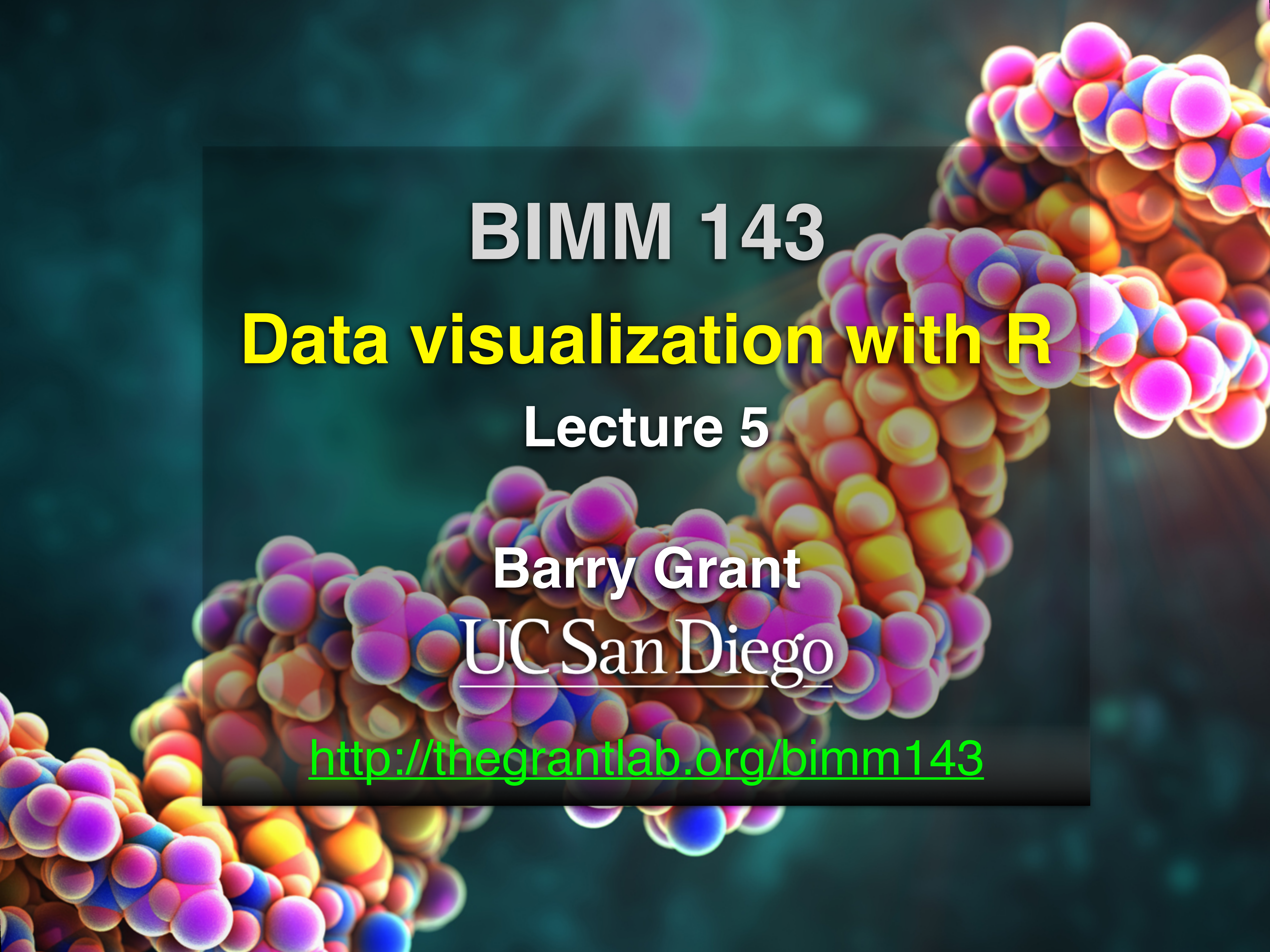

BIMM 143

Data visualization with R

Lecture 5

Barry Grant

UC San Diego

http://thegrantlab.org/bimm143

Recap From Last Time:

- What is R and why should we use it?
- Familiarity with R's basic syntax.
- Familiarity with major R data structures namely **vectors** and **data.frames**.
- Understand the basics of using **functions** (arguments, vectorizion and re-cycling).
- Appreciate how you can use R scripts to aid with reproducibility.

[MPA Link]

Today’s Learning Goals

- Appreciate the major elements of **exploratory data analysis** and why it is important to visualize data.

- Be conversant with **data visualization best practices** and understand how good visualizations optimize for the human visual system.

- Be able to generate informative graphical displays including **scatterplots**, **histograms**, **bar graphs**, **boxplots**, **dendrograms** and **heatmaps** and thereby gain exposure to the extensive graphical capabilities of R.

- Appreciate that you can build even more complex charts with **ggplot** and additional R packages such as **rgl**.

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Why visualize at all?

Over-the-Counter

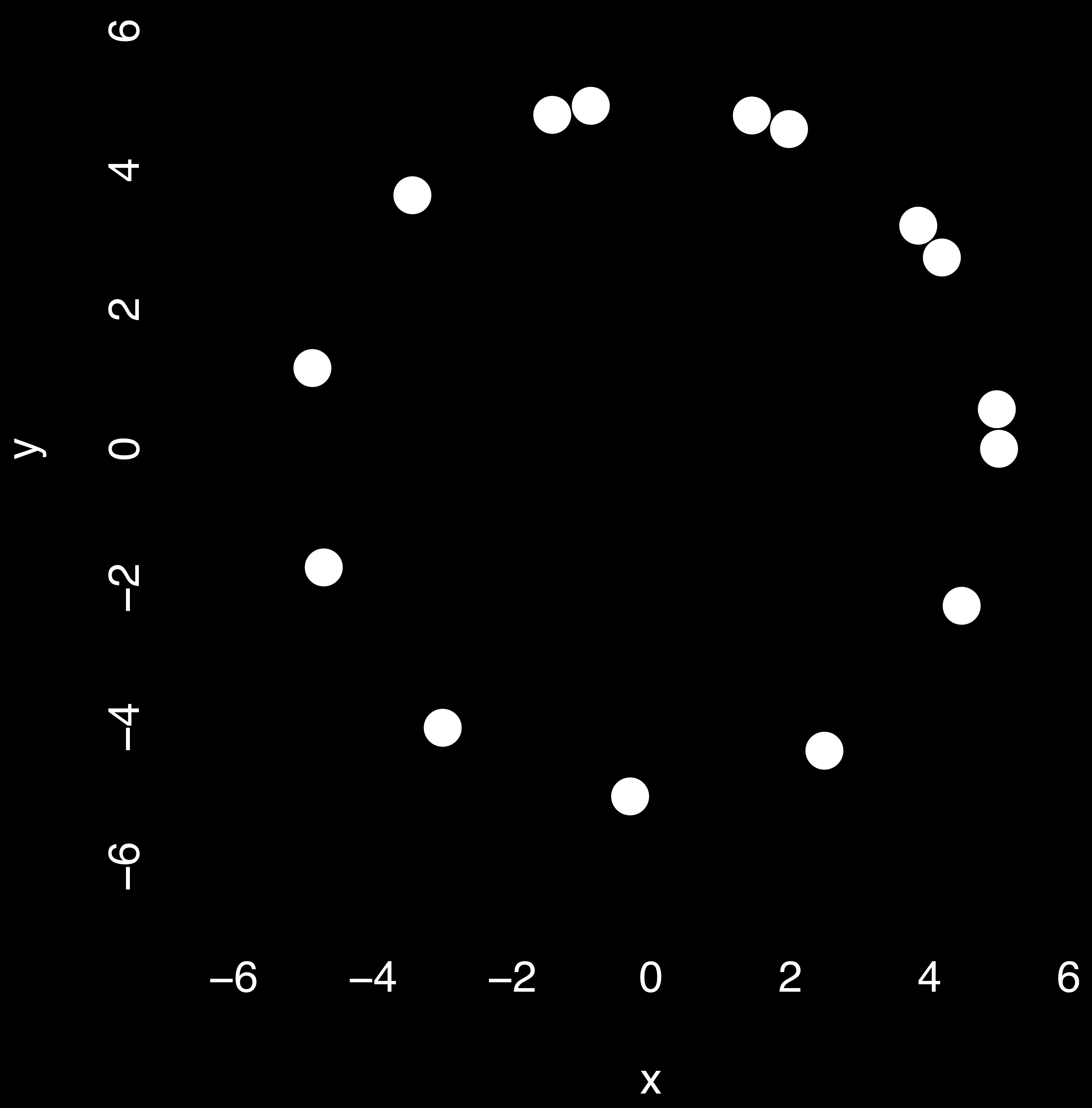
National Market System

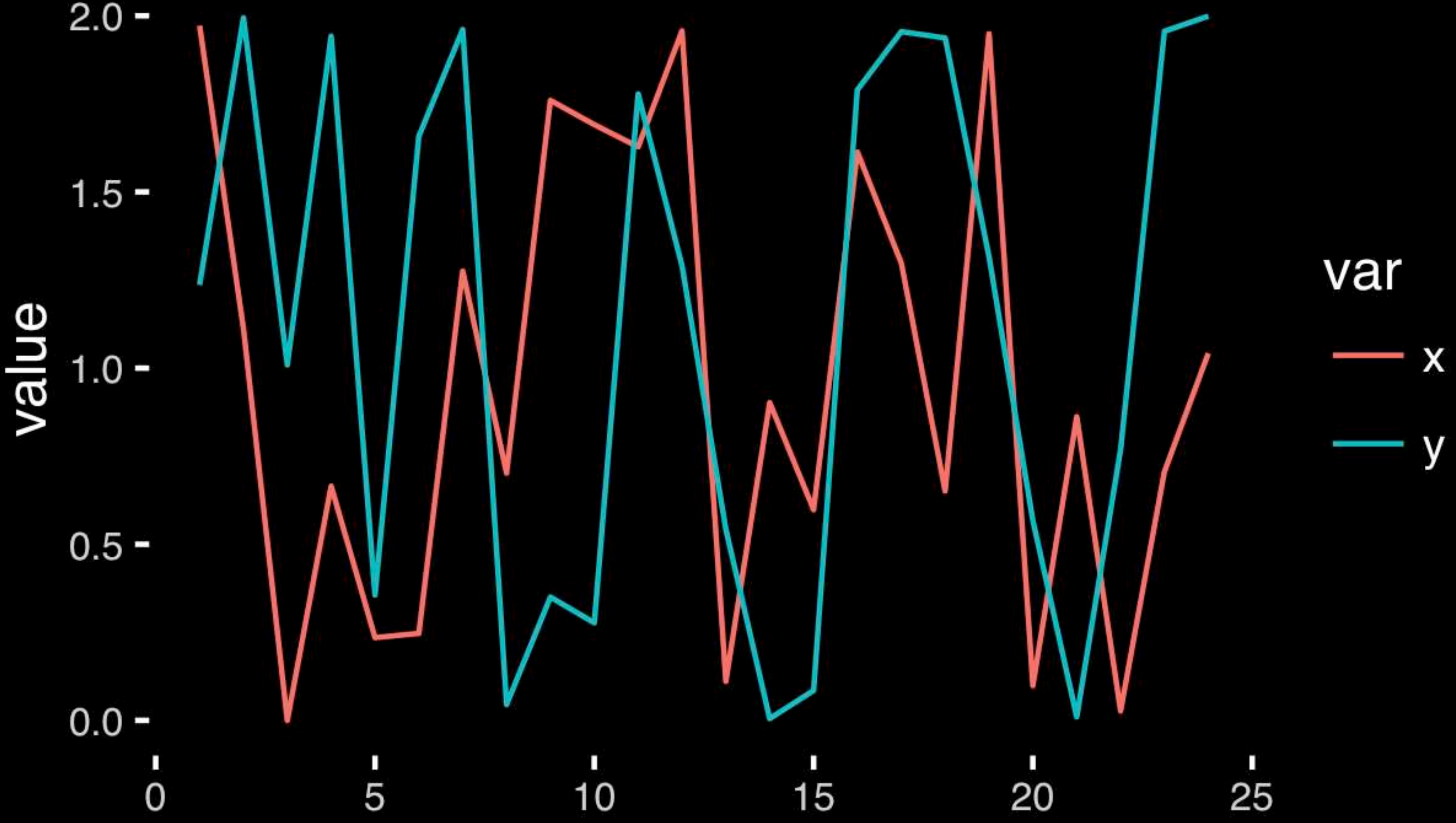
The companies listed below reflect the volume in 100's of shares on a daily basis and the closing price and net change are reflected from the previous day based on trades as provided under the NASD National Market System.

