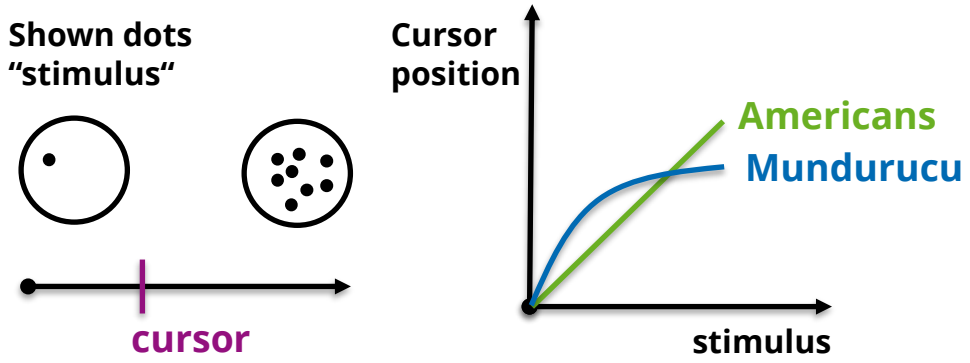


Goals of data visualization

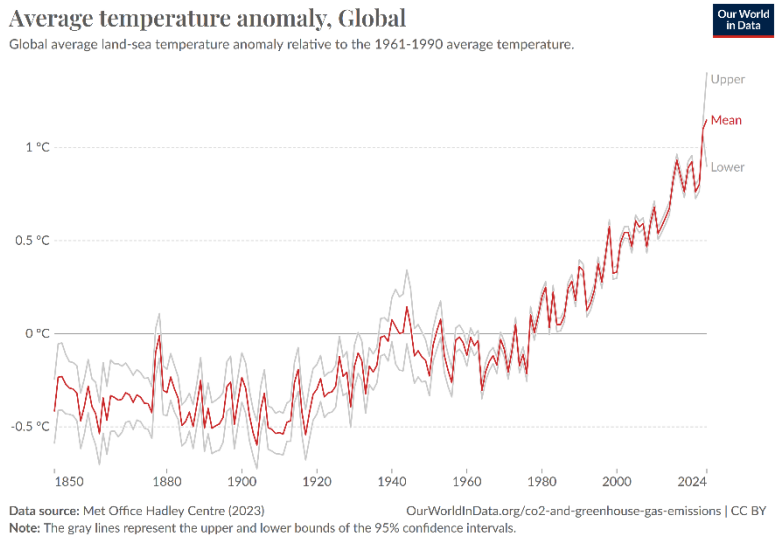
- Summarizing, reduction, different views on data
- Exploration, discover patterns, generation of hypotheses
- Reasoning, justification
- Planning, scheduling, resource distribution
- Easier to transport and memorize content
- Stimulation and creativity
- ...

Why are there “good” / “bad” visualizations?

- [Apparent content errors and deceptions]
- biological and physical limitations of human eyes & brain
  - Max. number of distinctive shades of grey
  - Bad quantification of areas and angles
  - Color blindness
  - …
- Socio-cultural habits and practices
  - Reading directions (left-to-right, top-to-bottom)
  - Different number systems or scales
  - Associations of colors with traits and characteristics (red: warm/attention/signal)
  - …
- Educational and research field habits and practices
  - Familiarity and interpretation of (complex) plot types (box-plot, heatmaps …)
  - Trade-off between information accuracy and reduction
  - Visualization and comprehension of errors and uncertainty
  - …



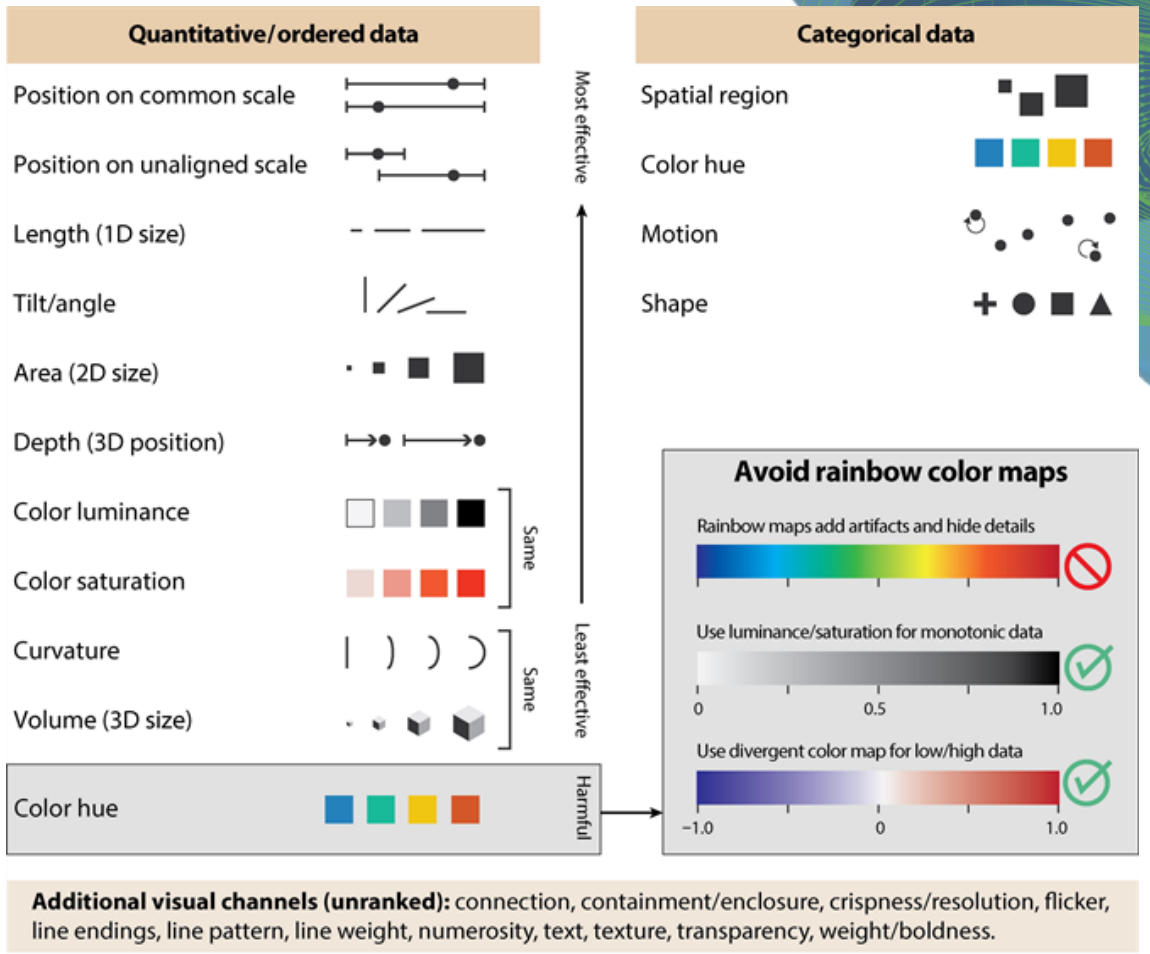
Dehaene, Stanislas, et al. **"Log or linear? Distinct intuitions of the number scale in Western and Amazonian indigene cultures."** *Science* (2008)



