

Visualizing Information

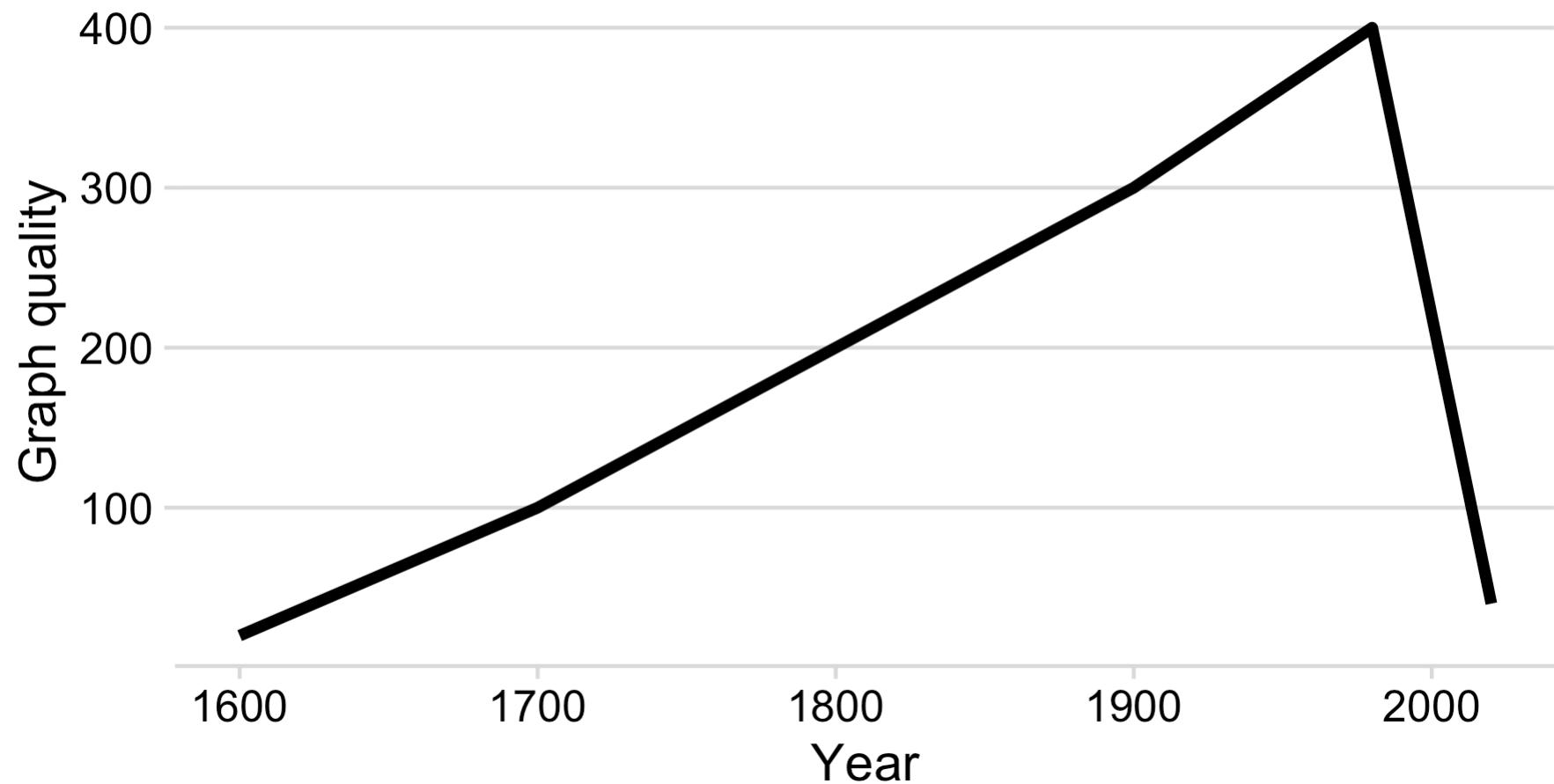
John Paul Helveston, Ph.D.

The George Washington University

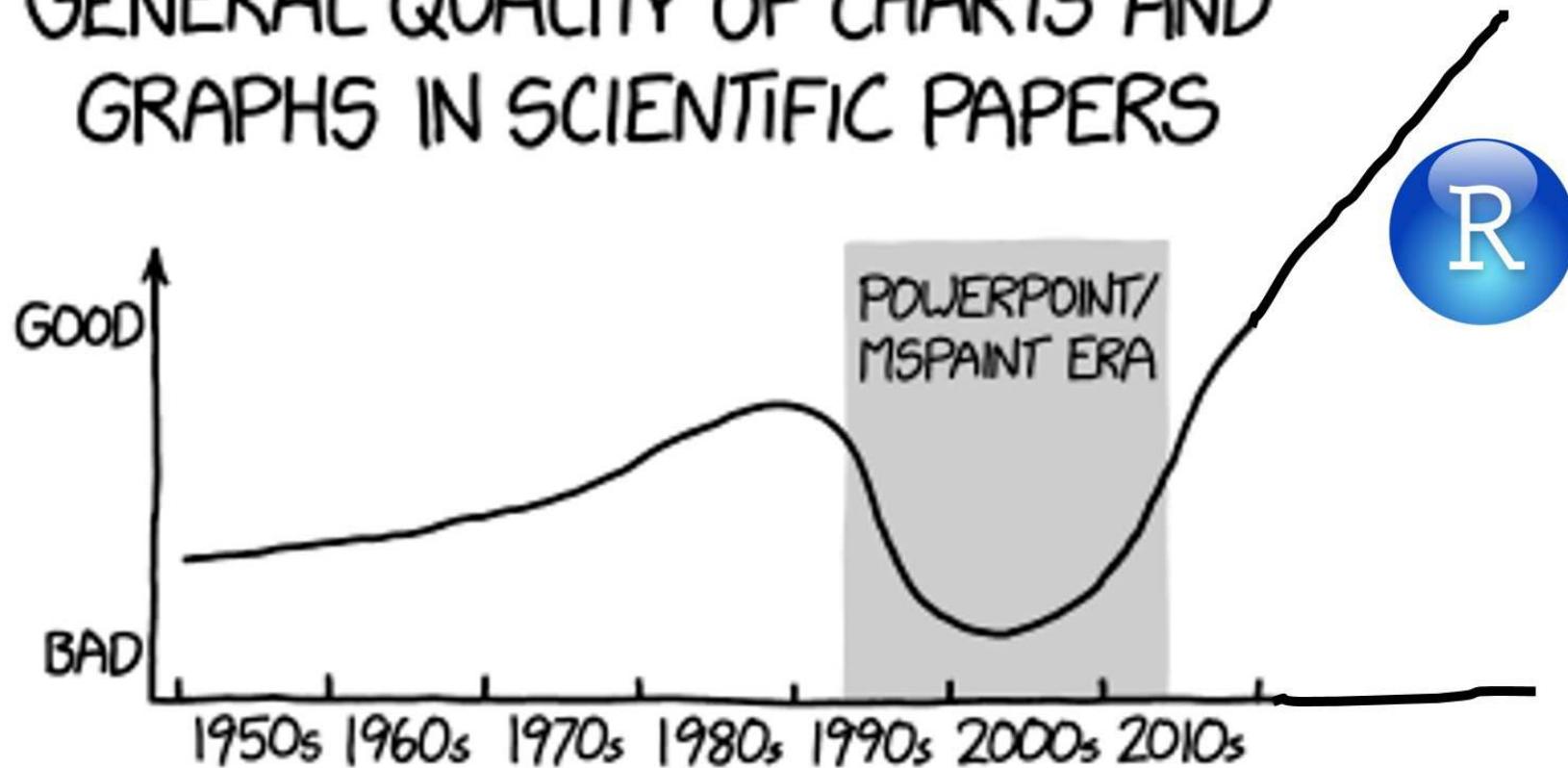
Dept. of Engineering Management & Systems Engineering

Download [this cheatsheet](#) for today's content

Graphing quality over time



GENERAL QUALITY OF CHARTS AND GRAPHS IN SCIENTIFIC PAPERS



From [here](#)

*"Having word processing software
doesn't make us great writers."*

– Stephen Few

We don't write paragraphs like this

People **sometimes do** this [use poor graphic choices] because they've seen **similar charts in newspapers** or on the web and they're naively following a **bad example**. People who know better **sometimes do** this **because** they care more about **the visual impact** than the **clarity** of communication. *If we wanted* to tell the **truth in a way** people can easily understand, this **is not** an **effective approach**.

Image from Few (2012, pg. 227)

We don't write paragraphs like this

People sometimes do this [use poor graphic choices] because they've seen similar charts in newspapers or on the web and they're naively following a bad example. People who know better sometimes do this because they care more about the visual impact than the clarity of communication. If we wanted to tell the truth in a way people can easily understand, this is not an effective approach.

Image from Few (2012, pg. 227)

So don't make graphs like this

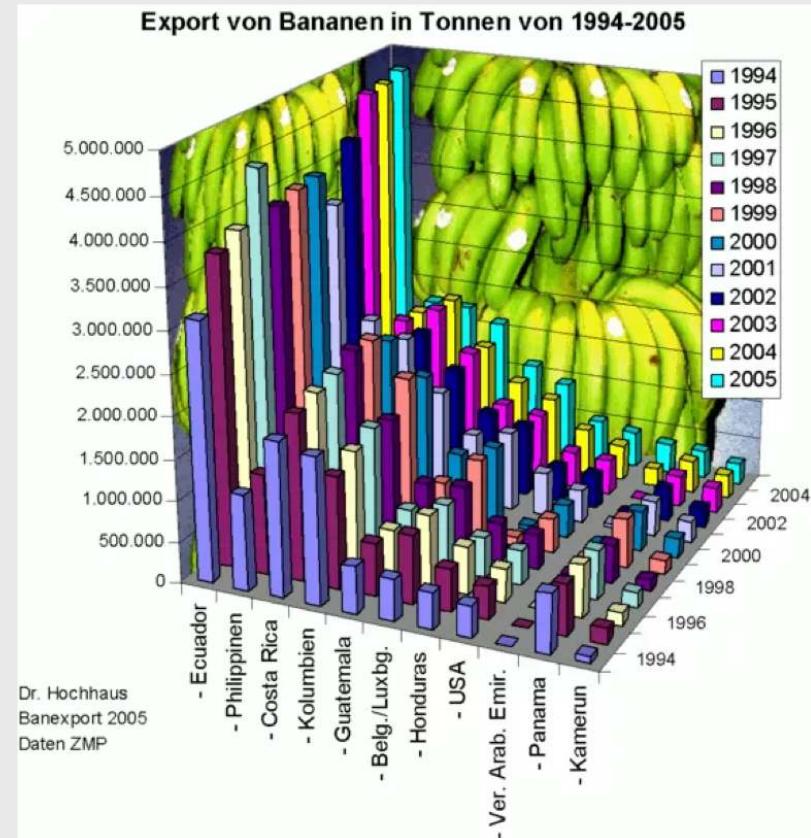


Image from excelcharts.com

Visualizing Information

1. The Psychology of Data Viz

2. 5 Data Viz Don'ts

BREAK

3. 5 Data Viz Do's

Visualizing Information

1. The Psychology of Data Viz

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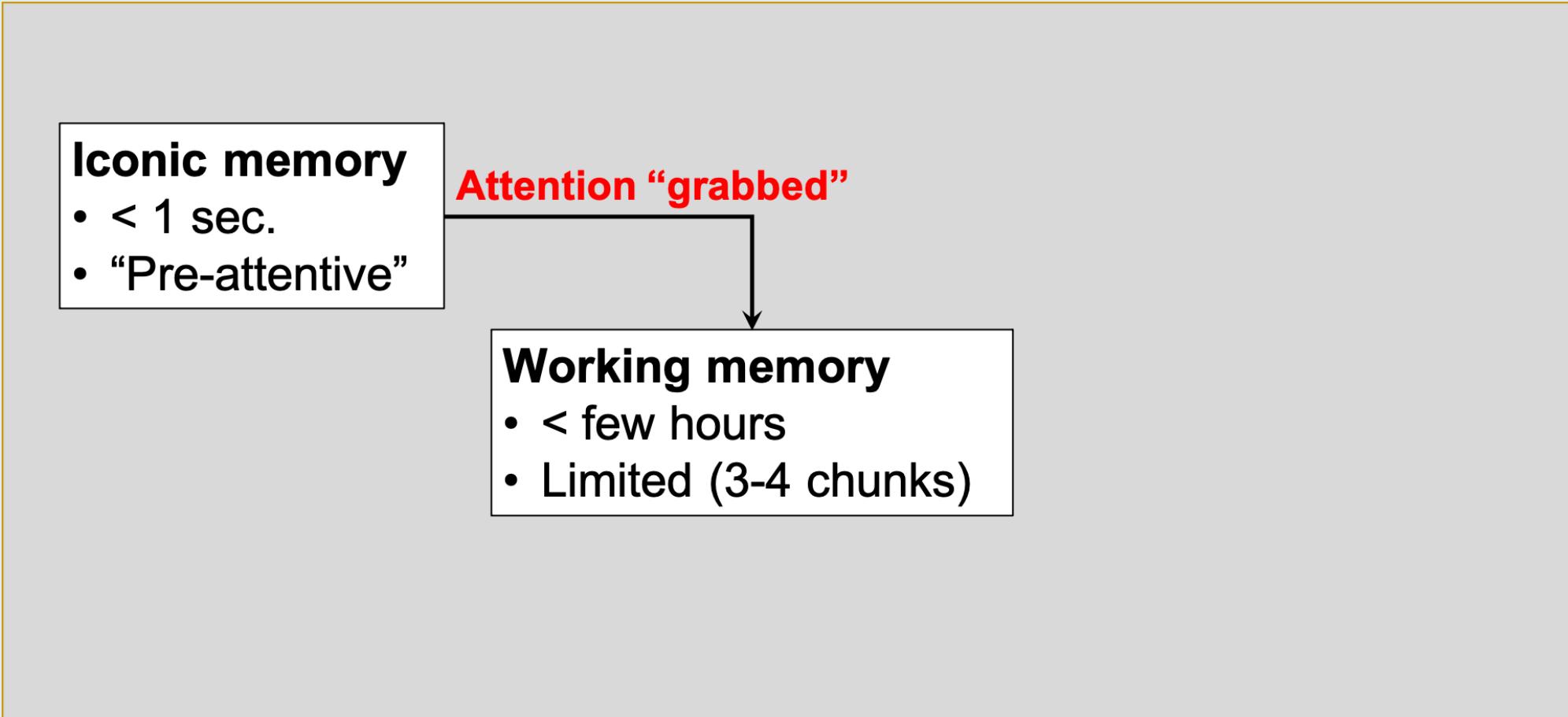
Check out John Rauser's [talk](#) on YouTube

Good visualizations optimize for our
Visual-Memory System

A (very) simplified model of the visual-memory system

- Iconic memory**
 - < 1 sec.
 - “Pre-attentive”

A (very) simplified model of the visual-memory system



A (very) simplified model of the visual-memory system

Effective charts focus on this

Iconic memory

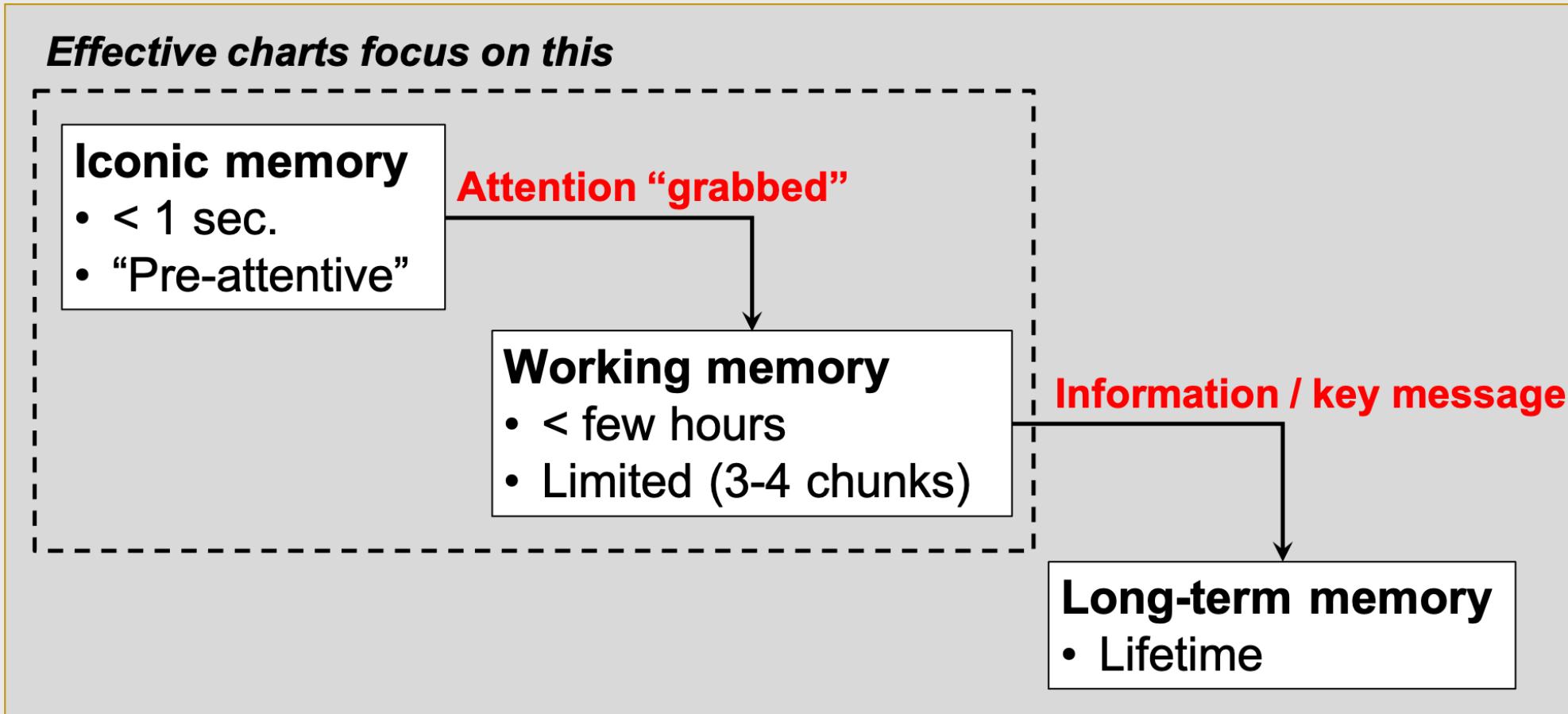
- < 1 sec.
- “Pre-attentive”

Attention “grabbed”

Working memory

- < few hours
- Limited (3-4 chunks)

A (very) simplified model of the visual-memory system



Two objectives of effective charts:

1. Grab & direct attention (iconic memory)
2. Reduce processing demands (working memory)

The power of pre-attentive processing

Count all the "5"s

The power of pre-attentive processing

Count all the "5"s

821134907856412043612
304589640981709812734
123450986124790812734
029860192837401489363
123479827961203459816
234009816256908127634
123459087162342015237
123894789237498230192

The power of pre-attentive processing

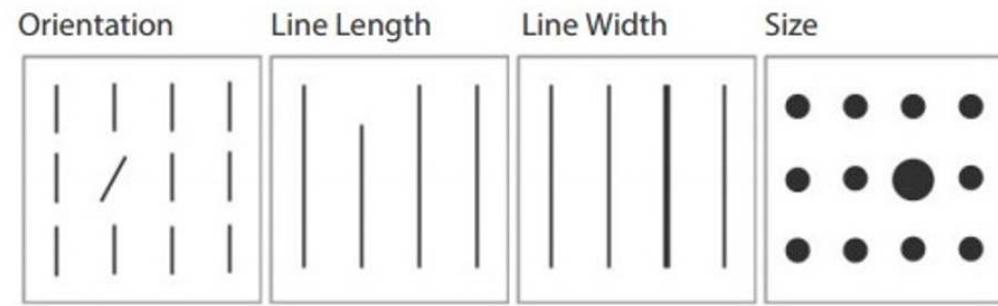
Count all the "5s

The power of pre-attentive processing

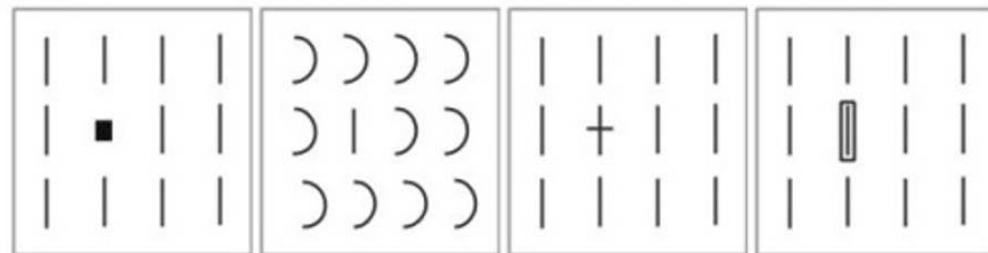
Count all the "5s

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304**5**89640981709812734
1234**5**0986124790812734
029860192837401489363
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1234**5**908716234201**5**237
123894789237498230192

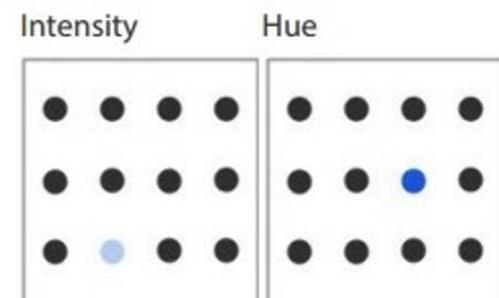
Form



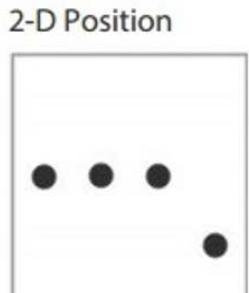
Shape, Curvature, Added Marks, and Enclosure



Color



Spatial Position

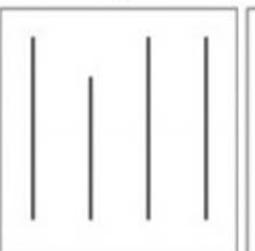


Form

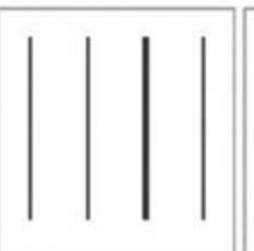
Orientation



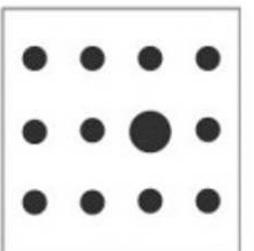
Line Length



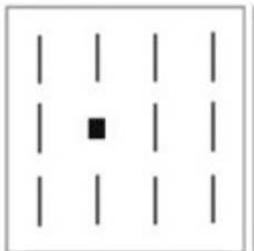
Line Width



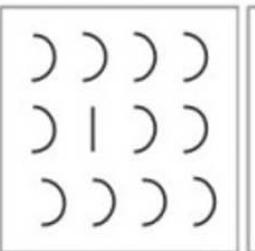
Size



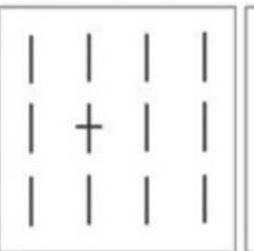
Shape



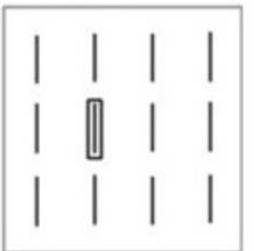
Curvature



Added Marks

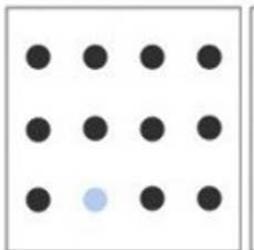


Enclosure

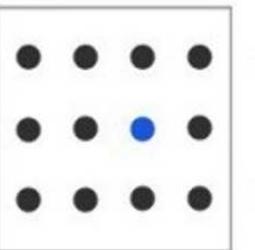


Color

Intensity

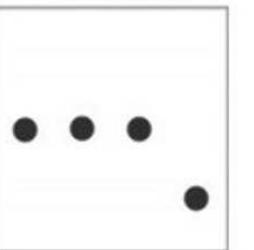


Hue

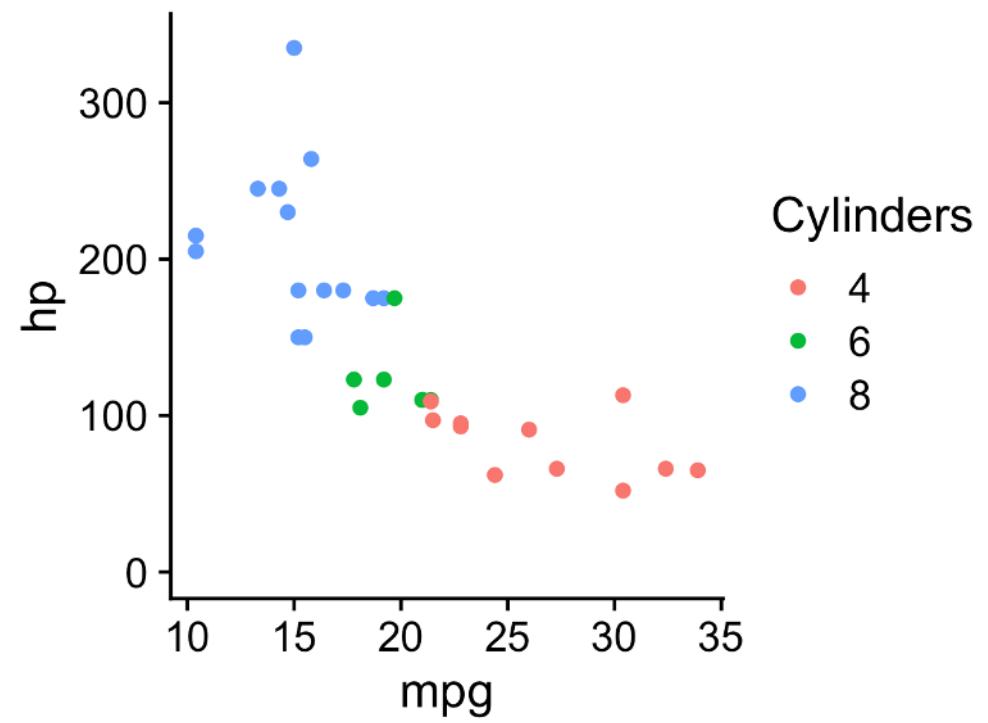


Spatial Position

2-D Position



Pre-attentive attributes

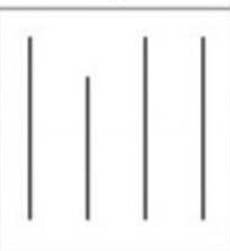


Form

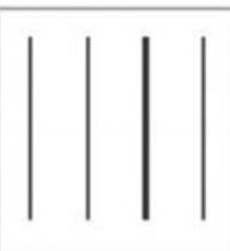
Orientation



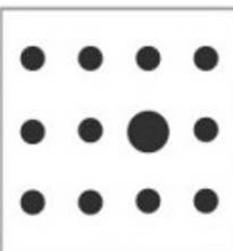
Line Length



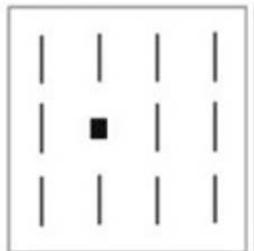
Line Width



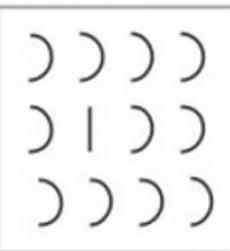
Size



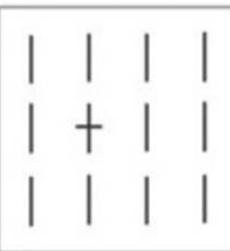
Shape



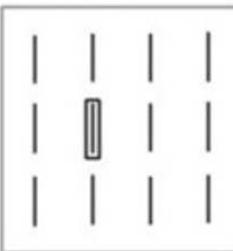
Curvature



Added Marks

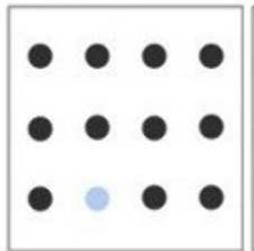


Enclosure

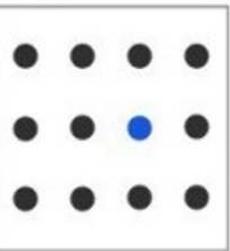


Color

Intensity

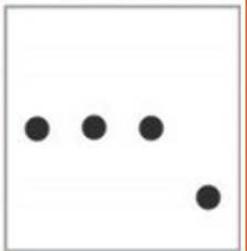


Hue



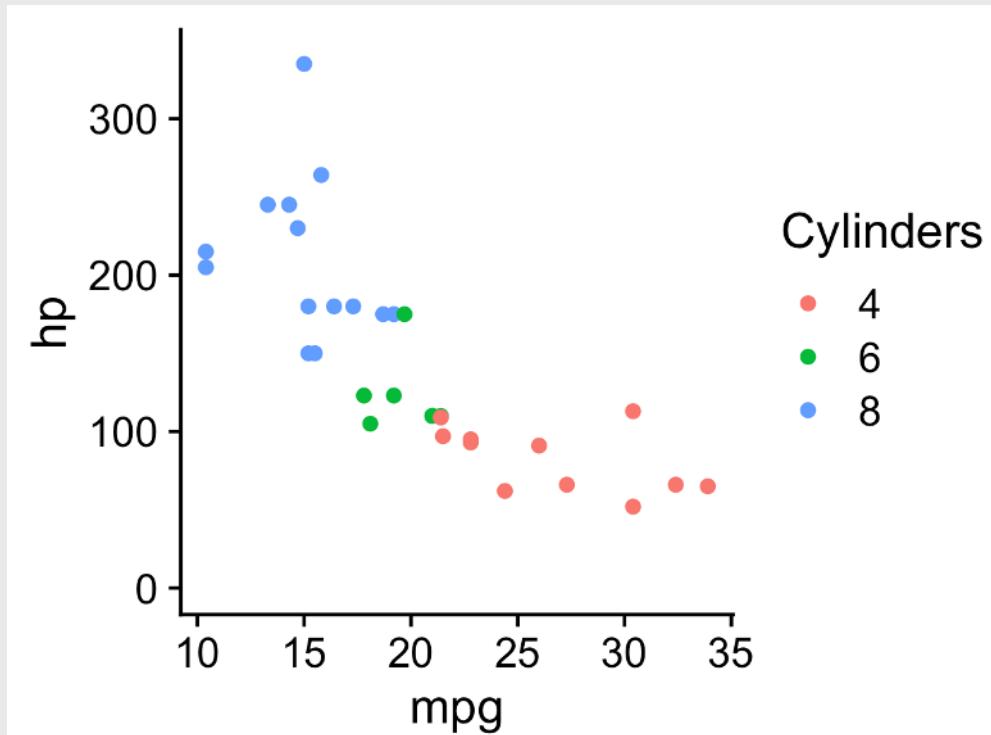
Spatial Position

2-D Position



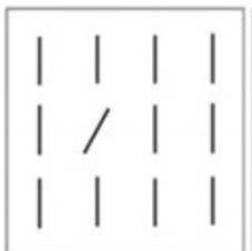
Pre-attentive attributes

Numerical (ratio) data

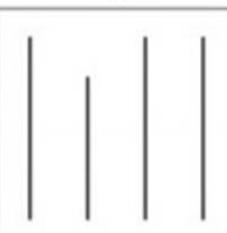


Form

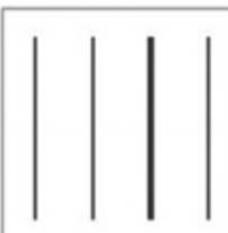
Orientation



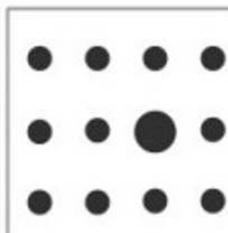
Line Length



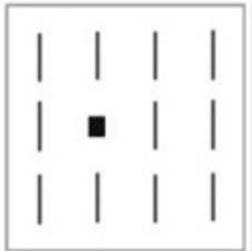
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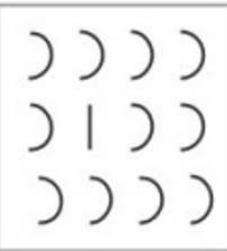
Size



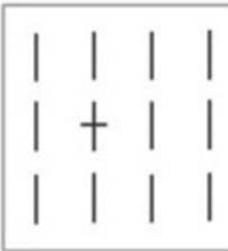
Shape



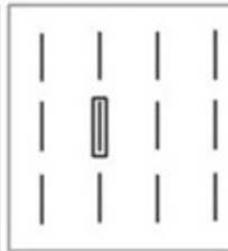
Curvature



Added Marks

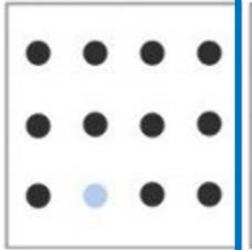


Enclosure

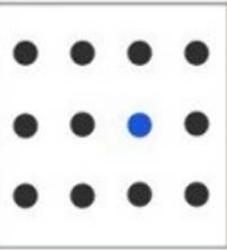


Color

Intensity

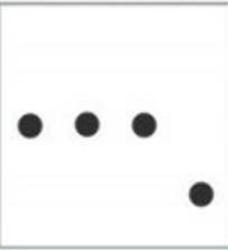


Hue



Spatial Position

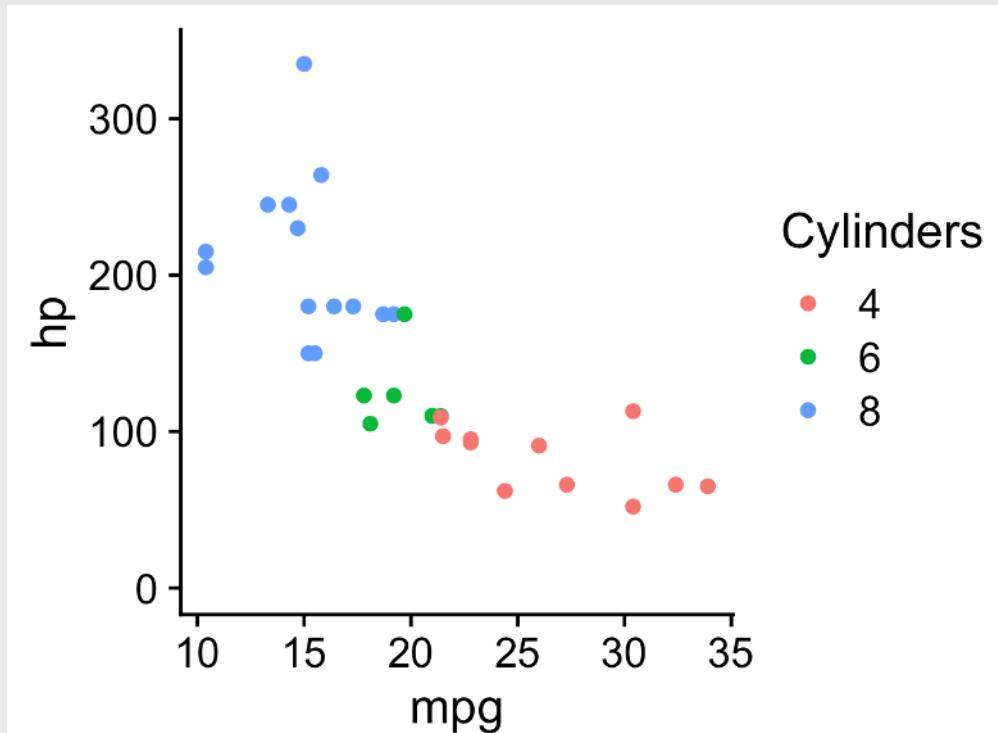
2-D Position



Pre-attentive attributes

Numerical (ratio) data

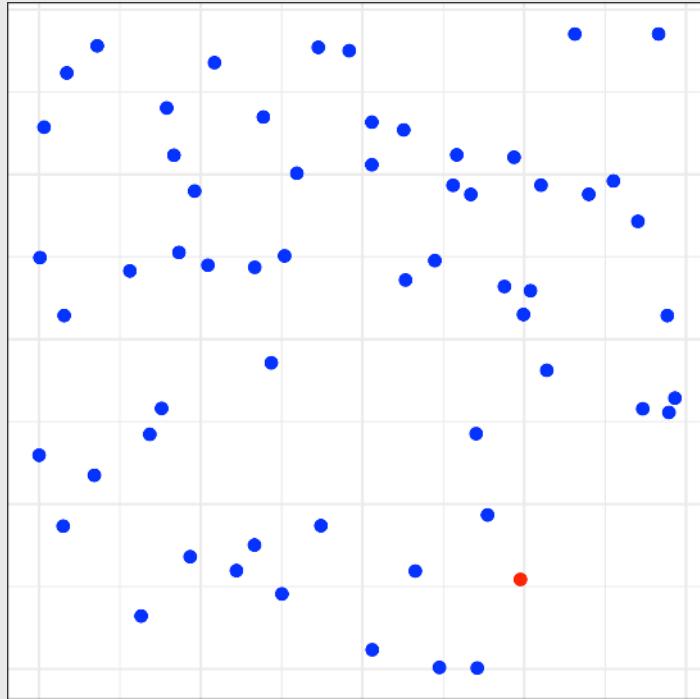
Categorical (ordinal) data



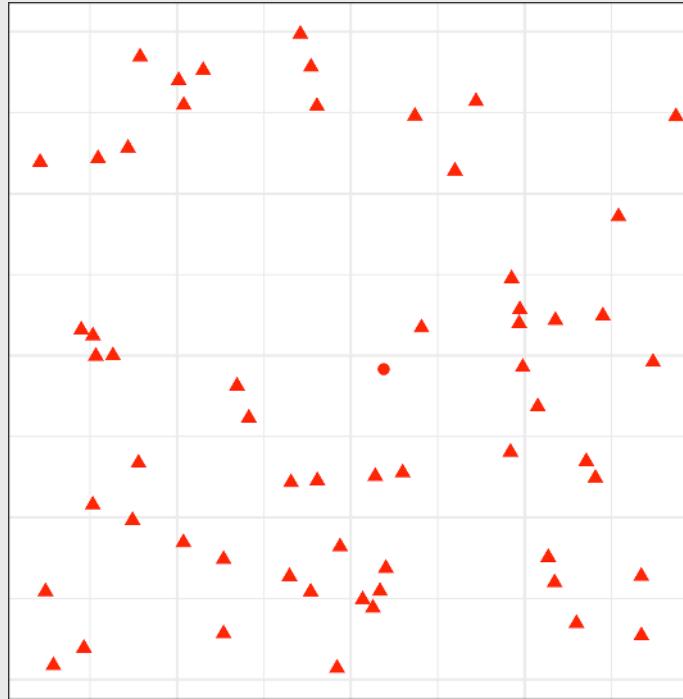
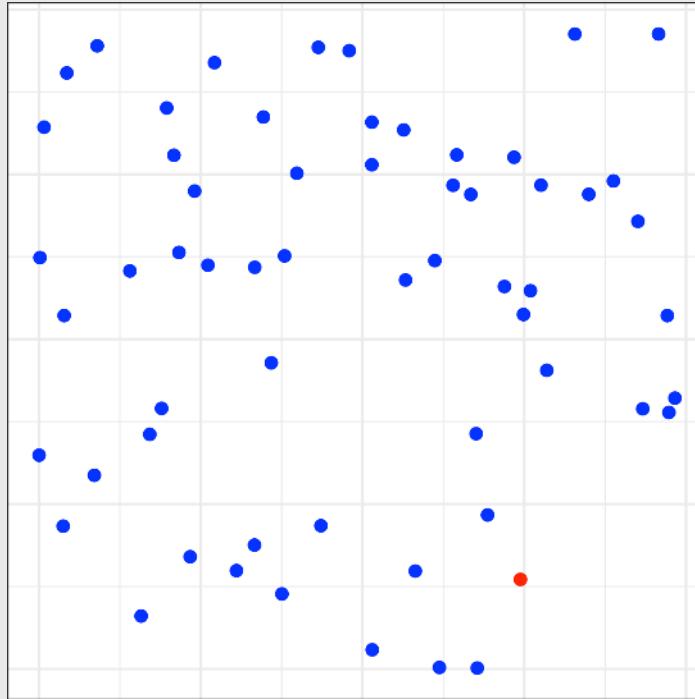
Not all pre-attentive attributes are equal

Where is the red dot?

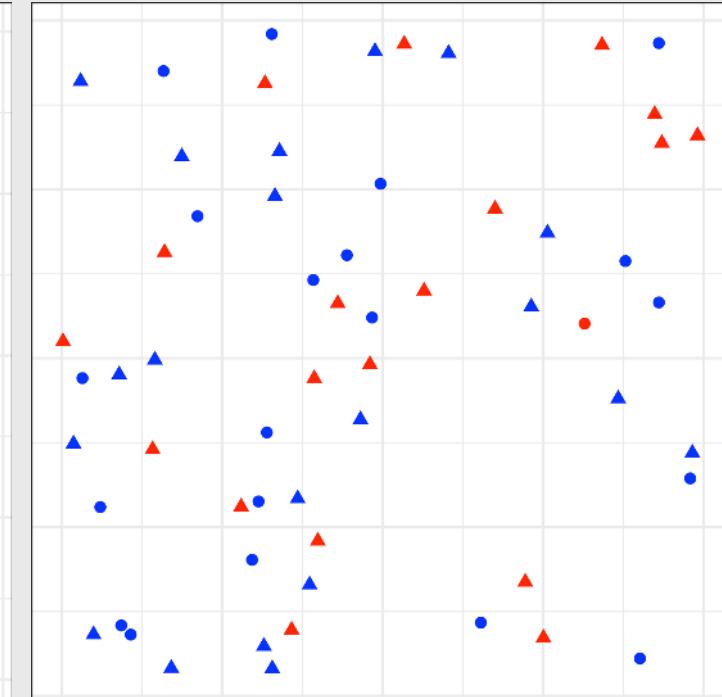
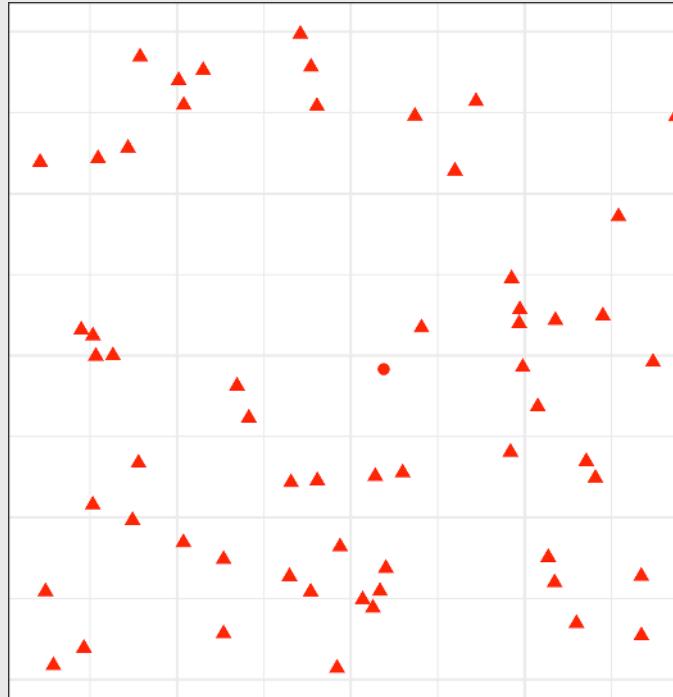
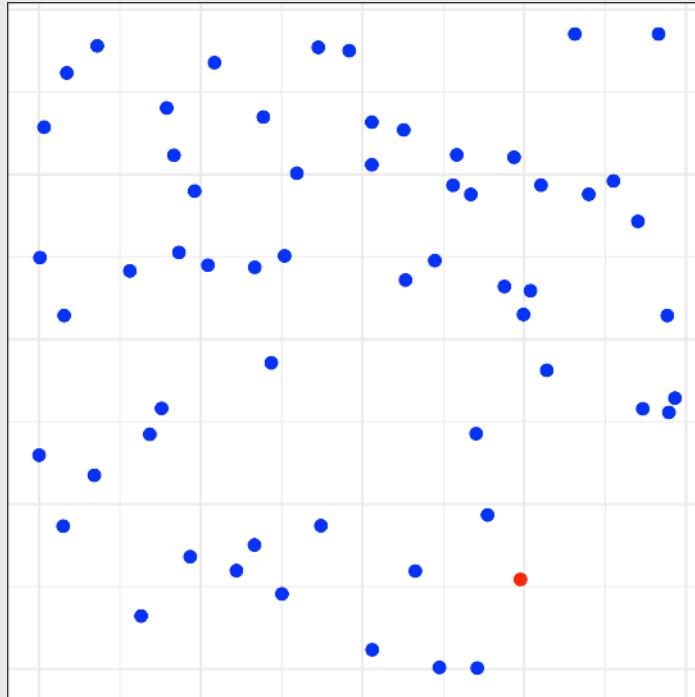
Where is the red dot?



