

Data Visualization in R with **ggplot2**

Principles of Data Visualization

Cédric Scherer

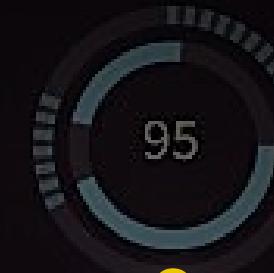
Physalia Courses | March 2-6 2020

Photo by Richard Strozyński

Data Visualization
is any graphical representation
of information and data

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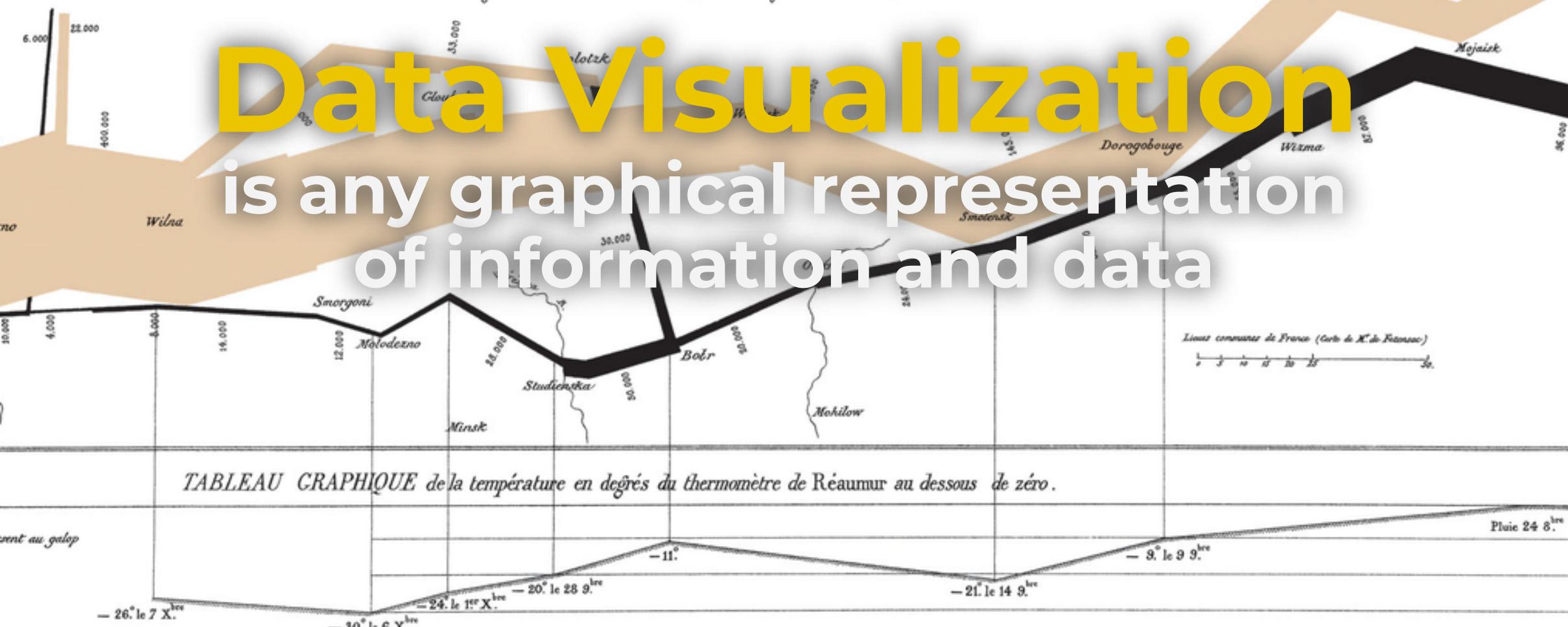
Carte Figurative des pertes successives en hommes de l'Armée Française dans la Campagne de Russie 1812-1813.

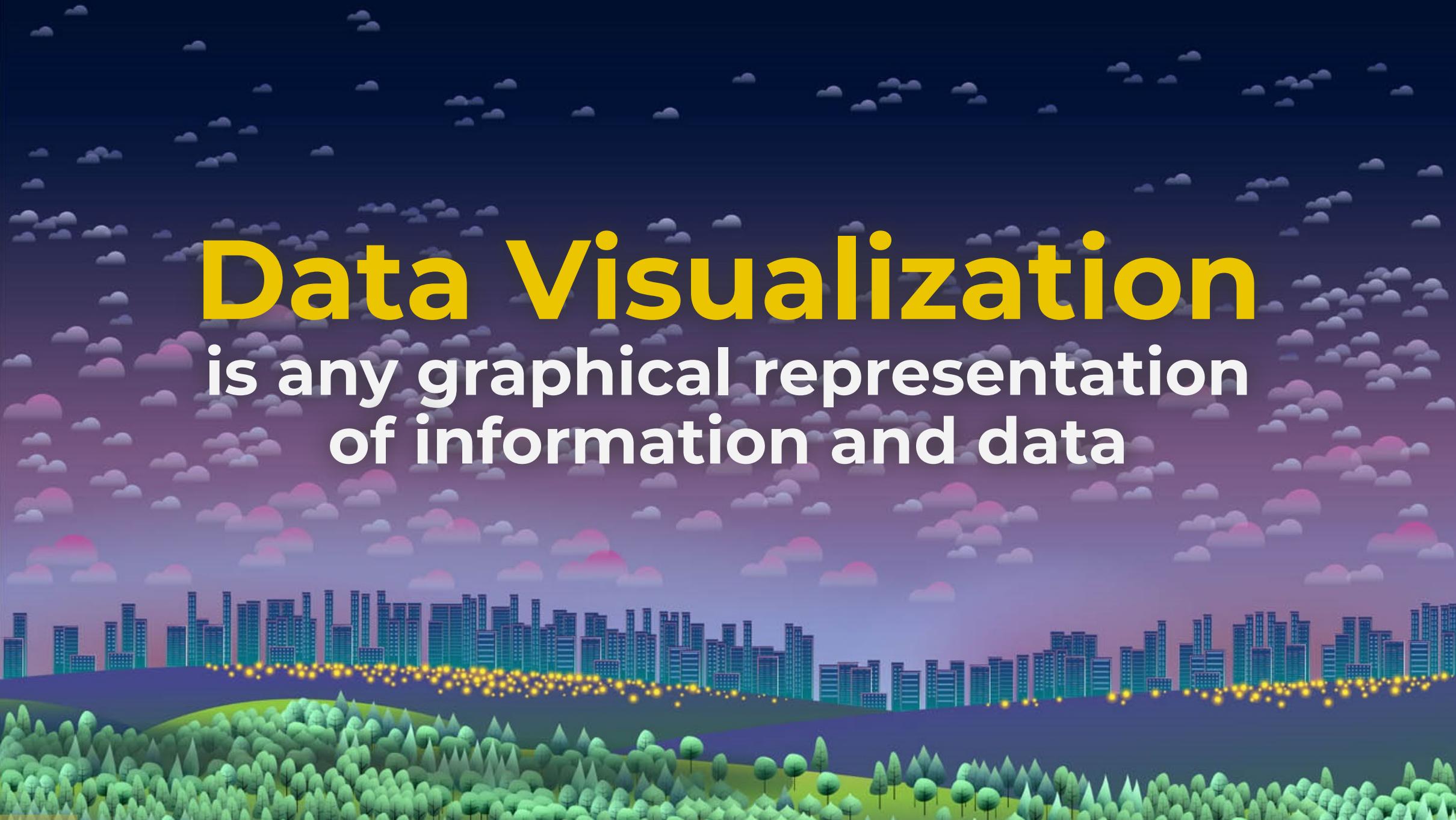
Dessinée par M. Minard, Inspecteur Général des Ponts et Chaussées en retraite.

Paris, le 20 Novembre 1869.

Les nombres d'hommes perdus sont représentés par les largeurs des zones colorées à raison d'un millimètre pour dix mille hommes; ils sont de plus écrits en lettres des zones. Le rouge désigne les hommes qui ont été en Russie; le noir ceux qui en sortent. — Les renseignements qui ont servi à dresser la carte ont été puisés dans les ouvrages de M. M. Chiers, de Séguir, de Fezensac, de Chambray et le journal inédit de Jacob, pharmacien de l'Armée depuis le 28 Octobre.

Pour mieux faire juger à l'œil la diminution de l'armée, j'ai supposé que les corps du Prince Jérôme et du Maréchal Davout qui avaient été détachés sur Minsk et Mohilow et qui rejoignirent vers Oescha et Witebsk, avaient toujours marché avec l'armée.





Data Visualization
is any graphical representation
of information and data



"A View on Despair" by Sonja Kuijpers/STUDIO TERP

You might be wondering what you are viewing here.



"A View on Despair" by Sonja Kuijpers/STUDIO TERP

You might be wondering what you are viewing here.

Each element represents a person who committed suicide in the Netherlands in 2017.



"A View on Despair" by Sonja Kuijpers/STUDIO TERP

Each category/method of suicide is represented by a certain element:



hanging (strangulation)



taking drugs/alcohol/medicines



in front of train or metro



drowning



jumping from height



other method*



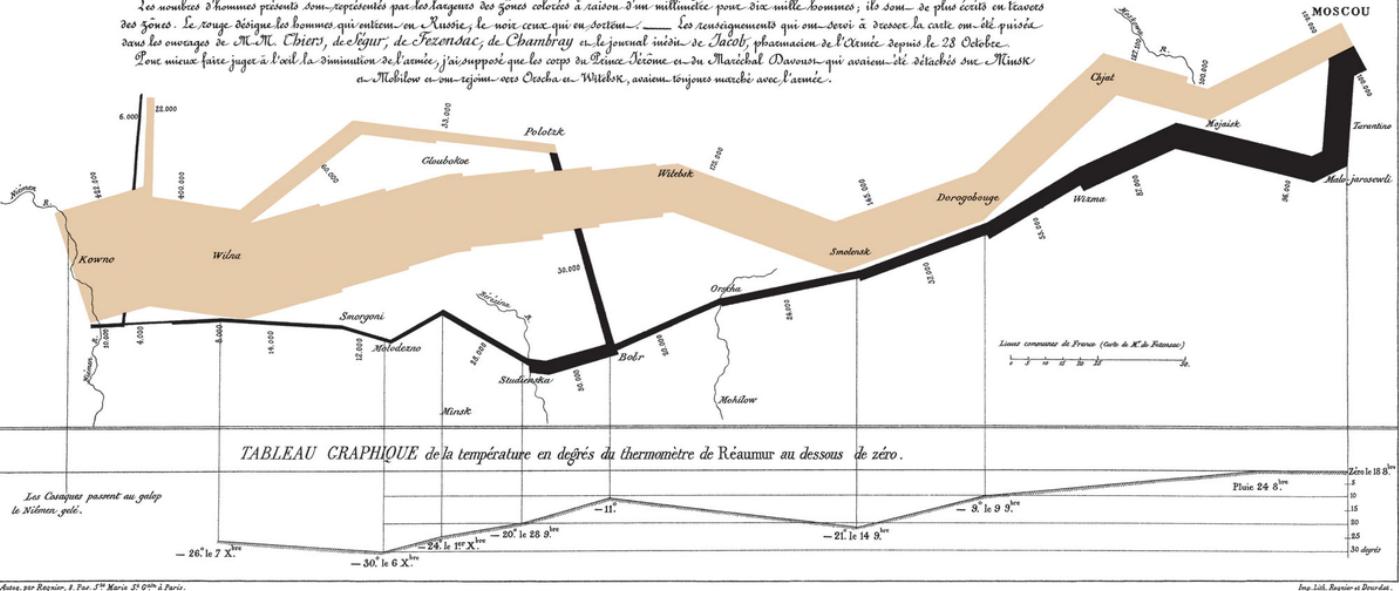
unknown method

Carte Figurative des pertes successives en hommes de l'Armée Française dans la Campagne de Russie 1812-1813.

Dessiné par M. Minard, Inspecteur Général des Ponts et Chaussées en retraite Paris, le 20 Novembre 1869.

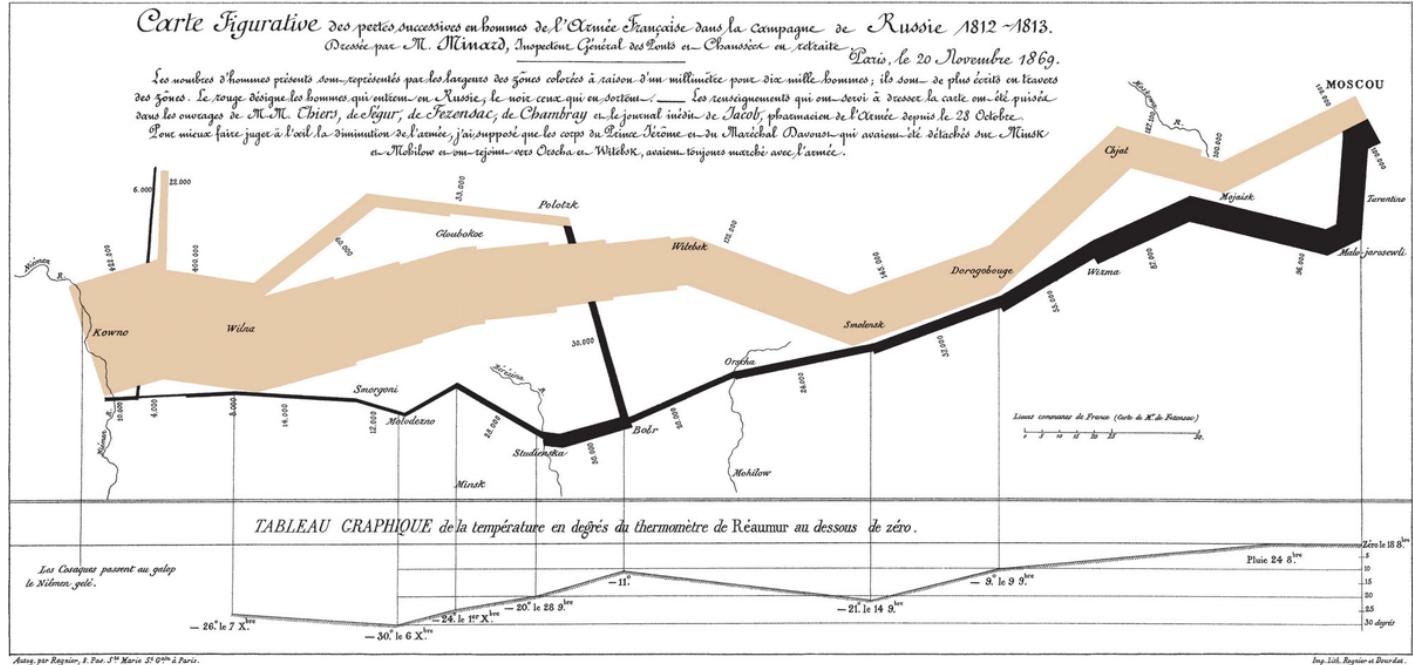
Les nombres d'hommes perdus sont représentés par les larges de zones colorées à raison d'un millimètre pour dix mille hommes; ils sont de plus écrits en lettres dans les zones. Le rouge désigne les hommes qui entrent en Russie, le noir ceux qui en sortent. — Les renseignements qui ont servi à dresser la carte ont été prisés dans les ouvrages de M. Chiers, de Fozendac, de Chambray et le journal médical de Jacob, pharmacien de l'Armée depuis le 28 Octobre.