Basic elements of visualization (1)

Visual variables

- Position
- Size, length, area
- Shape
- Color: hue, brightness, saturation
- Orientation
- Texture, grain
- …



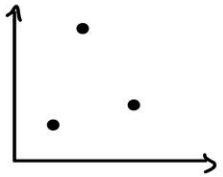
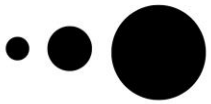
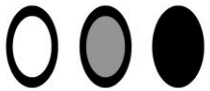
Ikuomenisan, G. and Morgan, Y. (2022) Systematic Review of Graphical Visual Methods in Honeypot Attack Data Analysis. Journal of Information Security, 13, 210-243. https://doi.org/10.4236/jis.2022.134012

Basic elements of visualization (1)

Important traits of visual variables

- Selective (group➔1)
- associative (n➔cluster)
- Quantitative
- Order (* > * > * > *)
- Distinctive

Visual Variables

		Characteristics				
		Selective	Associative	Quantitative	Order	Length
Position		yes	yes	yes	yes	infinite
Size		yes	no	partially	yes	Selection: ~ 5 Distinction: ~ 20
Shape		no	mostly	no	no	Infinite
Value		yes	no	no	yes	Selection: < 7 Distinction: ~ 10
Color		yes	yes	no	no	Selection: < 7 Distinction: ~ 10
Orientation		yes	yes	no	no	~5 (Infinite)
Texture		yes	yes	no	multi	infinite

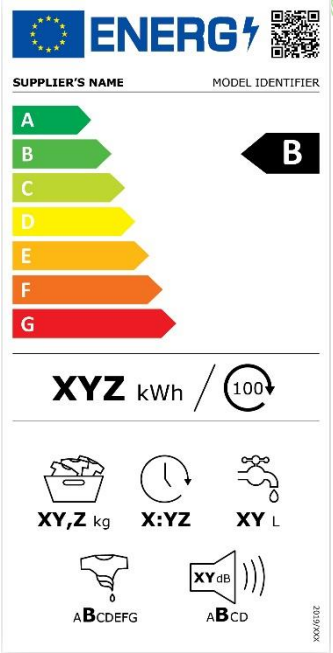
Theoretical aspects – data characteristics

Data characteristics strongly influence their suitable visualization

- Data type
  - Nominal, categorical

  - Ordinal

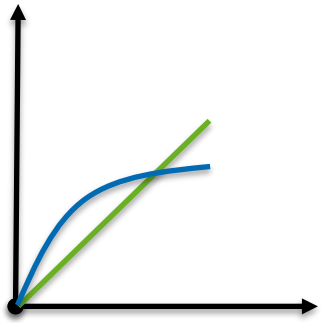
  - Quantitative:
    - scale,
    - range,
    - relation,
    - unit

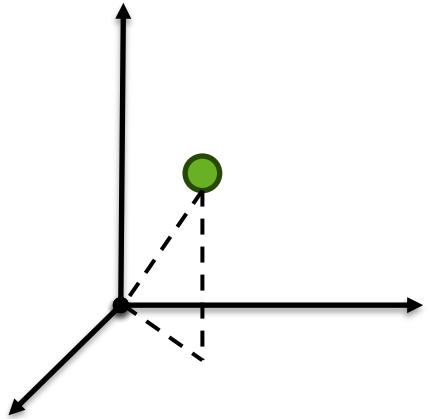


Theoretical aspects – data characteristics

Data characteristics strongly influence their suitable visualization

- Dimensionality
  - 1D, series
  - 2D, 3D
  - N-dimensions

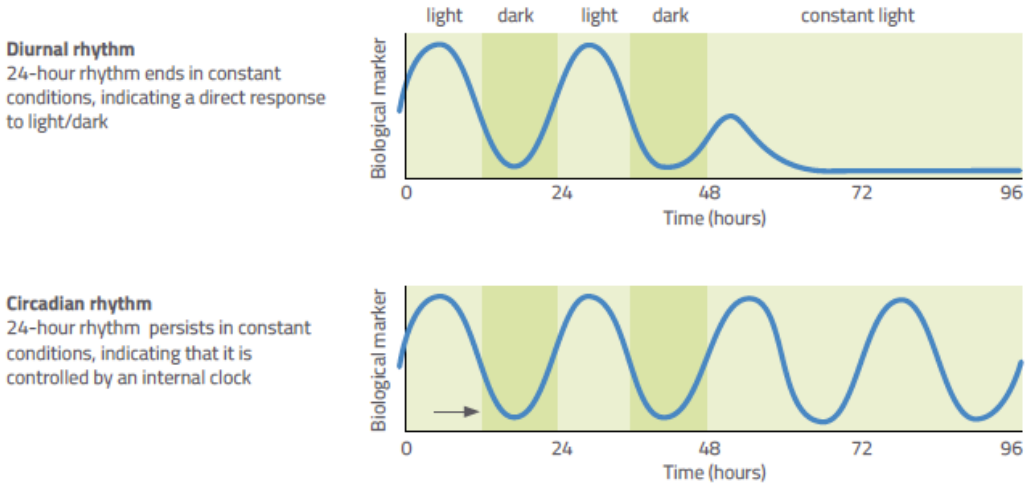




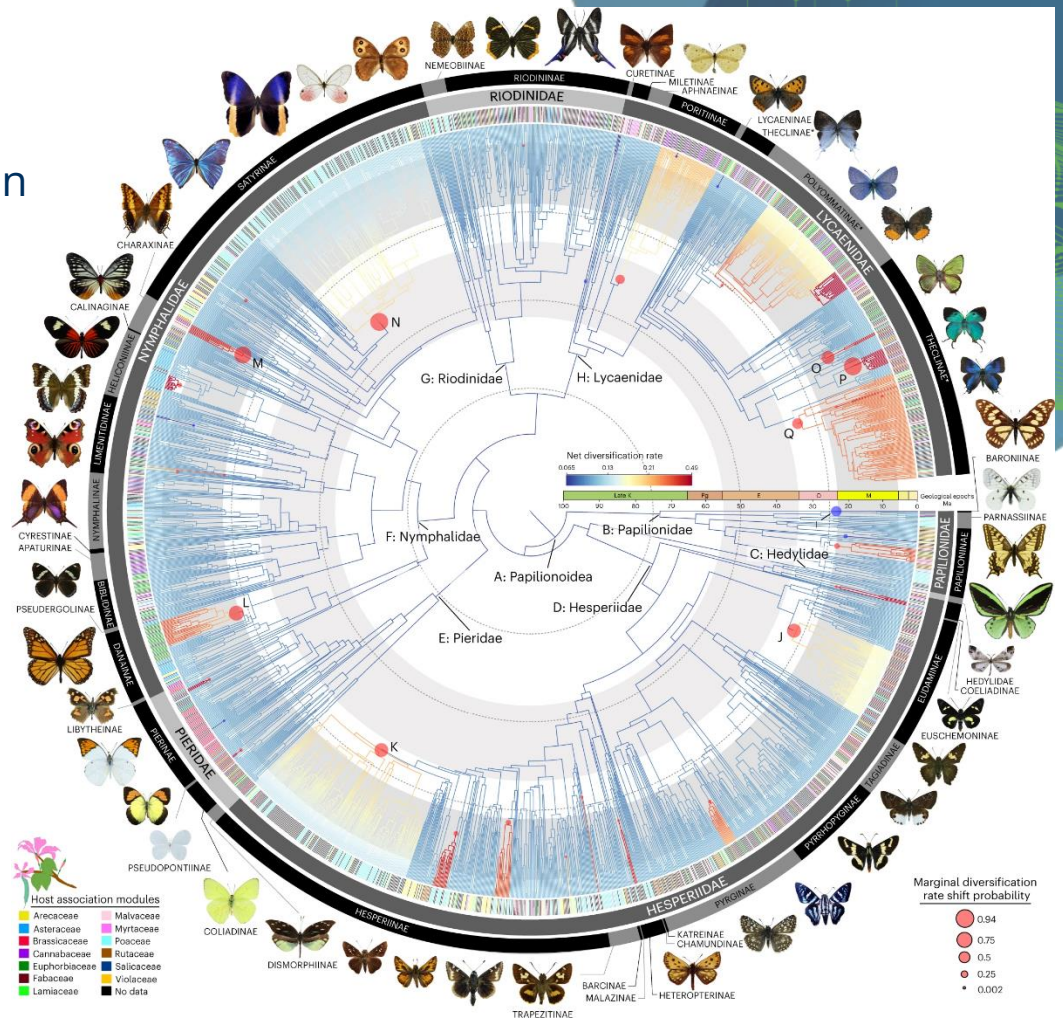
Theoretical aspects – data characteristics

