A quick introduction on data visualization

Alessio Cardillo (@a_cardillo)

Instituto Pirenaico de Ecología (IPE) – CSIC, Zaragoza (Spain)

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Wednesday, June 5th 2024

Instituto
Pirenaico
de Ecología
CSIC

Who is Alessio Cardillo?

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- Italian (born and raised in Catania).
- Background in Physics (MSc, PhD).
- High mobility (both spatial and topic-wise).

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CORREDORAS

IPE
CSIC

GOBIERNO
DE ESPAÑA

MINISTERIO
DE CIENCIA, INNOVACIÓN
Y UNIVERSIDADES

AGENCIA
ESTATAL DE
INVESTIGACIÓN

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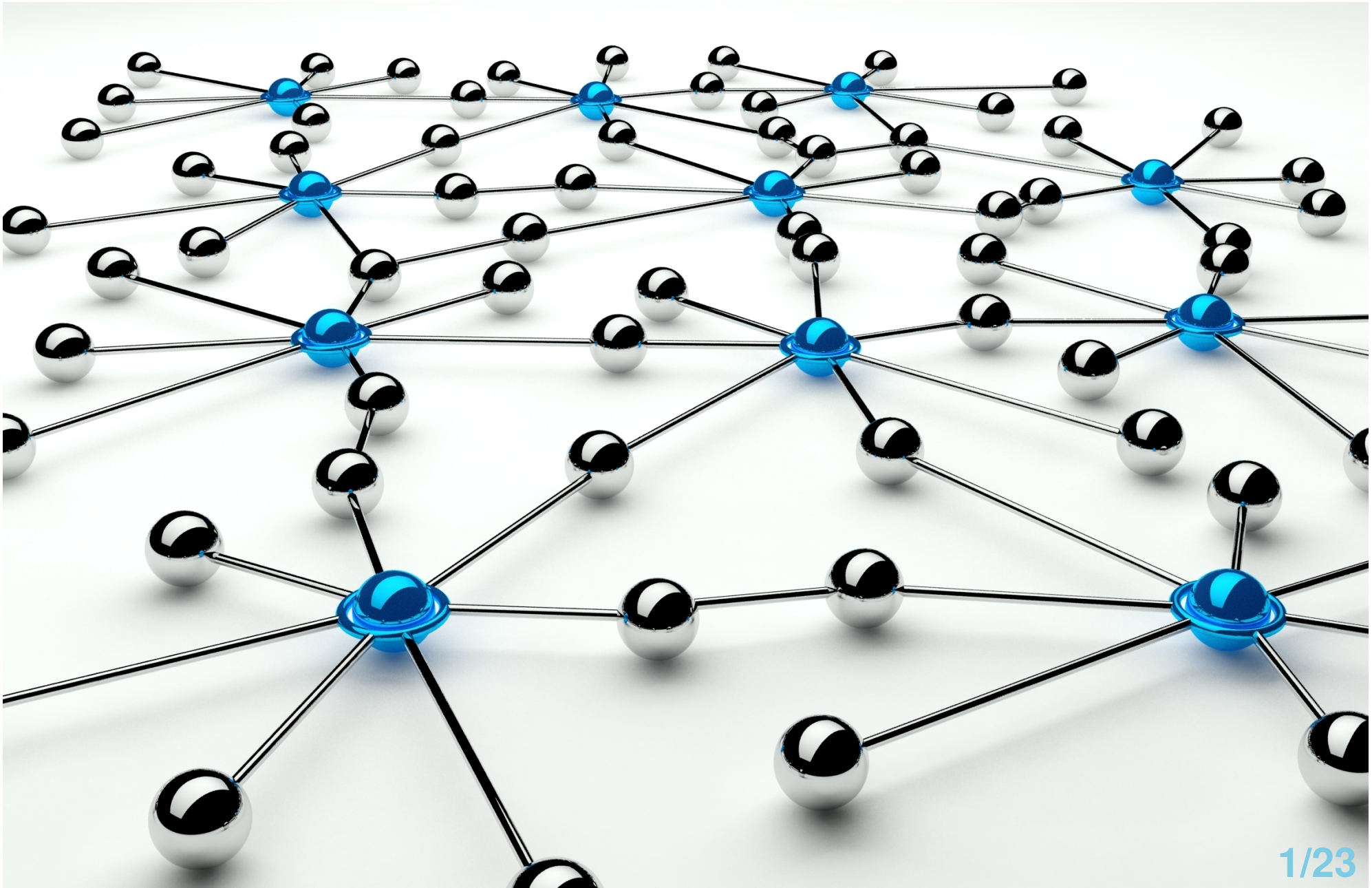
Who is Alessio Cardillo?



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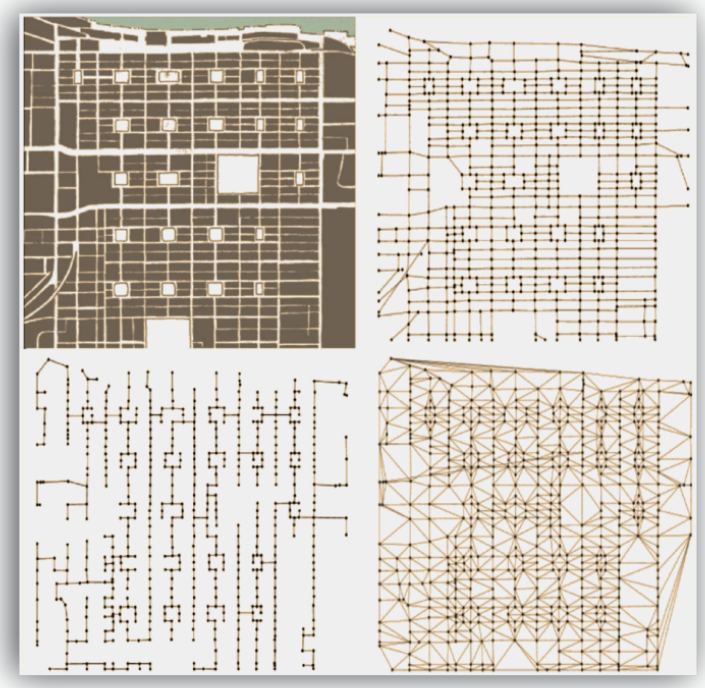
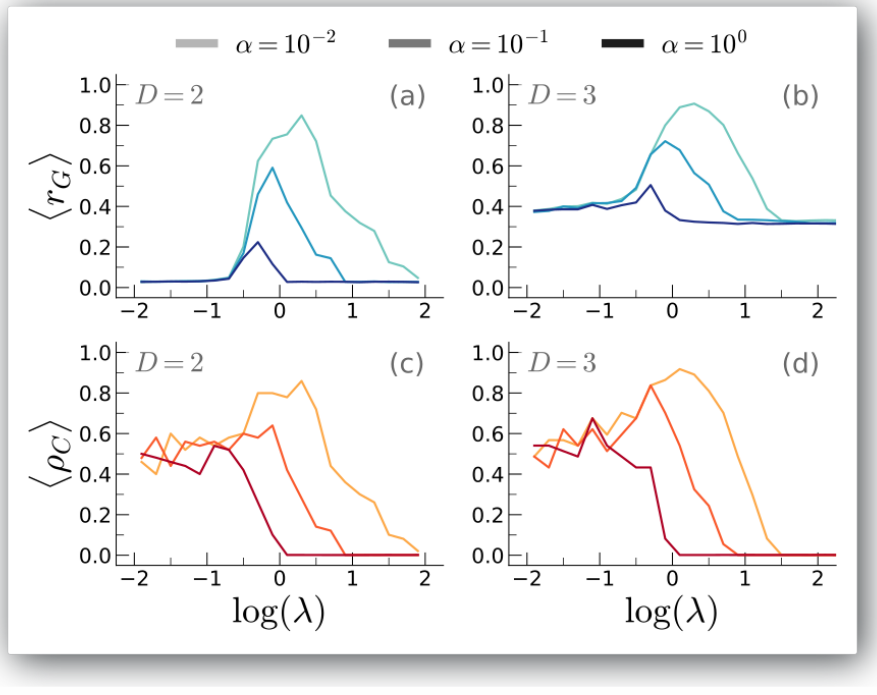


My first

My most recent



Why are we here?

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Why dataviz is important?

- We learn (also) through vision
  "*A picture is worth a thousand words*" (1911, A. Brisbane)

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Why dataviz is important?

- We learn (also) through vision "*A picture is worth a thousand words*" (1911, A. Brisbane)
- Complex concepts require **effective** communication methods.

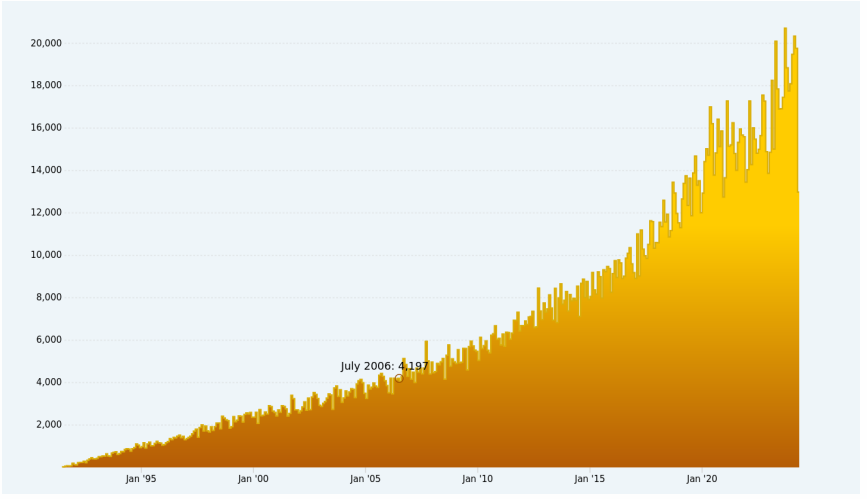
```
* Beautiful is better than
ugly.
* Explicit is better than
implicit.
* Simple is better than
complex.
* Complex is better than
complicated.
* Flat is better than nested.
* Sparse is better than dense.
* Readability counts.
```

(The Zen of Python)

Why are we here?

Why dataviz is important?

- We learn (also) through vision "*A picture is worth a thousand words*" (1911, A. Brisbane)
- Complex concepts require **effective** communication methods.
- The proliferation of content calls for ways to **stand out**.



Why are we here?

Why dataviz is important?

- We learn (also) through vision "*A picture is worth a thousand words*" (1911, A. Brisbane)
- Complex concepts require **effective** communication methods.
- The proliferation of content calls for ways to **stand out**.
- Dissemination to general and non-specialized audience.

Summary

What we are going to talk today

- Definition/history of data visualization.
- How we “see” things.
- Visual encoders and
  (partial) diagrams’ phenotype.
- Principles of figure design.
- Take home messages.
- Hands-on (if time allows).

Summary

What we are NOT going to talk today

- Solutions based on a specific software.
- Tailored solutions for your specific problems.
- Interactive visualization.
- Infographic and (many) artistic aspects.

What is data visualization?

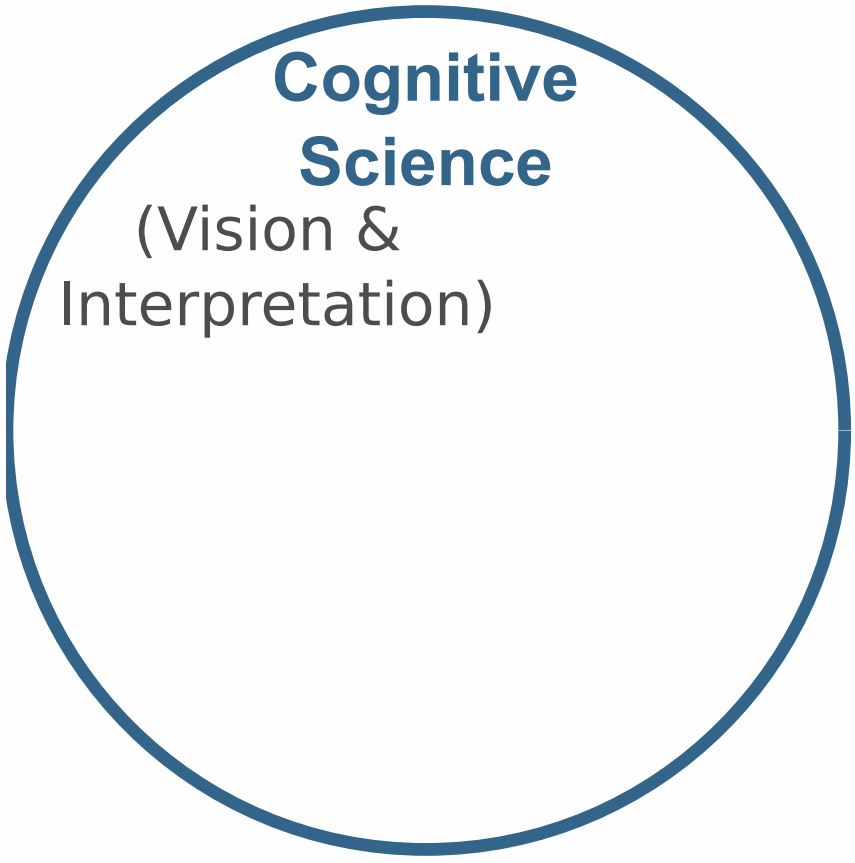
Data visualization

Data visualization

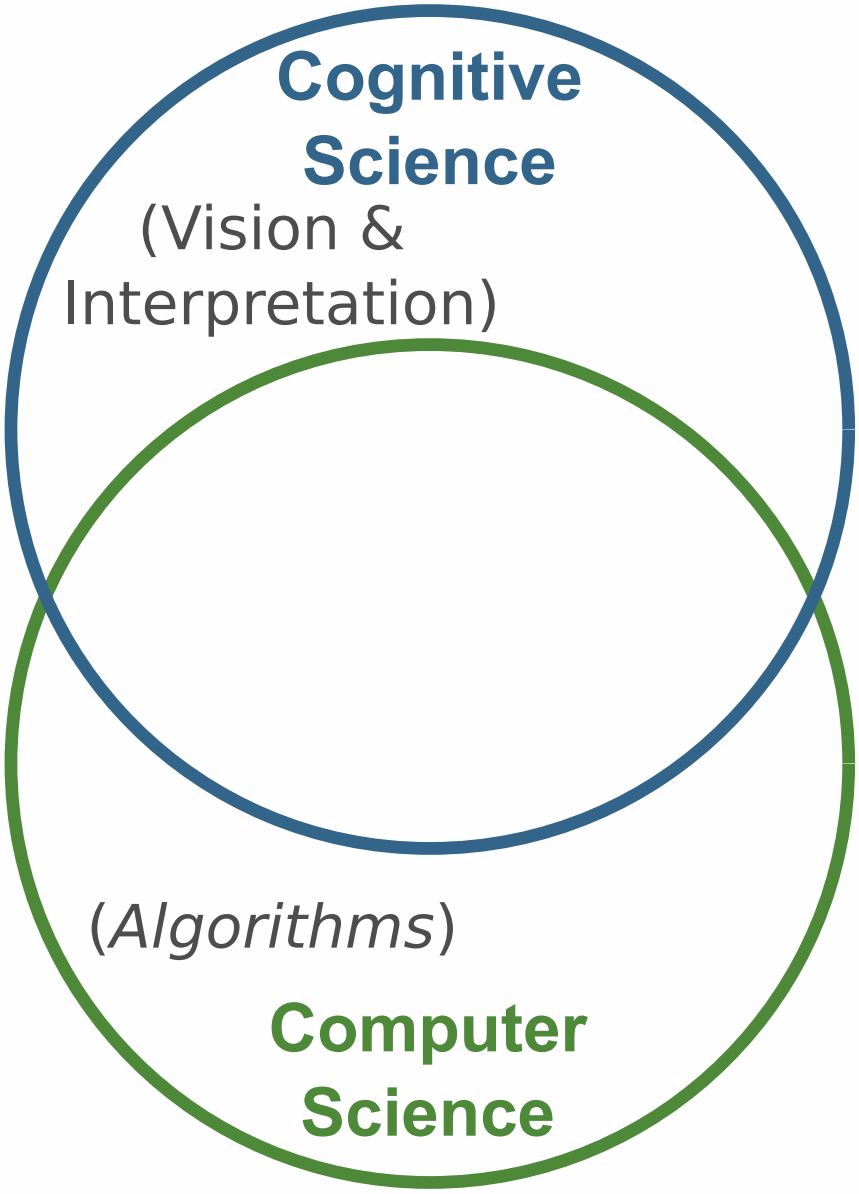
Data visualization is the process of **translating raw data into** graphs, **images** that explain numbers and **allow us to gain insight** from them.

Data visualization

Data visualization



Data visualization



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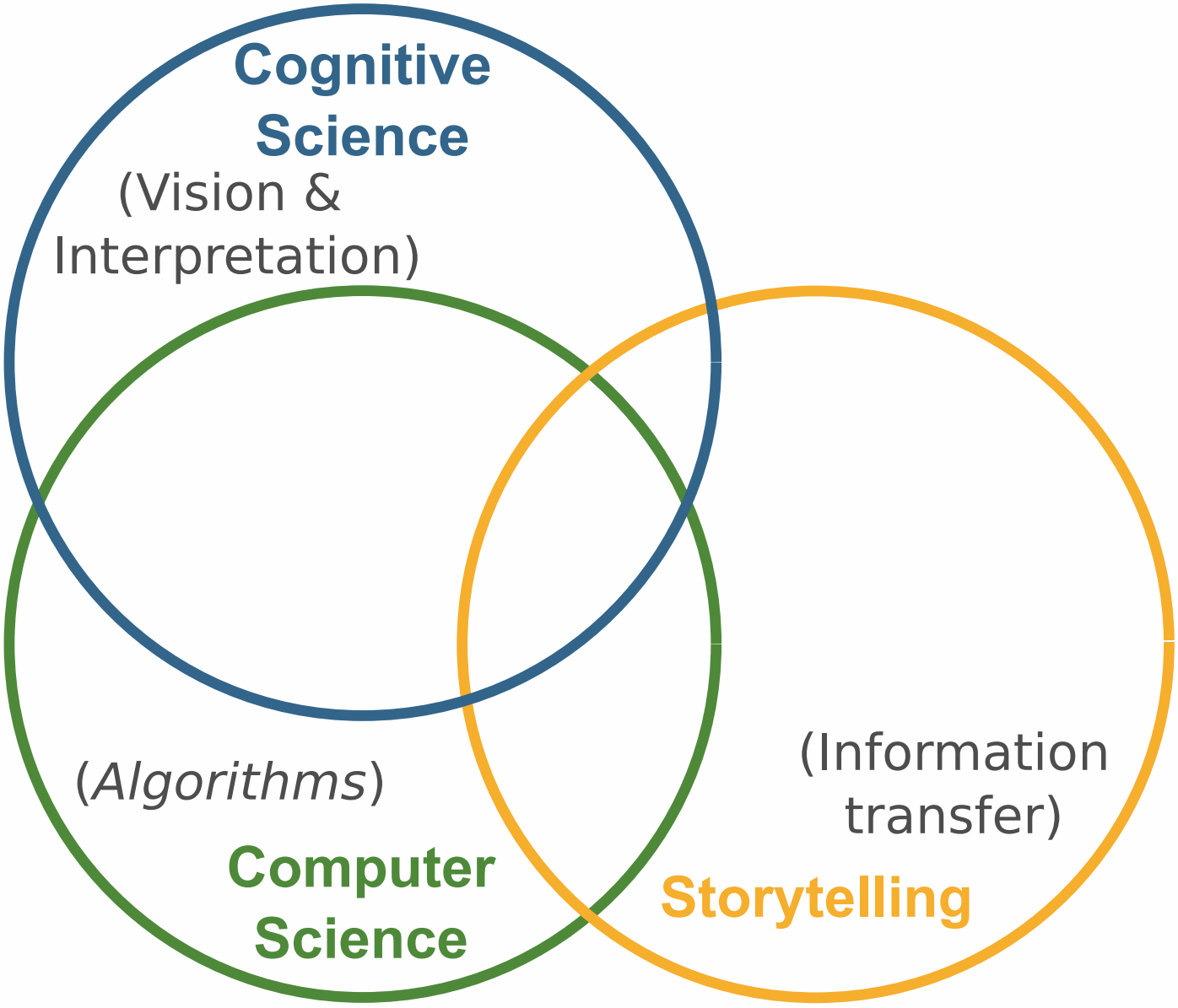

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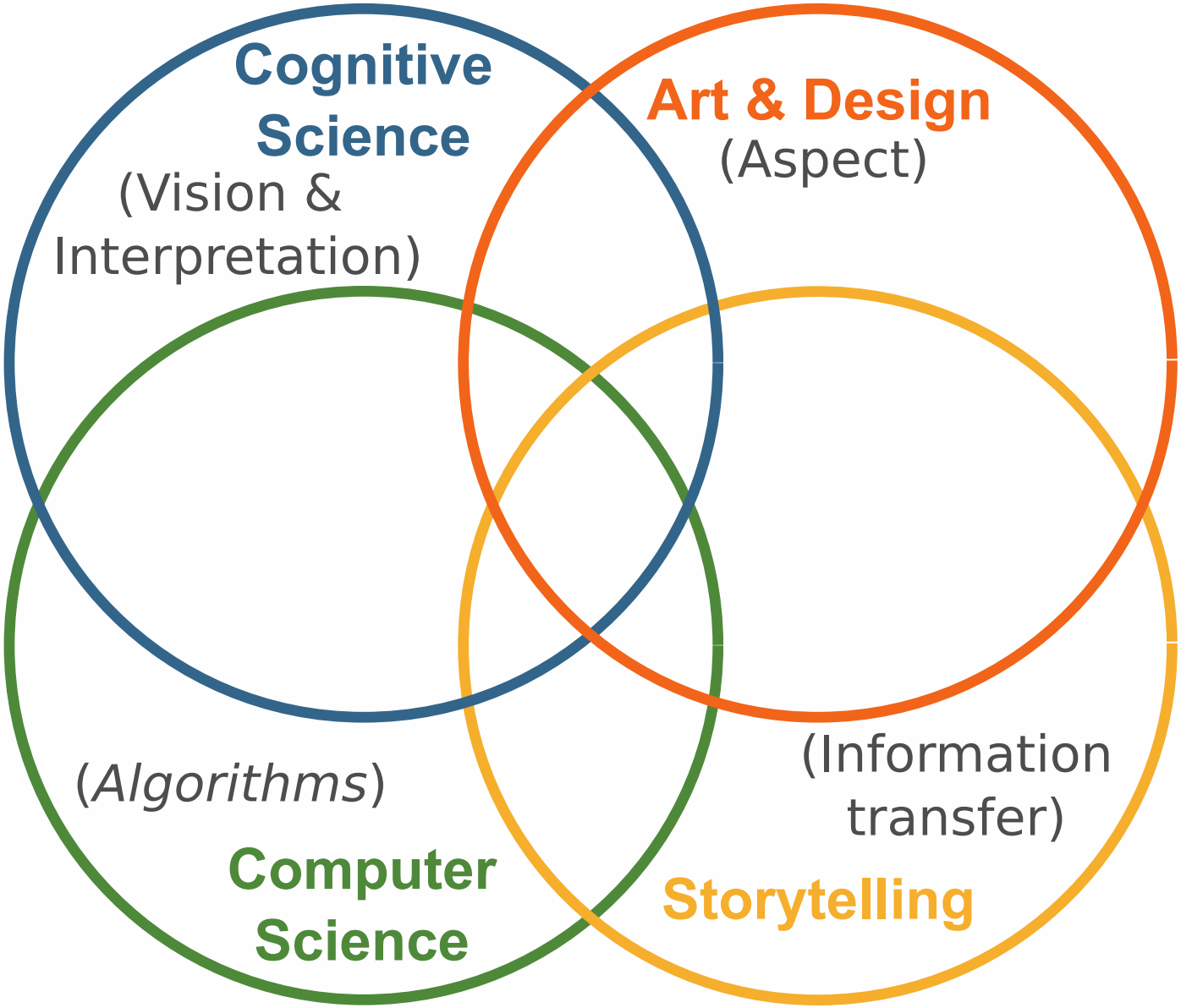