Pour mieux faire juger à l'œil la diminution de l'armée, j'ai supposé que les corps du Prince Iérome et du Maréchal Davout, qui avaient été détachés sur Minsk en Moldovia et au rejoindre avec Orléans en Witebsk, avaient toujours marché avec l'armée.



"Figurative Map of the Successive Losses in Men of the French Army in the Russian Campaign 1812–1813" by Charles Joseph Minard

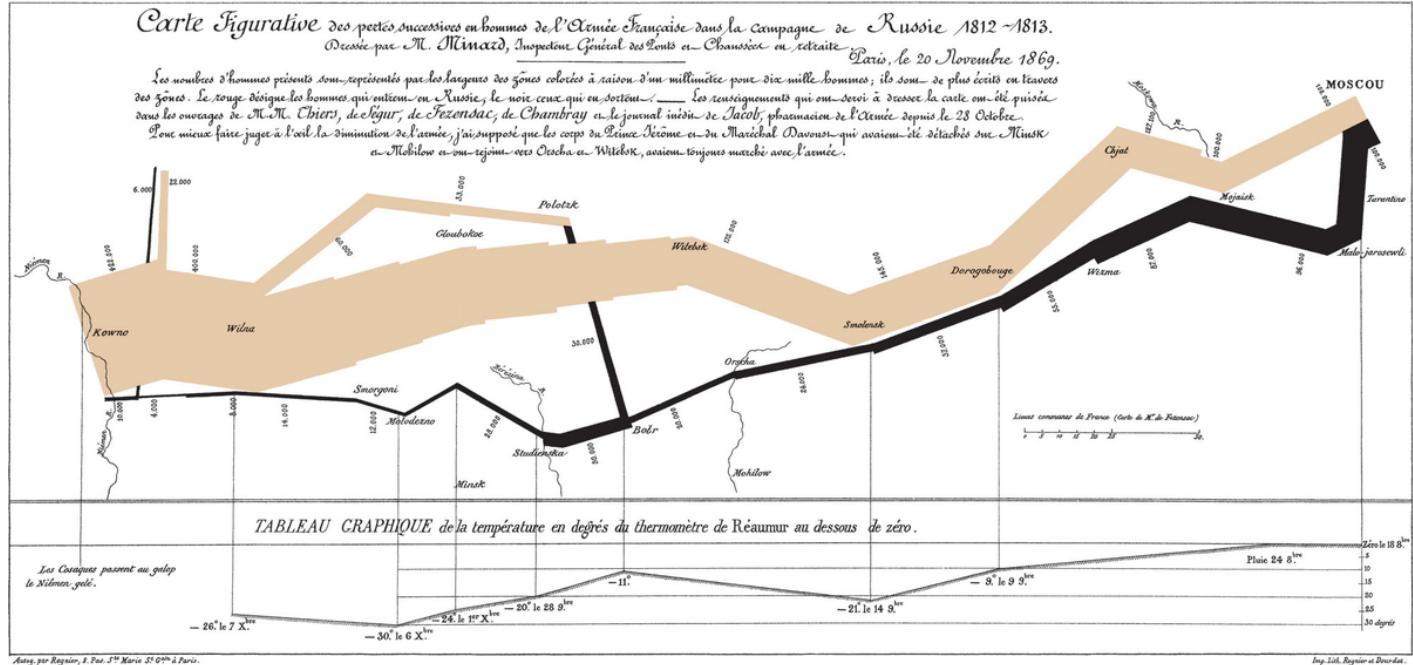
You might be wondering what you are viewing here.



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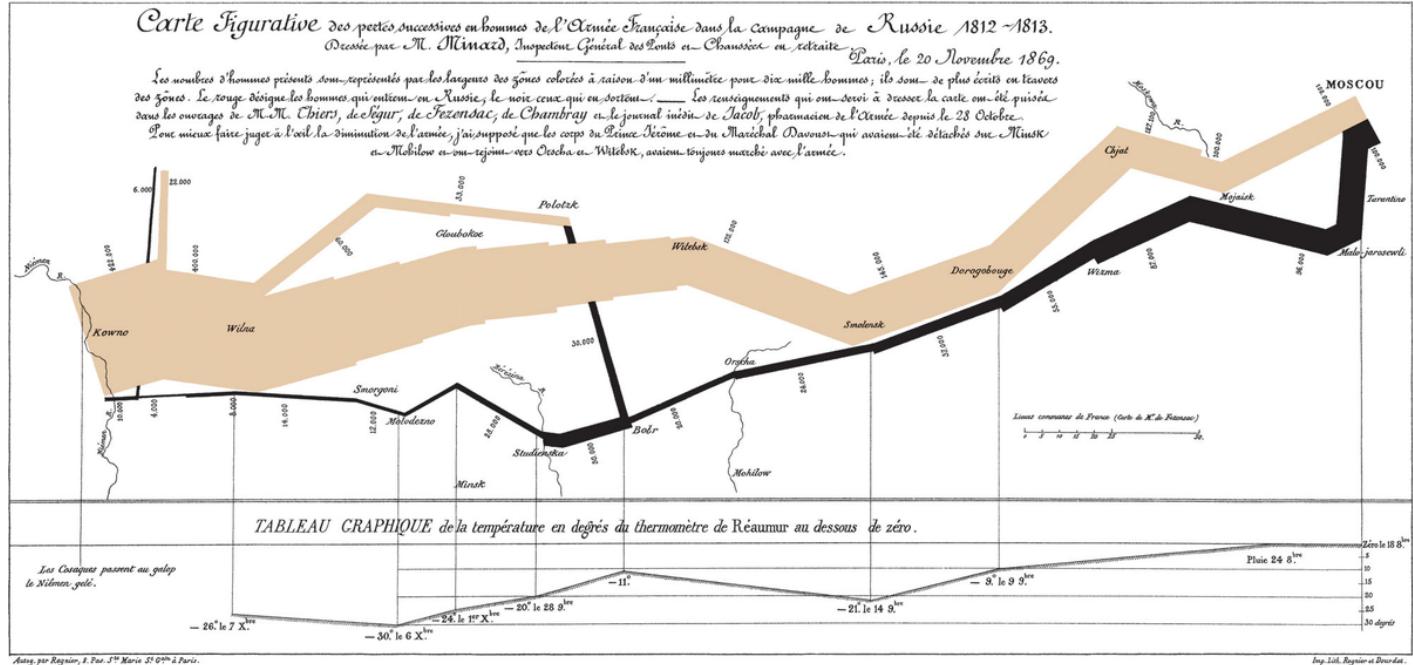
- shows the path of Napoleon's troops across the Russian Empire of Alexander I
- displays the progress of the troops in the form of a stream whose width indicates the size of the “Great Army”



"Figurative Map of the Successive Losses in Men of the French Army in the Russian Campaign 1812–1813" by Charles Joseph Minard

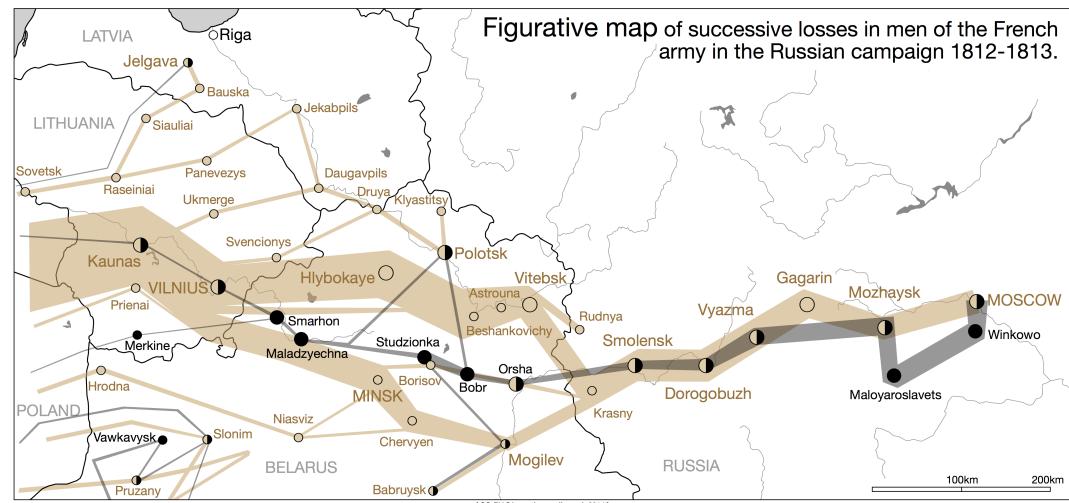
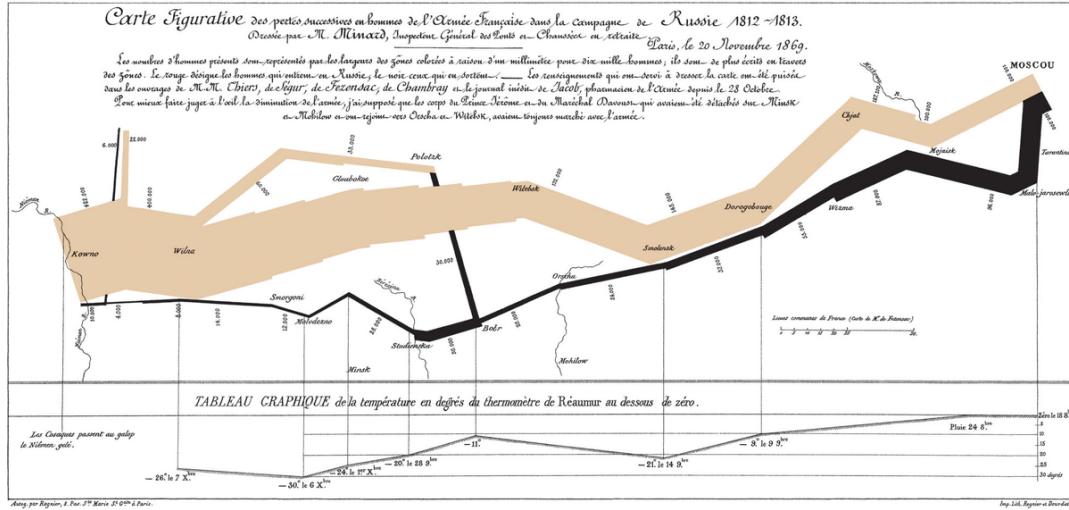
- encodes 6 variables in a simple (?) and modern way:

- width → size of Napoleon's army
- x-axis → longitude of the army's position
- y-axis → latitude of the army's position
- color → direction of the army's movement
- line chart → temperature during the army's retreat
- annotations → locations and army size (main chart) + date along retreat path (line chart)

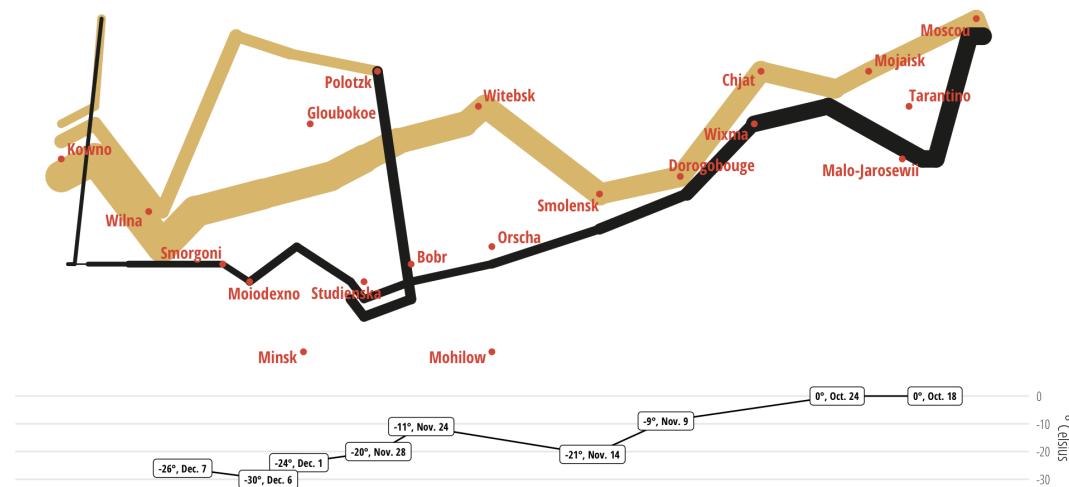
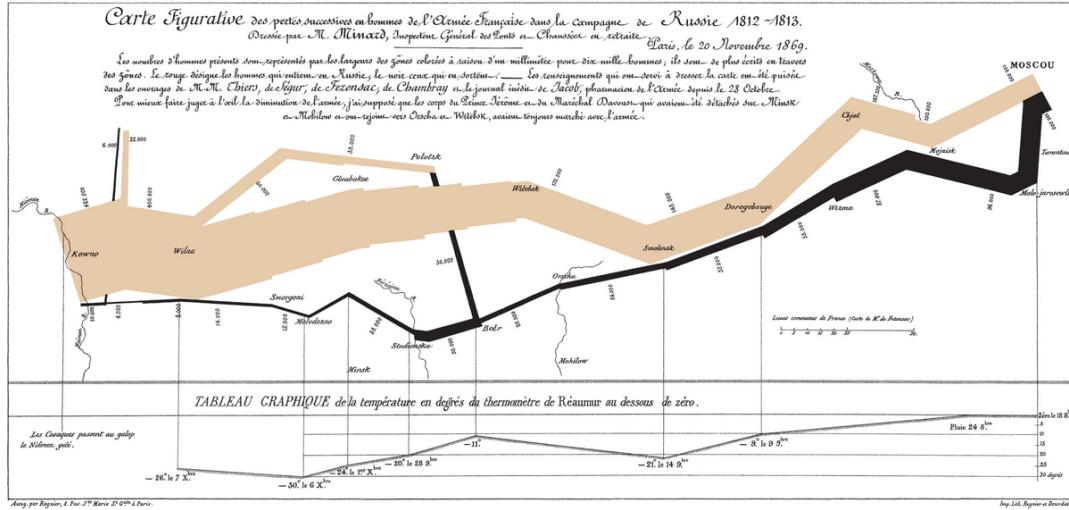


"Figurative Map of the Successive Losses in Men of the French Army in the Russian Campaign 1812–1813" by Charles Joseph Minard

- generally considered as the first data visualization (1869)
- Edward Tufte calls Minard's graphic of Napoleon in Russia one of the “best statistical drawings ever created”.