Stock	Sales	Close	Chg.
—A—			
[illegible]	[illegible]	[illegible]	[illegible]
—B—			
[illegible]	[illegible]	[illegible]	[illegible]
—D—			
[illegible]	[illegible]	[illegible]	[illegible]
—F—			
[illegible]	[illegible]	[illegible]	[illegible]
—H—			
[illegible]	[illegible]	[illegible]	[illegible]
—J-K—			
[illegible]	[illegible]	[illegible]	[illegible]
—O-P—			
[illegible]	[illegible]	[illegible]	[illegible]

	x	y
1	5.00	0.00
2	4.18	2.75
3	1.98	4.59
4	-0.86	4.92
5	-3.43	3.64
6	-4.86	1.16
7	-4.70	-1.70
8	-2.99	-4.01
9	-0.30	-4.99
10	2.49	-4.34
11	4.46	-2.25
12	4.97	0.57
13	3.84	3.20
14	1.45	4.79
15	-1.42	4.79

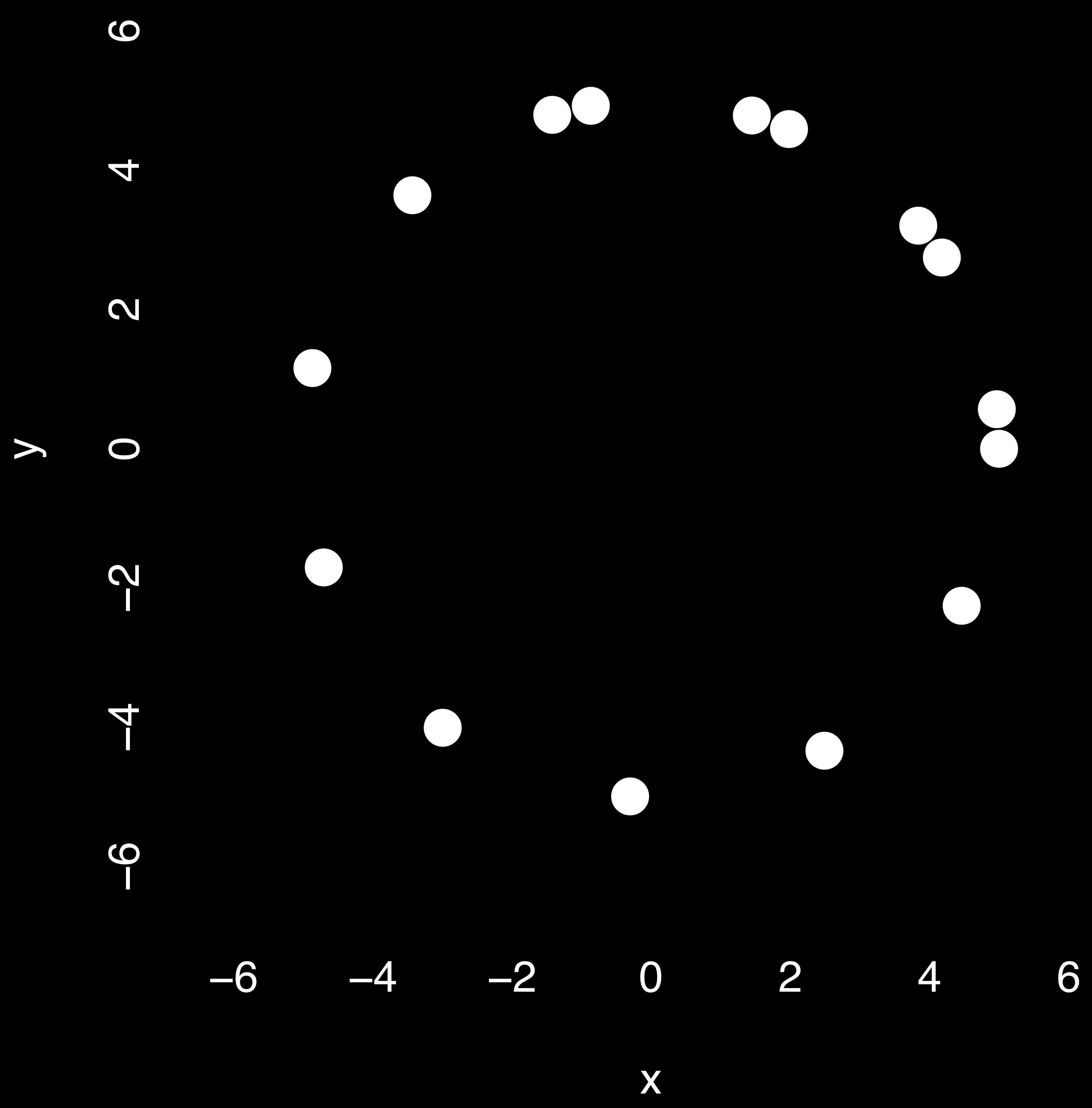
	x	y
Min.	-4.86	-4.99
1st Qu.	-2.21	-1.98
Median	1.45	1.16
Mean	0.65	0.87
3rd Qu.	4.01	4.12
Max.	5.00	4.92


6
4
2
0
−2
−4
−6
y
−6
−4
−2
0
2
4
6
x



value
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
var
x
y

https://bioboot.github.io/bimm143_F18/class-material/05_draw_circle_points/

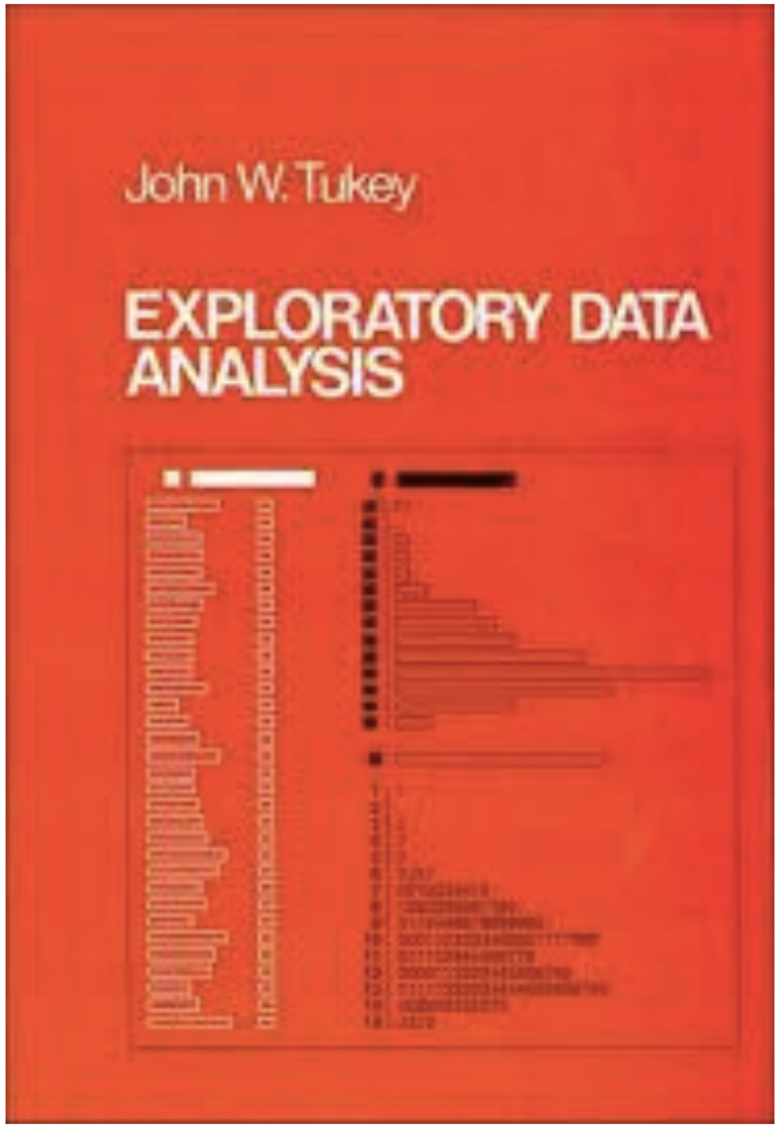


Exploratory Data Analysis

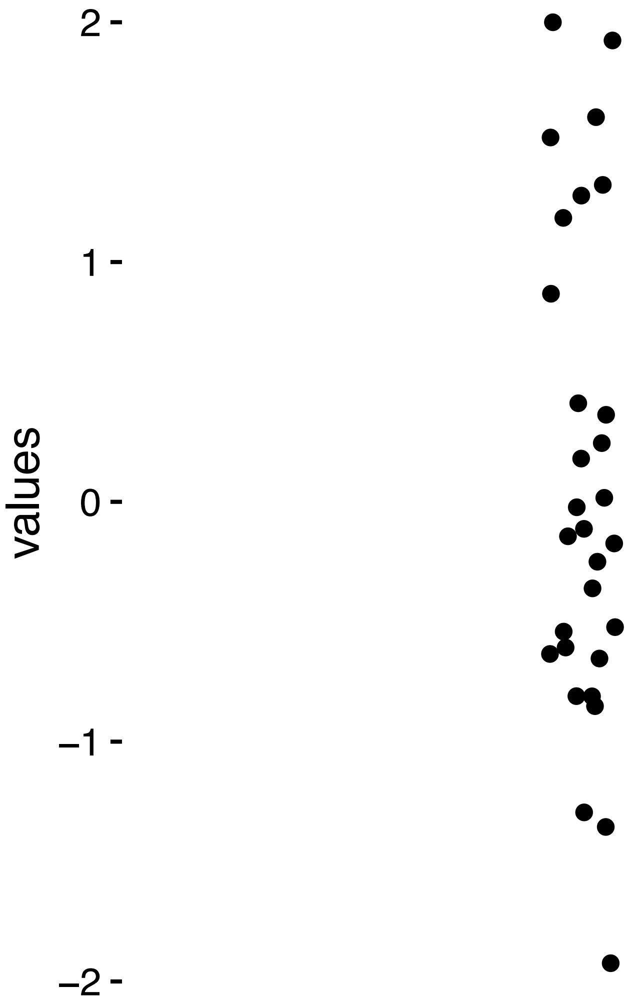
- ALWAYS look at your data!
- If you can’t see it, then don’t believe it!
- Exploratory Data Analysis (EDA) allows us to:
    1. Visualize distributions and relationships
    2. Detect errors
    3. Assess assumptions for confirmatory analysis
- EDA is the first step of data analysis!

Exploratory Data Analysis 1977

- Based on insights developed at Bell Labs in the 60's
- Techniques for visualizing and summarizing data
- What can the data tell us? (in contrast to "confirmatory" data analysis)
- Introduced many basic techniques:
  - 5-number summary, box plots, stem and leaf diagrams,…
- 5 Number summary:
  - extremes (min and max)
  - median & quartiles
  - More robust to skewed & longtailed distributions



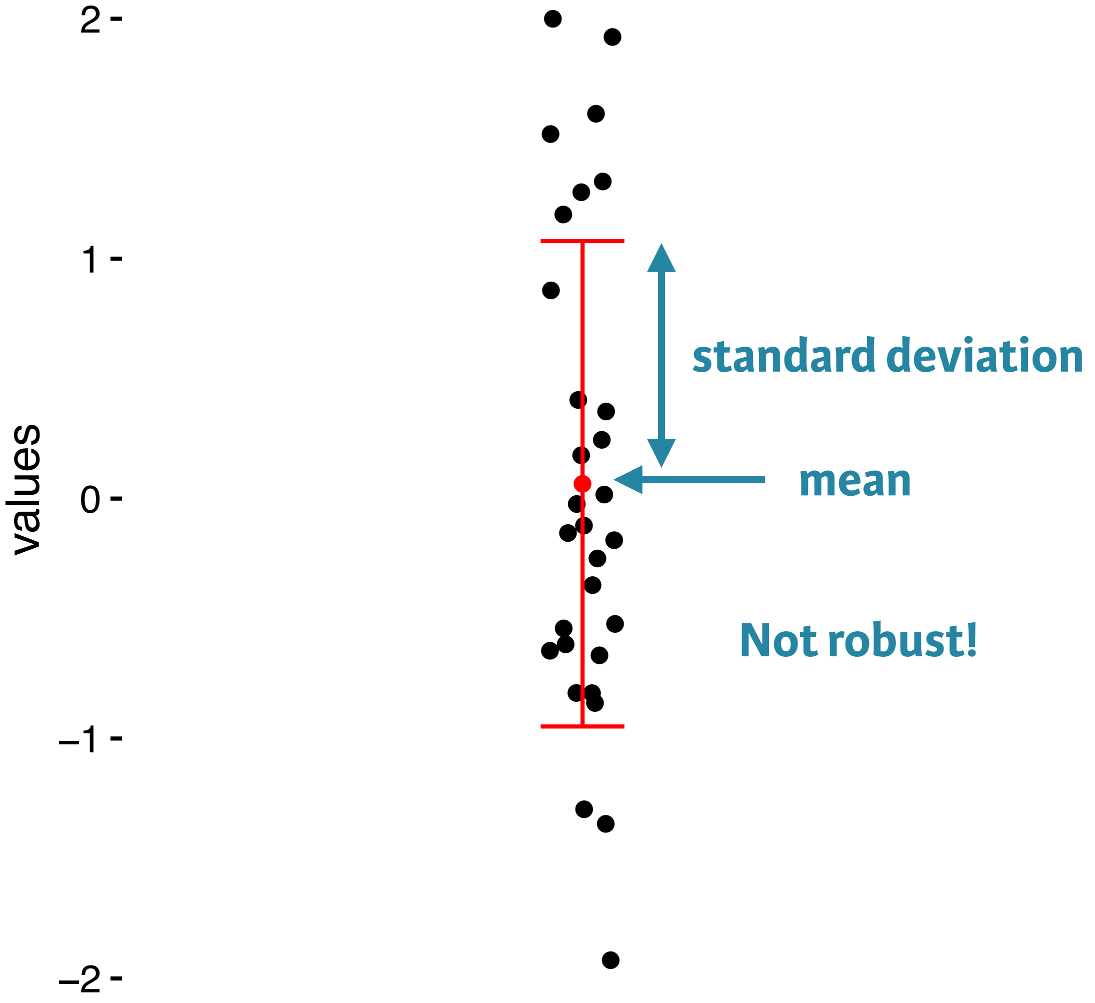
Side-note: How to summarize data?



```
x <- rnorm(1000,0)
```

