Data visualization: Making great graphs with familiar tools

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Brown University October 28, 2022







Pie I have eaten



Pie I have not yet eaten

Outline

1 Live experiment

10 mins

2 Graph makeover with three design principles 30 mins

Captured a graph in the wild

Original version

Captured a graph in the wild



Captured a graph in the wild



Which is more understandable?

Protocol for our experiment right now

- 1. Pose a question
- 2. Display the **original** for 5 seconds
- 3. Display the **revised** for 5 seconds
- 4. Type into chat:

Which did you get the answer from?

What is this graph about? Drug companies (or "the industry") run clinical trials on new drugs and send the data to the FDA.

The FDA wants companies to use a standard data format called CDISC.

"Clinical study cycle time" is the total time needed for a drug trial.



On average, how much time do clinical trials save by using CDISC?

Original

Impact of CDISC Standards on Clinical Study Cycle Time



Current industry average CDISC Standards Impact Savings using CDISC standards (mos)

Note: Figures are benchmarks based on aggregate data; study-specific cycle times and cost metrics will vary.



© CDISC 2009

Revised

CDISC standards save eight months of clinical cycle study time



Study conduct does not include patient participation time.

Figures are benchmarks based on aggregate data; study-specific cycle times and cost metrics will vary.



© CDISC 2009

Which did you get the answer from?

What does 5 seconds matter?

Attention economy Exponential growth of information

What does 5 seconds matter?

Attention economy Exponential growth of information

Data visualization allows us to quickly find patterns in large amounts of data.

Explosion of the data visualization field



Explosion of the data visualization field



Explosion of the data visualization field





Data Visualization Society presents **Information is Beautiful** Awards



The New York Times



Three design principles



Data-ink ratio

Edward Tufte, 1983



SECOND EDITION

The Visual Display of Quantitative Information

EDWARD R. TUFTE

Data-ink ratio

Edward Tufte, 1983

SECOND EDITION

The Visual Display of Quantitative Information

EDWARD R. TUFTE

Data ink =

The ink used to display the data itself,

or the "non-erasable core" of a graphic

Data-ink ratio

Edward Tufte, 1983

SECOND EDITION

The Visual Display of Quantitative Information

EDWARD R. TUFTE

Data ink =

The ink used to display the data itself, or the "non-erasable core" of a graphic

Data ink ratio =

Data ink

Non-data ink

Identify non-data ink



Current industry average CDISC Standards Impact Savings using CDISC standards (mos)

Identify non-data ink



The mortal sin of 3-D

APPLIED COGNITIVE PSYCHOLOGY Appl. Cognit. Psychol. 14: 151–162 (2000)

Do Irrelevant Depth Cues Affect the Comprehension of Bar Graphs?

MARTIN H. FISCHER*

Department of Psychology, University of Munich, Germany

SUMMARY

Eight participants decided whether two- or three-dimensional bars embedded within twoor three-dimensional frames were semantically consistent with written inequalities of the form 'A > B'. Inequalities were presented either before (Experiment 1) or after the graphs (Experiment 2). In Experiment 1, irrelevant depth cues were associated with slower decision times and there was no processing cost associated with an inconsistency between the

This is all the non-data ink





This is all the non-data ink





Current industry average CDISC Standards Impact Savings using CDISC standards (mos)

Cognitive ergonomics

Cognitive ergonomics

Make life easy and comfortable for the body at work

Cognitive ergonomics // // Make life easy and comfortable for the

mind at work

Make life easy and comfortable for the body at work

Cognitive ergonomics / Make life easy and comfortable for the Make life easy and comfortable for the

mind at work

body at work

Reduce mental workload, decision-making, cognition, executive functioning, attention management, etc.



Current industry average CDISC Standards Impact Savings using CDISC standards (mos)



Current industry average CDISC Standards Impact Savings using CDISC standards (mos)

The mortal sin of pie charts






Humans are bad at judging area, much better at judging length



More than about 5 categories are unintelligible



Current industry average CDISC Standards Impact Savings using CDISC standards (mos)



















Current industry average CDISC Standards Impact Savings using CDISC standards (mos)





Whoever controls the reference controls the message.