Data characteristics strongly influence their suitable visualization

- Other aspects
  - Graphs and networks (+trees)
  - Temporal data and time series
  - Cyclic data and axis

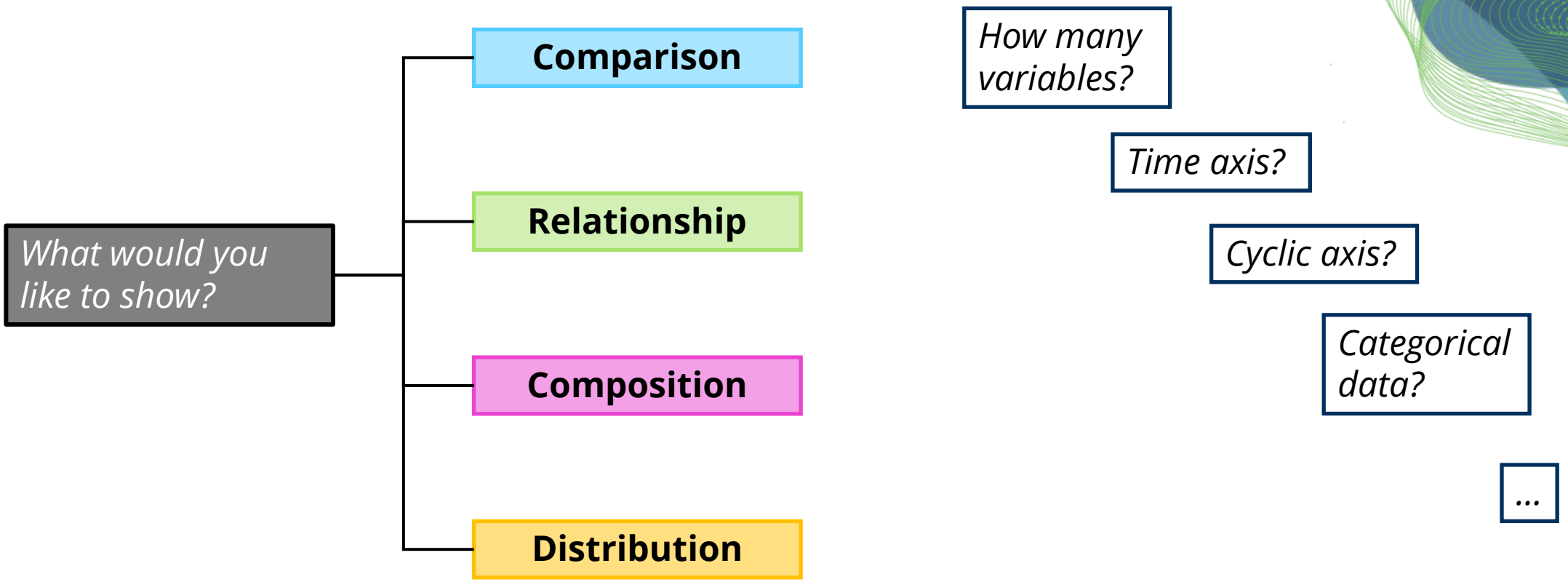


Katharine Hubbard | www.scienceinschool.org I Science in School I Issue 48 : Autumn 2019 I 11