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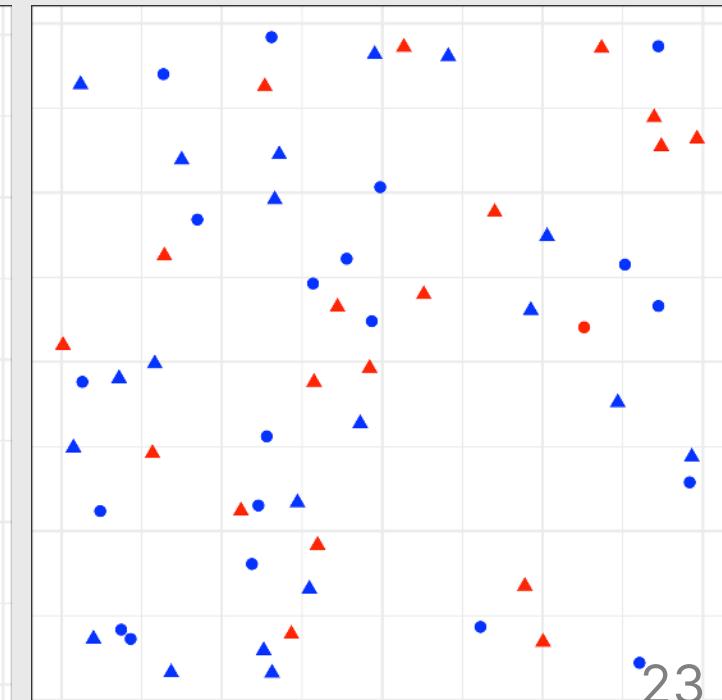
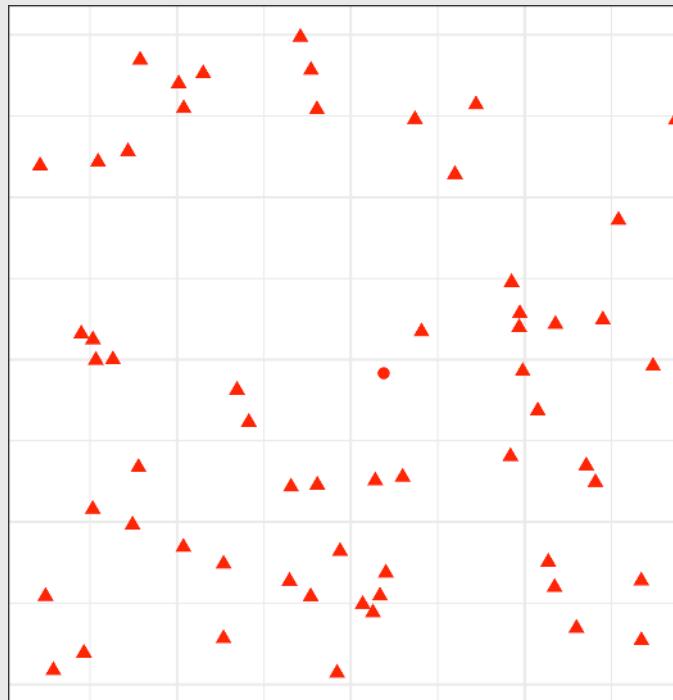
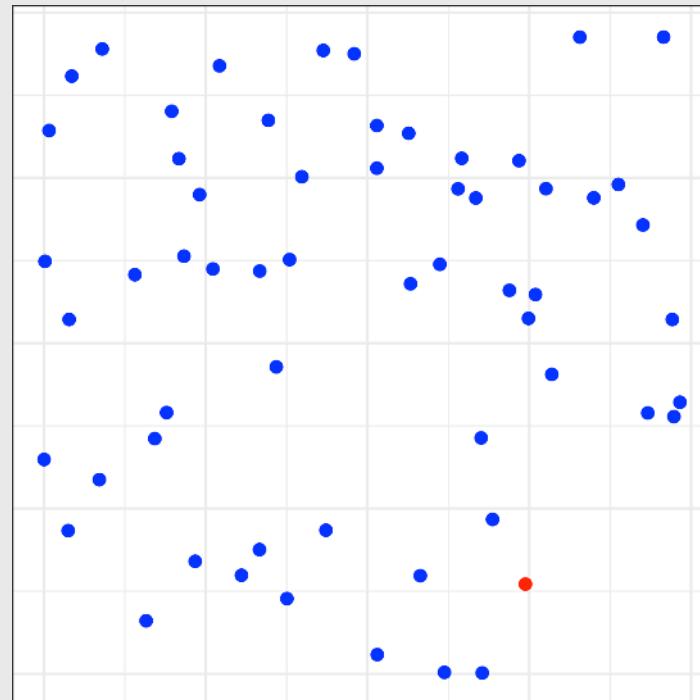


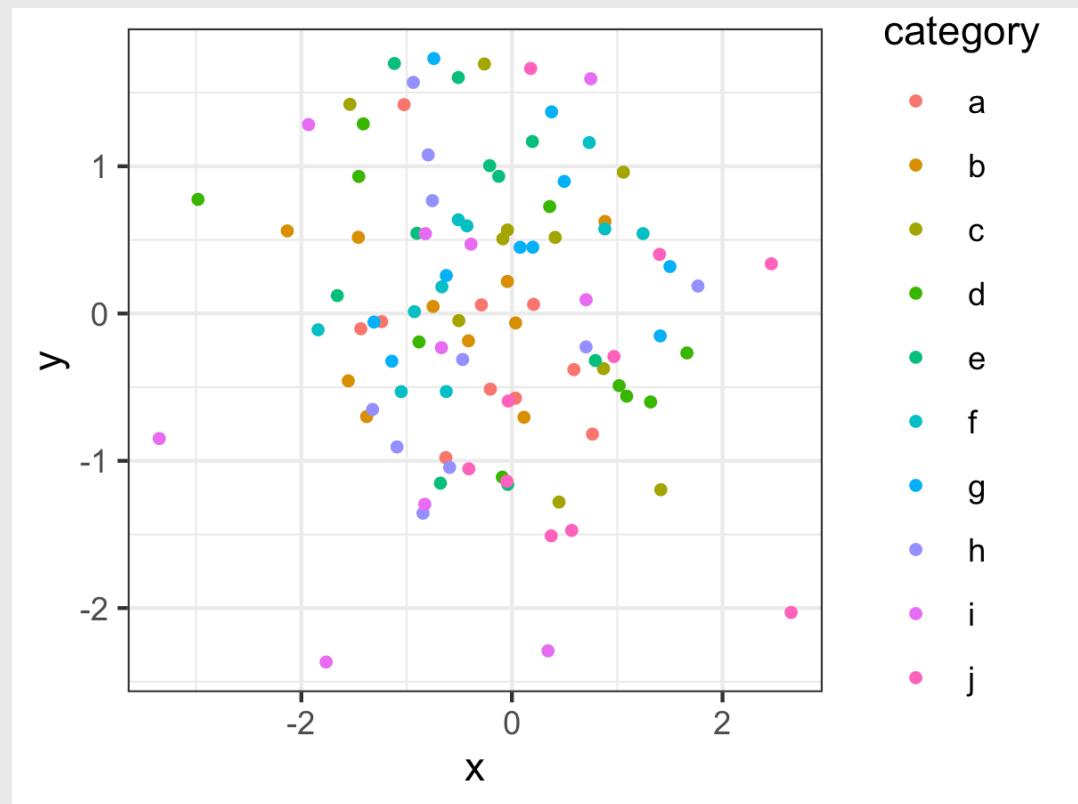
Where is the red dot?

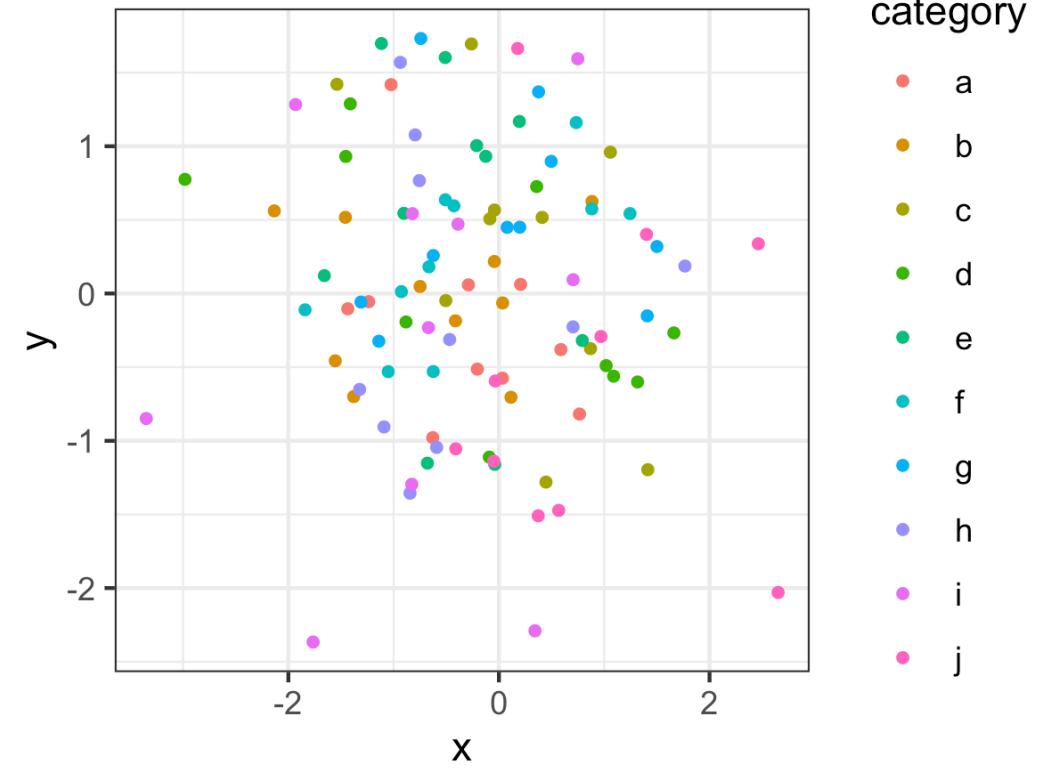


For categorical data:

1. Hue (color) > shape
2. Less is more (stay in working memory!)

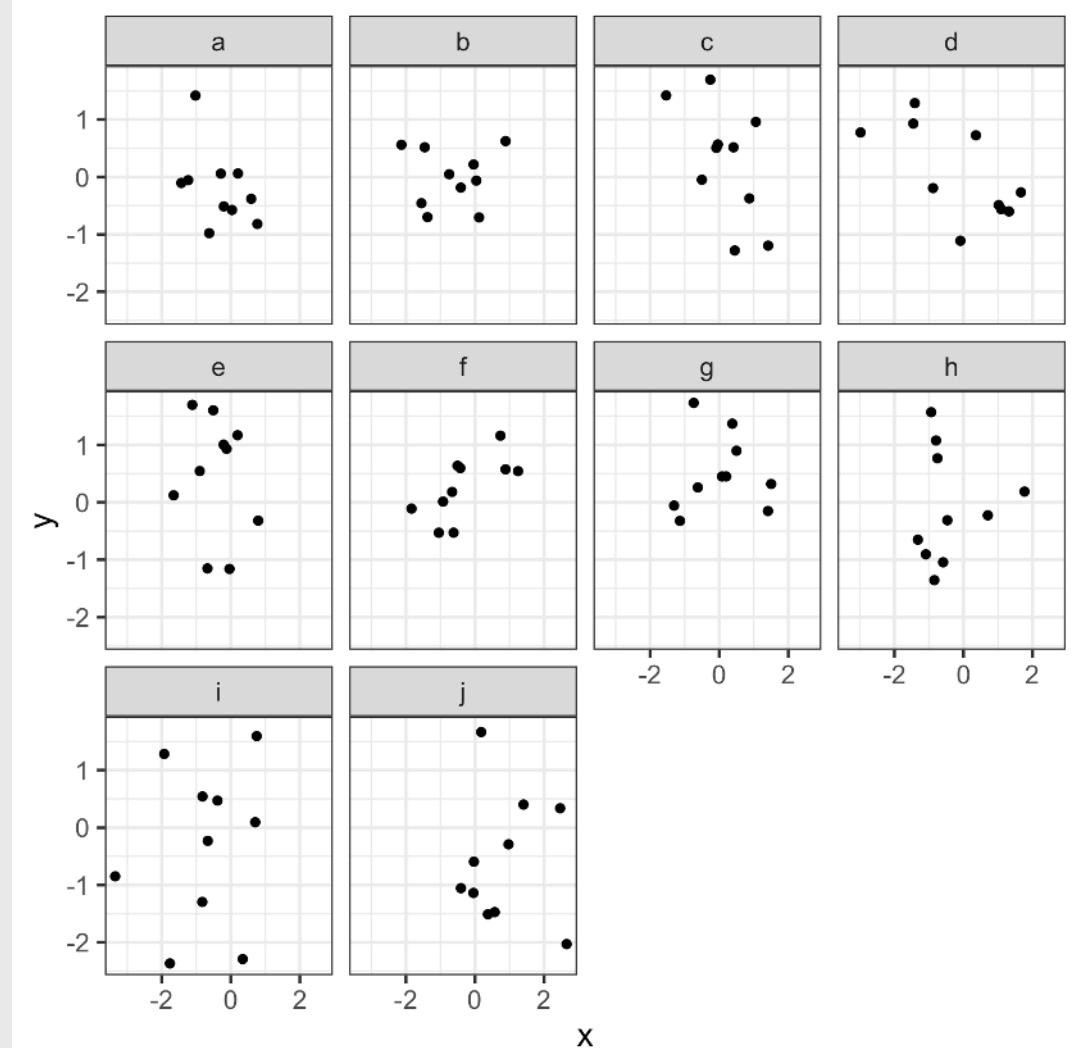


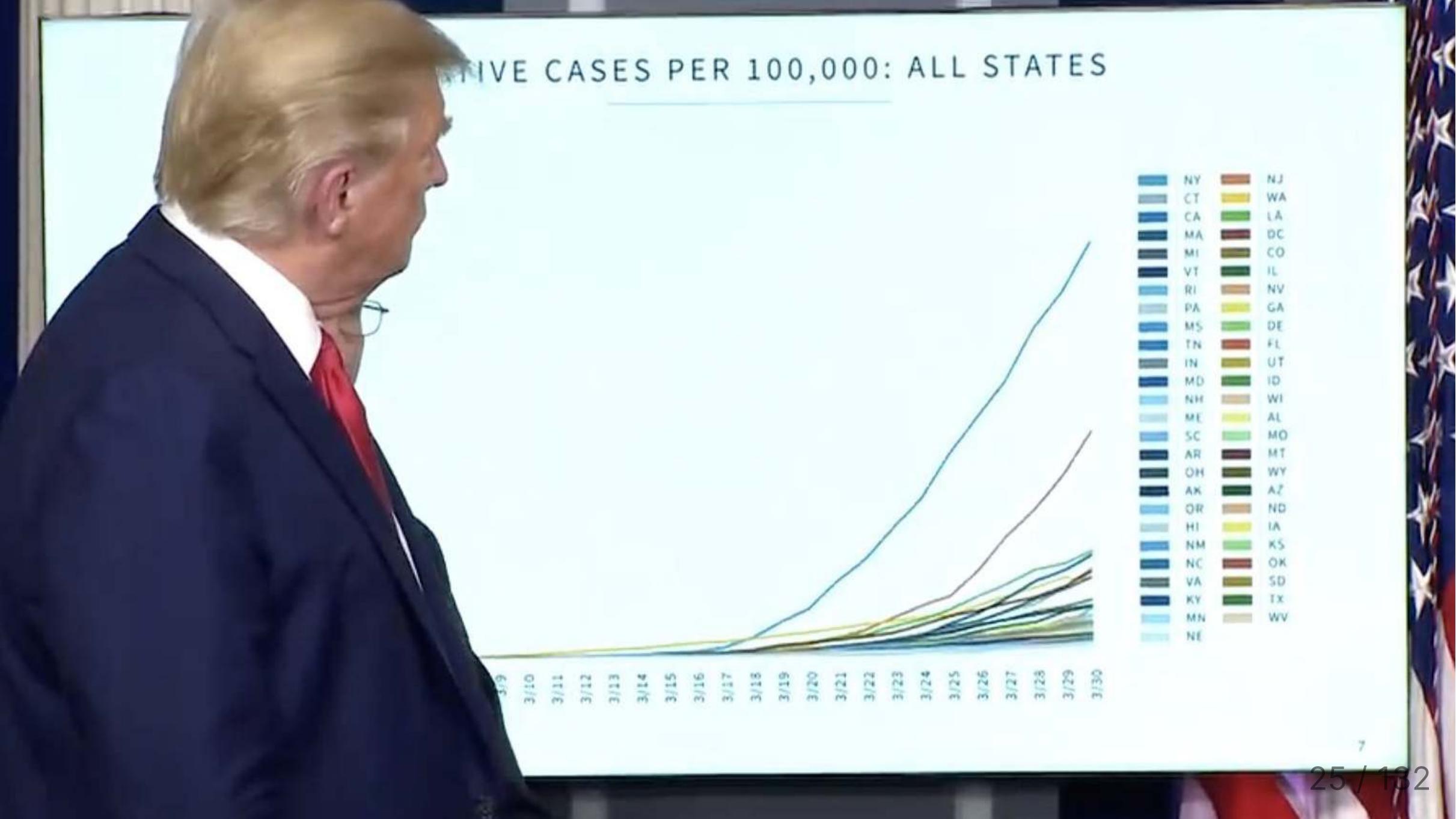




category

- a
- b
- c
- d
- e
- f
- g
- h
- i
- j





What about *quantitative* data?

Graphical Perception and Graphical Methods for Analyzing Scientific Data

William S. Cleveland and Robert McGill

Graphs provide powerful tools both for analyzing scientific data and for communicating quantitative information. The computer graphics revolution, which began in the 1960's and has intensified during the past several years, stimulated the invention of graphical meth-

mation from graphs; theory and experimental data are then used to order the tasks on the basis of accuracy. The ordering has an important application: data should be encoded so that the visual decoding involves tasks as high in the ordering as possible, that is, tasks per-

Summary. Graphical perception is the visual decoding of the quantitative and qualitative information encoded on graphs. Recent investigations have uncovered basic principles of human graphical perception that have important implications for the display of data. The computer graphics revolution has stimulated the invention of many graphical methods for analyzing and presenting scientific data, such as box plots, two-tiered error bars, scatterplot smoothing, dot charts, and graphing on a log base 2 scale.

ods: types of graphs and types of quantitative information to be shown on graphs (1-4). One purpose of this article is to describe and illustrate several of these new methods.

What has been missing, until recently, in this period of rapid graphical invention and deployment is the study of graphs and the human visual system. When a graph is constructed, quantitative and categorical information is encoded, chiefly through position, shape, size, symbols, and color. When a person looks at a graph, the information is visually decoded by the person's visual sys-

tem with greater accuracy. This is illustrated by several examples in which some much-used graphical forms are presented, set aside, and replaced by new methods.

Elementary Tasks for the Graphical Perception of Quantitative Information

The first step is to identify elementary graphical-perception tasks that are used to visually extract quantitative information from a graph. (By "quantitative information" we mean numerical values

al field that comes without apparent mental effort. We also perform cognitive tasks such as reading scale information, but much of the power of graphs—and what distinguishes them from tables—comes from the ability of our preattentive visual system to detect geometric patterns and assess magnitudes. We have examined preattentive processes rather than cognition.

We have studied the elementary graphical-perception tasks theoretically, borrowing ideas from the more general field of visual perception (7, 8), and experimentally by having subjects judge graphical elements (1, 5). The next two sections illustrate the methodology with a few examples.

Study of Graphical Perception: Theory

Figure 2 provides an illustration of theoretical reasoning that borrows some ideas from the field of computational vision (8). Suppose that the goal is to judge the ratio, r , of the slope of line segment BC to the slope of line segment AB in each of the three panels. Our visual system tells us that r is greater than 1 in each panel, which is correct. Our visual system also tells us that r is closer to 1 in the two rectangular panels than in the square panel; that is, the slope of BC appears closer to the slope of AB in the two rectangular panels than in the square panel. This, however, is incorrect; r is the same in all three panels.

The reason for the distortion in judging Fig. 2 is that our visual system is geared to judging angle rather than slope. In their work on computational theories of vision in artificial intelligence, Marr (8) and Stevens (9) have investigated how people judge the slant and tilt (10) of the surfaces of three-dimensional objects. They argue that we judge slant and tilt as

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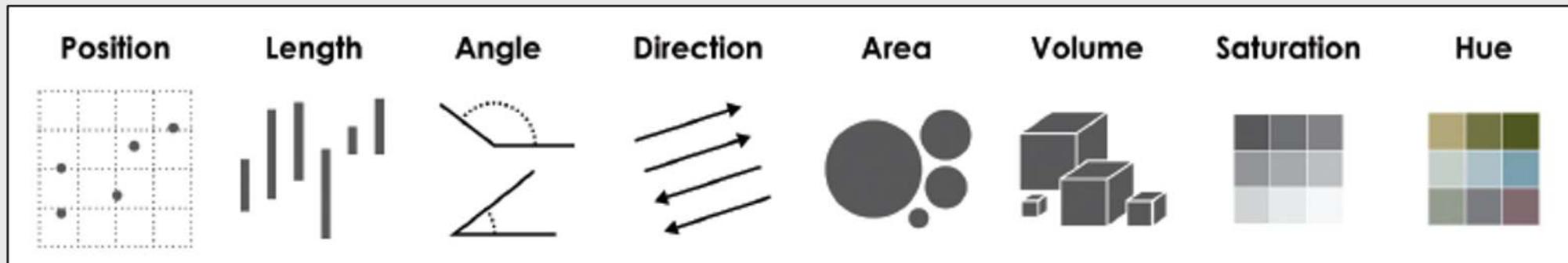
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Cleveland, W. S., & McGill, R. (1985). Graphical perception and graphical methods for analyzing scientific data. *Science, New Series*, 229(4716), 828-833.

Hierarchy for *numerical* data



More Accurate

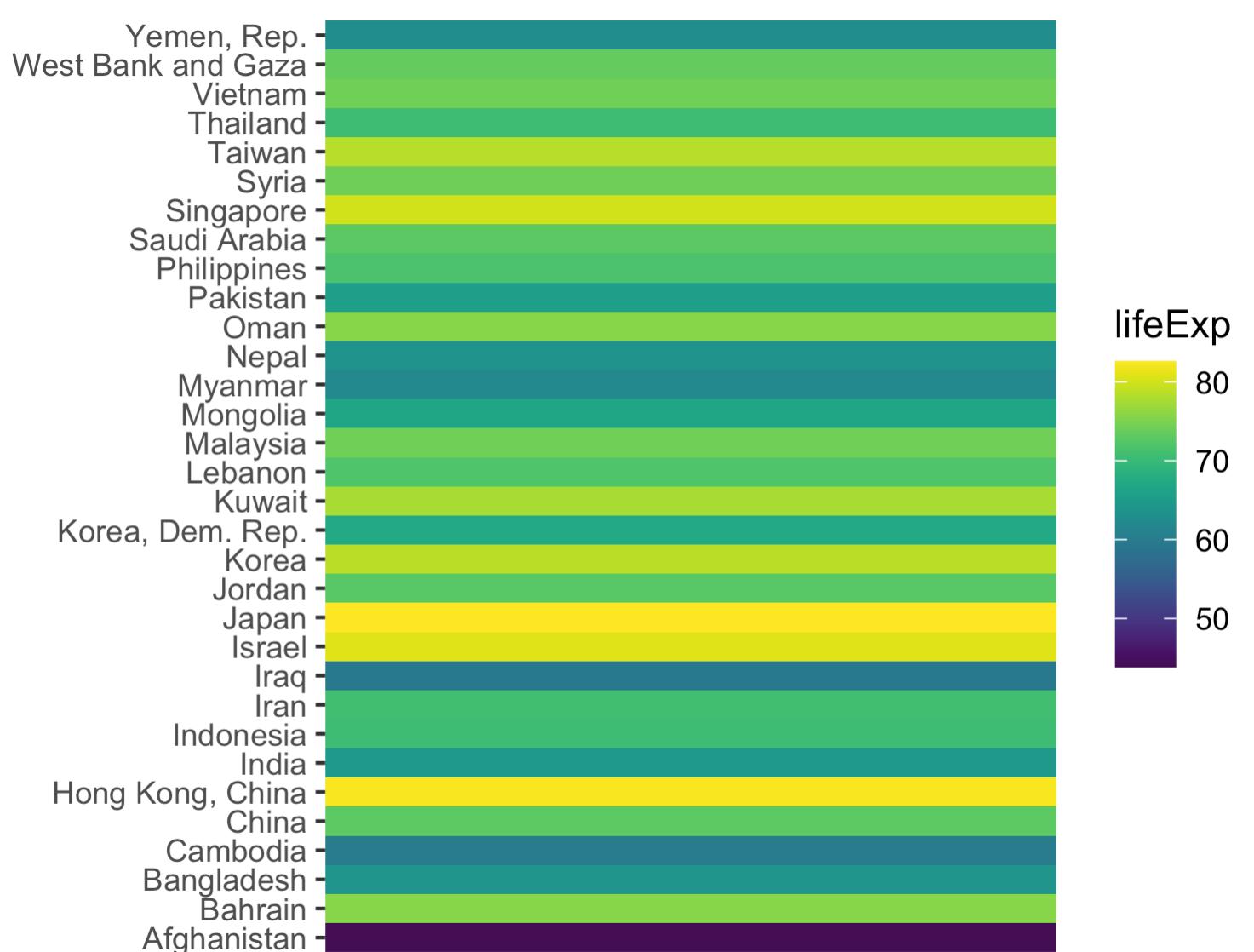
Less Accurate

Example: Life expectancy in countries in Asia

```
#>   country lifeExp  
#> 1      1 43.828  
#> 2      62 59.545  
#> 3      19 59.723  
#> 4      88 62.069  
#> 5     140 62.698  
#> 6      90 63.785  
#> 7      9 64.062  
#> 8      59 64.698  
#> 9      98 65.483  
#> 10     84 66.803  
#> 11     70 67.297  
#> 12     128 70.616  
#> 13     60 70.650  
#> 14     61 70.964  
#> 15     102 71.688  
#> 16     73 71.993  
#> 17     68 72.535  
#> 18     110 72.777  
#> 19      25 72.961  
#> 20     139 73.422
```

1. Position on a common scale
2. Position on non-aligned scales
3. Length
4. Angle
5. Area
6. Color saturation
7. **Color hue**

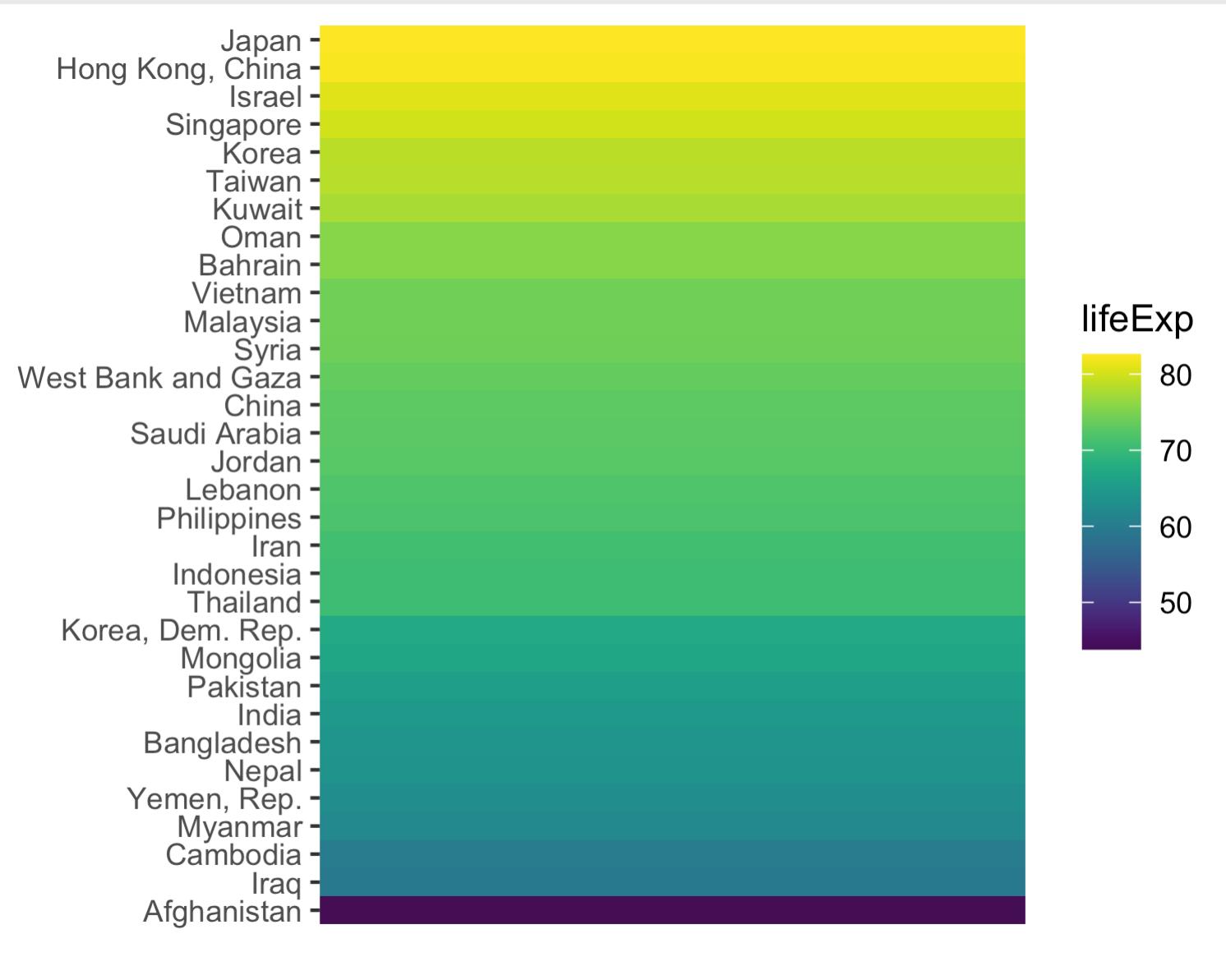
- **✗ Discriminate**
- **✗ Rank**
- **✗ Ratio**



1. Position on a common scale
2. Position on non-aligned scales
3. Length
4. Angle
5. Area
6. Color saturation
7. **Color hue**

Sorting helps a bit...

- ✗ **Discriminate**
- ✓ **Rank**
- ✗ **Ratio**



1. Position on a common scale
2. Position on non-aligned scales
3. **Length**
4. Angle
5. Area
6. Color saturation
7. Color hue

- / **Discriminate**
- / **Rank**
- **Ratio**



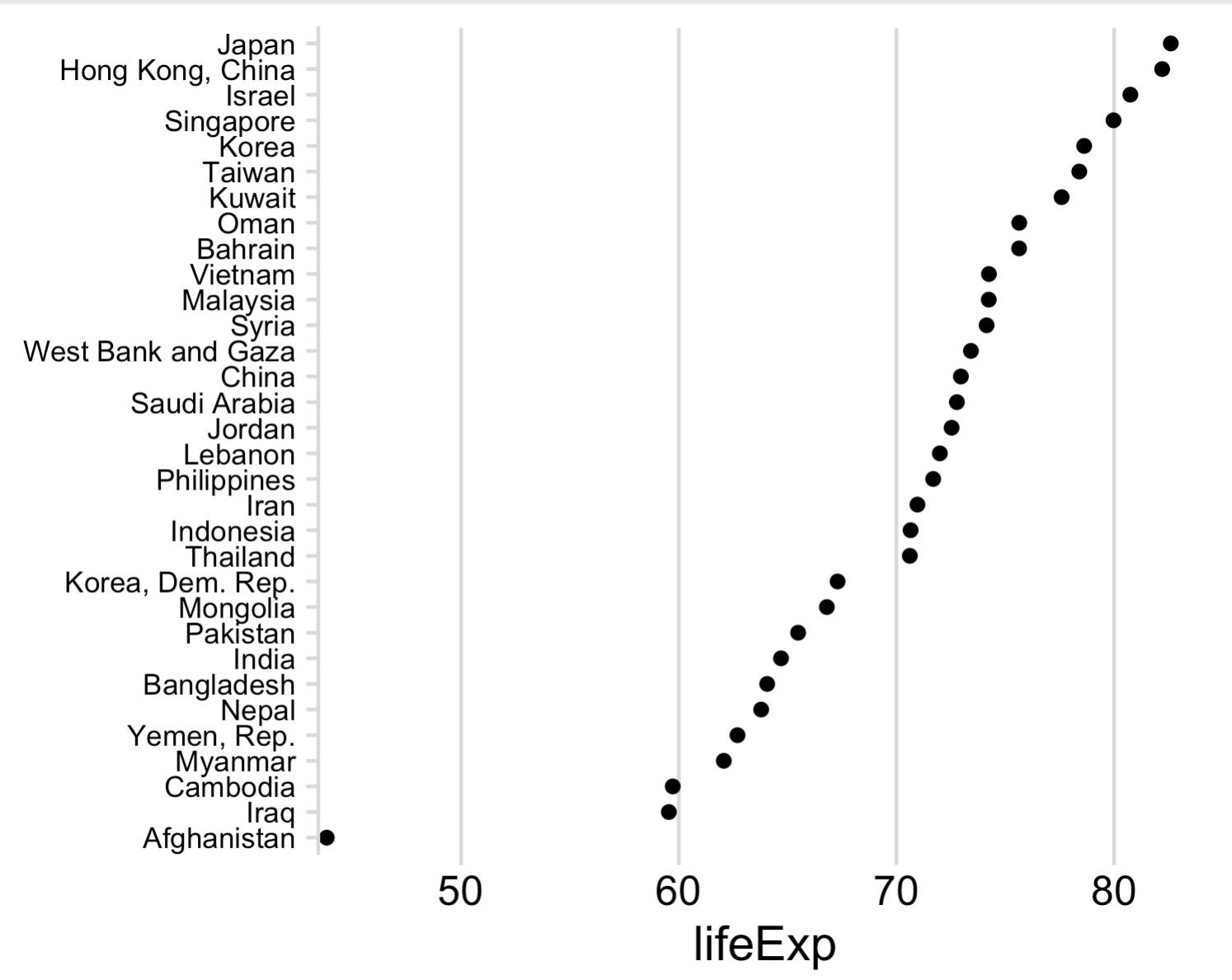
1. Position on a common scale
2. **Position on non-aligned scales**
3. Length
4. Angle
5. Area
6. Color saturation
7. Color hue

- / **Discriminate**
- / **Rank**
- **Ratio**



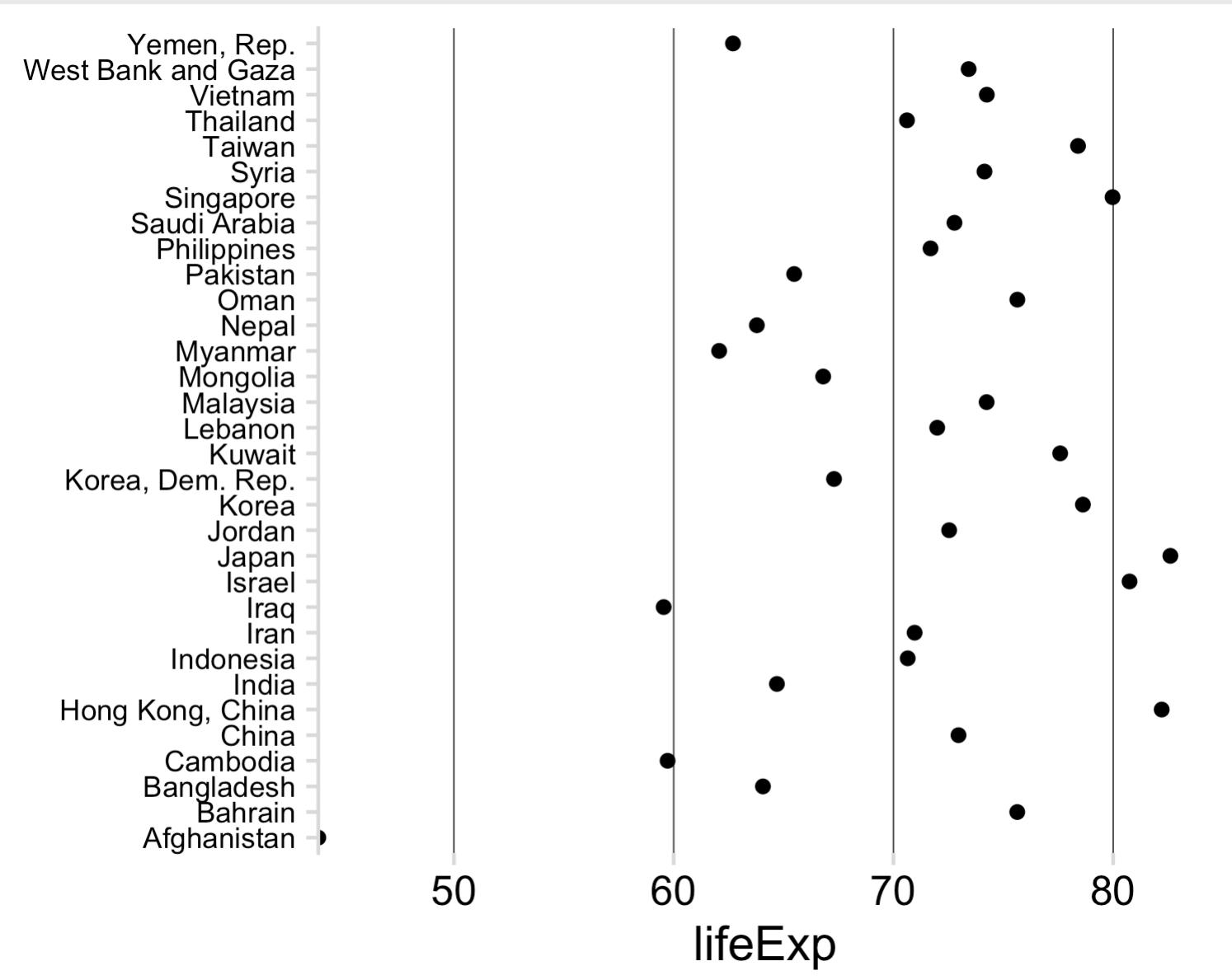
1. Position on a common scale
2. Position on non-aligned scales
3. Length
4. Angle
5. Area
6. Color saturation
7. Color hue

- **Discriminate**
- **Rank**
- **Ratio**



1. Position on a common scale
2. Position on non-aligned scales
3. Length
4. Angle
5. Area
6. Color saturation
7. Color hue

Sorting still matters!



Gestalt Psychology

The whole has a reality that is entirely separate from the parts



WWF

Reification

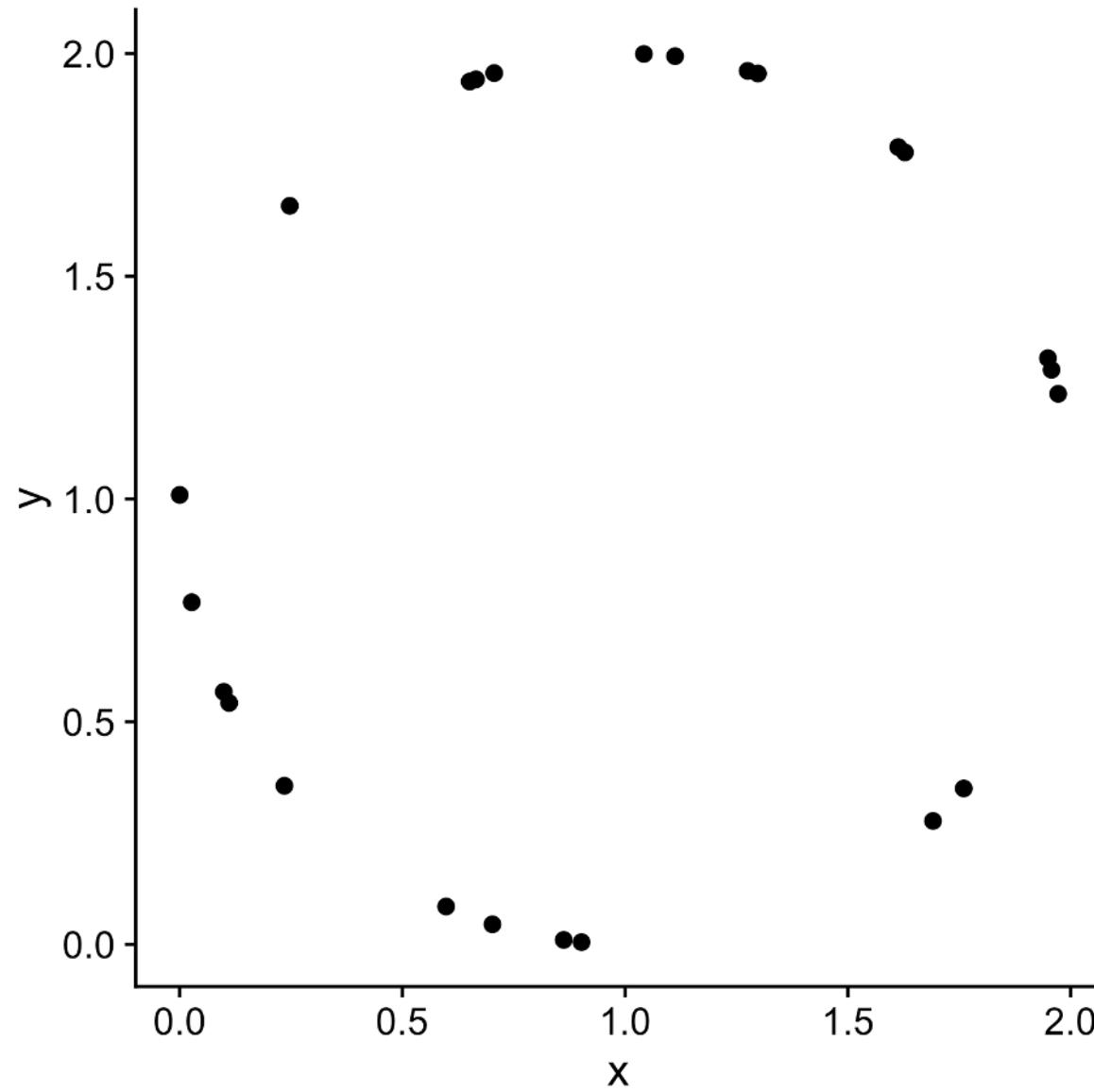


Emergence



Law of Closure

Our minds fill in
the missing
information



Prägnanz

We strongly prefer to interpret stimuli as regular, simple, and orderly

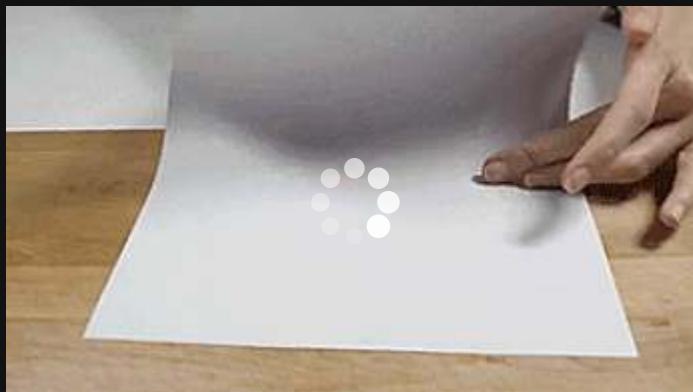
Prägnanz

We strongly prefer to interpret stimuli as regular, simple, and orderly



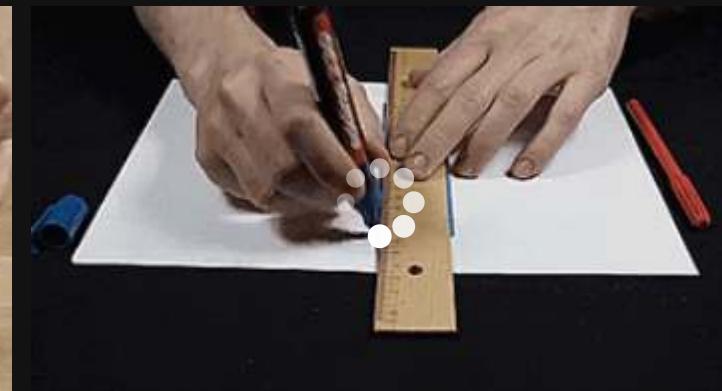
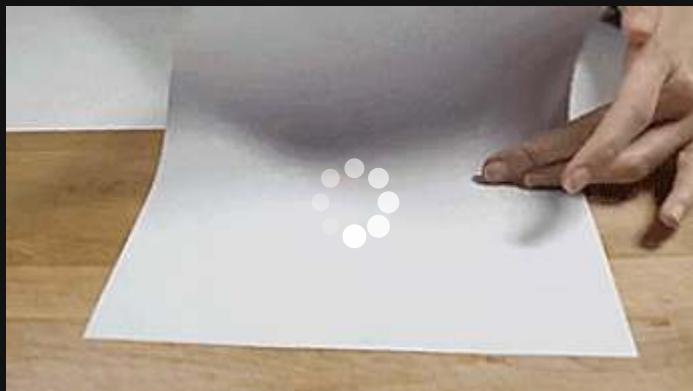
Prägnanz

We strongly prefer to interpret stimuli as regular, simple, and orderly



Prägnanz

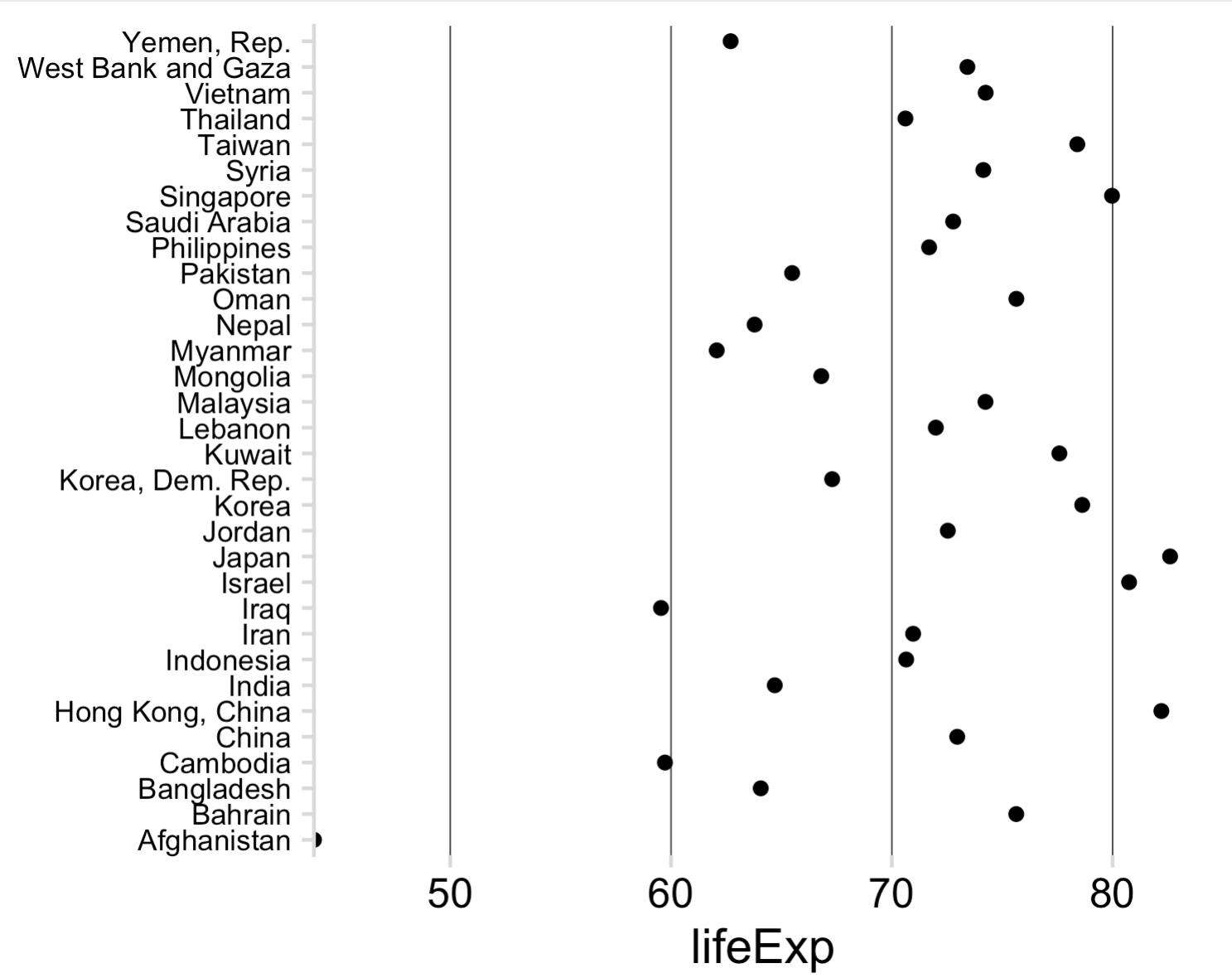
We strongly prefer to interpret stimuli as regular, simple, and orderly



Prägnanz

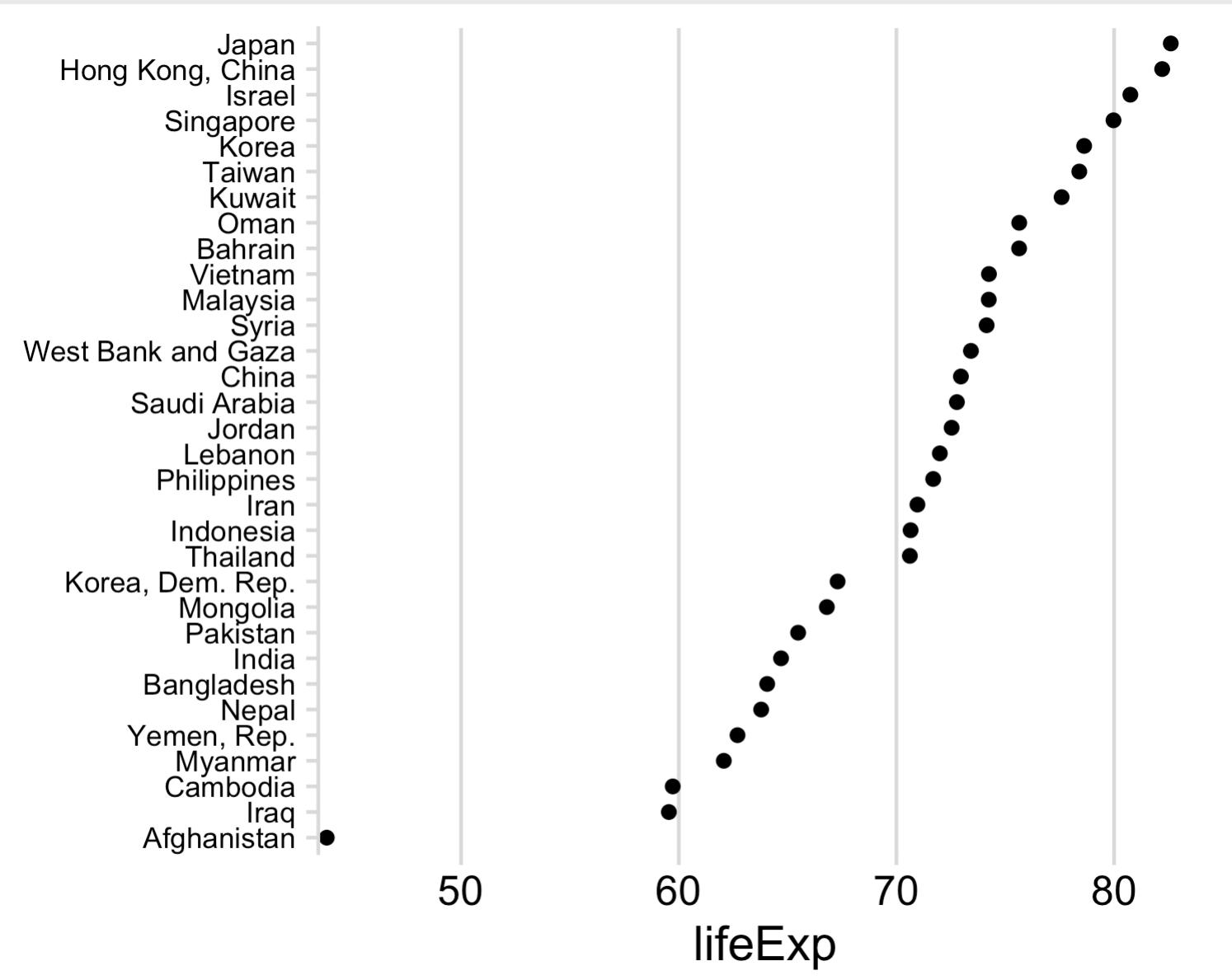
This should cause
you cognitive pain

It's the graphical
equivalent of this:



Prägnanz

This makes our brains happy 😊



Visualizing Information

1. The Psychology of Data Viz

2. 5 Data Viz Don'ts

BREAK

3. 5 Data Viz Do's

5 Data Viz Don'ts

1. Don't use chart chunk
2. Don't make 3D plots
3. Don't use pattern fills
4. Don't use red & green together
5. Don't lie

5 Data Viz Don'ts

1. Don't use chart chunk
2. Don't make 3D plots
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4. Don't use red & green together
5. Don't lie

"Erase non-data ink."