Dona Wong



Current industry average CDISC Standards Impact Savings using CDISC standards (mos)







Current industry average CDISC Standards Impact Savings using CDISC standards (mos)



Current industry average CDISC Standards Impact Savings using CDISC standards (mos)



Current industry average CDISC Standards Impact

Where we are



Current industry average CDISC Standards Impact

A pause in honor of white space



"The courage of emptiness"

Andy Kirk



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Search Google or type URL



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Search Google or type URL

White space can be used as virtual ink

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White space can be used as virtual ink

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White space can be used as virtual ink

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Supporting text

Stephen Few
Supporting text



Current industry average CDISC Standards Impact

Text needed to understand the data, but not the data itself





Current industry average CDISC Standards Impact

Text needed to understand the data, but not the data itself

Regularize supporting text

One font only Arial, Times New Roman, etc.

No variants narrow, condensed, SMALL CAPS, etc.

Same background as slide

De-emphasize supporting text

Smaller than other text

No underline, bold, highlight, italics

Use % black

% black drives % attention

Hey, look at me!

I am less important

Nothing to see here

Notes on original graph

Study Conduct does not include patient participation time.

Note: Figures are benchmarks based on aggregate data; study-specific cycle times and cost metrics will vary.

Notes on original graph

Study conduct does not include patient participation time.

Figures are benchmarks based on aggregate data; study-specific cycle times and cost metrics will vary.

Regularize & de-emphasize supporting text



Study conduct does not include patient participation time.

Figures are benchmarks based on aggregate data; study-specific cycle times and cost metrics will vary.

Column labels



- Current industry average
 CDISC standards impact

Column labels



Text orientation and legibility

Best legibility

Worse legibility

Just terrible

Text orientation and legibility

Best legibility Worse legibility worse legibility and <u>D</u> Just terrible

Cat astr ophi c legi bility

When your column labels are slanted....



... convert to a bar chart for label legibility



Add series labels





Study conduct Analysis & reporting

Add series labels



Distance between data and its labels: Too far



Distance between data and its labels: **Closer...**



Distance between data and its labels: Right on top



Distance between data and its labels: Data is the label



Put labels right on top of series



Finally, draw attention to the message



Give the conclusion right in the title

CDISC standards save eight months of clinical cycle study time



Finally, replace notes and logo

CDISC standards save eight months of clinical cycle study time



Study conduct does not include patient participation time.

Figures are benchmarks based on aggregate data; study-specific cycle times and cost metrics will vary.



Impact of CDISC Standards on Clinical Study Cycle Time



Current industry average CDISC Standards Impact Savings using CDISC standards (mos)

Note: Figures are benchmarks based on aggregate data; study-specific cycle times and cost metrics will vary.



© CDISC 2009



What is the primary aim of your graph? What do you want viewers to take from your graph? What is the important comparison to be made? What is the appropriate reference? Where do you want to steer the viewer's attention?



Three design principles

Know your message and design for it

Data-ink ratio

Cognitive ergonomics

Thank you

Kate Miller, PhD MPH Senior Biostatistician katemill@stanford.edu



Typical constraints on graphs in medical journals

Editorial norms and standards

"Time series data must be presented in a line chart."

Unfamiliarity

Reviewer X: "I've never seen this kind of chart before. Please replace it with a bar chart."

Fees for color

Typical constraints on graphs in medical journals

Editorial norms and standards

"Time series data must be presented in a line chart."

Unfamiliarity

Reviewer X:

"I've never seen this kind of chart before. Please replace it with a bar chart."

Fees for color

Every principle we talked about today can be applied under these constraints.