Side-note: Mean & standard deviation

Fine for normally distributed data



standard deviation

mean

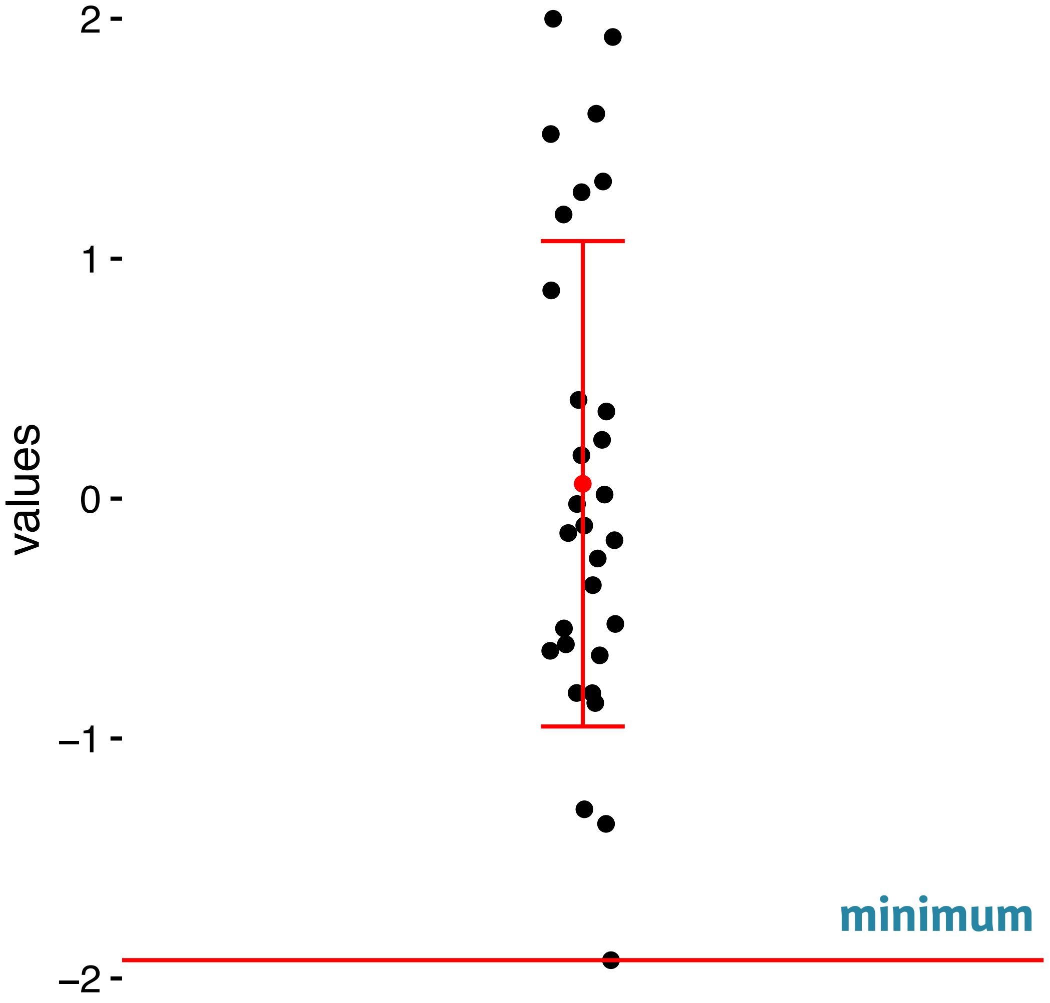
Not robust!

```
x <- rnorm(1000,0)

mean(x)
sd(x)
```

Side-note: 5 number summary

Minimum, Q1, Q2, Q3, and maximum



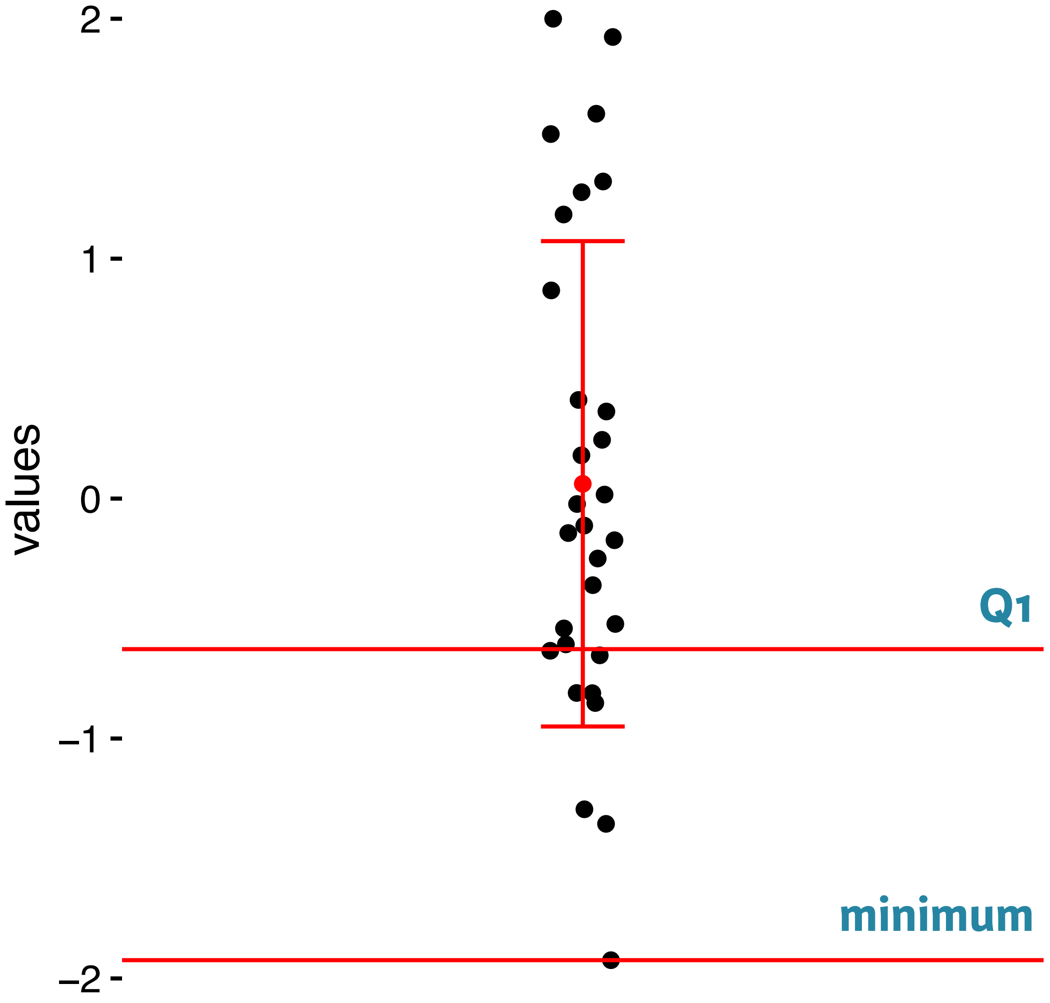
```
x <- rnorm(1000,0)

mean(x)
sd(x)

summary(x)
```

Side-note: 5 number summary

Minimum, Q1, Q2, Q3, and maximum



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Side-note: 5 number summary

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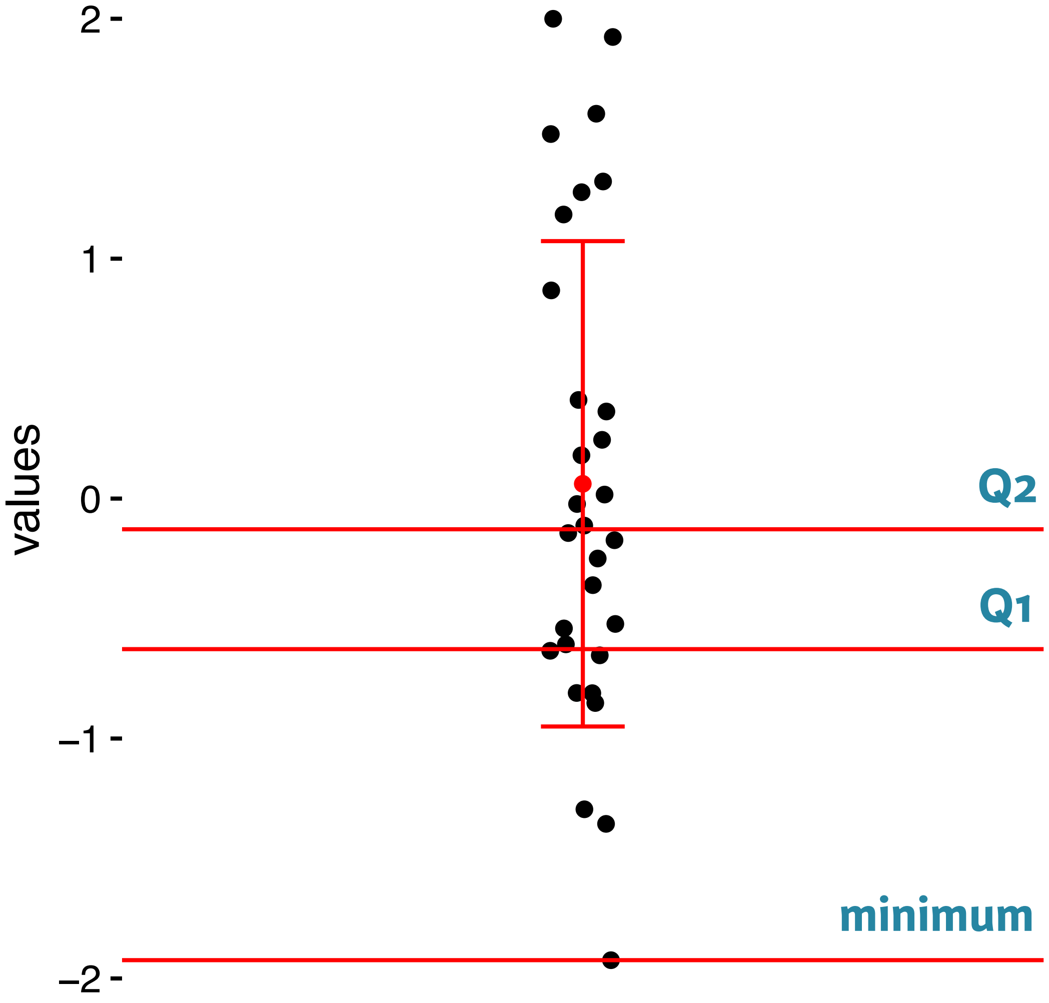

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mean(x)
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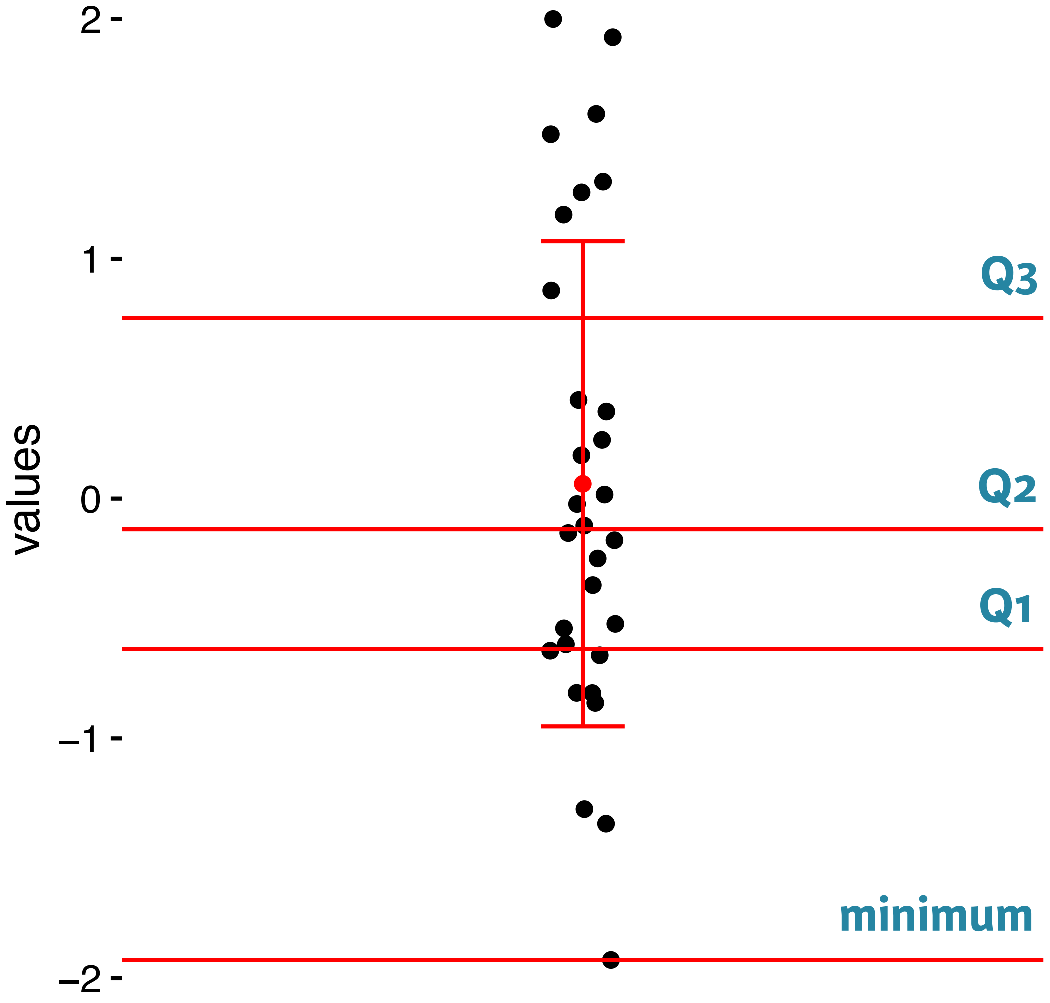

```
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mean(x)
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summary(x)
```
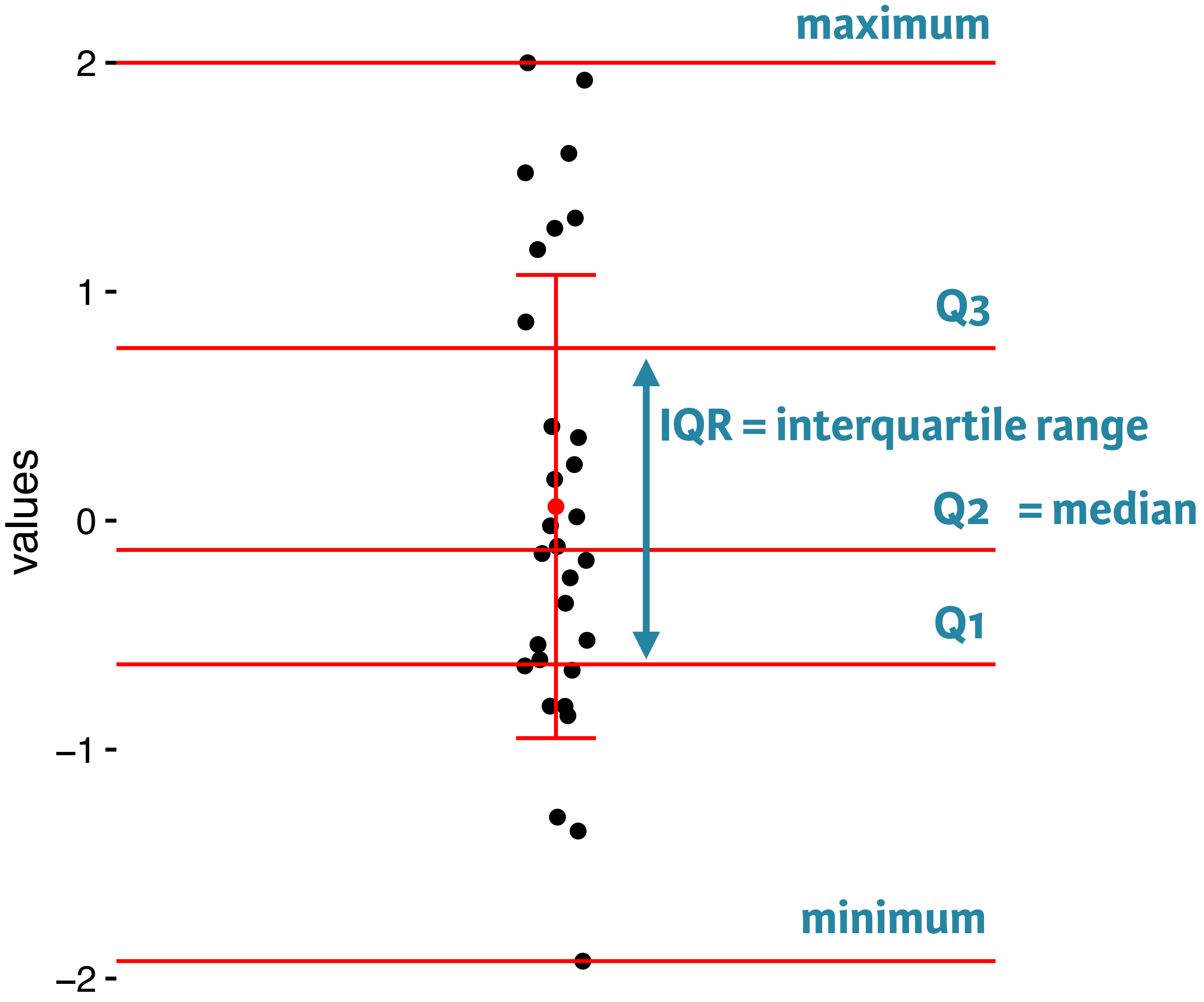