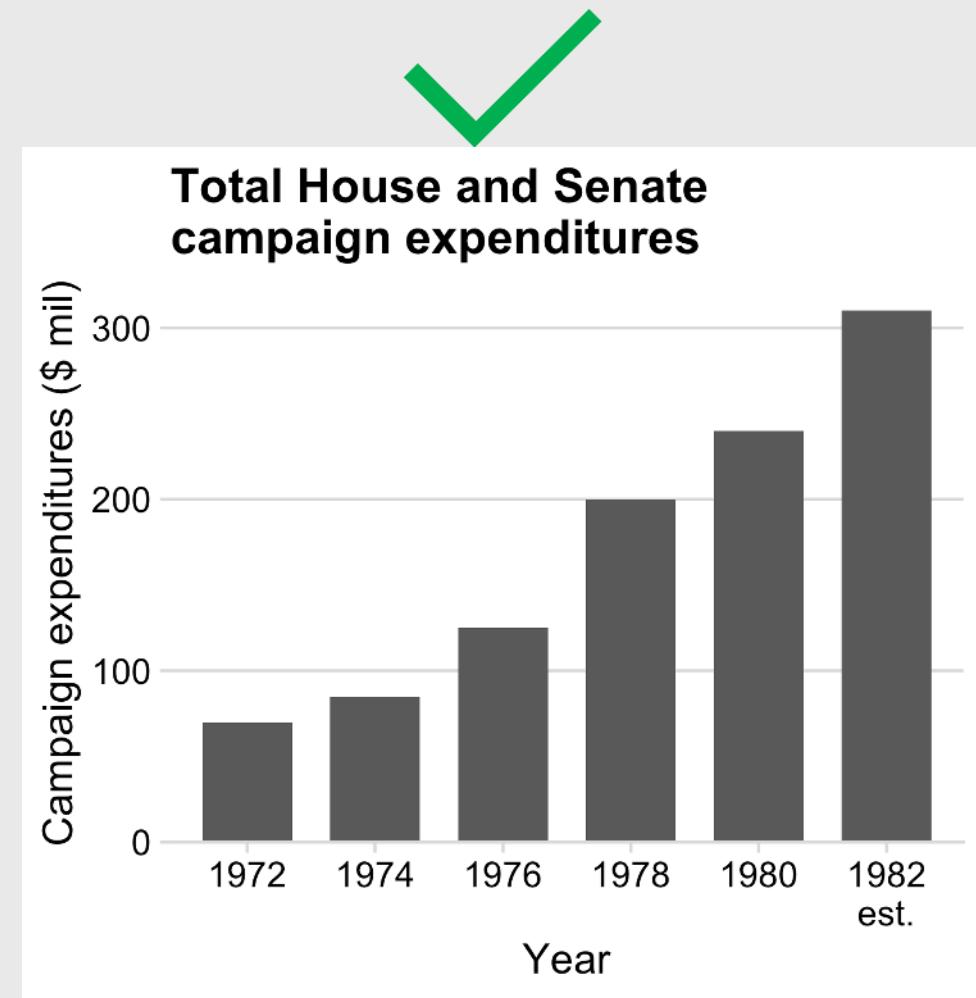
— Ed Tufte



Figure 1.6: 'Monstrous Costs' by Nigel Holmes, in Healy, 2018



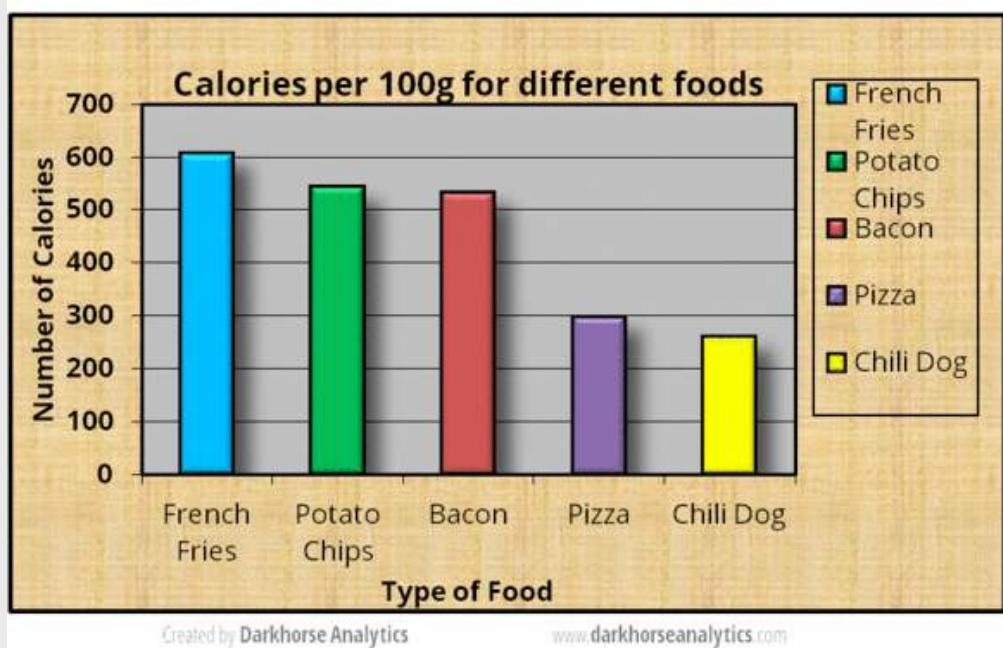
Figure 1.6: 'Monstrous Costs' by Nigel Holmes, in Healy, 2018



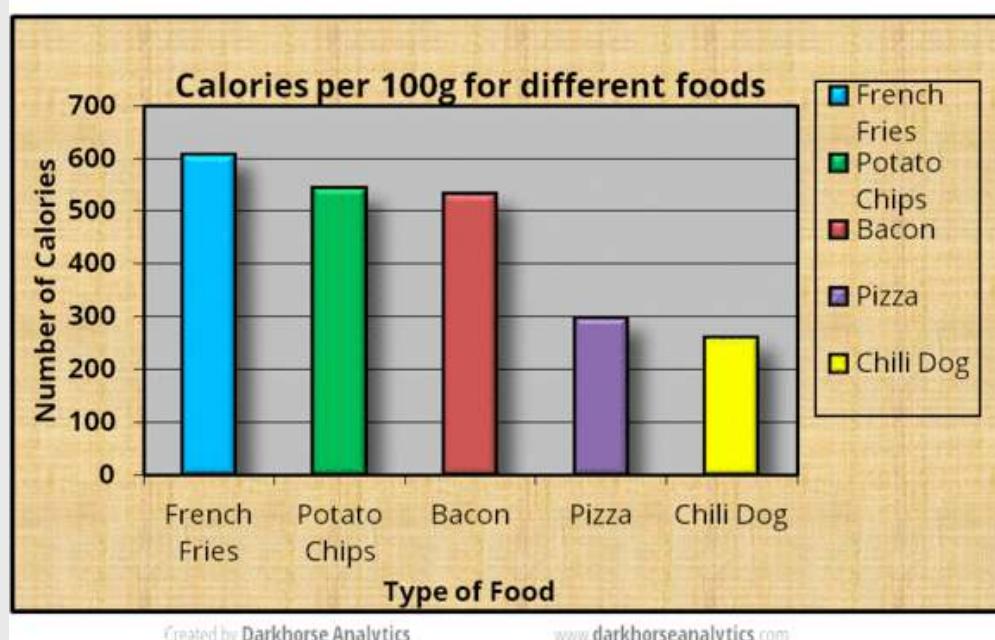
Remove
to improve
(the **data-ink** ratio)



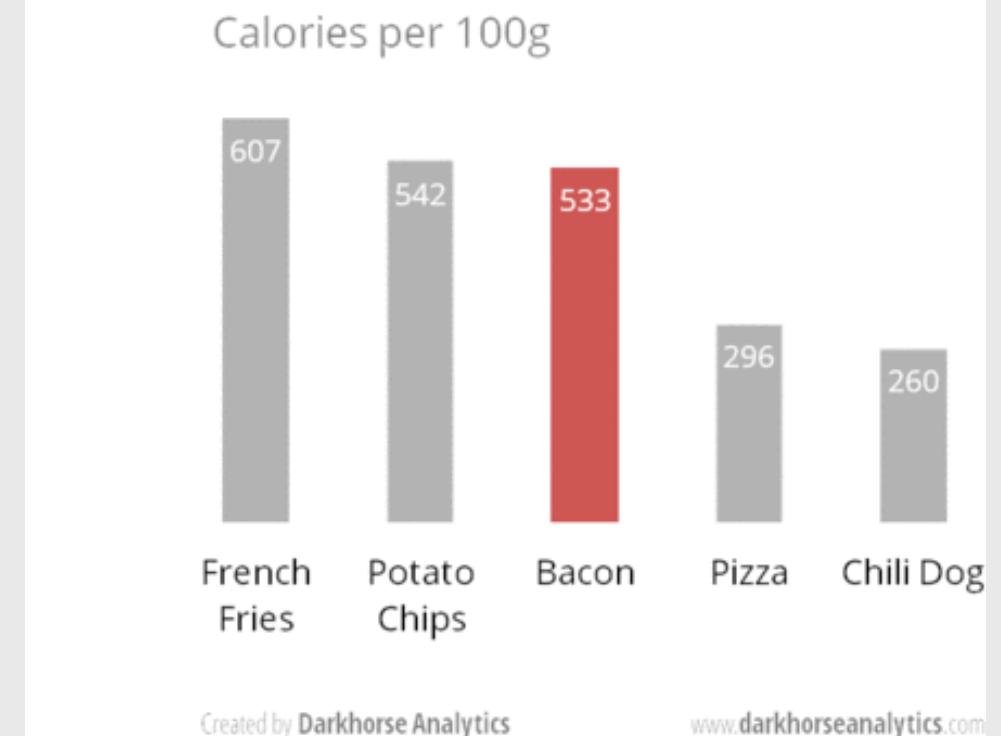
Before



Before



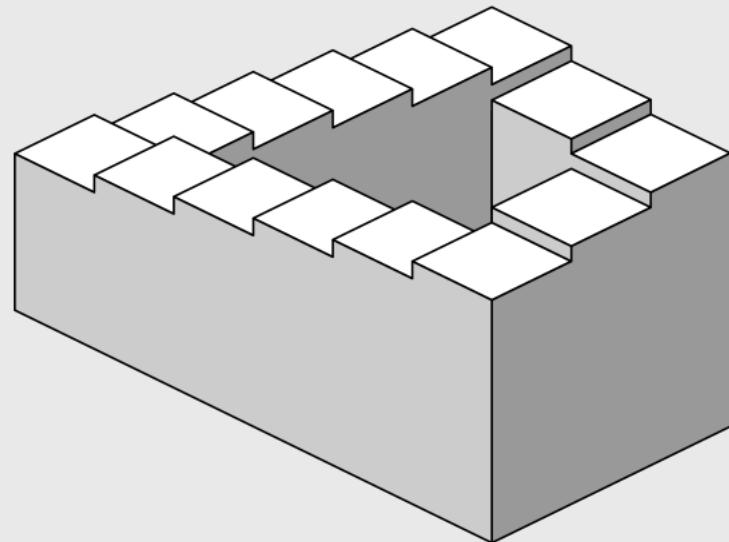
After



5 Data Viz Don'ts

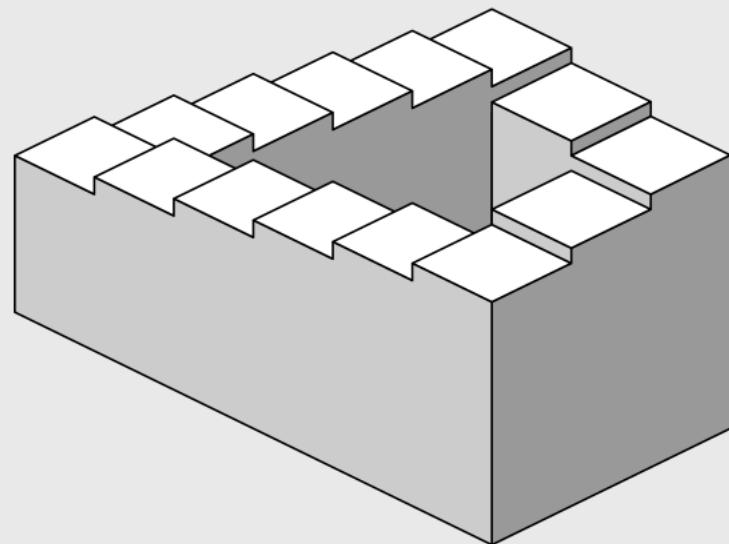
1. Don't use chart chunk
2. **Don't make 3D plots**
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5. Don't lie

Humans aren't good at
distinguishing 3D space



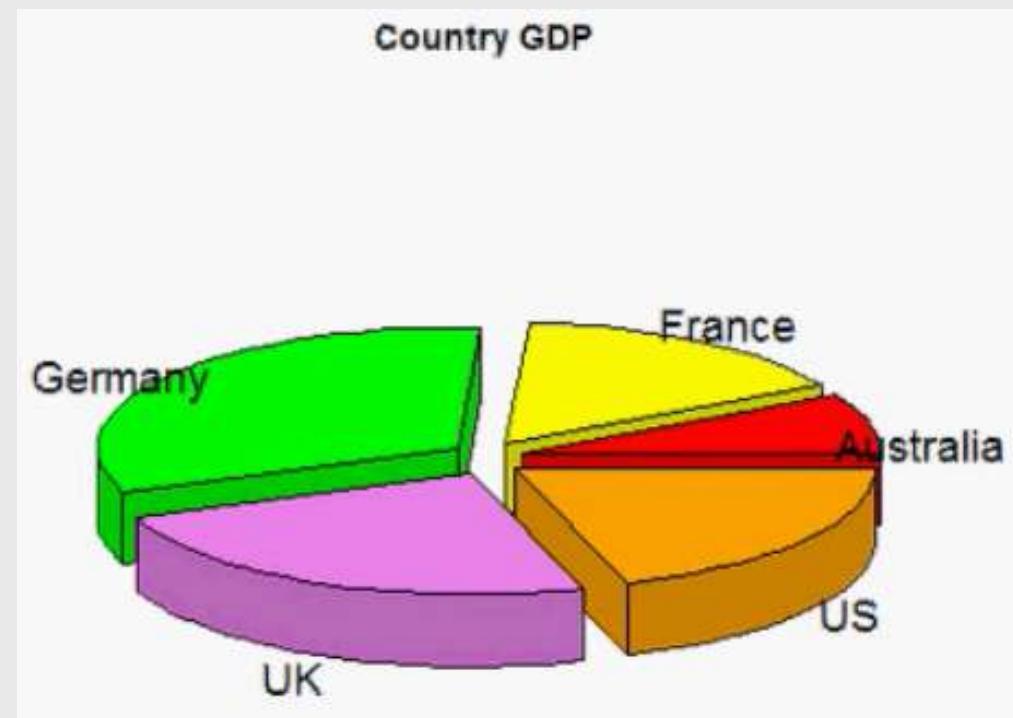
Penrose Stairs, made famous by
M.C. Escher (1898-1972)

Humans aren't good at distinguishing 3D space

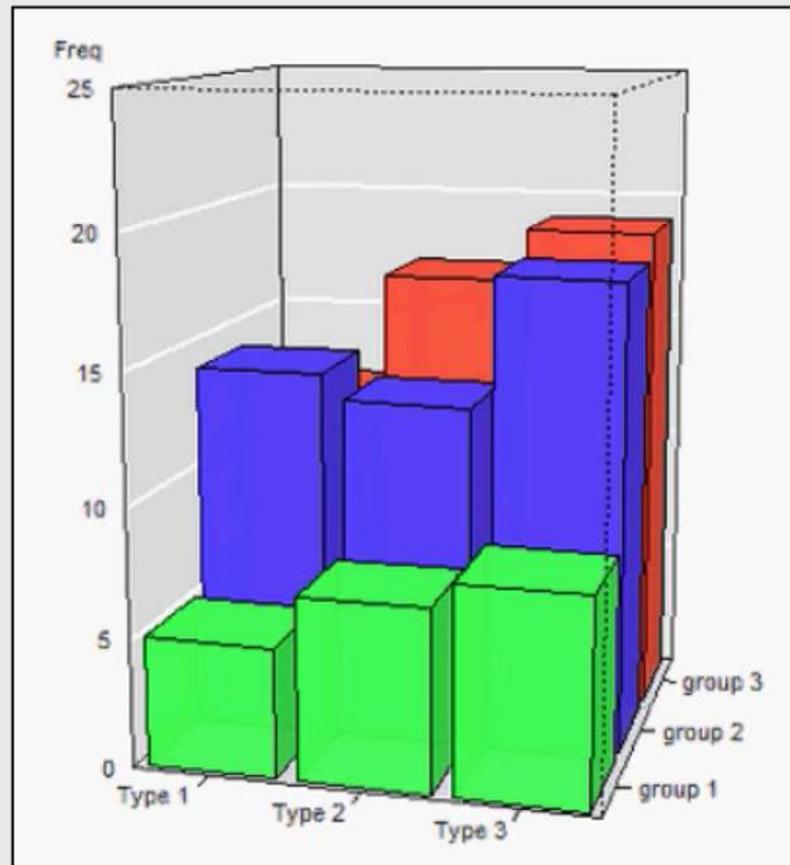


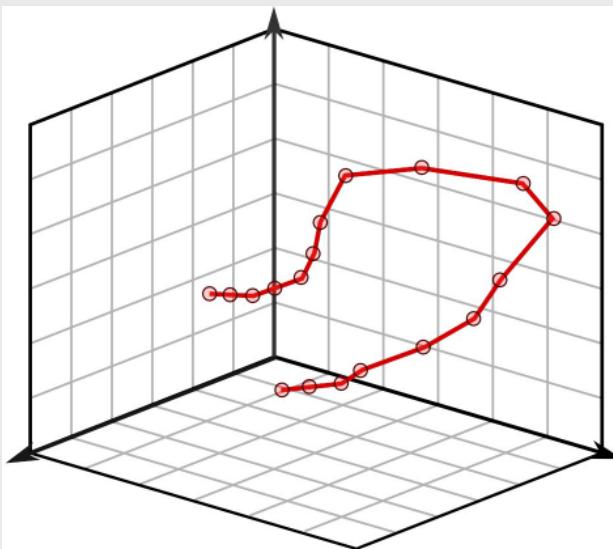
Penrose Stairs, made famous by
M.C. Escher (1898-1972)

Ink proportions !=
true proportions



Occlusion: geoms are obscured



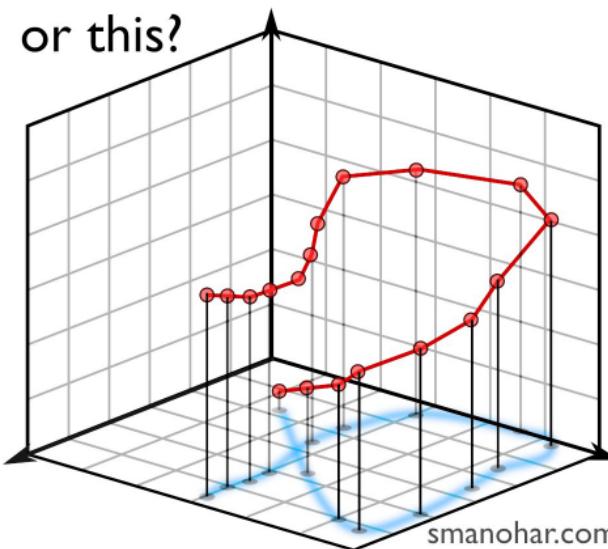
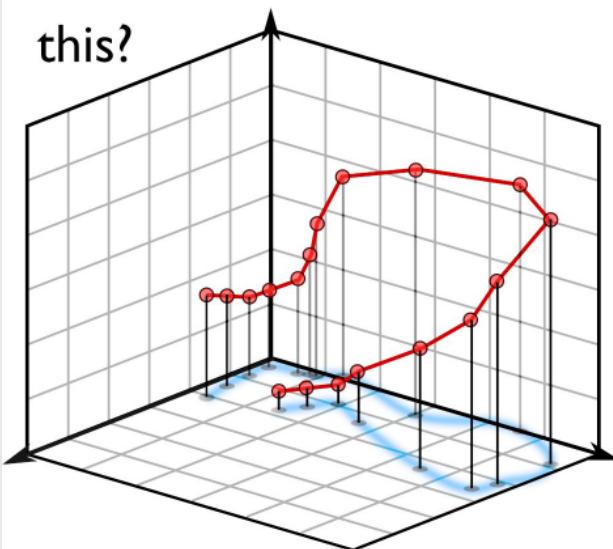


Please never do this.

3D plots are ambiguous without a projection.

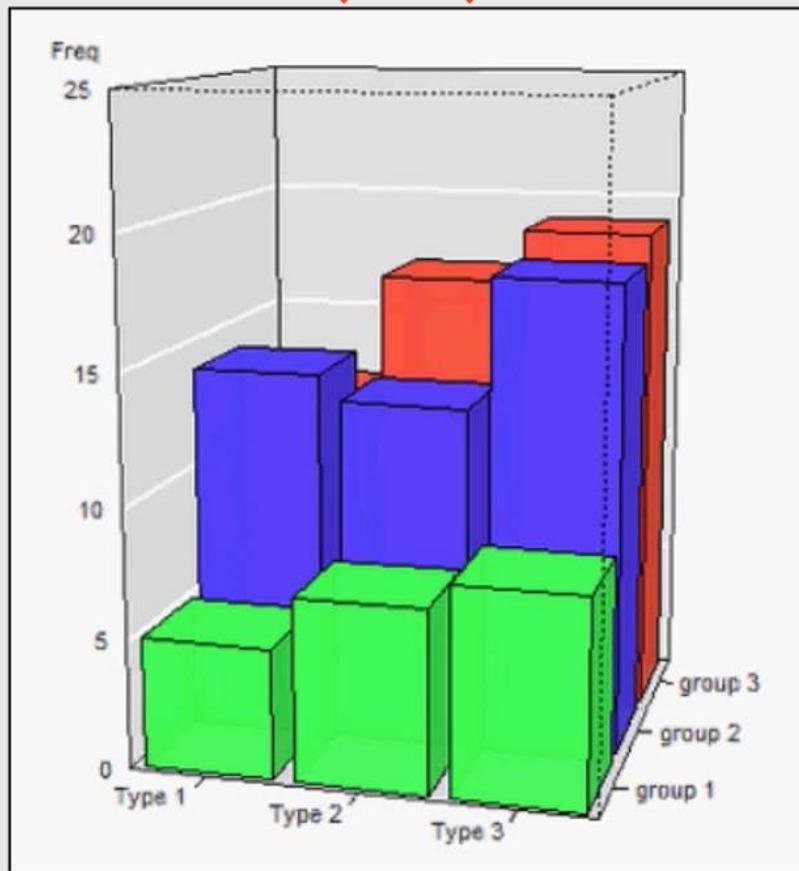
Each point has a whole line of possible 3D locations.

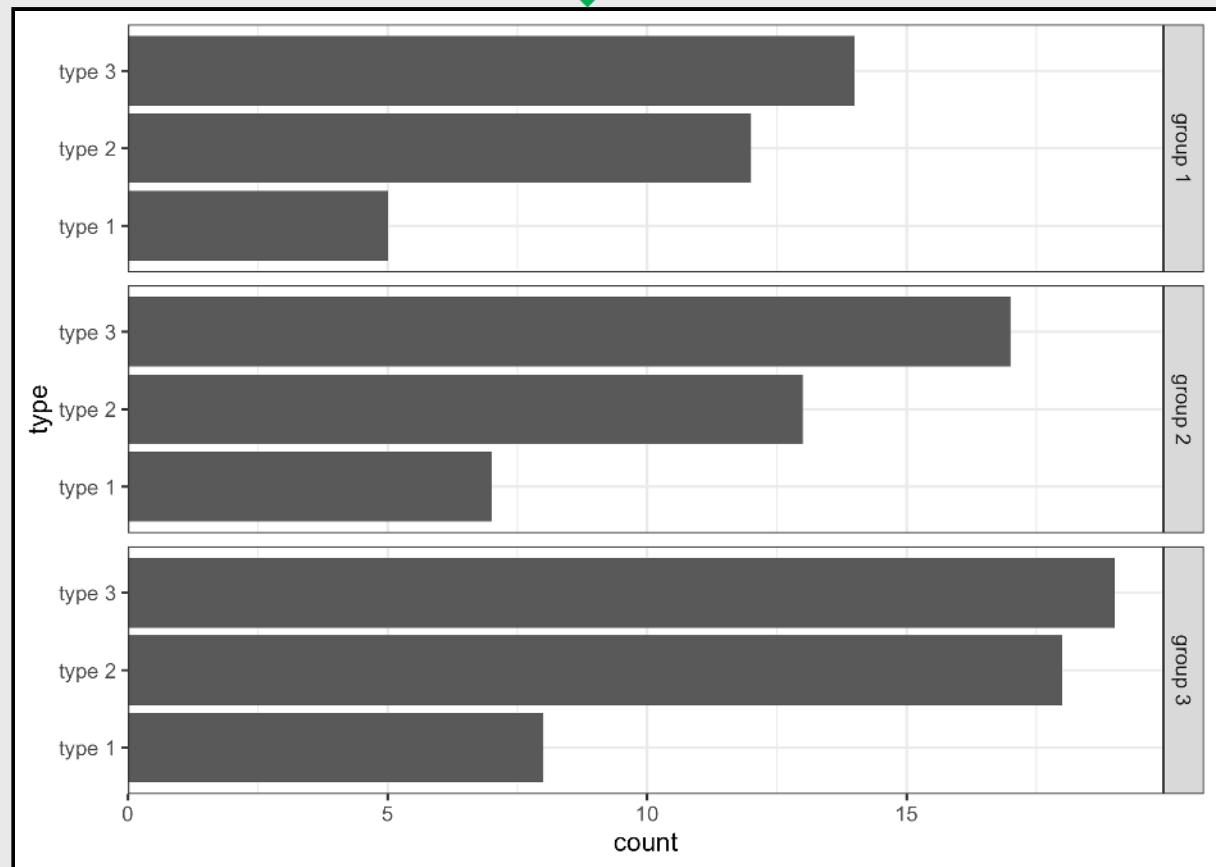
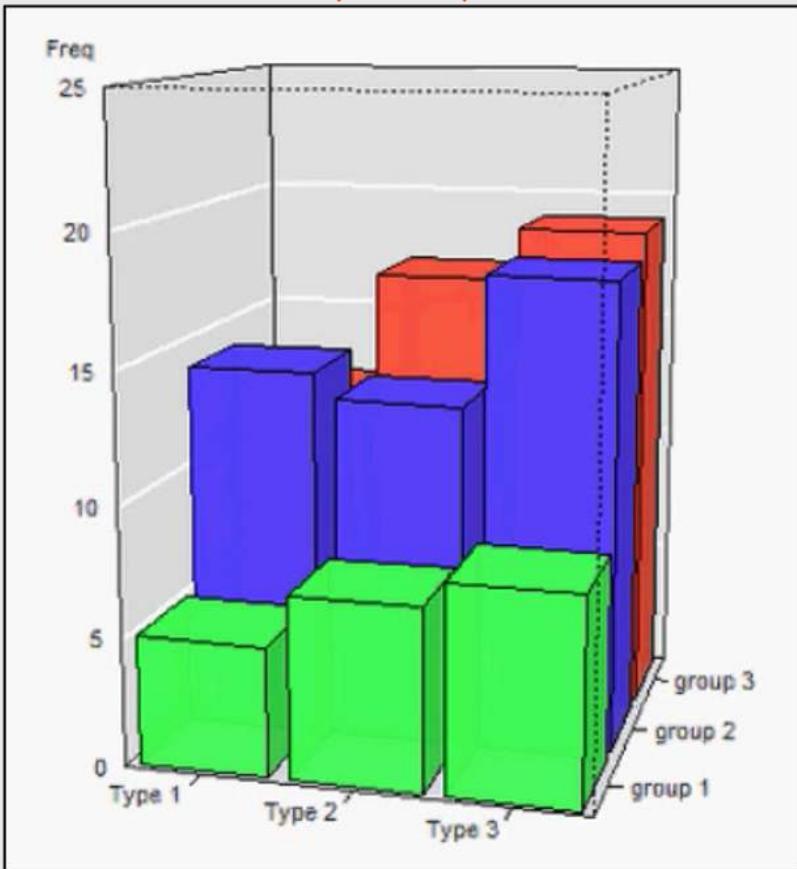
Do you mean...



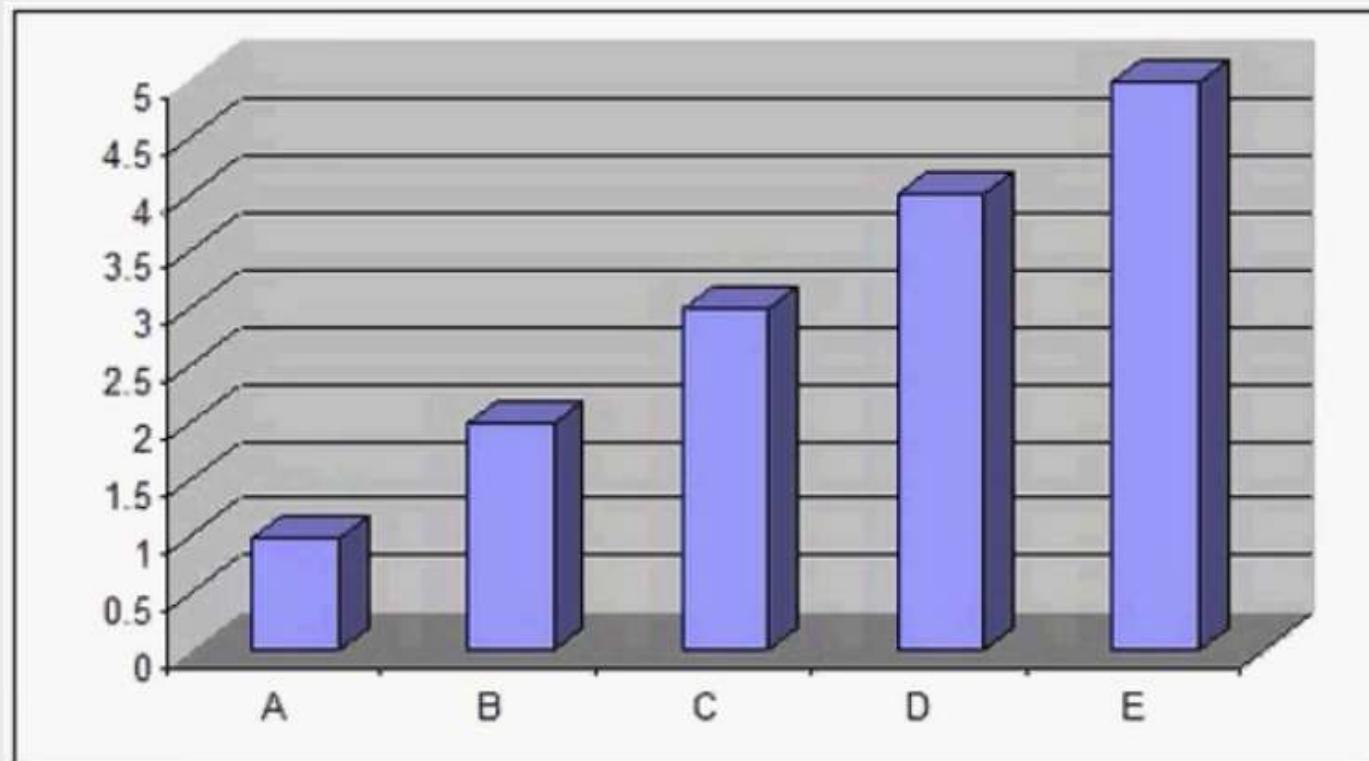
Multiple interpretations

+

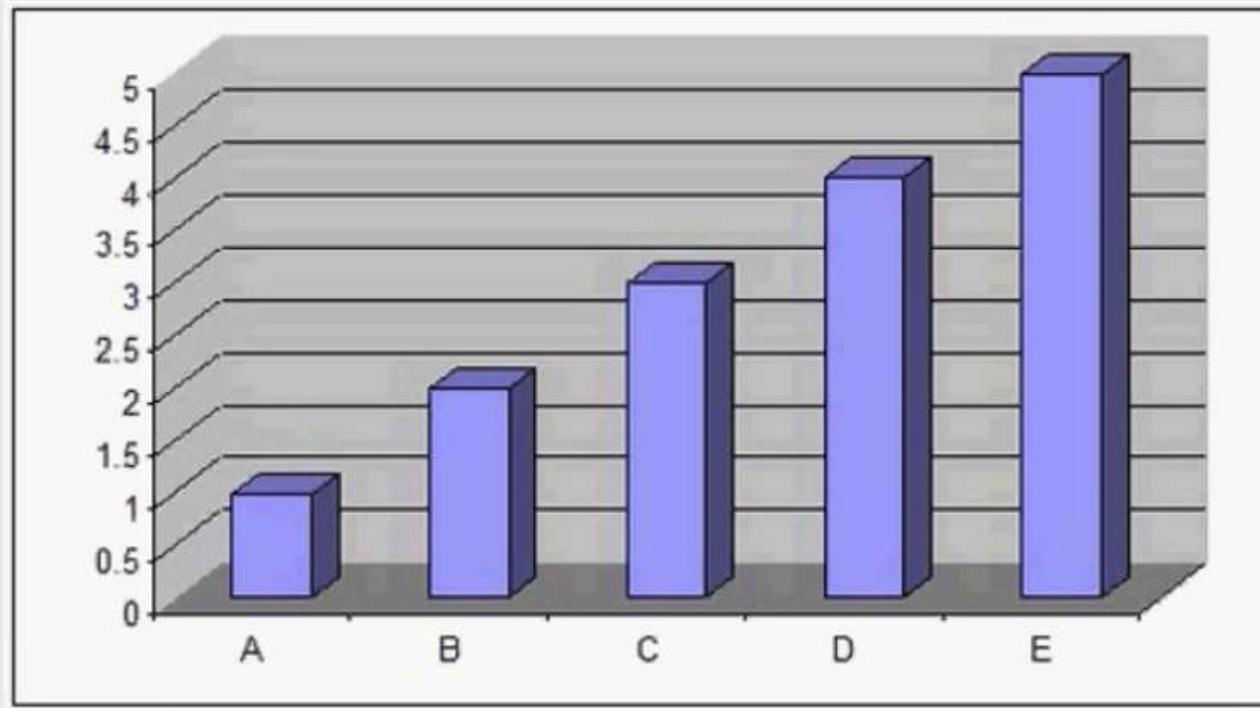


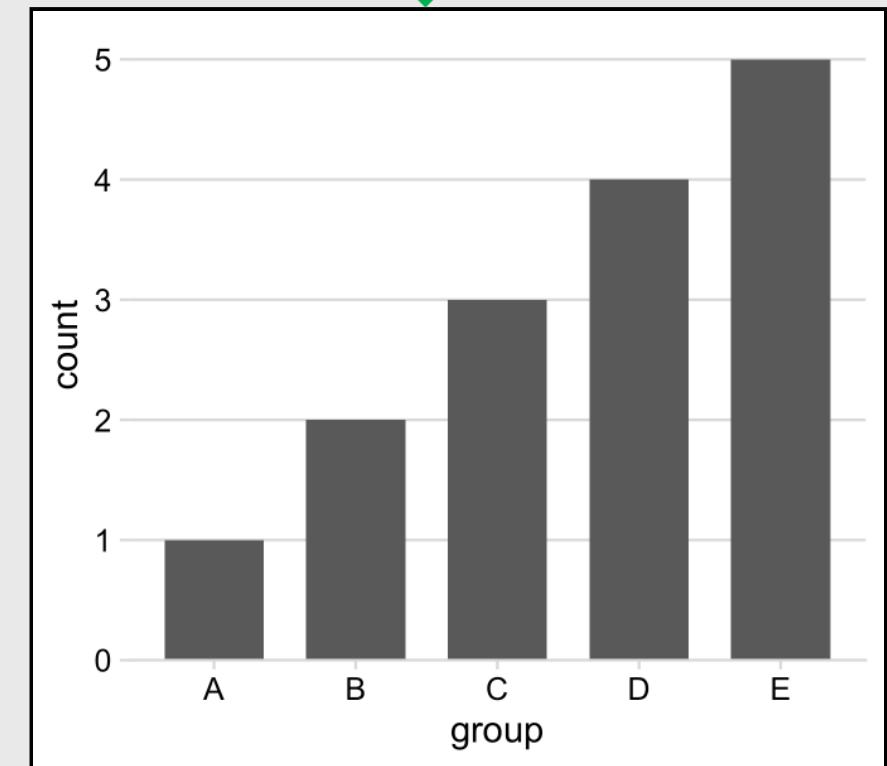
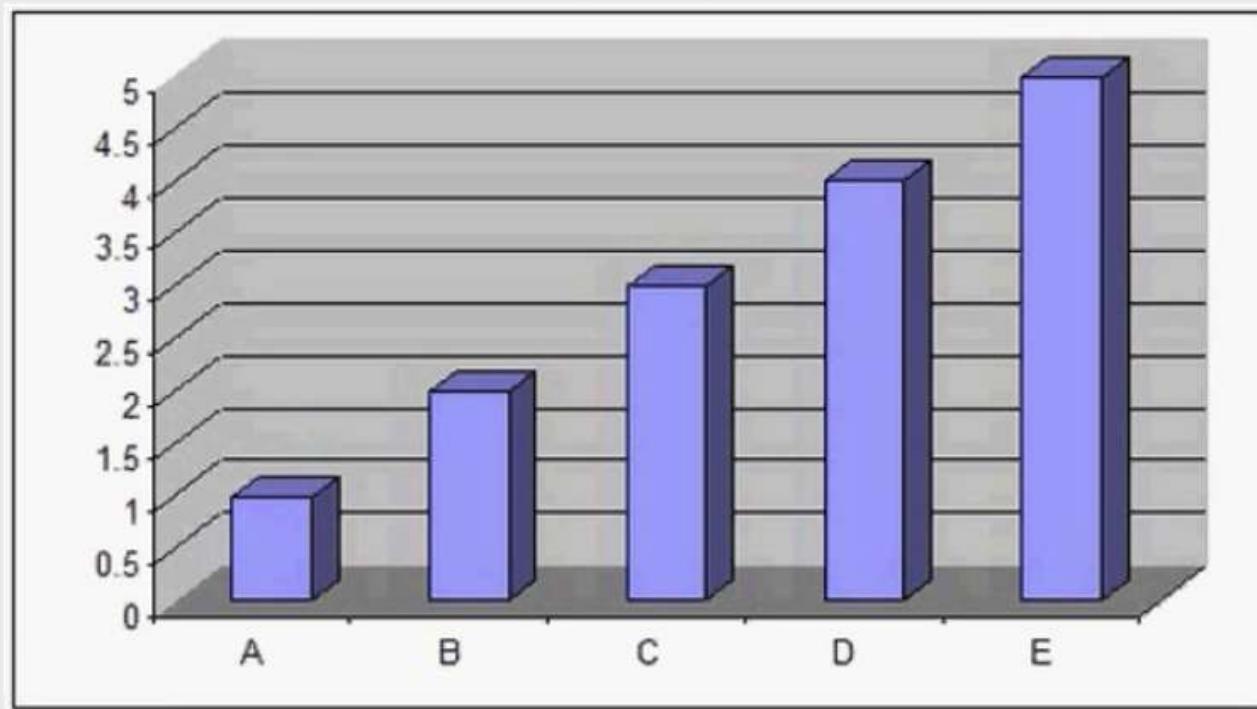


The third dimension distracts from the data
(this is what Tufte calls "chart junk")



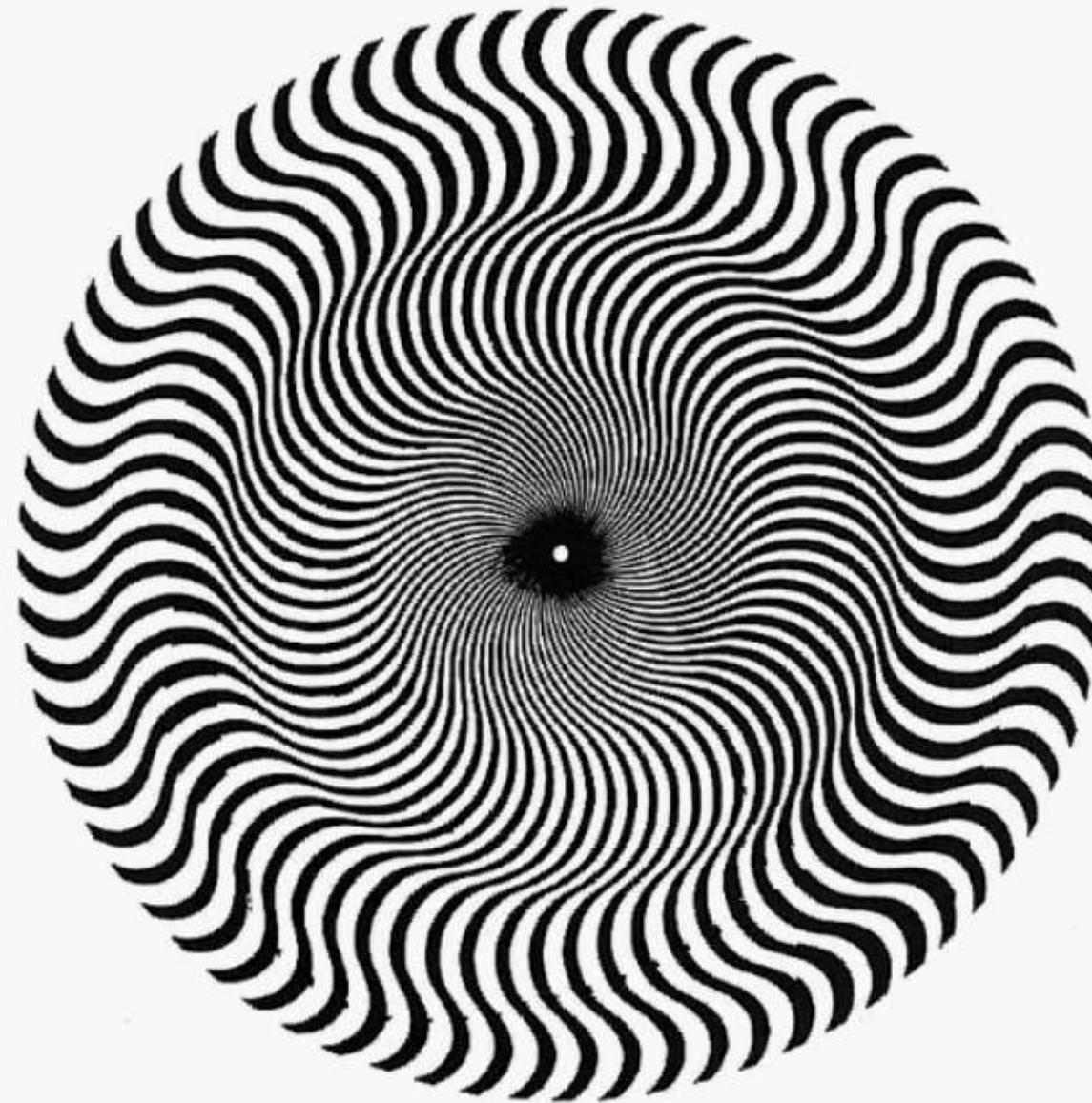
✗



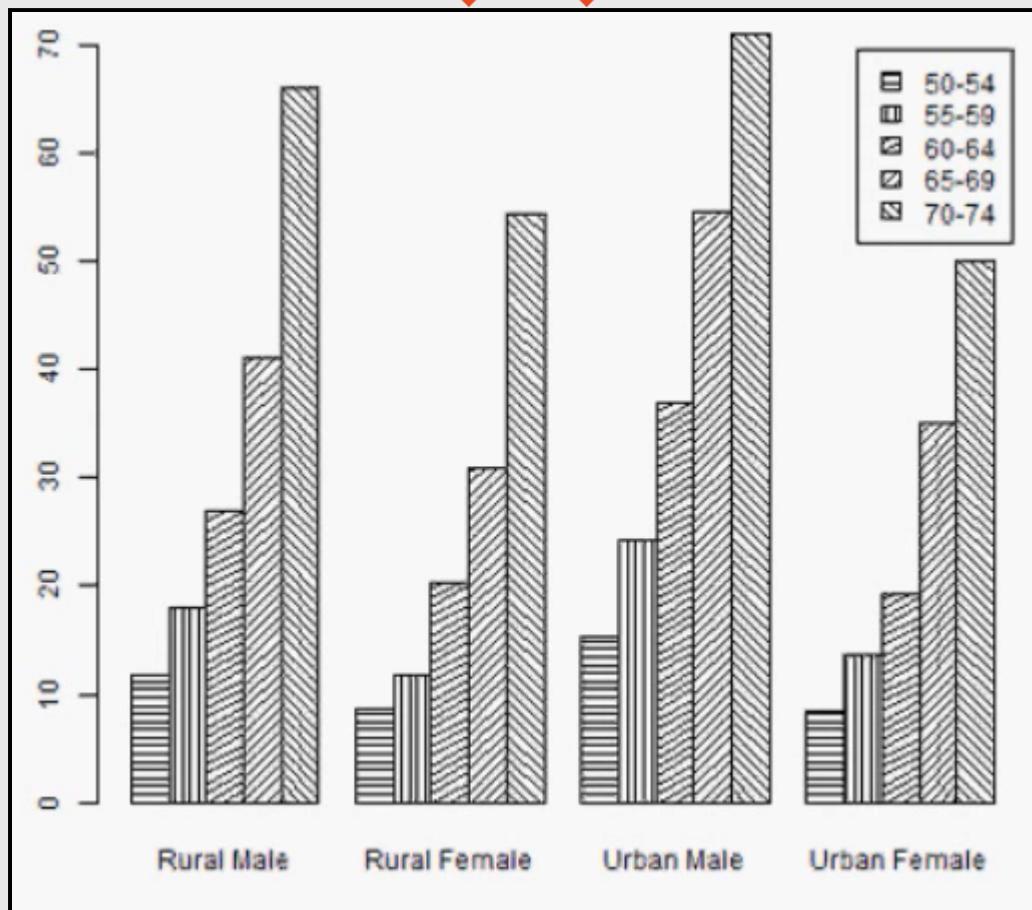


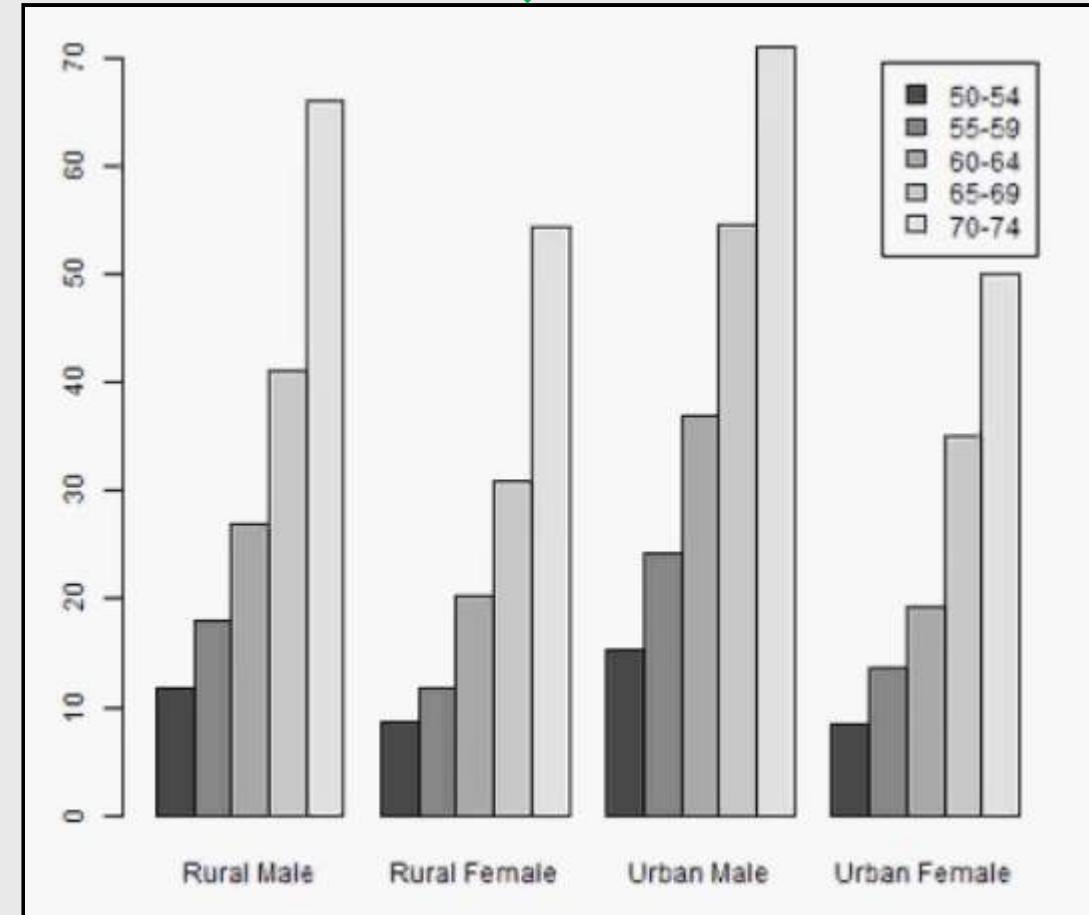
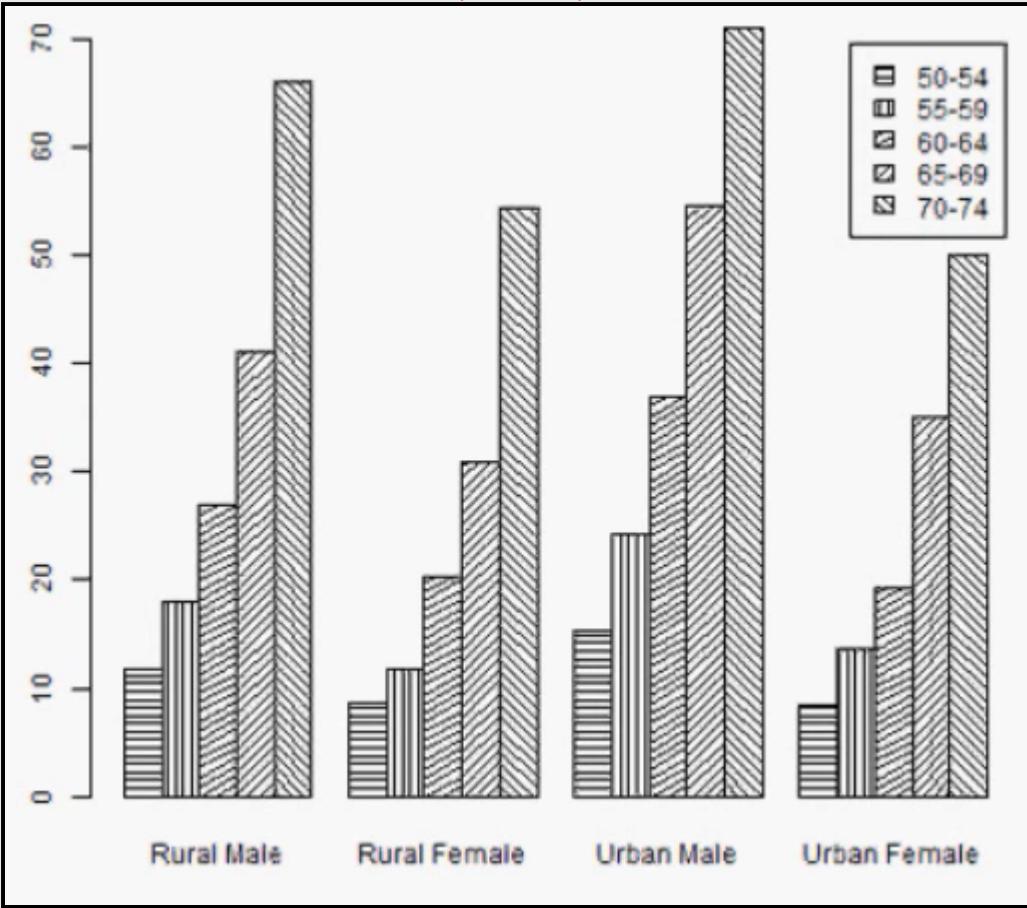
5 Data Viz Don'ts