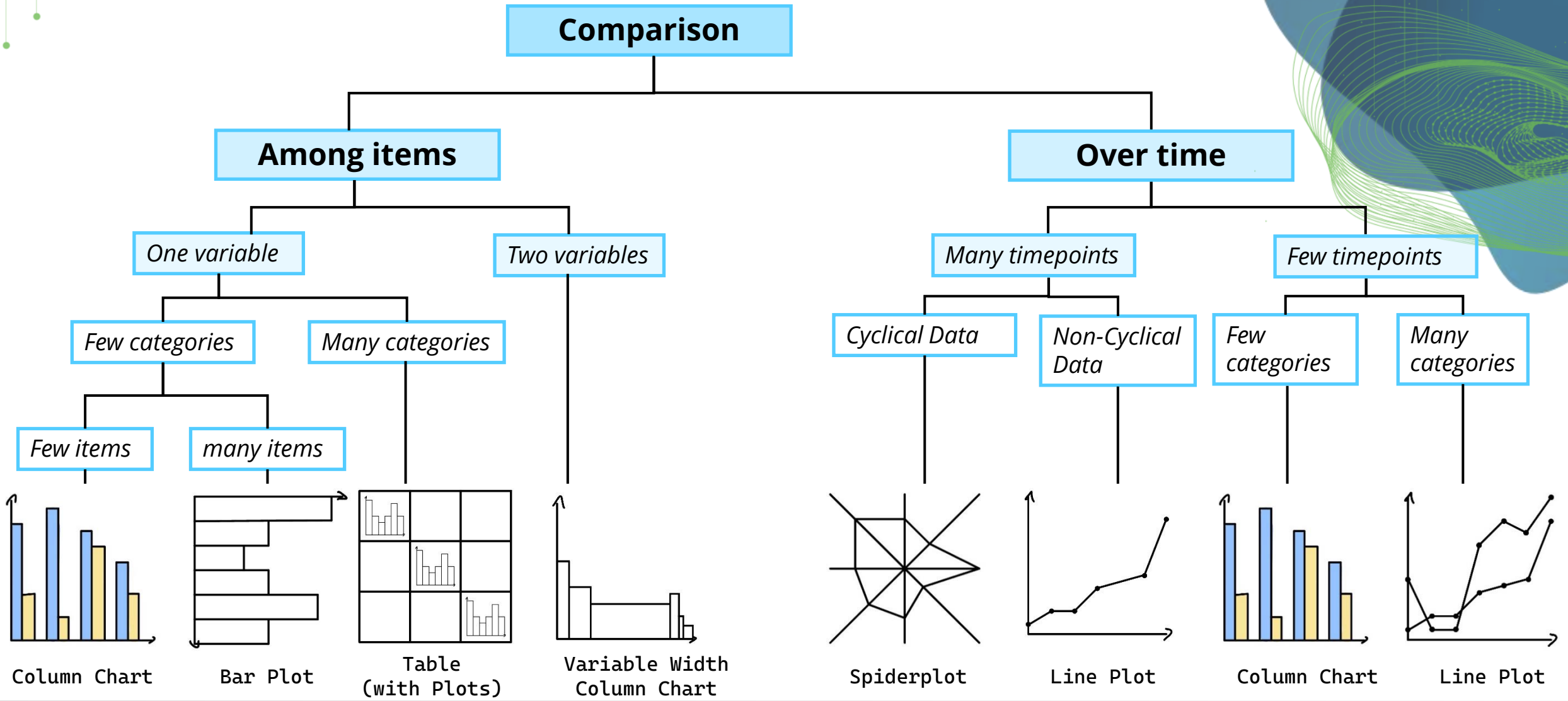


Kawahara, A.Y., Storer, C., Carvalho, A.P.S. et al. A global phylogeny of butterflies reveals their evolutionary history, ancestral hosts and biogeographic origins. Nat Ecol Evol 7, 903–913 (2023). https://doi.org/10.1038/s41559-023-02041-9

Theoretical aspects – How to decide on plot types



Theoretical aspects – How to decide on plot types (2)



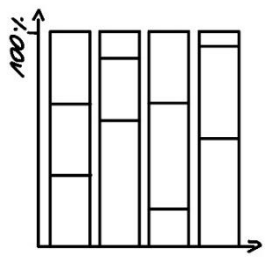
Theoretical aspects – How to decide on plot types (3)

Composition

Changing Over Time

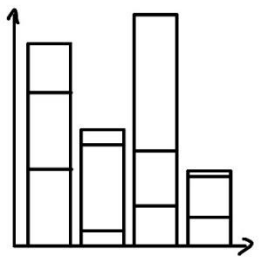
Few Periods

Only Relative Differences Matter



Stacked 100% Column Chart

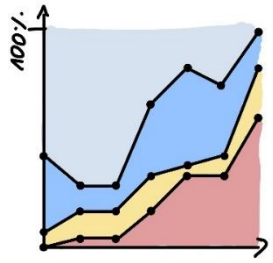
Relative and Absolute Differences Matter



Stacked Column Chart

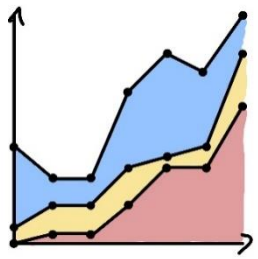
Many Periods

Only Relative Differences Matter



Stacked 100% Area Chart

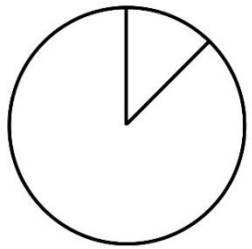
Relative and Absolute Differences Matter



Stacked Area Chart

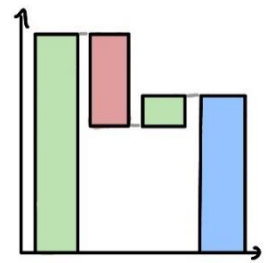
Static

Simple Share of Total



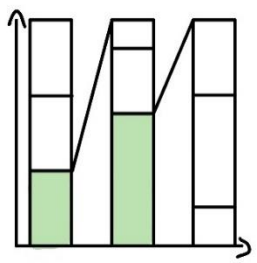
Pie Chart

Accumulation or Subtraction to Total



Waterflow Chart

Components of Components



Stacked 100% Column Chart with Subcomp.

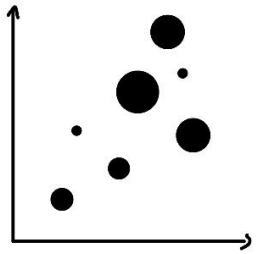
Theoretical aspects – How to decide on plot types (4)

Relationship

Two Variables

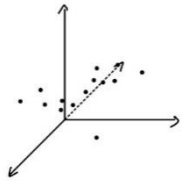
2D Scatterplot

3 Variables



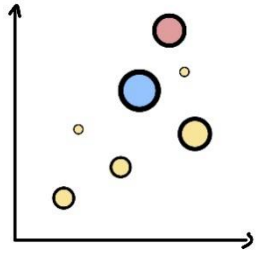
Scatterplot with 1 additional attribute (e.g. Bubble Plot)

Interactive?