The map created by Charles Joseph Minard projected in the geographical reality with the most accurate information on the actual route of different corps by Martin Grandjean



The map created by Charles Joseph Minard and a version coded in **ggplot2** by Andrew Heiss

The map even made it into the article "A Layered Grammar of Graphics" by Hadley Wickham that introduced [ggplot2](#)

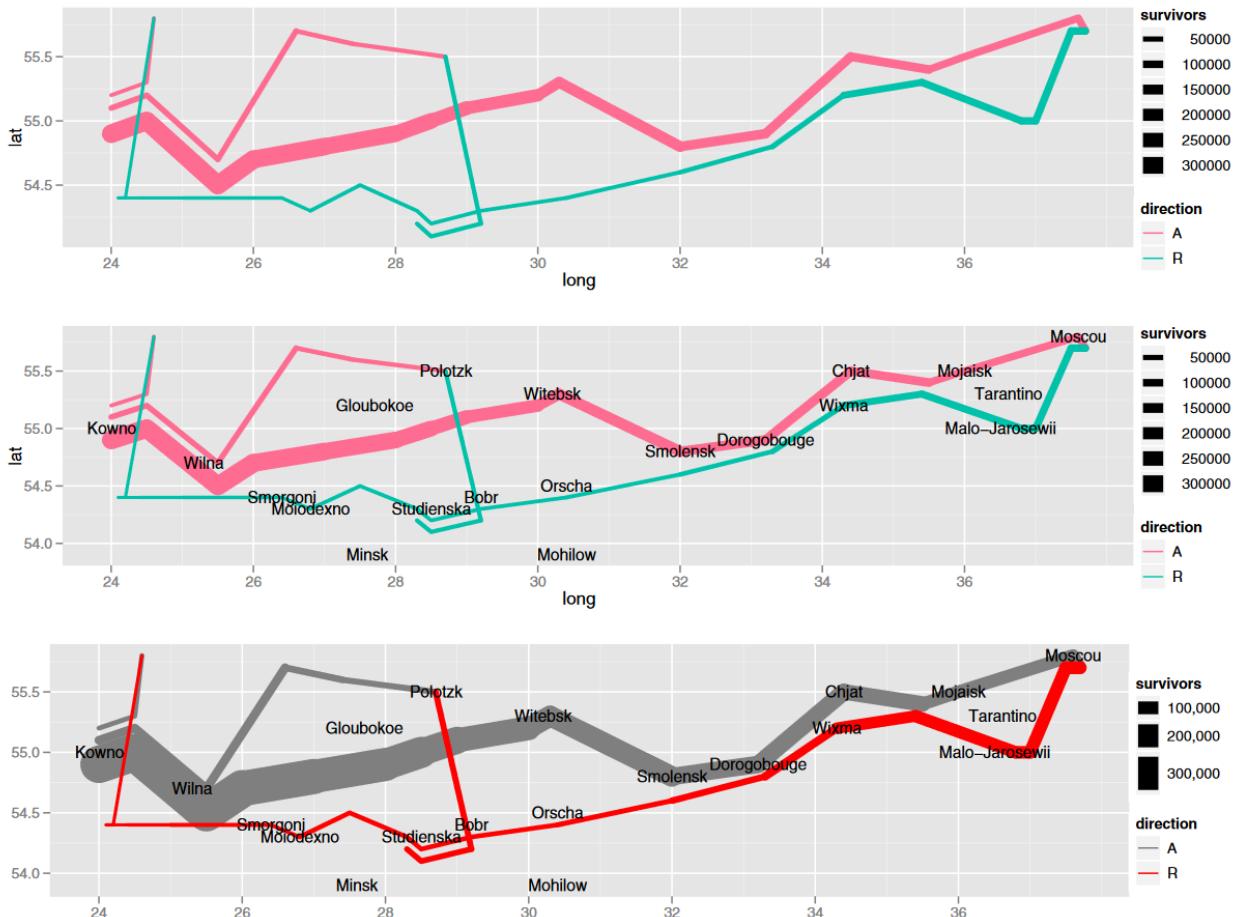


Figure 12. Iteratively reproducing the depiction of Napoleon's March by Minard. (Top) Displaying the key troop movement data. (Center) Adding town locations as reference points. (Bottom) Tweaking scales to produce polished plot.

Data Visualization is part art and part science.

Claus O. Wilke, "Fundamentals of Data Visualization"

Data visualization is part art and part science.

- *The challenge is to get the art right without getting the science wrong and vice versa.*
- *A data visualization first and foremost has to accurately convey the data.*
- *At the same time, a data visualization should be aesthetically pleasing.*
- *If a visualization is "good" or "bad" matters for both communication and impact!*



How to Develop an Eye for Good Data Visualization

→ Information

→ Story

→ Goal

→ Visual Form

How to Develop an Eye for Good Data Visualization

→ **Information (Integrity)**

→ **Story (Interestingness)**

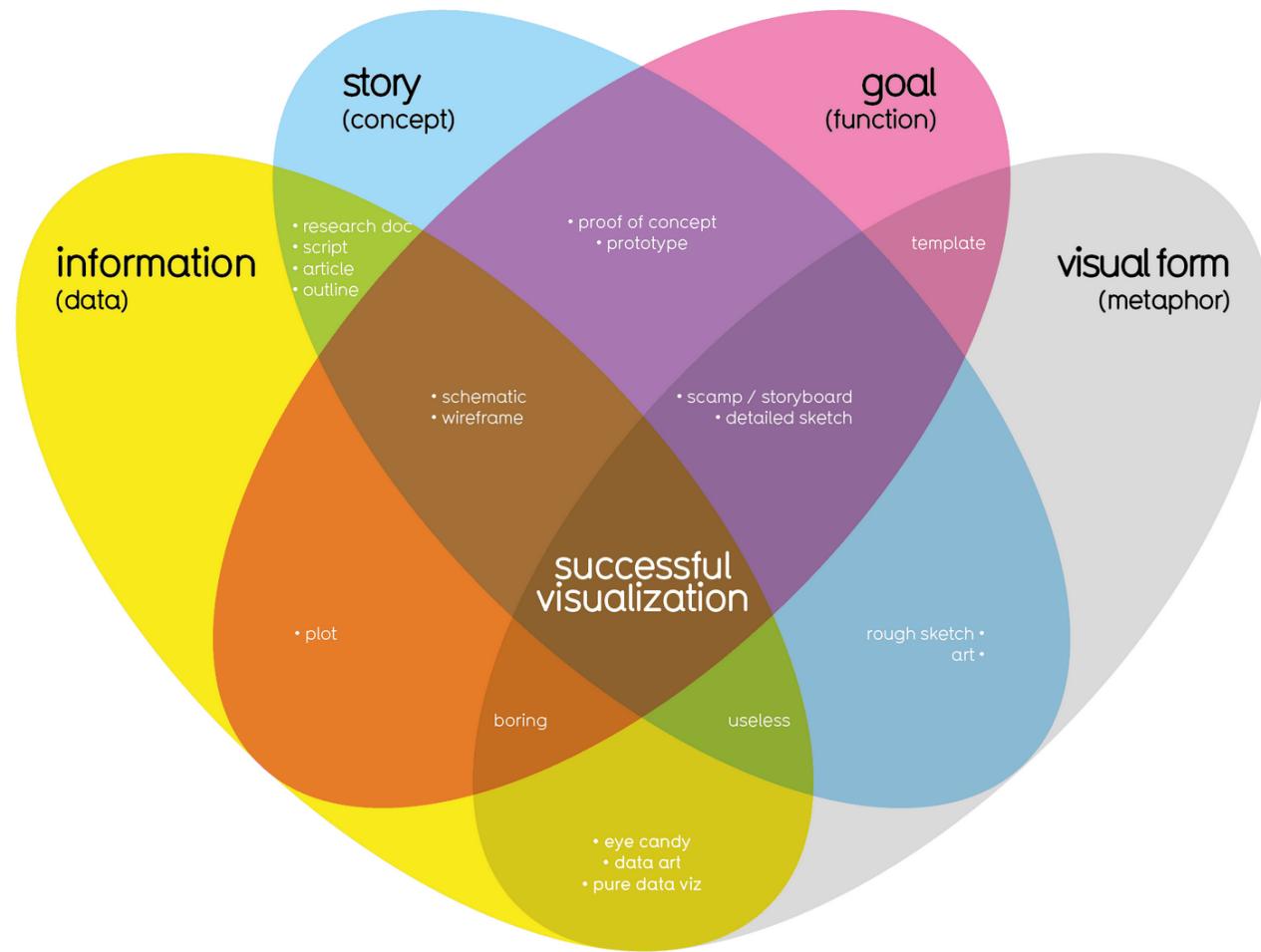
→ **Goal (Usefulness)**

→ **Visual Form (Beauty)**

How to Develop an Eye for Good Data Visualization

- **Information** Understand your data and be accurate
- **Story** Be clear about the story of your visualization
- **Goal** Select charts that successfully transport your story
- **Visual Form** Follow design rules and data visualization principles
 - + inspiration, training and (a bit of) talent*

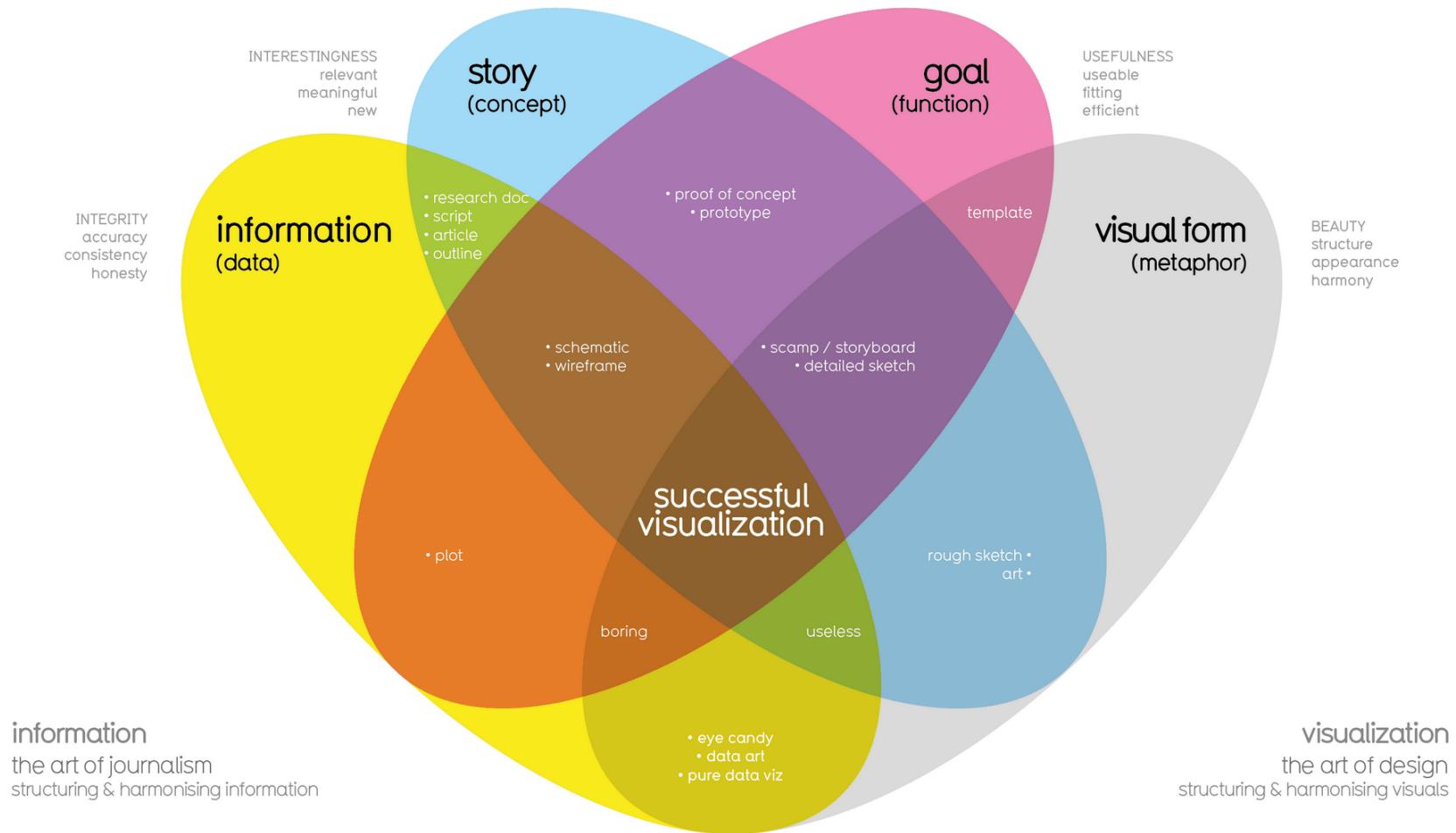
What Makes a Good Visualization?

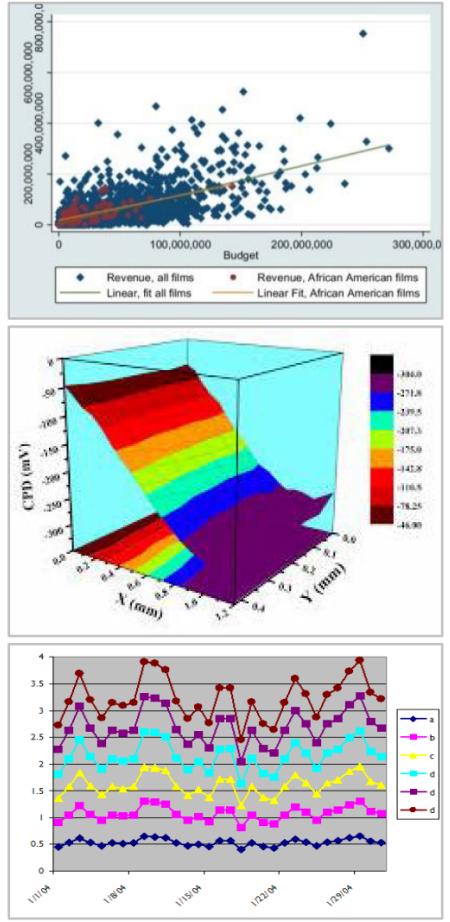


Visualization by David McCandless ([Information is Beautiful](#))

What Makes a Good Visualization?

explicit (implicit)