1. Don't use chart chunk
2. Don't make 3D plots
3. Don't use pattern fills
4. Don't use red & green together
5. Don't lie



+



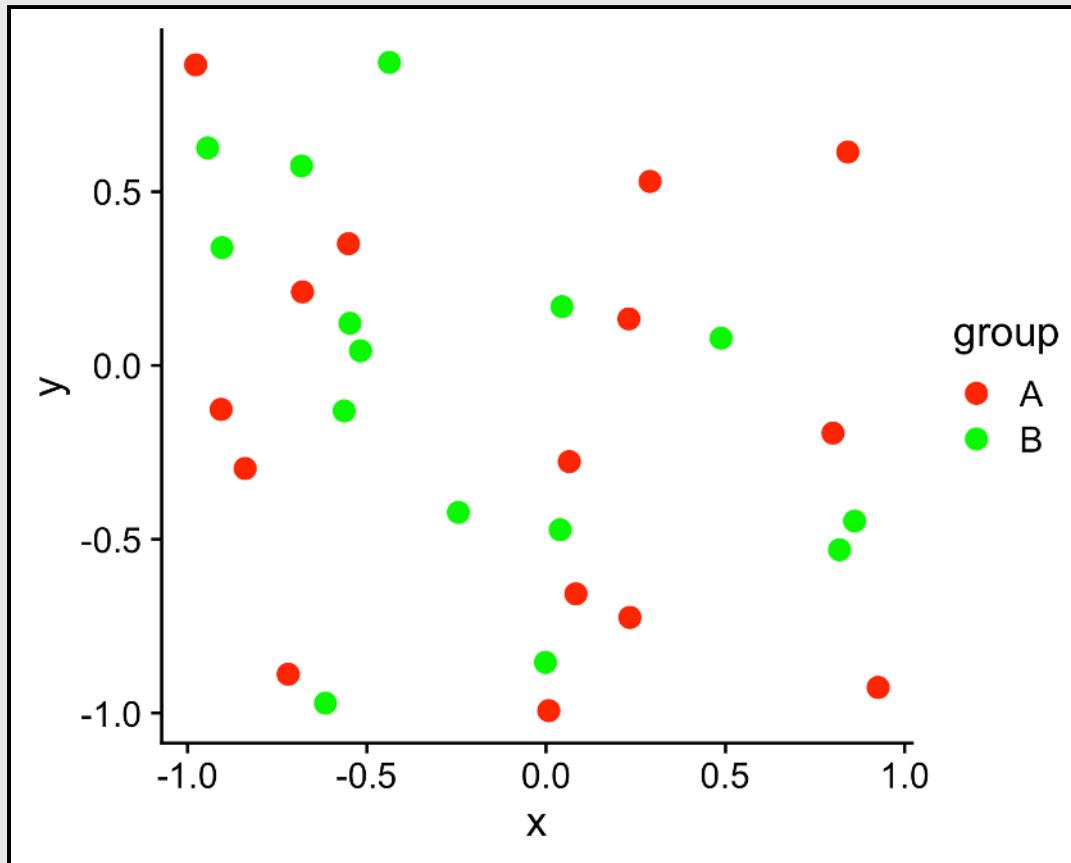


5 Data Viz Don'ts

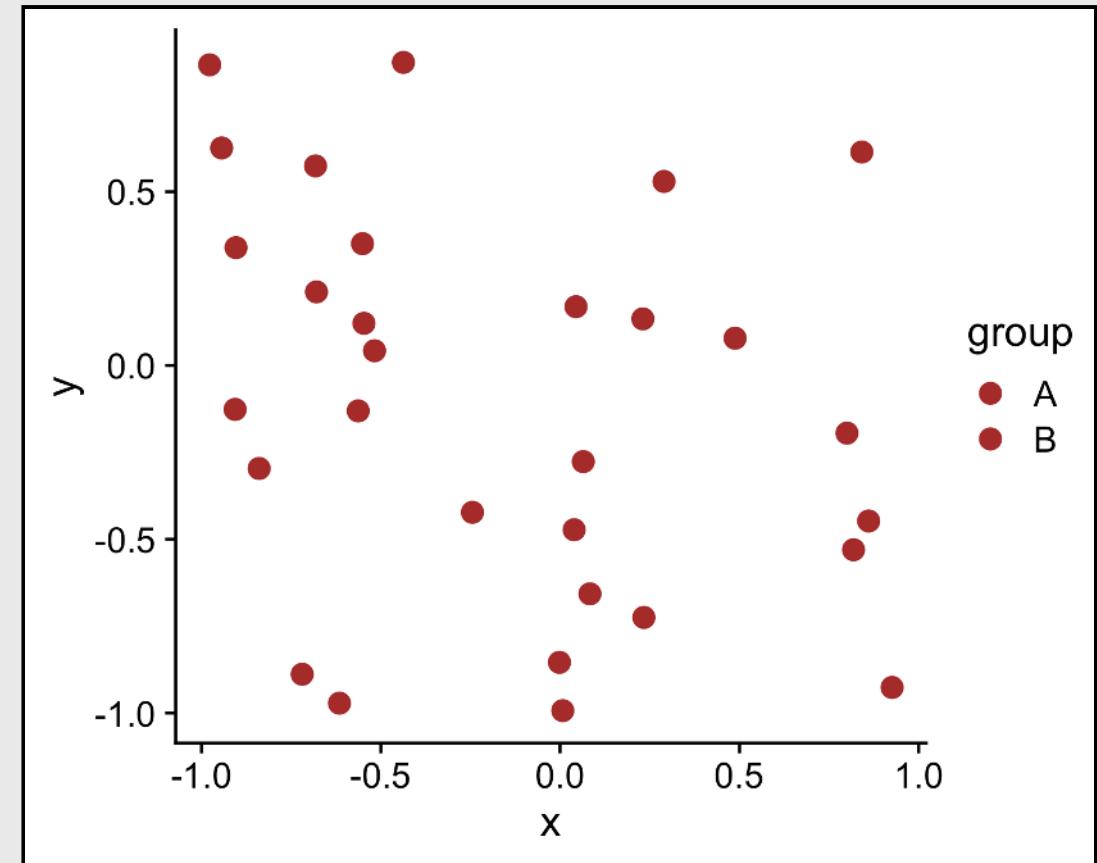
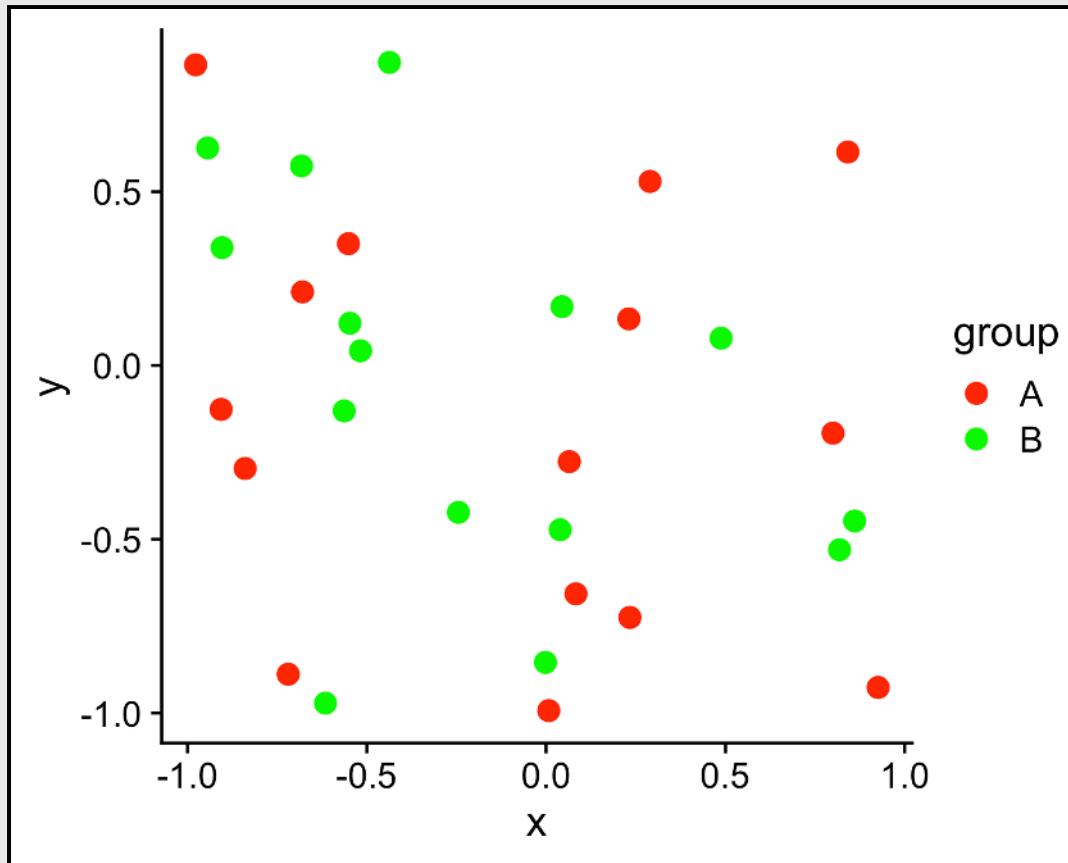
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10% of males and 1% of females are color blind

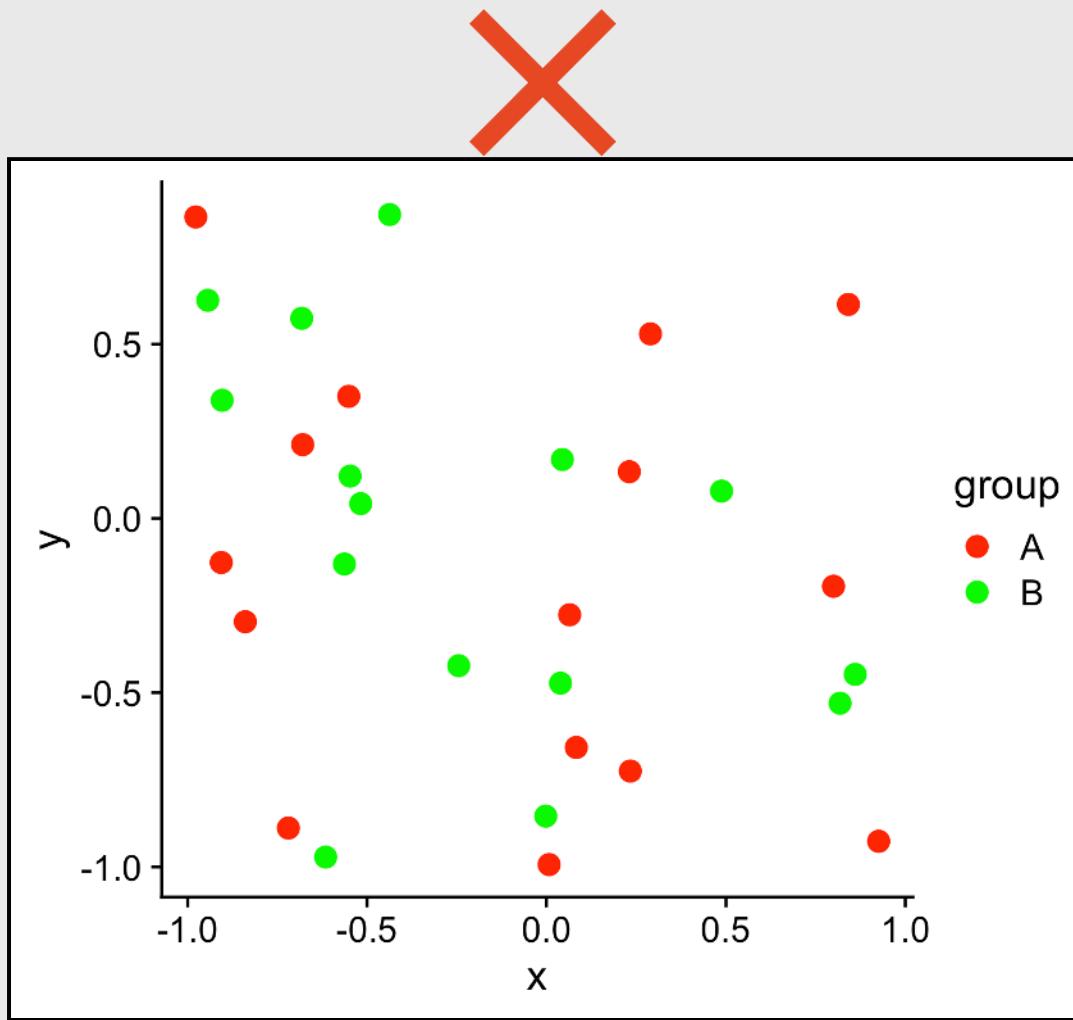
10% of males and 1% of females are color blind



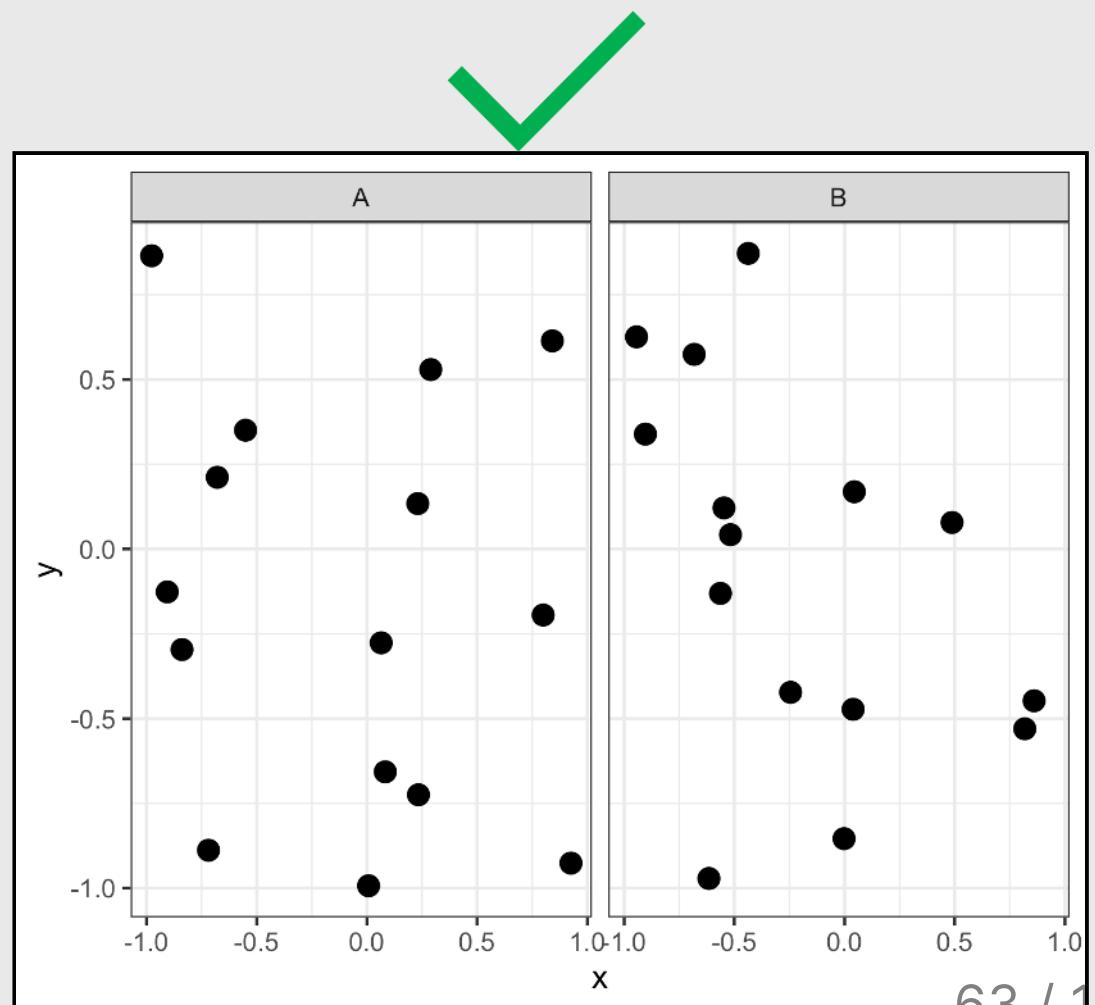
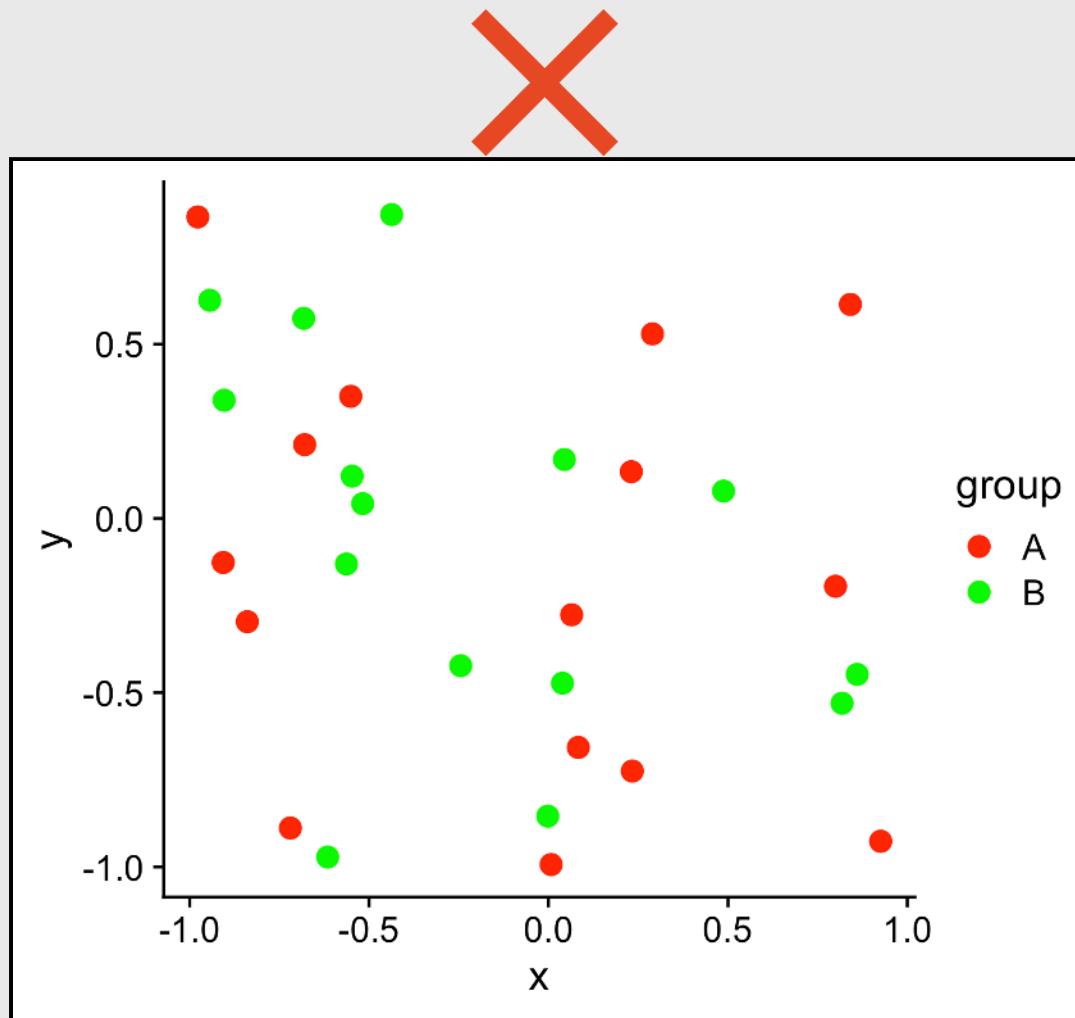
10% of males and 1% of females are color blind



Facets can be used to avoid color altogether



Facets can be used to avoid color altogether



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Bar charts should always start at 0

Bar charts should always start at 0

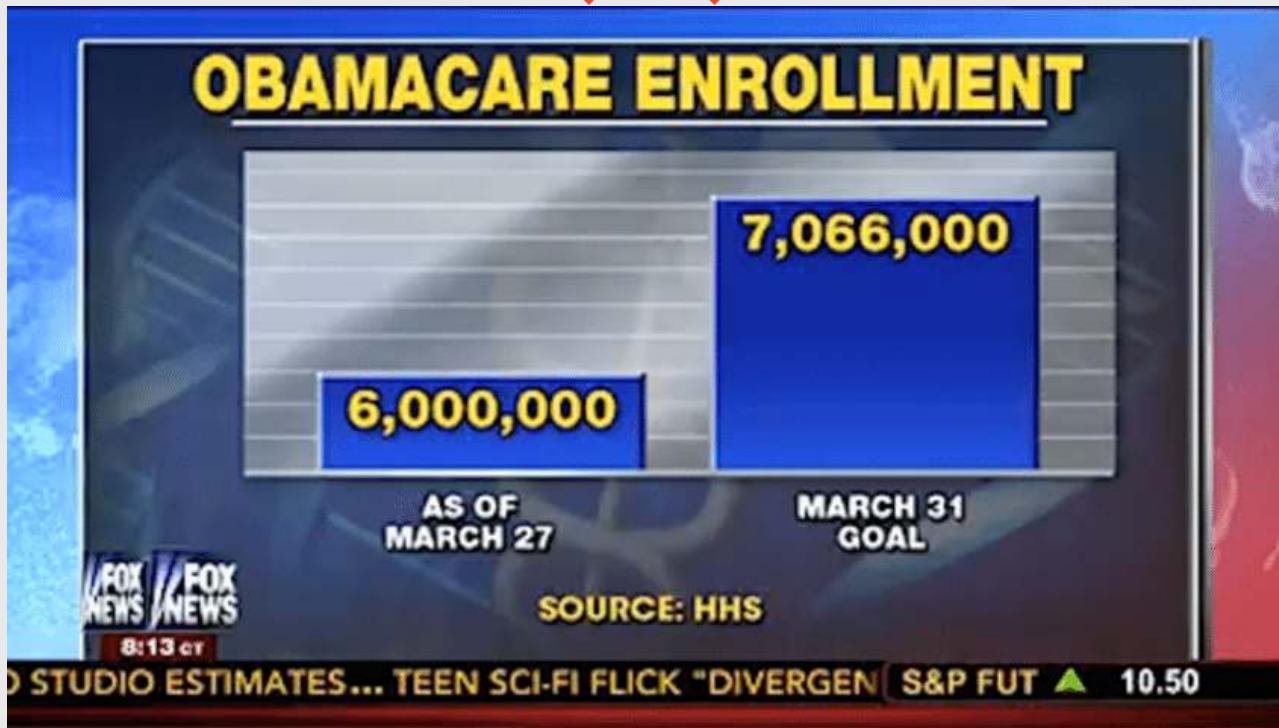


Image from <http://livingqlikview.com/the-9-worst-data-visualizations-ever-created/>

Bar charts should always start at 0

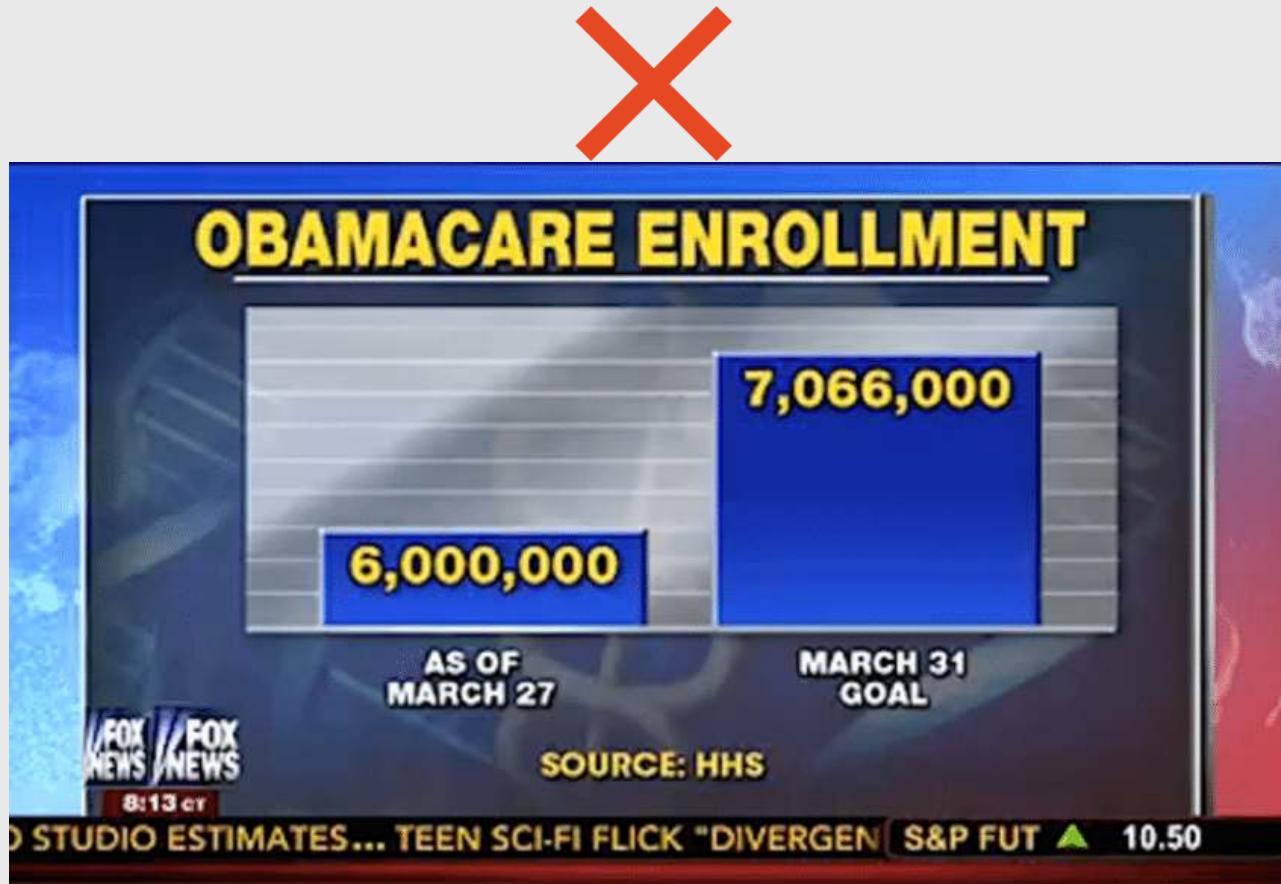
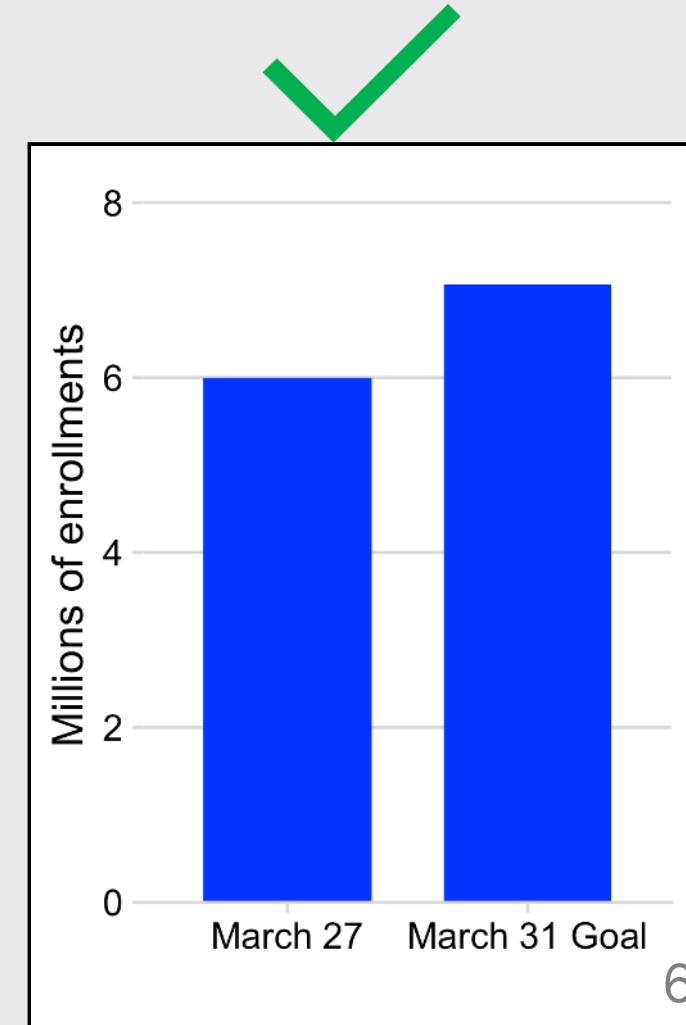


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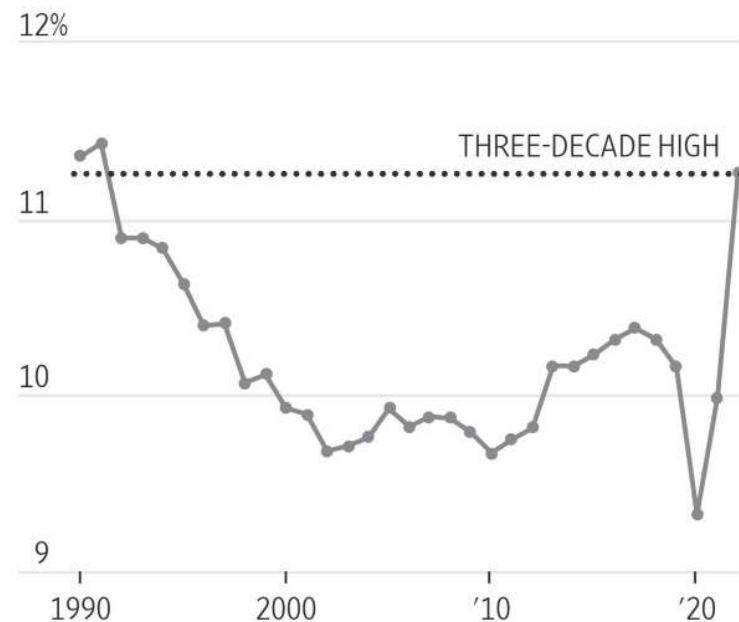
Don't cherry pick your data



It's Been 30 Years Since Food Ate Up This Much of Your Income

Ongoing high costs are leading food manufacturers and restaurants to keep prices elevated.

Food spending's share of disposable income

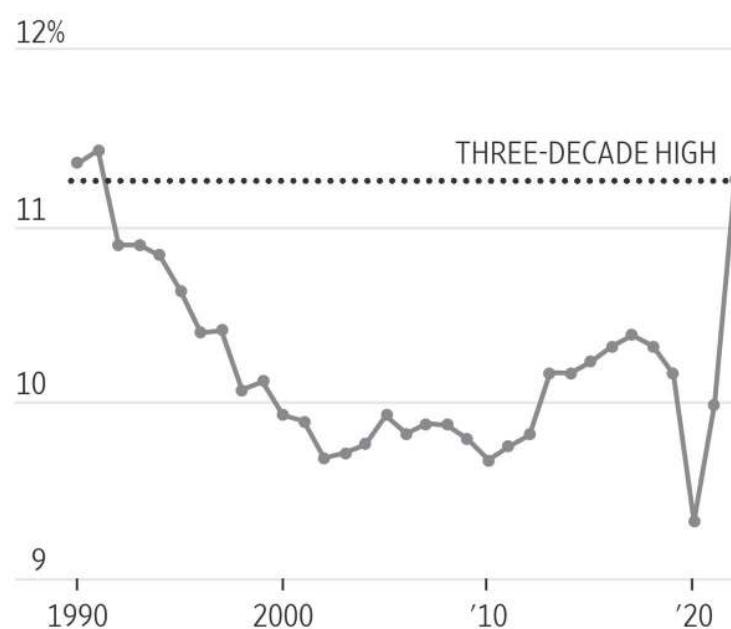




It's Been 30 Years Since Food Ate Up This Much of Your Income

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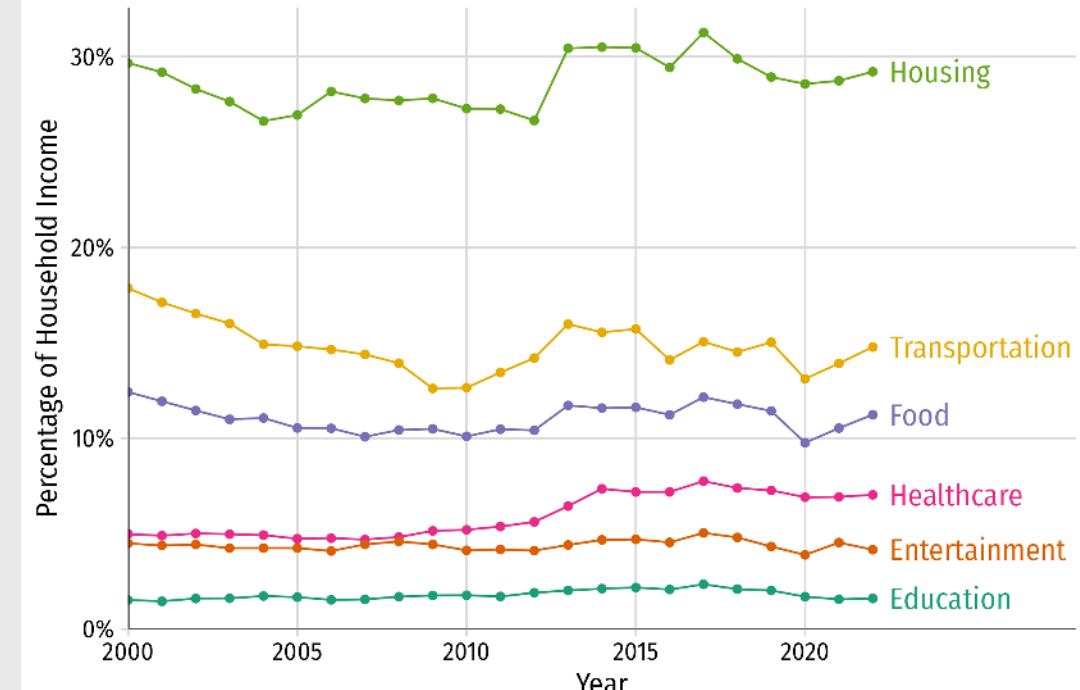


Don't cherry pick your data



U.S. Expenditures as Percentage of Household Income

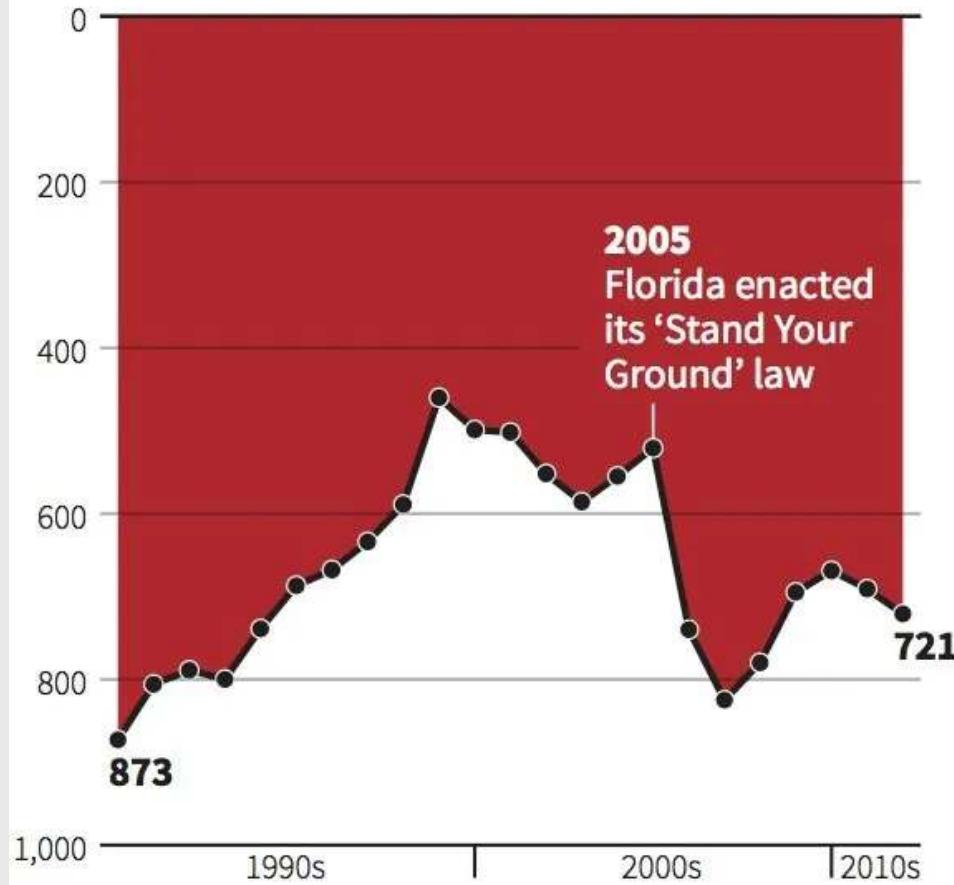
Percentages computed using post-tax income



Data source: US BLS: <https://www.bls.gov/cex/tables/top-line-means.htm>

Gun deaths in Florida

Number of murders committed using firearms



Source: Florida Department of Law Enforcement

C. Chan 16/02/2014

REUTERS

Use common conventions

- "Up" on Y axis should mean larger
- Time moves left to right

<https://www.livescience.com/45083-misleading-gun-death-chart.html>

Make sure your chart makes sense

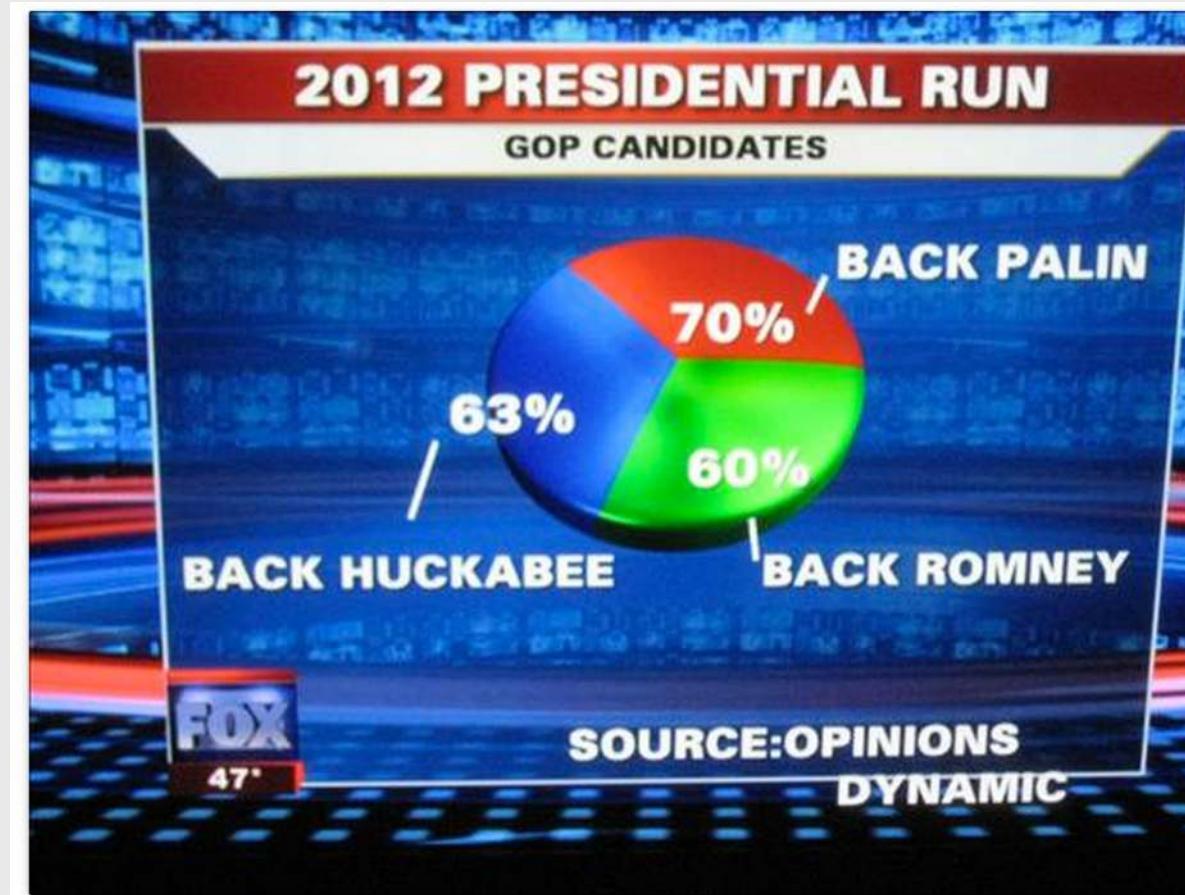


Image from <http://livingqlikview.com/the-9-worst-data-visualizations-ever-created/>

Intermission!

Stand up, Move around, Stretch!