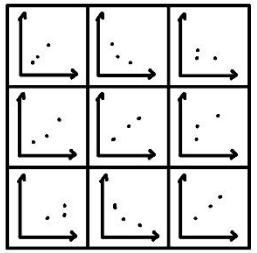


3D Scatterplot

More Variables



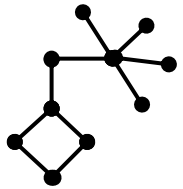
Scatterplot with additional attributes



Scatterplot Matrix

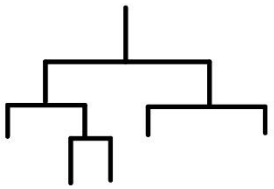
Hierarchy

other



Networks

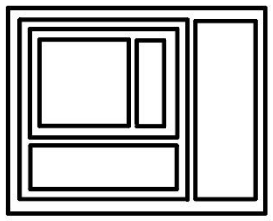
Tree-hierarchy



Rooted or unrooted Trees

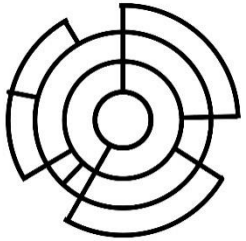
+Composition

Few categories



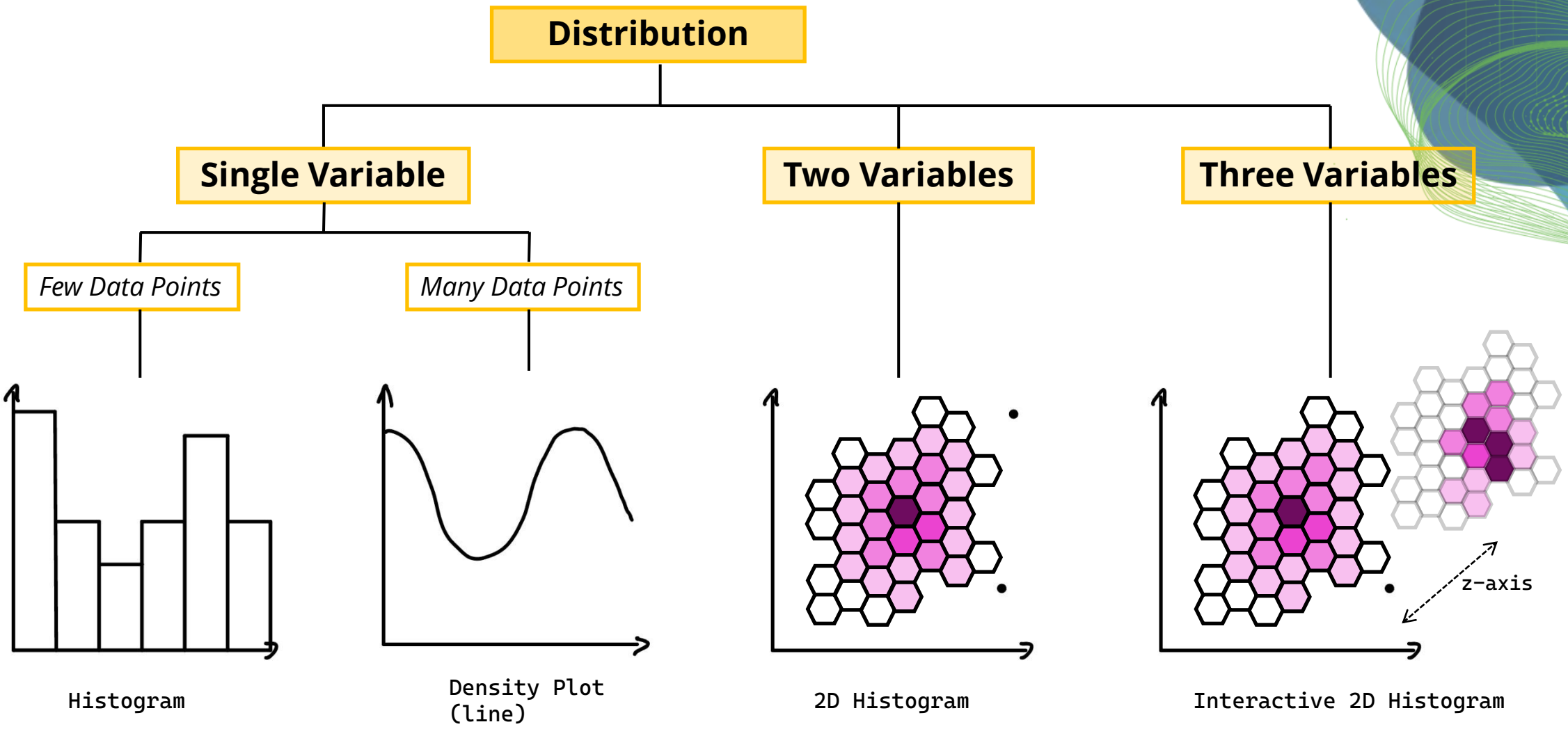
TreeMap

Many categories



Sunburst

Theoretical aspects – How to decide on plot types (5)



Comparison of plotting interfaces and their philosophies

matplotlib

seaborn

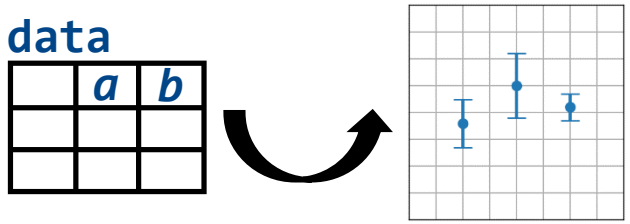
seaborn.objects

ggplot2

The Grammar of Graphics,
Leland Wilkinson, 2005
https://doi.org/10.1007/0-387-28695-0

Plot type driven ⟵ ⟶ **Data and geometry driven**

Comparison of plotting interfaces and their philosophies (2)



matplotlib

```
x=data['a'].drop_duplicates()
y=data['b'].groupby(['a']).mean()
yerr=data['b'].groupby(['a']).sd()

errorbar(x,y,yerr)
```

1) Choose plot type
2) Extract or calculate variables
3) Stuff into plot API

seaborn

```
pointplot(
          data,
          x='a', y='b',
          errorbar='sd'
          )
```

1) Choose basic type
2) Define data and variables

seaborn.objects

```
so.Plot(data,x='a', y='b')
 .add(    so.Dot(),
          so.Agg())
 .add(    so.Range(),
          so.Est(errorbar='sd'))
```

1) Define data and variables
2) Choose plot geometries
3) Define statistics

Plot type driven ⟷ **Data and geometry driven**

Comparison of plotting interfaces and their philosophies (3)

matplotlib

seaborn

seaborn.objects

intuitive

good/nice plots

flexibility

...

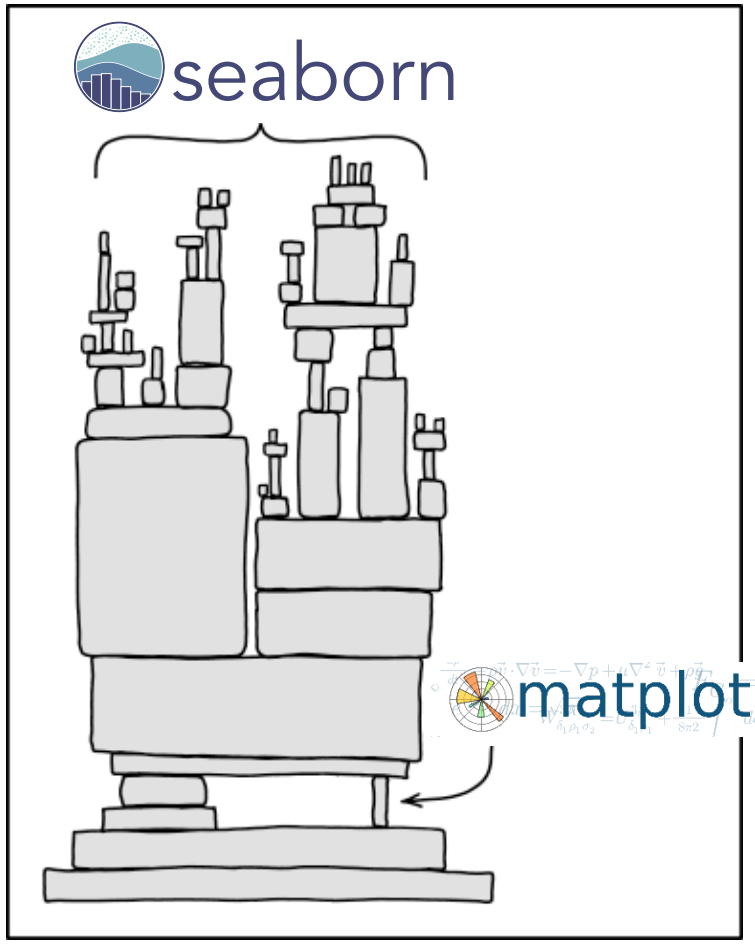
fast implementation

code readibility

What do you see as pro's and con's?