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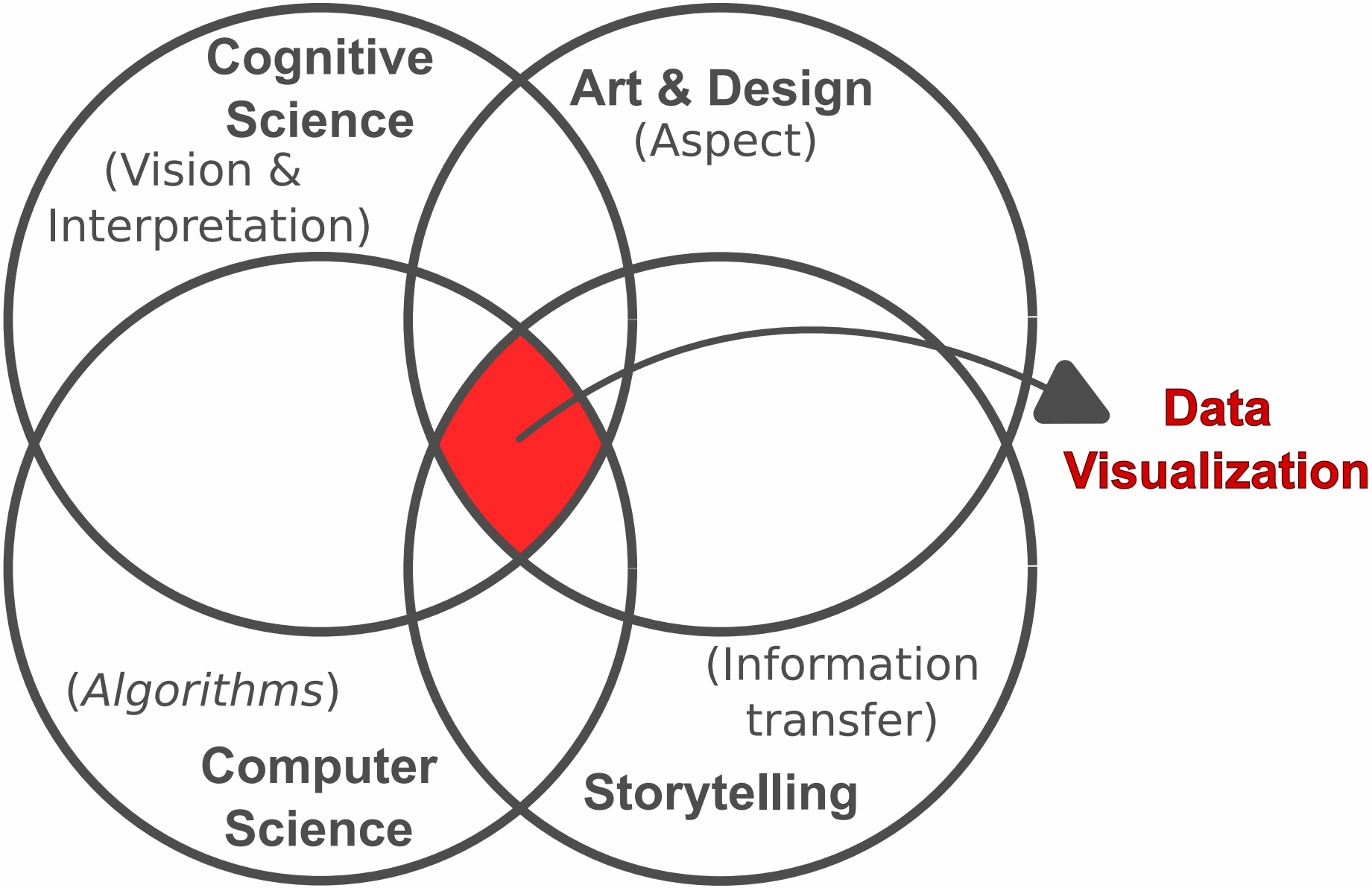


Data visualization

Data visualization

Data visualization

time

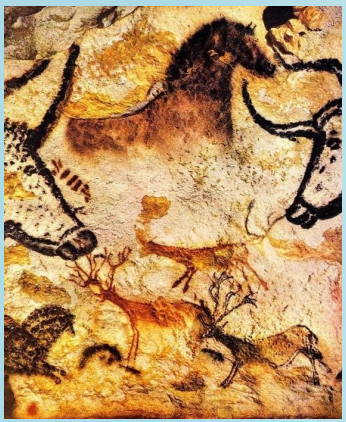
~ 15000 BC

~ 2700 BC

85 - 165

Ptolemy's maps

Lascaux cave drawings



Incan quipus

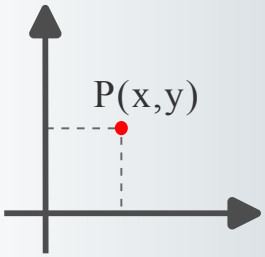
Data visualization

time

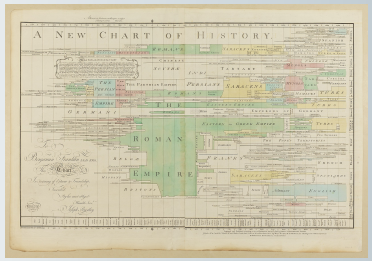
1637

1890

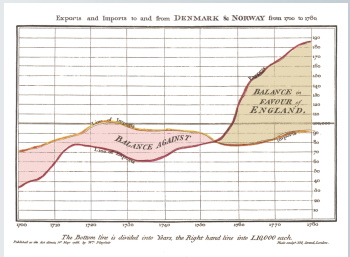
Cartesian coordinates
(Descartes & Fermat)

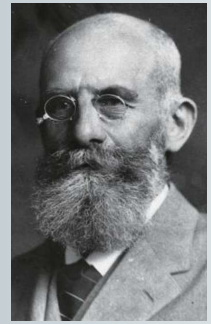


Joseph Priestley, 1765
(New chart of history)

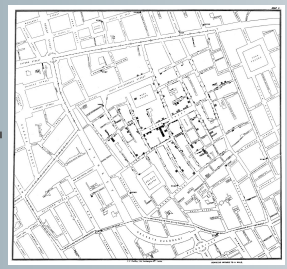


William Playfair, 1786-1801
(line- , area-, bar- charts)

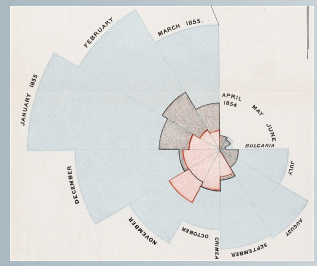




Gestalt
(C. von Ehrenfels)



John Snow, 1854
(Map of cholera
in London)



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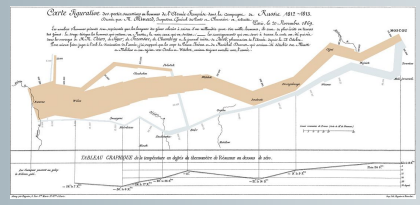

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Data visualization

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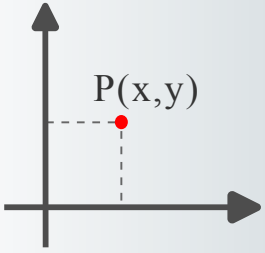

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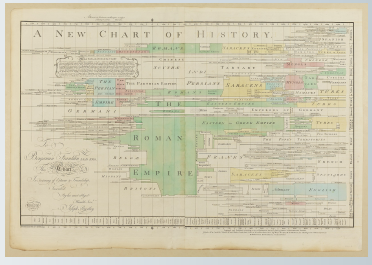

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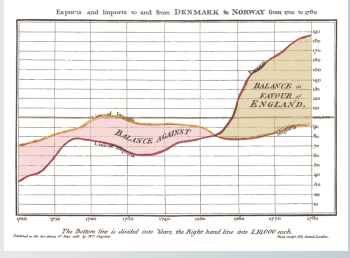

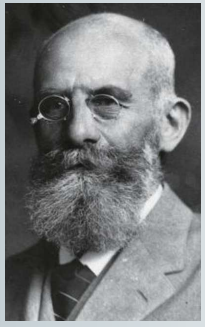

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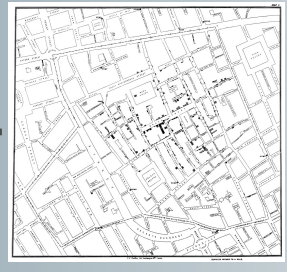

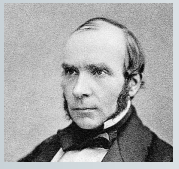

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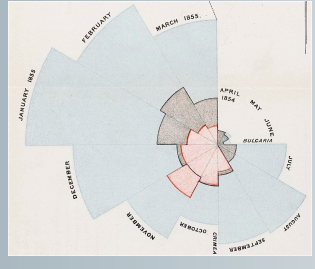

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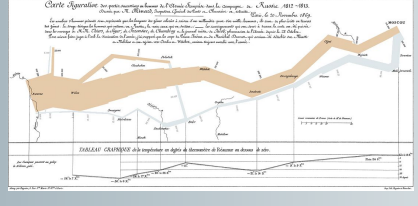

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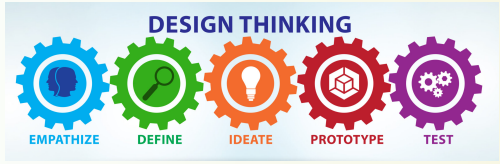
Data visualization

time

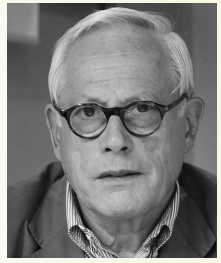
1950

199X
20XX

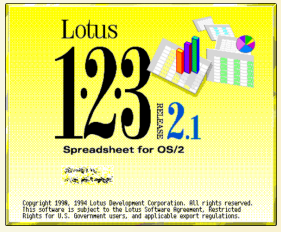
Foundations of design thinking (1950 - 1960)



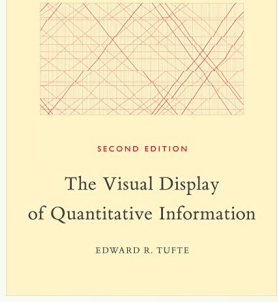
Dieter Rams - Principles of Good design (1970)



Lotus 1-2-3 spreadsheet (1983)



Edward Tufte's book (1983)



Sight, perception, and cognition

Seeing things

Seeing, **perceiving**, and **knowing** are different phenomena. In particular:

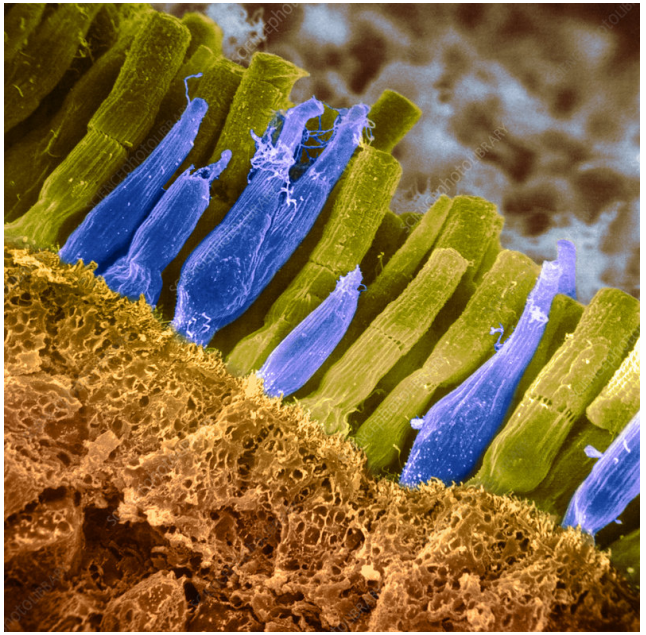
$$\text{SEEING} = \text{SIGHT} + \text{PERCEPTION} + \text{COGNITION}$$

Seeing things

Seeing things

The human eye

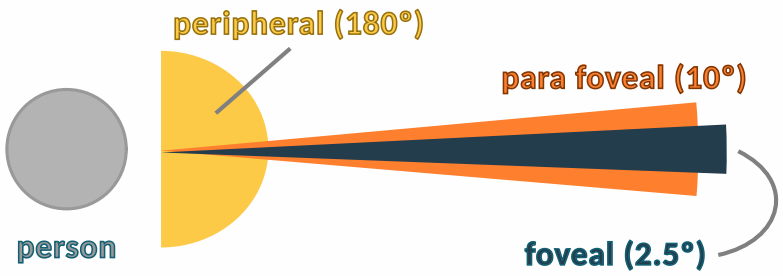
- Two types of photoreceptors: **Rods** ($\approx 10^8$) and **Cones** ($\approx 10^7$).



Seeing things

The human eye

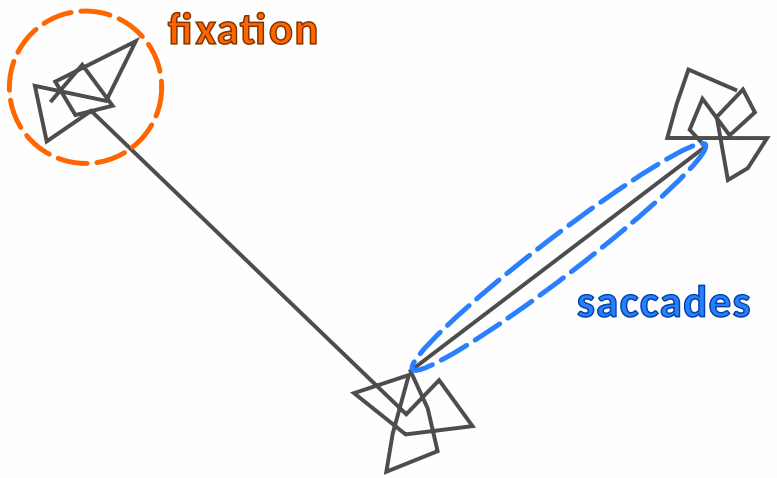
- Visual acuity is not homogeneous across the visual field (colors only in the foveal region)!



Seeing things

The human eye

- Sight explores the visual field akin to a Levy flight (***saccades*** and ***fixation***).



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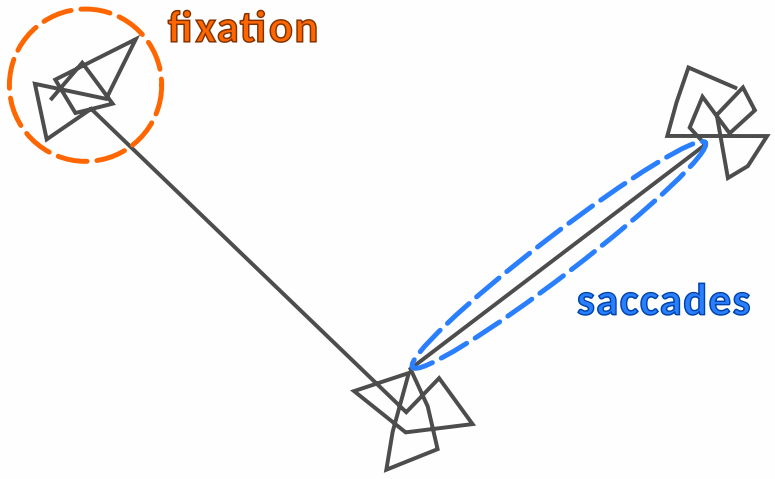
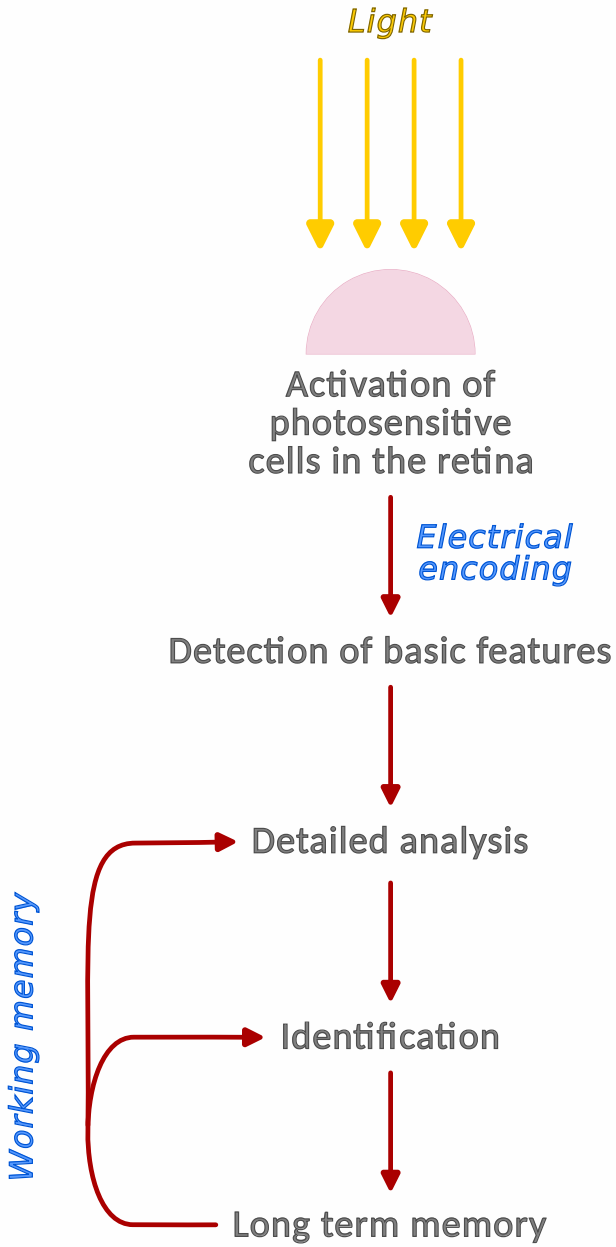


Tips

1. Fixations **ARE NOT RANDOM**!
2. Do not introduce multiple “new stuff” at the same time (the eye will not notice it).
3. Leverage saccades and fixation to **convey better** your message!

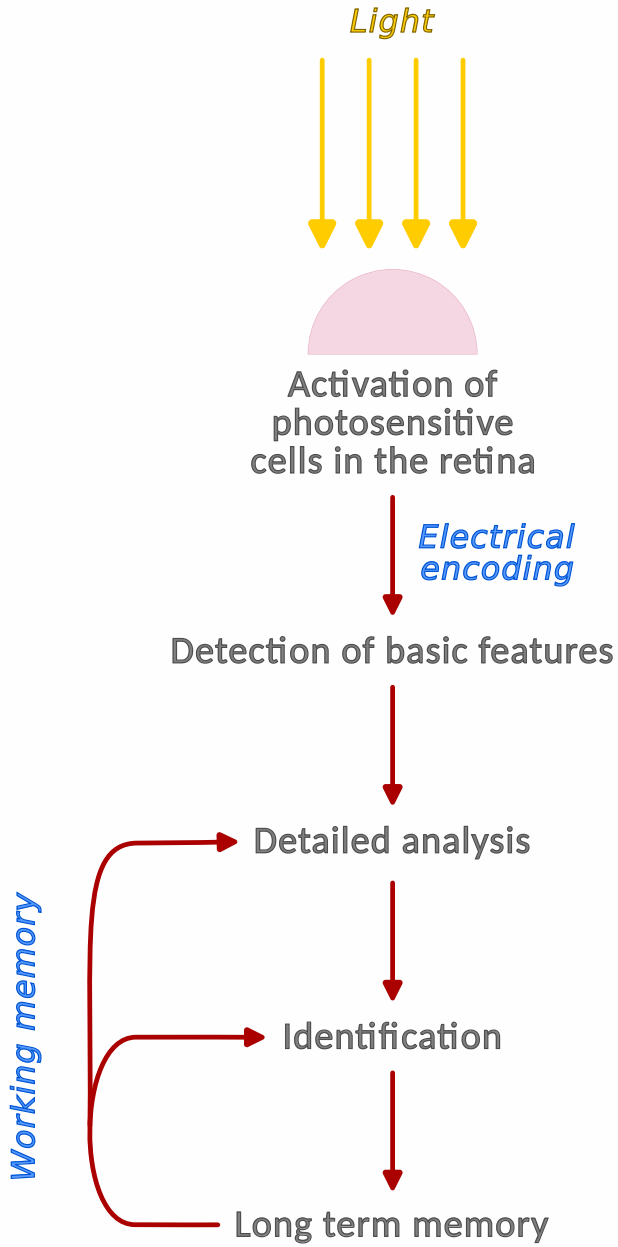
Seeing things



Perception

- What retina gets **is not** what your brain perceives.