05 : 00

Visualizing Information

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BREAK

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5 Data Viz Do's

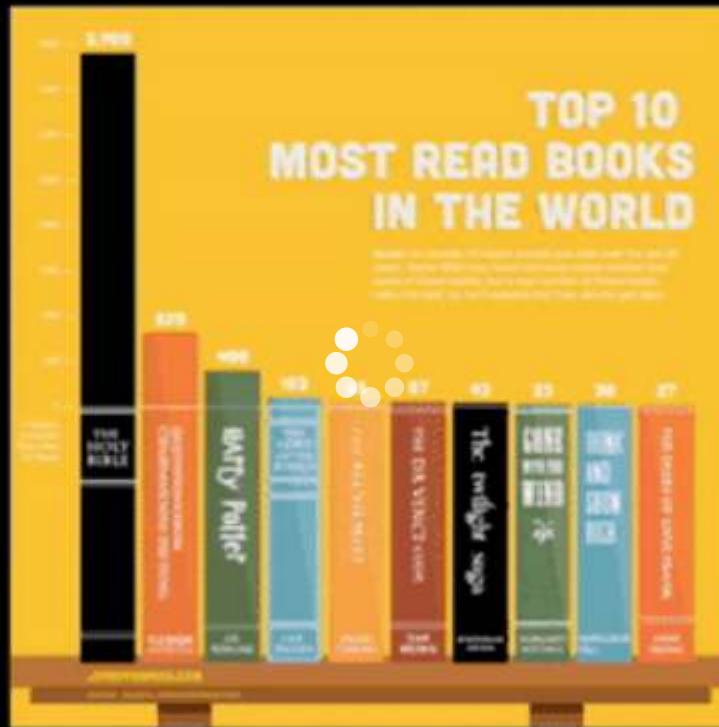
1. Annotate your charts
2. Eliminate legends
3. Show amounts with bars, dots, and lollipops
4. Show proportions with bars and waffles (not pies)
5. Show trends with lines, bars, and heatmaps

5 Data Viz Do's

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Text is usually the single most important component on your chart

STEP 1: Encoding



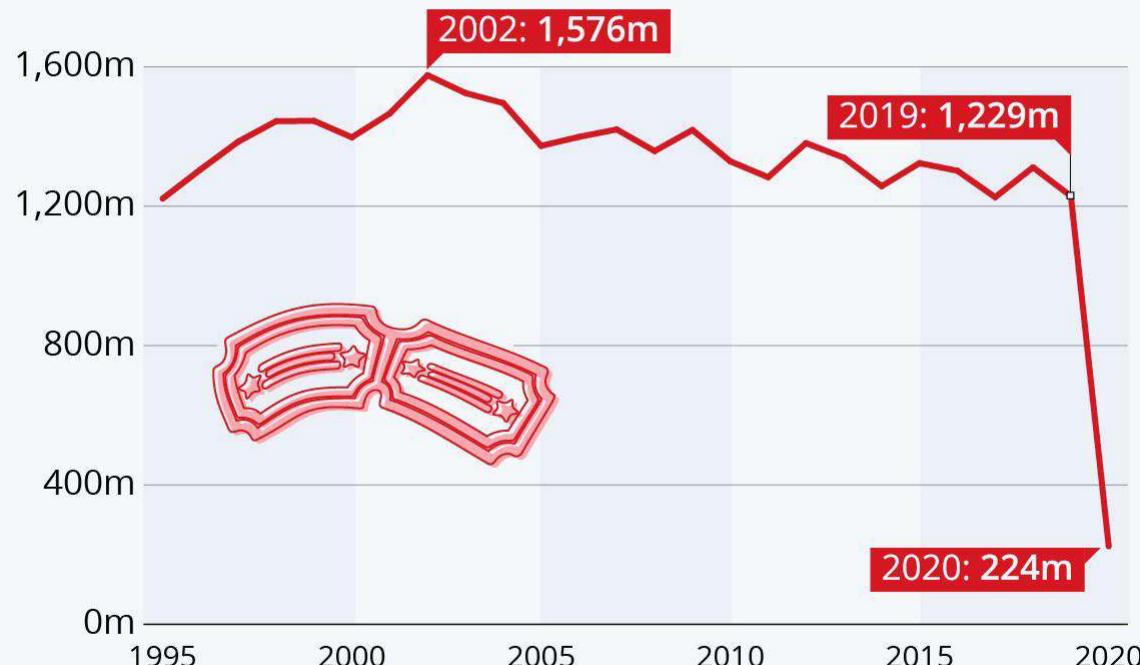
10 SECONDS



= eye fixation

Are Americans Falling Out of Love With the Cinema?

Estimated number of tickets sold at the North American box office since 1995



Source: The Numbers



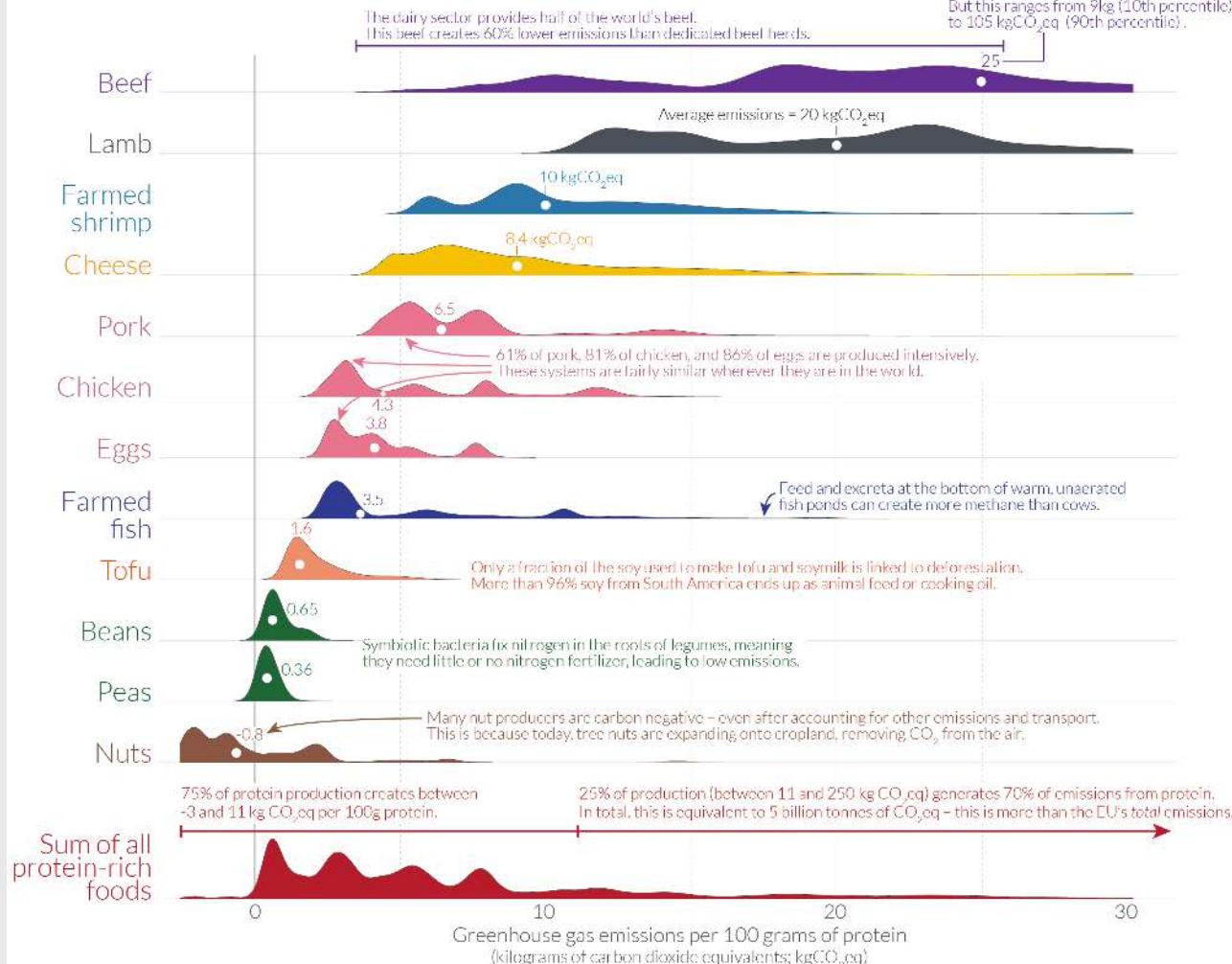
statista

How does the carbon footprint of protein-rich foods compare?

Greenhouse gas emissions from protein-rich foods are shown per 100 grams of protein across a global sample of 38,700 commercially viable farms in 119 countries.

The height of the curve represents the amount of production globally with that specific footprint. The white dot marks the median greenhouse gas emissions for each food product.

Our World
in Data



Note: Data refers to the greenhouse gas emissions of food products across a global sample of 38,700 commercially viable farms in 119 countries.

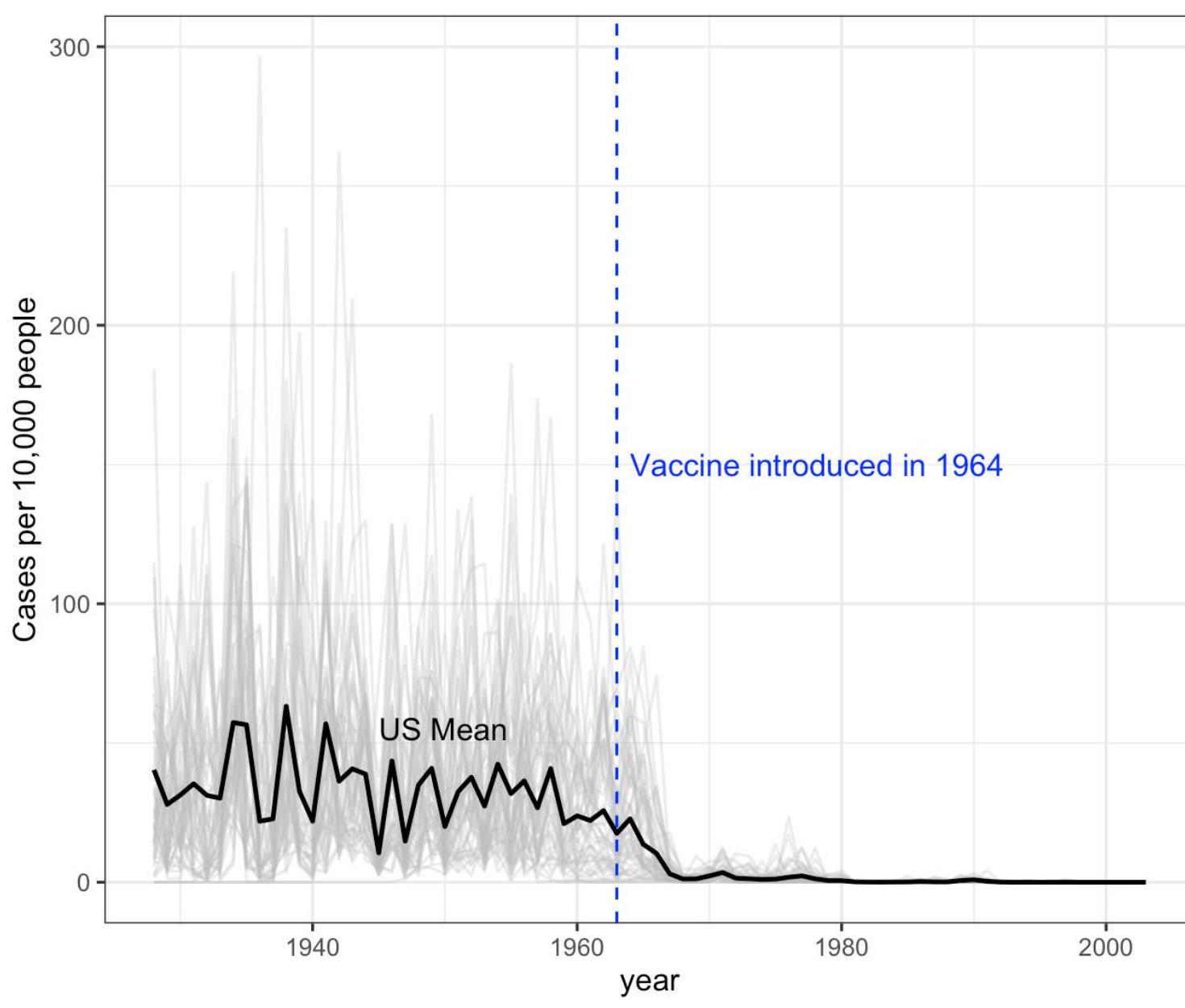
Emissions are measured across the full supply chain, from land-use change through to the retailer and includes on-farm processing, transport, packaging and retail emissions.

Data source: Joseph Poore and Thomas Neff (2018). Reducing food's environmental impacts through producers and consumers. *Science*.

OurWorldInData.org Research and data to make progress against the world's largest problems. Licensed under CC BY by the authors Joseph Poore & Hannah Ritchie.

Good annotations should tell a story

<https://ourworldindata.org/less-meat-or-sustainable-meat>



Use reference
lines to provide
context

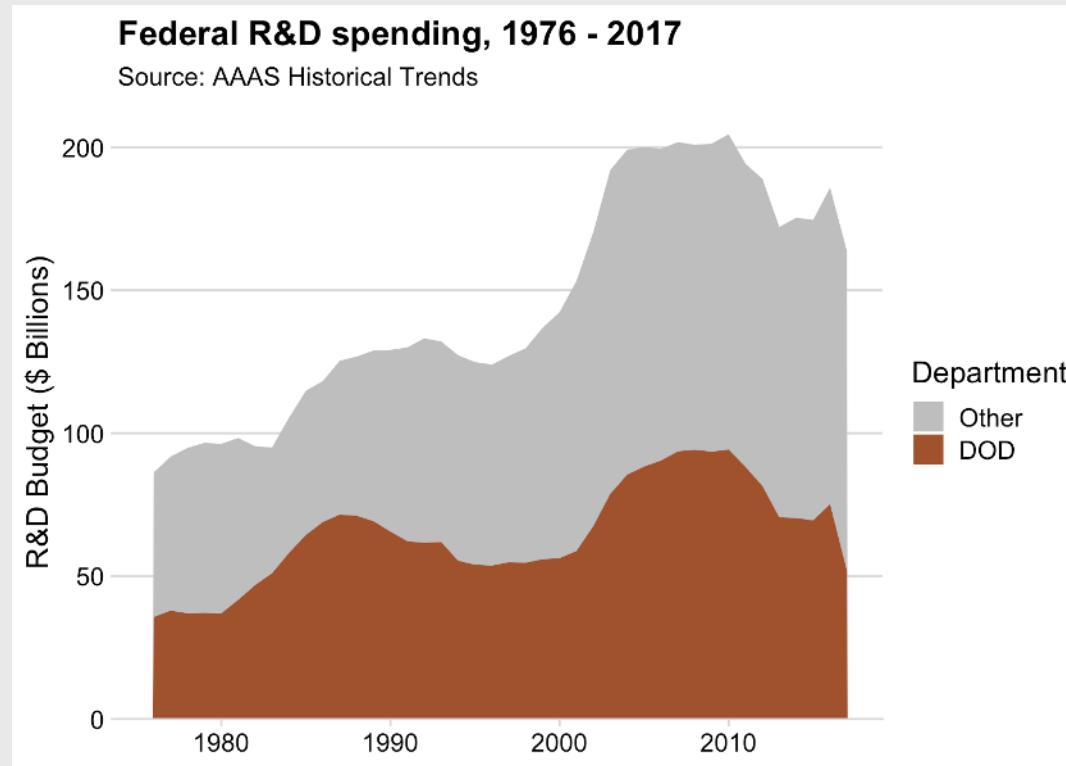
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Legends suck

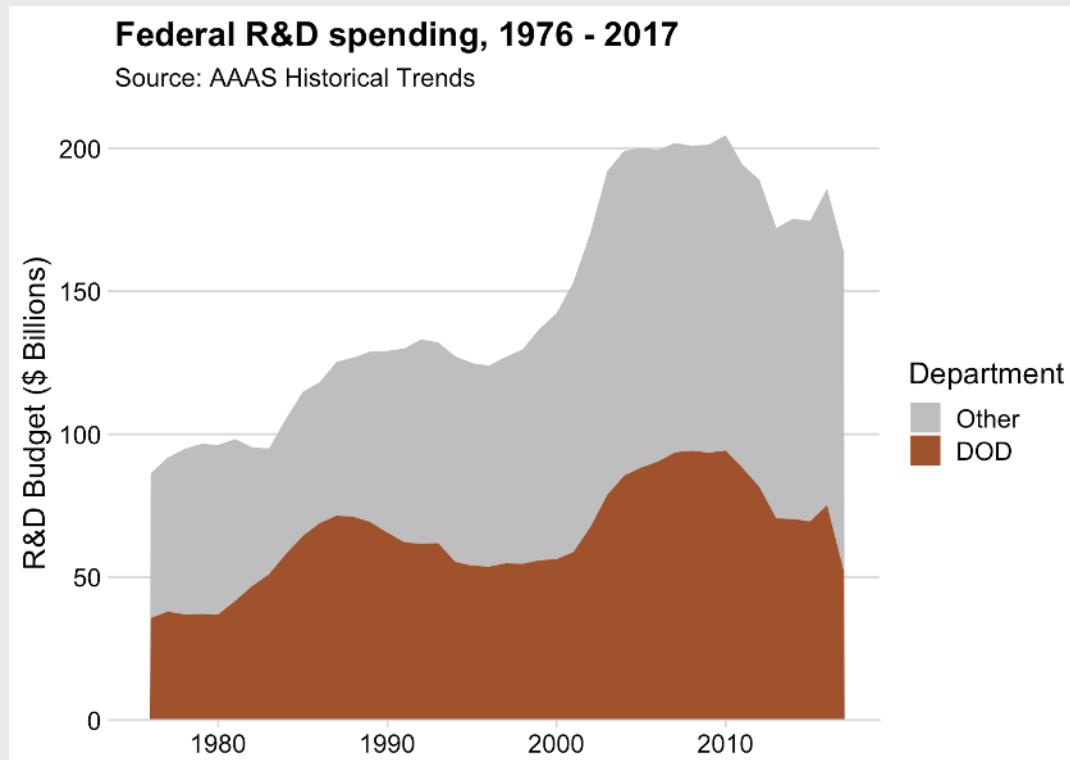
Legends suck

Legends require look-up task

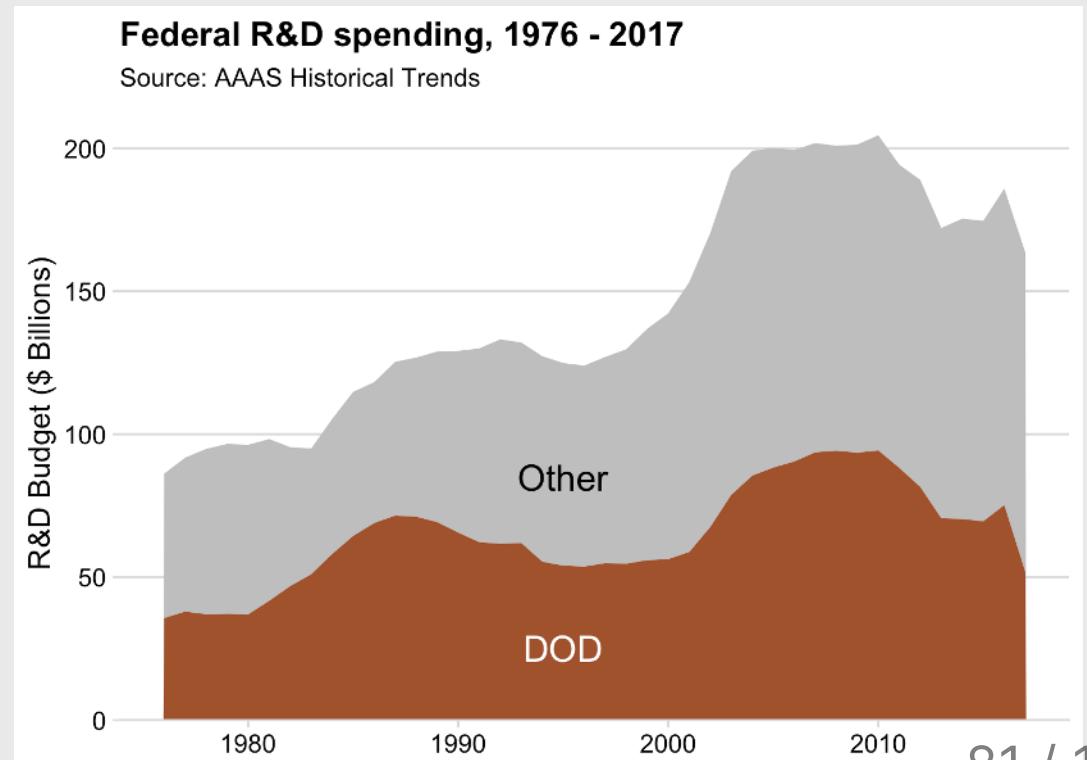


Legends suck

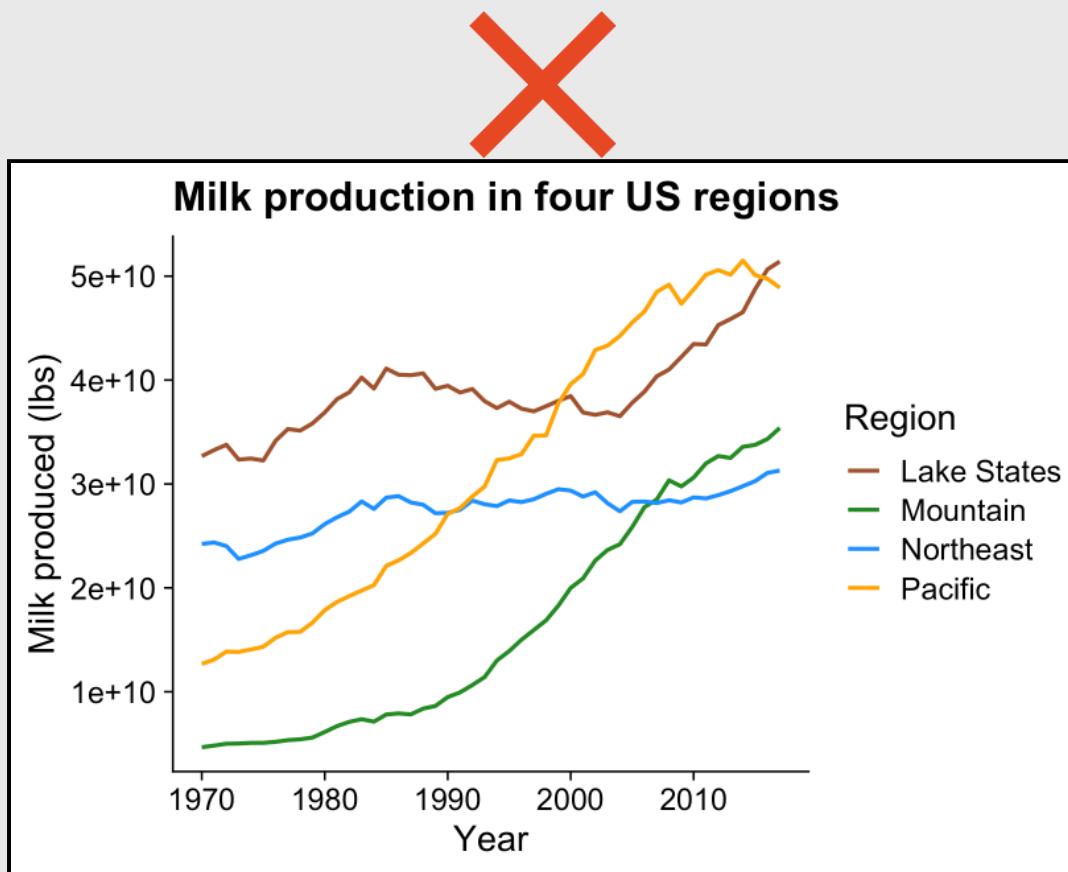
Legends require look-up task



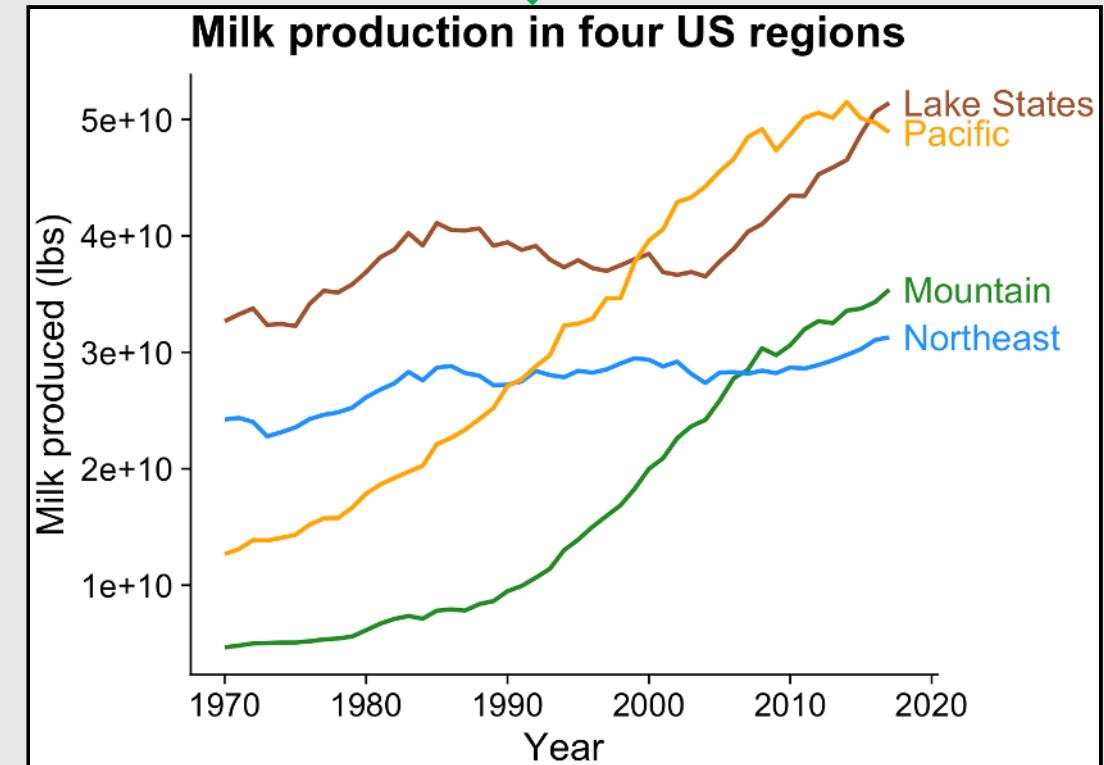
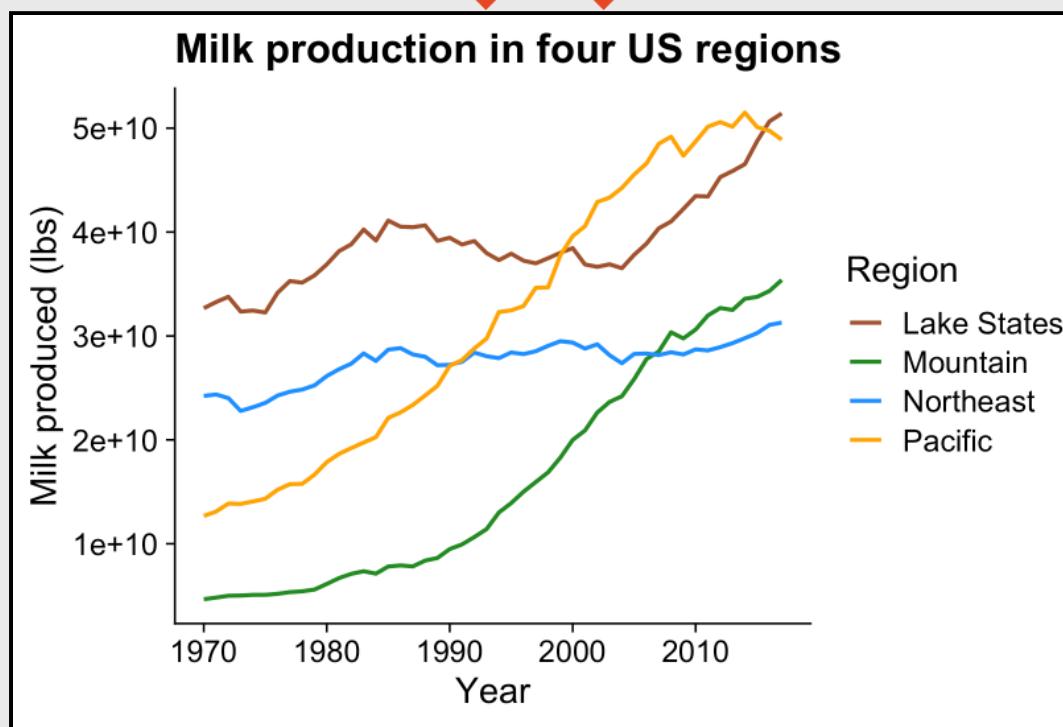
Direct labeling is much better



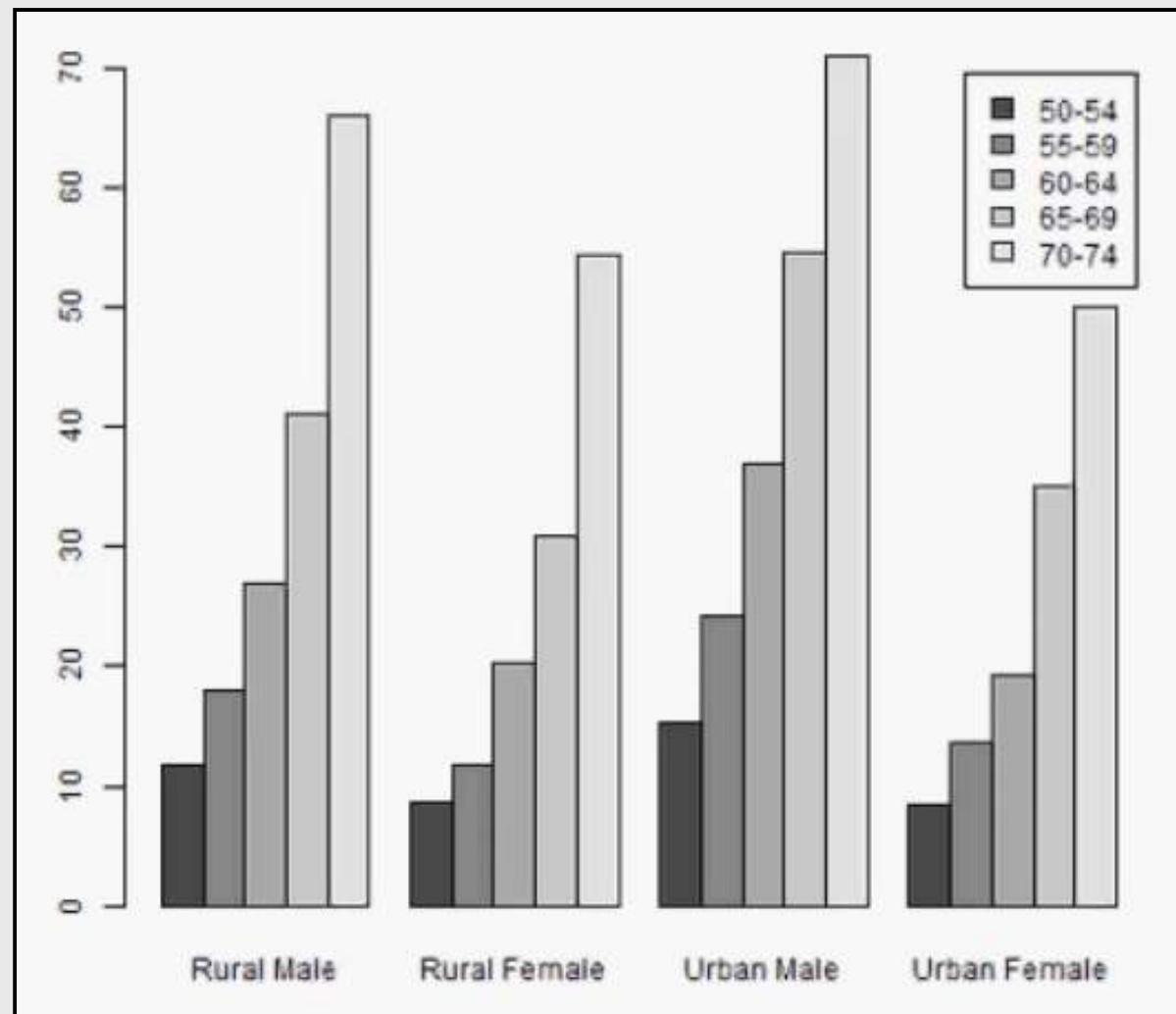
Directly label things to remove legends!



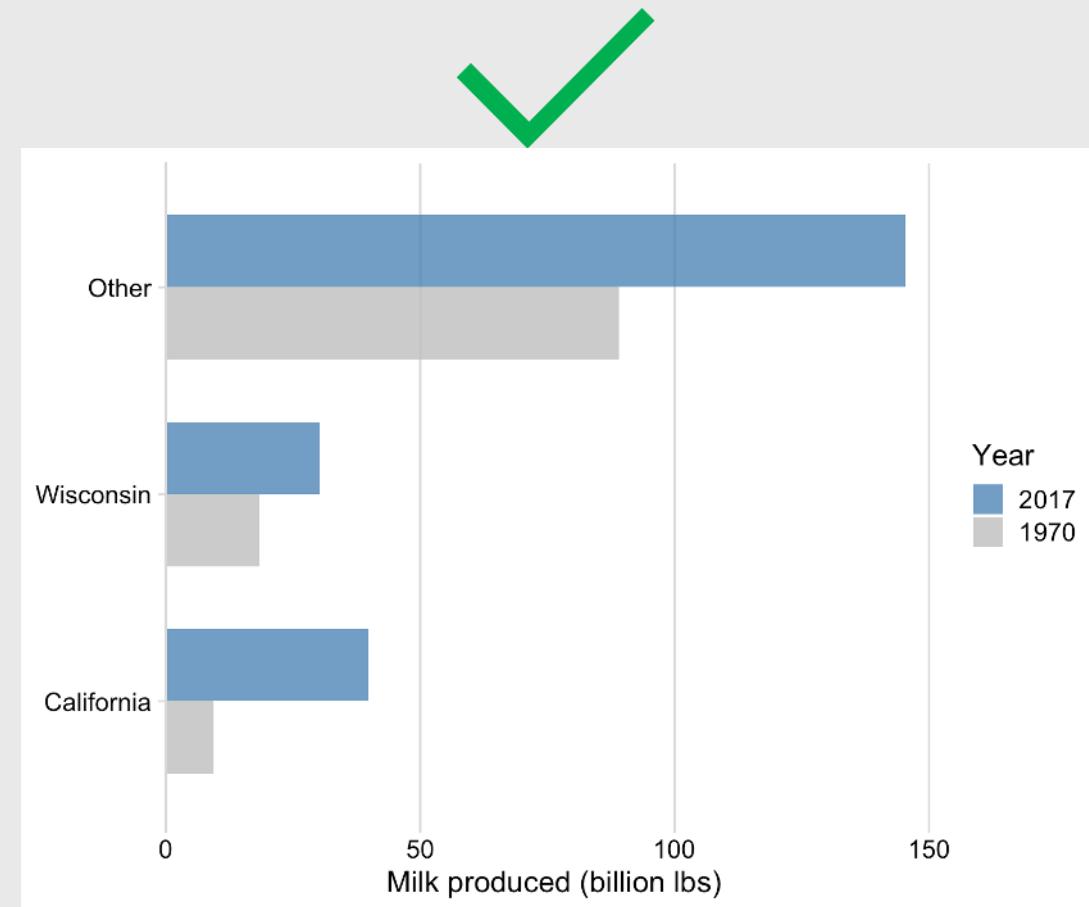
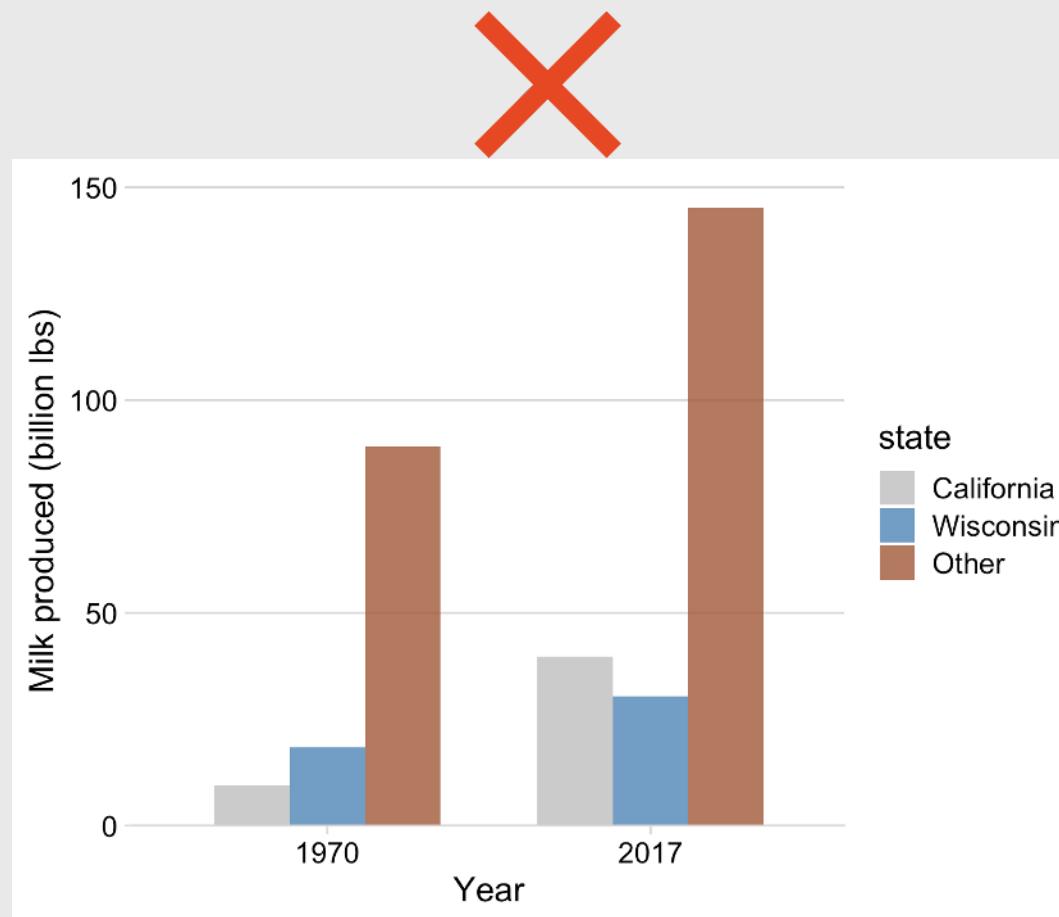
Directly label things to remove legends!



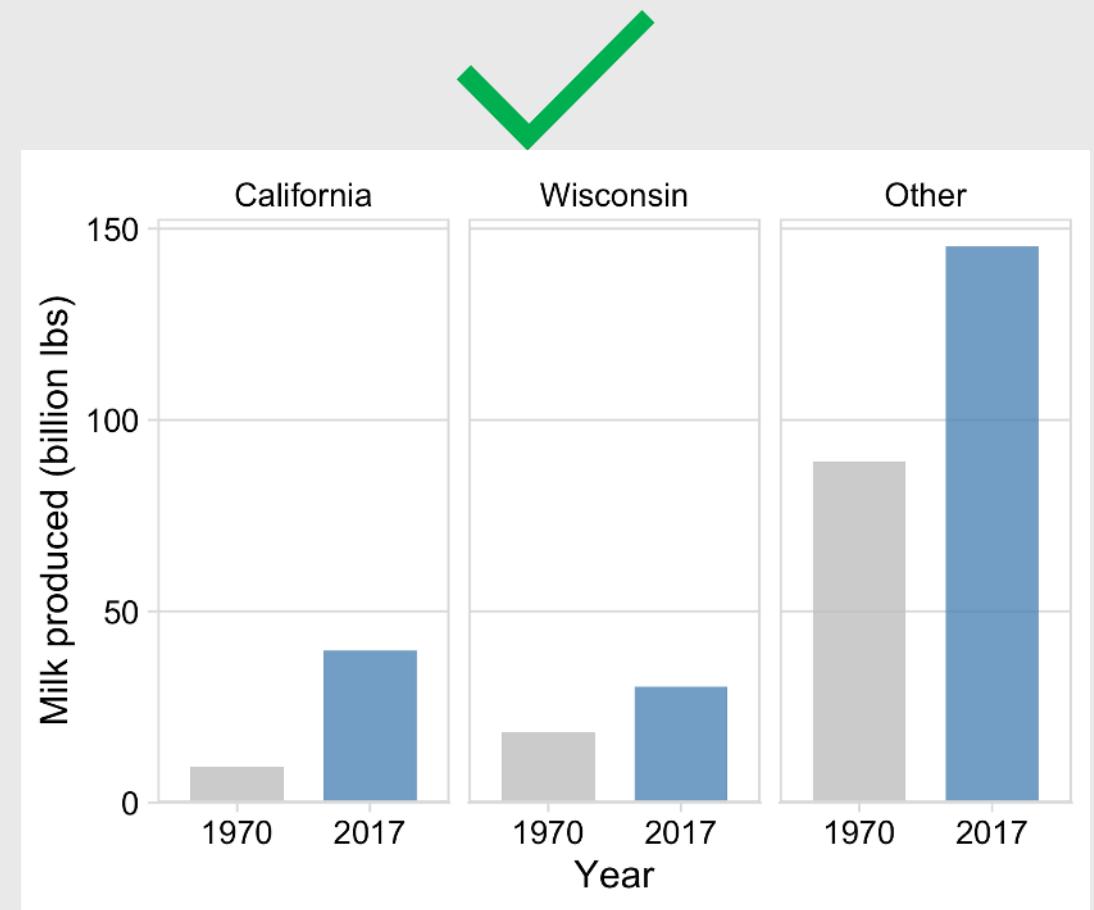
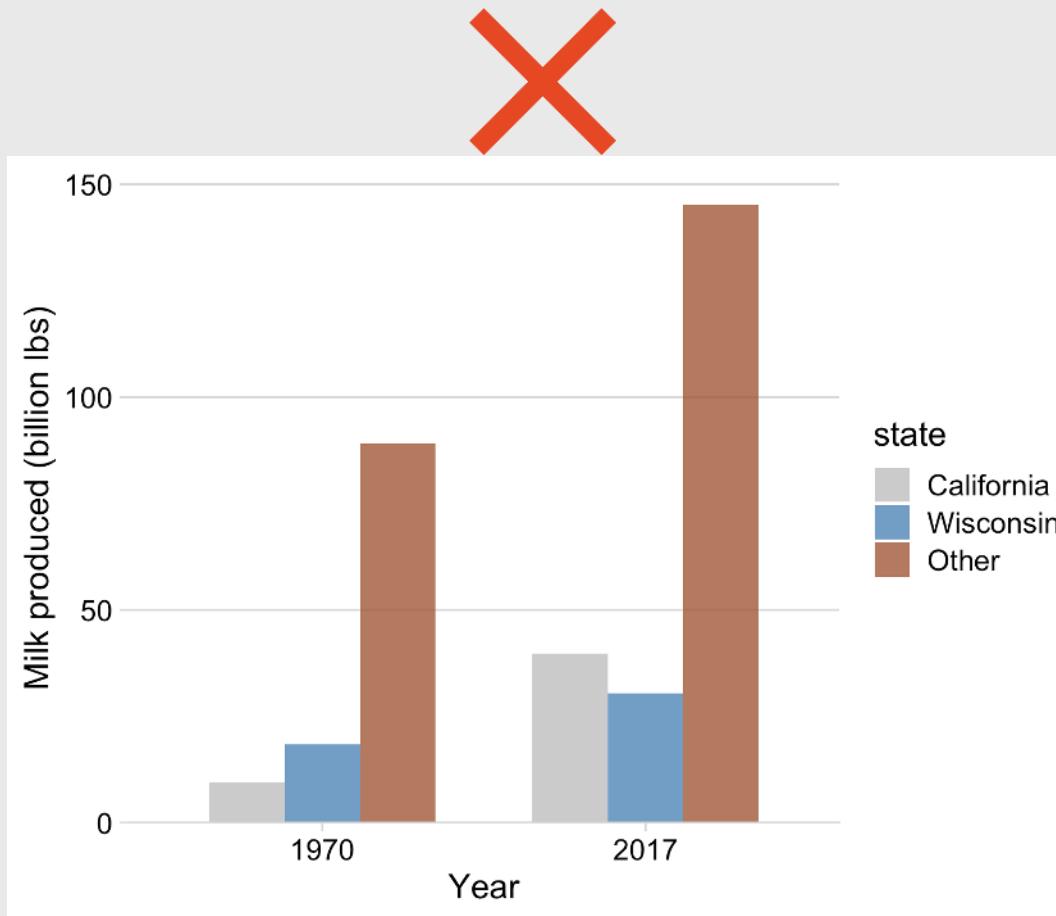
Exception: When you have repeated categories



If you use a legend, use **few categories as possible**



Or use faceting to eliminate the legend!



5 Data Viz Do's

1. Annotate your charts

2. Eliminate legends

Match your chart type to your message

3. Show amounts with bars, dots, and lollipops

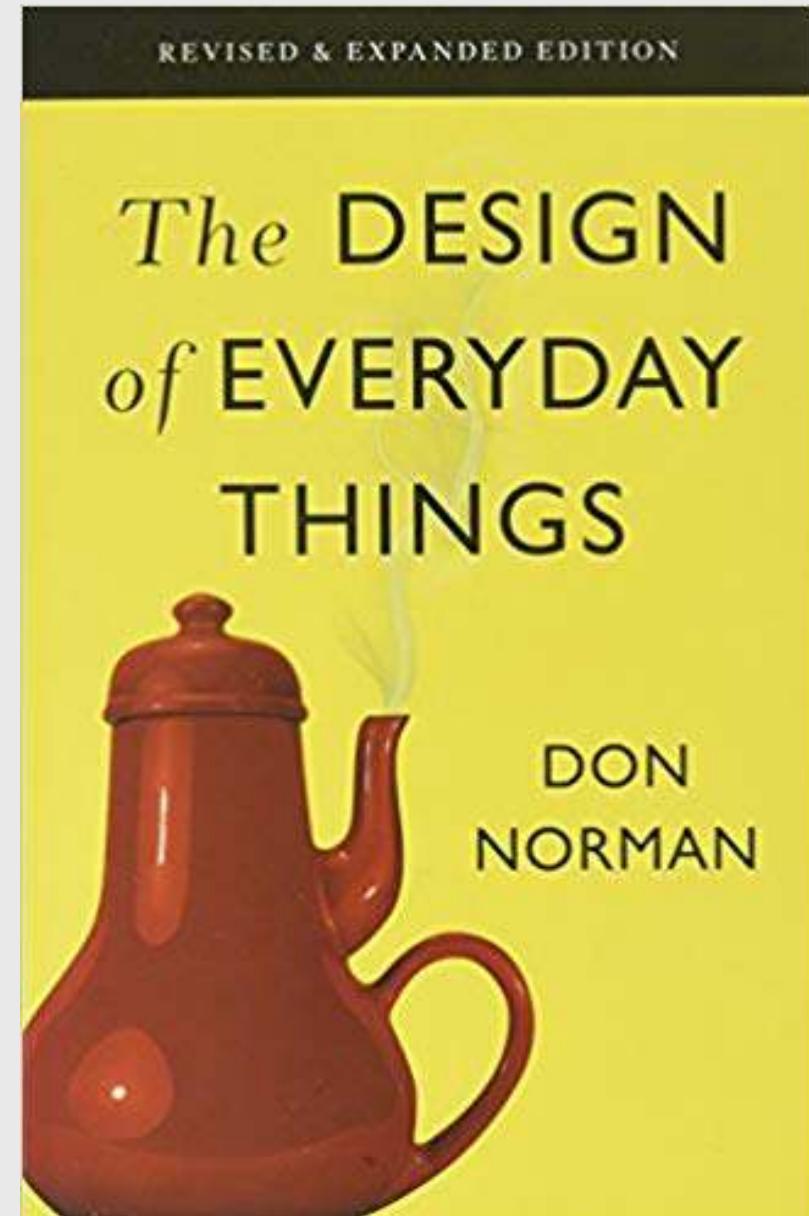
4. Show proportions with bars and waffles (not pies)

5. Show trends with lines, bars, and heatmaps



Norman door (n.):

1. A door where the design tells you to do the opposite of what you're actually supposed to do.
2. A door that gives the wrong signal and needs a sign to correct it.