Plot type driven ⟵ ⟶ **Data and geometry driven**

History and problem of plotting libraries in python

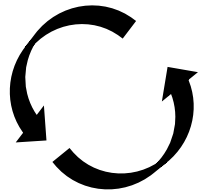


MATLAB
plot interface

Data format: keep it tidy, save time later

- Mostly long-format is preferable for plotting
- Pandas and other libraries have functions to convert formats
- Keep and make data tidy before plotting saves a lot of time and work

long format



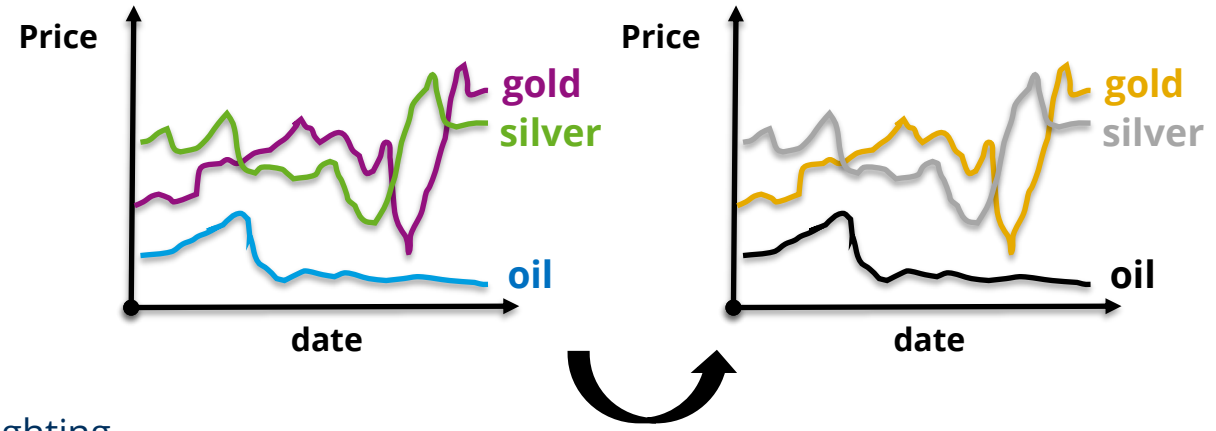
wide format

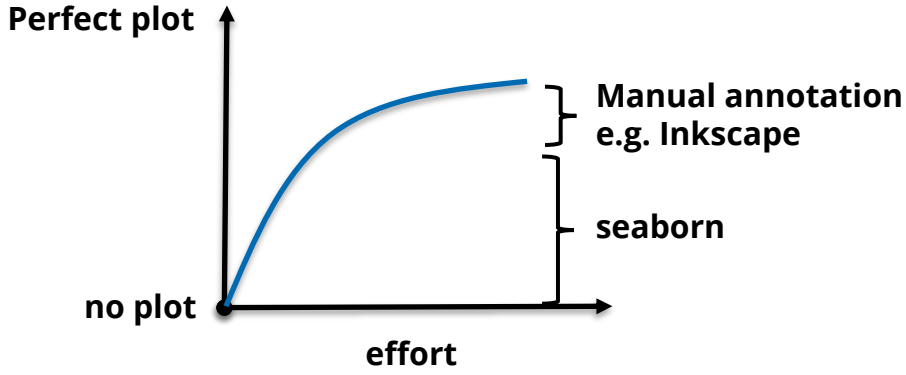
Athletes	100m	Long.jump	Shot.put	High.jump	400m	110m.hurdle	Discus	Pole.vault	Javeline	1500m	Points
SEBRLE	11.04	7.58	14.83	2.07	49.81	14.69	43.75	5.02	63.19	291.7	8217
CLAY	10.76	7.4	14.26	1.86	49.37	14.05	50.72	4.92	60.15	301.5	8122
KARPOV	11.02	7.3	14.77	2.04	48.37	14.09	48.95	4.92	50.31	300.2	8099
BERNARD	11.02	7.23	14.25	1.92	48.93	14.99	40.87	5.32	62.77	280.1	8067

Athletes	Discipline	Value
SEBRLE	100m	11.04
SEBRLE	Long.jump	7.58
SEBRLE	Shot.put	14.83
SEBRLE	High.jump	2.07
SEBRLE	400m	49.81
SEBRLE	110m.hurdle	14.69
SEBRLE	Discus	43.75
SEBRLE	Pole.vault	5.02
SEBRLE	Javeline	63.19
SEBRLE	1500m	291.7
SEBRLE	Points	8217
CLAY	100m	10.76
CLAY	Long.jump	7.4
CLAY	Shot.put	14.26
CLAY	High.jump	1.86
CLAY	400m	49.37
CLAY	110m.hurdle	14.05
CLAY	Discus	50.72
CLAY	Pole.vault	4.92
CLAY	Javeline	60.15
CLAY	1500m	301.5
CLAY	Points	8122

Dos and Don’ts

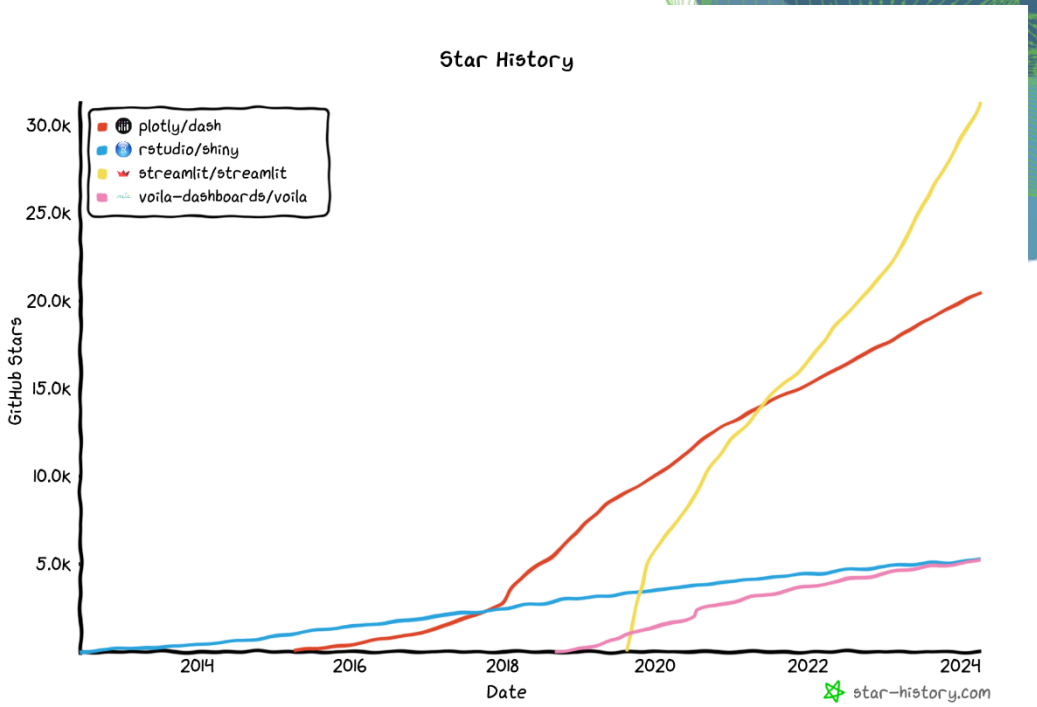
- Usage of colors, shapes and textures
  - **Consistency!**
  - Intuitive choice of colors etc. (plants ➔ green)
- Purpose and goal determine the visualization
  - Data exploration: high complexity and many details
  - For a publication: **1-2 key messages per plot**, use highlighting and annotations
- Think about the **visual habits** of the target audience
- There is **no single best** visualization, but **many bad** ways of visualization
- Find a good trade-off between programming and manual adjustments or annotations