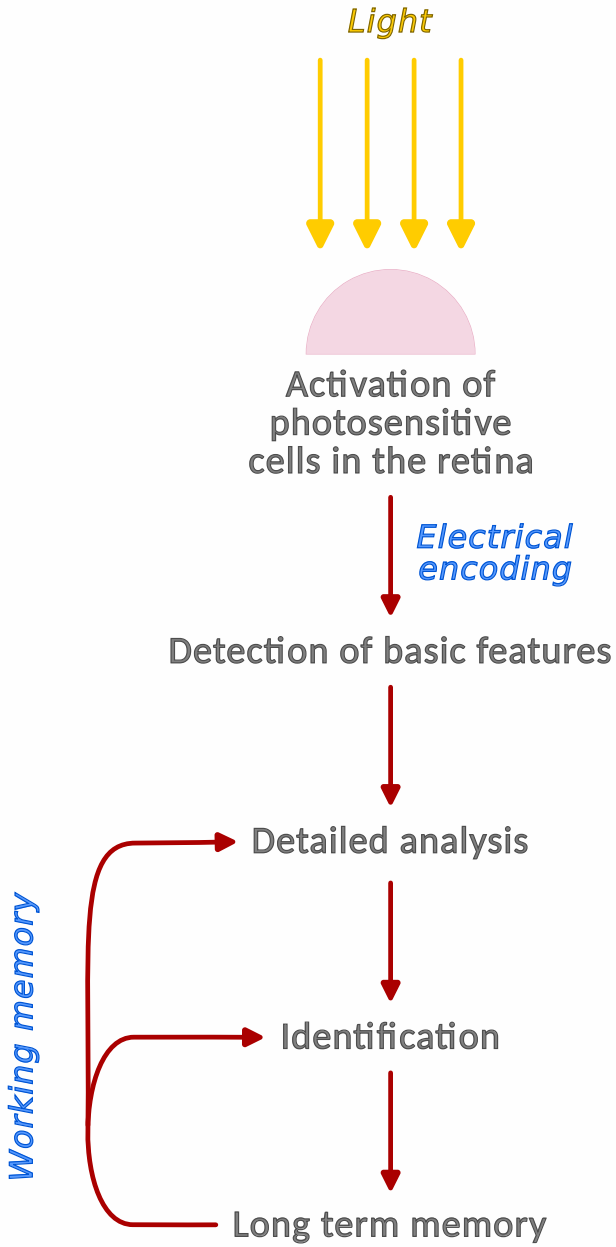
Seeing things



Perception

- The relationship between **working memory** and **long term memory** is similar to that between RAM (*i.e.*, quick but with limited capacity) and HD (*i.e.*, high capacity and reliable but slow).

Seeing things



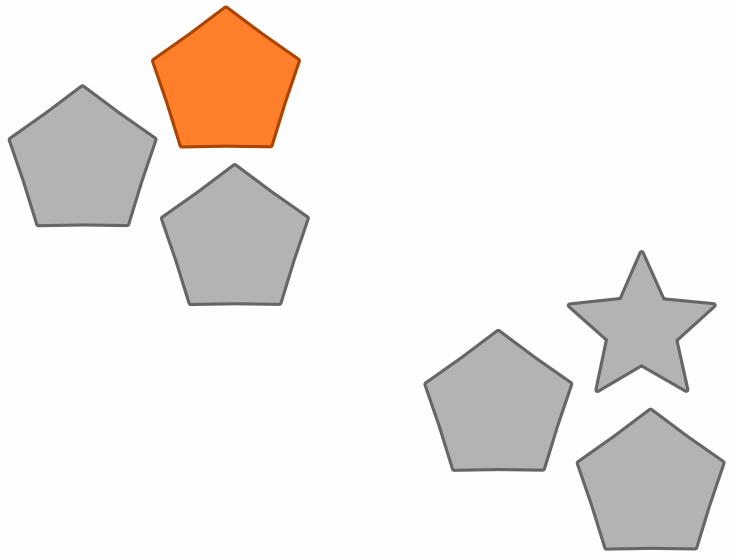
Perception

- The brain compares what it **sees** with what it **remembers**.

Seeing things

Cognition

- The brain **loves** differences!



Seeing things

Cognition

- Objects can be identified according to their **main features**, **components**, and **configuration**.

Seeing things

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  features

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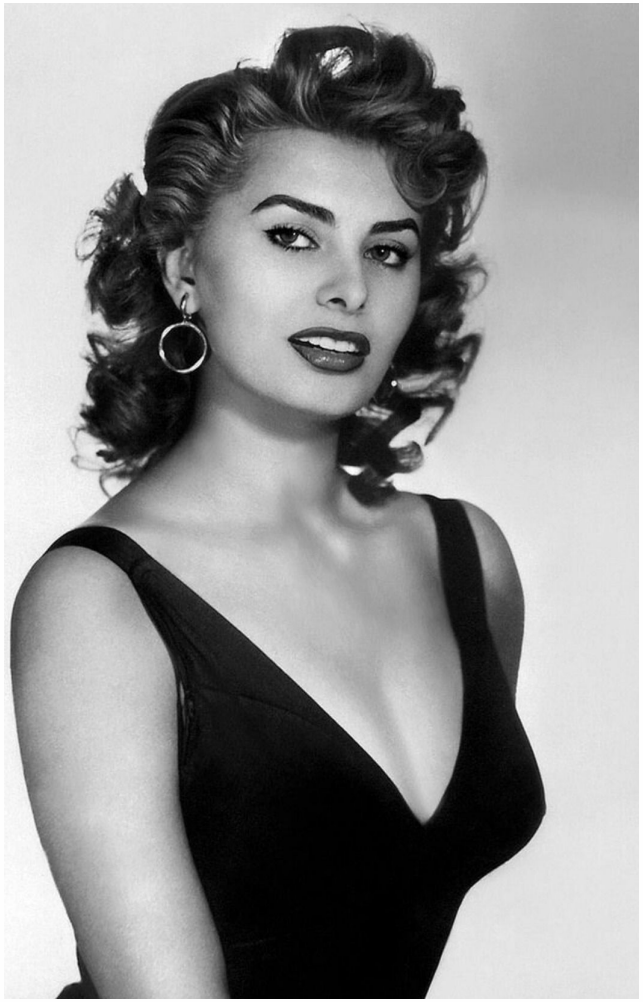


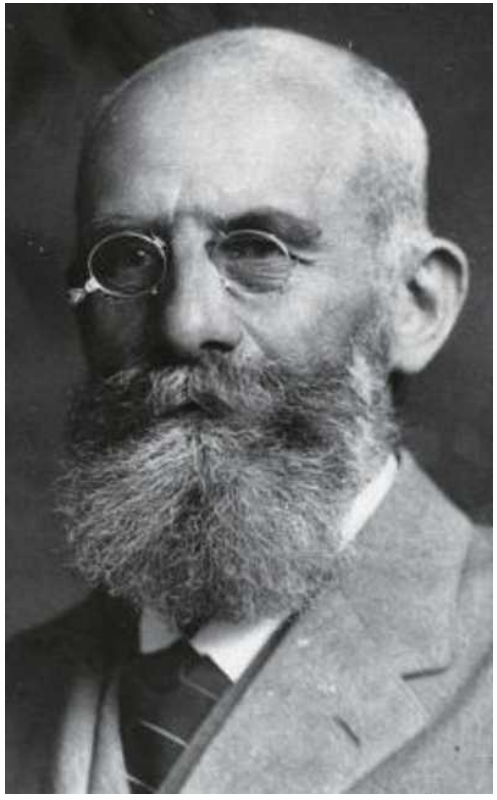
Seeing things

Tip

The more an object is **stylized**, the easier it gets to be **recognized** (less cognitive burden), and the better the picture conveys that object's **function** (very handy in presentations and modeling).

Gestalt

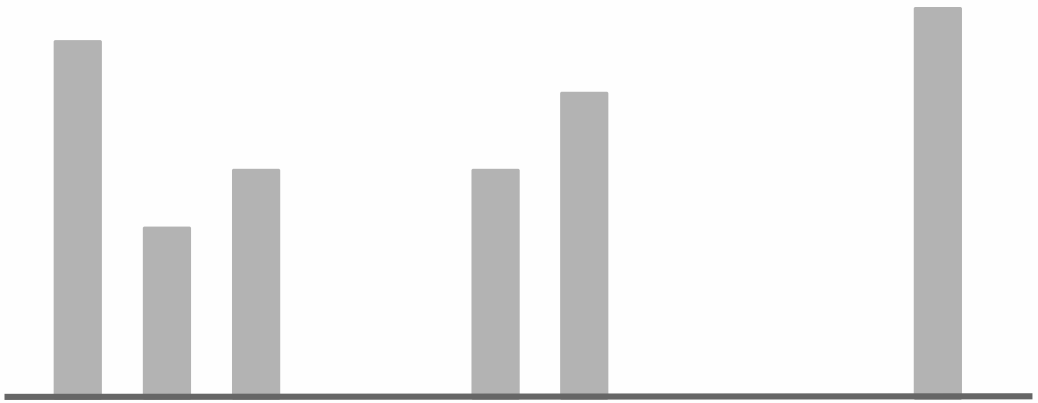
- Established at the beginning of the XXth century by Christian von Ehrenfels.
- It emphasises the processing of *entire patterns and configurations*, and **not merely individual components** (*i.e.*, the brain perceives things like “aggregates” gestalt → pattern).



Gestalt

Gestalt's laws of grouping

Proximity



Gestalt

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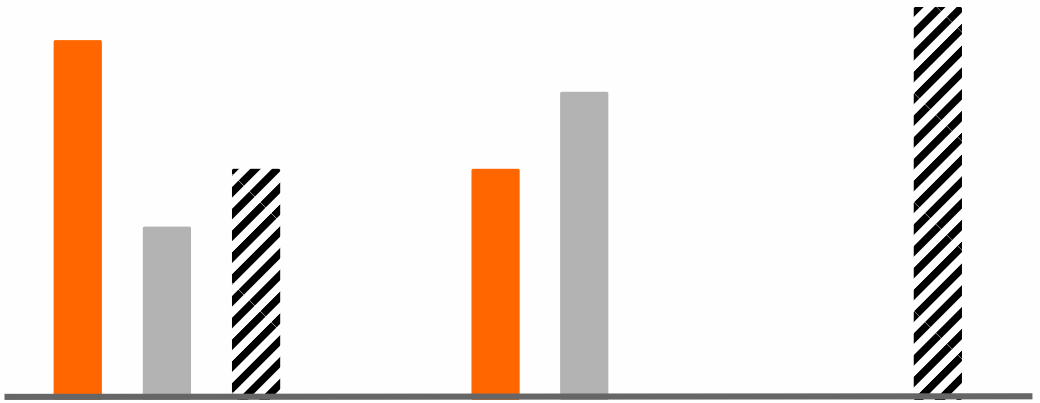
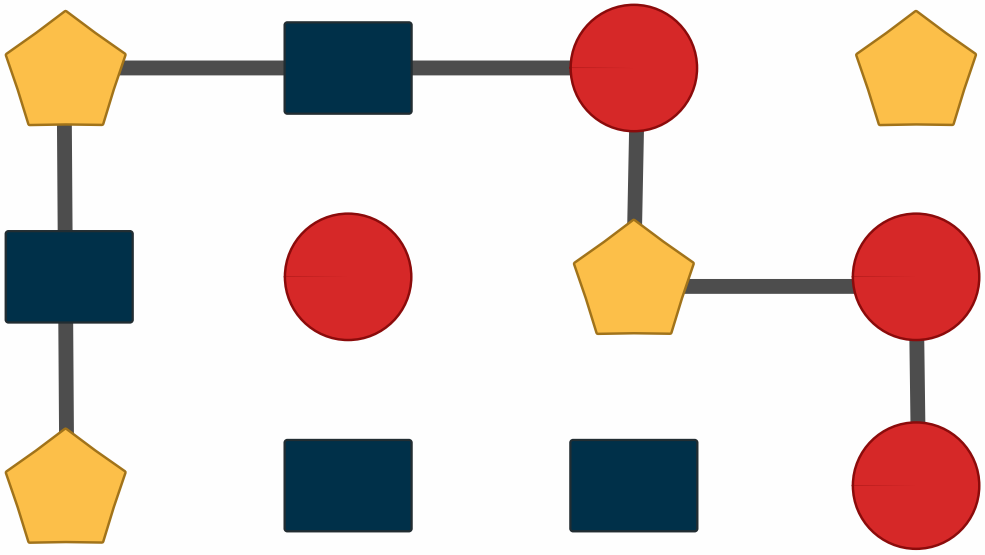
Similarity



Gestalt

Gestalt's laws of grouping

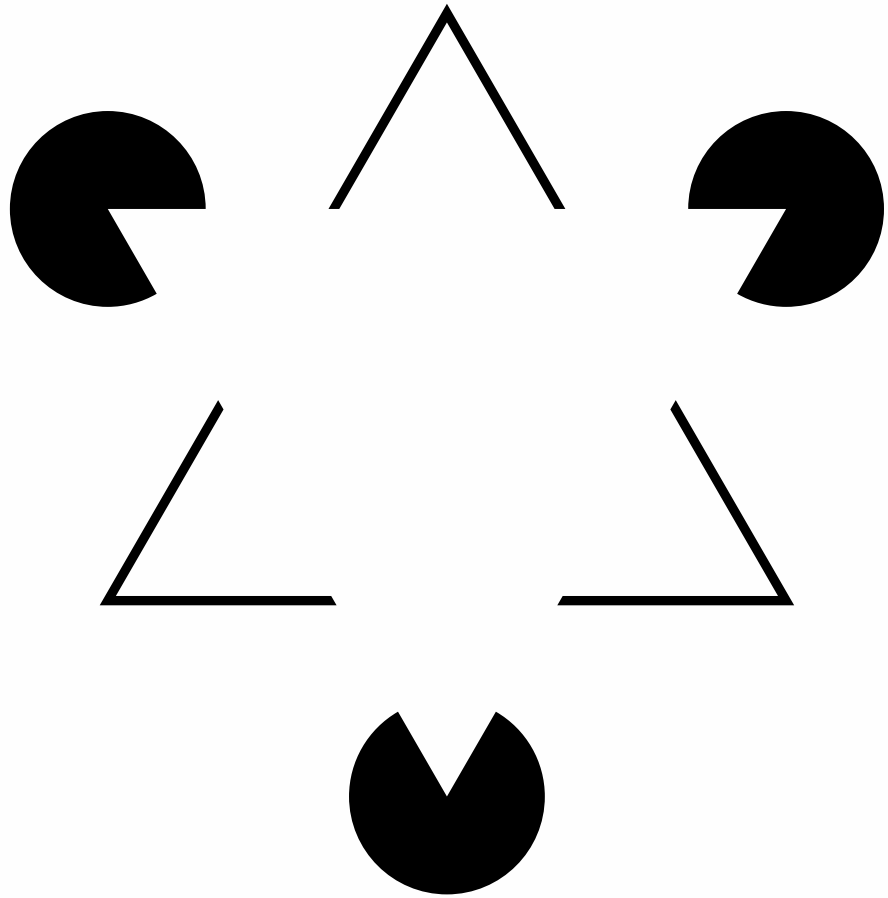
Connectedness



Gestalt

Gestalt's laws of grouping

Continuity



- Kanizsa's Triangle: https://en.wikipedia.org/wiki/Gaetano_Kanizsa

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Gestalt's laws of grouping

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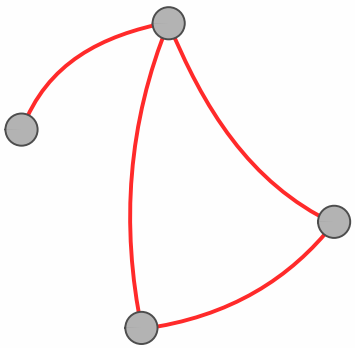

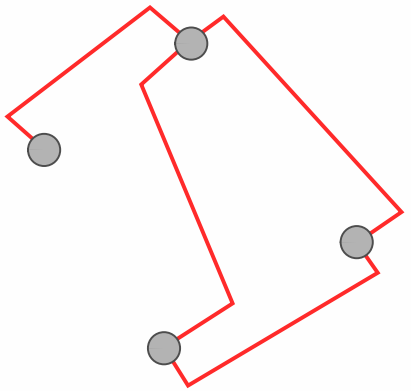

Gestalt

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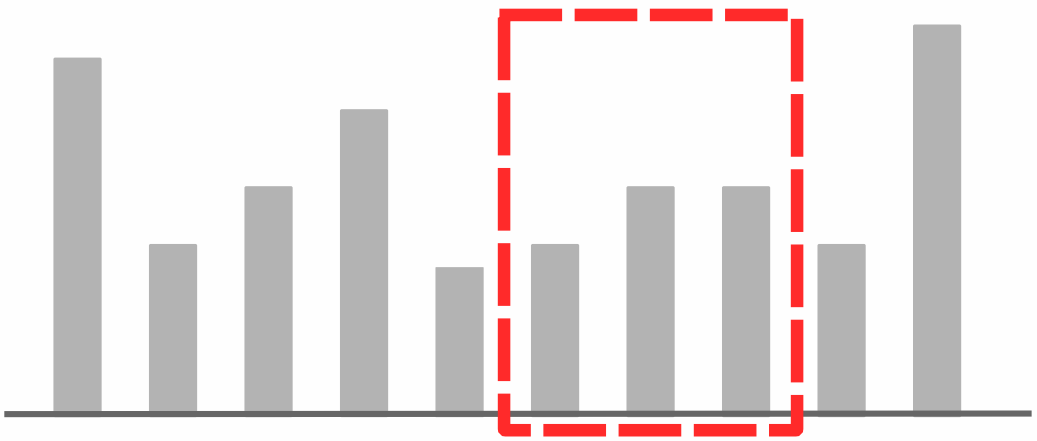
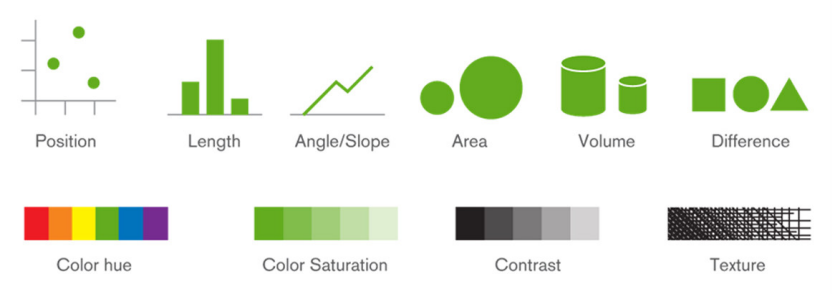
Closure



Visual encoders

Visual encoders

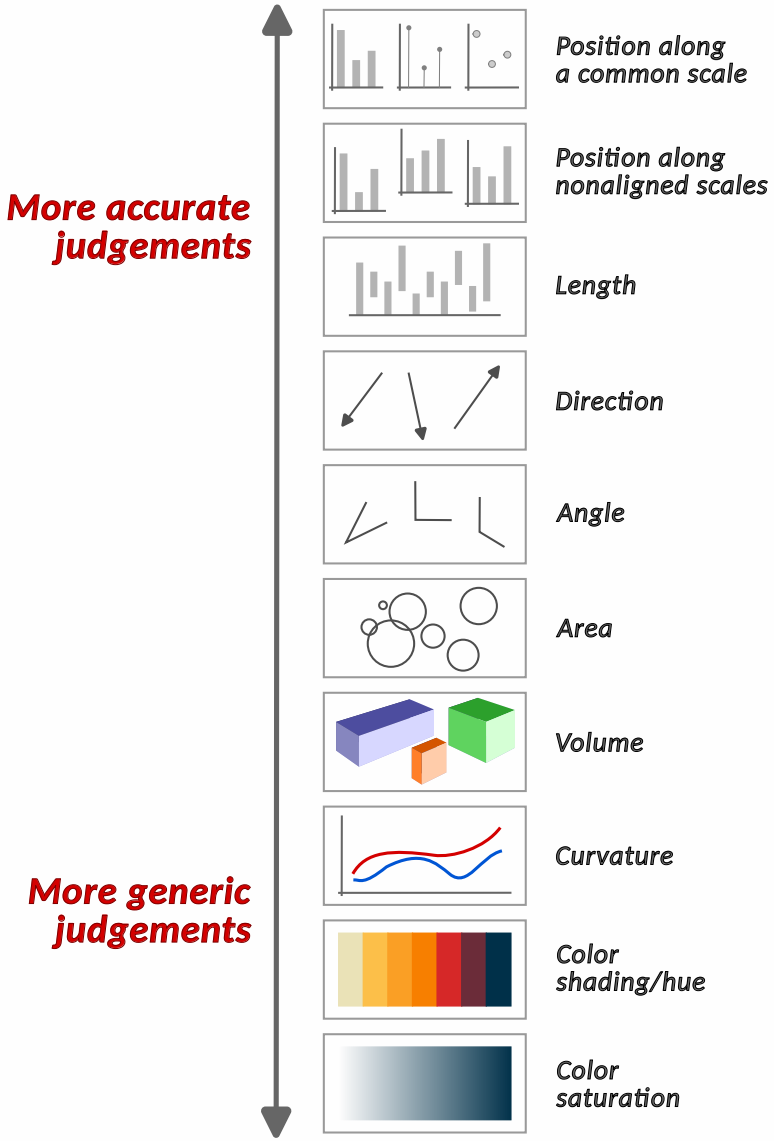


Visual encoders

- Our brain is able to process several types of information encoders.
- Depending on the case, we can use one encoding, or combine together more of them.
- Be careful! We are not all able to perceive encoders equally! (*e.g.*, color blindness)

- `https://blog.qlik.com/visual-encoding`
- K. Börner *et al.* Proc. Natl. Acad. Sci. USA, **116**, 1857 (2019).

Visual encoders

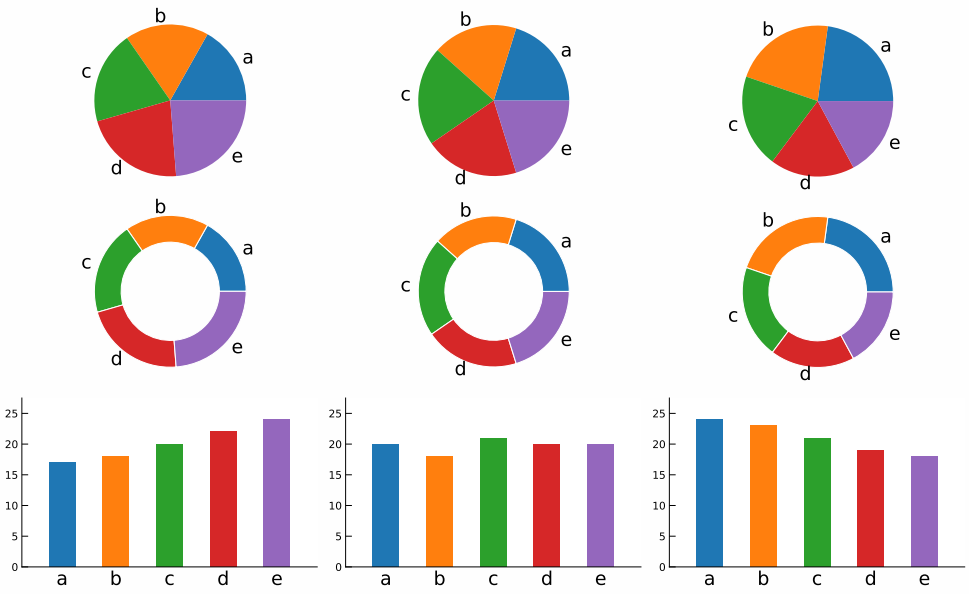


Cleveland and McGill made a **ranked list** of graphic forms (*i.e.*, visual encoders) to encode data based on the brain's ability to process them for comparing/discriminating.