Please feel empowered to drive the field forward



Resources

s Edition (10 ed.)	Print Publication Date: Feb 2020	
N-13 9780190246556	Read More lished online: Feb 2020	
Figures.		Download PDF
Chapter: Tables, Figures, and	l Multimedia	
Figures.		
The term <i>figure</i> refers to any gr matrixes, algorithms, illustration explain methods, to present ev	raphical display used to present information ns, digital images, photographs, and other o ridence and quantitative results, to highlight	i or data, ⁴ including statistical graphs, maps, clinical images. Figures may be used to clarify or trends and associations or relationships among
data, to clarify complex concep tables, the figure with its title a	ots, or to illustrate items or procedures. Figu nd legend should be understandable withou	res should be accurate, clear, and concise. As with it undue reference to the text.
In scientific articles, the choice Some of the most common typ	of a particular type of figure depends on th es of figures in biomedical publications are	e purpose and type of information being displayed. discussed herein.

AMA Manual of Style: A AMA Manual of Style Committee

Previous Edition (10 ed.)

Publisher: Oxford University Press

Wong B nature methods points of view Advanced Create alert Create RSS Sorted b Save Email Send to 18 results Points of view: Networks. Gehlenborg N, Wong B. Nat Methods. 2012 Feb;9(2):115. doi: 10.1038/nmeth.1862. Cite PMID: 22396963 No abstract available. Share Points of view: arrows. Wong B. 2 Nat Methods. 2011 Sep;8(9):701. doi: 10.1038/nmeth.1676. Cite PMID: 21984999 No abstract available. Share Points of View: Typography. Wong B. 3 Nat Methods. 2011 Apr;8(4):277. doi: 10.1038/nmeth0411-277. Cite PMID: 21574271 No abstract available. Share Points of view: plotting symbols. Krzywinski M, Wong B. 4 Nat Methods. 2013 Jun;10(6):451. doi: 10.1038/nmeth.2490. Cite PMID: 23866328 No abstract available. Share Points of view: Integrating data. Gehlenborg N, Wong B. 5

Nat Methods. 2012 Apr;9(4):315. doi: 10.1038/nmeth.1944. Cite PMID: 22563597 No abstract available. Share
That said, many journals have graphics standards



Graphics editorial series in Nature

Regular editorial on graphics for 6 years

By Bang Wong

Ended 2016

POINTS OF VIEW

Design of data figures

Data figures or graphs are essential to life-science communication. Using these tools authors encode information that readers later decode. It is imperative that graphs are interpreted correctly. Despite the importance and widespread use of graphs, we primarily rely on our intuition, common sense and precedent in published material when creating them—a largely unscientific approach.

Because accurately interpreting visual variables is such a vital step in understanding graphs, a rational framework for creating effective graphs would accommodate the needs of the reader and focus on the strengths of human perception. Conversely, we want to avoid displays of data that are misleading or difficult to discern. For example, it can be tough to accurately judge the differences between two curves (Fig. 1a). The disparity is actually constant but our perceptual system is attuned to detecting minimal distances so the divergence appears to decrease. Another shortcoming limits our ability to accurately judge relative area. This diminishes the usefulness of bubble charts. For example, the larger circle

Table 1 | Elementary perceptual tasks

ank	Aspect to compare
1	Positions on a common scale
2	Positions on the same but nonaligned scales
3	Lengths
4	Angles, slopes
5	Area
6	Volume, color saturation
7	Color hue

THIS MONTH

Tasks are ordered from most to least accurate. Information adapted from ref. 2.

When communicating with graphs, we want readers to perceive patterns and trends. This is distinct from conveying information through tables in which we report precise names and numbers. Cleveland and McGill's study assessed people's ability to judge the relative magnitude between two values encoded with a particular visual variable (for example, length, angle and others). In other words, they asked people to estimate how many times bigger *A* is when compared to *B*. Accuracy in their study does not imply reading out precise values from data points in graphs.