Side-note: 5 number summary

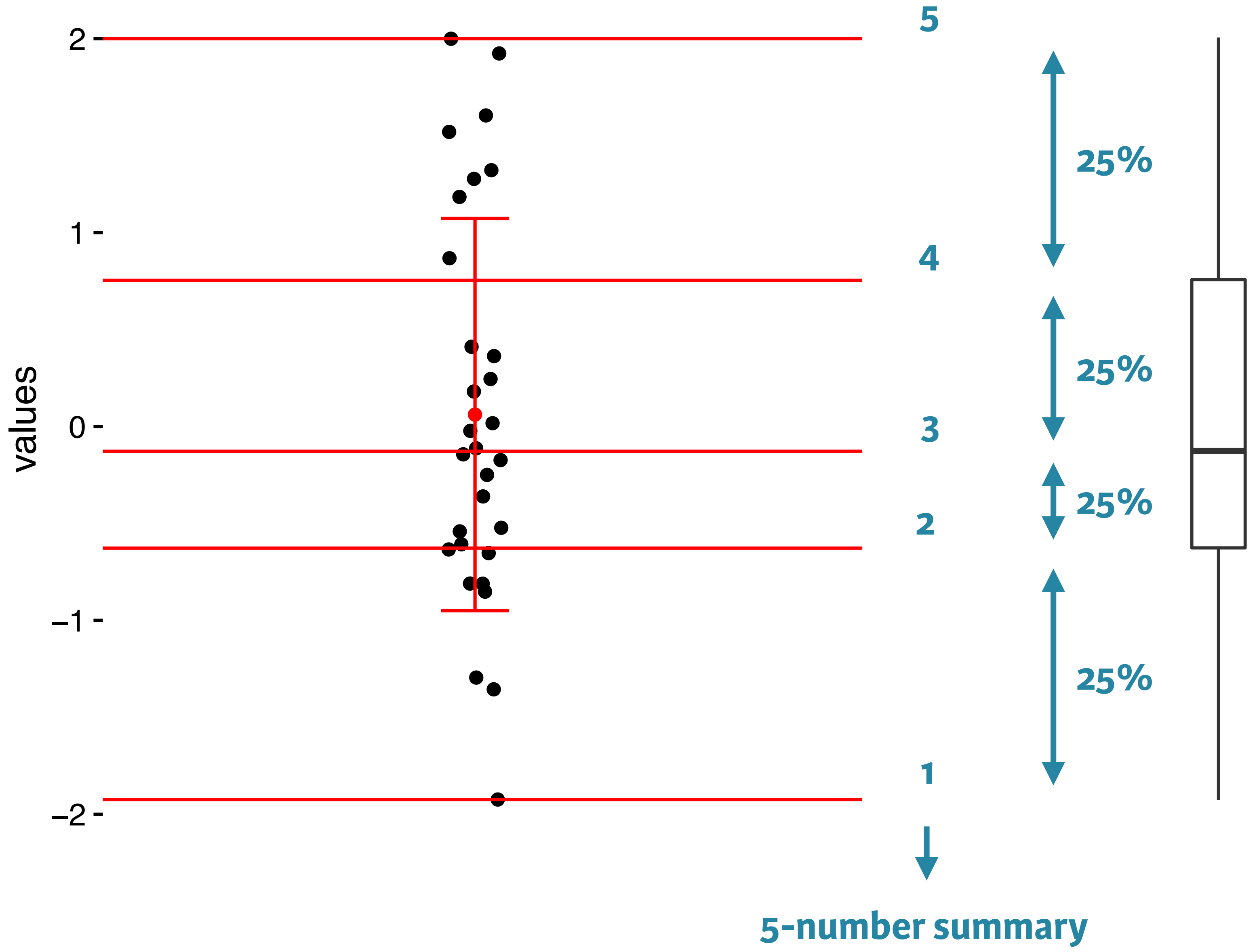
Minimum, Q1, Q2, Q3, and maximum



```
x <- rnorm(1000,0)

mean(x)
sd(x)

summary(x)
```

Side-note: boxplot

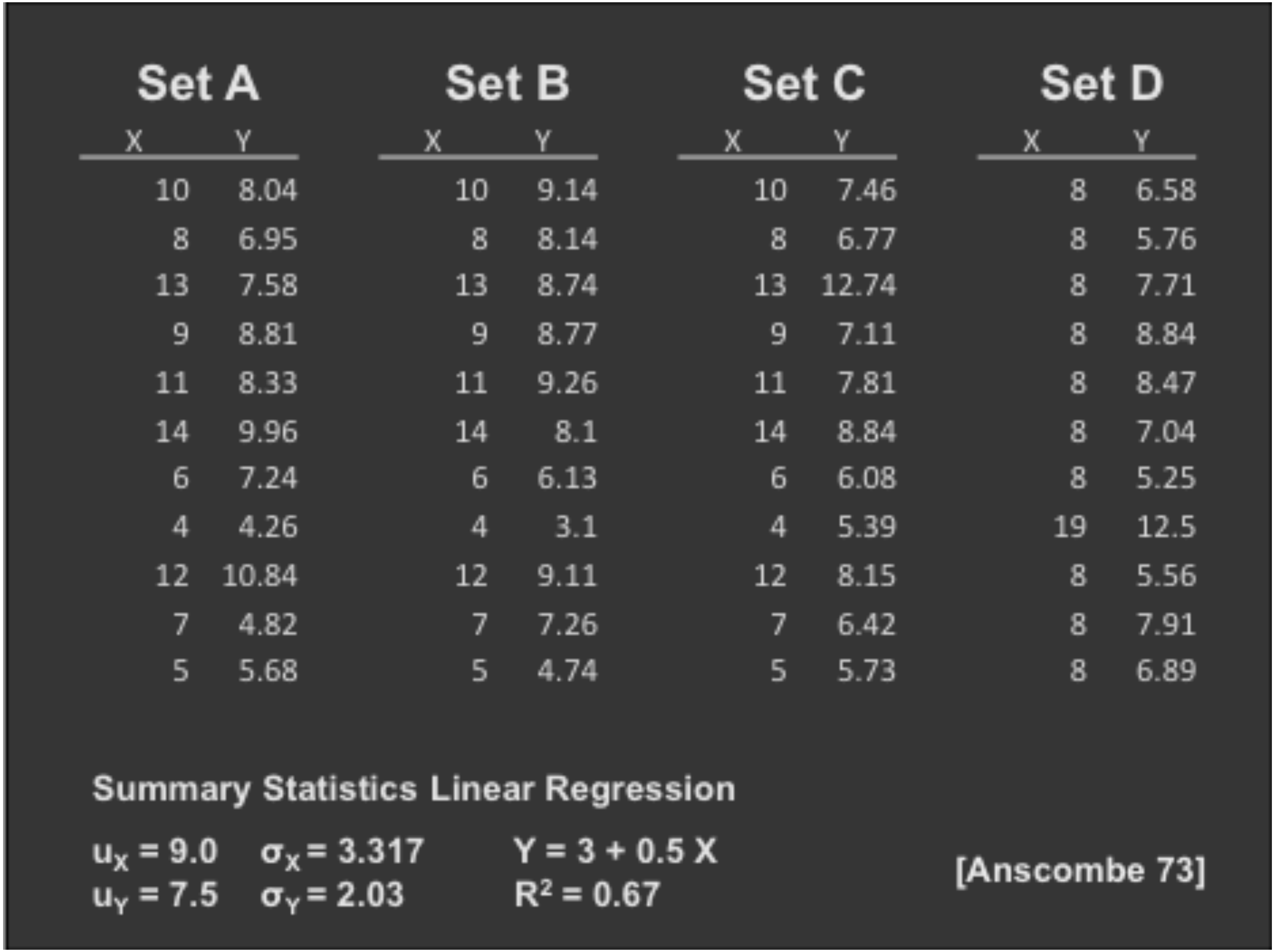
Graphical form of the 5 number summary!



```
x <- rnorm(1000,0)

mean(x)
sd(x)

summary(x)

boxplot(x)
```

Also called <u>box-and-whisker</u> plots;
See also hist(); violin plots etc.

The Trouble with Summary Stats



Set A		Set B		Set C		Set D	
X	Y	X	Y	X	Y	X	Y
10	8.04	10	9.14	10	7.46	8	6.58
8	6.95	8	8.14	8	6.77	8	5.76
13	7.58	13	8.74	13	12.74	8	7.71
9	8.81	9	8.77	9	7.11	8	8.84
11	8.33	11	9.26	11	7.81	8	8.47
14	9.96	14	8.1	14	8.84	8	7.04
6	7.24	6	6.13	6	6.08	8	5.25
4	4.26	4	3.1	4	5.39	19	12.5
12	10.84	12	9.11	12	8.15	8	5.56
7	4.82	7	7.26	7	6.42	8	7.91
5	5.68	5	4.74	5	5.73	8	6.89