This list allow us to understand why, for instance, a bar chart is better than a bubble map which, in turn, is better than a heatmap.

- W. S. Cleveland, and R. McGill, Jour. Am. Stat. Ass., **79**, 531–554 (1984). DOI: 10.1080/01621459.1984.10478080

Visual encoders



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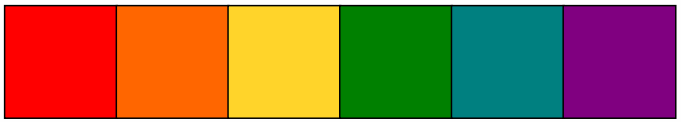
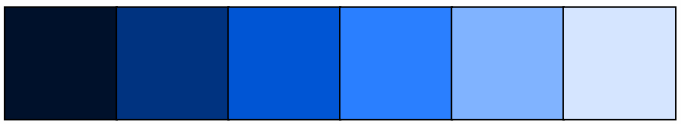
Color encoders

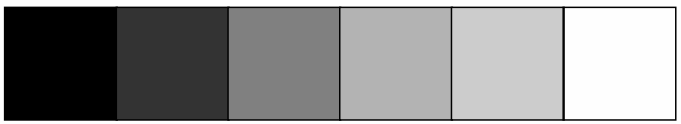
Color encoders



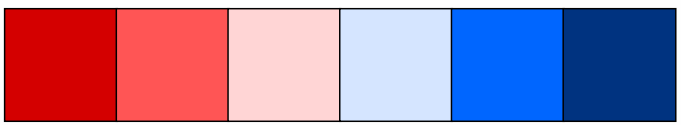
Hue
(category)



Saturation/Lightness
(increment)

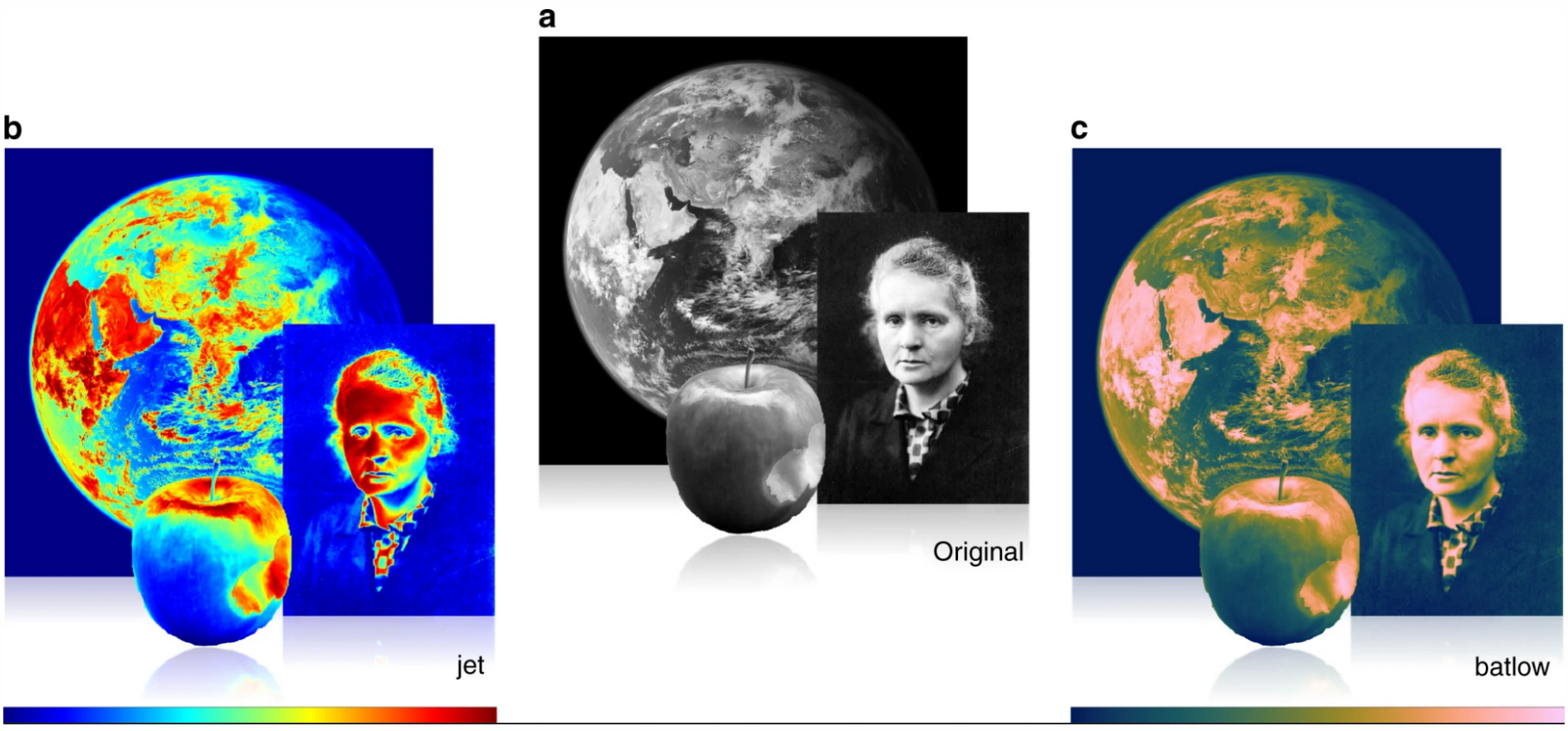


Contrast
(differences)



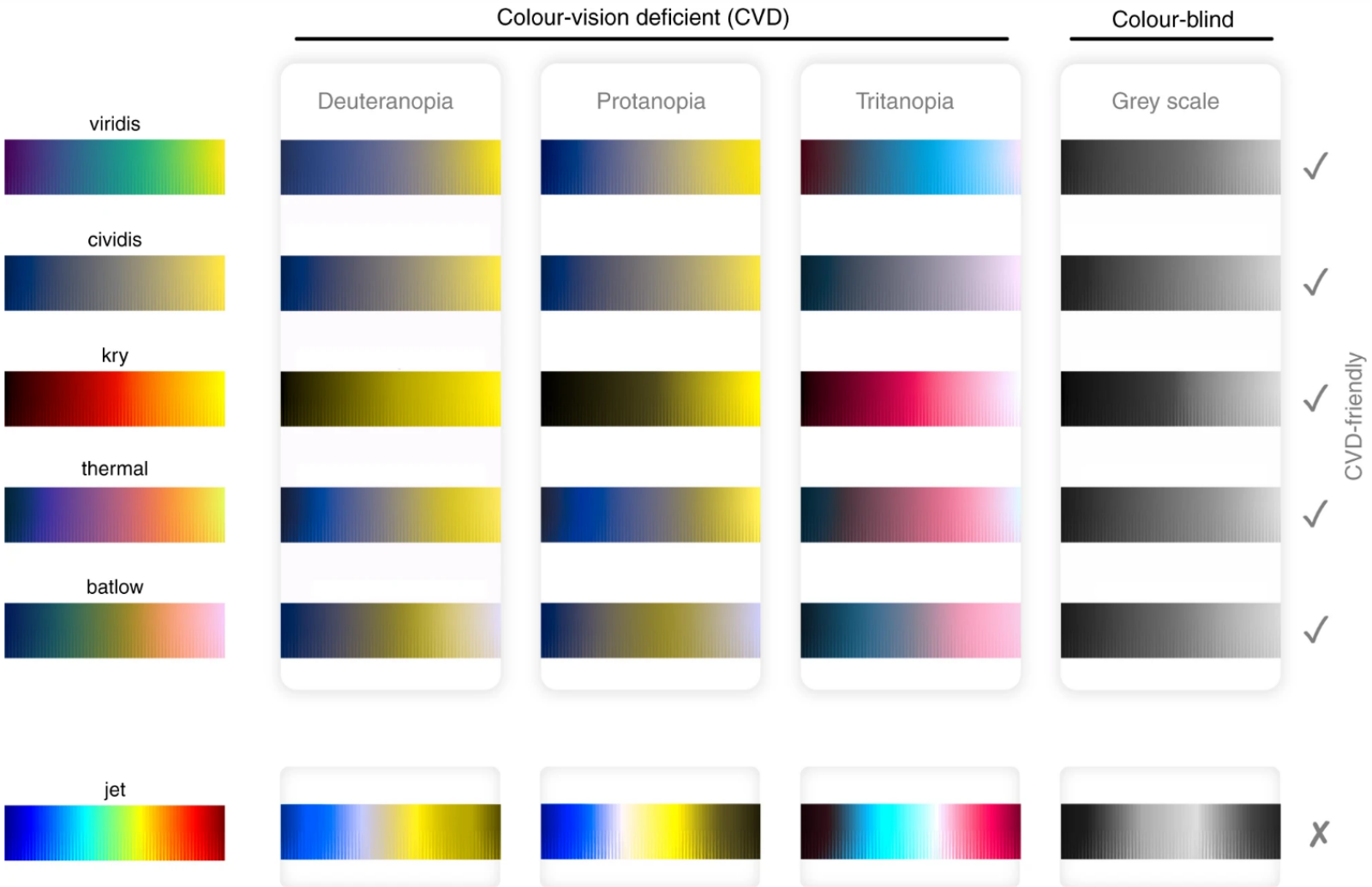
Divergence
(opposing effects)

Color encoders



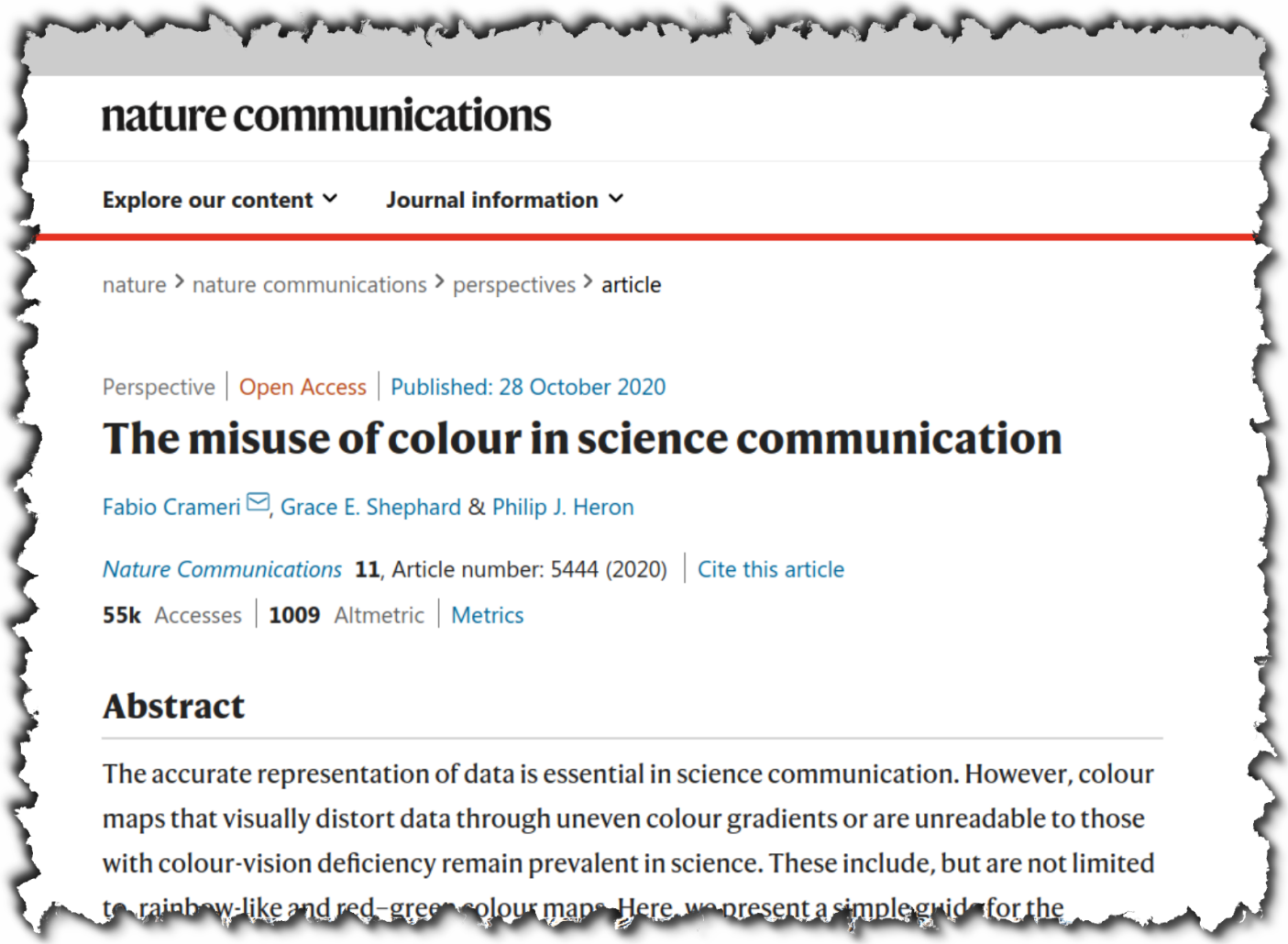
- https://www.nature.com/articles/s41467-020-19160-7

Color encoders



- https://www.nature.com/articles/s41467-020-19160-7
- https://matplotlib.org/tutorials/colors/colormaps.html

Color encoders



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The misuse of colour in science communication

Fabio Crameri ✉, Grace E. Shephard & Philip J. Heron

Nature Communications **11**, Article number: 5444 (2020) | Cite this article

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Abstract

The accurate representation of data is essential in science communication. However, colour maps that visually distort data through uneven colour gradients or are unreadable to those with colour-vision deficiency remain prevalent in science. These include, but are not limited to, rainbow-like and red–green colour maps. Here, we present a simple guide for the

- https://www.nature.com/articles/s41467-020-19160-7

Color encoders

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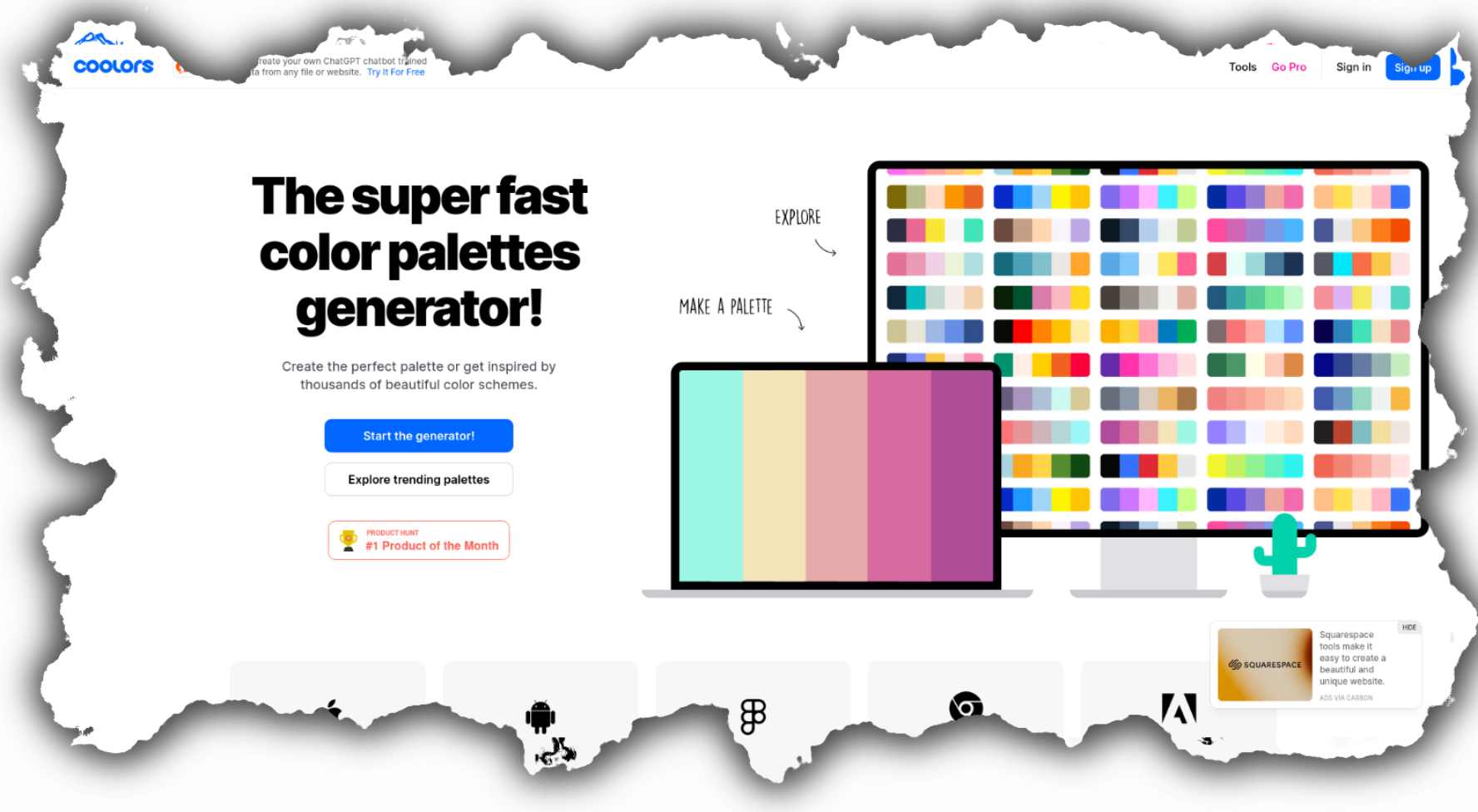
Guide to Acceptable Use of Color in "(Color online)" Figures

Figures submitted as color PostScript (or EPS) files will be published online in color at no extra charge to the author. Care should be taken to ensure that captions and text references to the figures are appropriate for both the online color and print grayscale versions, and that the figure will be sufficiently clear in both versions. We suggest captions contain phrasing such as "... the red (dark gray) line ..." as well as beginning with "(Color online)".