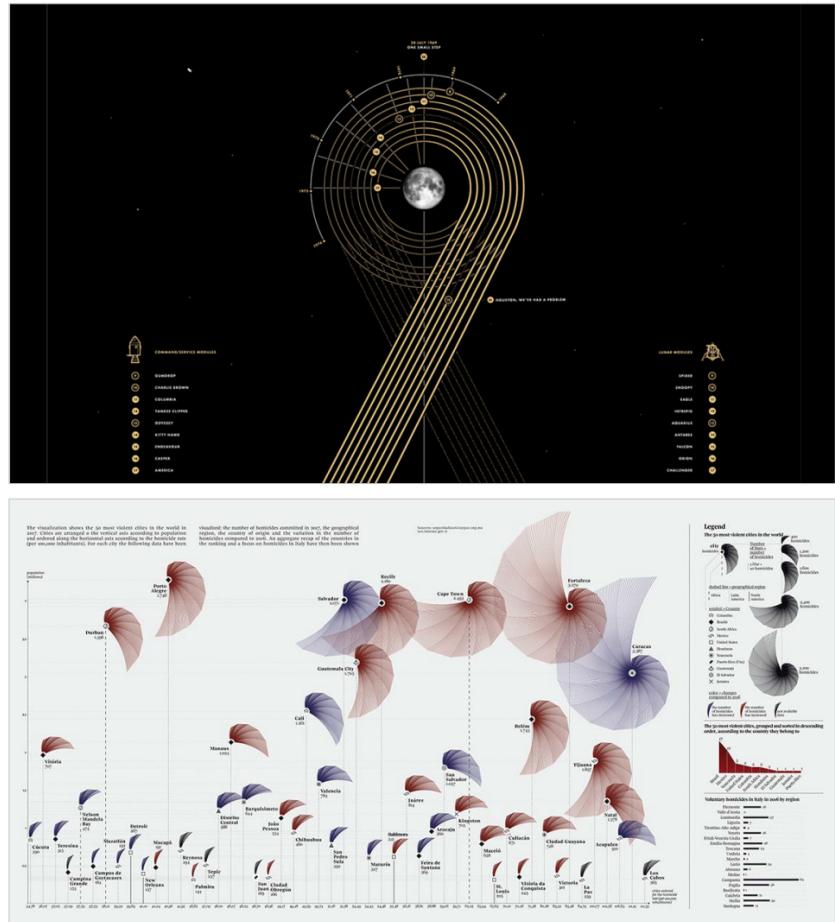




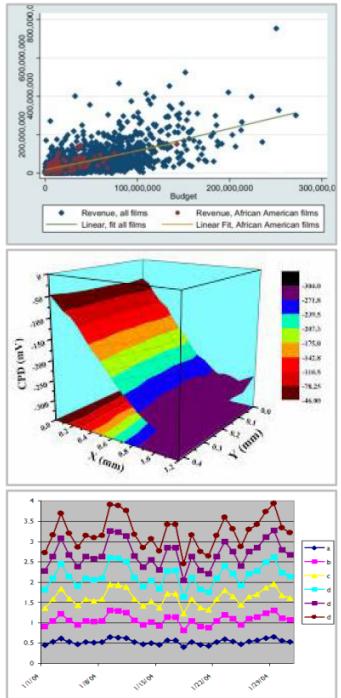
Anonymous



Sonia Kuijpers



Upper: Paul Button
Lower: Frederica Fragapane



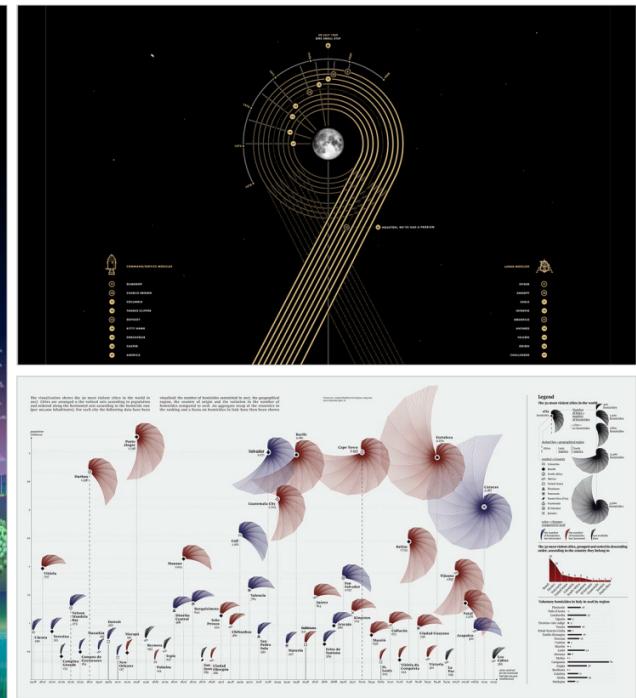
Anonymous

We aim for DataViz that:

- is informative
- reduces complexity
- is easy to grasp
- is visually appealing
- draws attention



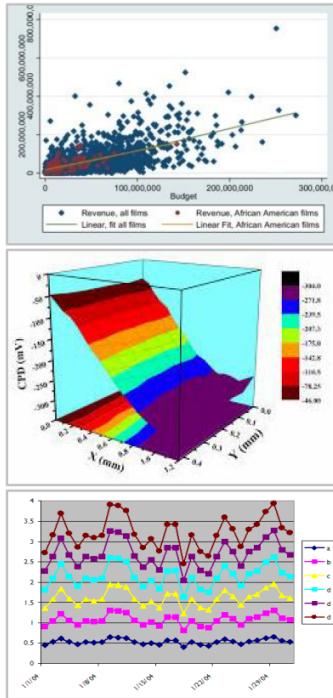
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Lower: Frederica Fragapane



Gradient from poorly designed & uninformative data visualization to data art



Anonymous

We aim for DataViz that:

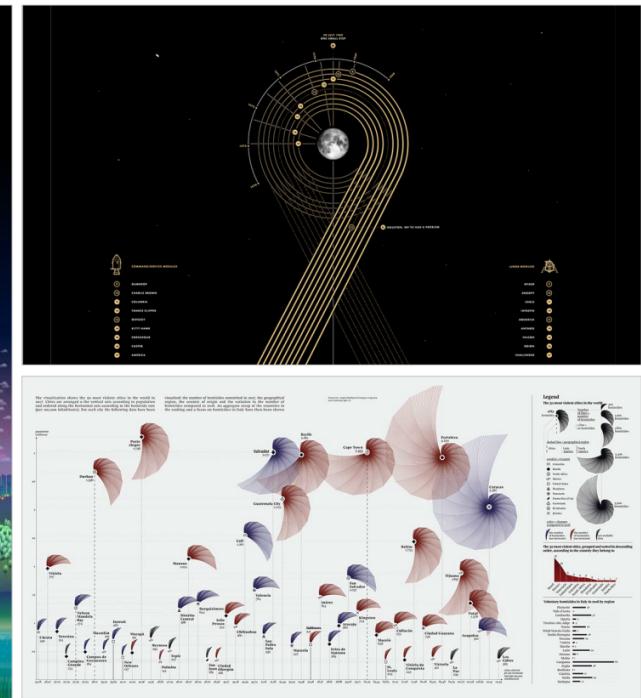
- is informative
- reduces complexity
- is easy to grasp
- is visually appealing
- draws attention

but:

- is not too abstract
- is not too “unusual”



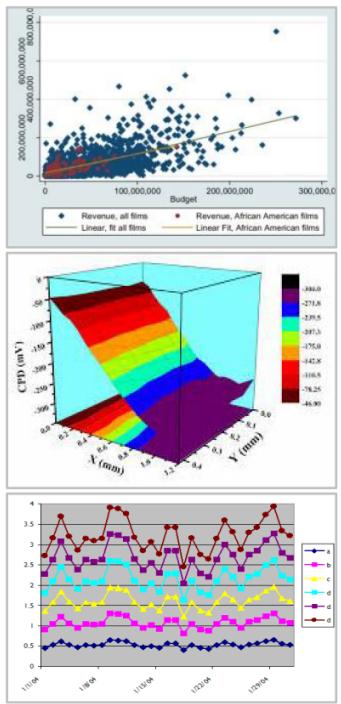
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Gradient from poorly designed & uninformative data visualization to data art



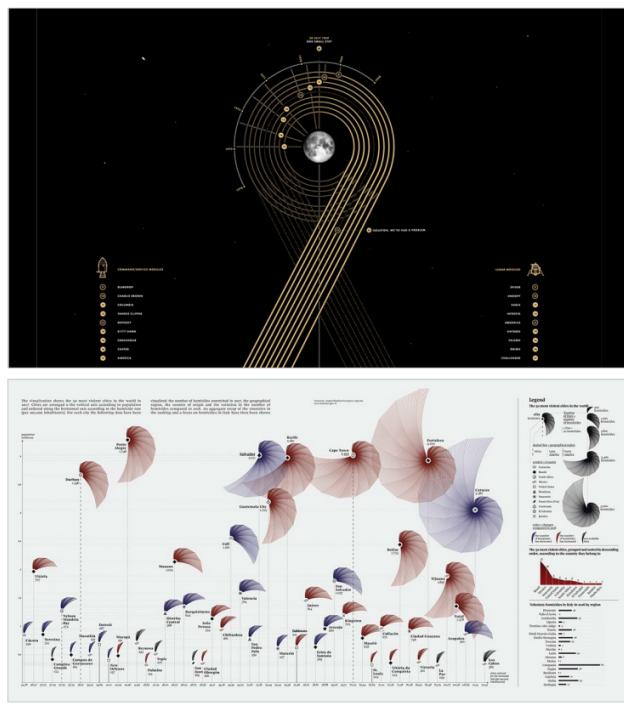
Anonymous



Upper: Cédric Scherer
Lower: Jake Kaupp



Sonia Kuijpers



Upper: Paul Button
Lower: Frederica Fragapane



Gradient from poorly designed & uninformative data visualization to data art

Know Your
Types of Data

Types of Data

- Quantitative (numerical) versus qualitative (categorical) data
- Ordered versus unordered data
- Continuous versus discrete data

Types of Data – Your Turn!

- Quantitative (numerical) versus qualitative (categorical) data
- Ordered versus unordered data
- Continuous versus discrete data
- What are the data types of:
 - "female"?

Types of Data – Your Turn!

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- Quantitative (numerical) versus qualitative (categorical) data
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- What are the data types of:
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 - 2019/09/26 "17:01:35"?

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 - 1?

Types of Data – Your Turn!

- Quantitative (numerical) versus qualitative (categorical) data
- Ordered versus unordered data
- Continuous versus discrete data
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 - "female" → qualitative + discrete + unordered
 - 2019/09/26 "17:01:35" → quantitative + continuous + ordered
 - 1 → quantitative + continuous + ordered

Types of Data – Your Turn!

- Quantitative (numerical) versus qualitative (categorical) data
- Ordered versus unordered data
- Continuous versus discrete data
- What are the data types of:
 - "female" → qualitative + discrete + unordered
 - 2019/09/26 "17:01:35" → quantitative + continuous + ordered
 - 1 → quantitative + continuous + ordered
or: quantitative + discrete + ordered
or: qualitative + discrete + ordered
or: qualitative + discrete + unordered

NOMINAL

UNORDERED DESCRIPTIONS



ORDINAL

ORDERED DESCRIPTIONS



BINARY

ONLY 2 MUTUALLY
EXCLUSIVE OUTCOMES



CONTINUOUS

measured data, can have ∞ values within possible range.



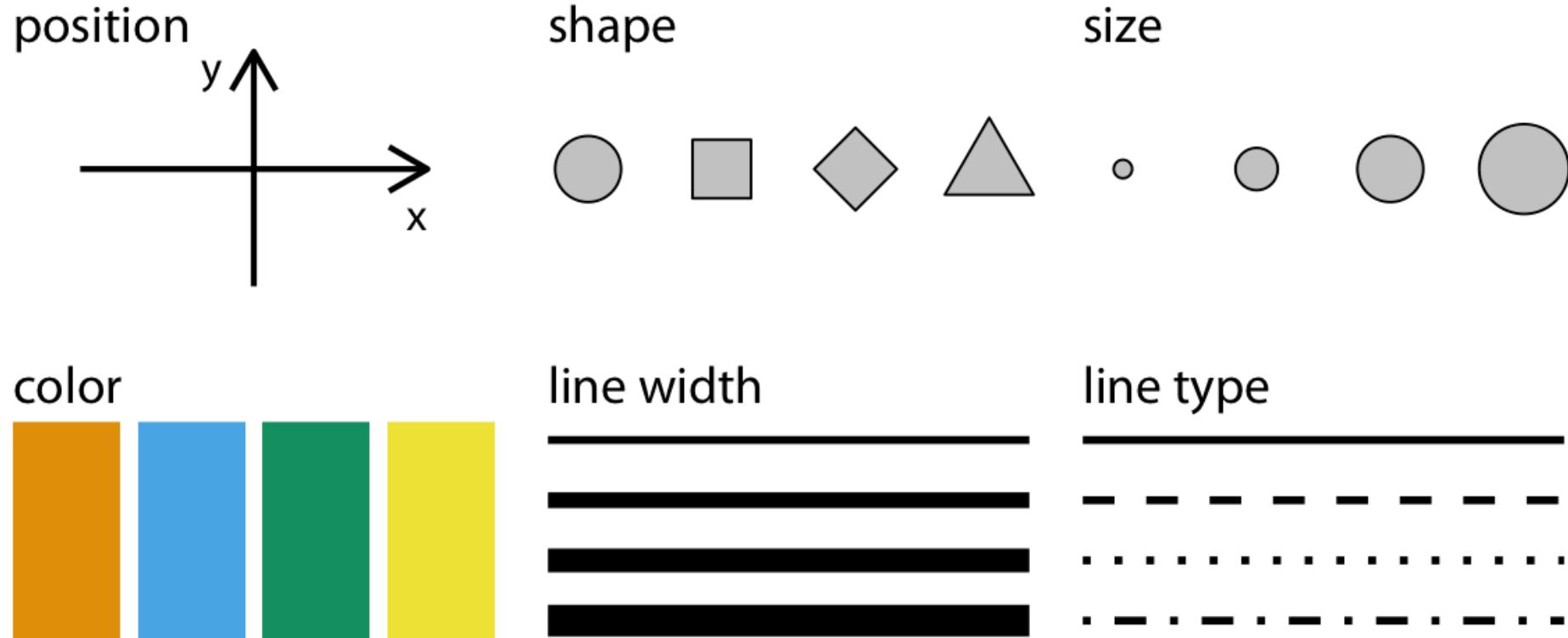
DISCRETE

OBSERVATIONS CAN ONLY EXIST
AT LIMITED VALUES, OFTEN COUNTS.



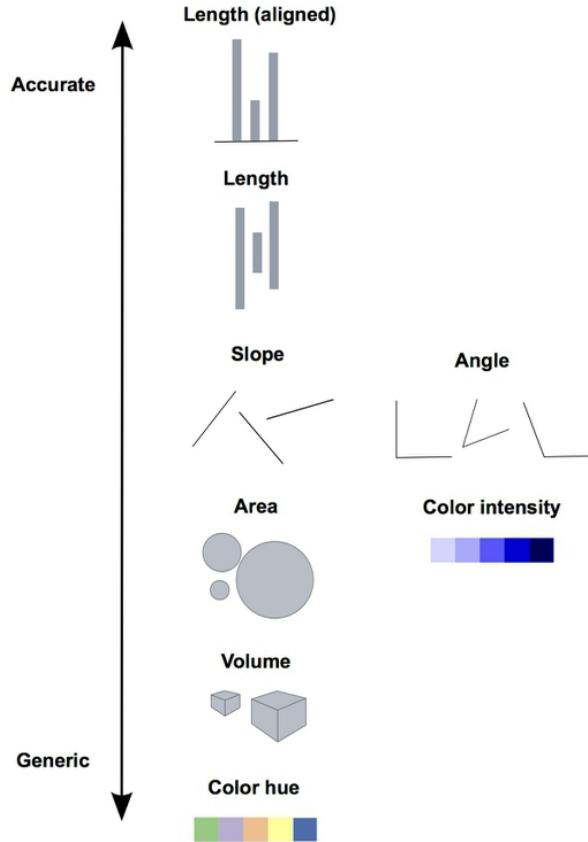
Mapping Data to Aesthetics

Data visualizations map values into quantifiable features (aesthetics)



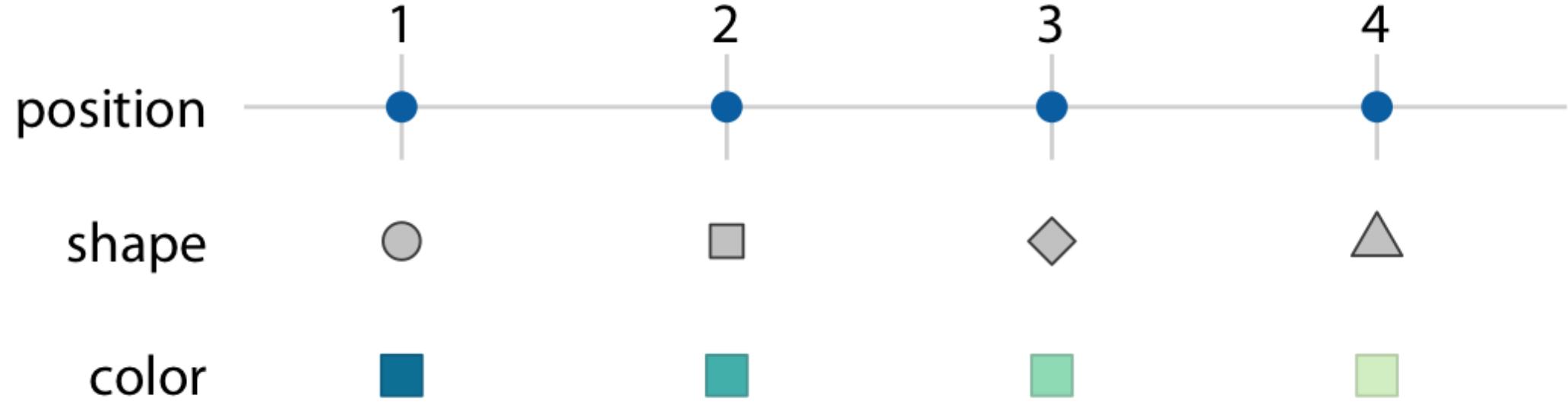
Source: "Fundamentals of Data Visualization" by Claus Wilke