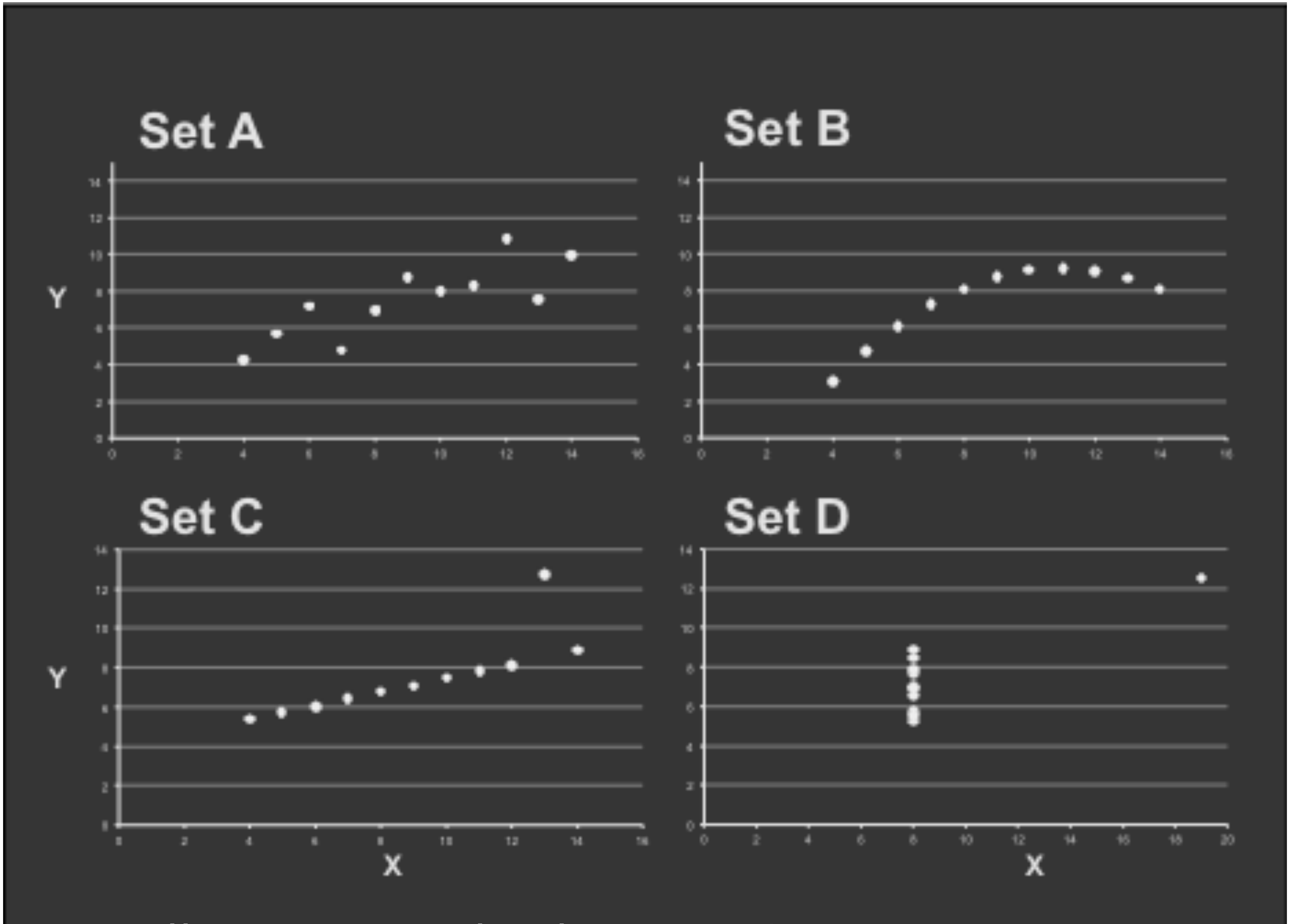
Summary Statistics Linear Regression

$u_X = 9.0$ $\sigma_X = 3.317$ $Y = 3 + 0.5 X$

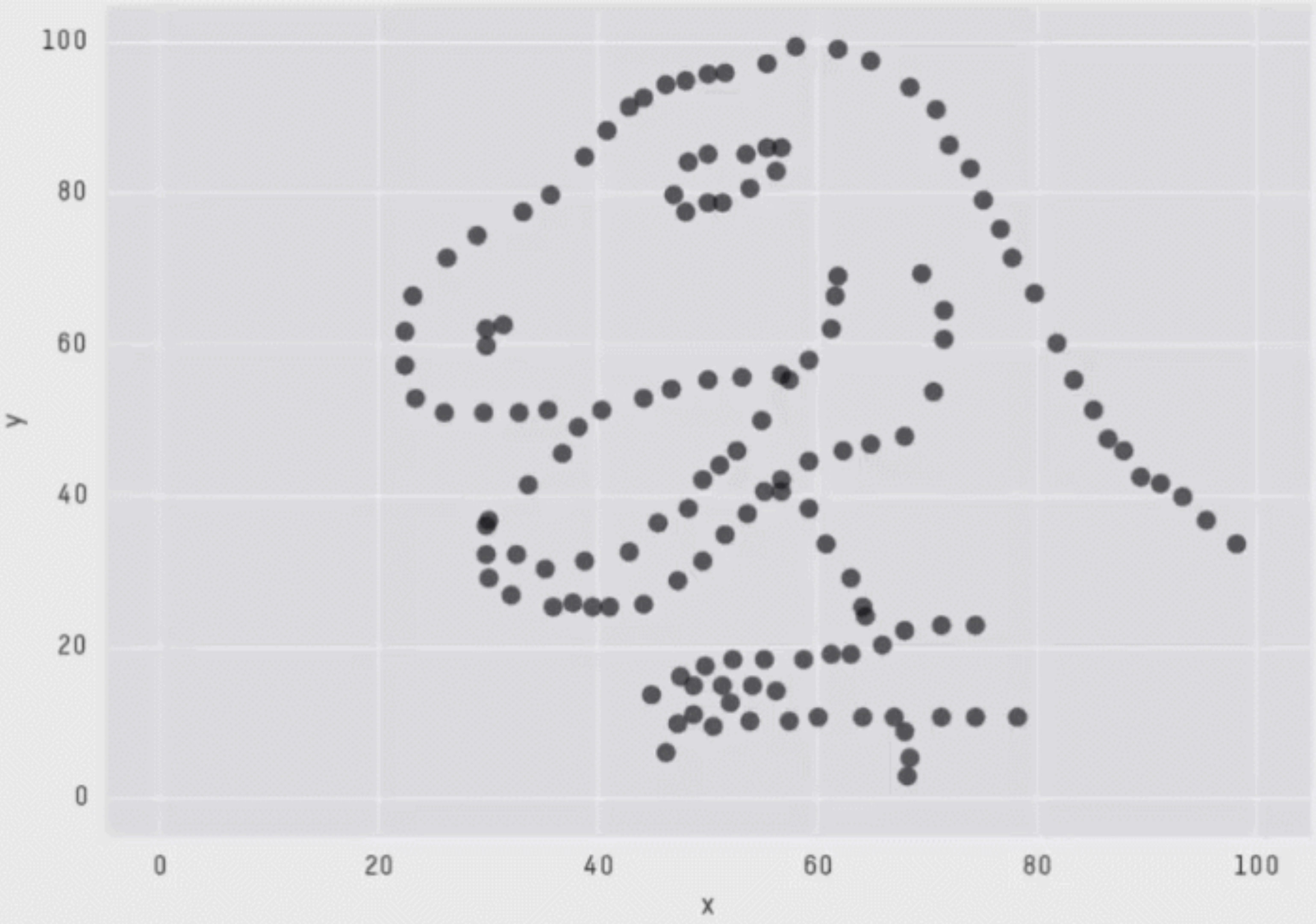
$u_Y = 7.5$ $\sigma_Y = 2.03$ $R^2 = 0.67$

[Anscombe 73]

Looking at Data



https://en.wikipedia.org/wiki/Anscombe%27s_quartet



```
X Mean: 54.2659224
Y Mean: 47.8313999
X SD  : 16.7649829
Y SD  : 26.9342120
Corr. : -0.0642526
```

Key point: You need to visualize your data!

https://github.com/stephlocke/datasauRus

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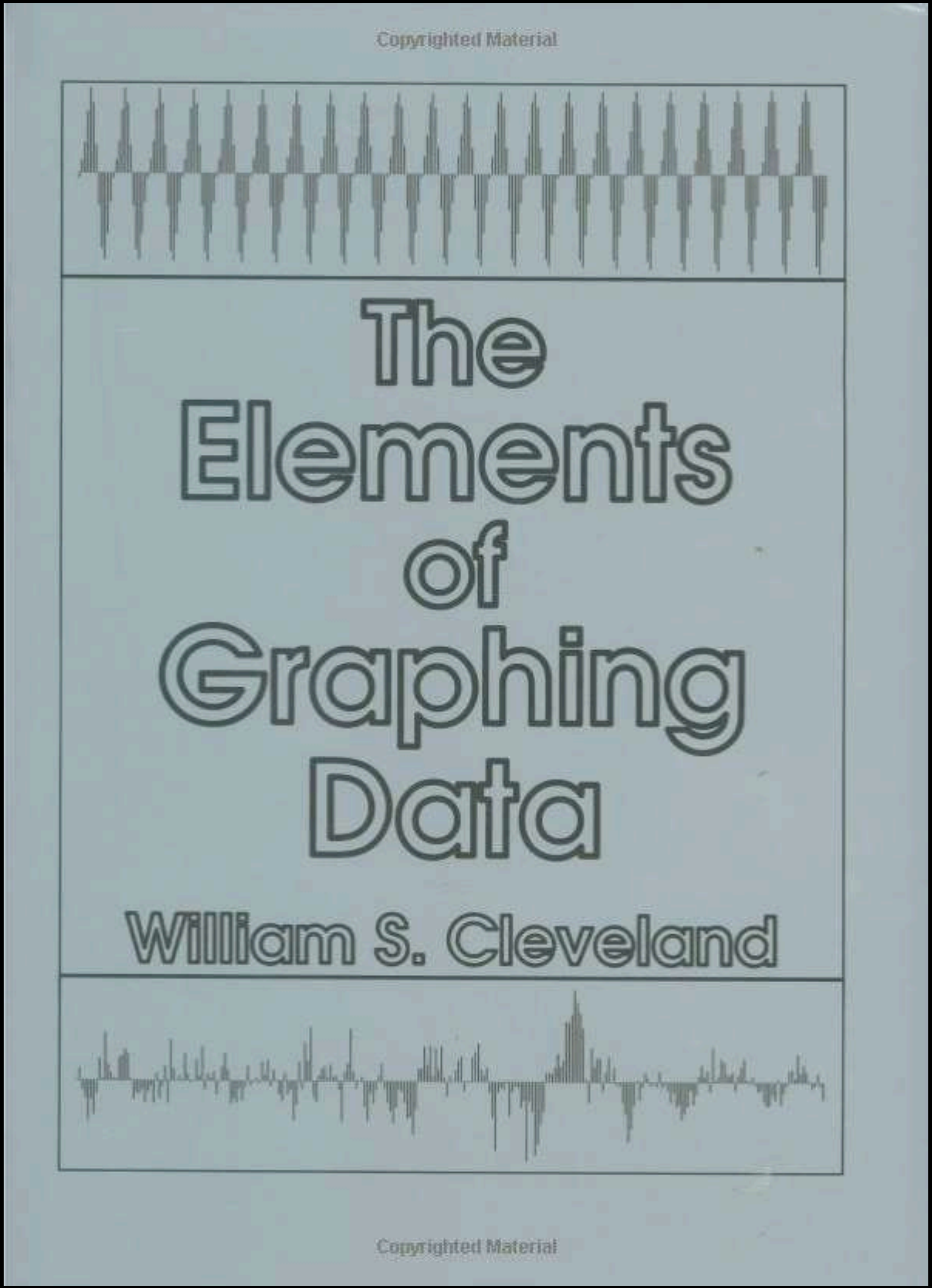
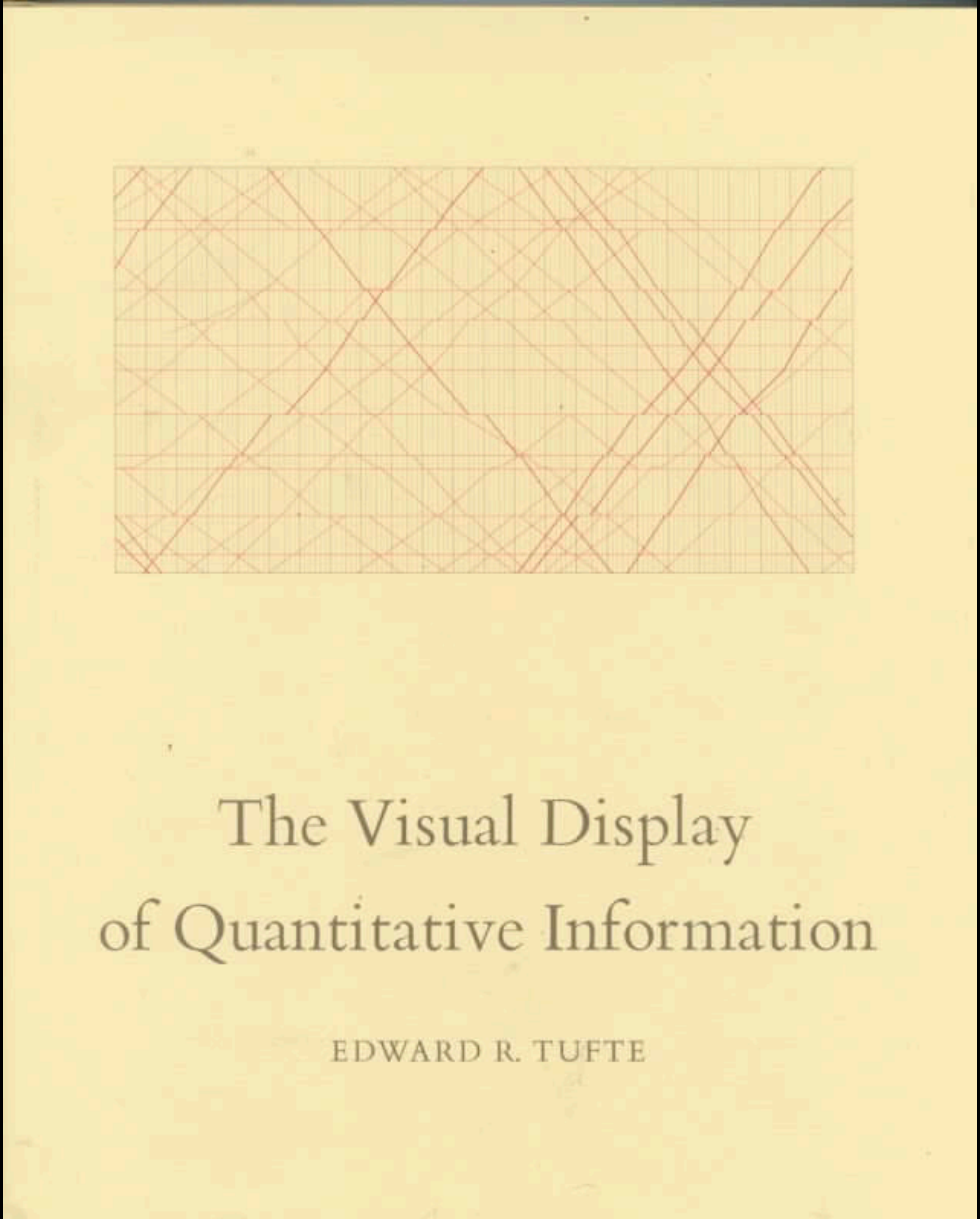