As submitted in color **As submitted in grayscale**

- https://journals.aps.org/authors/guide-acceptable-color-online-figures-h24

Color encoders



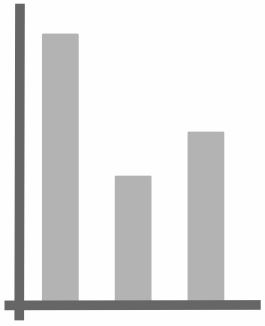
- https://coolors.co/

Diagrams’ phenotypes

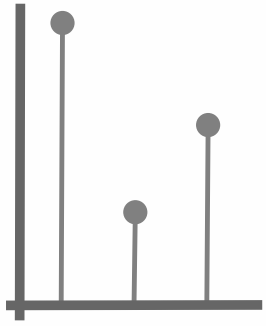
Diagrams' types

- Amounts
- Distributions
- Proportions
- x–y relationships
- Geospatial data

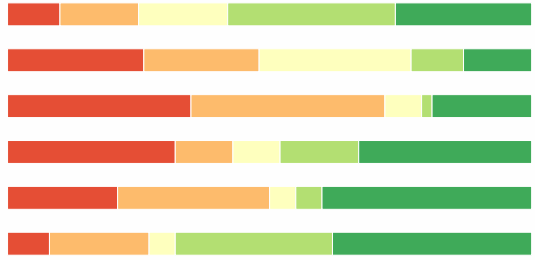
Amounts



Bars

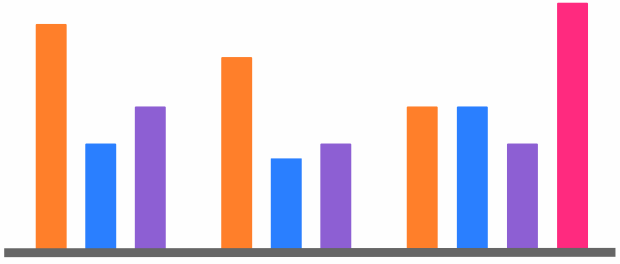


Lollipop

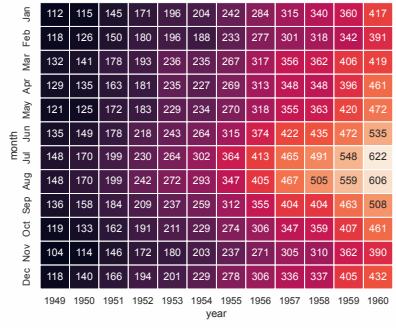


Stacked bars

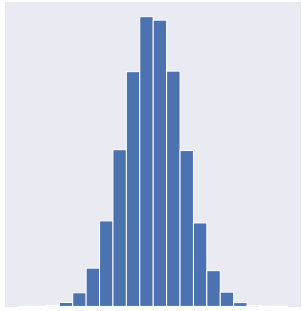
Grouped bars



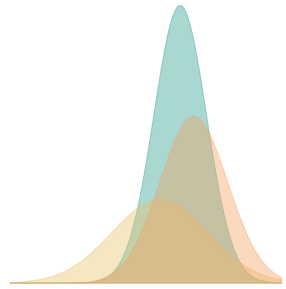
Heatmap



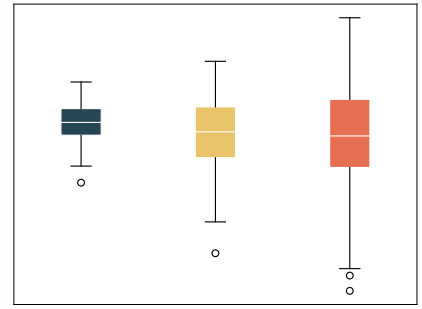
Distributions



Histogram

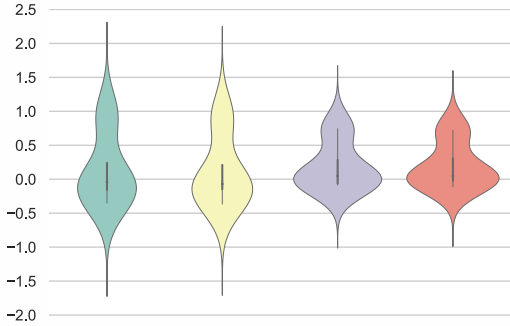


Overlapping densities

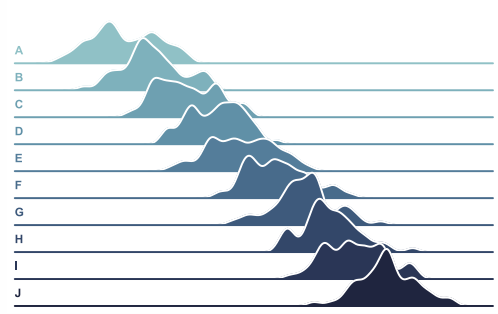


Boxplot

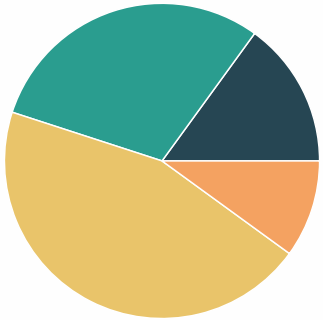
Violin plot



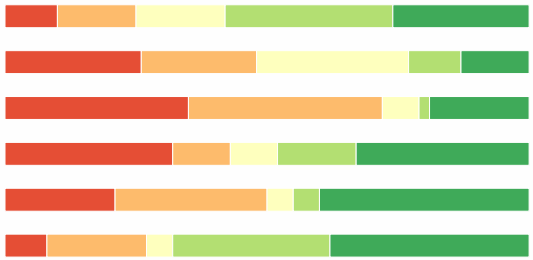
Ridgeline plot



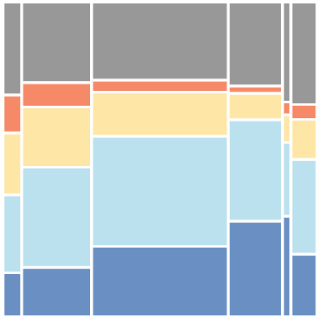
Proportions



Pie chart

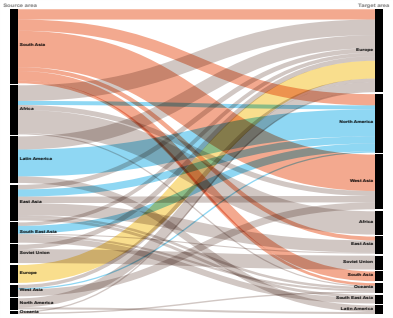


Stacked bars

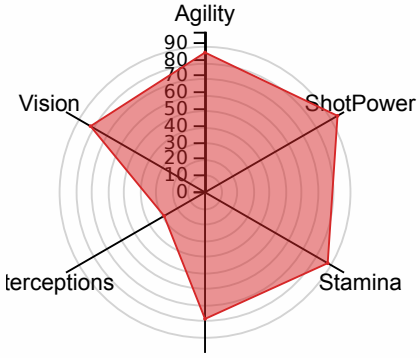


Mosaic plot

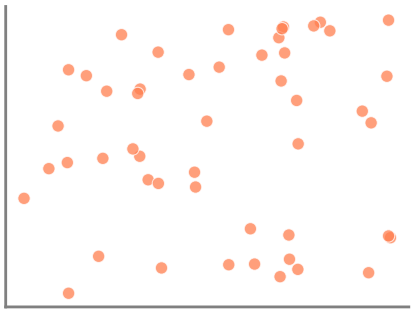
Parallel sets



Radar plot

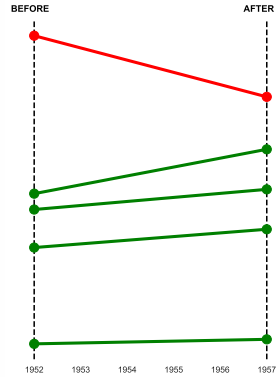


x-y relationships



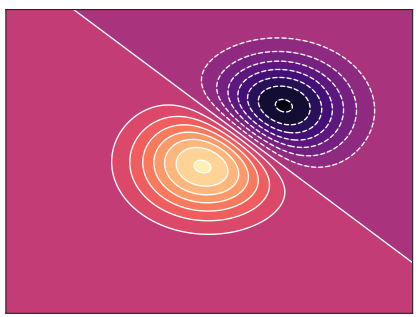
Scatterplot

Bubble chart

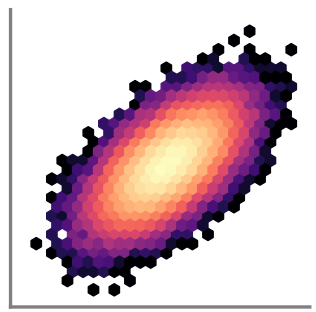


Slopegraph

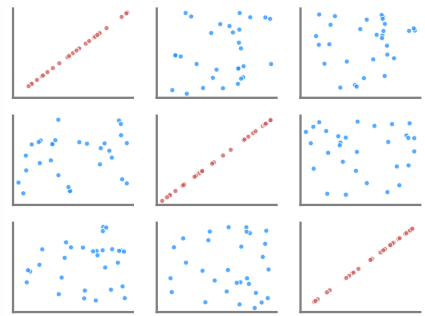
Density contours



Hex bins

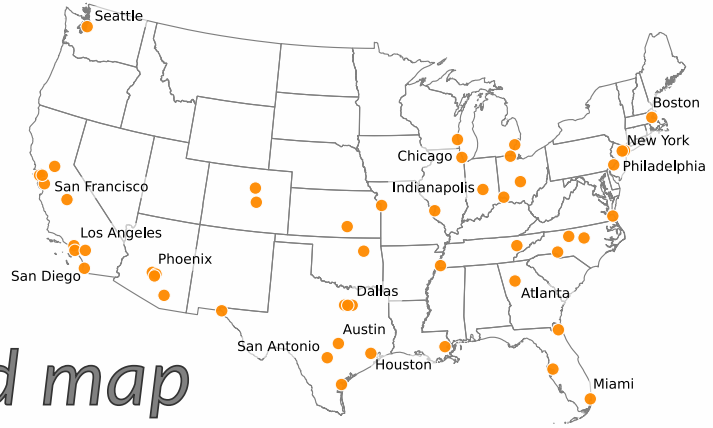


Correlogram

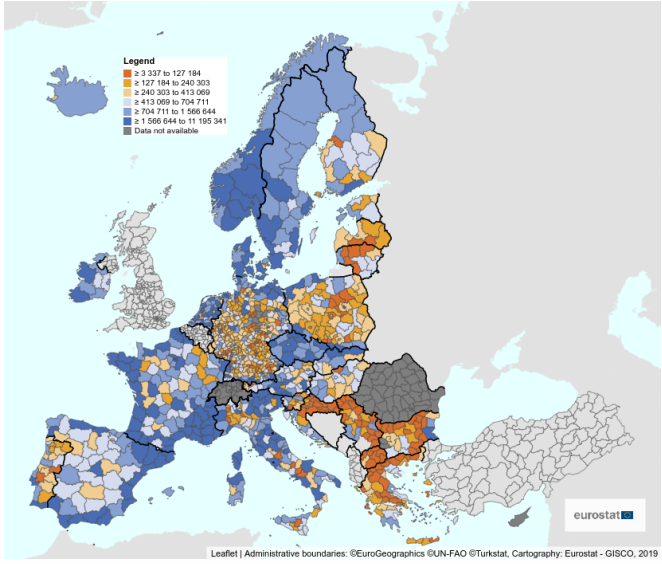


Geospatial data

Map



Annotated map



Choropleth

Each diagram's type has **strengths** but also **weaknesses**!

Principles of figure design

Principle of proportional ink

- The **Principle of proportional ink** can guide us to design more ***effective*** visualizations.

  The sizes of shaded areas in a visualization need to be proportional to the data values they represent.

• C. T. Bergstrom and J. West. (2017) https://www.callingbullshit.org/tools/tools_proportional_ink.html

Principle of proportional ink

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- We can summarize this principle in the so-called Tufte's **lie factor**, L:

$$L = \frac{\text{Effect in graph}}{\text{Effect on data}}$$

• E. R. Tufte, *The Visual Display of Quantitative Information*. Graphics Press (Cheshire, CT) 2001.

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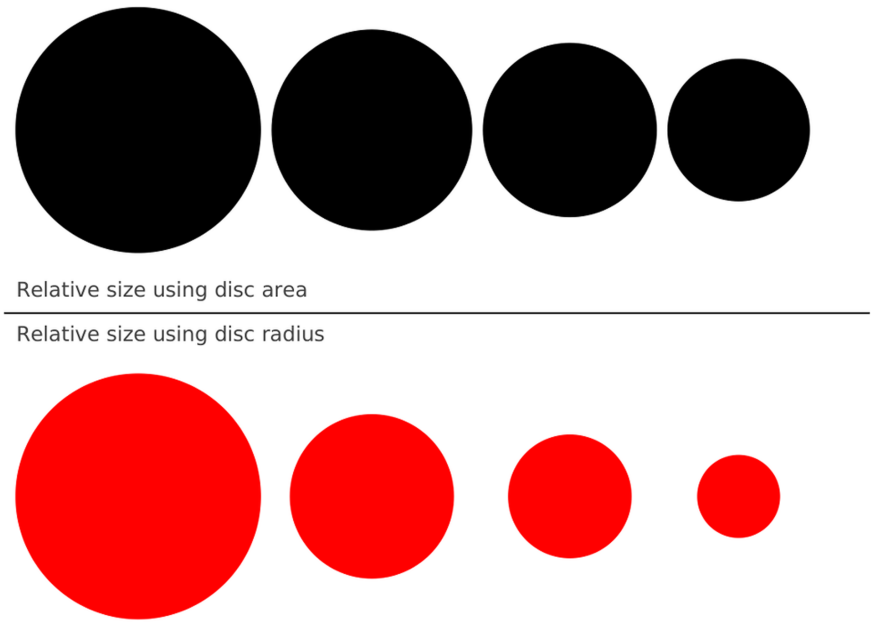
$$L = \frac{\text{Effect in graph}}{\text{Effect on data}}$$

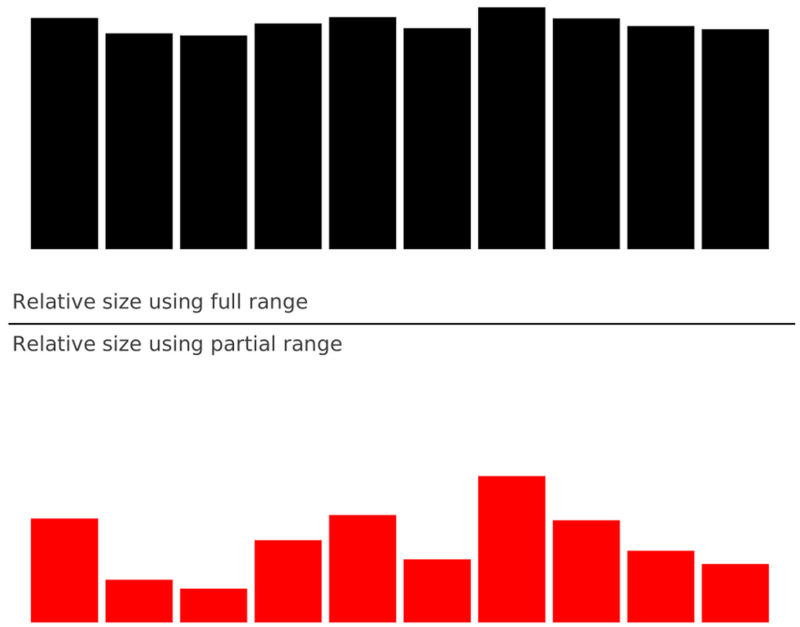
- If $L > 1$, the plot **OVERSTATES THE EFFECT** (*i.e.*, it is lying)!
  (**Note:** This is the case in $\approx 99\%$ of 3D plots).

• E. R. Tufte, *The Visual Display of Quantitative Information*. Graphics Press (Cheshire, CT) 2001.

Principle of proportional ink

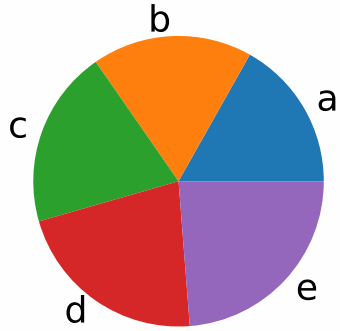
Principle of proportional ink

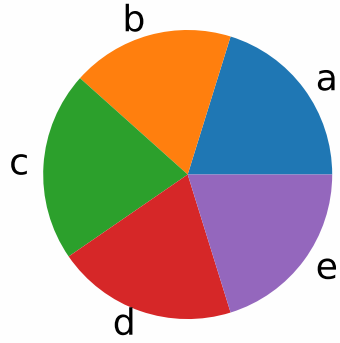


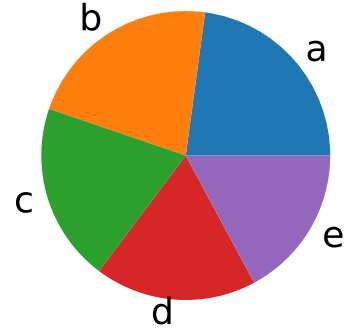


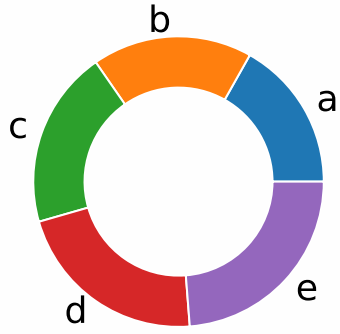
- N. P. Rougier *et al.* Ten Simple Rules for Better Figures. PLoS Comput Biol **10**, e1003833 (2014).

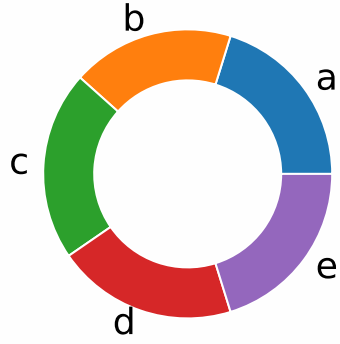
Principle of proportional ink

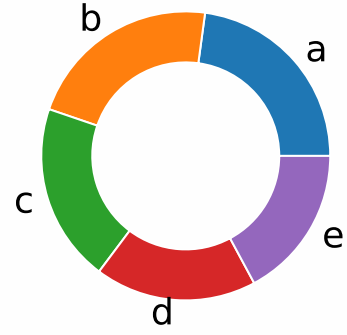


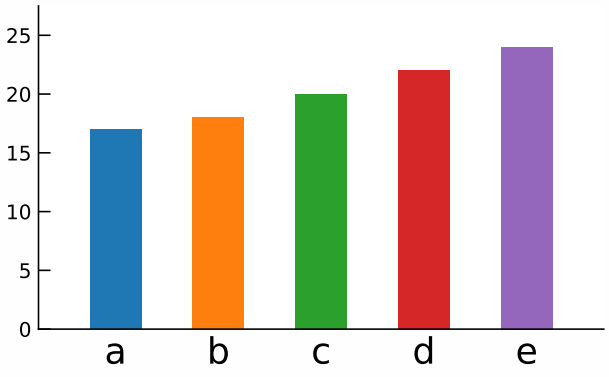


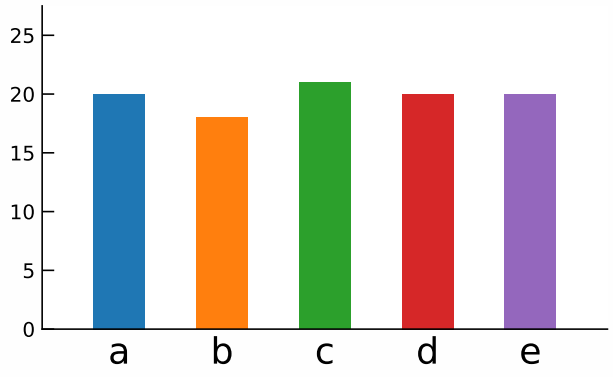


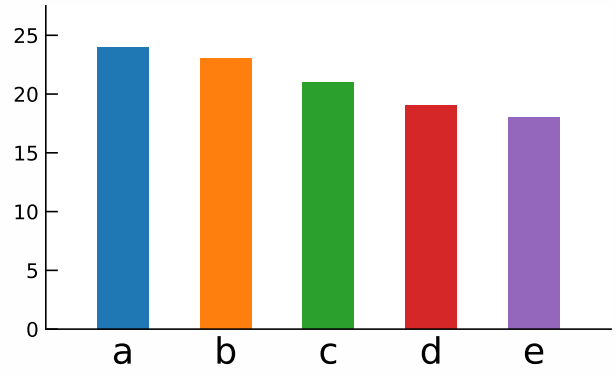












Point overlap

Point overlap

Three ways of dealing with point overlap

1. Changing the **transparency** (*a.k.a.* alpha level) of the points.

Point overlap

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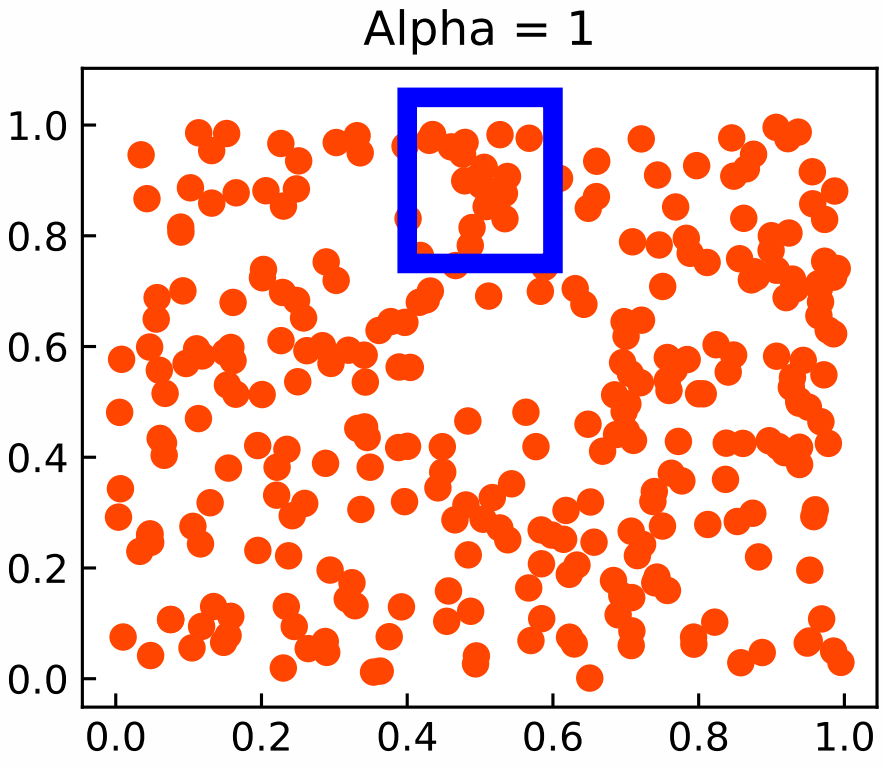
2. Adding a **border** to visually separate the points.

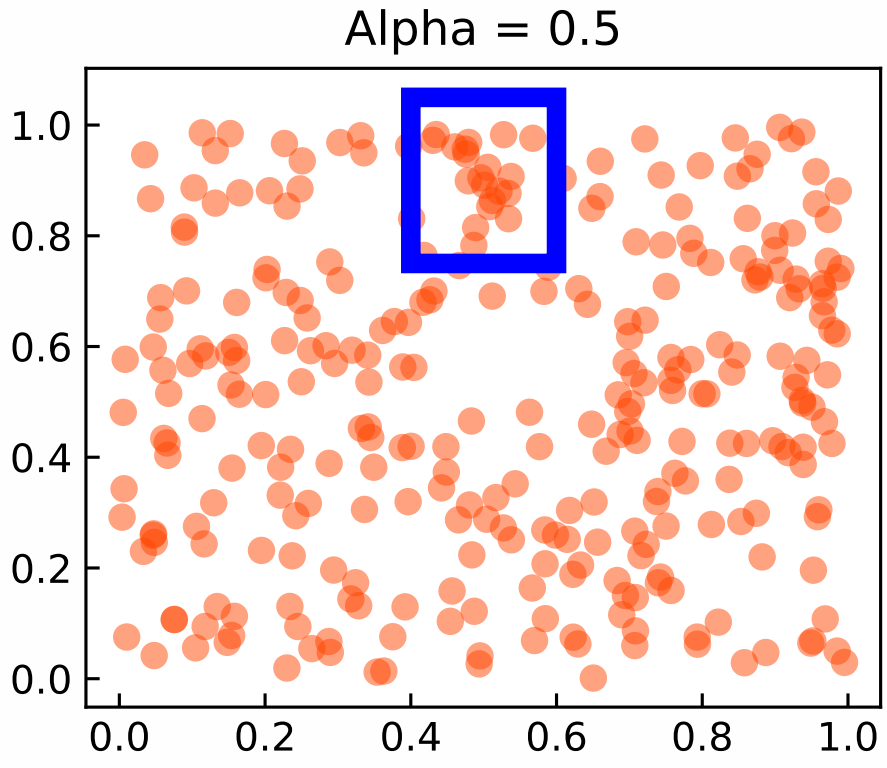
Point overlap

Three ways of dealing with point overlap

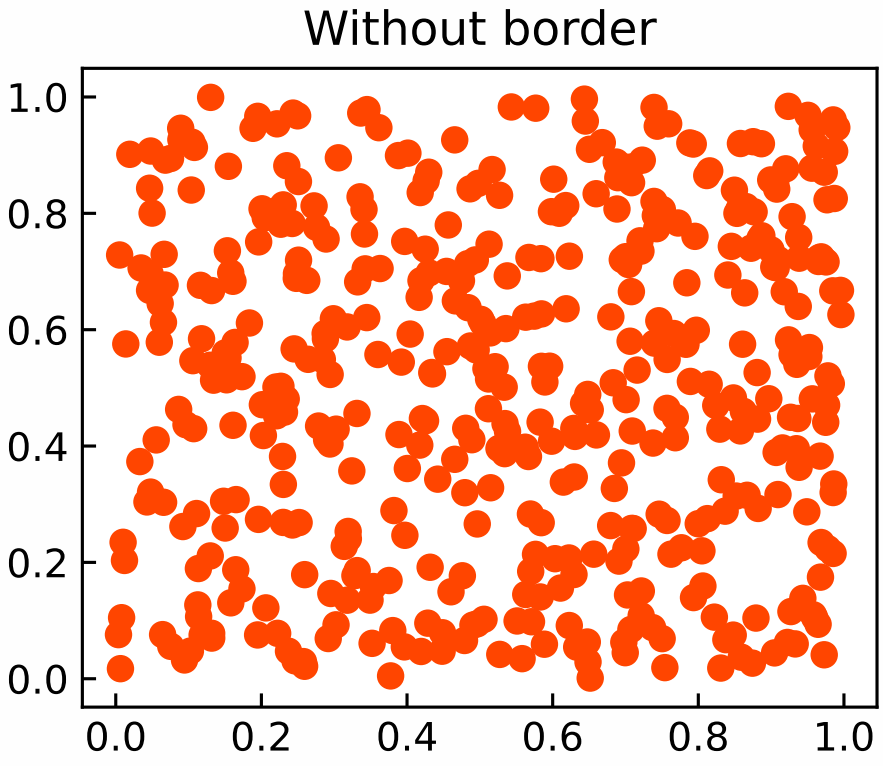
1. Changing the **transparency** (*a.k.a.* alpha level) of the points.
2. Adding a **border** to visually separate the points.
3. Manipulate (a bit) the points' positions (*a.k.a.* jitter).