Dos and Don’ts

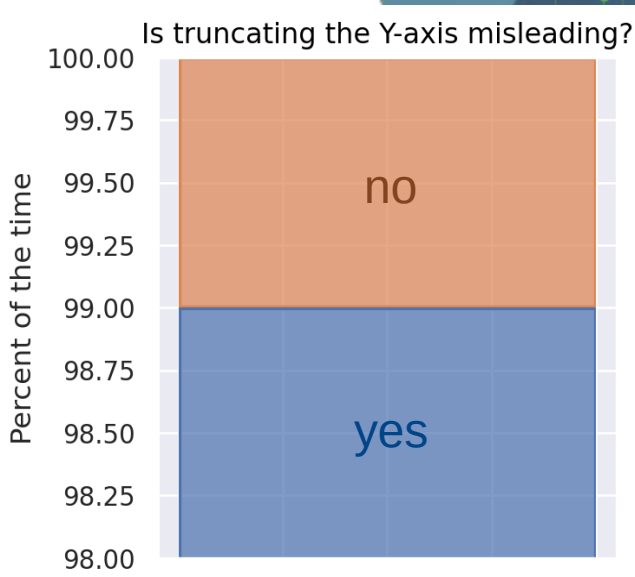
- Output format
  - Prefer loss-less zoomable formats: svg, pdf
  - Raster vs. vector files
- Be careful with 3D plots
  - Think about if really necessary?
  - Recommended if interactive and not as static plot
- **Interactive plots**, and dashboards
  - Highly recommended, very empowering, more and more common
  - Problem: not supported in static publications like PDF and most journals
  - Examples:
    - https://plotly.com/examples/
    - https://shiny.posit.co/r/gallery/
    - …



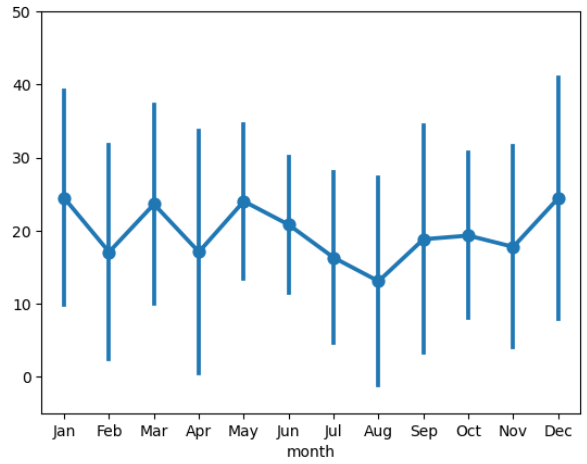
Self-created (15th April 24) via https://star-history.com/

Dos and Don'ts: "Chart-crimes"

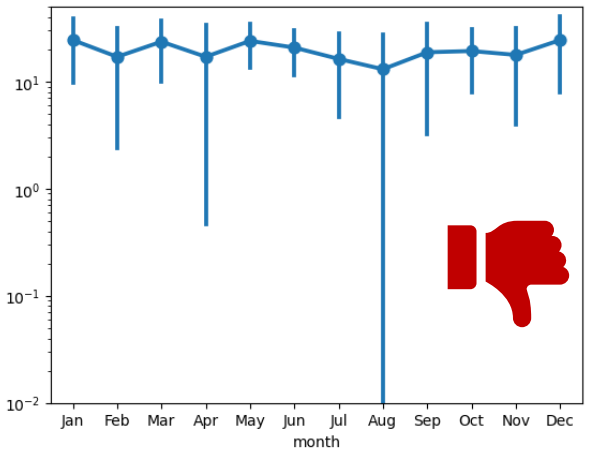
- Cheating with Y-axis
  - Multiple Y-axis
  - Free Y-axis, cutted Y-axis
  - No axis at all …
- Problems with log-scales
  - Zero values
  - Not suitable for error-bars, box-plots



Original meme probably from WyoWeeds
http://imgur.com/HZe4vKy

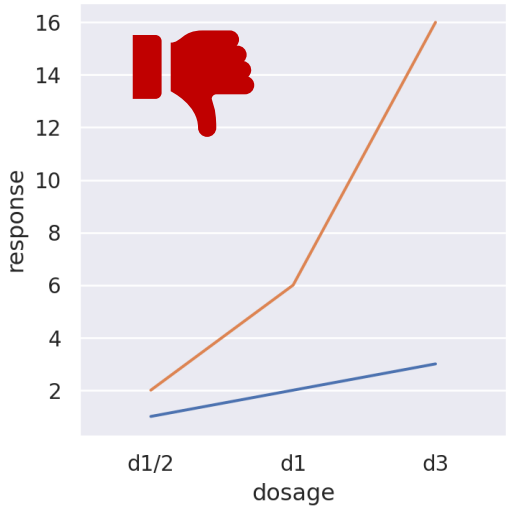


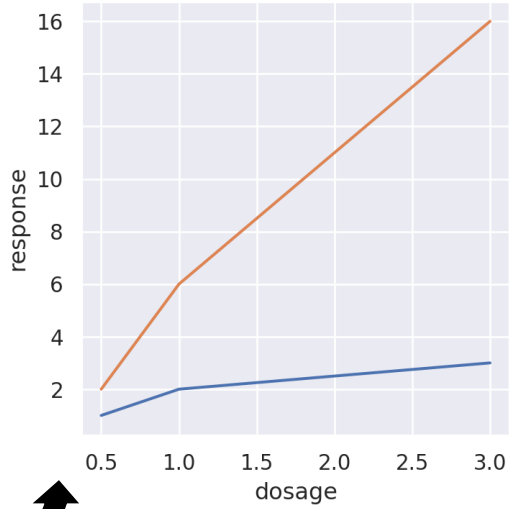
Y-axis log-scale



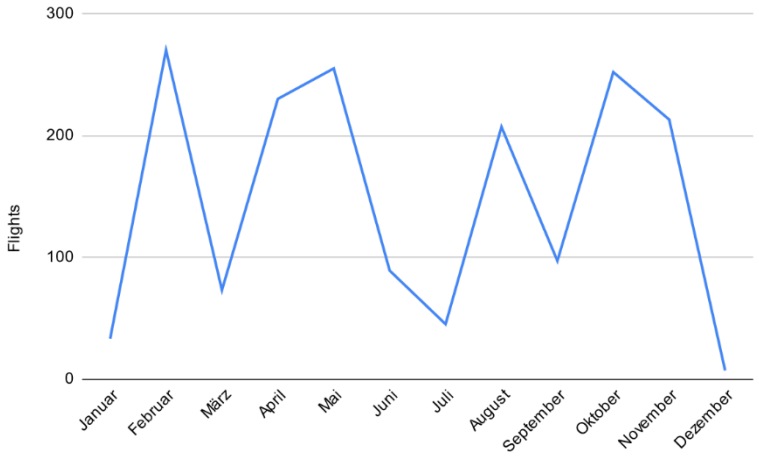
Dos and Don'ts: "Chart-crimes"