Data visualizations map values into quantifiable features (aesthetics)



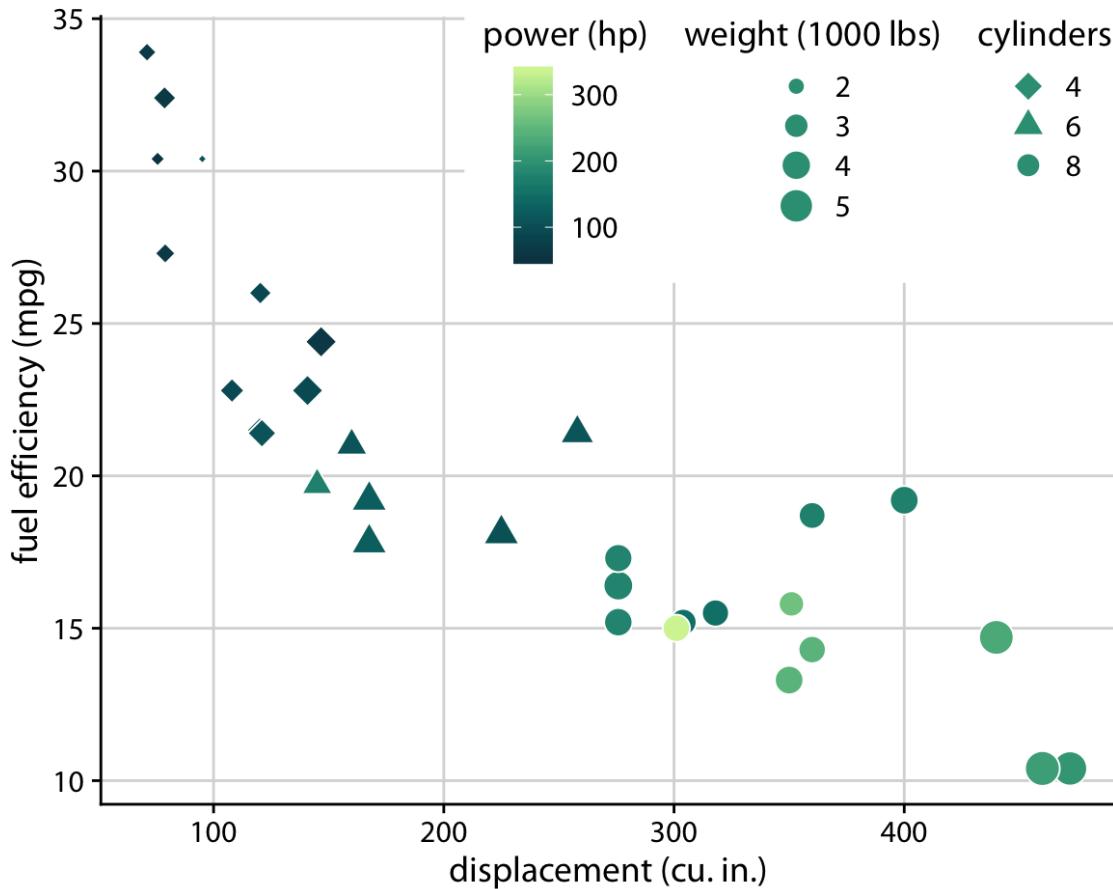
Source: Peter Aldhous based on experiments by William Cleveland and Robert McGill

Scales map data values onto aesthetics



Source: "Fundamentals of Data Visualization" by Claus Wilke

Scales map data values onto aesthetics



Source: "Fundamentals of Data Visualization" by Claus Wilke

Colors and Common Pitfalls

Color Terminology

Hue: color, like blue or red

Chroma: how pure a color is (saturation)

Value: how light or dark a color is

Tint: created by adding white to a hue

Tone: created by adding grey to a hue

Shade: created by adding black to a hue



Color Palette Types

Categorical



Color Palette Types

Categorical



Sequential: Single-Hue



Color Palette Types

Categorical



Sequential: Single-Hue



Sequential: Multi-Hue



Color Palette Types

Categorical



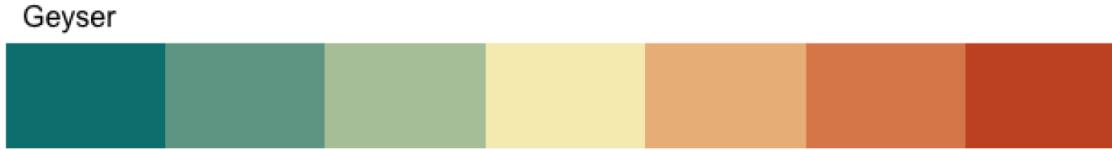
Sequential: Single-Hue



Sequential: Multi-Hue



Diverging



Color Palette Types

Categorical



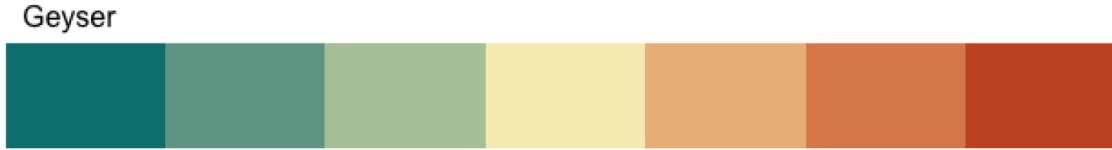
Sequential: Single-Hue



Sequential: Multi-Hue



Diverging



Cyclical



Rainbow Color Map (Still) Considered Harmful

Publisher: IEEE

2 Author(s)

David Borland ; Russell M. Taylor li [View All Authors](#)

172
Paper
Citations

3
Patent
Citations

9091
Full
Text Views

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Medical Physics

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[Med Phys.](#) 2015 Jun; 42(6): 2942–2954.

Published online 2015 May 20. doi: [10.1118/1.4921125](https://doi.org/10.1118/1.4921125)

PMCID: PMC5148121

PMID: 26127048

Effect of color visualization and display hardware on the visual assessment of pseudocolor medical images

[Silvina Zabala-Travers](#), [Mina Choi](#), [Wei-Chung Cheng](#), and [Aldo Badano](#)^{a)}

10 March 2017

Interpretation of the rainbow color scale for quantitative medical imaging: perceptually linear color calibration (CSDF) versus DICOM GSDF

[Frédérique Chesterman](#); [Hannah Manssens](#); [Céline Morel](#); [Guillaume Serrell](#); [Bastian Piepers](#); [Tom Kimpe](#)

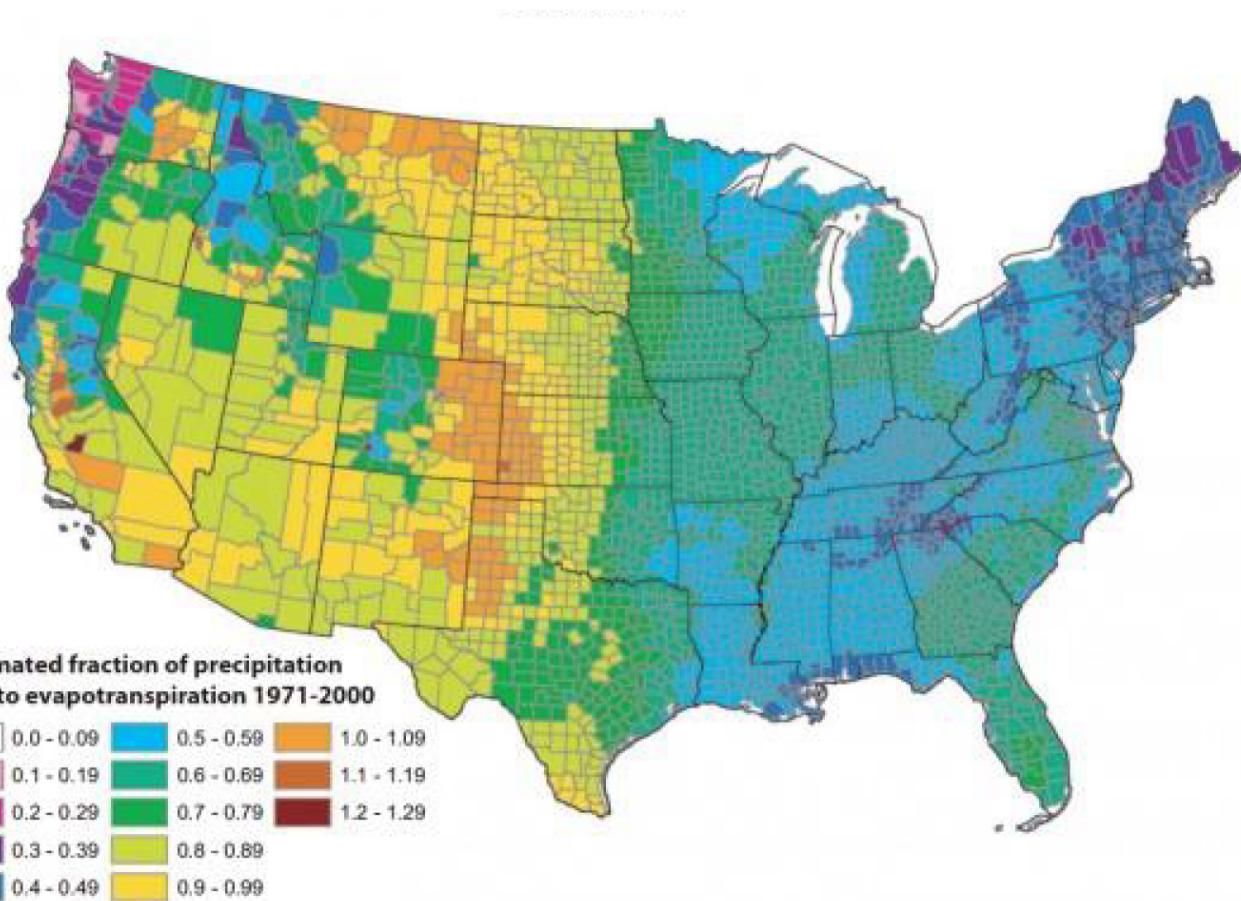


FIGURE 13. Estimated Mean Annual Ratio of Actual Evapotranspiration (ET) to Precipitation (P) for the Conterminous U.S. for the Period 1971-2000. Estimates are based on the regression equation in Table 1 that includes land cover. Calculations of ET/P were made first at the 800-m resolution of the PRISM climate data. The mean values for the counties (shown) were then calculated by averaging the 800-m values within each county. Areas with fractions >1 are agricultural counties that either import surface water or mine deep groundwater.

Source: eagereyes.org/basicss/rainbow-color-map

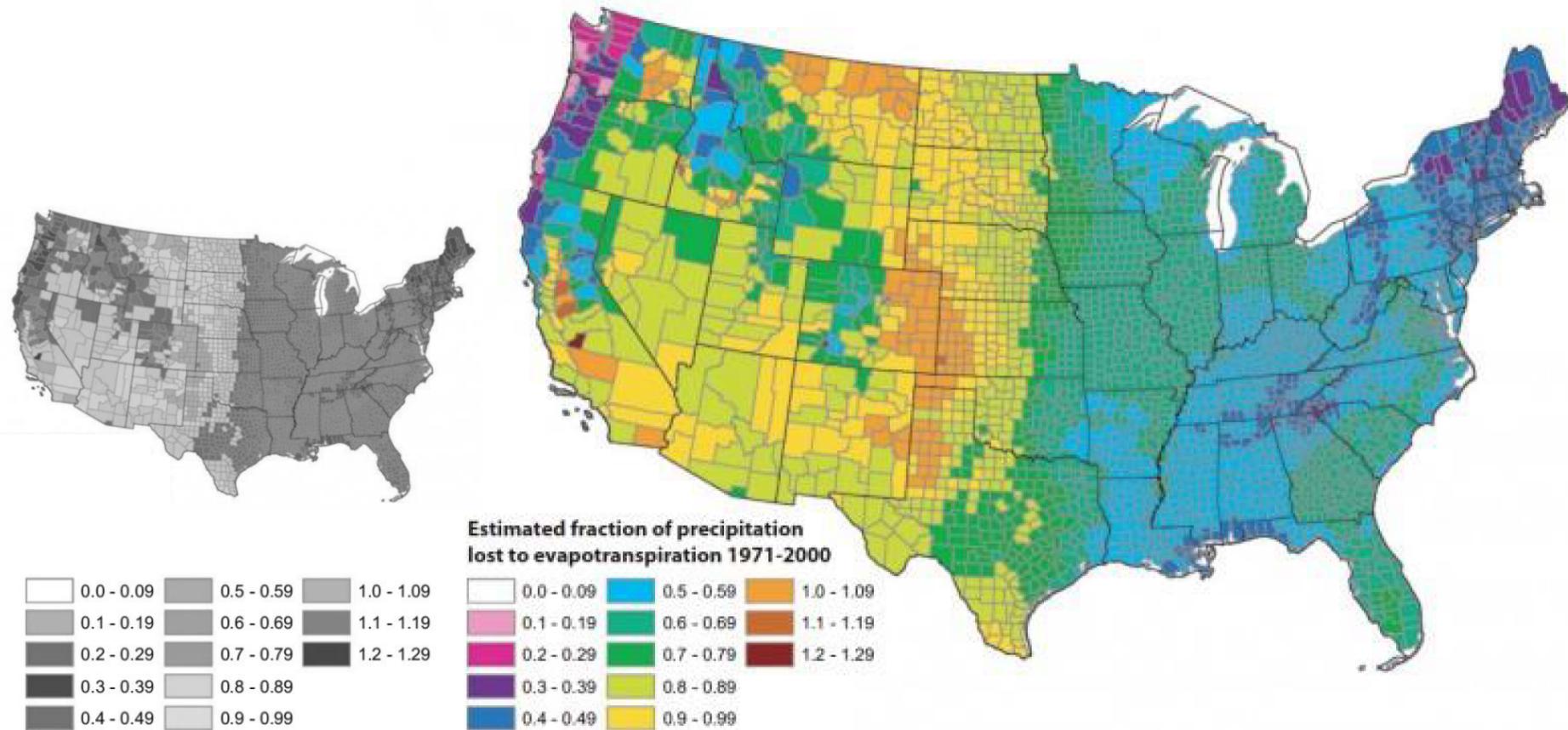


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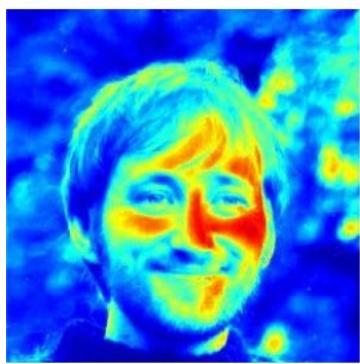