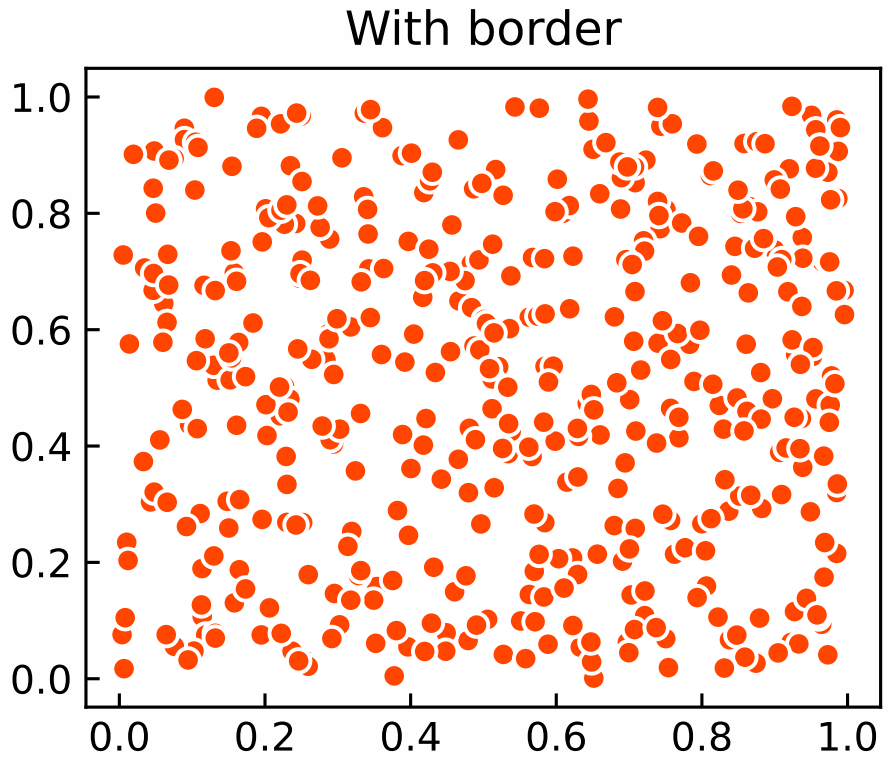
Point overlap



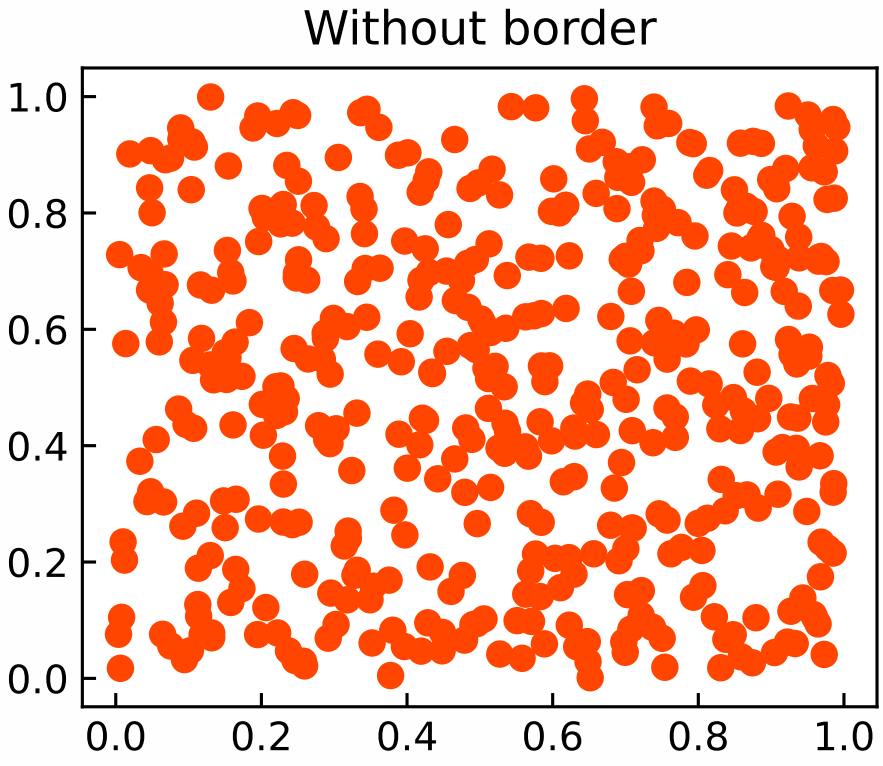


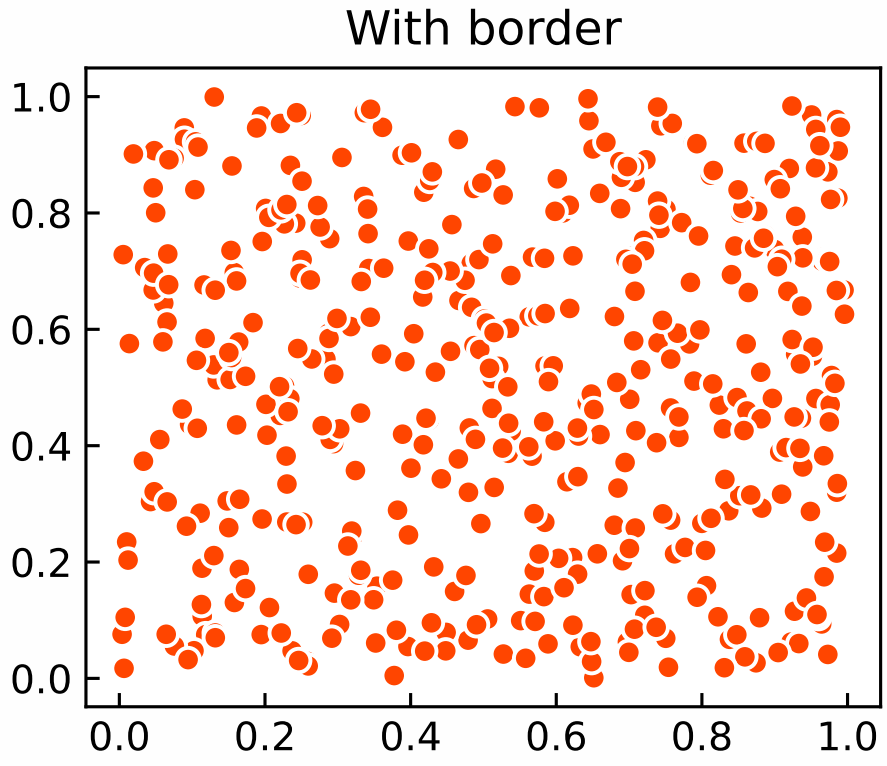
Point overlap





Point overlap





Beware

Adding a border increases the visibility, but *de-facto* reduces the **effective size** of your points!

Point overlap

Definition

Applying **jitter** to the points, *i.e.*, to displace each point randomly by a small amount in either one (or both) of the coordinates.

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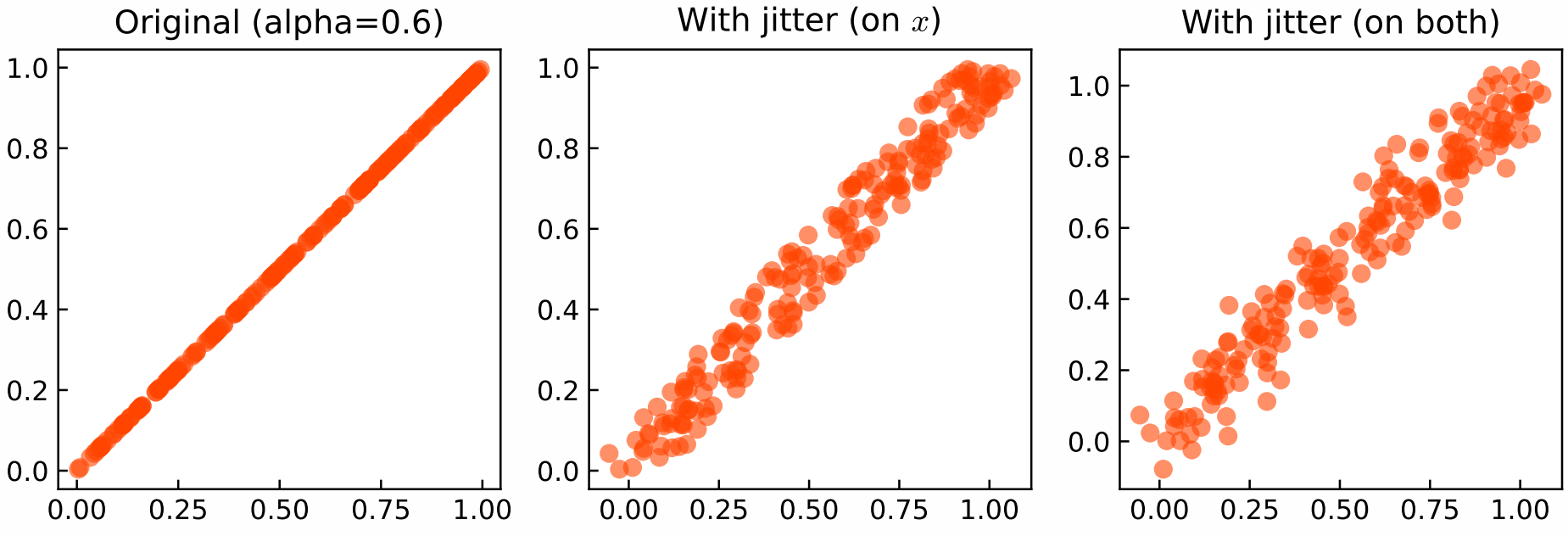
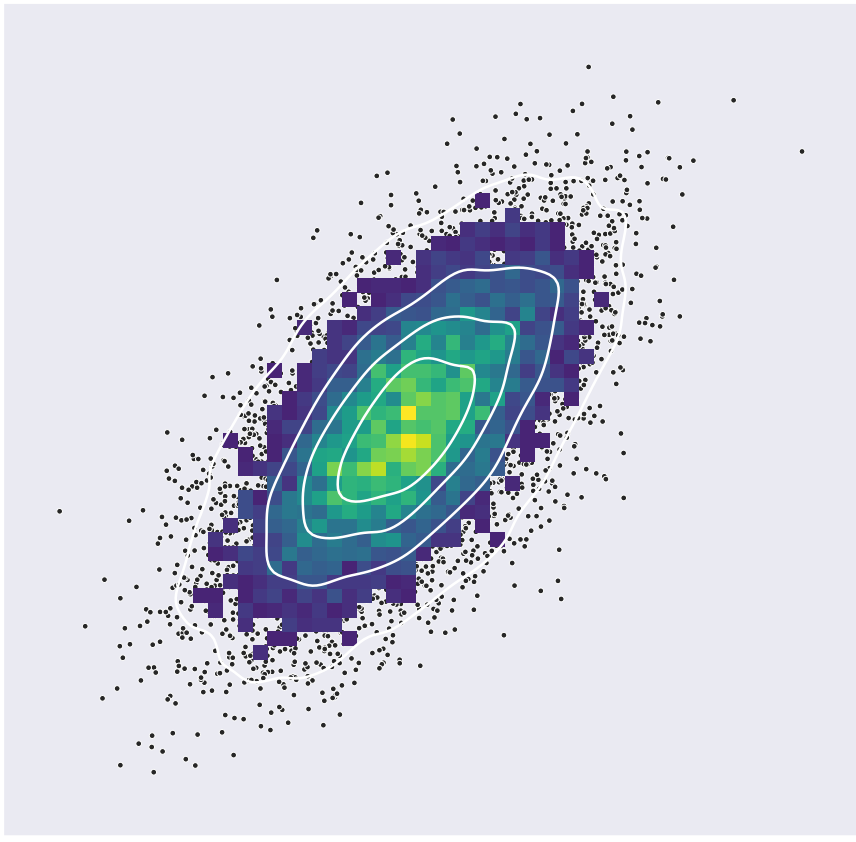
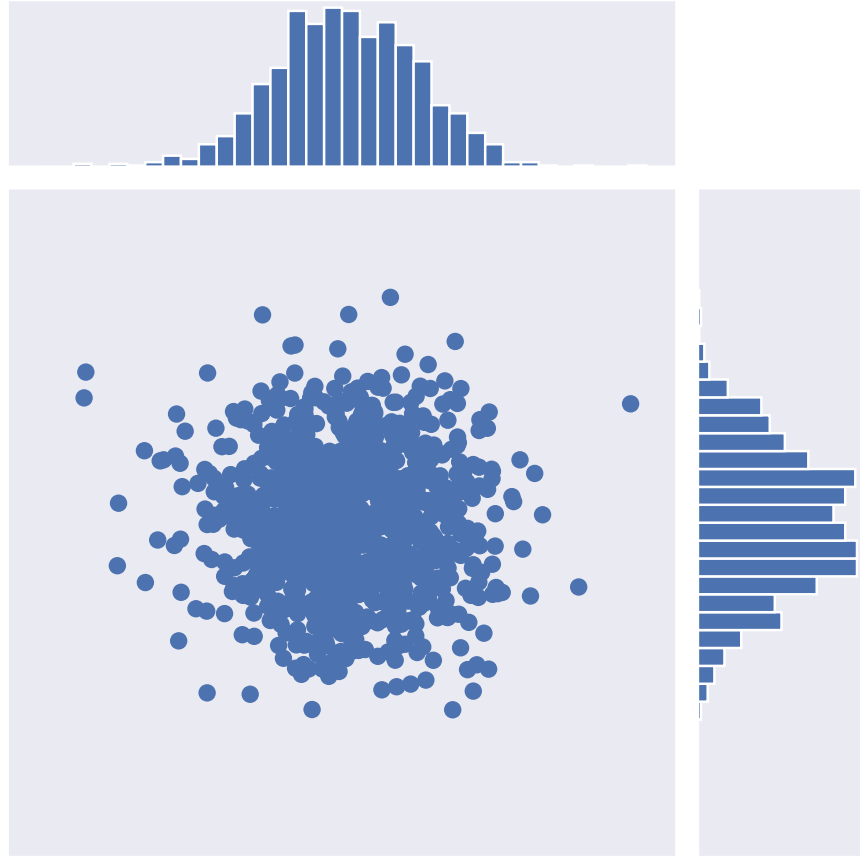
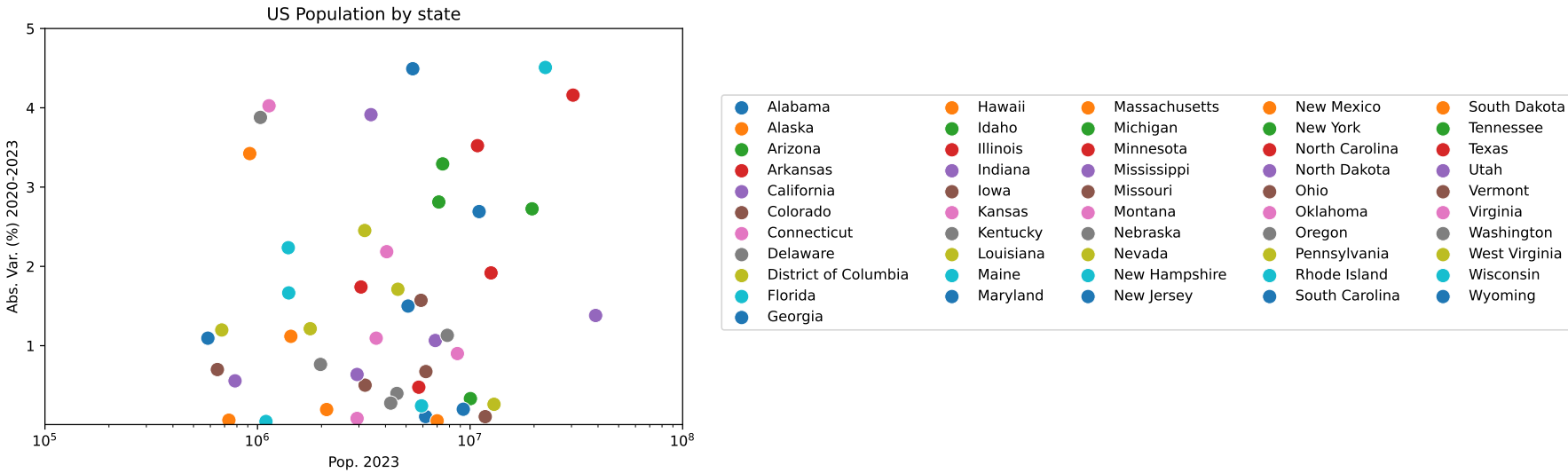


Point overlap





Excess of color use



- Annual Estimates of the Resident Population for the United States, Regions, States, District of Columbia, and Puerto Rico: April 1, 2020 to July 1, 2023 (NST-EST2023-POP). Available online at:

`https://www2.census.gov/programs-surveys/popest/tables/2020-2023/state/totals/NST-EST2023-POP.xlsx`

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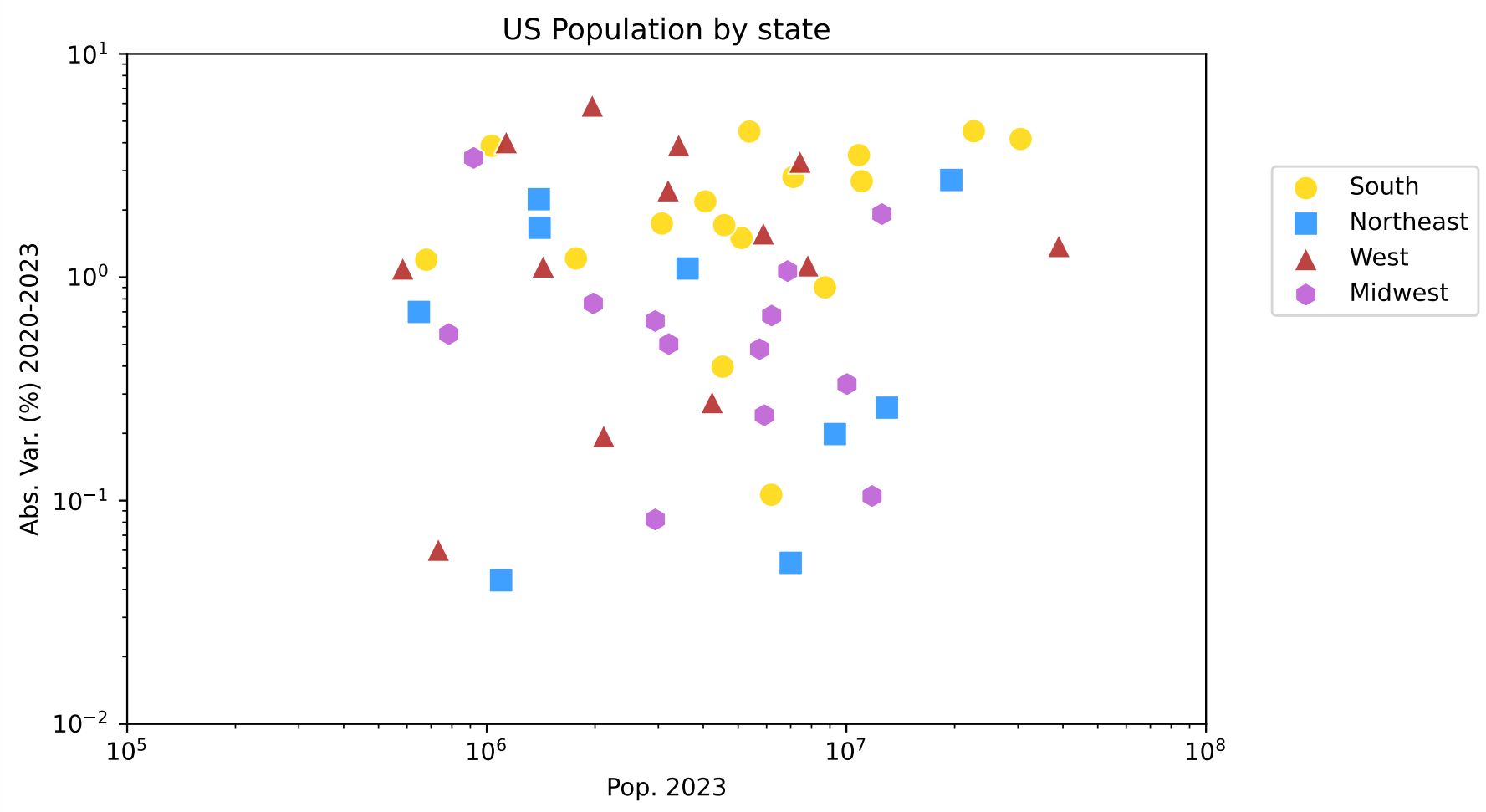