- Line-plots
  - Line-plots not suitable if X-axis is categorical or non-quantitative
  - Spaghetti line-plots
  - In-appropriate use of splines (smoothing)

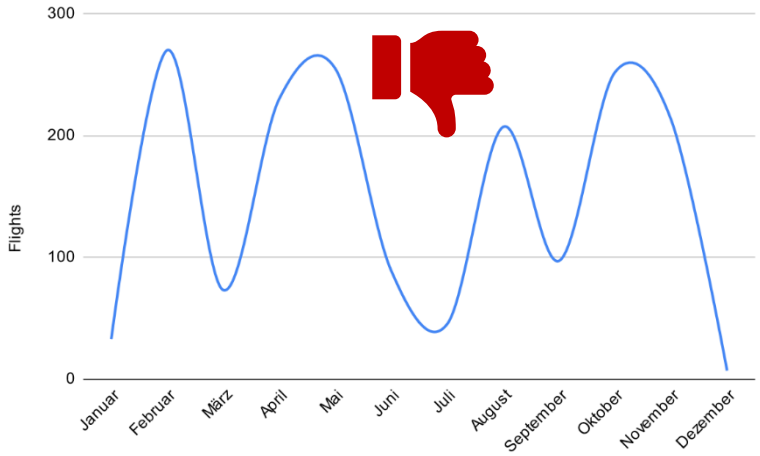




x-axis is quantitative



faking resolution

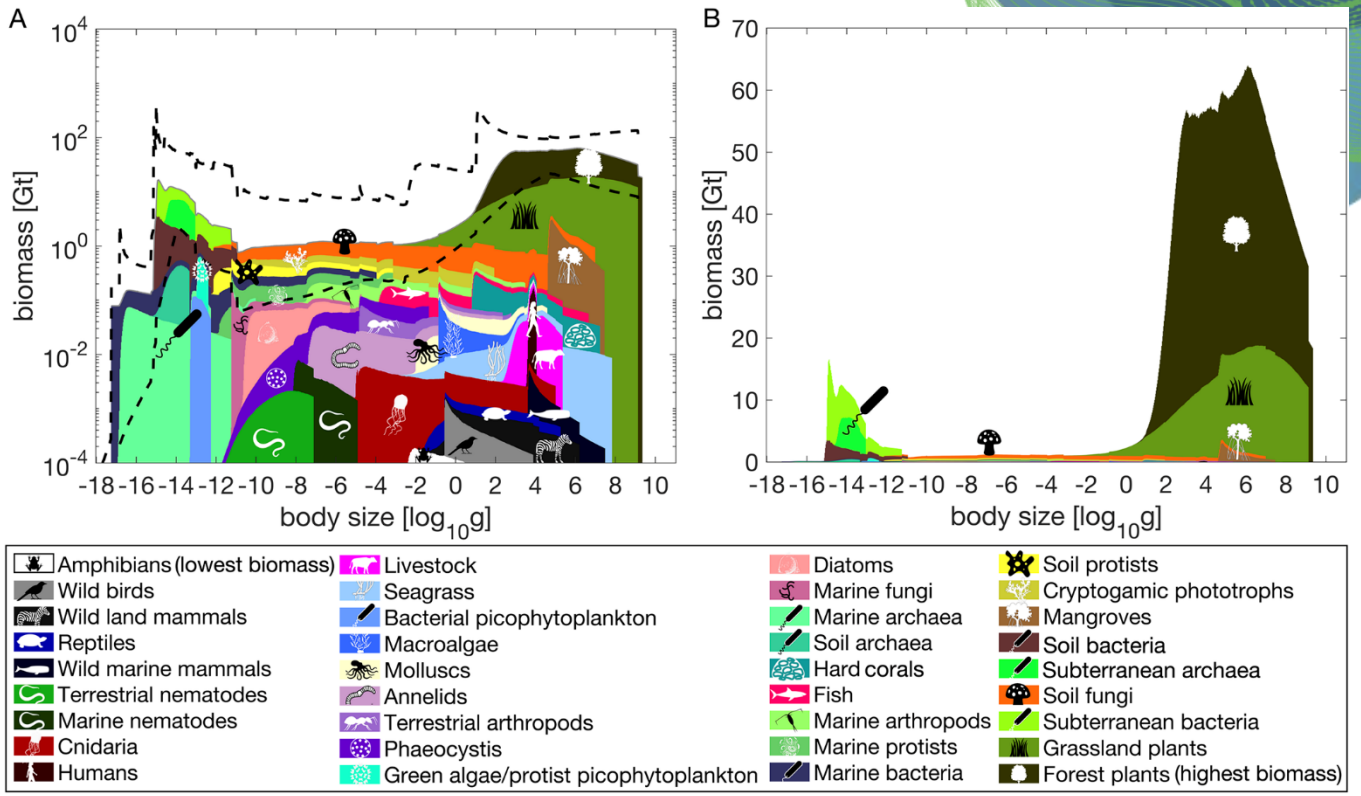


Dos and Don’ts: “Chart-crimes”

- Not proportional visualization of data
- Missing axis descriptions, legends or plain wrong content representation

- Plots with areas and angles
  - Pie-charts, especially 3D
  - Are areas proportional to data?

- High complexity,
  - ask yourself “Do I need more than 3”:
  - Colors
  - Categories
  - Lines
  - Annotations
  - …



Tekwa EW, Catalano KA, Bazzicalupo AL, O’Connor MI, Pinsky ML (2023) The sizes of life. PLoS ONE 18(3): e0283020. https://doi.org/10.1371/journal.pone.0283020

Resources and further reading

- Prof. Sheelagh Carpendale
  - https://www.cs.sfu.ca/~sheelagh/
  - Online lecture https://www.youtube.com/watch?v=geQcMZV8LZs
- Books
  - https://www.storytellingwithdata.com/books
  - The Grammar of Graphics https://books.google.de/books?id=YGgUswEACAAJ
- Online resources
  - https://seaborn.pydata.org/
  - https://matplotlib.org/
  - https://www.data-to-viz.com/
  - https://r-graph-gallery.com/
  - Checklist https://ly.uxlib.net/assets/subject/data-viz/datacated-visual-best-practices-checklist.pdf
- Dashboard
  - https://shiny.rstudio.com/tutorial/
  - https://plotly.com/examples/

Hands on sessions

matplotlib

seaborn

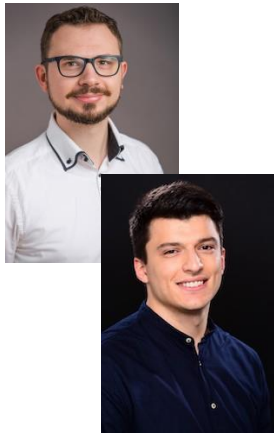
seaborn.objects

Day 3.3a „Basic Plotting“
13:30–15:00 Room: „Zwenkauer See“ (?)

Step-by-step introduction to plot with standard seaborn API

Day 3.3b „Advanced Plotting“
13:30–15:00 Room: „Markkleeberger See“ (?)

Introduction to seaborn.objects API and high-level visualization tips & tricks



Plot type driven ⟷ **Data and geometry driven**