Norman door



Norman door



Non-Norman door



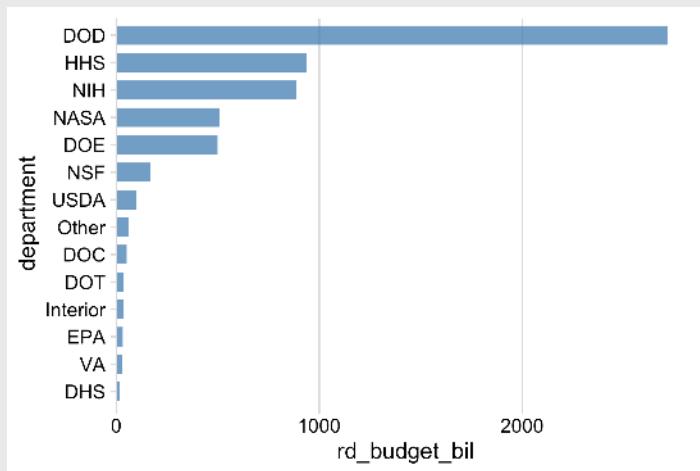
Match your chart type to your message

Show amounts with:

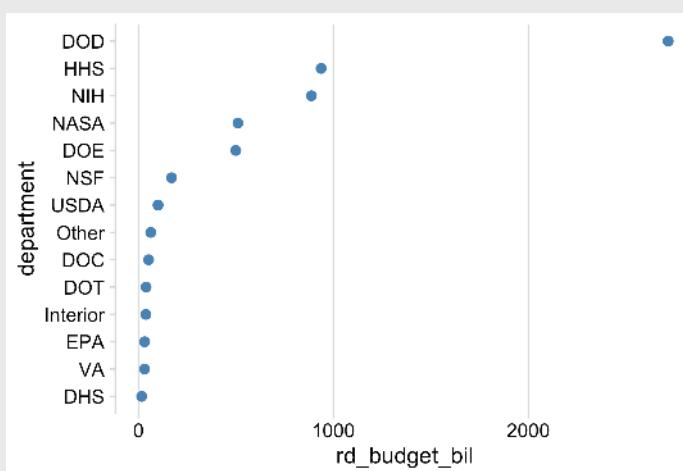




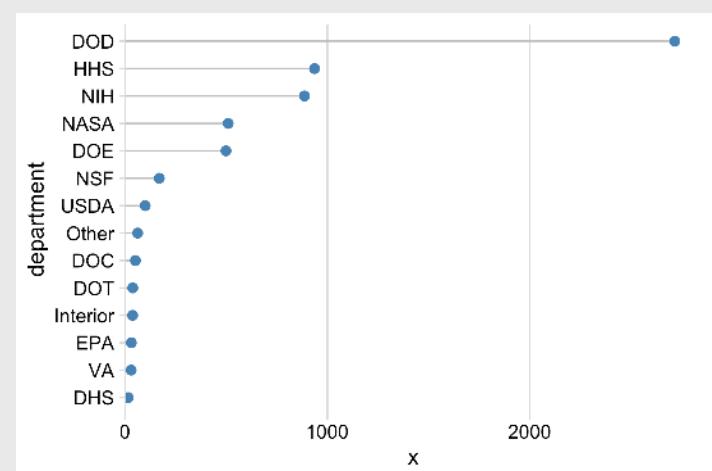
Bar chart



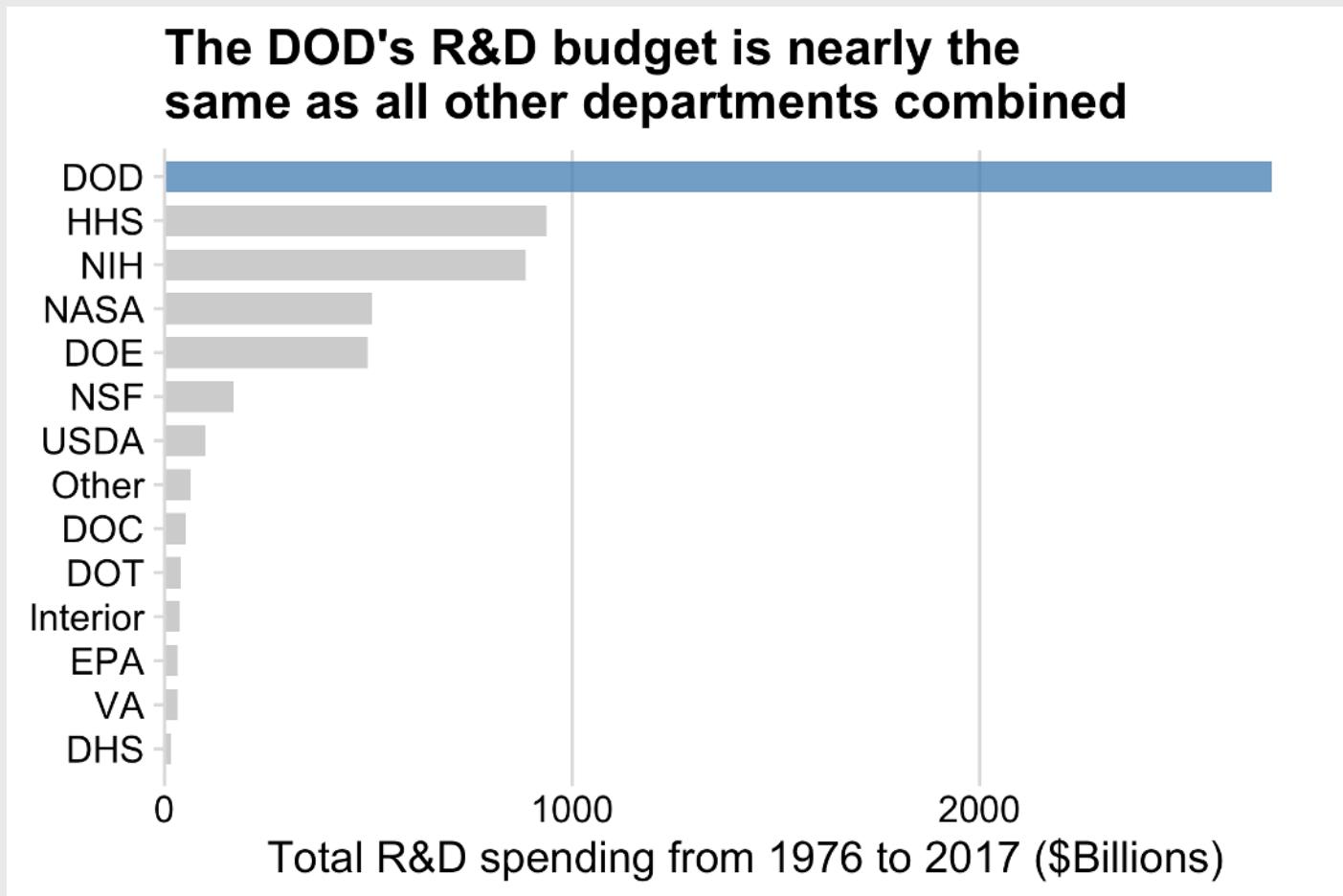
Dot chart



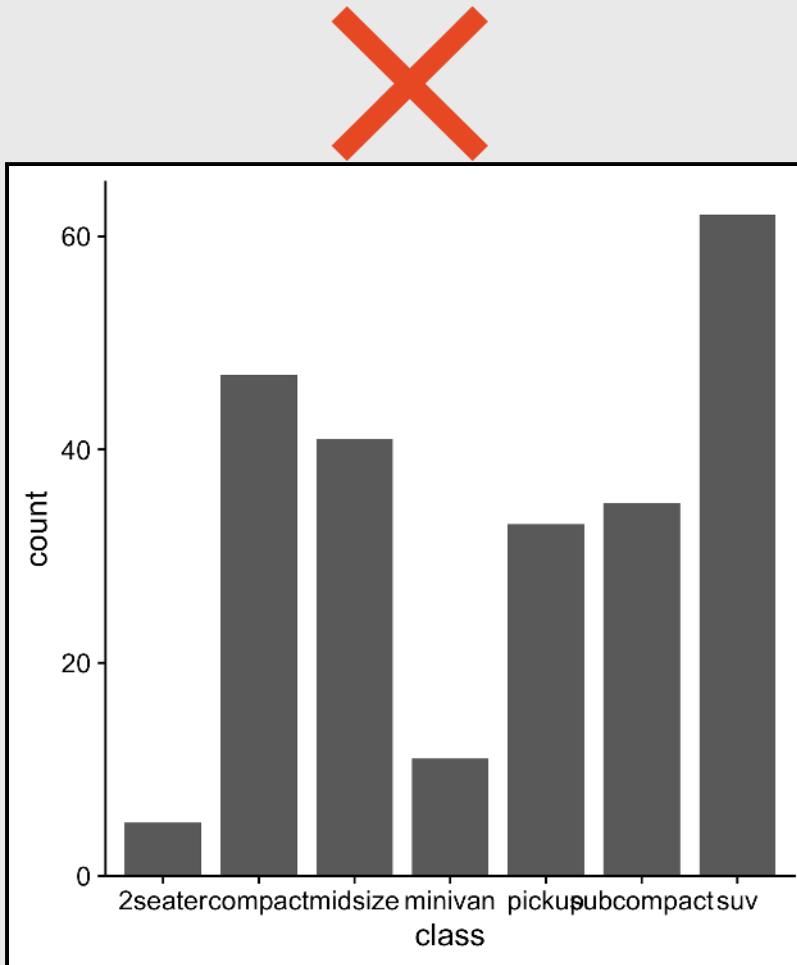
Lollipop chart



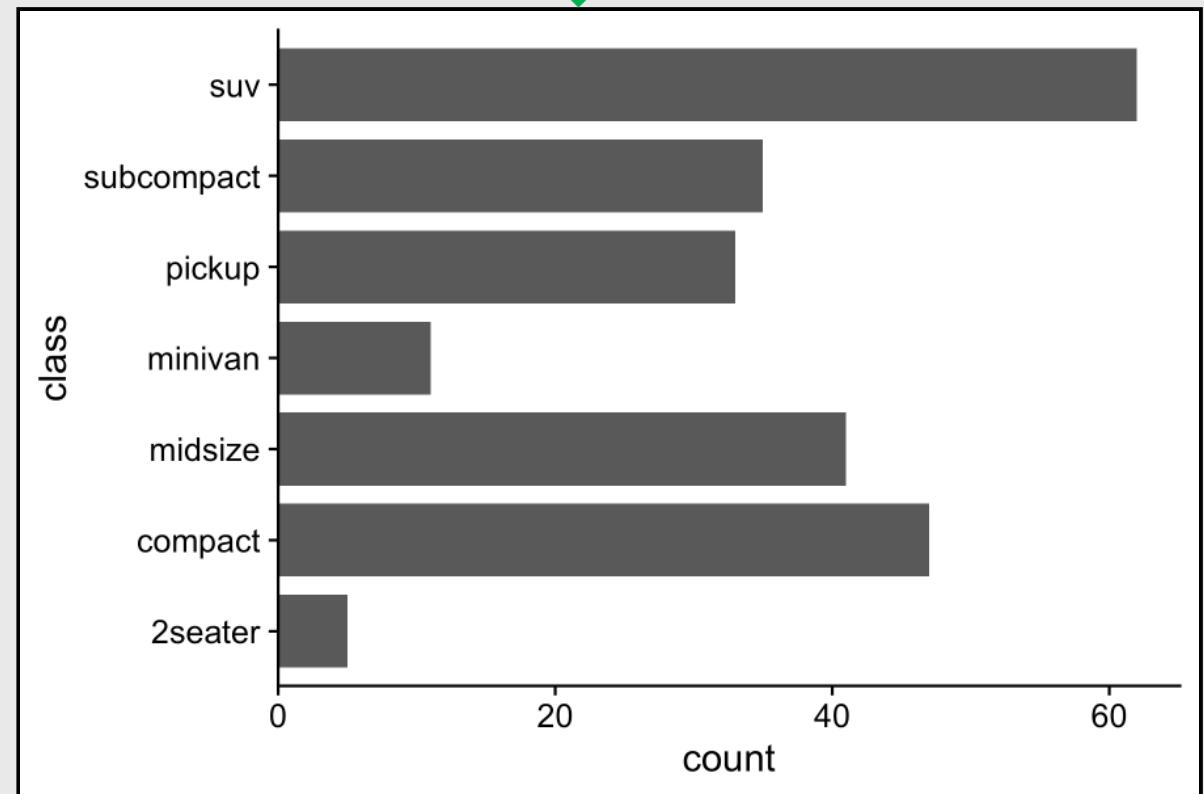
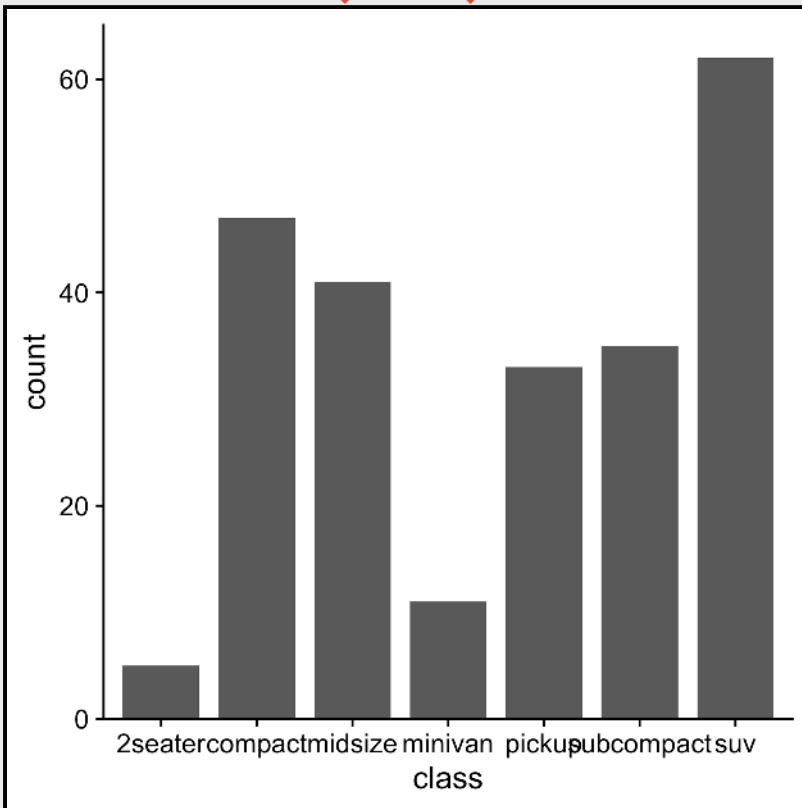
Bars are good for highlighting specific categories



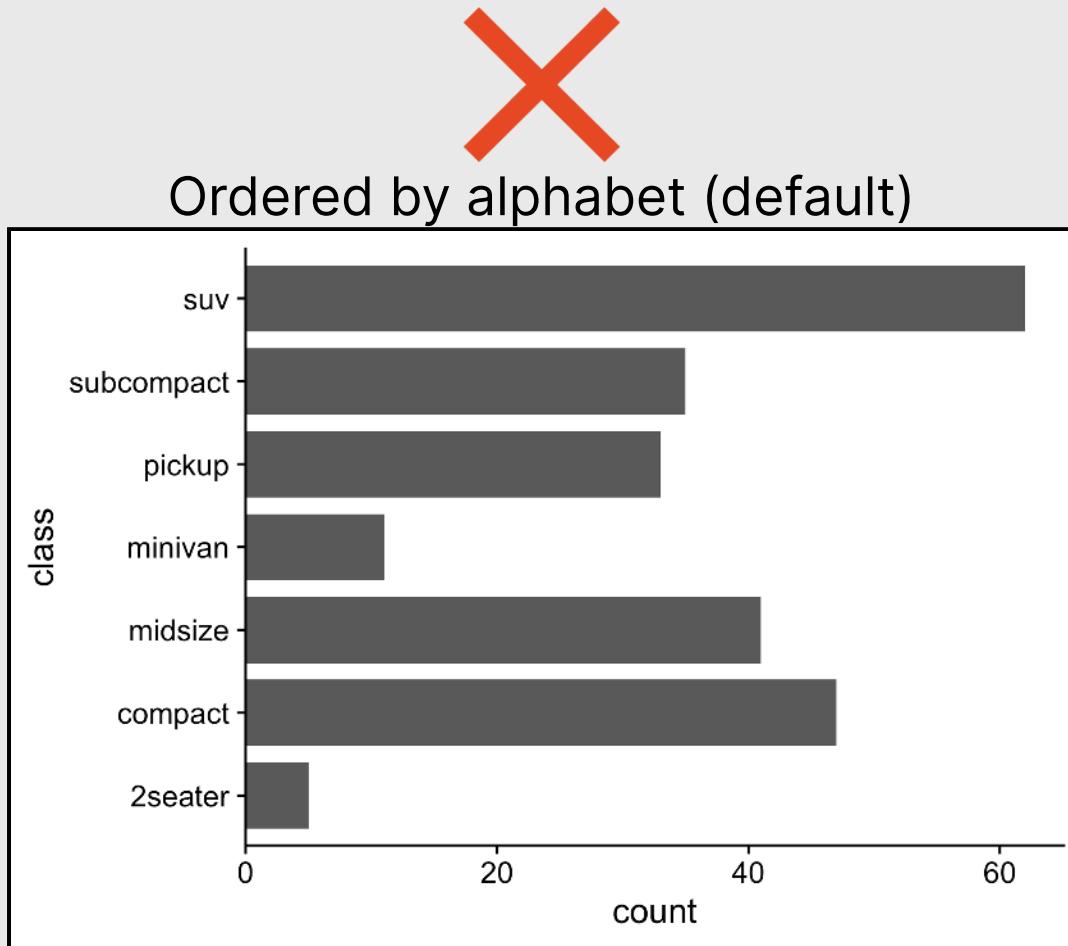
Rotate axes if you can't read them



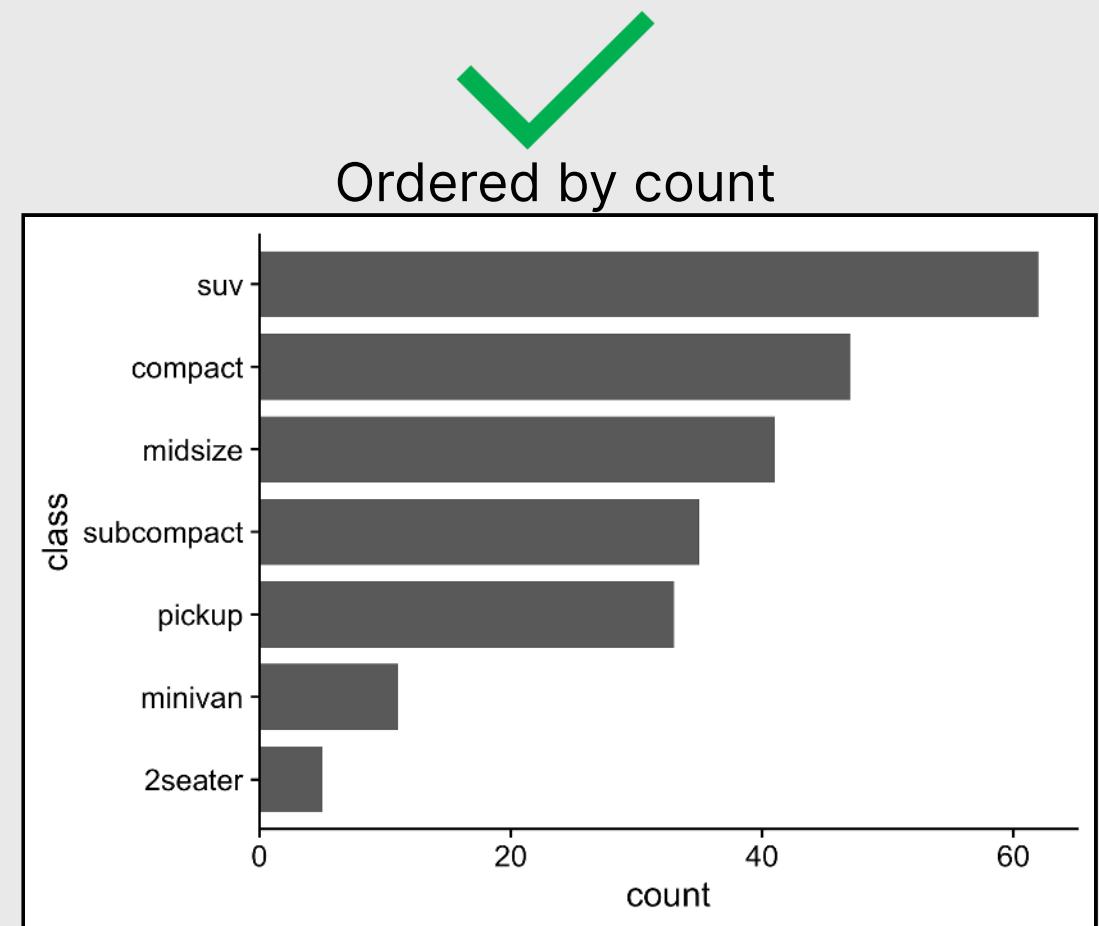
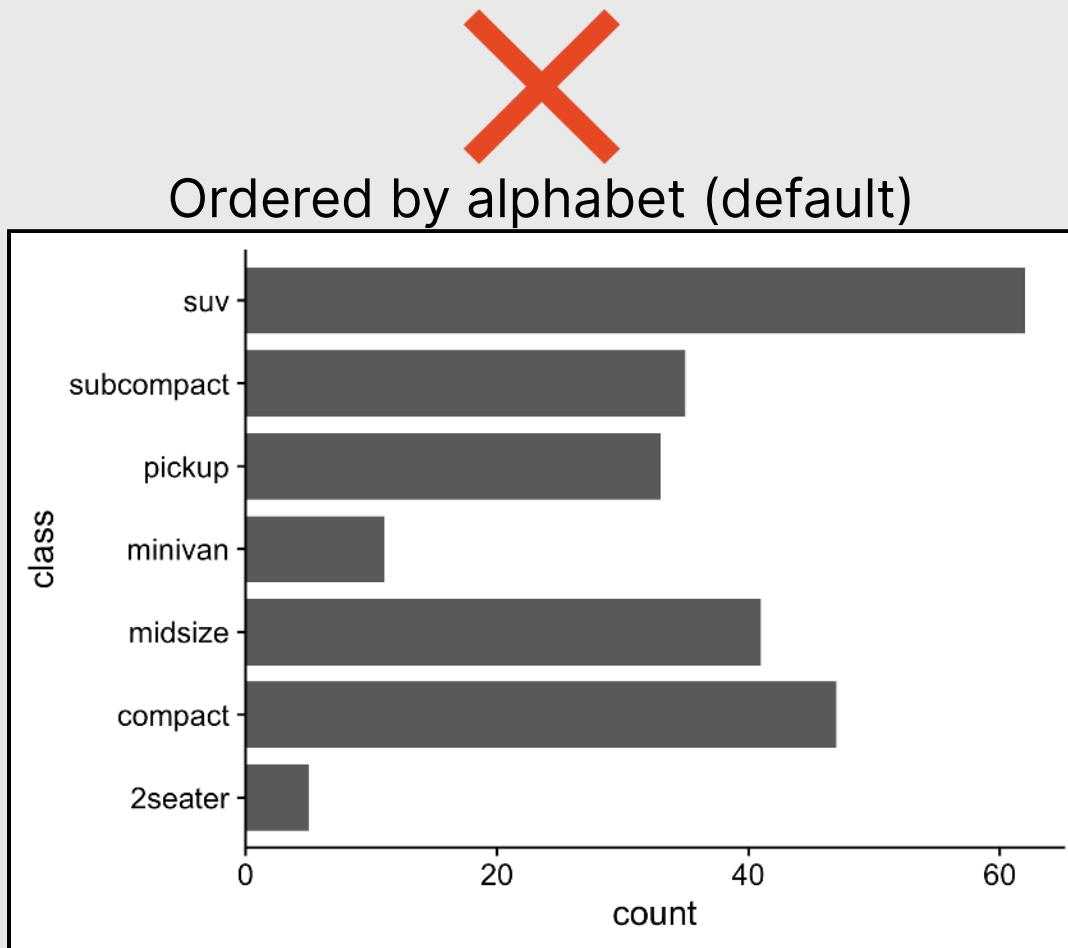
Rotate axes if you can't read them



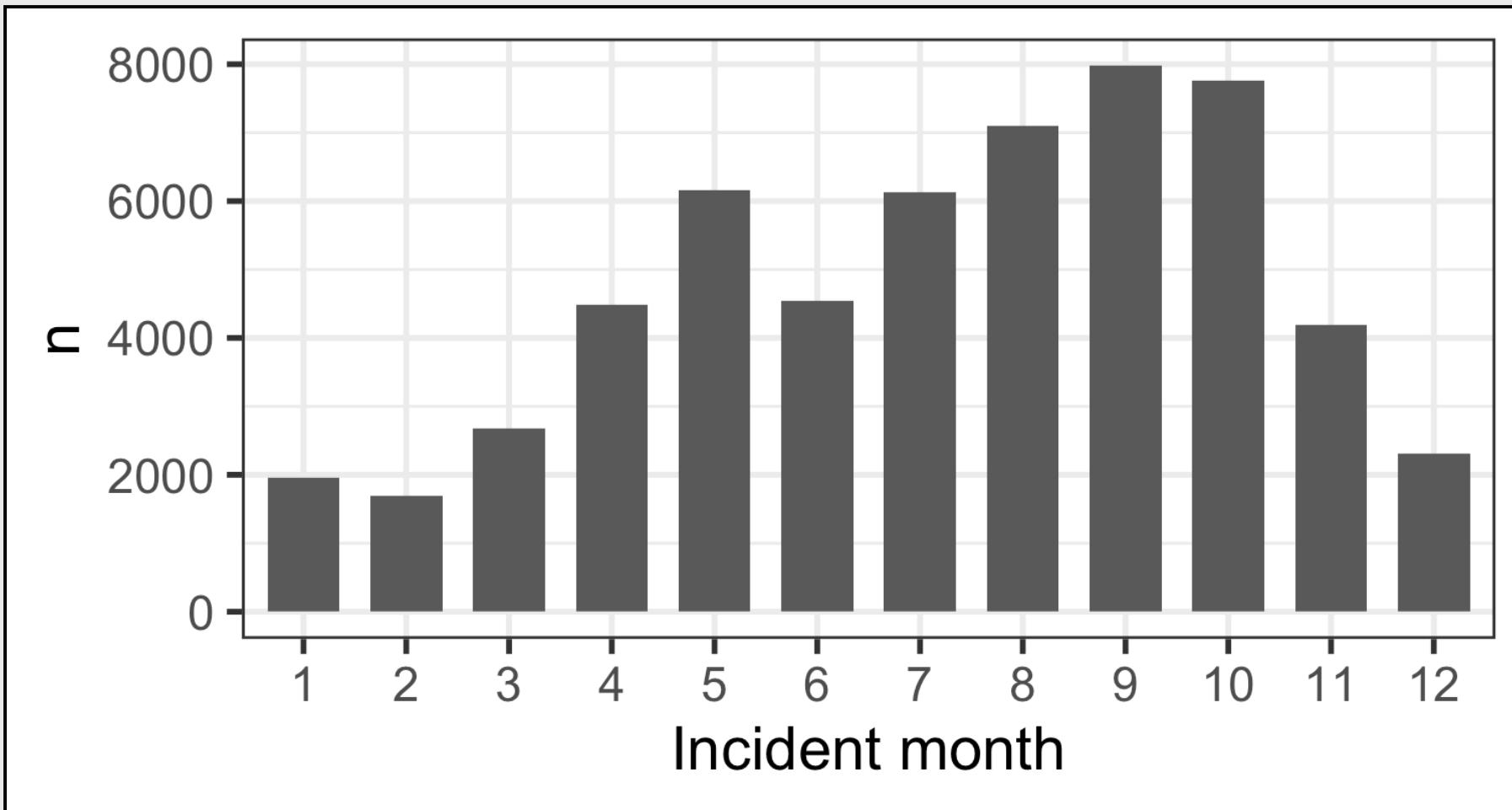
Default order is almost always wrong



Default order is almost always wrong

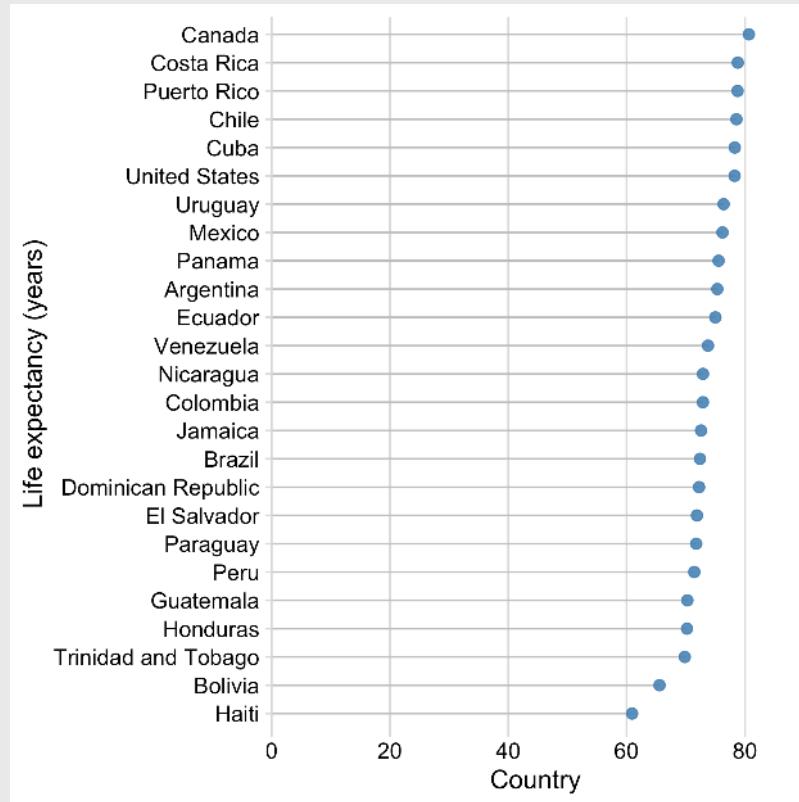
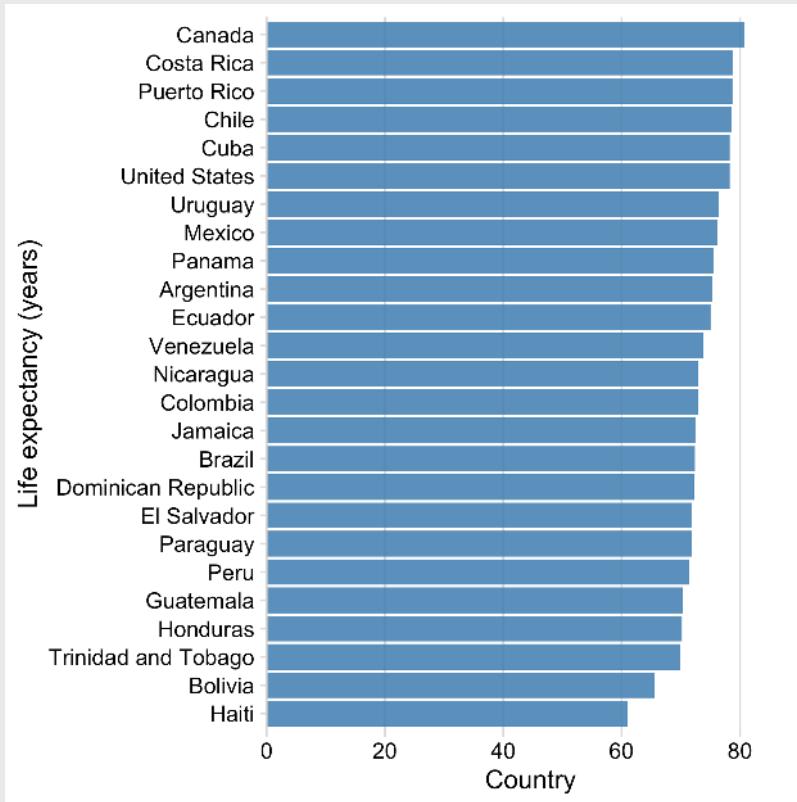


Exception: When the order matters

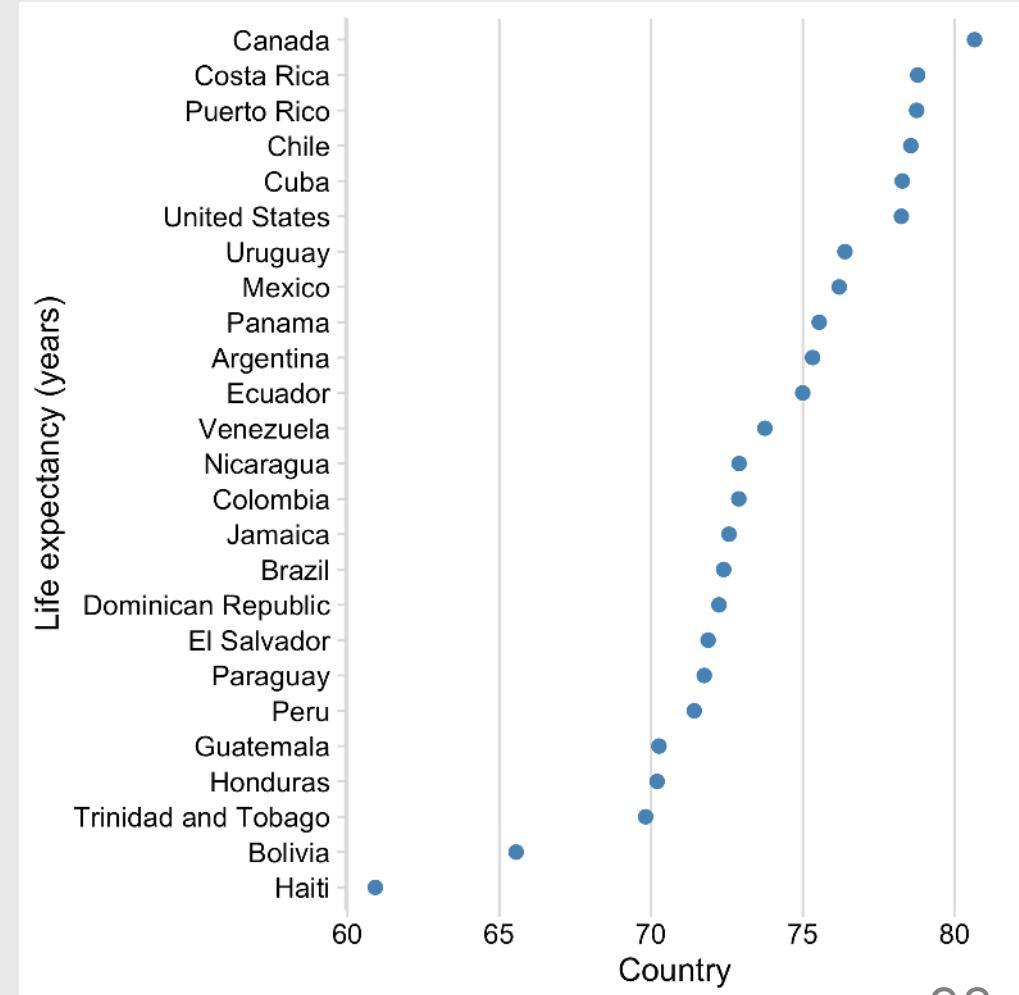
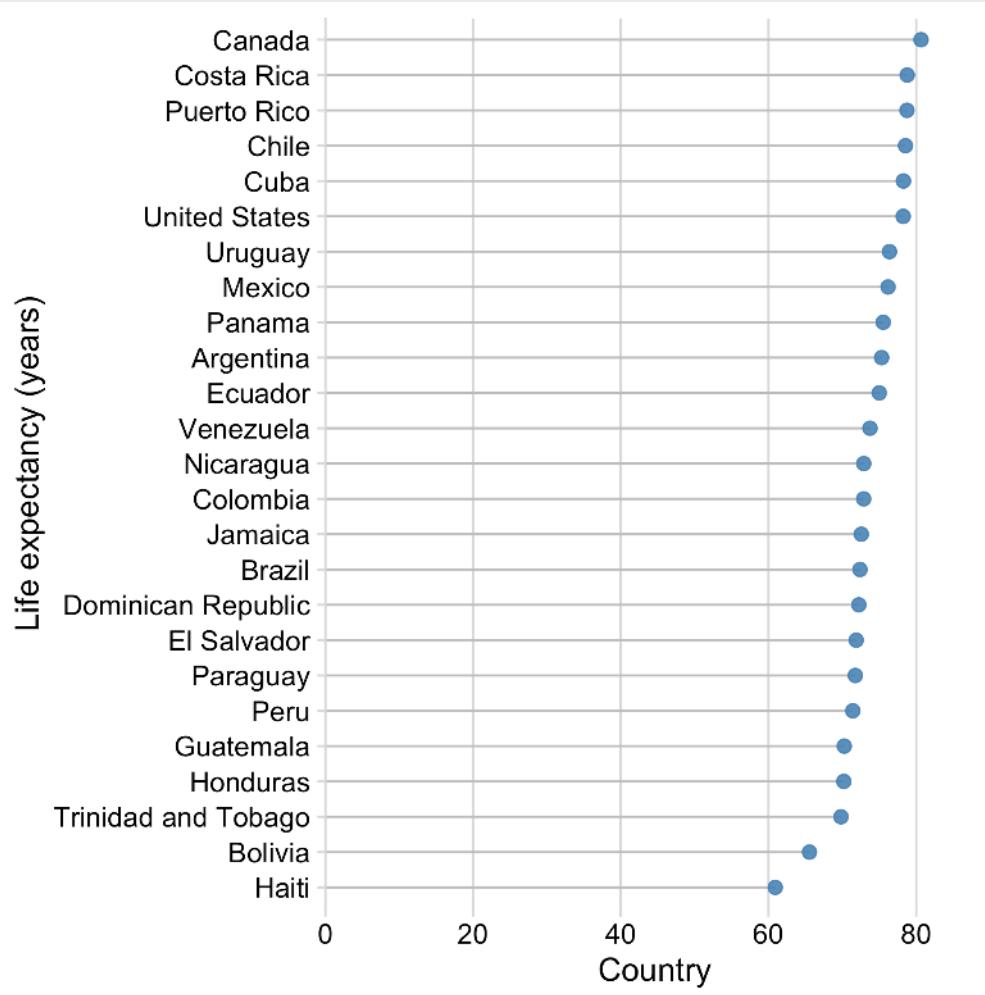


Use lollipops when:

- The bars are overwhelming
- You're not highlighting categories



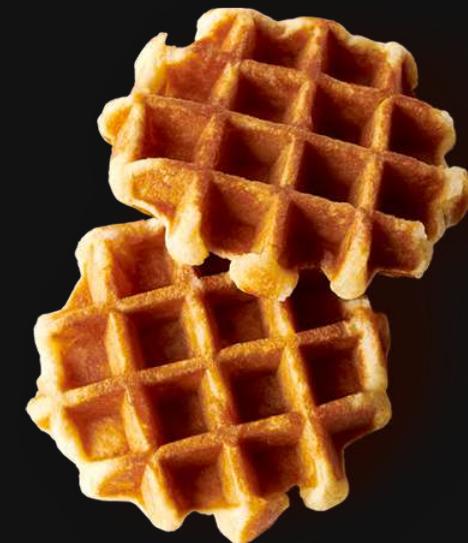
Or use dots



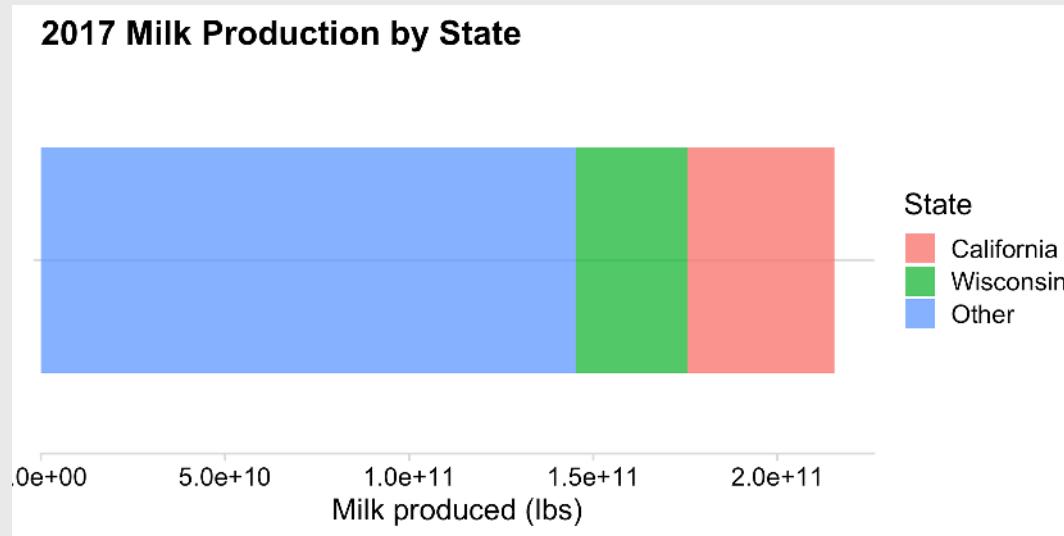
5 Data Viz Do's

1. Annotate your charts
2. Eliminate legends
3. Show amounts with bars, dots, and lollipops
4. Show proportions with bars and waffles (not pies)
5. Show trends with lines, bars, and heatmaps

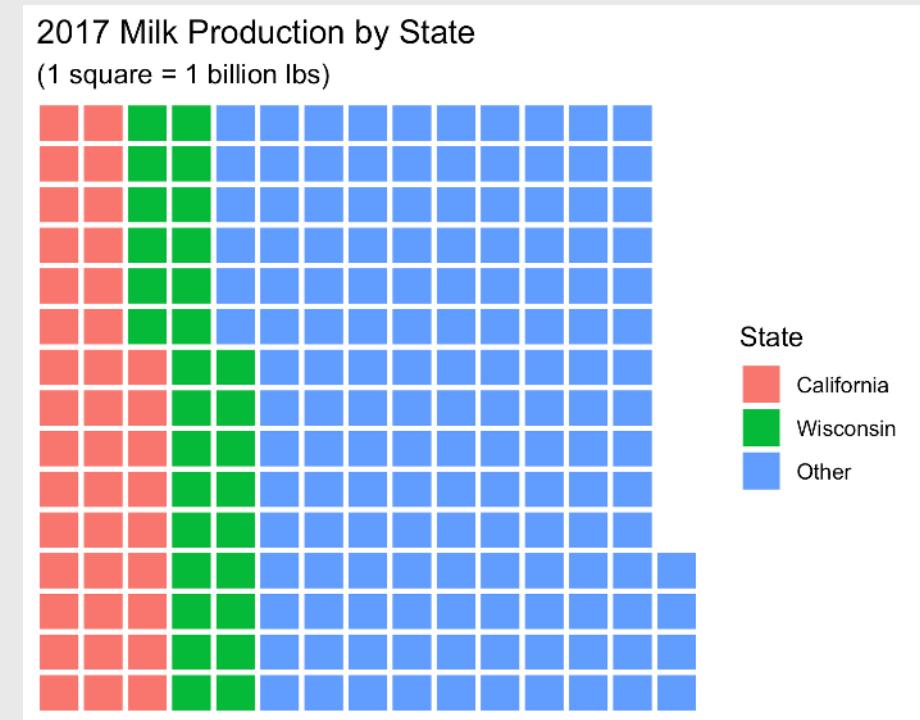
Show proportions with:



Bar charts

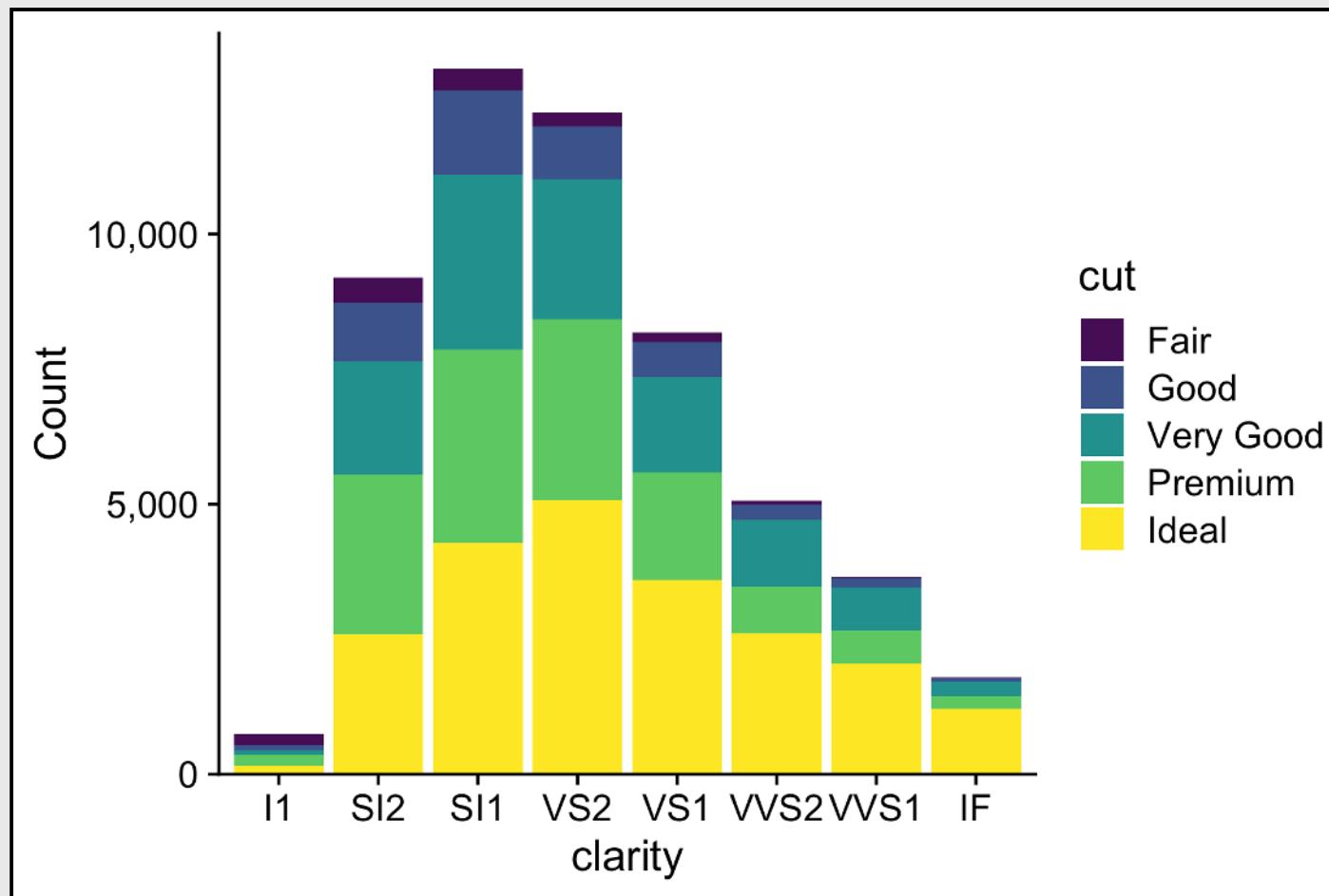


Waffle charts

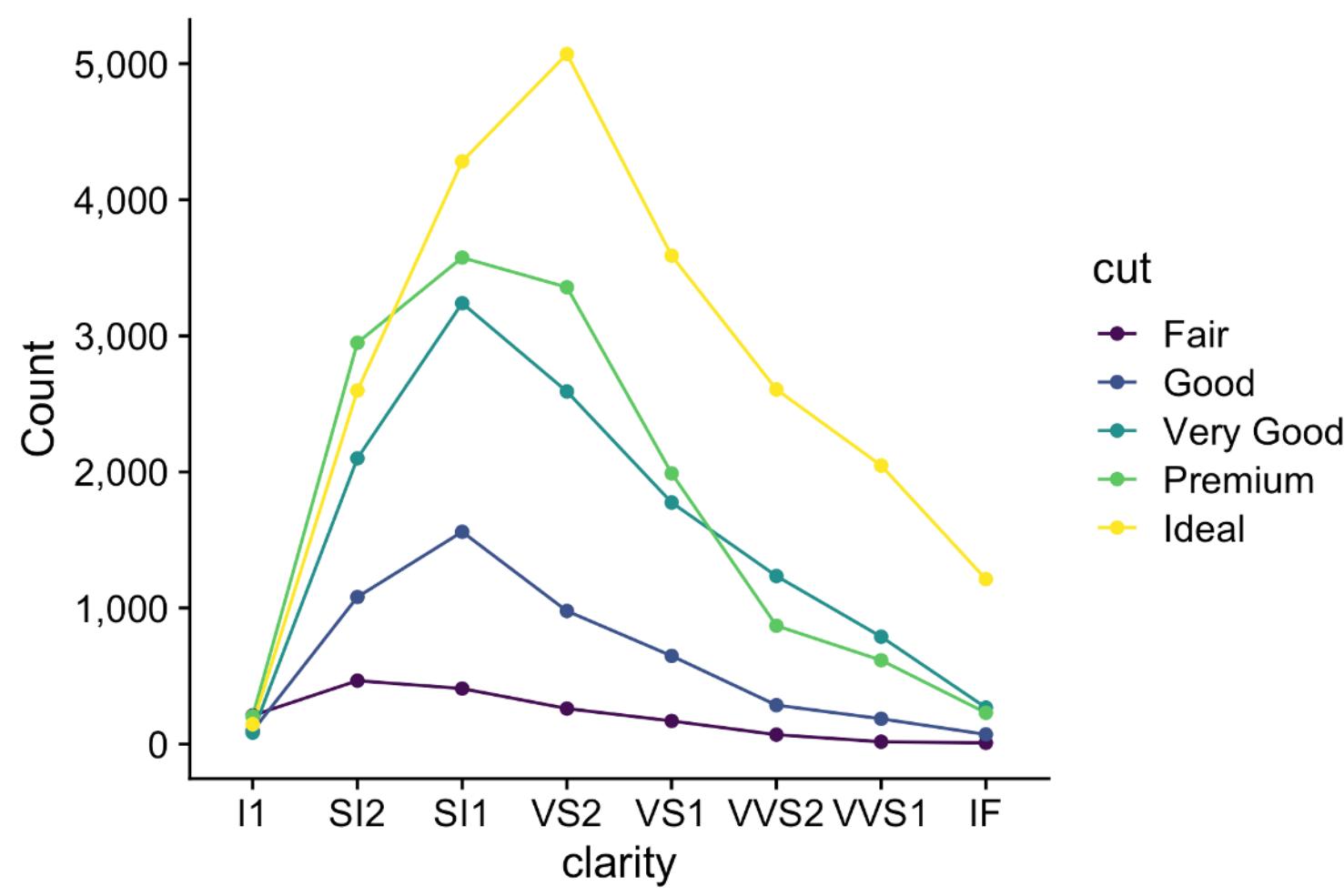


Stacked bars are rarely a good idea

Stacked bars are rarely a good idea



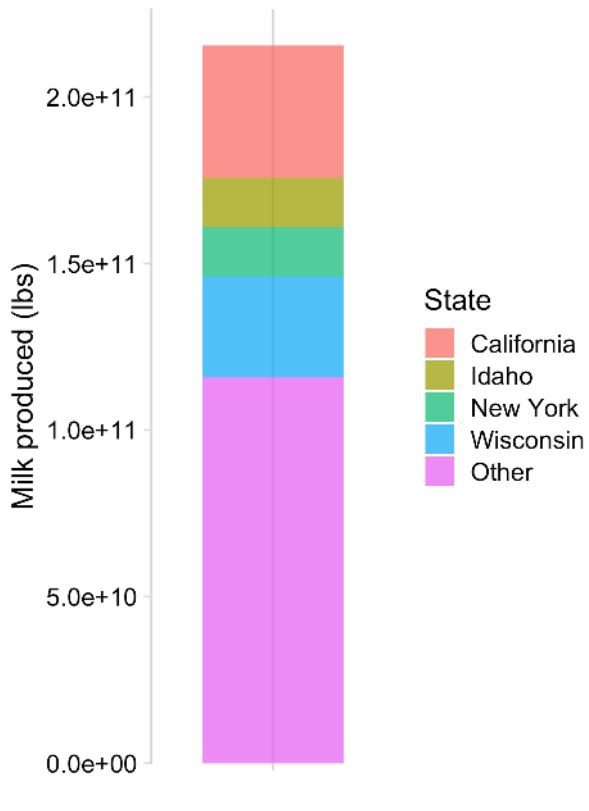
"Parallel coordinates" plot is a good alternative