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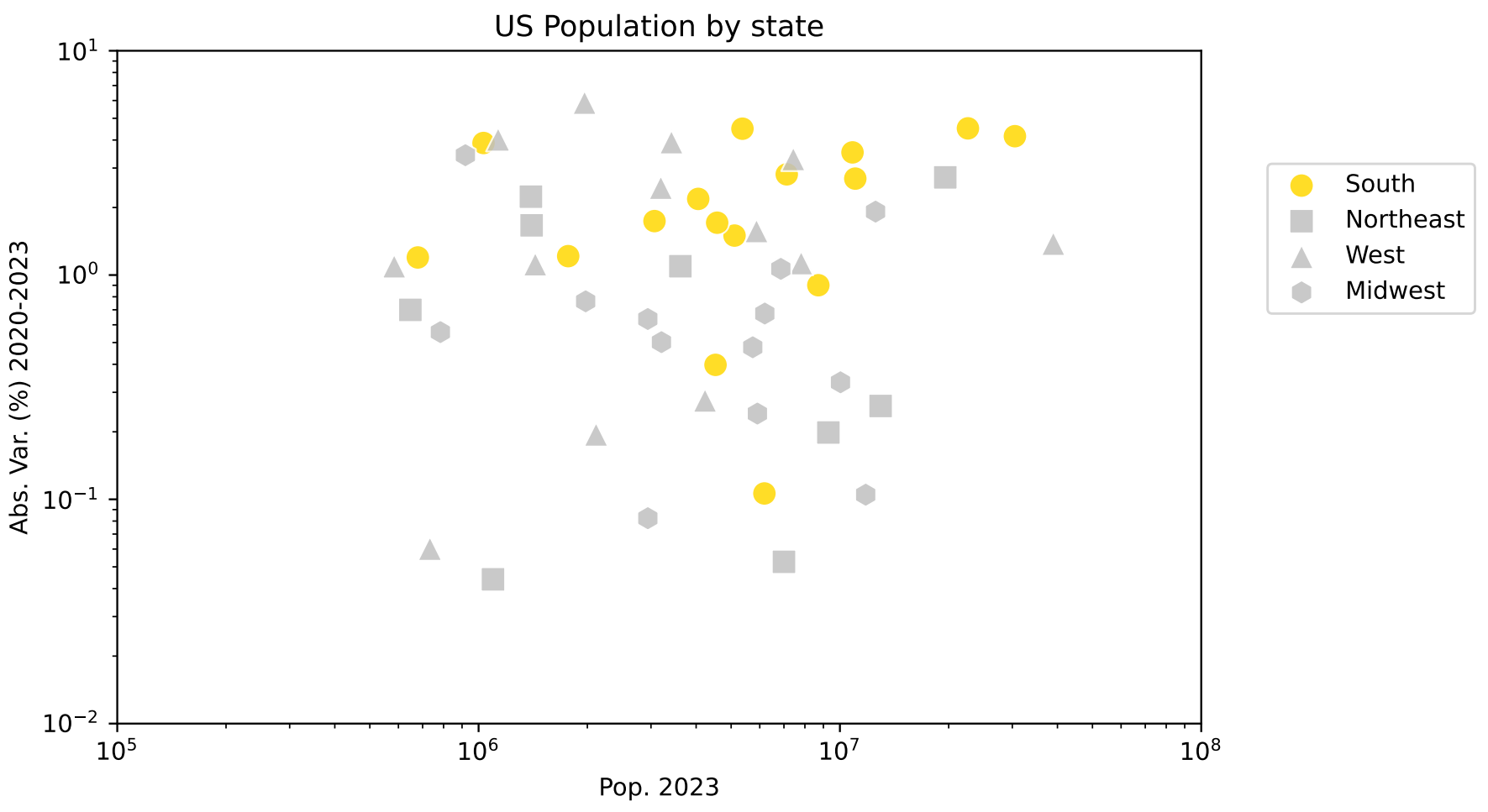

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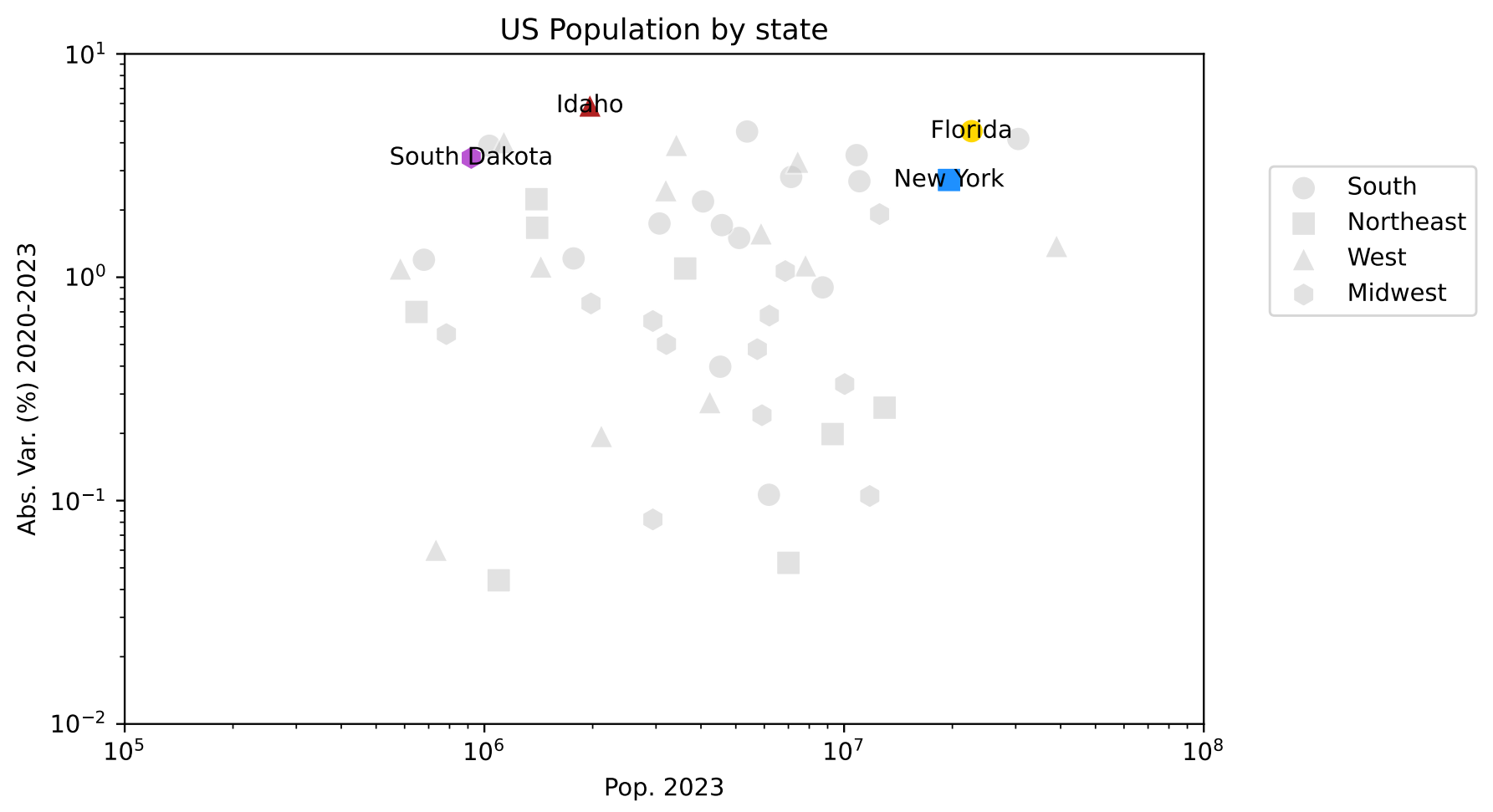
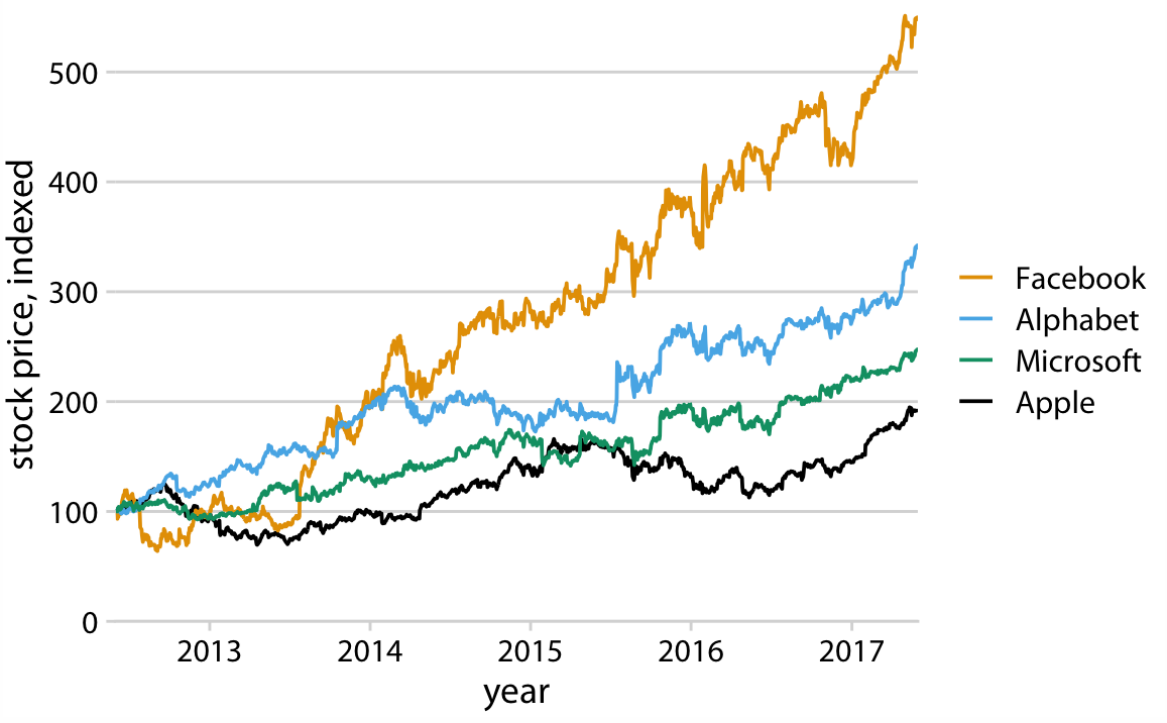


Legends & multi-panel figures

Rule of thumb

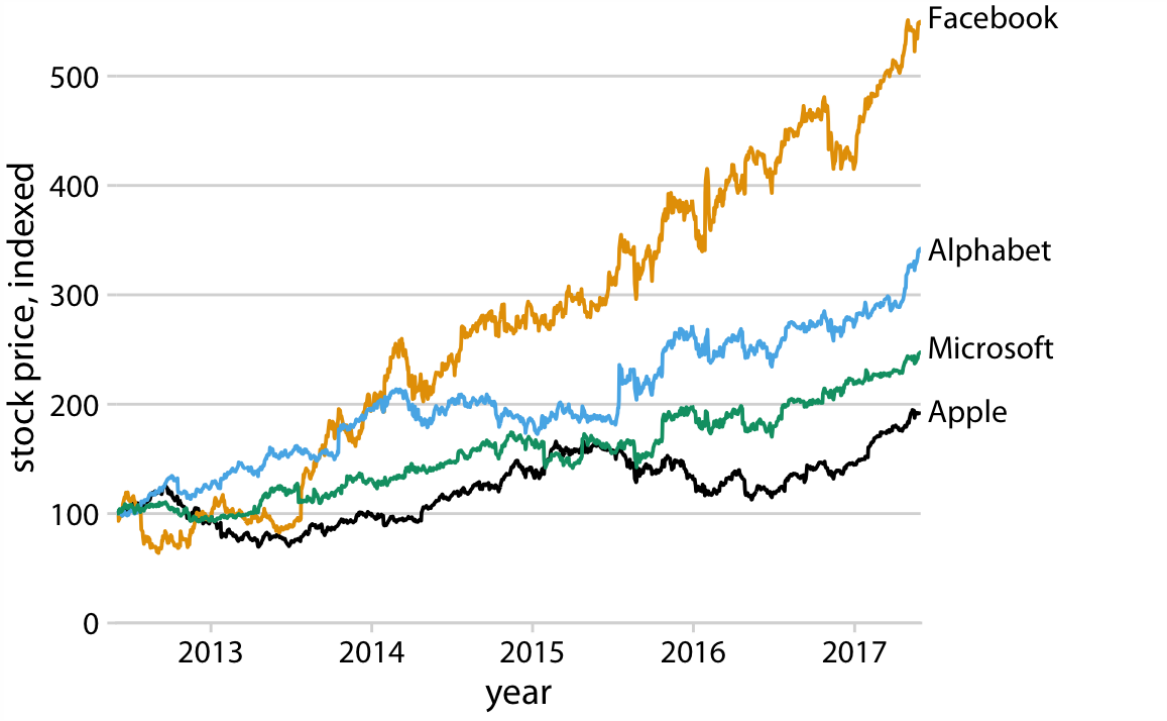
Whenever possible, design your figures such that they **do not** need a legend.

Legends & multi-panel figures



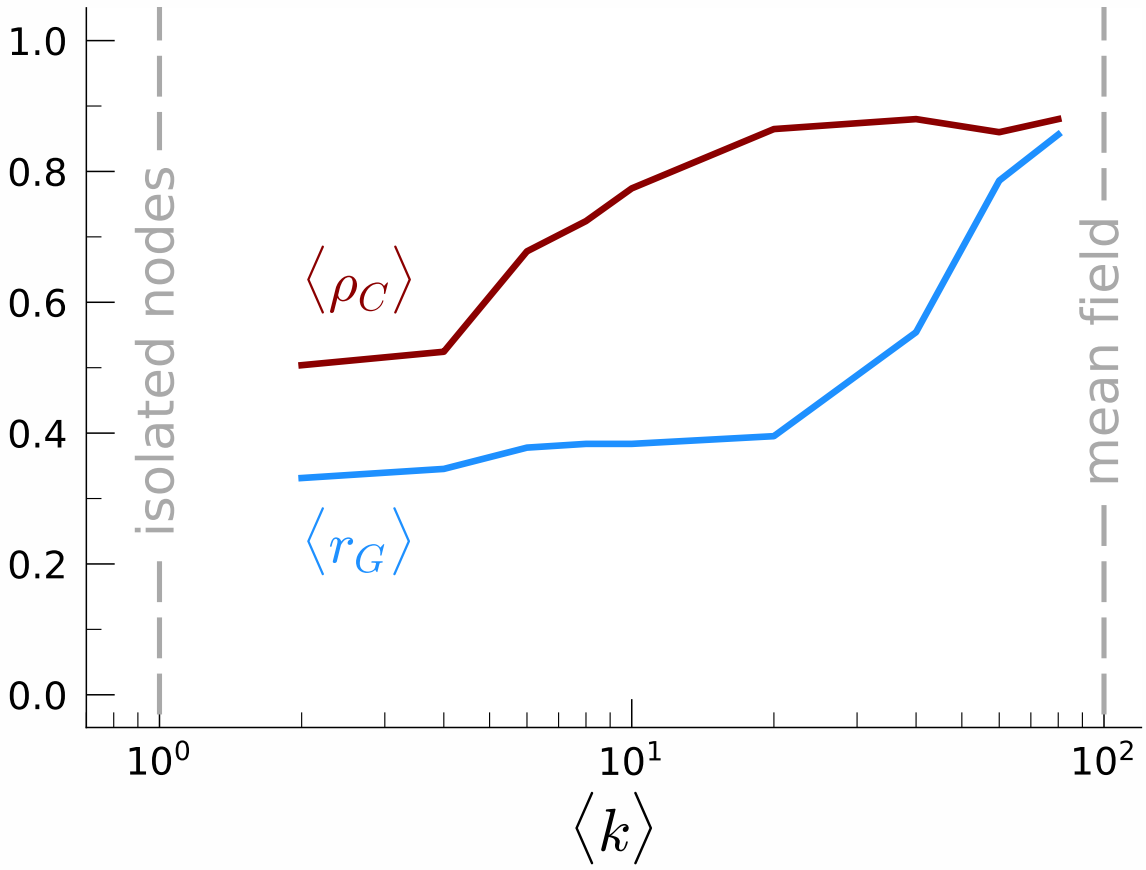
If there is a clear visual ordering in your data, make sure to **match it** in the legend.

Legends & multi-panel figures



Labeling your data with text is **much more effective** than using legends.

Legends & multi-panel figures



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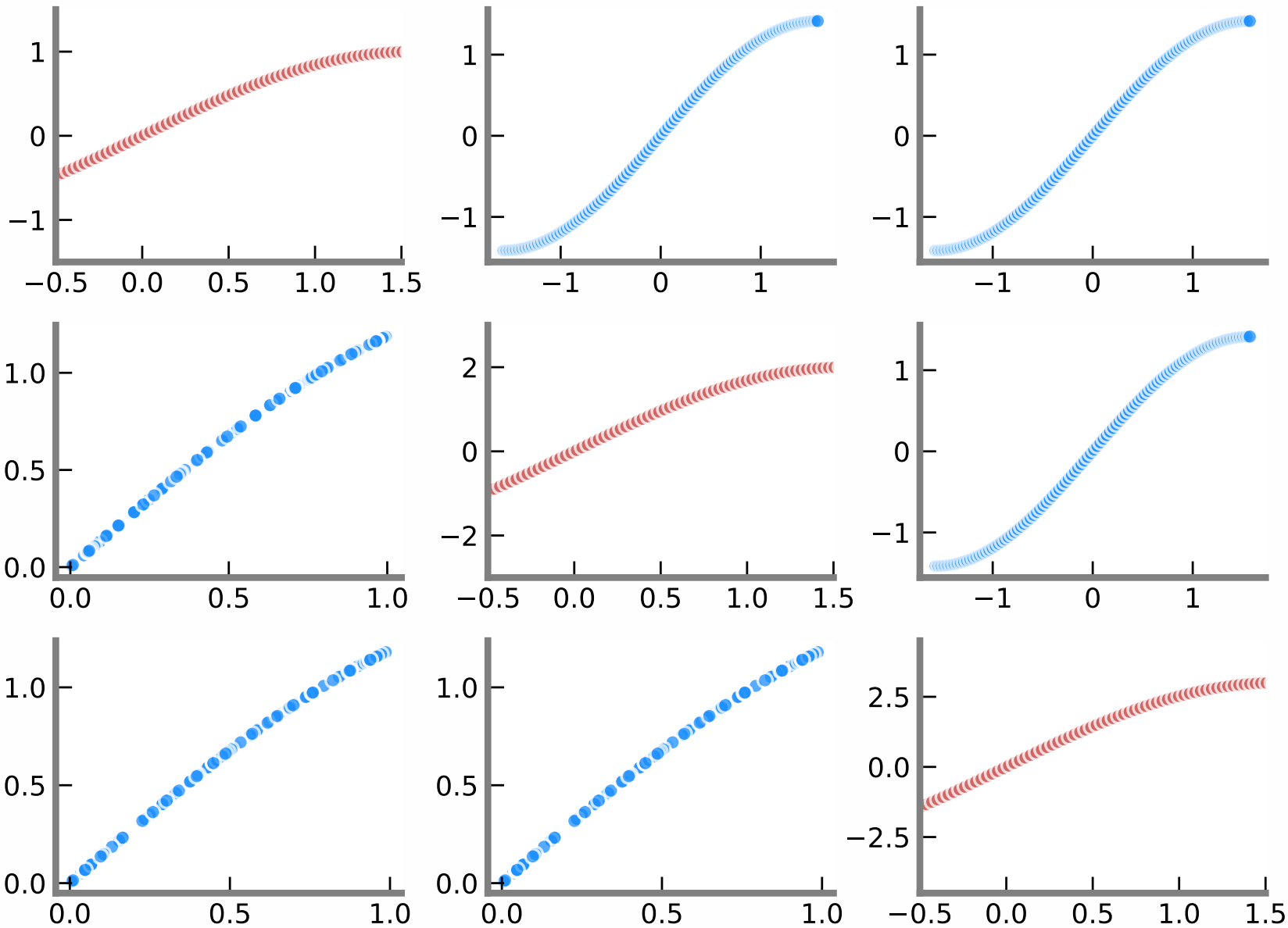

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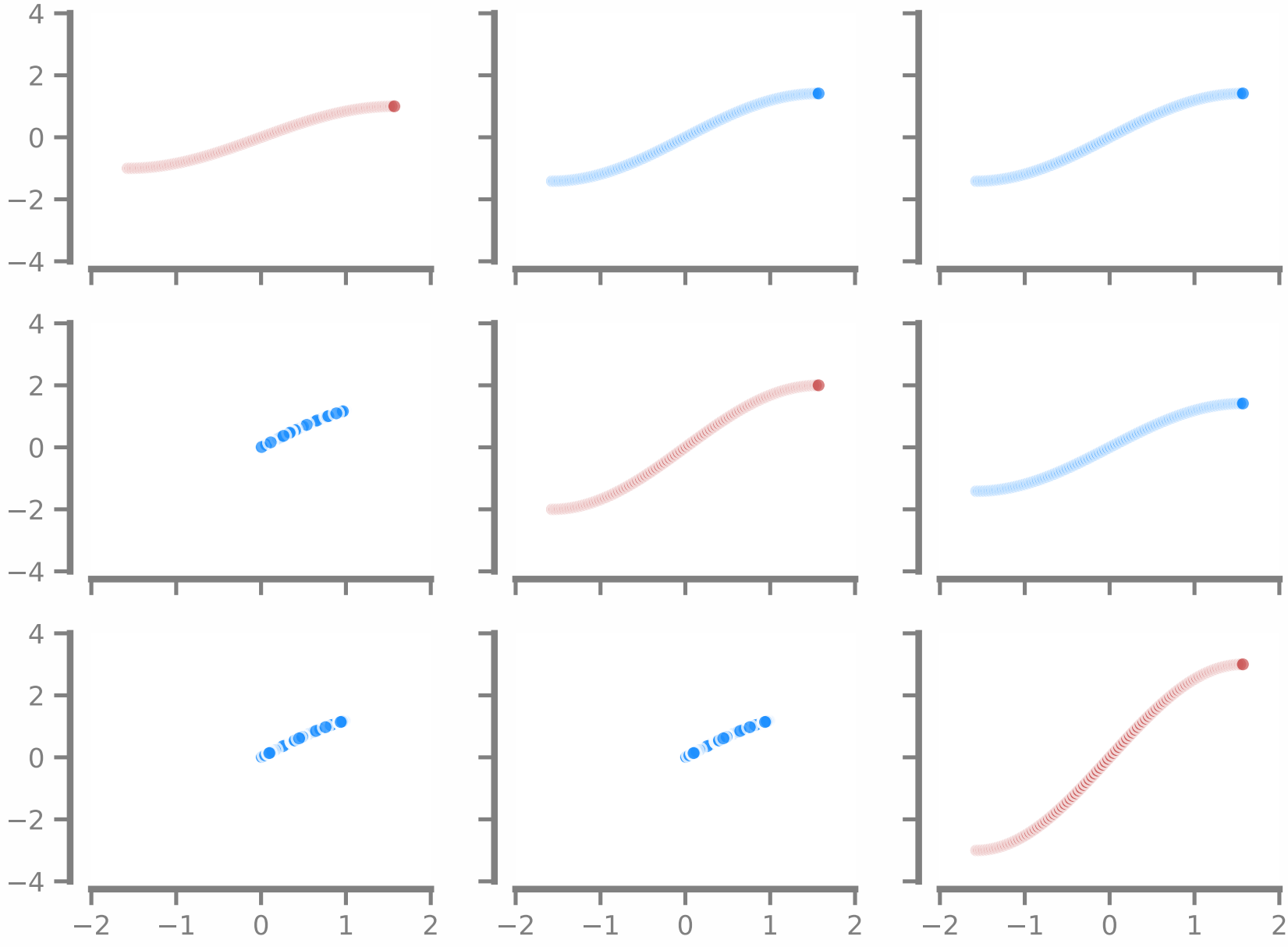