true-colour Phil

Source: fabiocramerich/batlow



true-colour Phil

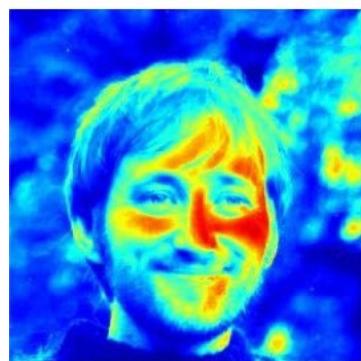


rainbow Phil
is distorted

Source: fabiocramerich/batlow



true-colour Phil



rainbow Phil
is distorted



batlow Phil
is flawless

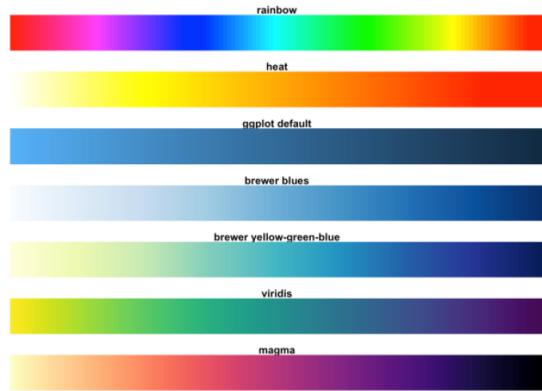
Source: fabiocramerich/batlow

Choice of Color Palettes

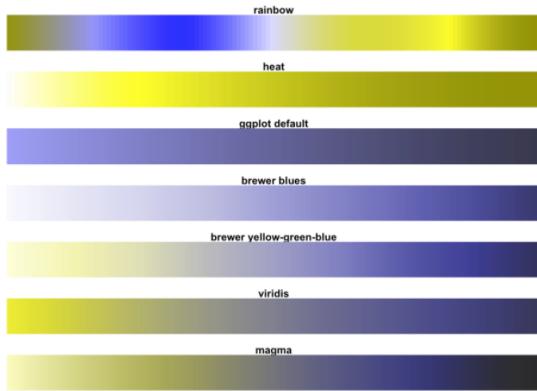


Source: cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html

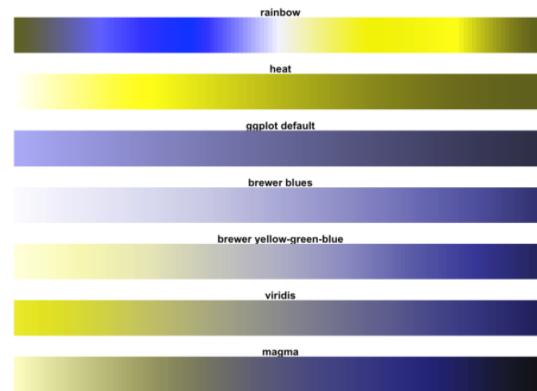
Choice of Colors Palettes & Color-Vision Deficiency (CVD)



Deutanopia: present in 6% of males



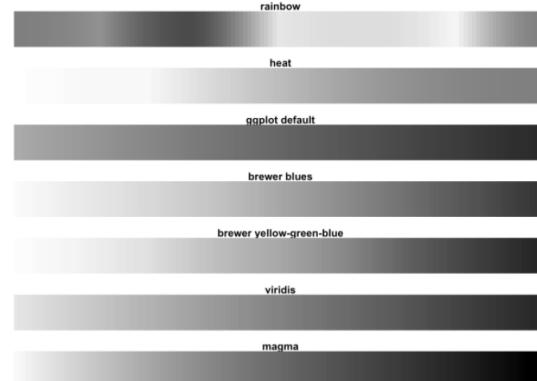
Protanopia: present in 1% of males



Tritanopia: present in 0.008% of humans



Monochromacy: present in 0.001% of humans



... and present in ~75% of university printers! ☺

Modified from cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html

To make sure your visualizations work for people with CVD don't just rely on provided color palettes.

To make sure your visualizations work for people with CVD don't just rely on provided color palettes.

Instead, test your figures in a color-blindness simulator!

Choice of the Color Palette & Accessibility

Choose color-blind friendly palettes:
projects.susielu.com/viz-palette

Test your final visualization:
color-blindness.com/coblis-color-blindness-simulator

Create a CVD-version of your ggplot in R:
github.com/clauswilke/colorblindr

Choice of the Color Palette & Accessibility

original



deuteranomaly



protanomaly

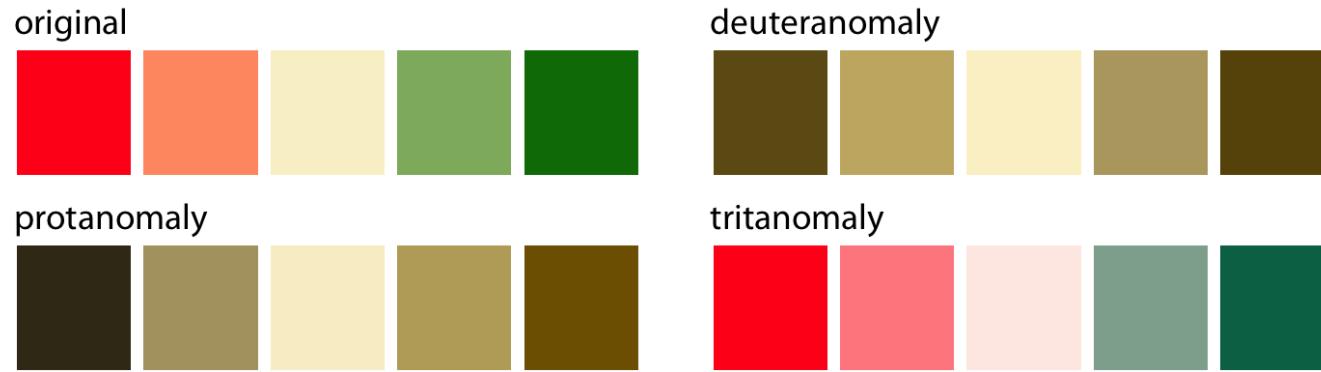


tritanomaly



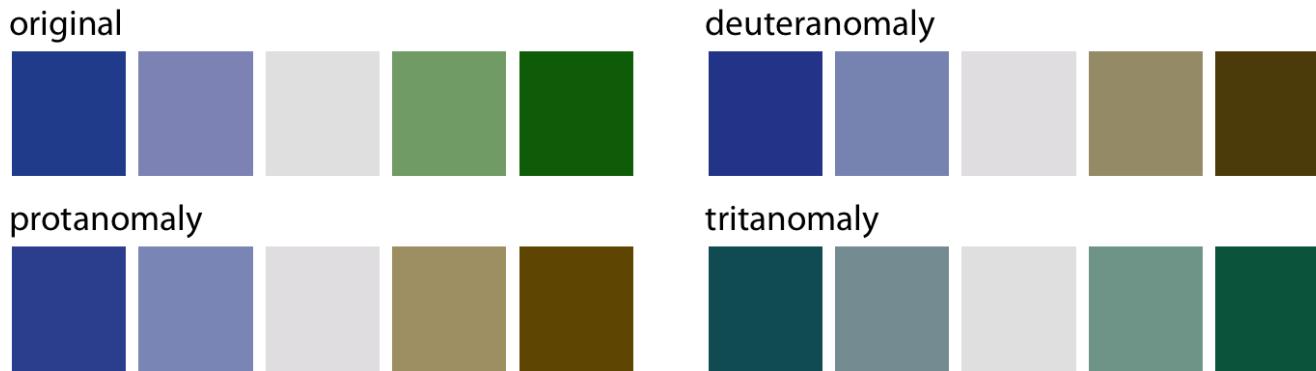
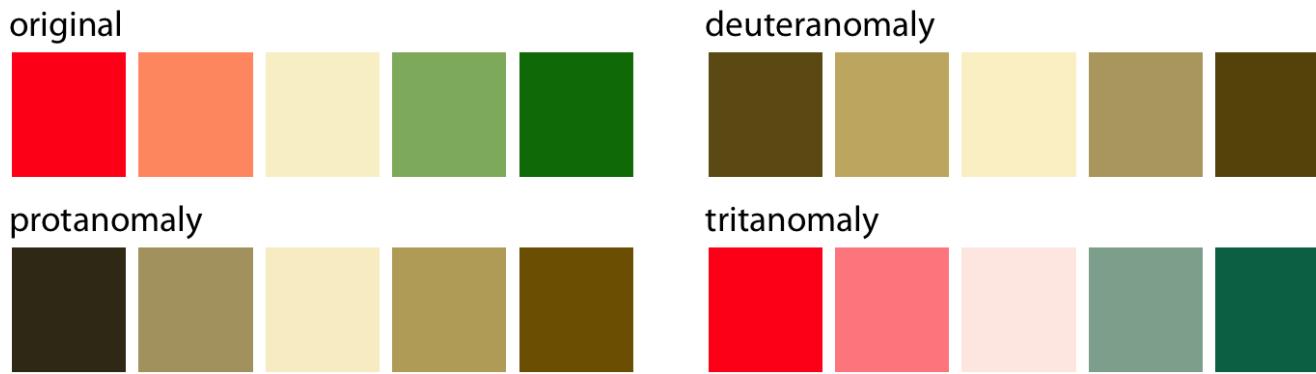
Source: "Fundamentals of Data Visualization" by Claus Wilke

Choice of the Color Palette & Accessibility



Source: "Fundamentals of Data Visualization" by Claus Wilke

Choice of the Color Palette & Accessibility



Source: "Fundamentals of Data Visualization" by Claus Wilke

Choice of the Color Palette & Accessibility

VIZ PALETTE

By: Elijah Meeks & Susie Lu

PICK

Use Chroma.js

Use Colorgorical

Use ColorBrewer

EDIT

7 Colors

- 1. #ffd700
- 2. #ffb14e
- 3. #fa8775
- 4. #ea5f94
- 5. #cd34b5
- 6. #9d02d7
- 7. #0000ff

Add

Replace

GET

String quotes

Object with metadata

```
[ "#ffd700",
  "#ffb14e",
  "#fa8775",
  "#ea5f94",
  "#cd34b5",
  "#9d02d7",
  "#0000ff" ]
```

#hex

rgb

hsl

COLORS IN ACTION

Background color: #ffffff

Font color: #000000

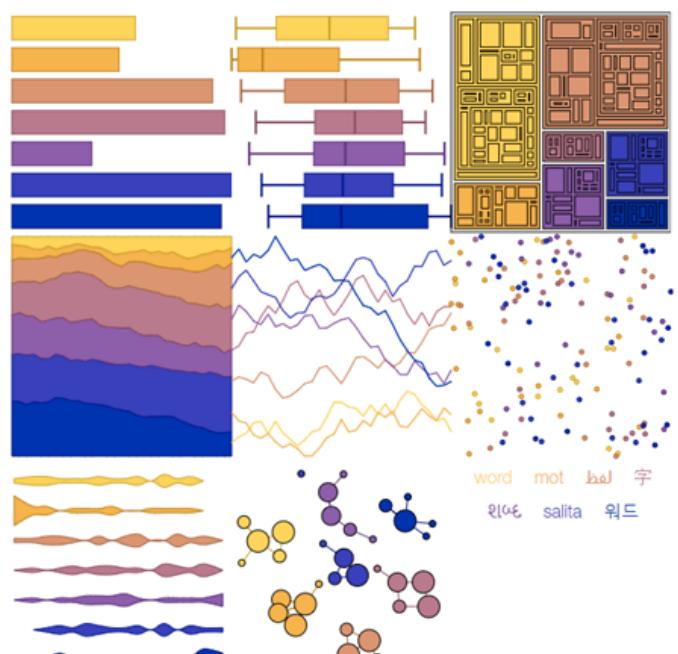
Charts made with [Semiotic](#)

Color Population: No Color Deficiency - 96% | Deuteranomaly - 2.7% | Protanomaly - 0.66% | Protanopia - 0.59% | Deutanopia - 0.56% | Greyscale

Sample font

Randomize Data

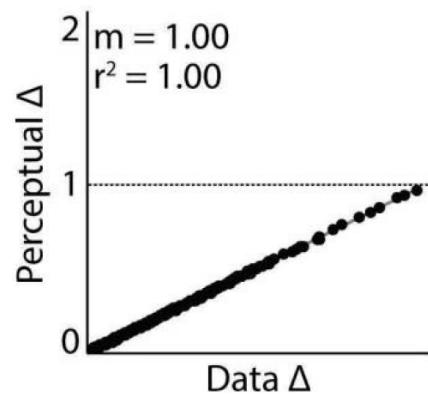
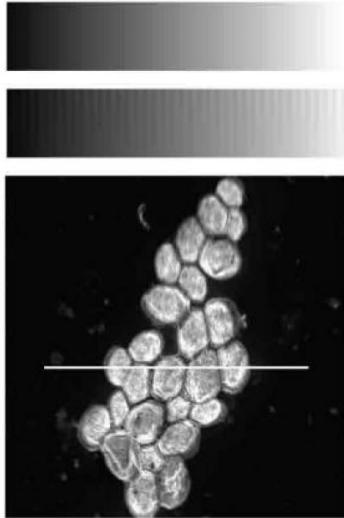
Stroke: Dark | None



word mot baj 字
শব্দ salita 워드

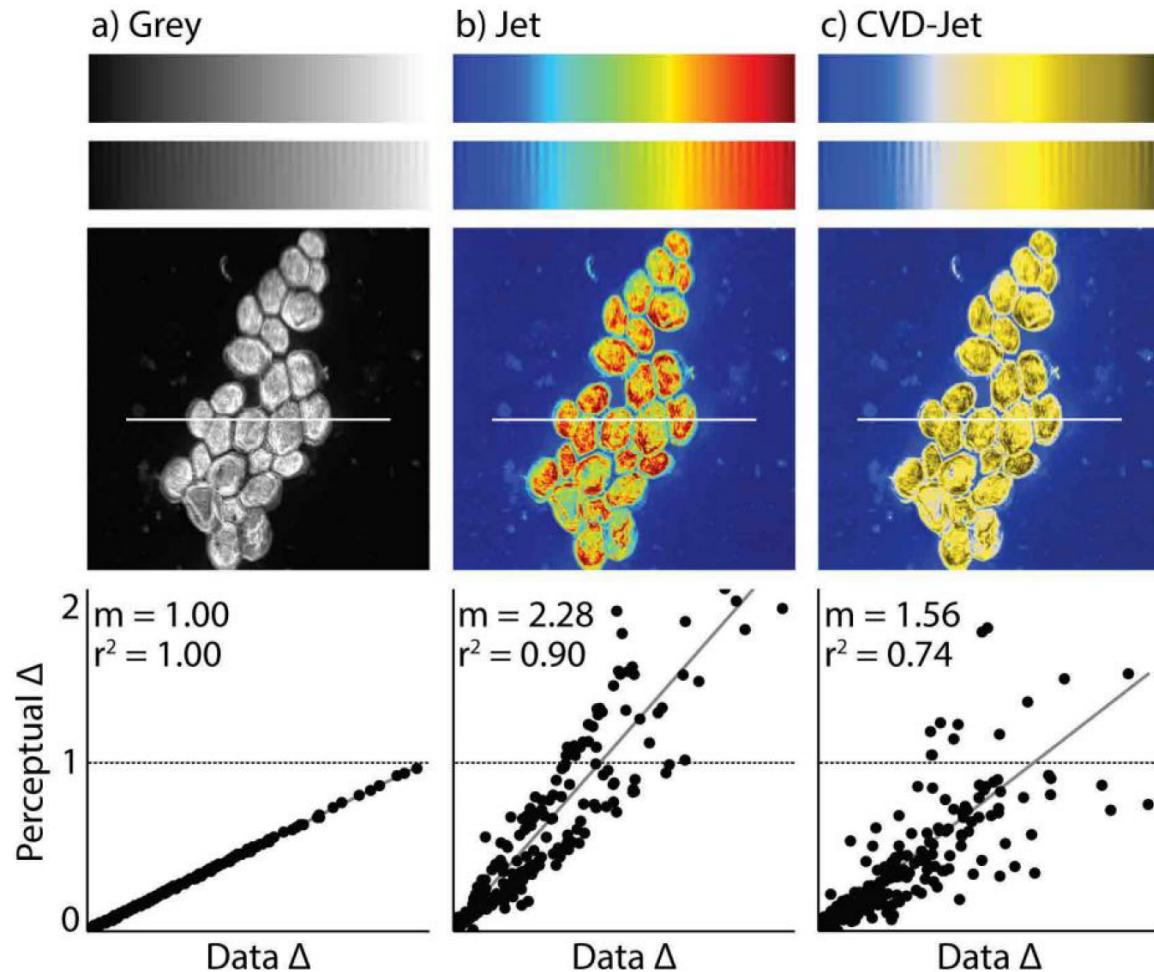
Choice of the Color Palette & Accessibility