Copyrighted Material

The Elements of Graphing Data

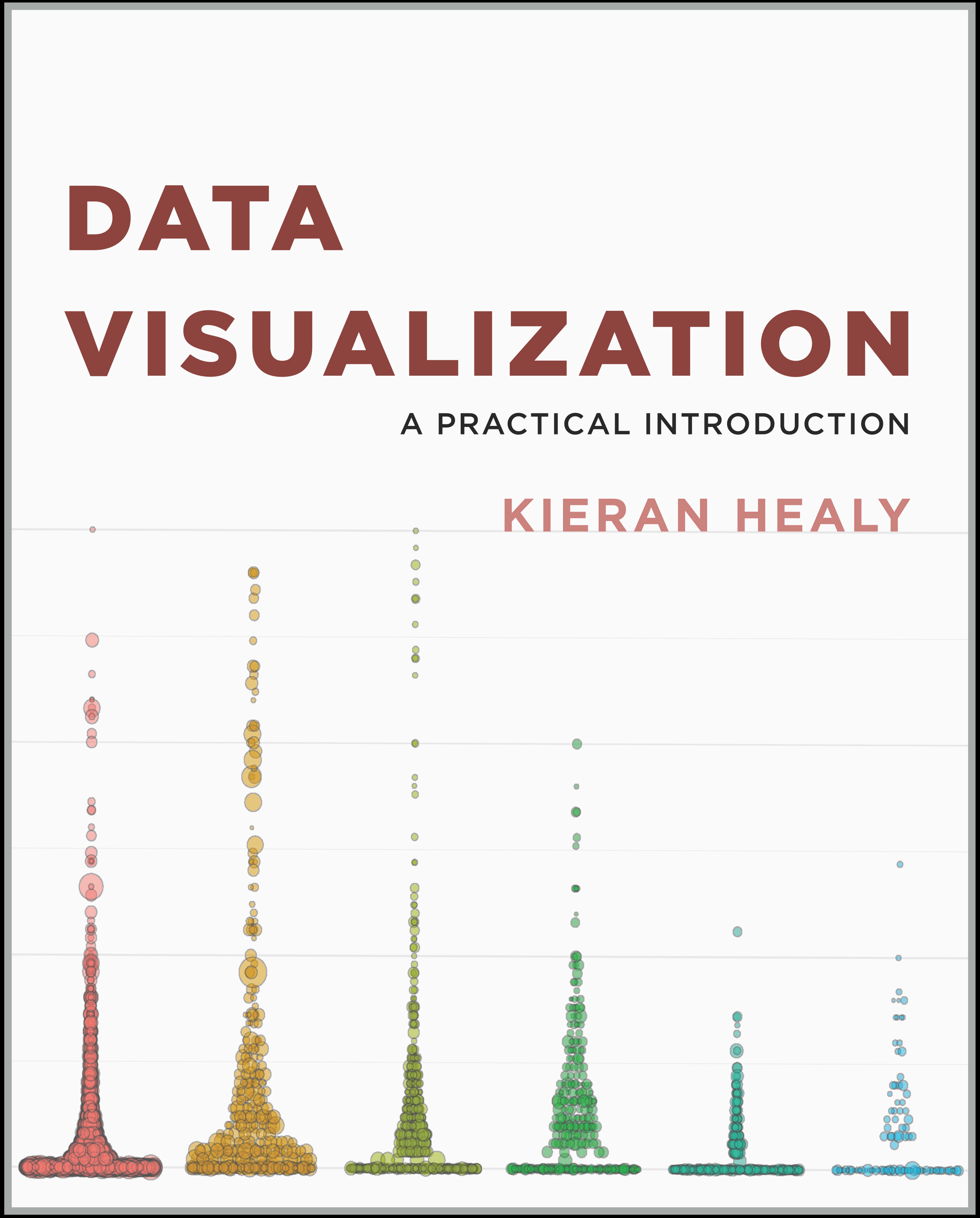
William S. Cleveland

Copyrighted Material



The Visual Display of Quantitative Information

EDWARD R. TUFTE



DATA VISUALIZATION

A PRACTICAL INTRODUCTION

KIERAN HEALY

http://socviz.co/

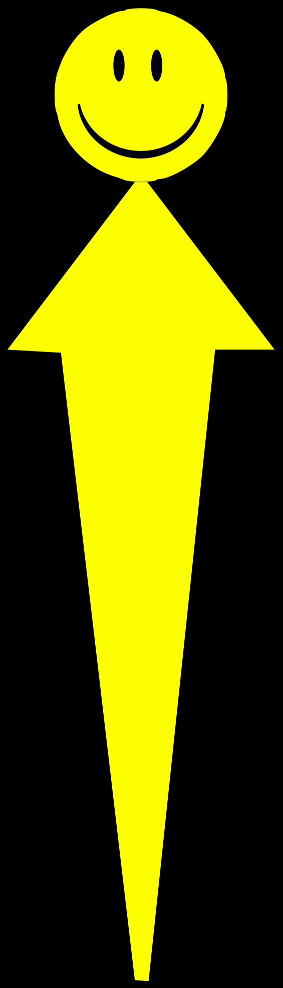
Key Point:

Good visualizations optimize for the human visual system.

Key Point: The most important measurement should exploit the highest ranked encoding possible

- Position along a common scale
- Position on identical but nonaligned scales
- Length
- Angle or Slope
- Area
- Volume or Density or Color saturation/hue

Key Point: The most important measurement should exploit the highest ranked encoding possible



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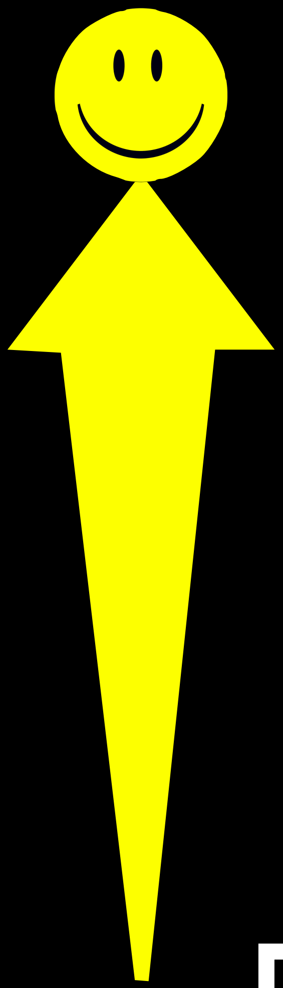
Key Point: The most important measurement should exploit the highest ranked encoding possible



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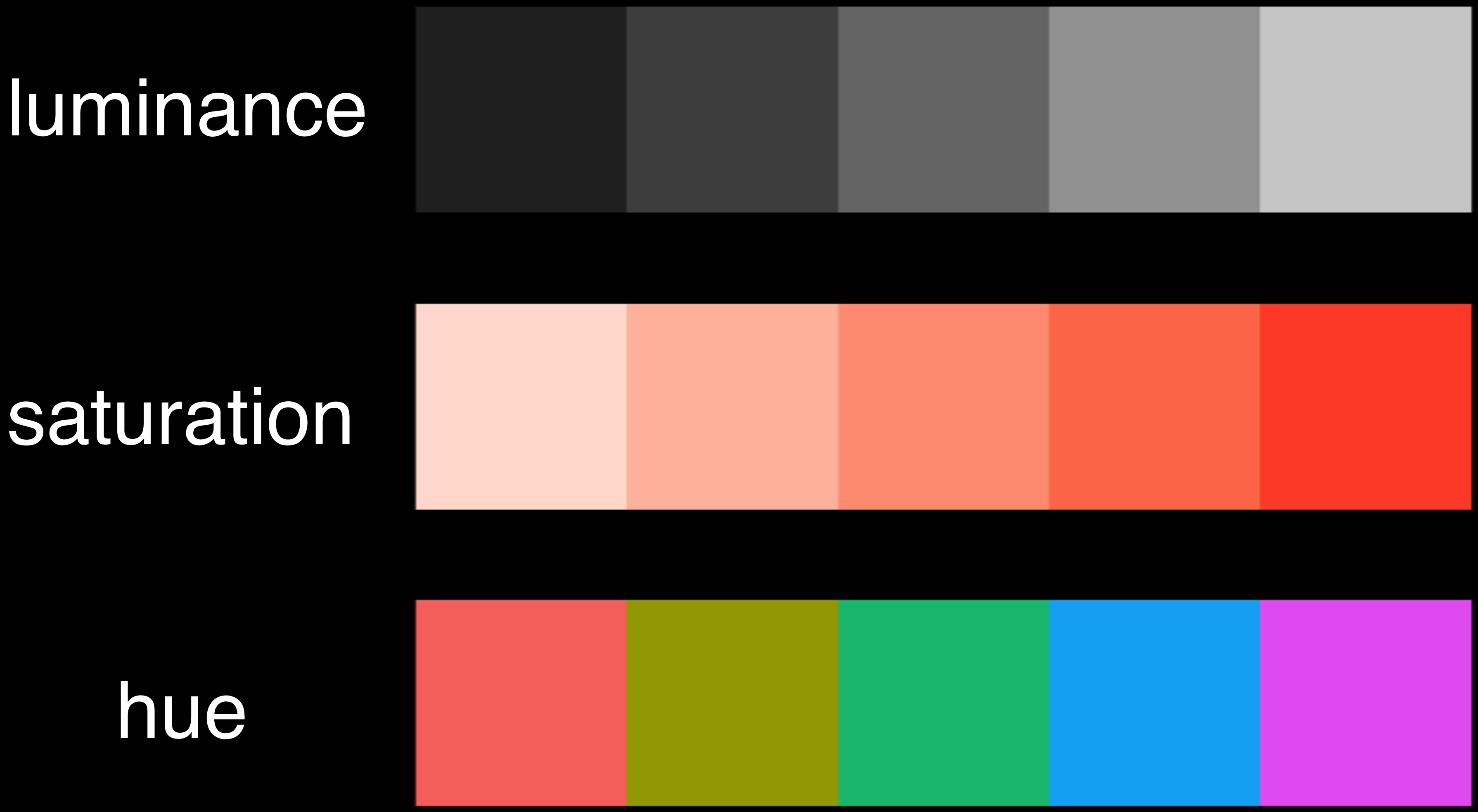
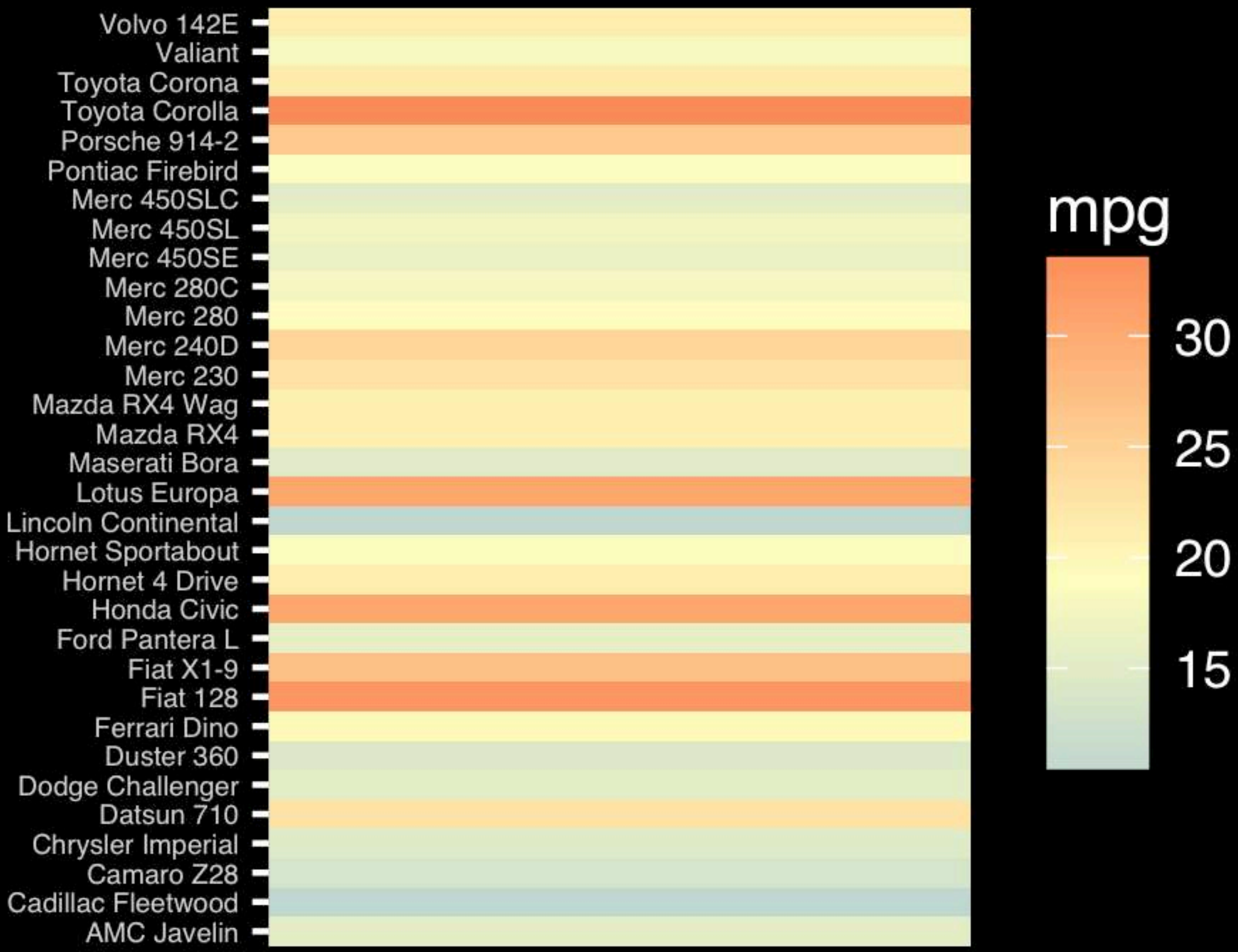