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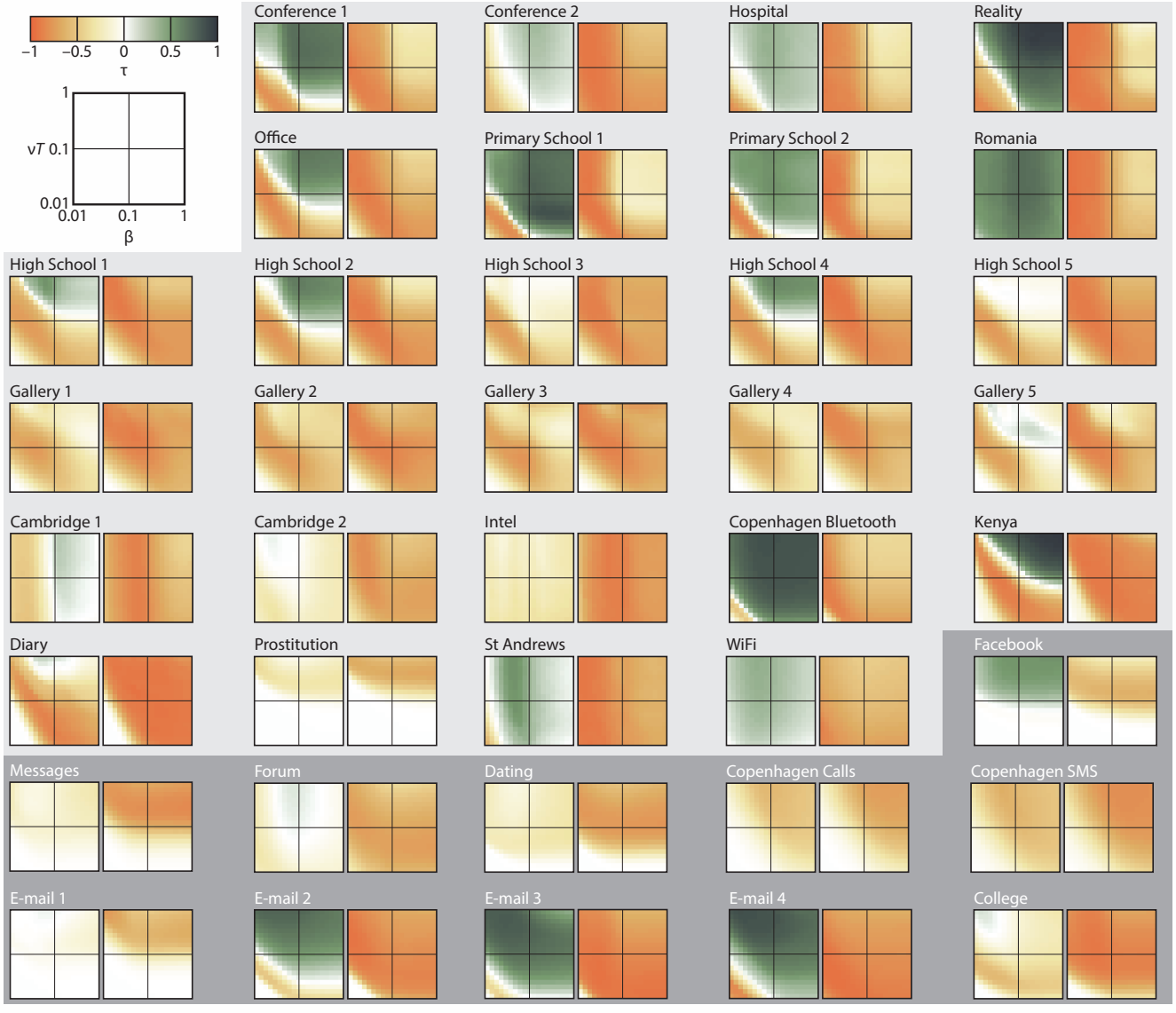

- https://viz.wtf/

Highlight what matters

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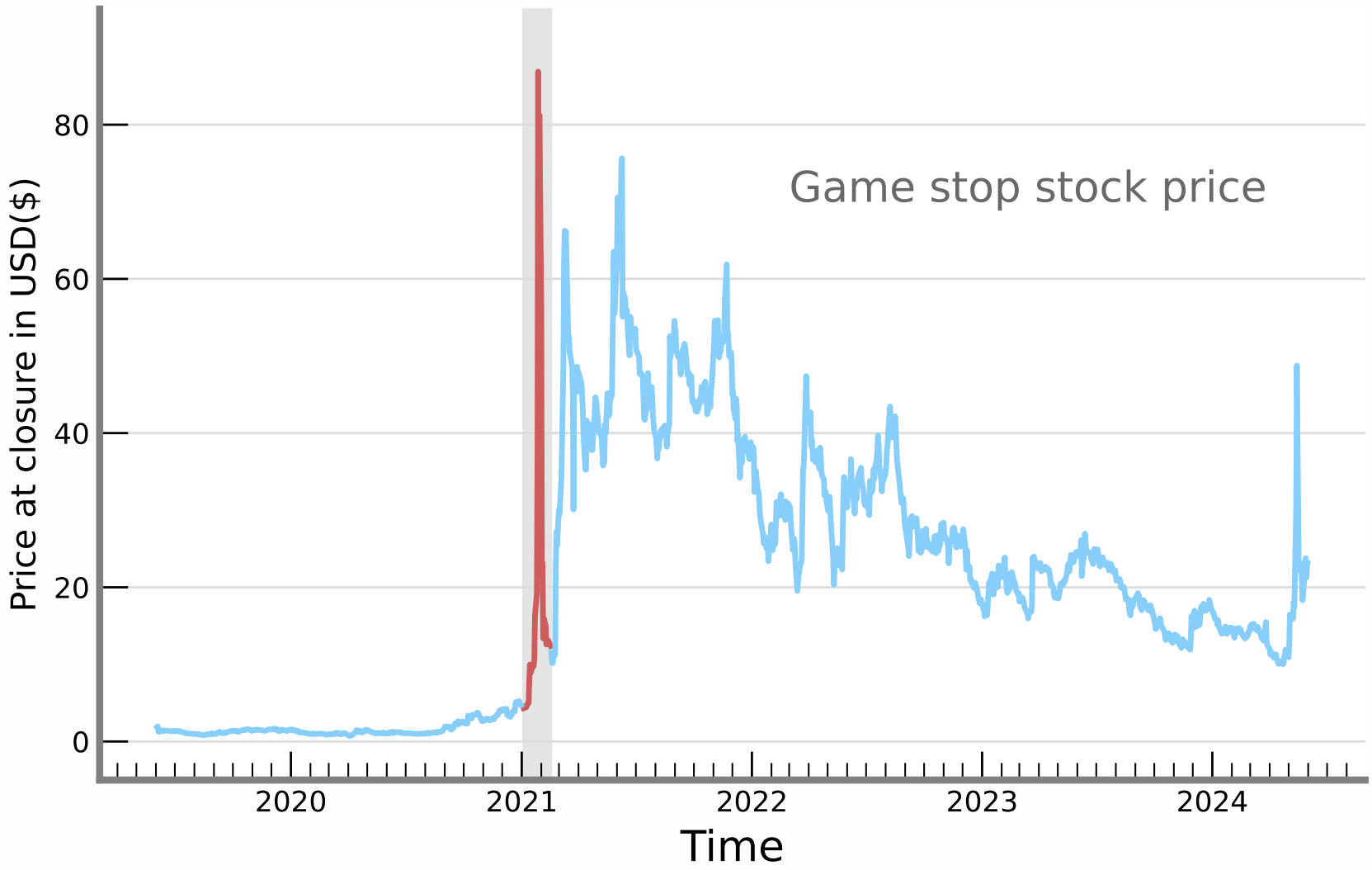


Highlight what matters

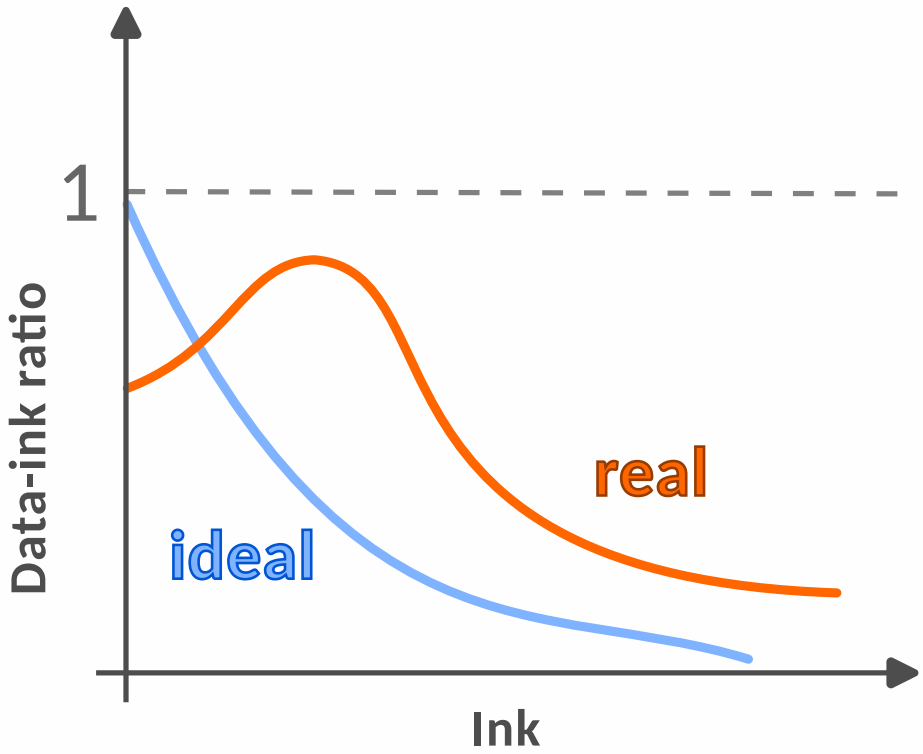
Data-ink ratio

A good graphical design aims to find a ***balance*** between the amount of ink used to display data and the overall amount of ink needed to prepare the graphic. In other words, we need to maximize the so-called **Data-ink ratio**.

$$\text{Data-ink ratio} = \frac{\text{data ink}}{\text{total ink}}$$

Remember: there is always time to add "stuff." Begin with a SIMPLE (but effective) design!

Highlight what matters



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Tip

Use the brain's ability to distinguish between foreground and background (and differences in general) and remember:

GRAY IS YOUR FRIEND

Tables

a

ugly

Rank	Title	Amount
1	*Star Wars: The Last Jedi*	$71,565,498
2	*Jumanji: Welcome to the Jungle*	$36,169,328
3	*Pitch Perfect 3*	$19,928,525
4	*The Greatest Showman*	$8,805,843
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b

ugly

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c

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- C. O. Wilke, *Fundamentals of Data Visualization: A Primer on Making Informative and Compelling Figures*. O'Reilly Media (2019).
- `https://www.data-to-viz.com/caveats.html`

Image formats

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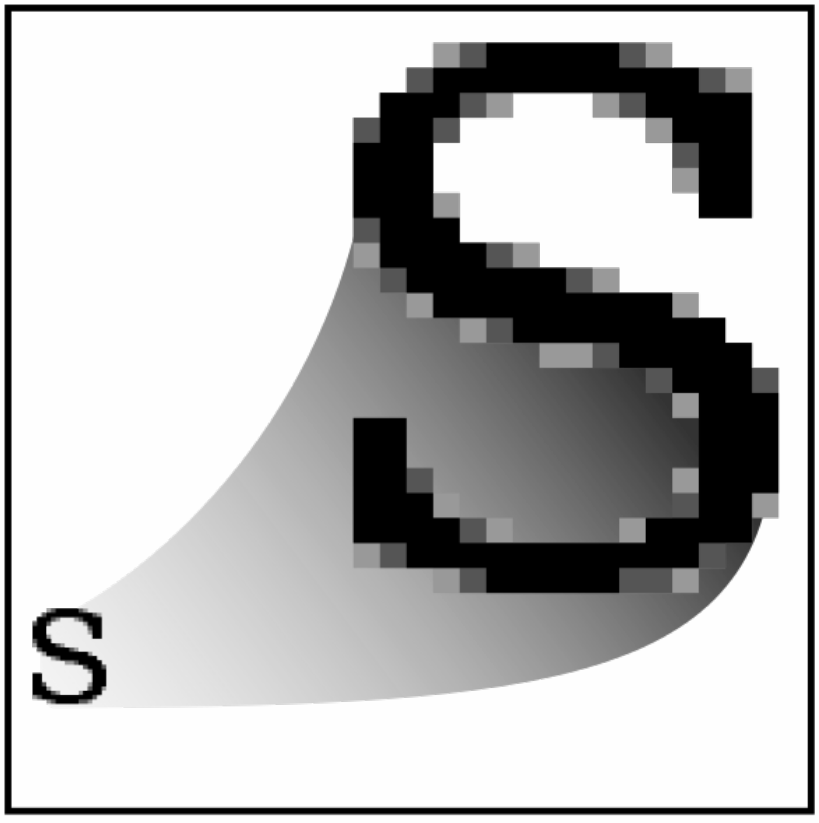
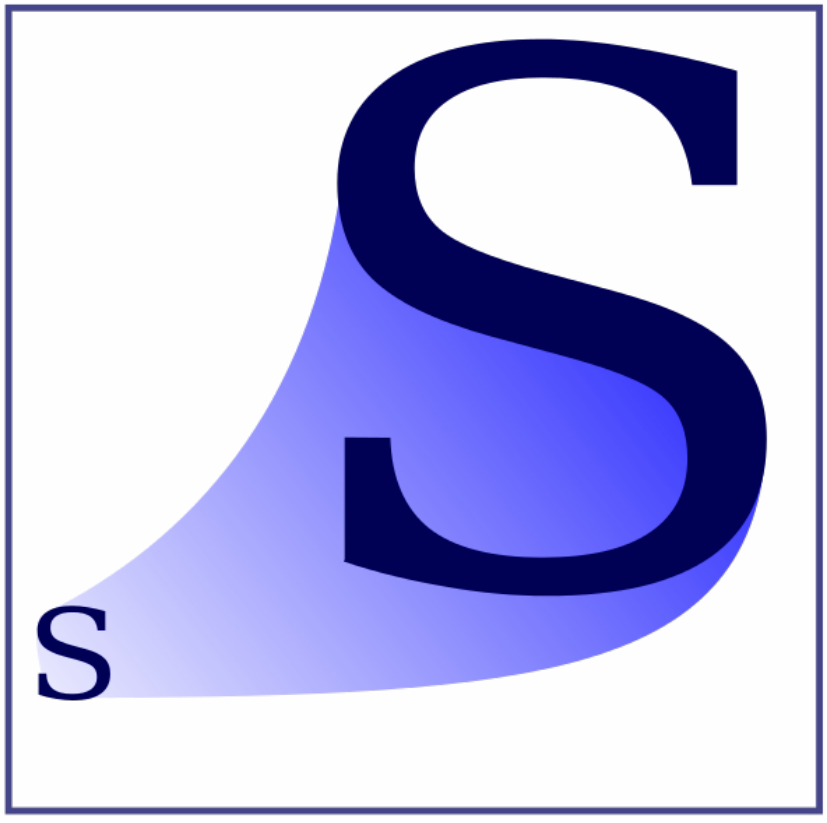


Raster

.jpeg .gif .png



Vector

.svg

Image formats

Image formats

Tip

Try to limit **as much as possible** the “manual” post-processing of your graphics, because it constitutes a bottleneck in the pipeline.

(more) Useful tips

My two cents of wisdom

- Tailor your content to your audience and medium. Try to imagine the ideal **audience** of your graphic, and the **support/medium** used to display it.

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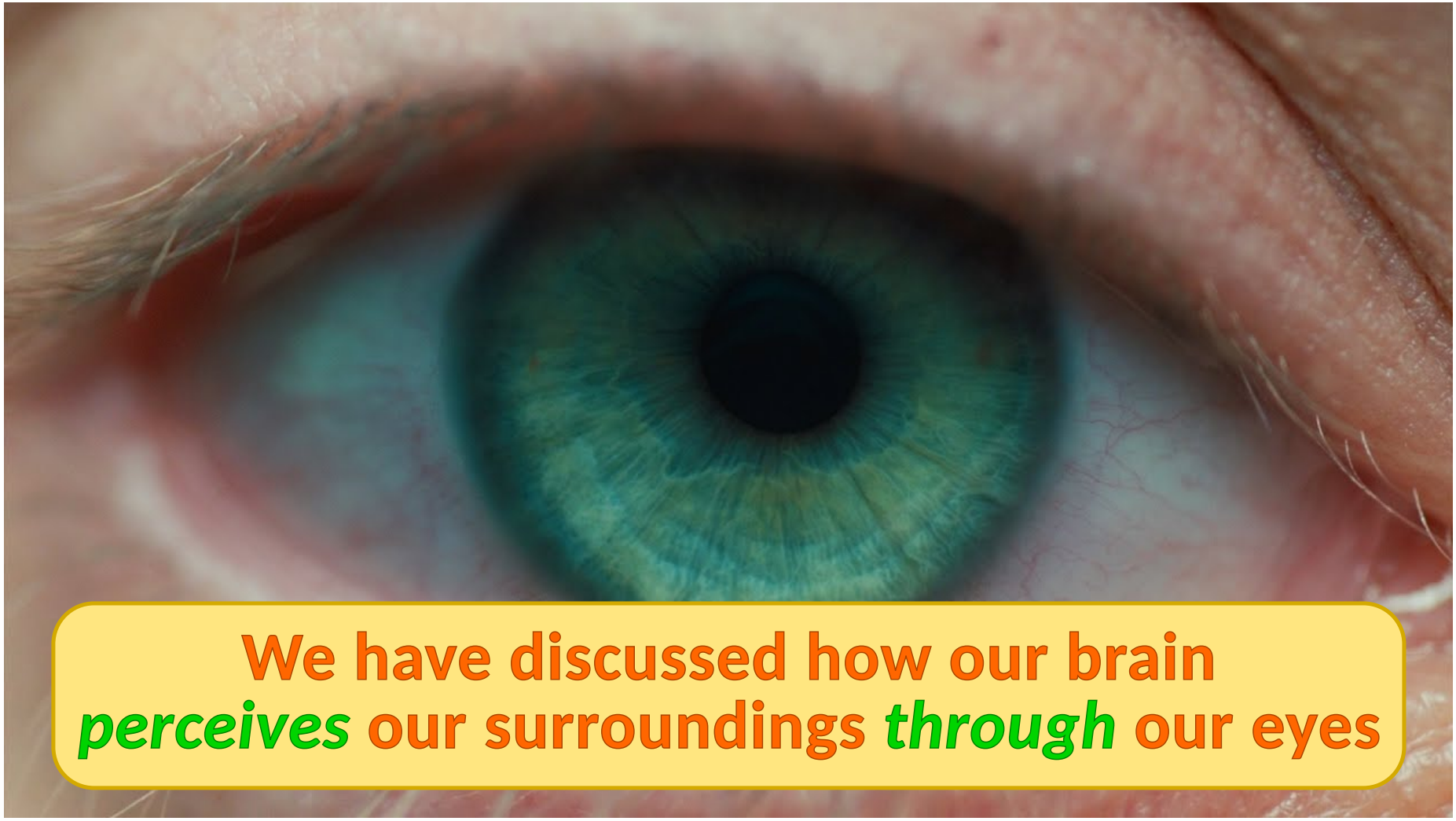
- NEVER USE 3D!
- Ensure to make your labels BIG ENOUGH!
- **ALWAYS** display the truth!

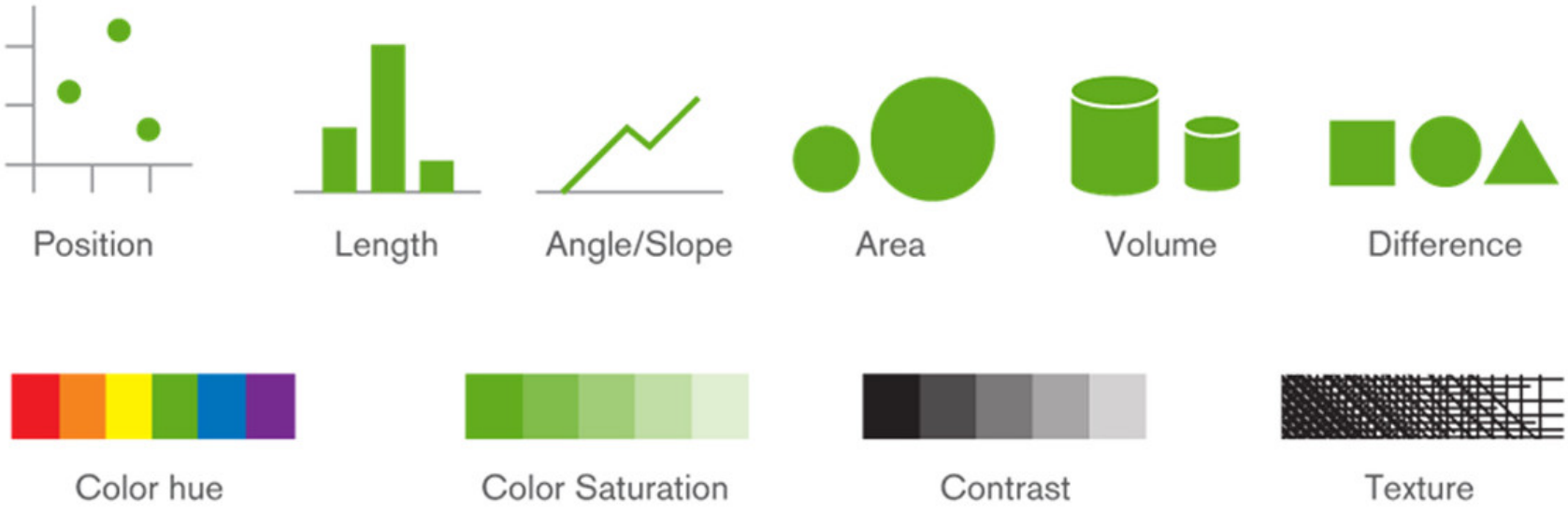
Summing up . . .

Take home messages



Take home messages

We have learned how to *encode* information to *convey* our message



Take home messages

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