Different graph types depend on different visual assessments

Default graphs in Excel and PowerPoint







Default graphs in Excel and PowerPoint



Mind-blowing examples

1. Wikipedia editorial decisions

http://notabilia.net/#/ref

2. Hospital infection pathways

https://www.scientificamerican.com/article/graphic-science-rfids-tags-track-possible-out break-pathways-in-hospital/?WT.mc_id=SA_printmag_2012-11

3. Hans Rosling: "200 Countries, 200 years, 4 minutes"

http://www.youtube.com/watch?v=jbkSRLYSojo

Wikipedia editorial decisions

- 1. Random user makes a Wikipedia page for a topic.
- 2. Editor nominates it for deletion.
- 3. Group of editors have a week for comments, vote to either keep or delete.
- 4. Senior editor makes final decision to keep or delete.







https://informationisbeautiful.net/visualizations/what-islamicgolden-age-thinkers-discovered-long-before-the-west/

The mortal sin of 3-D







Cost of novelty and innovation

Colin Ware,

Information Visualization, Perception for Design

Use tools that are consistent with other commonly used tools, unless the benefit of novelty outweighs the cost of inconsistency. p 24 In other words, it's often worth it to push for a new kind of design https://www.scientificamerican.com/article/graphic-science-rfids-tags-track-possible-ou eak-pathways-in-hospital/?WT.mc_id=SA_printmag_2012-11

Hospital interactions thingy

https://www.youtube.com/watch?feature=player_embedded&v=jbkSRLYSojo

How do you like your data?

Chart



Written explanation

Yesterday there was 4.3 A and 2.5 B. There was also 3.5 C and 4.5 D. However, today the numbers are smaller for A, C, and D.

Table

	Yesterday	Today	Tomorrow
Α	4.3	2.4	2
В	2.5	4.4	2
С	3.5	1.8	3
D	4.5	2.8	5

Verbal explanation





General Figure Guidelines

• Primary outcome data should not be presented in figures alone. Exact values with measure of variability should be reported in the text or table as well as in the abstract.

Back to top

- All symbols, indicators (including error bars), line styles, colors, and abbreviations should be defined in a legend.
- Each axis on a statistical graph must have a label and units of measure should be labeled.
- Do not use pie charts, 3-D graphs, and stacked bar charts as these are not appropriate for accurate statistical presentation of data and should be revised to another figure type or converted to a table.
- Error bars should be included in both directions, unless only 1-sided variability was calculated.
- Values for ratio data—odds ratios, relative risks, hazard ratios—should be plotted on a log scale. Values for ratio data should not be log transformed.
- For footnotes, use letters (a, b, c, etc) not symbols.
- Do not submit figures with more than 4 panels unless otherwise justified.
- See the AMA Manual of Style for more guidance on figure types and components.

Have some.

Posted on January 3, 2017 by Jessica Hagy



Storytelling with data



Raw death rates for 45–54–year–old non–Hisp whites

The trend in raw death rates since 2005 can be explained by age-aggregation bias

But the average age in this group is going up!

Age-aggregation bias in mortality trends

Andrew Gelman^{a,b} and Jonathan Auerbach^{a,1}

E816-E817 | PNAS | February 16, 2016 | vol. 113 | no. 7

Convert to bar chart for label legibility

APPLIED COGNITIVE PSYCHOLOGY Appl. Cognit. Psychol. 19: 953–962 (2005) Published online 24 March 2005 in Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/acp.1105

Designing Bar Graphs: Orientation Matters

MARTIN H. FISCHER¹*, NELE DEWULF^{1,2} and ROBIN L. HILL¹

¹University of Dundee, UK ²Ghent University, Belgium

SUMMARY

We investigated whether recent discoveries about the cognitive representation of numbers would predict performance in a graph comprehension task. Participants decided verbally whether statements of the form 'A > B' were correct descriptions of subsequently presented bar graphs. We observed longer decision times for horizontal compared to vertical bar graphs and for negative compared to positive number graphs. Comprehension was faster when the spatial layout of

A Layered Grammar of Graphics

Hadley WICKHAM

A grammar of graphics is a tool that enables us to concisely describe the components of a graphic. Such a grammar allows us to move beyond named graphics (e.g., the "scatterplot") and gain insight into the deep structure that underlies statistical graphics. This article builds on Wilkinson, Anand, and Grossman (2005), describing extensions and refinements developed while building an open source implementation of the grammar of graphics for R, ggplot2.