a) Grey



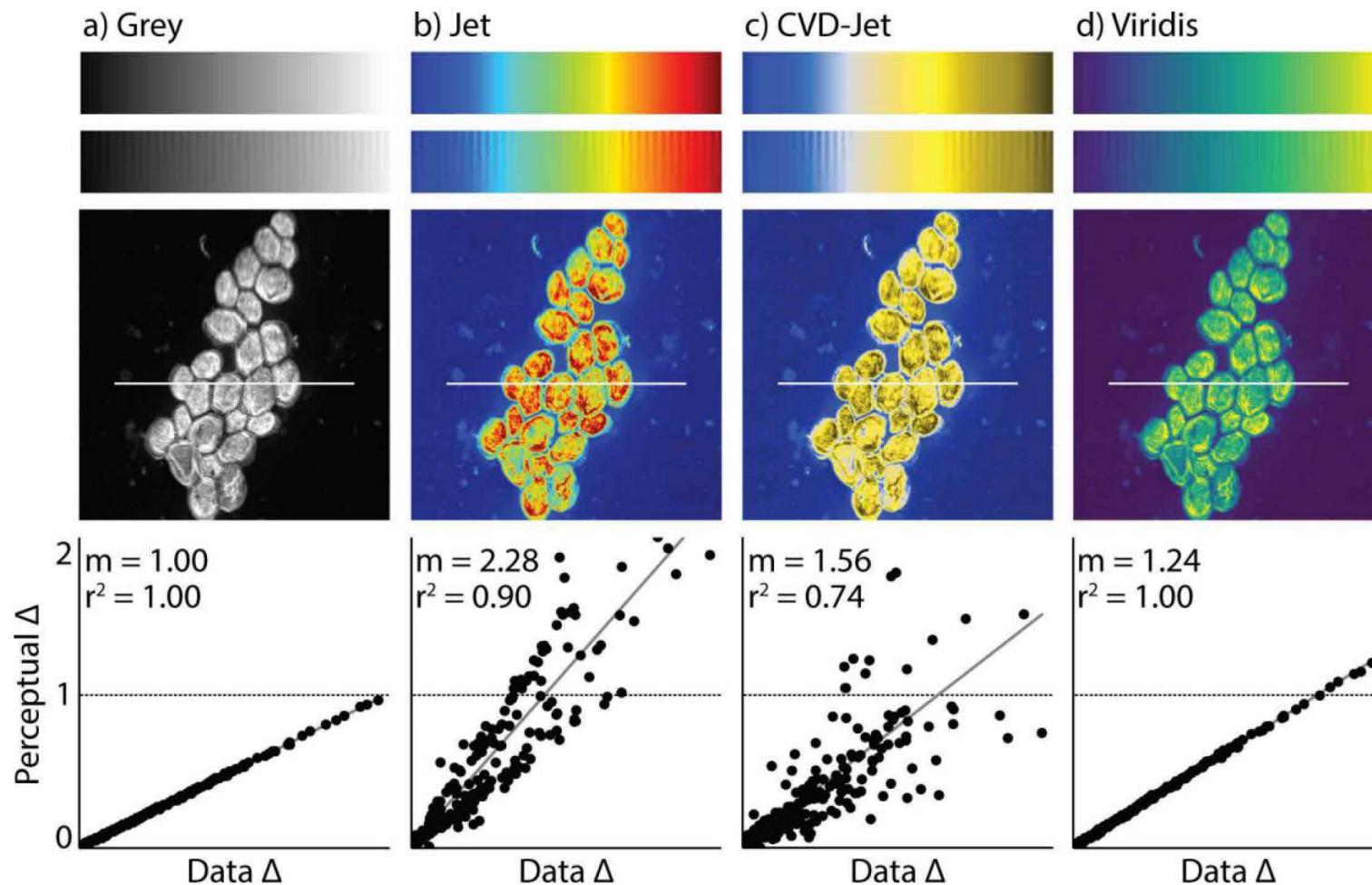
Modified from Nuñez, Anderton & Renslow (2018) PLOSone

Choice of the Color Palette & Accessibility



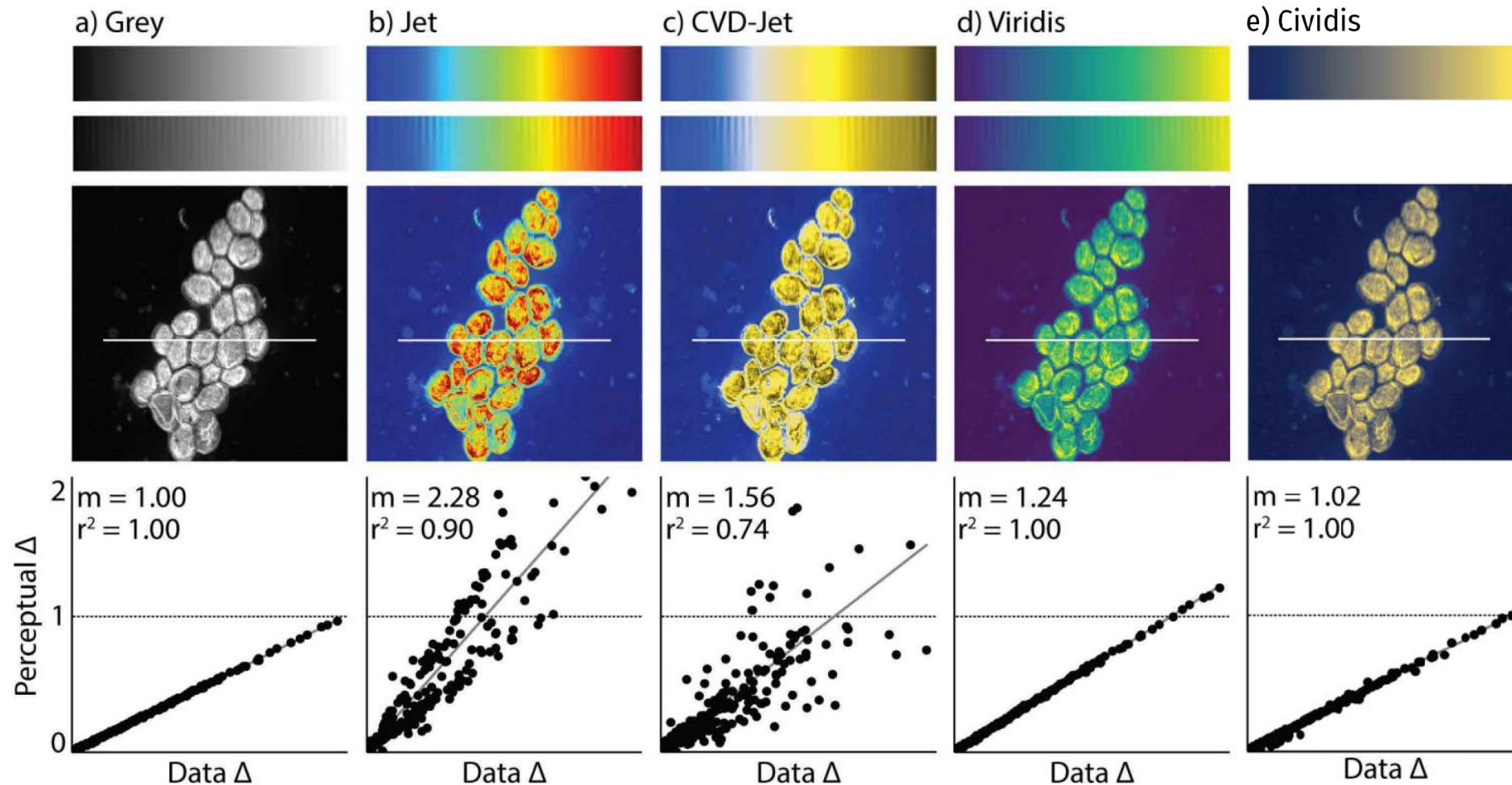
Modified from Nuñez, Anderton & Renslow (2018) PLOSone

Choice of the Color Palette & Accessibility



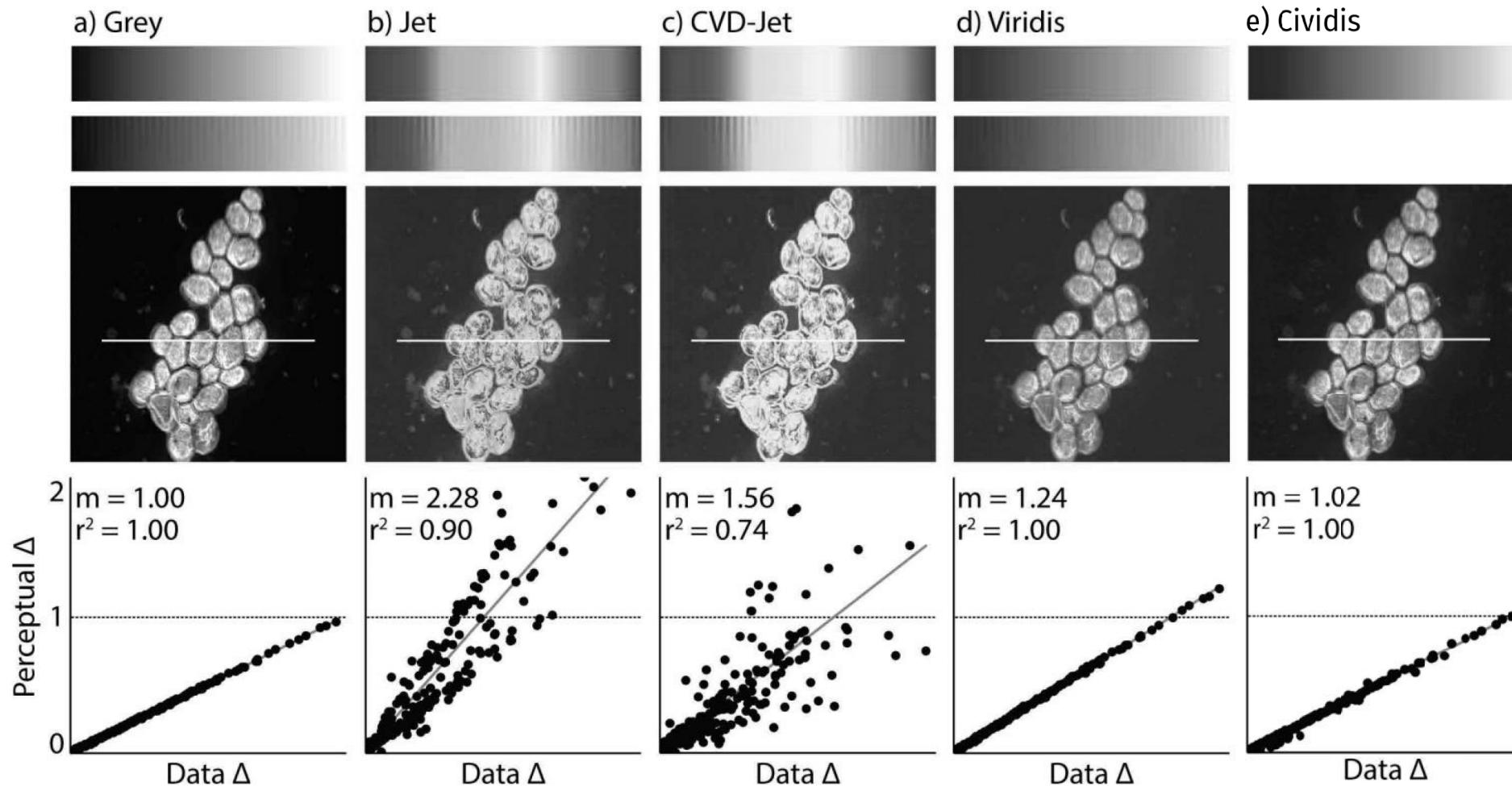
Modified from Nuñez, Anderton & Renslow (2018) PLOSone

Choice of the Color Palette & Accessibility



Modified from Nuñez, Anderton & Renslow (2018) PLOSone

Choice of the Color Palette & Accessibility



Modified from Nuñez, Anderton & Renslow (2018) PLOSone

The image is a graphic design centered around the word "TYPOGRAPHY". It features the word in multiple sizes and styles across the page. On the left side, there is a vertical column of words: "TYPOGRAPHY" (in a bold, serif font), "TYPOGRAPHY" (in a smaller, sans-serif font), "TYPOGRAPHY" (in a large, bold, serif font), "TYPOGRAPHY" (in a small, sans-serif font), "TYPOGRAPHY" (in a very large, bold, serif font), "TYPOGRAPHY" (in a small, sans-serif font), "TYPOGRAPHY" (in a large, bold, serif font), "TYPOGRAPHY" (in a small, sans-serif font), and "TYPOGRAPHY" (in a very large, bold, serif font). In the center, there is a row of decorative ligatures: "G", "H", "V", "P", "E", "T", "A", "Z", "R", "W". To the right of these ligatures, the word "TYPOGRAPHY" appears again in a large, bold, serif font. At the bottom right of the image, the word "Typography" is written in a large, bold, yellow sans-serif font.

Typography

You'll always be mine! ❤

FONTS MATTER

 YOU'LL ALWAYS BE MINE!

The Choice of the Font(s)

- The font(s) should fit the topic and audience - context matters.
- Avoid fancy fonts and squiggle letters.
- Use ways to visualize hierarchy.
- Avoid using ALL CAPS.
- Use a monospaced font with lining for numbers.

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- Use a monospaced font with lining for numbers.
- **Consistency is key!**

How to Visualize Hierarchy

I am important!

I am important, too!

Oh, hi there. Thanks for reading me...

Yeah, I know I am kinda boring. Sorry.