luminance

saturation

hue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Toyota Corolla
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Pontiac Firebird
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Merc 450SL
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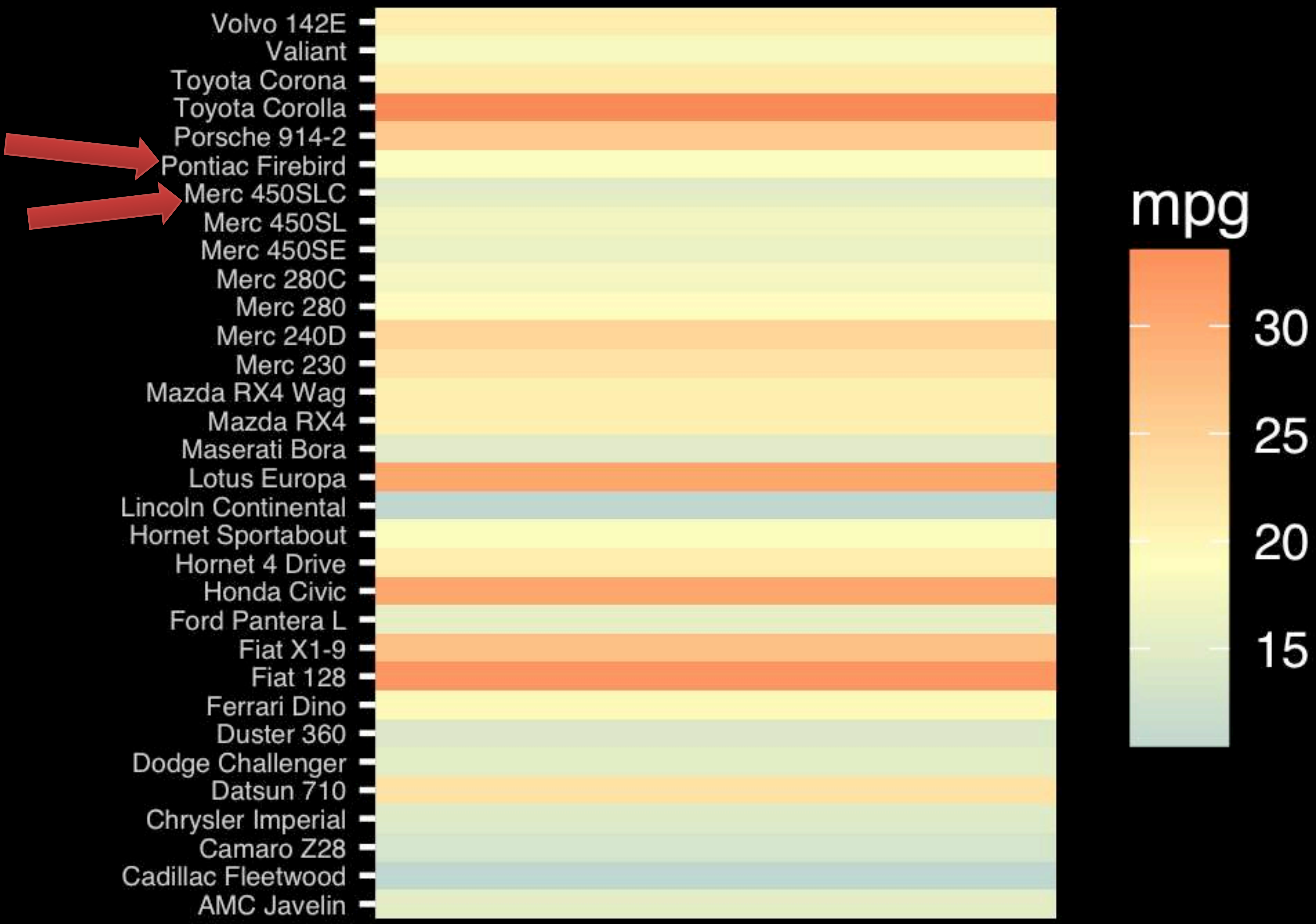
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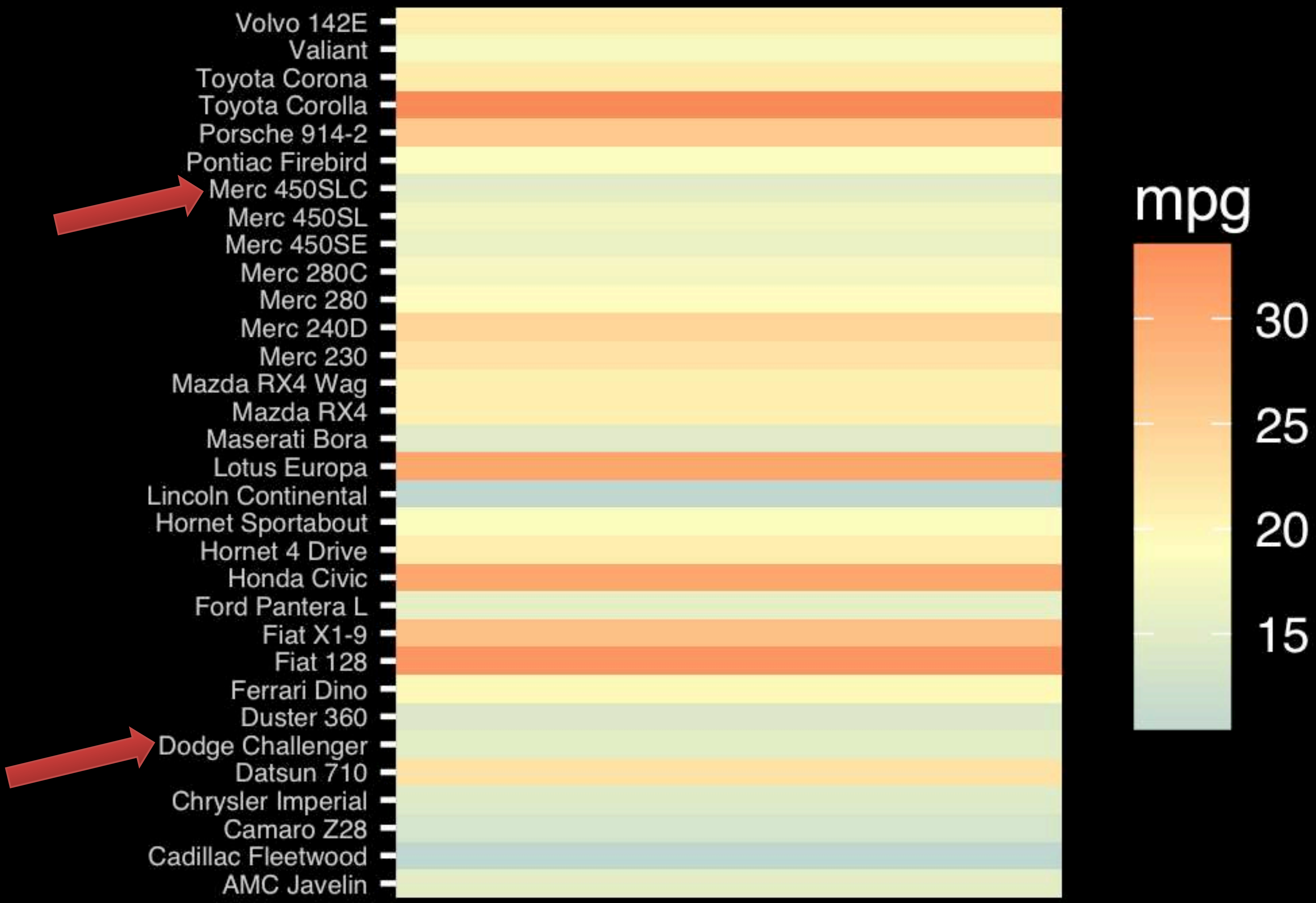
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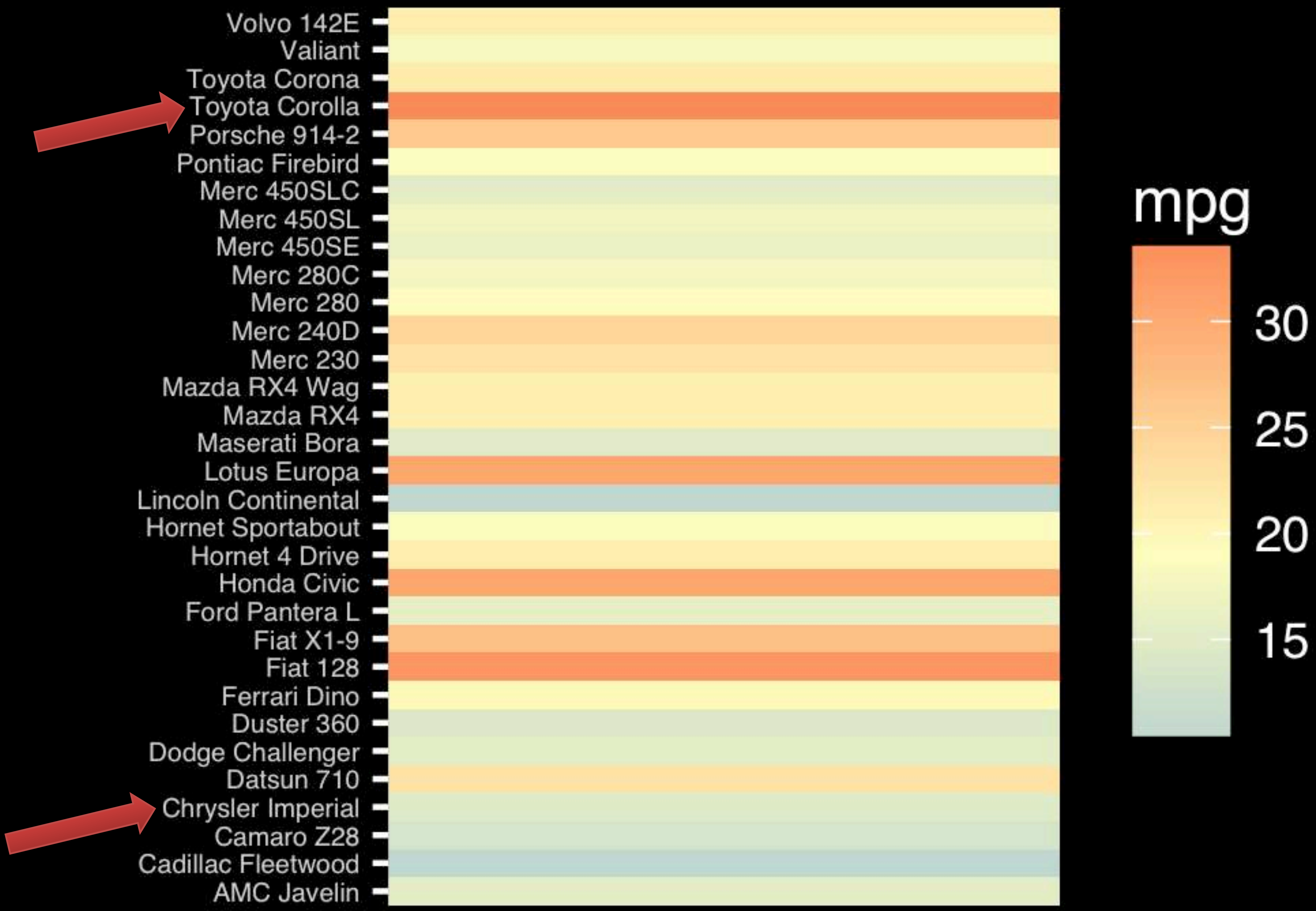