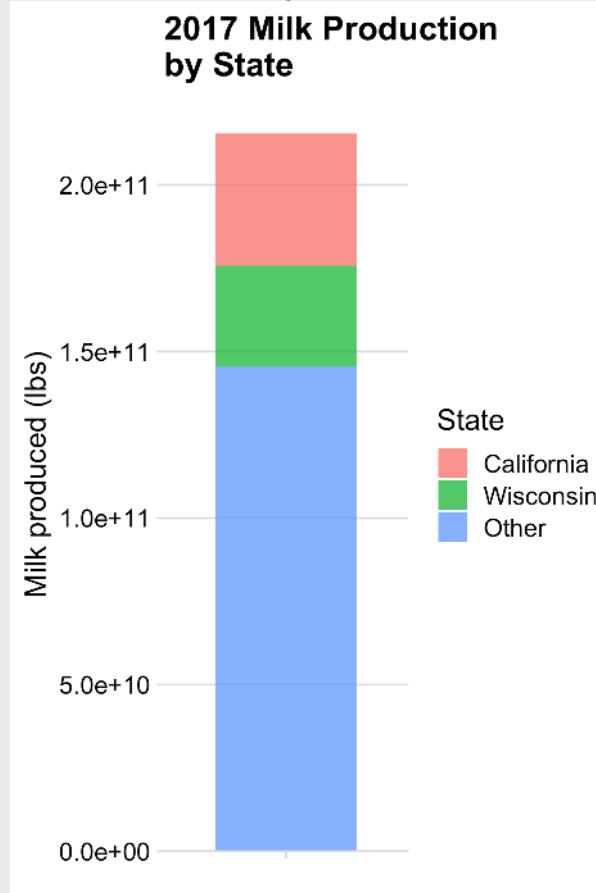
Where stacking is useful



2017 Milk Production
by State



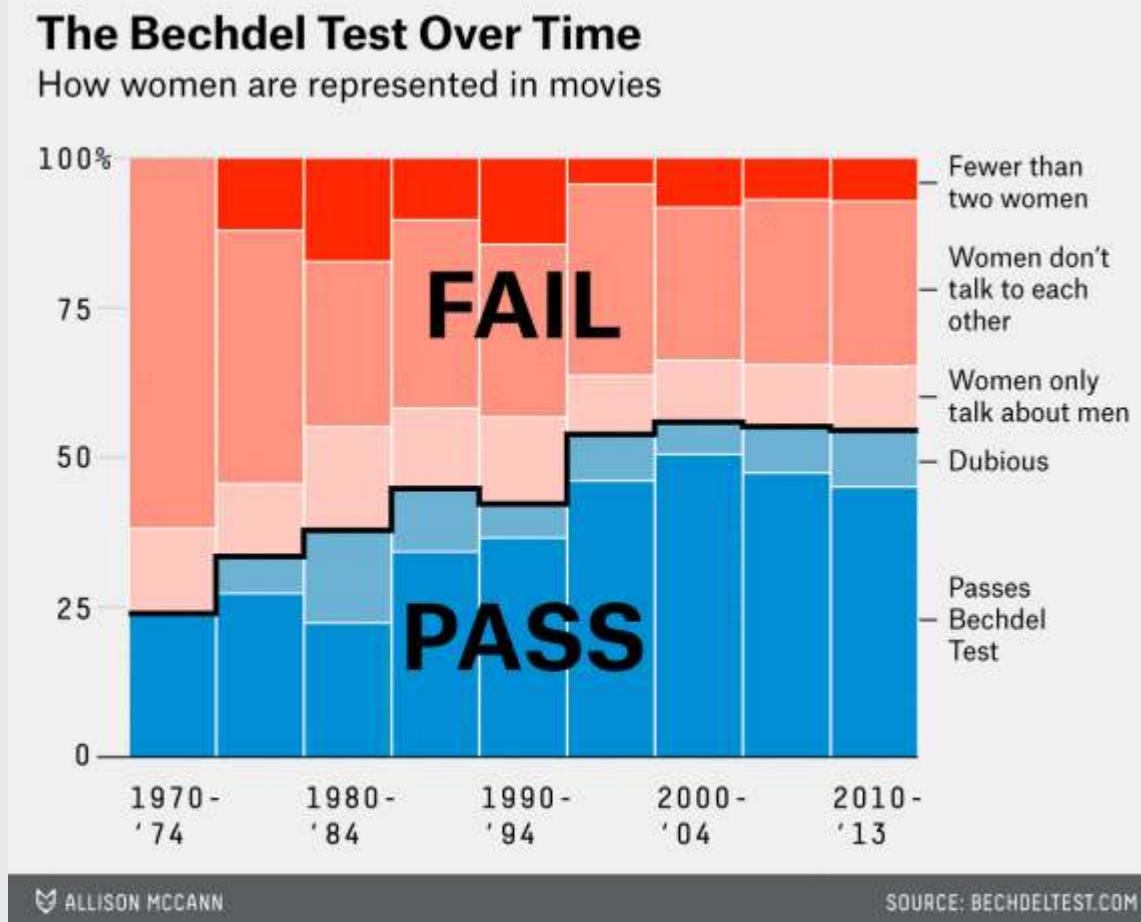
2017 Milk Production
by State



With 2 to 3 groups

Proportions over time

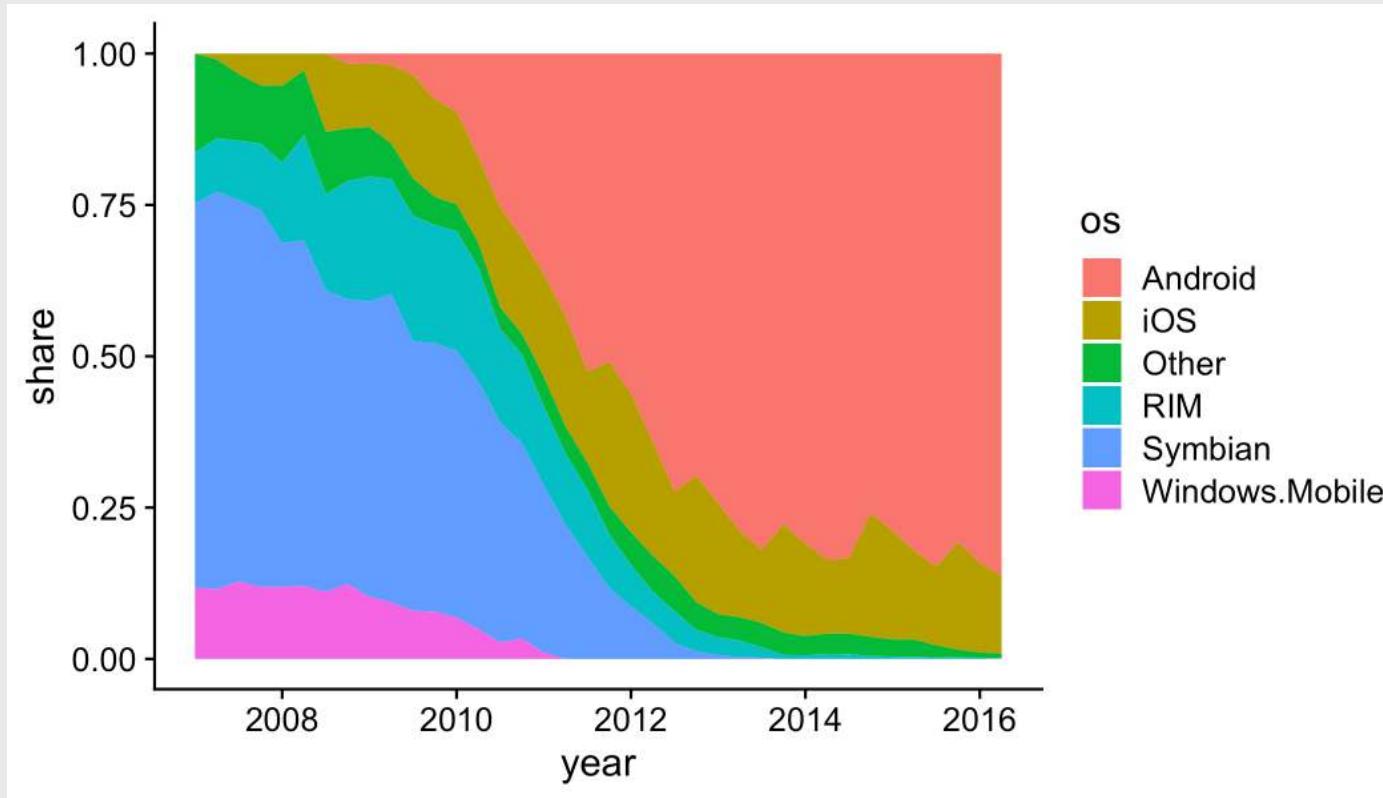
Where stacking is useful



With 2 to 3 groups

Proportions over time

Where stacking is useful

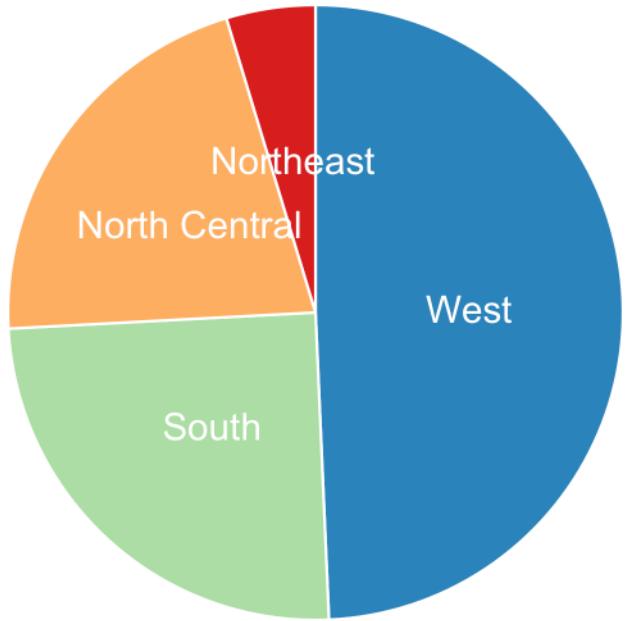


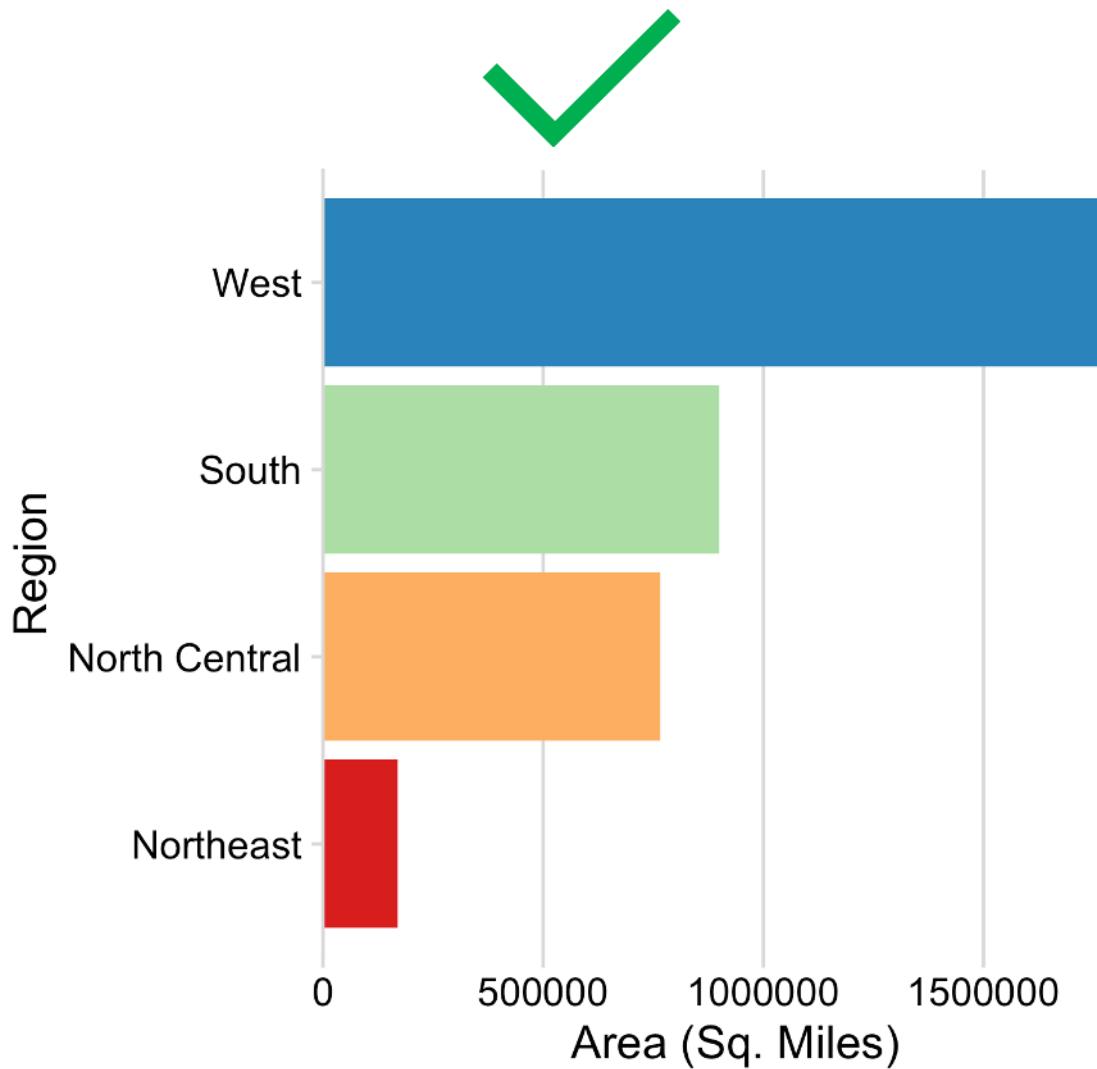
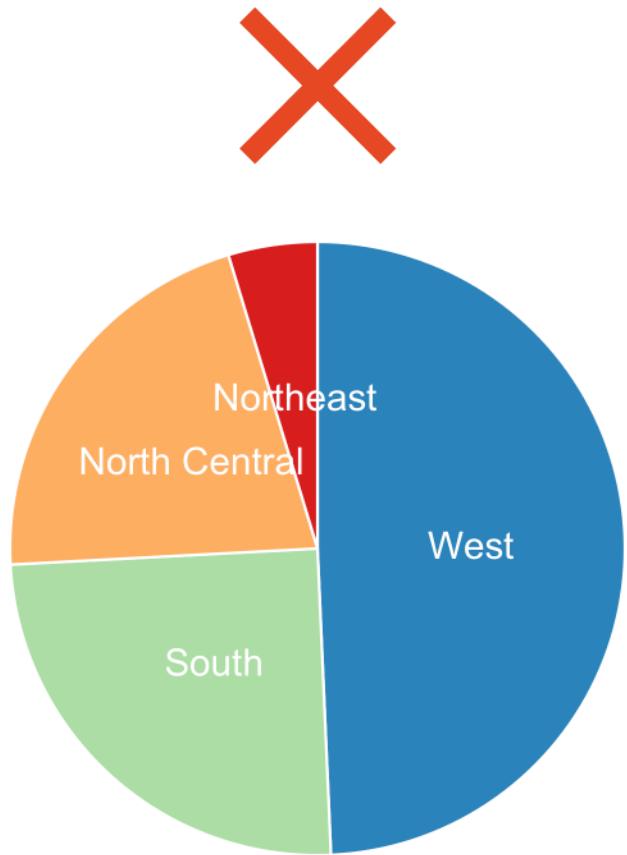
With 2 to 3 groups

Proportions over time

Pies are rarely a good idea

X



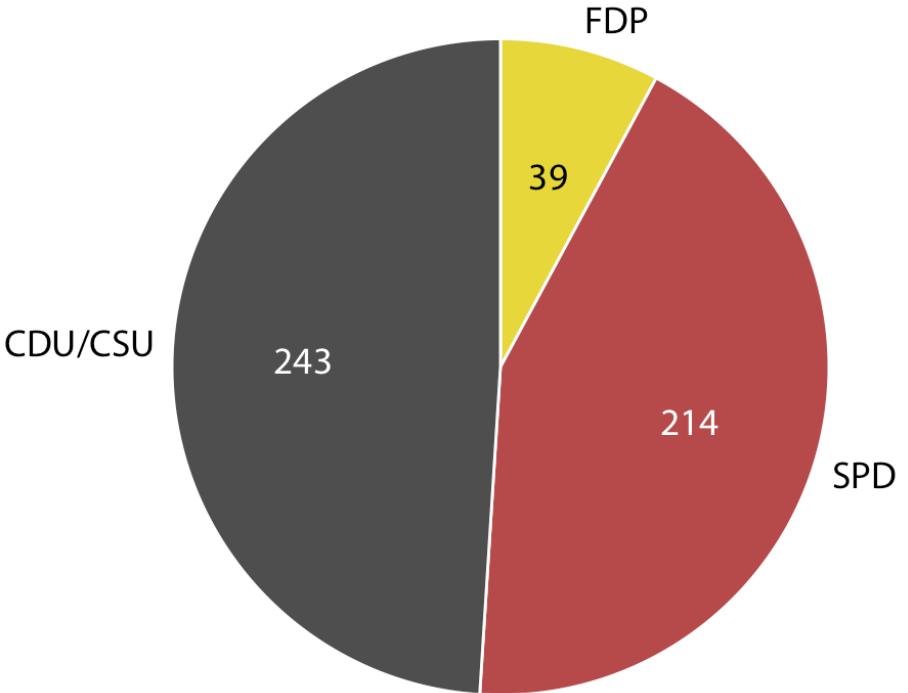


Exceptions:

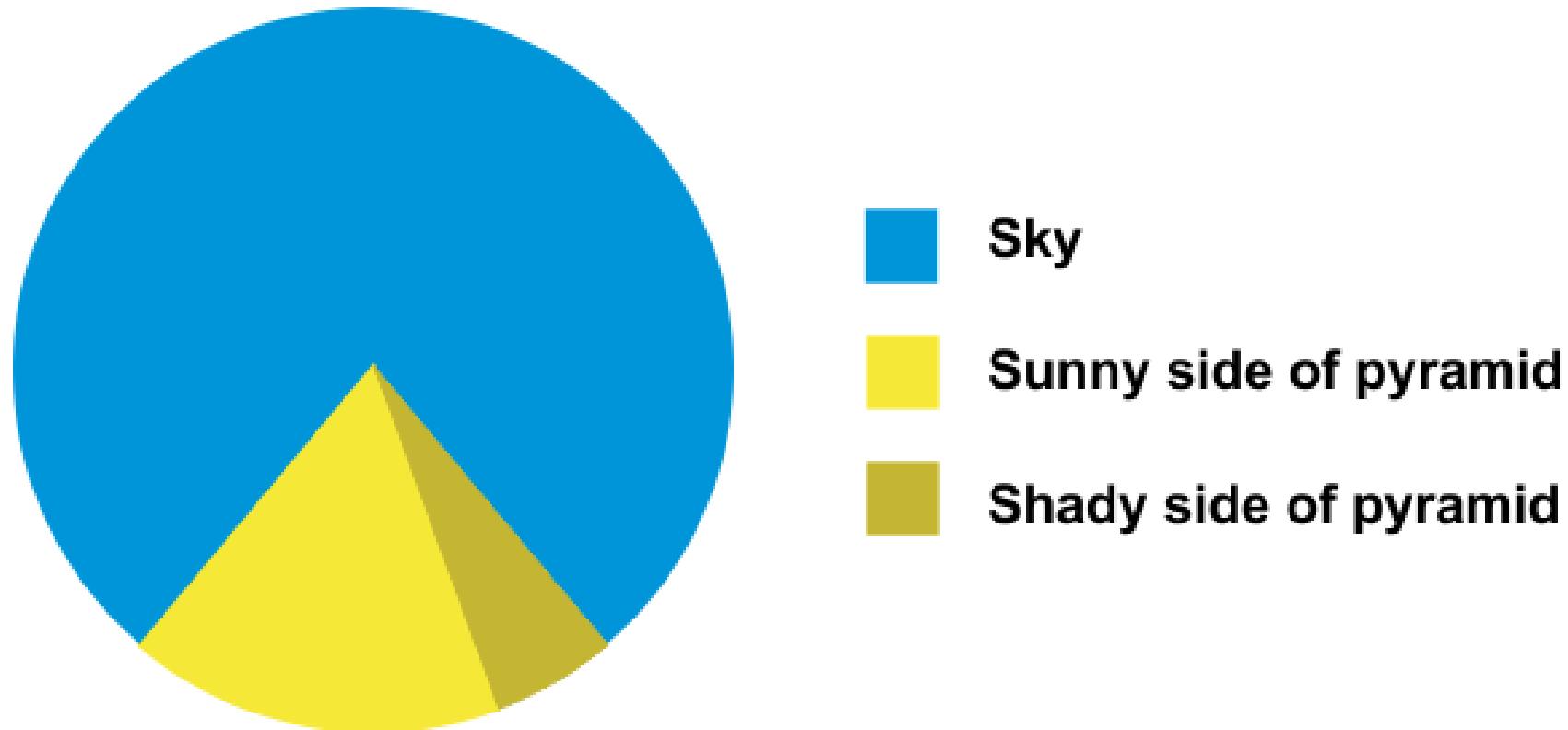
- Small data
- Simple fractions
- If sum of parts matters

Exceptions:

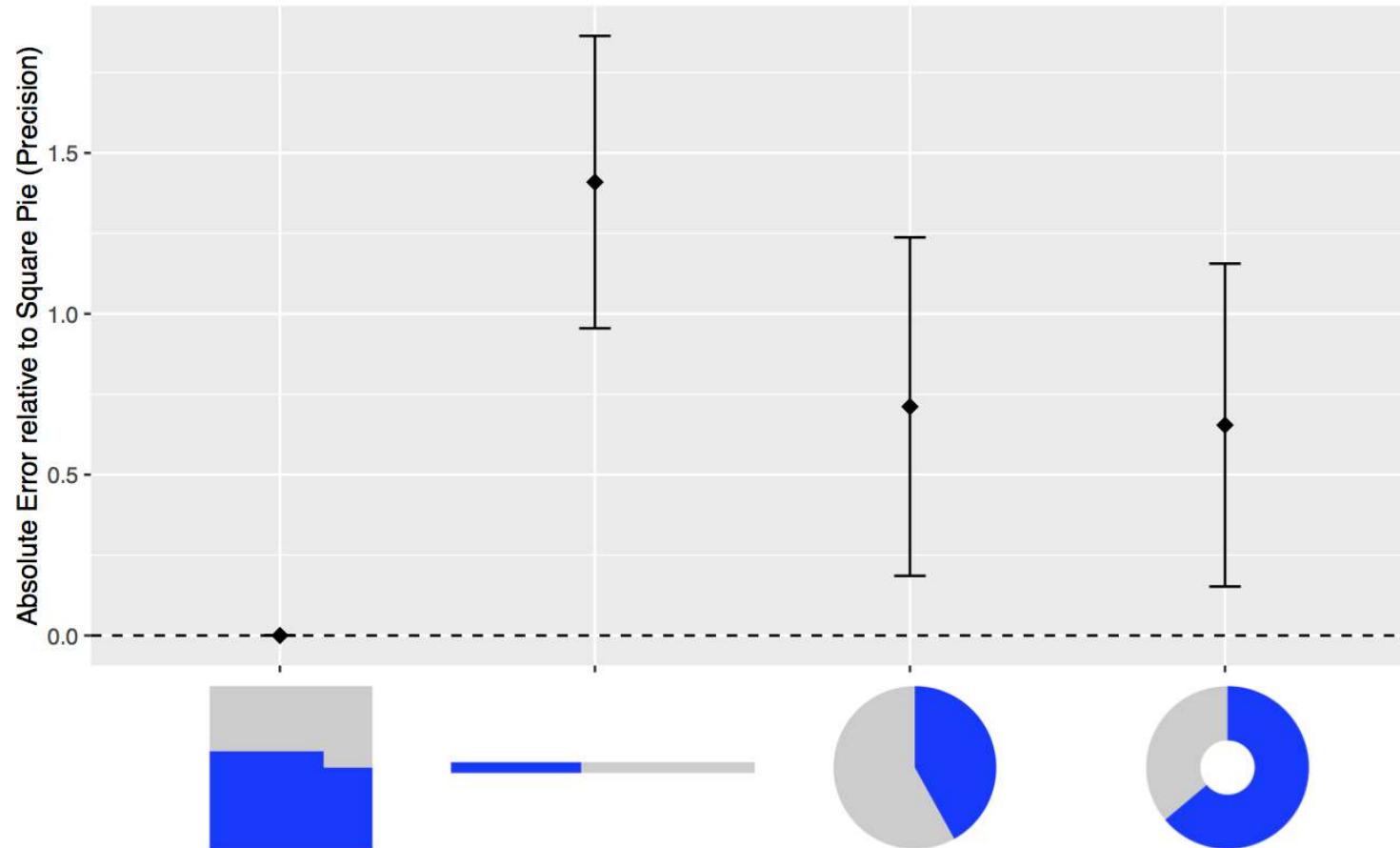
- Small data
- Simple fractions
- If sum of parts matters



Best pie chart of all time

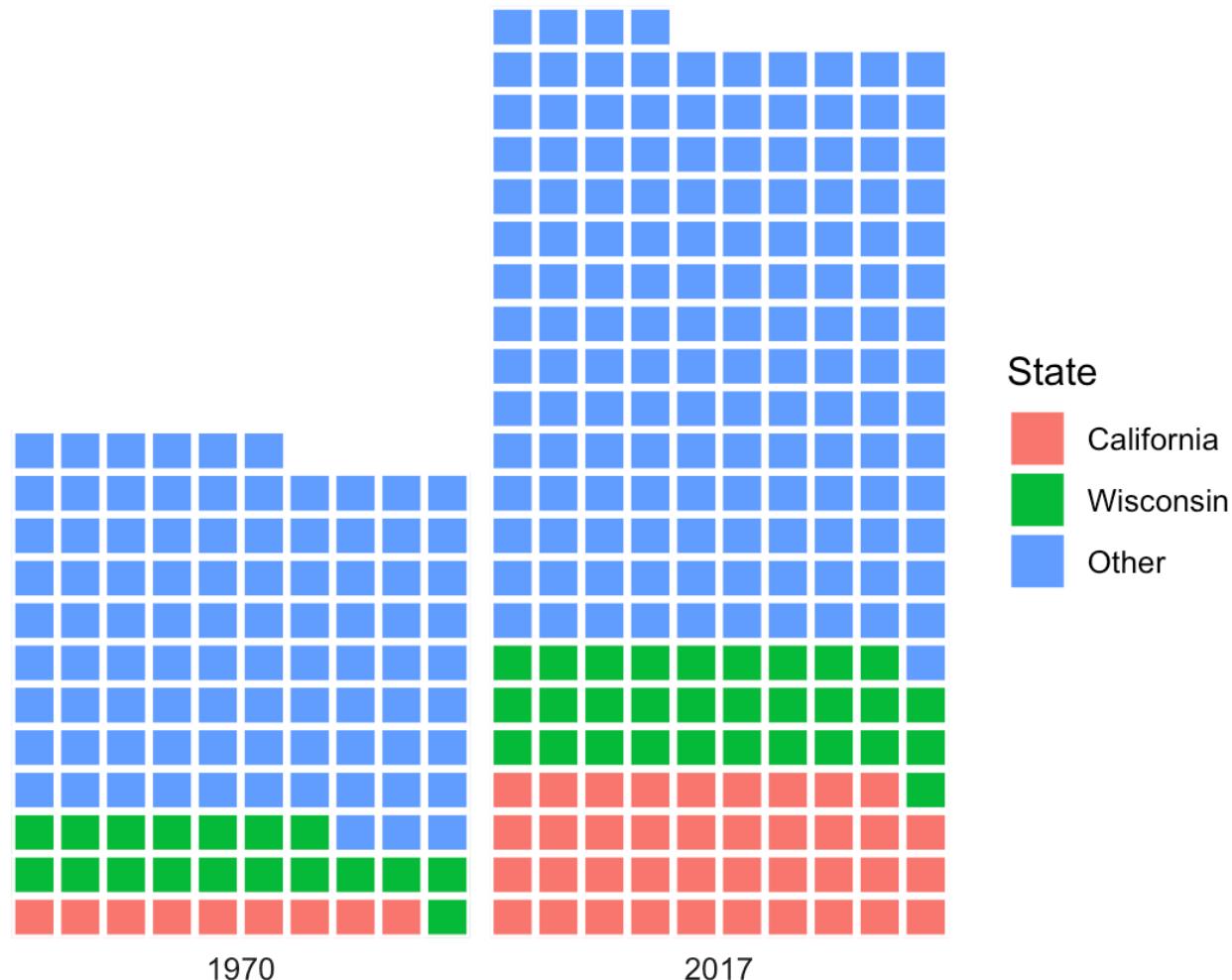


The best pies are **square pies**



1970 & 2017 Milk Production by State

(1 square = 1 billion lbs)

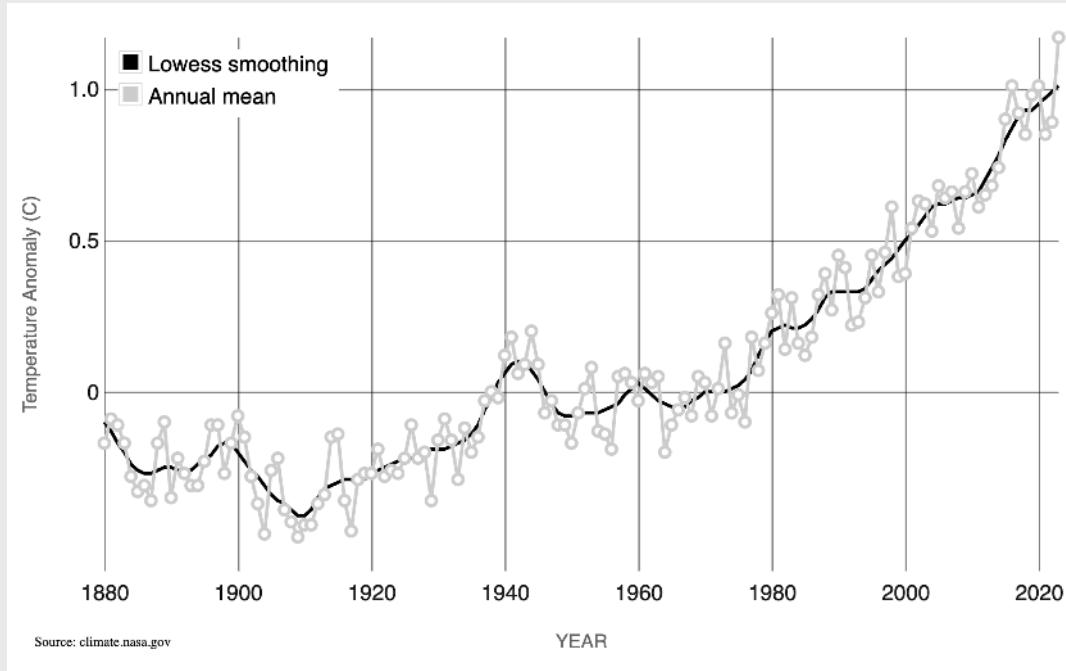


Waffles make
rough
comparisons easy

5 Data Viz Do's

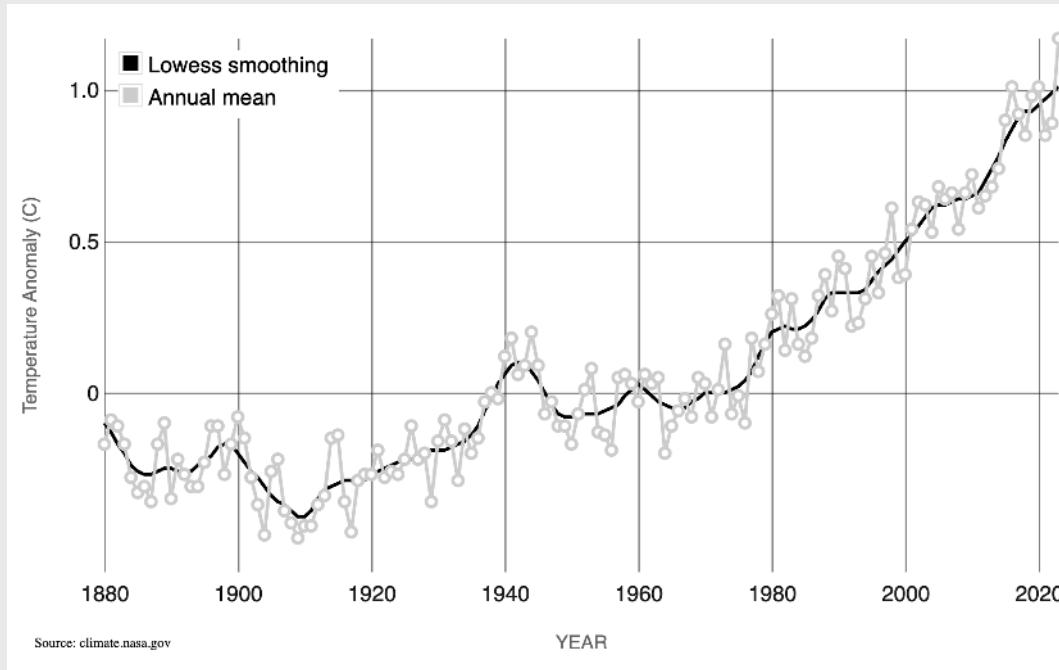
1. Annotate your charts
2. Eliminate legends
3. Show amounts with bars, dots, and lollipops
4. Show proportions with bars and waffles (not pies)
5. Show trends with lines, bars, and heatmaps

For small number of categories, **lines work**

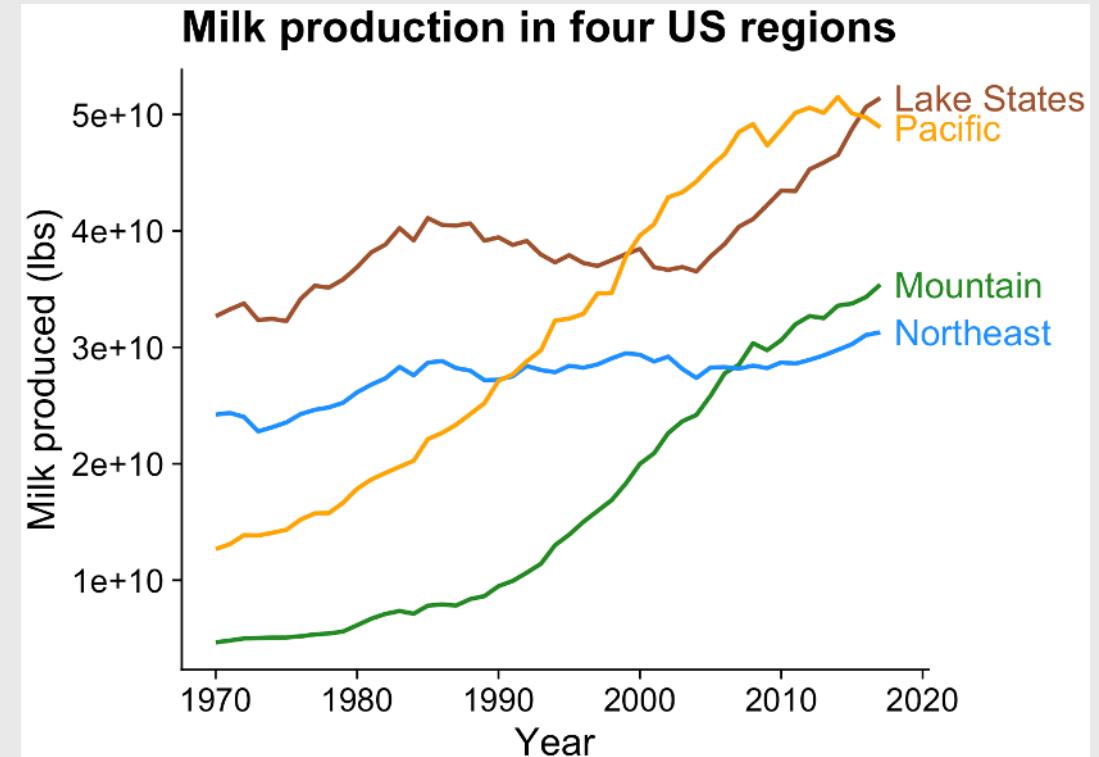


<https://climate.nasa.gov/vital-signs/global-temperature/>

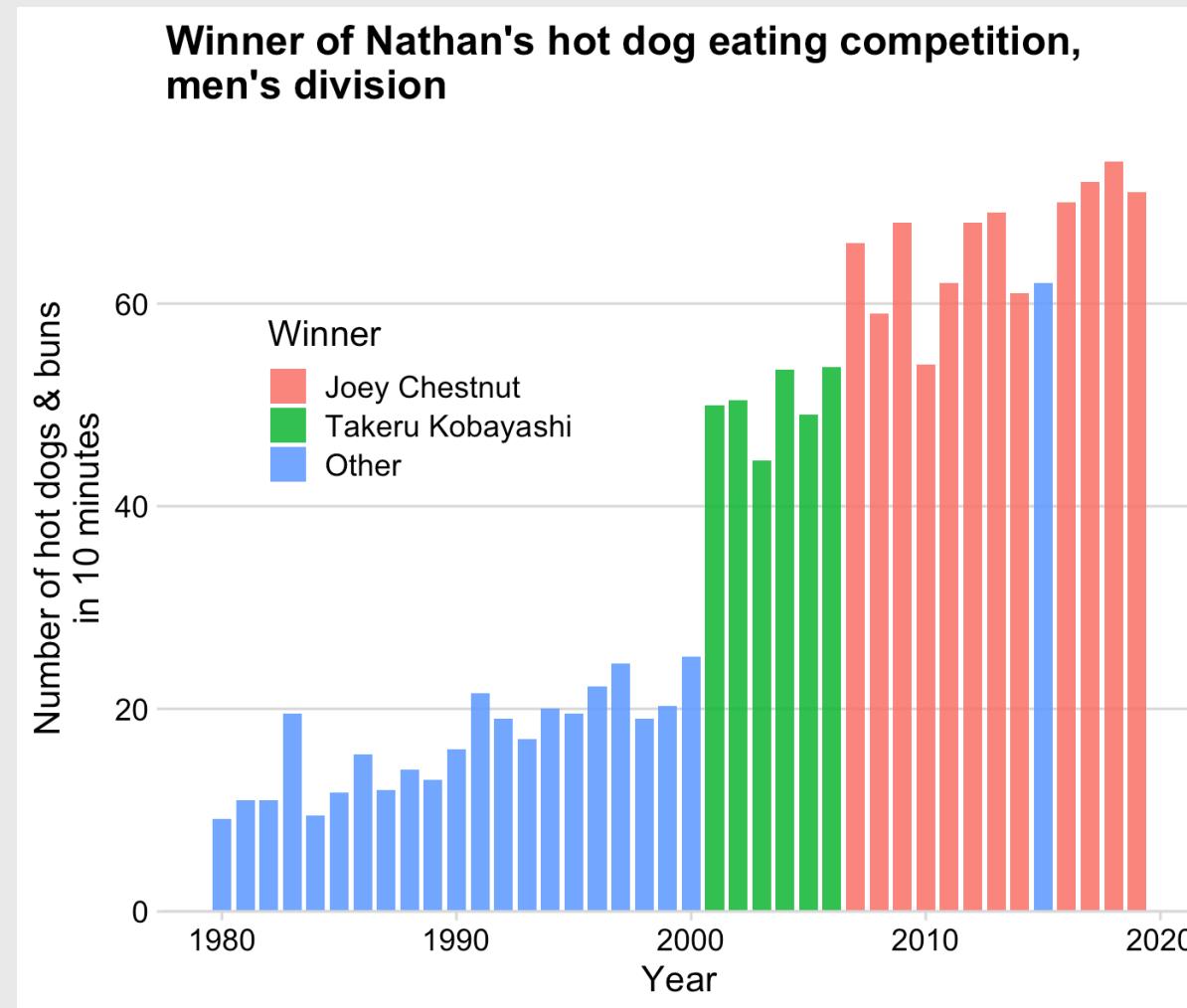
For small number of categories, **lines work**



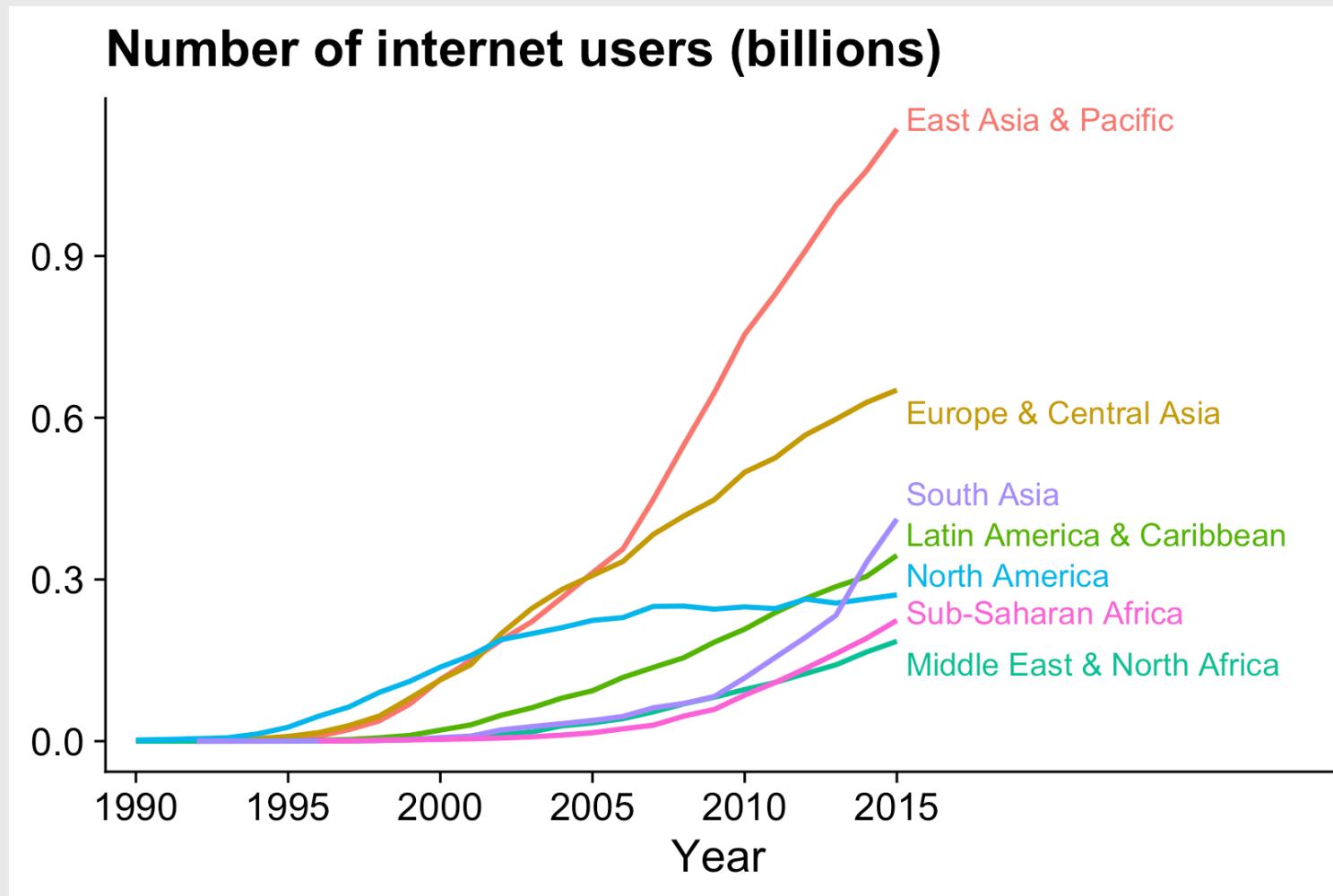
<https://climate.nasa.gov/vital-signs/global-temperature/>



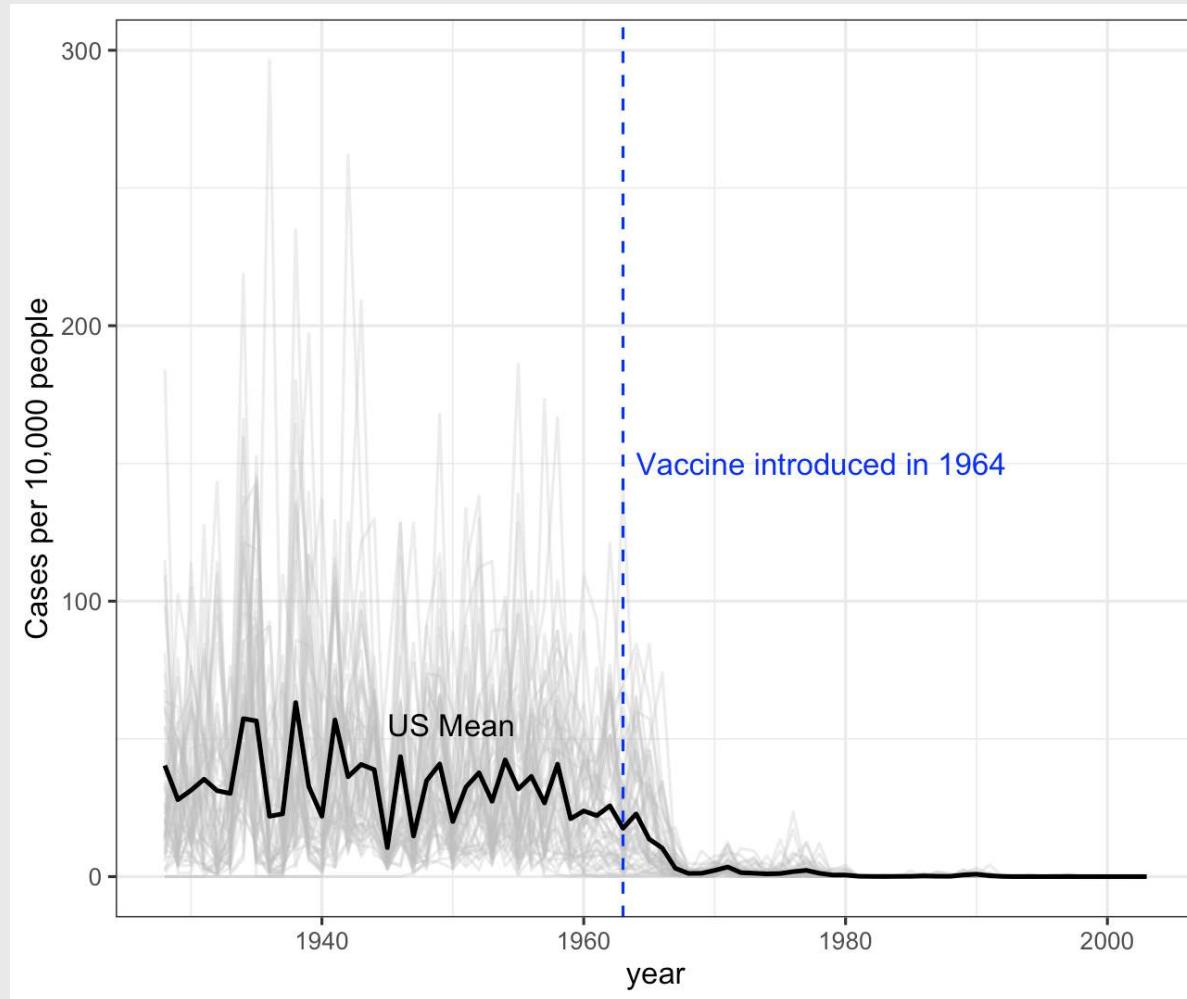
For small number of categories, **bars work**