How to Visualize Hierarchy

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Display Fonts

A Tale of Two Cities

Lobster Two

A Tale of Two Cities

Tangerine

A Tale of Two Cities

Raleway

A Tale of Two Cities

Abril Fatface

A Tale of Two Cities

Chunk

A TALE OF TWO CITIES

Cinzel

Source: wordpress.com

Text Fonts

A Tale of Two Cities

It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair, we had everything before us, we had nothing before us, we were all going direct to Heaven, we were all going direct the other way—in short, the period was so far like the present period, that some of its noisiest authorities insisted on its being received, for good or for evil, in the superlative degree of comparison only.

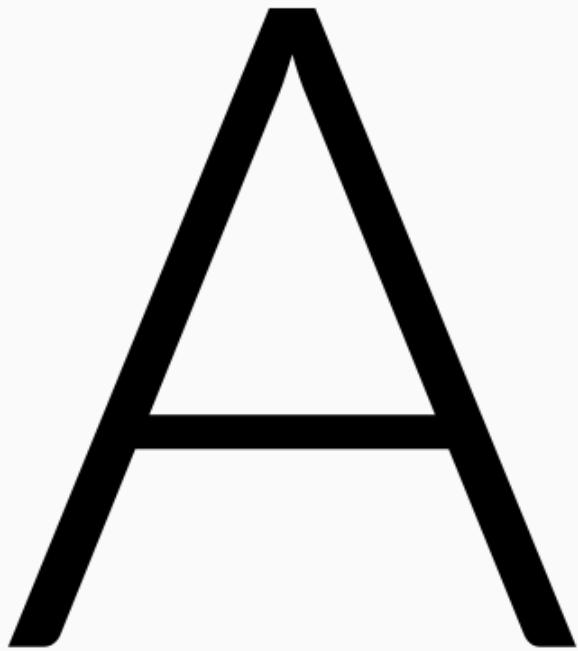
Open Sans

A Tale of Two Cities

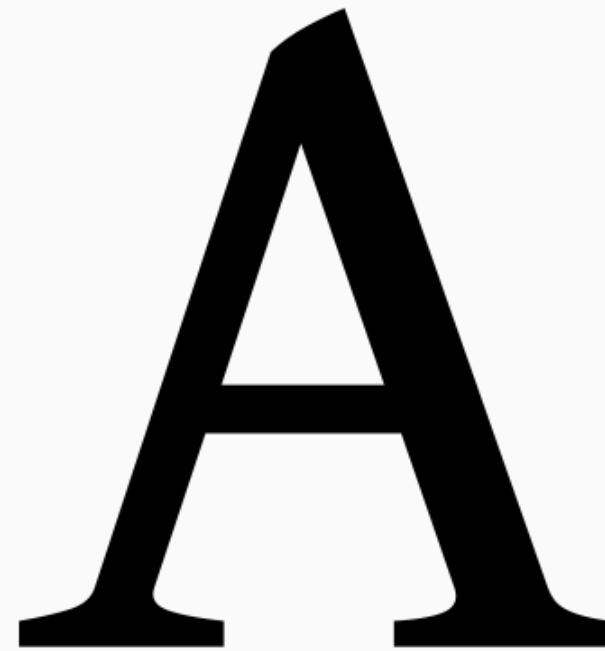
It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair, we had everything before us, we had nothing before us, we were all going direct to Heaven, we were all going direct the other way—in short, the period was so far like the present period, that some of its noisiest authorities insisted on its being received, for good or for evil, in the superlative degree of comparison only.

Libre Baskerville

Sans-Serif or Serif ?

A large, bold, black sans-serif letter 'A' centered on the page. It has a clean, modern appearance with straight lines and no decorative flourishes.

Lato

A large, bold, black serif letter 'A' centered on the page. It features traditional decorative elements like small vertical strokes at the top and bottom of the vertical stems and a distinct crossbar.

Gentium Book Basic

Keep it Simple

**Using lots of fonts
can make for a design
that is cluttered,
overcomplicated,
AND JUST NOT VERY NICE**

*But if you just use
a small selection,
you can keep your
design cleaner, clearer
and just much easier
to digest*

Tabular (Monospaced) Numbers

TABULAR

123.45
678.90

PROPORTIONAL

123.45
678.90

Source: invisionapp.com/inside-design/best-free-fonts-for-numbers

Number Fonts with Lining

LINING

123,456,789.0

OLDSTYLE

123,456,789.0

Source: invisionapp.com/inside-design/best-free-fonts-for-numbers

Quality of Number Symbols

NEUTON

\$123,456,789.00%

% is smaller than
other figures

ECONOMICA

\$123,456,789.00%

\$ is smaller than
other figures

SOURCE CODE PRO

\$123,456,789.00%

% has an
uncommon design

MARVEL

\$123,456,789.00☒

It doesn't have the
% symbol

Source: invisionapp.com/inside-design/best-free-fonts-for-numbers

Droid Serif

REGULAR

\$123,456,789.00%

BOLD

\$123,456,789.00%

Crimson Text

REGULAR

\$123,456,789.00%

SEMIBOLD

\$123,456,789.00%

BOLD

\$123,456,789.00%

Copse

REGULAR

\$123,456,789.00%

Kameron

REGULAR

\$123,456,789.00%

BOLD

\$123,456,789.00%

Open Sans

LIGHT \$123,456,789.00%
REGULAR \$123,456,789.00%
BOLD **\$123,456,789.00%**

Roboto Condensed

LIGHT \$123,456,789.00%
REGULAR \$123,456,789.00%
BOLD **\$123,456,789.00%**

Lato

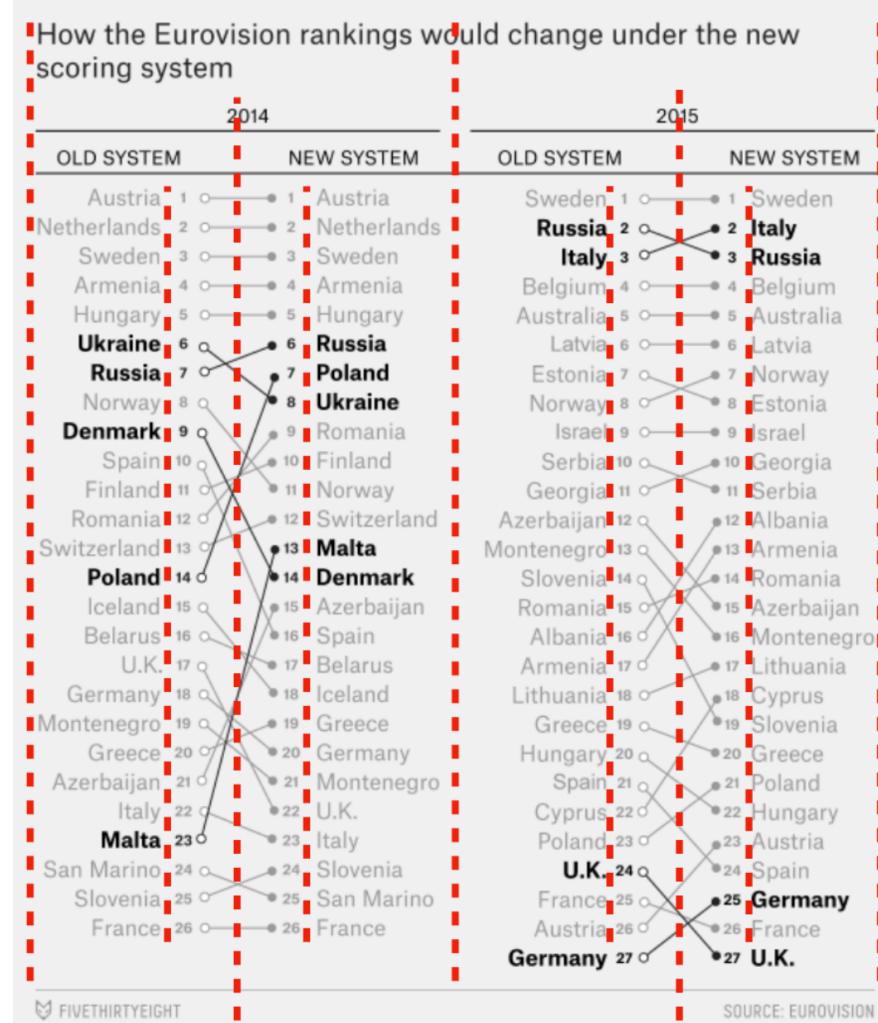
LIGHT \$123,456,789.00%
REGULAR \$123,456,789.00%
BOLD **\$123,456,789.00%**

Varela Round

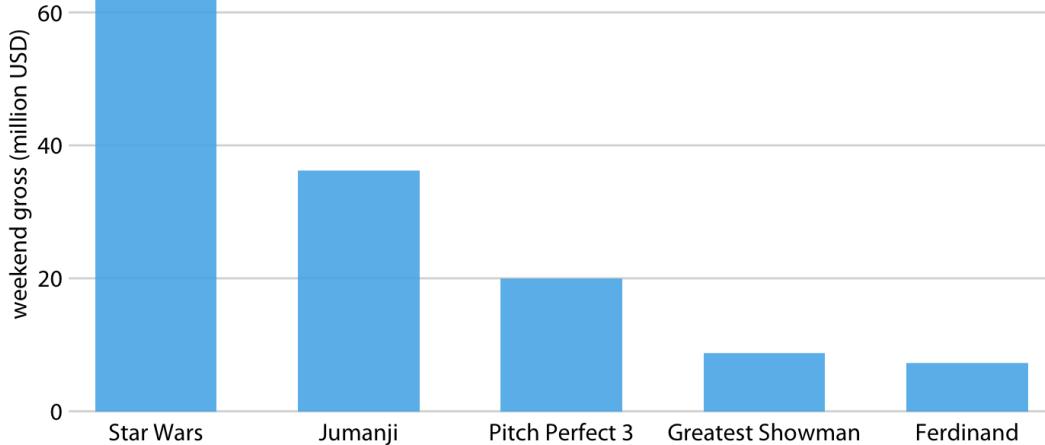
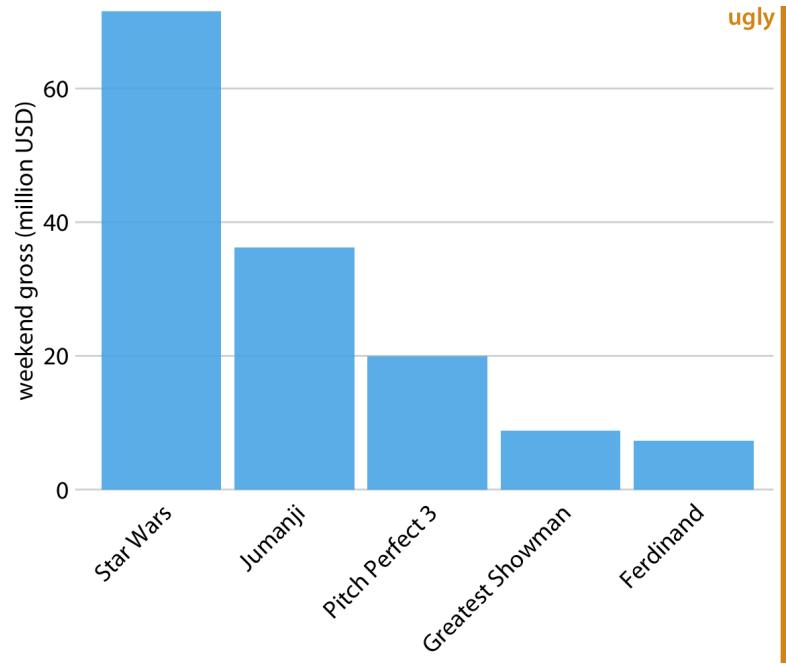
REGULAR \$123,456,789.00%

Allign Your Text!

- Left-align most text
 - Title should be left aligned
 - Labels and subtitles can be center or right aligned



(Don't) Rotate Your Text!



Source: "Fundamentals of Data Visualization" by Claus Wilke

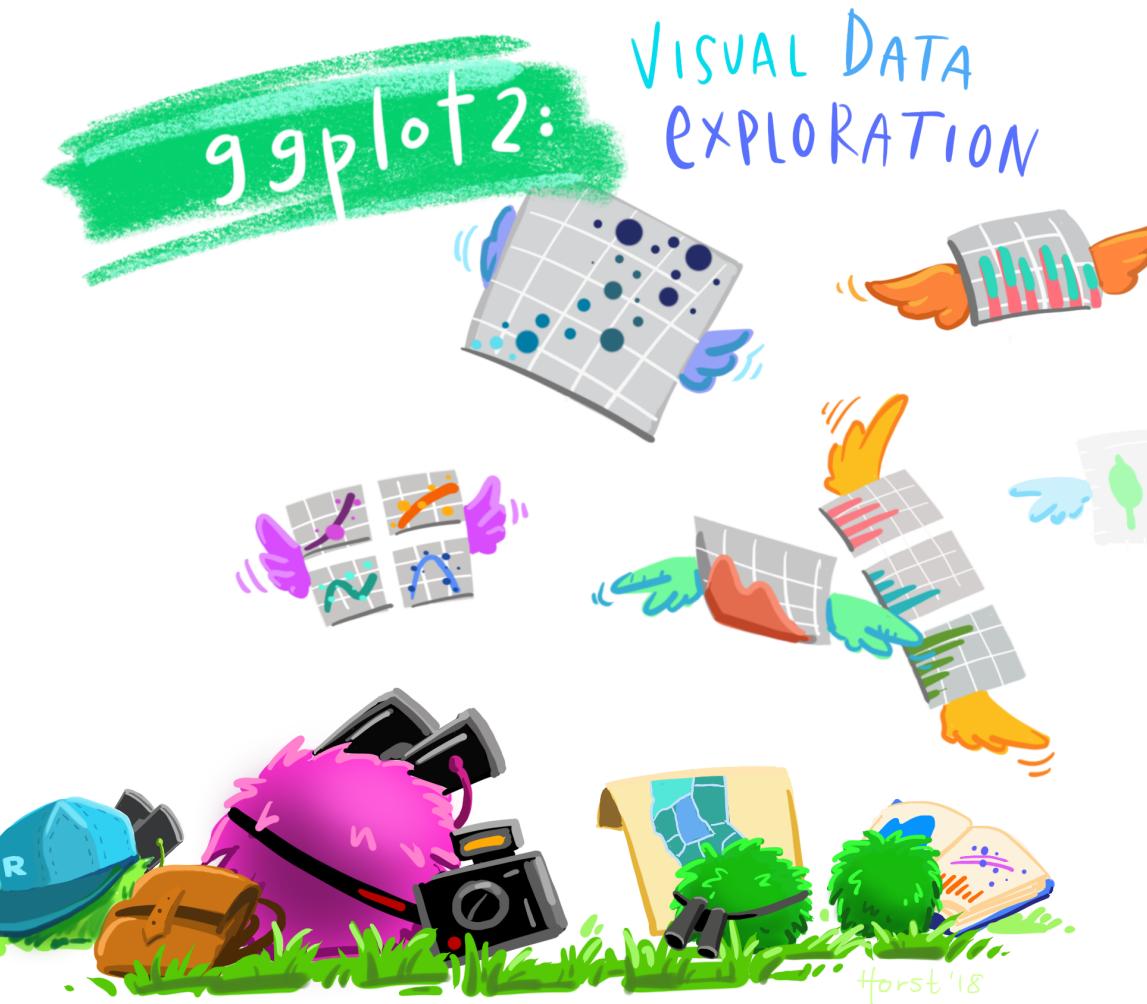


Illustration by Allison Horst (github.com/allisonhorst/stats-illustrations)