The topics in this article include an introduction to the grammar by working through the process of creating a plot, and discussing the components that we need. The grammar is then presented formally and compared to Wilkinson's grammar, highlighting the hierarchy of defaults, and the implications of embedding a graphical grammar into a programming language. The power of the grammar is illustrated with a selection of examples that explore different components and their interactions, in more detail. The article concludes by discussing some perceptual issues, and thinking about how we can build on the grammar to learn how to create graphical "poems."

Supplemental materials are available online.



https://www.nytimes.com/interactive/2015/02/23/business/economy/the-changing-nature-of-middle-class-jobs.html

Roots

Traditional statistics

Psychology

Graphic design

18th century

Roots

Traditional statistics

Psychology

Graphic design

18th century

20th century

Computer Science

ML statistics

Roots	Habits of mind	
Traditional statistics	Data is sparse	
Psychology	and expensive	
Graphic design	Theory-driven	
18 th century		

20th century

Computer Science ML statistics Data is cheap and abundant

Atheoretic

Roots	Habits of mind	Foundational text
Traditional statistics Psychology Graphic design	Data is sparse and expensive Theory-driven	The Visual Display of Quantitative Information
8 th century		

20th century

1

Computer Science ML statistics Data is cheap and abundant Atheoretic

A Layered Grammar of Graphics Wickham, 2010





20th century

Is this true across cultures?

Relnecke K, Gajos K. Quantifying visual preferences around the world. CHI'14, April 26–May 1, 2014, Toronto, Canada. doi.org/10.1145/2556288.2557052



Is this true across cultures?

Online panel of nearly 40,000 people 42 countries with 1000+ participants: China, India, US, South Africa, 25 countries in Europe, 5 more in the Americas, 8 more in Asia and Australia.

Adjusted for age and gender

- Visual complexity
- ----- Colorfulness

Relnecke K, Gajos K. Quantifying visual preferences around the world. CHI'14, April 26–May 1, 2014, Toronto, Canada. doi.org/10.1145/2556288.2557052



Supporting text is already regularized



Faux = 4.125, P = 0.049, treatment; Faux = 1.527, P = 0.1603, interaction, *P = 0.0133 vs. PBS, week 38; **P < 0.0081 and ****P < 0.0001 vs. PBS, week 14.

De-emphasize it



Saccades



Harsh et al., "Seeing" data like an expert: an eye-tracking study using graphical data representations, CBE Life Sci Educ, 2019, 18(3)

Example from a high-profile journal

Proceedings of the National Academy of Sciences



Gelman, Auerbach, Age-aggregation bias in mortality trends, PNAS, 2016 113(7): E816-7

Eye movements over a graph

Saccades



Harsh et al., "Seeing" data like an expert: an eye-tracking study using graphical data representations, CBE Life Sci Educ, 2019, 18(3)

Add series labels



Nascent research considering this question



RCT of "informative" vs. "generic" figure titles among technical readers.

Nascent research considering this question



RCT of "informative" vs. "generic" figure titles among technical readers. No difference to accuracy of judgments or perceived credibility of data. Informative titles required less mental effort, more esthetically pleasing
Know your message and design for it



"If I had an hour to solve a problem, I'd spend 55 minutes thinking about the problem and five minutes thinking about solutions."

- Einstein

Know your message and design for it



"If I had an hour to solve a problem, I'd spend 55 minutes thinking about the problem and five minutes thinking about solutions."

- Einstein

"If I had an hour to make a data visualization, I'd spend 55 minutes thinking about my message and five minutes thinking about the design."

- A skilled visualizer