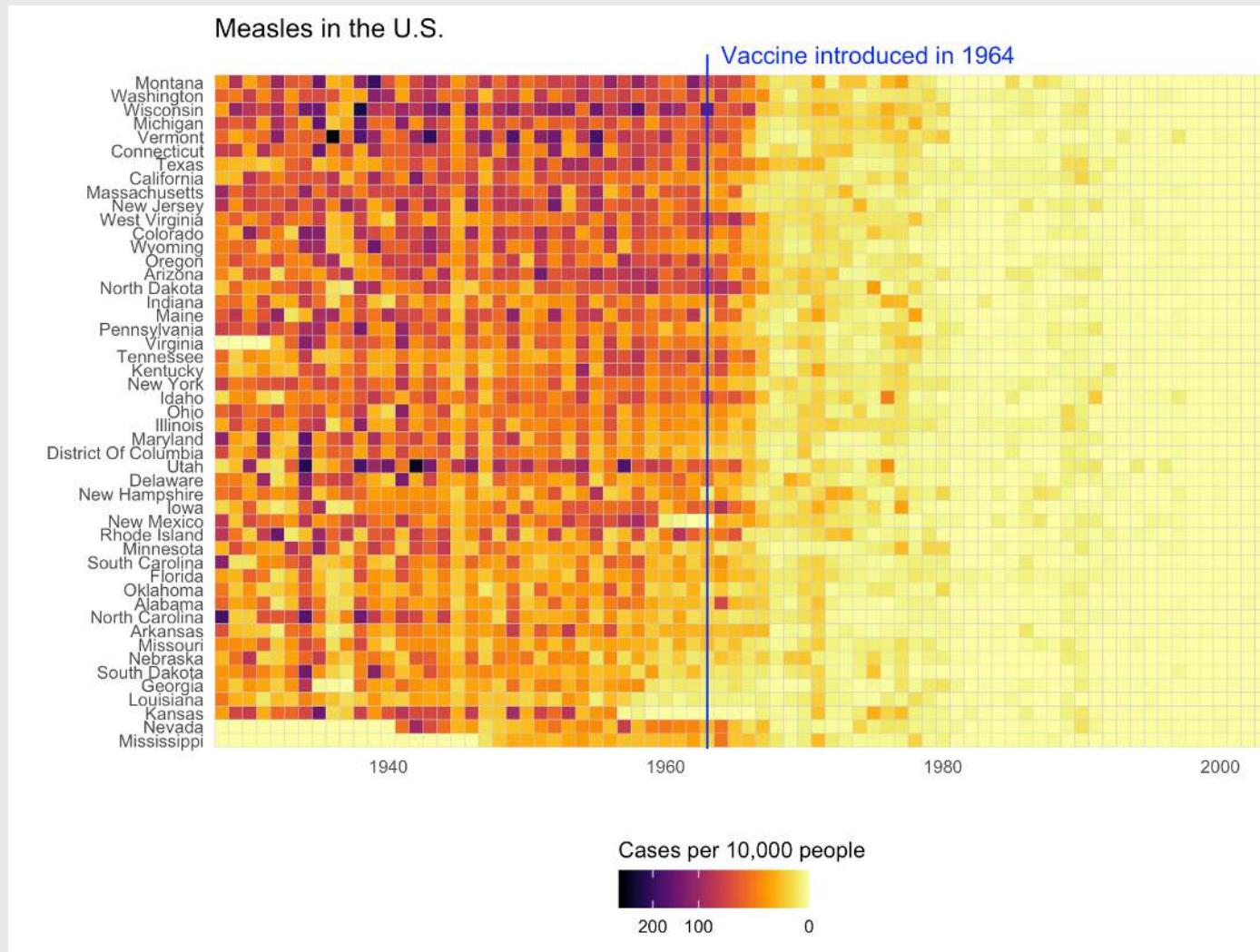
With many categories, lines don't work



With many categories, **summary lines work**



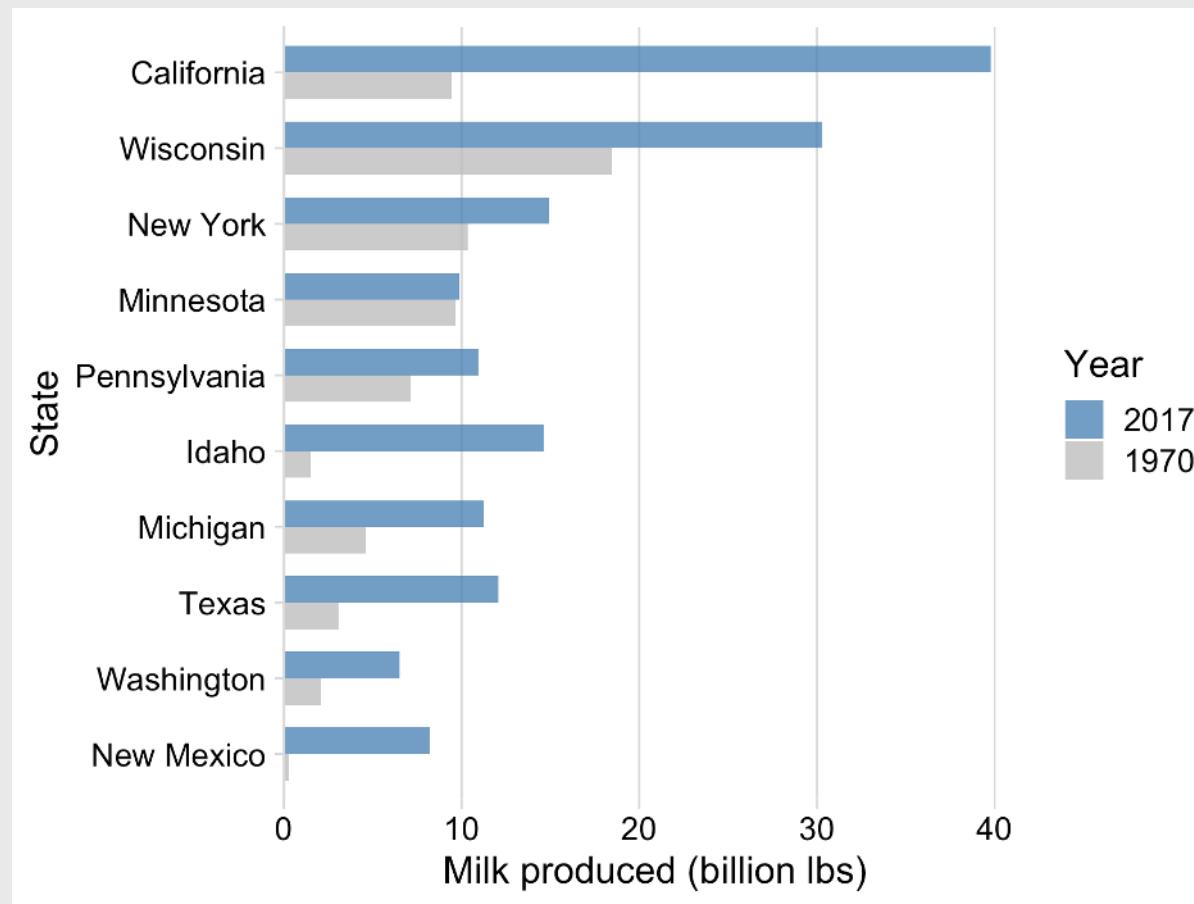
With many categories, **heatmaps work**



Bonus suggestions!

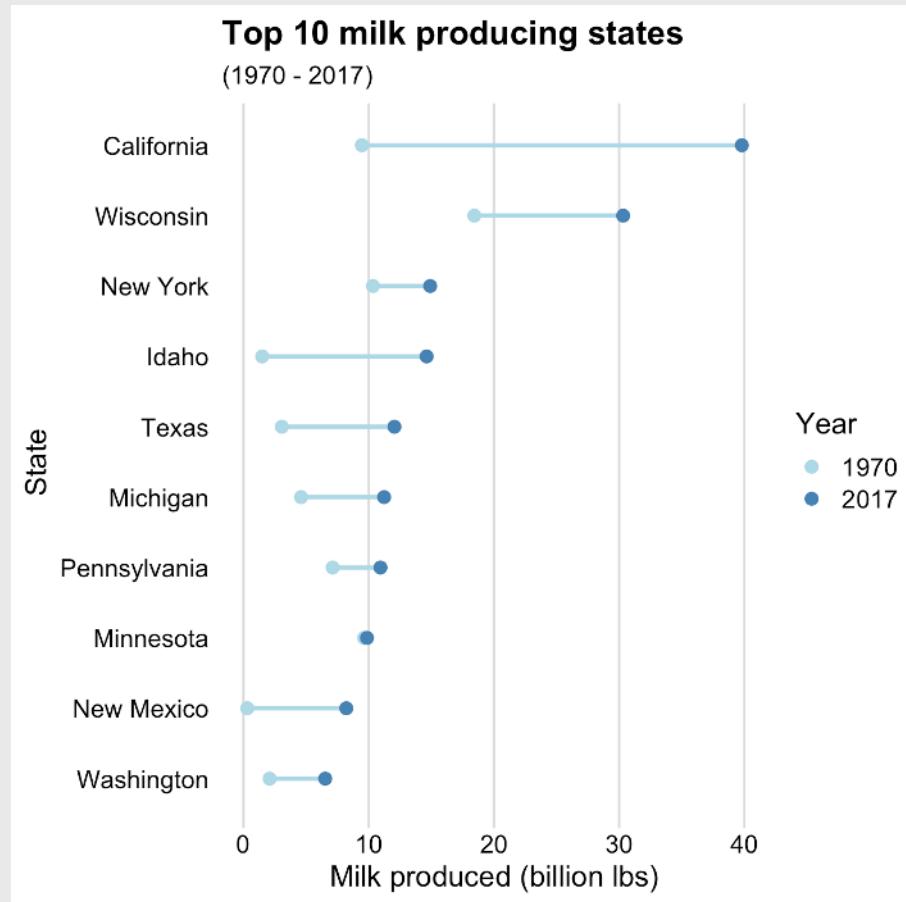
With **more than 2** things, dodged bars can get confusing

Still comparing 2 time periods, but across **10** categories



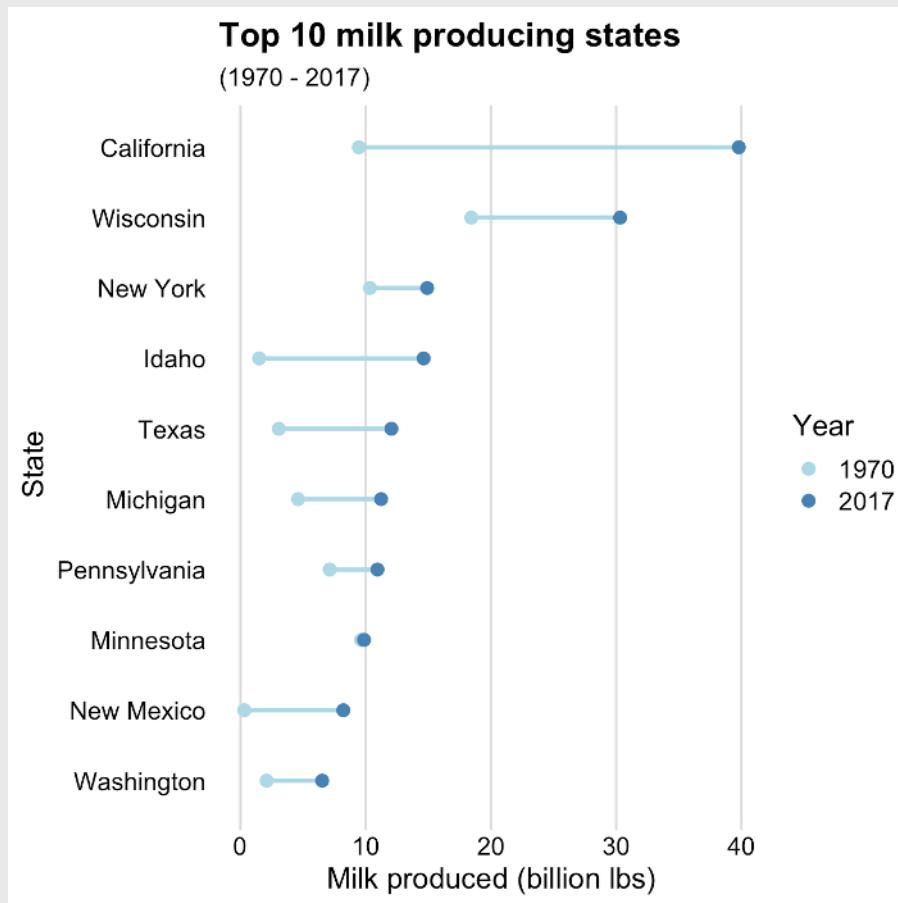
Dumbbell charts highlight:

- Compare **magnitudes** across two periods / groups



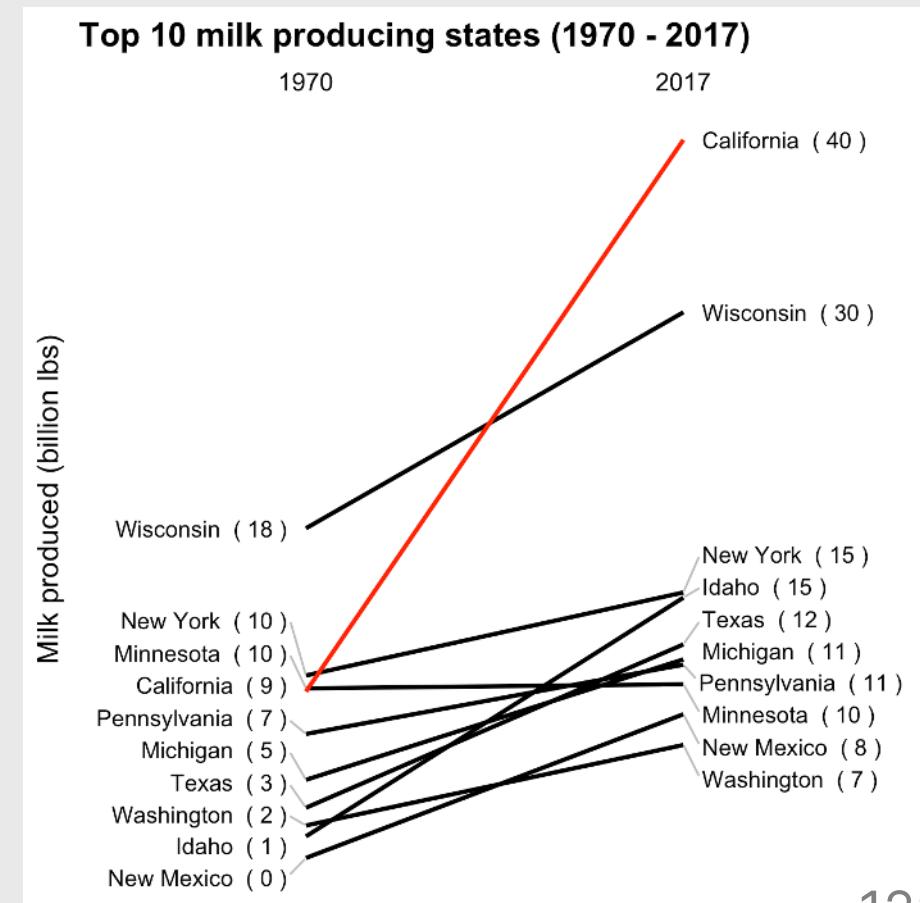
Dumbbell charts highlight:

- Compare **magnitudes** across two periods / groups



Slope charts highlight:

- *Change in rankings*
- Highlight individual categories

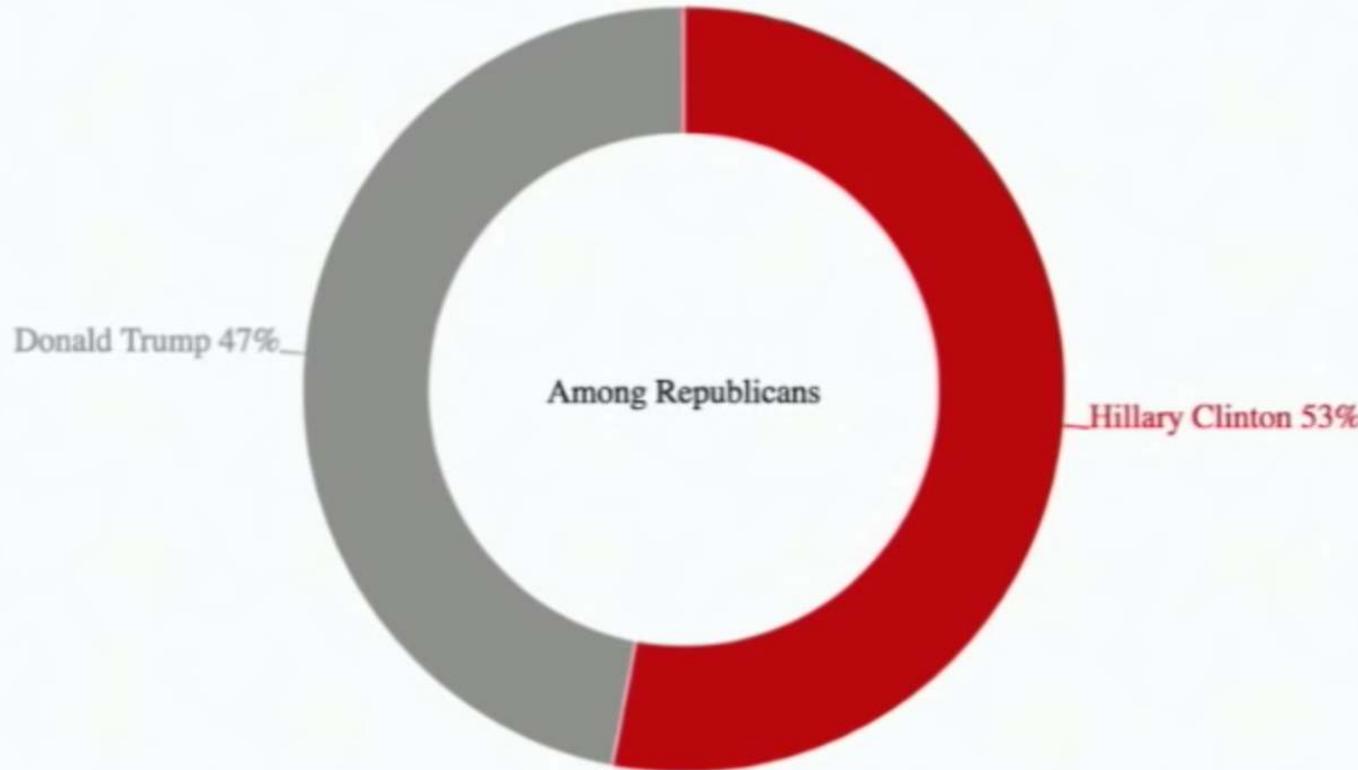


Consider using tables for small data

Who do you think did a better job in tonight's debate?

Among Republicans

Among Democrats



Share

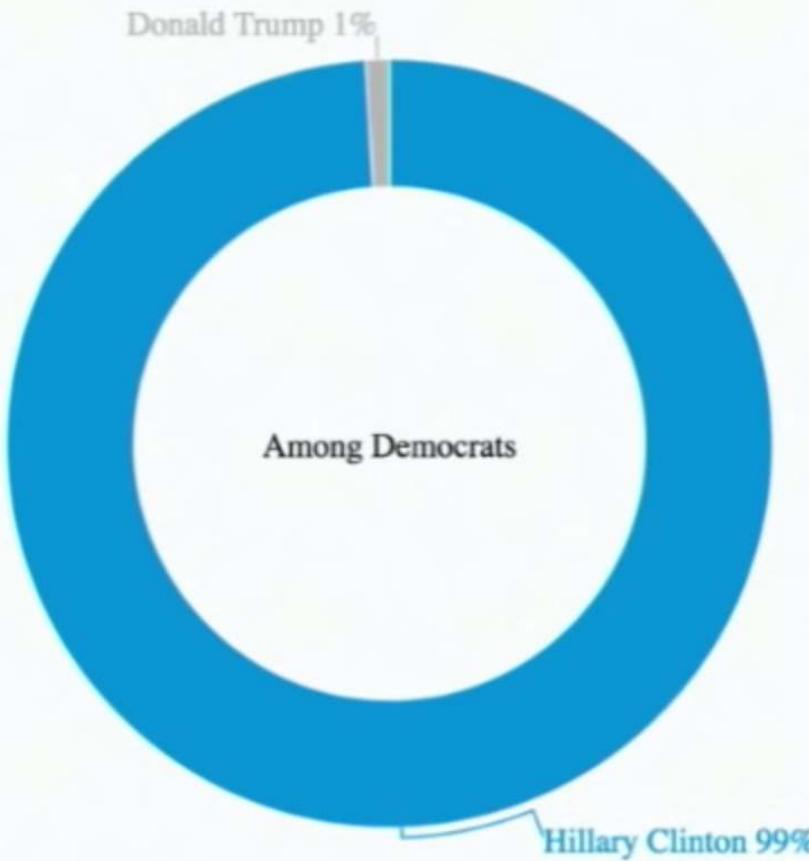
POLITICO

124 / 132

Who do you think did a better job in tonight's debate?

Among Republicans

Among Democrats



Who do you think did a better job in tonight's debate?

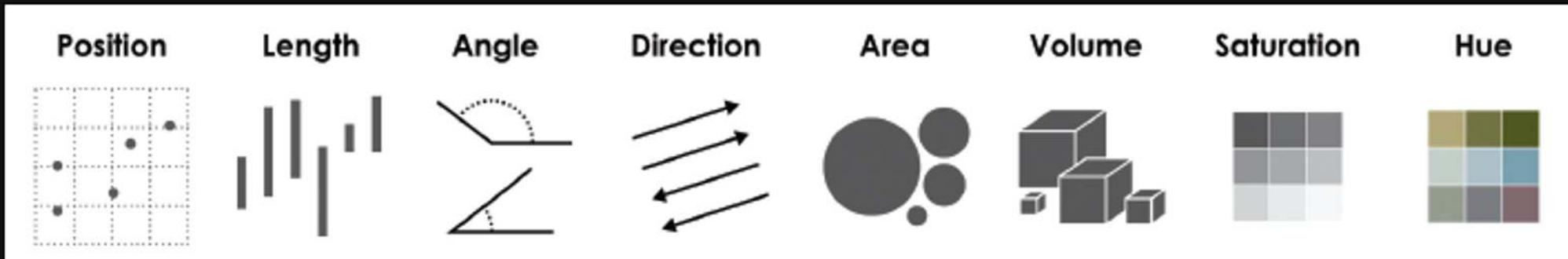
	Clinton	Trump
Among Democrats	99%	1%
Among Republicans	53%	47%

Your turn - go [here](#)

10:00

For your "bad" visualization:

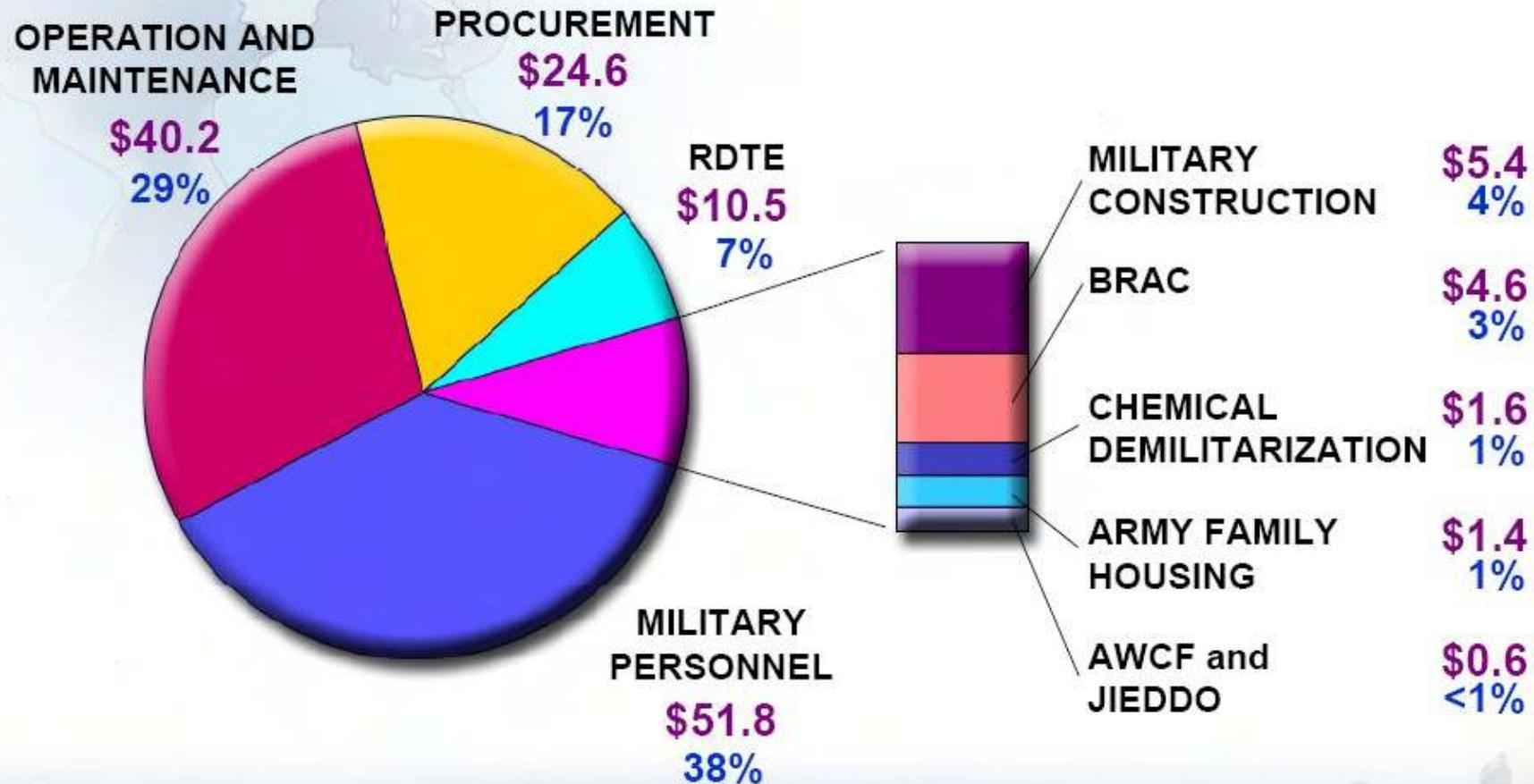
- 1) Identify where the graphic falls on Cleveland's pattern recognition hierarchy

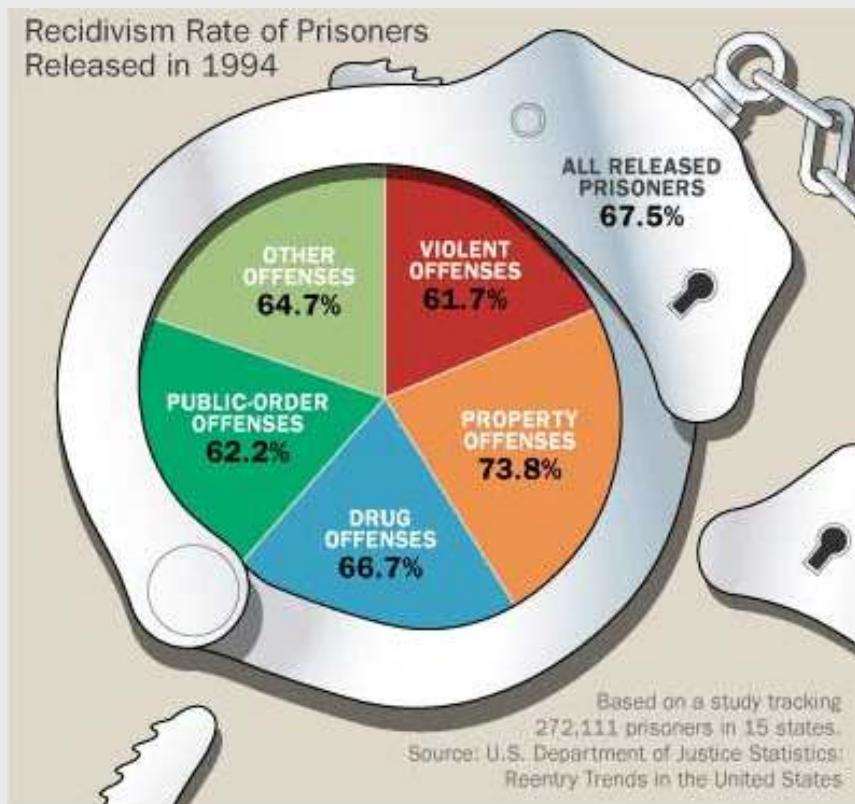


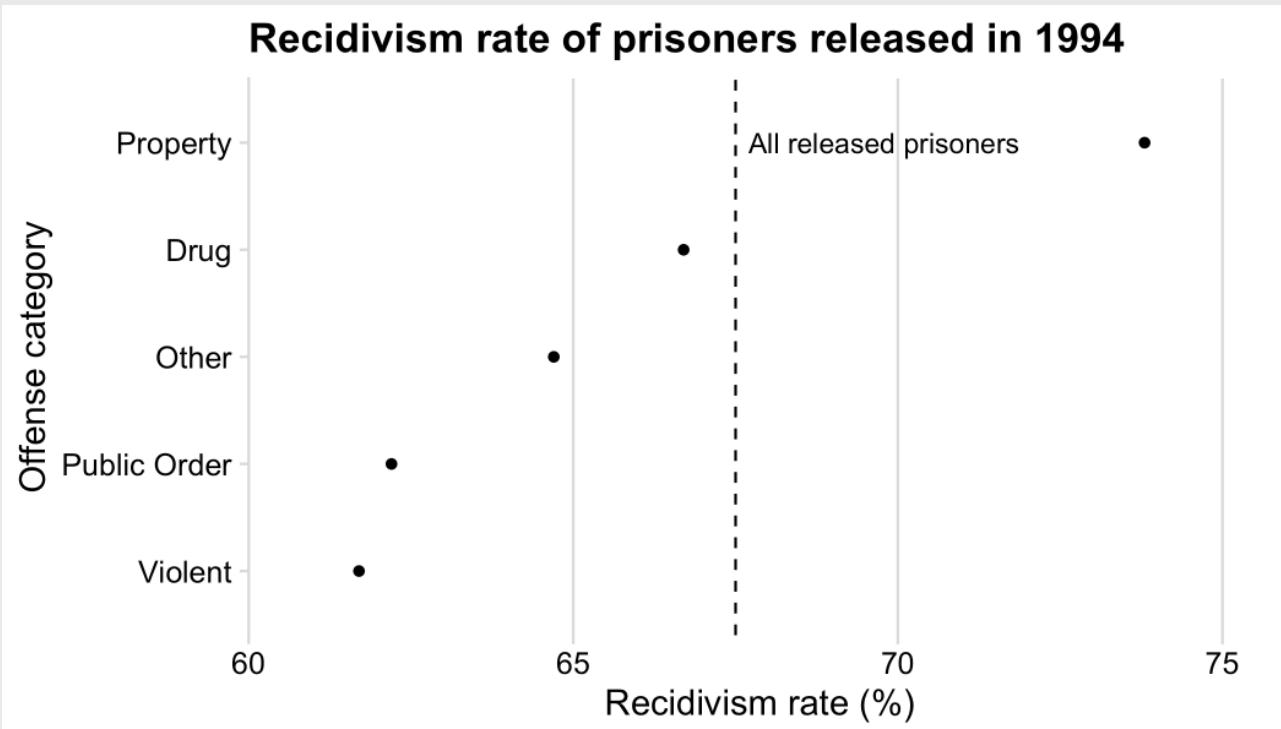
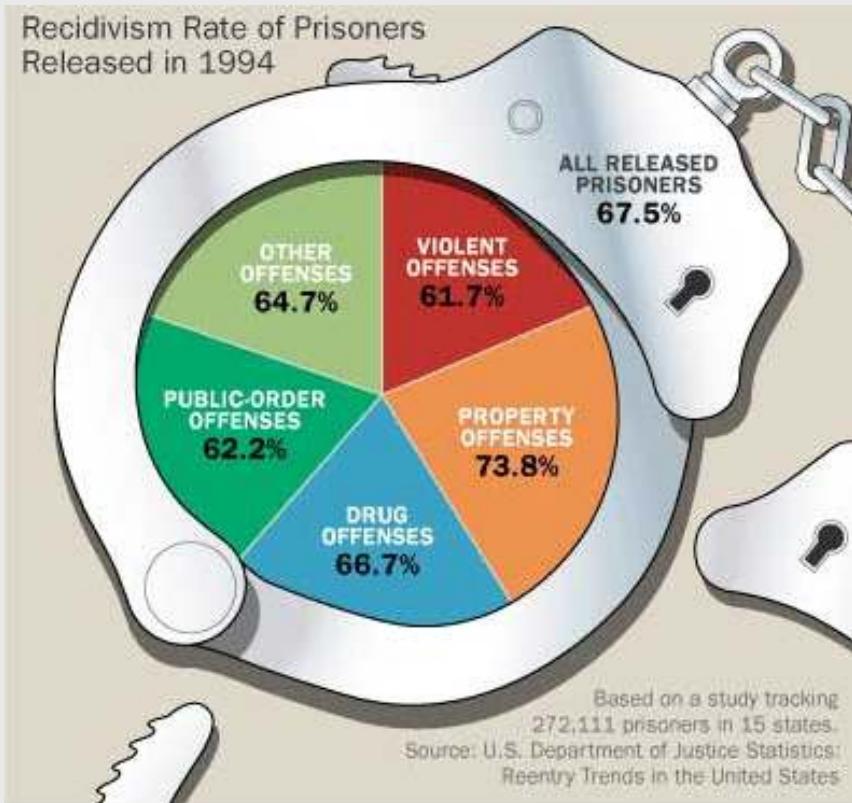
- 2) Any design rules that are broken
- 3) Suggest at least two improvements

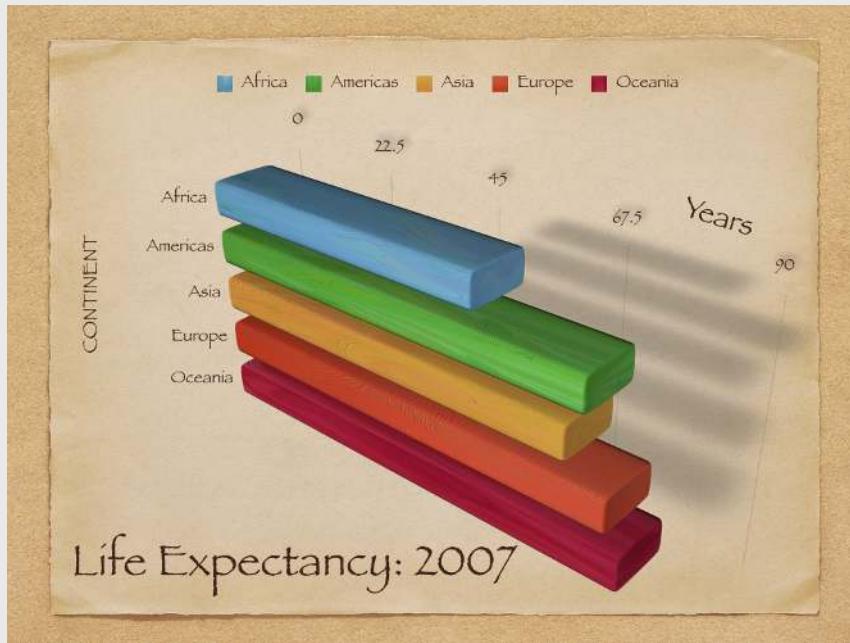


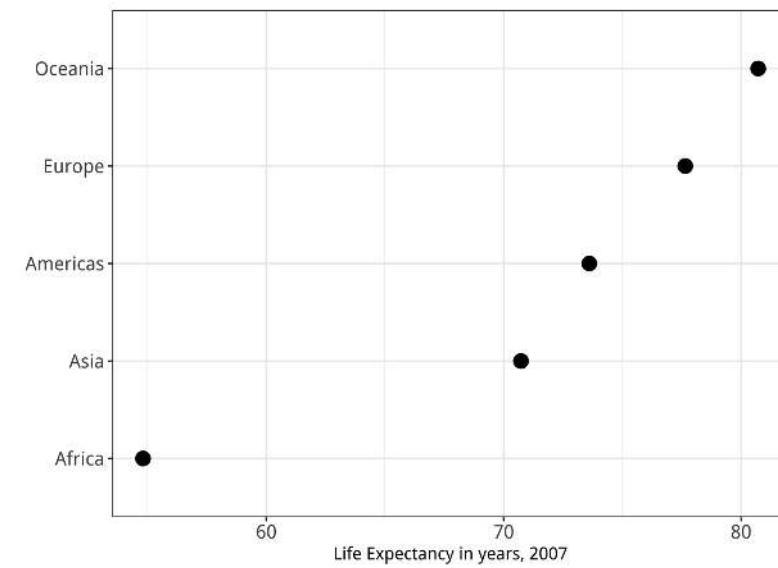
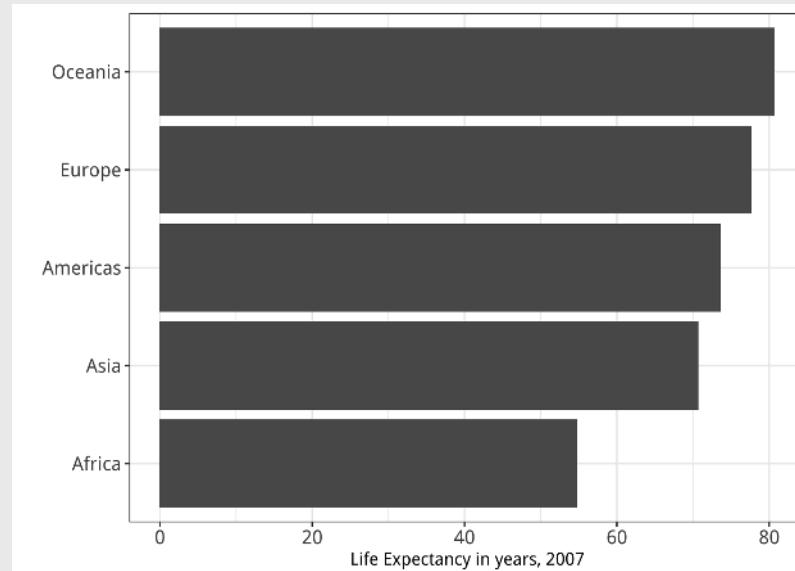
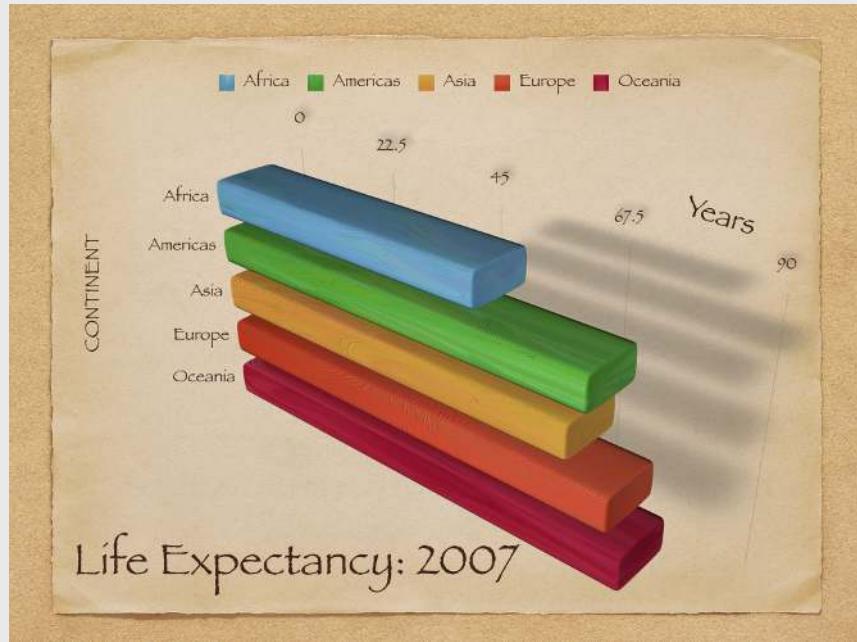
FY09 Obligation Authority











Most fatal bear attacks occur in July and August

Total fatal bear attacks (grizzly, black, and polar), 1900 to present



Source: News archives, Wikipedia

Vox

Most fatal bear attacks occur in July and August

Total fatal bear attacks (grizzly, black, and polar), 1900 to present



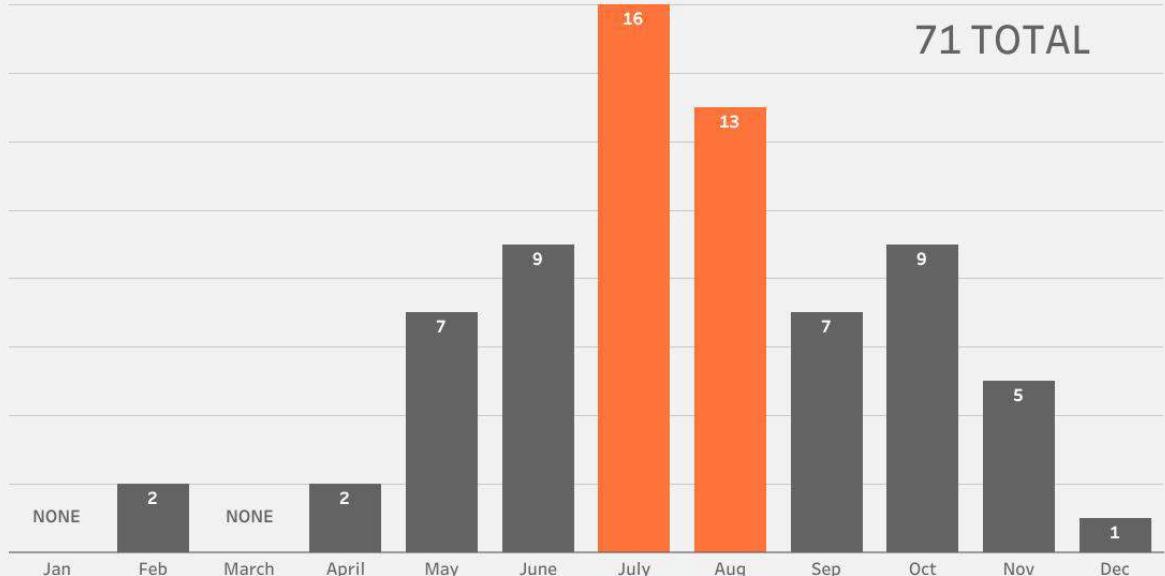
Source: News archives, Wikipedia

Vox

BEAR ATTACKS IN U.S. PARKS & WILDERNESS AREAS

Most fatal bear attacks occur in July and August

Total fatal bear attacks by grizzly, black and polar bears from 1900 to present



Source: News archives, Wikipedia (as of 10/2016)

Created by Jeffrey A. Shaffer | MakeoverMonday 2019WK21



Hillary Clinton

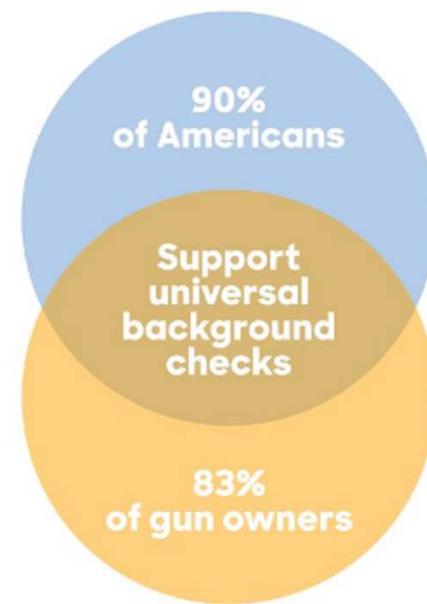
Follow

Dear Congress,

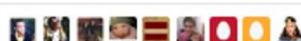
Let's get this done.

Thanks,

The vast majority of Americans



RETWEETS 2,308 LIKES 5,333





Hillary Clinton

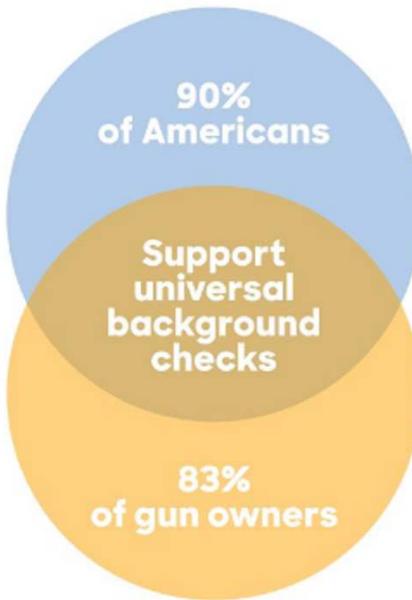
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2,308

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People who know
how to make
Venn Diagrams

Hillary's graphic
design staff

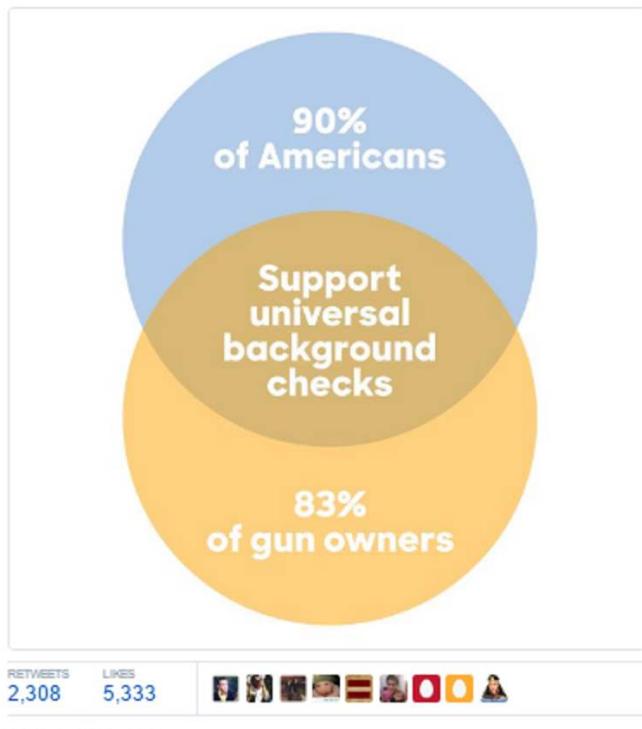


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Let's get this done.

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The vast majority of Americans



Follow

People who know
how to make
Venn Diagrams

Hillary's graphic
design staff

The vast majority of Americans support universal background checks, including gun owners