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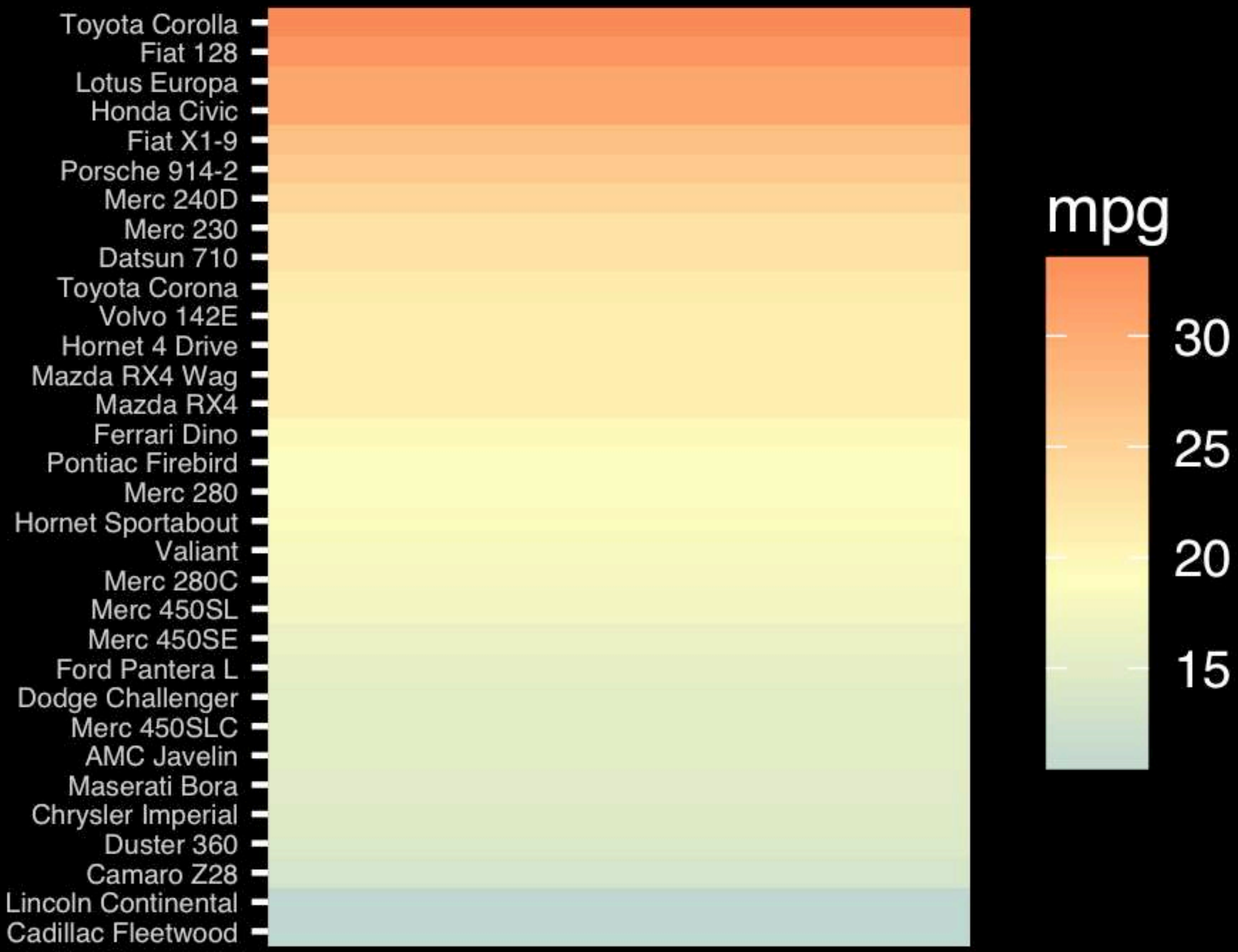
Observation: Alphabetical is almost never the correct ordering of a categorical variable.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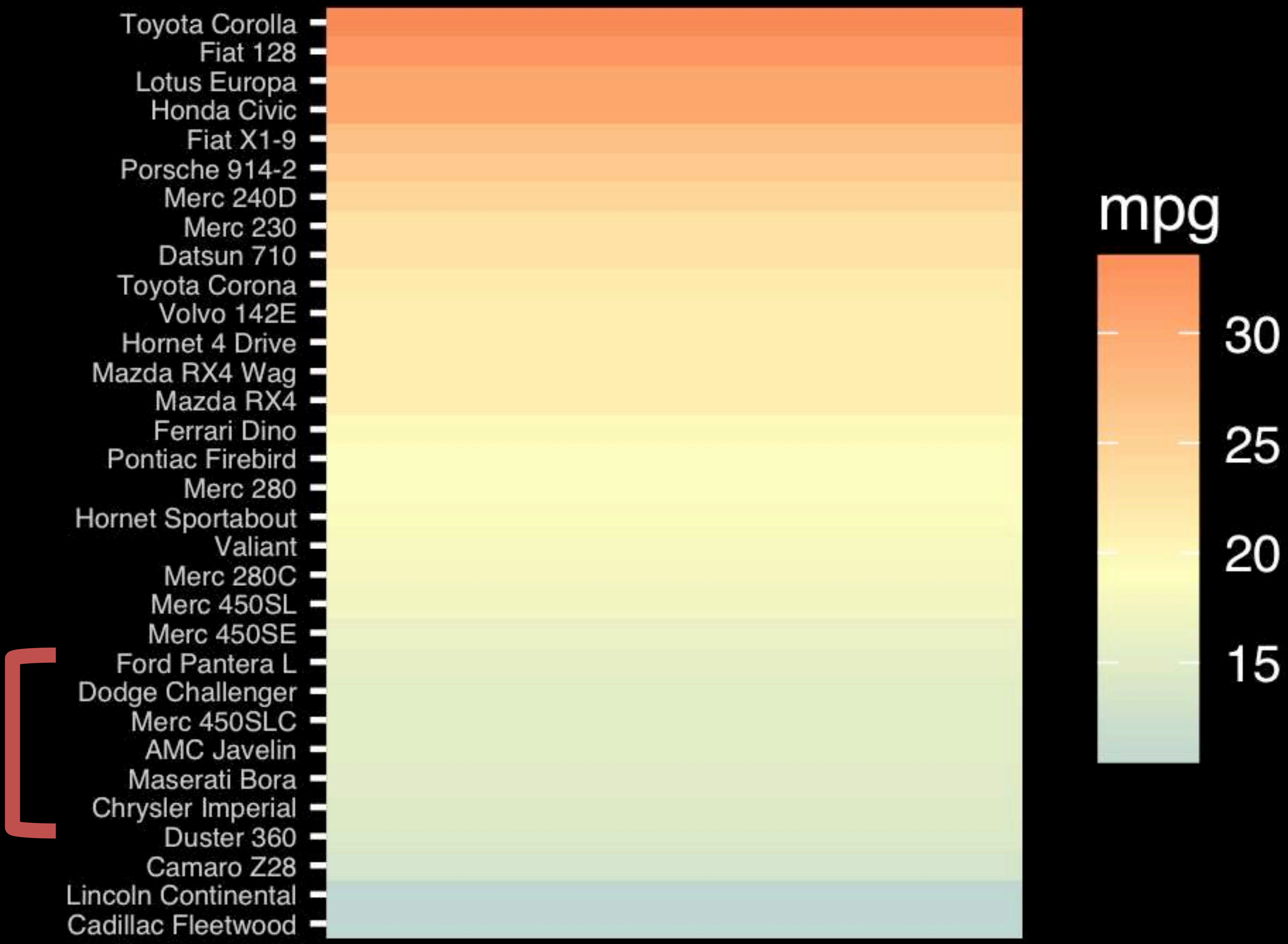
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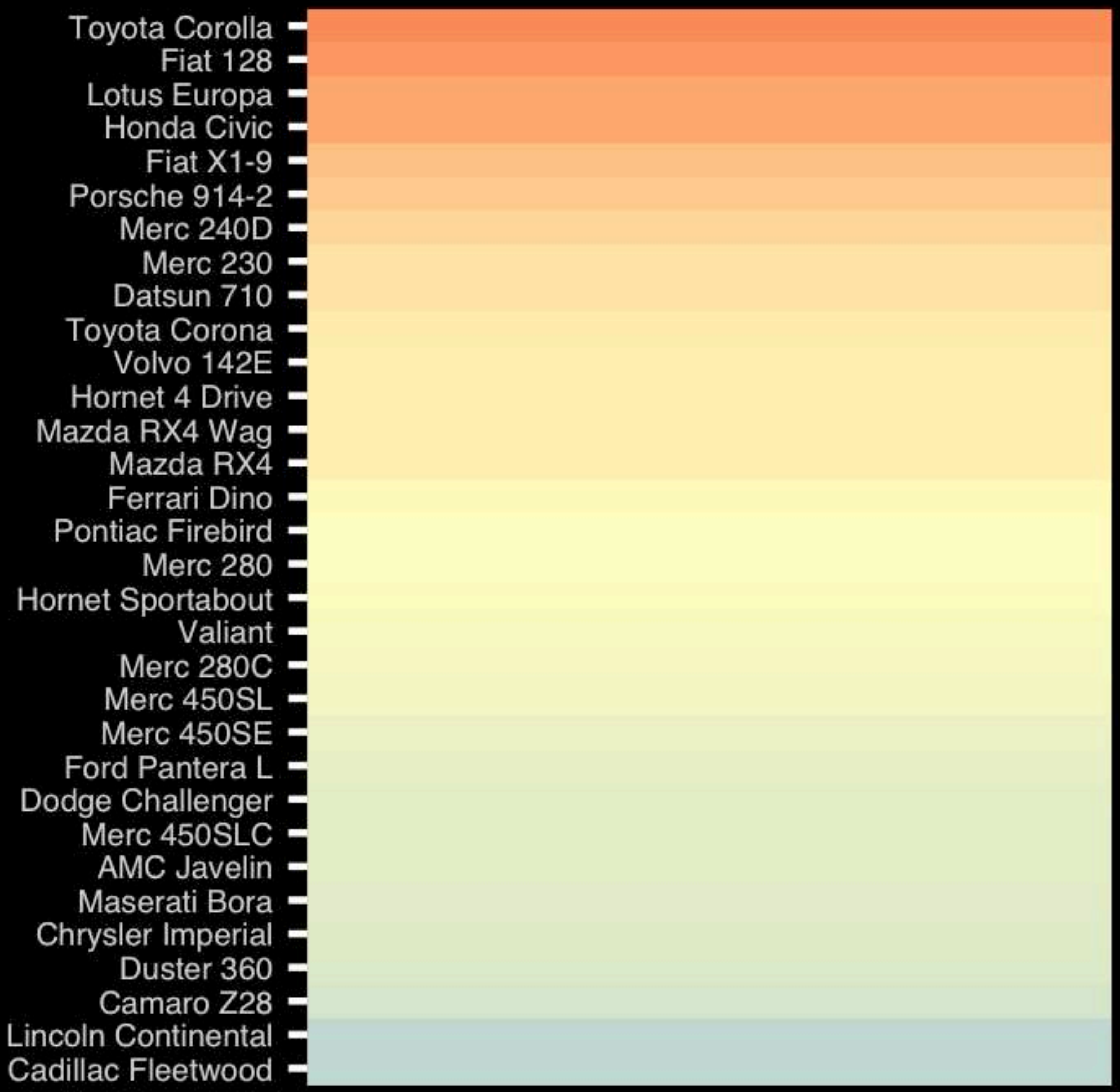
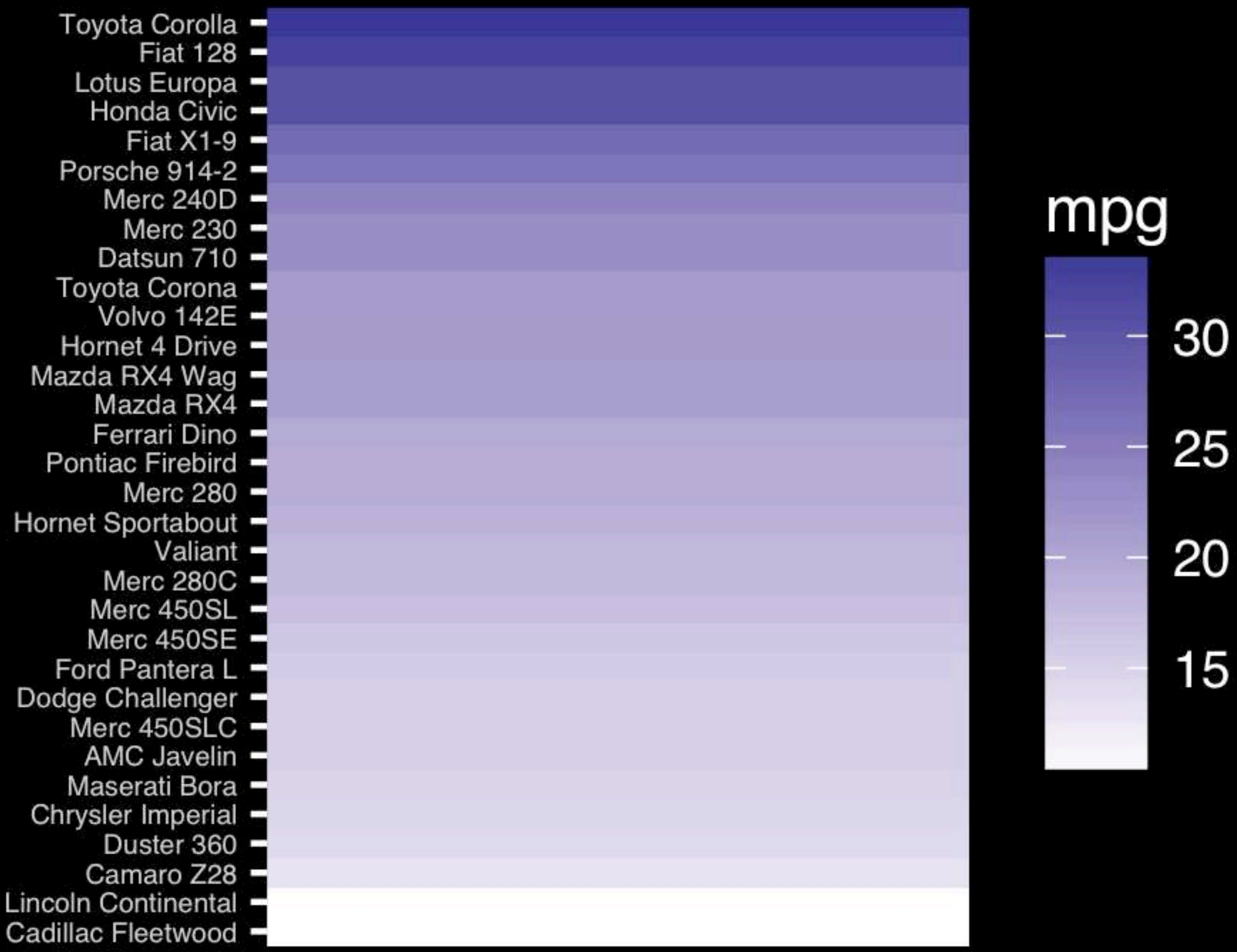


If we did not have the legend would you know which was low or high mpg?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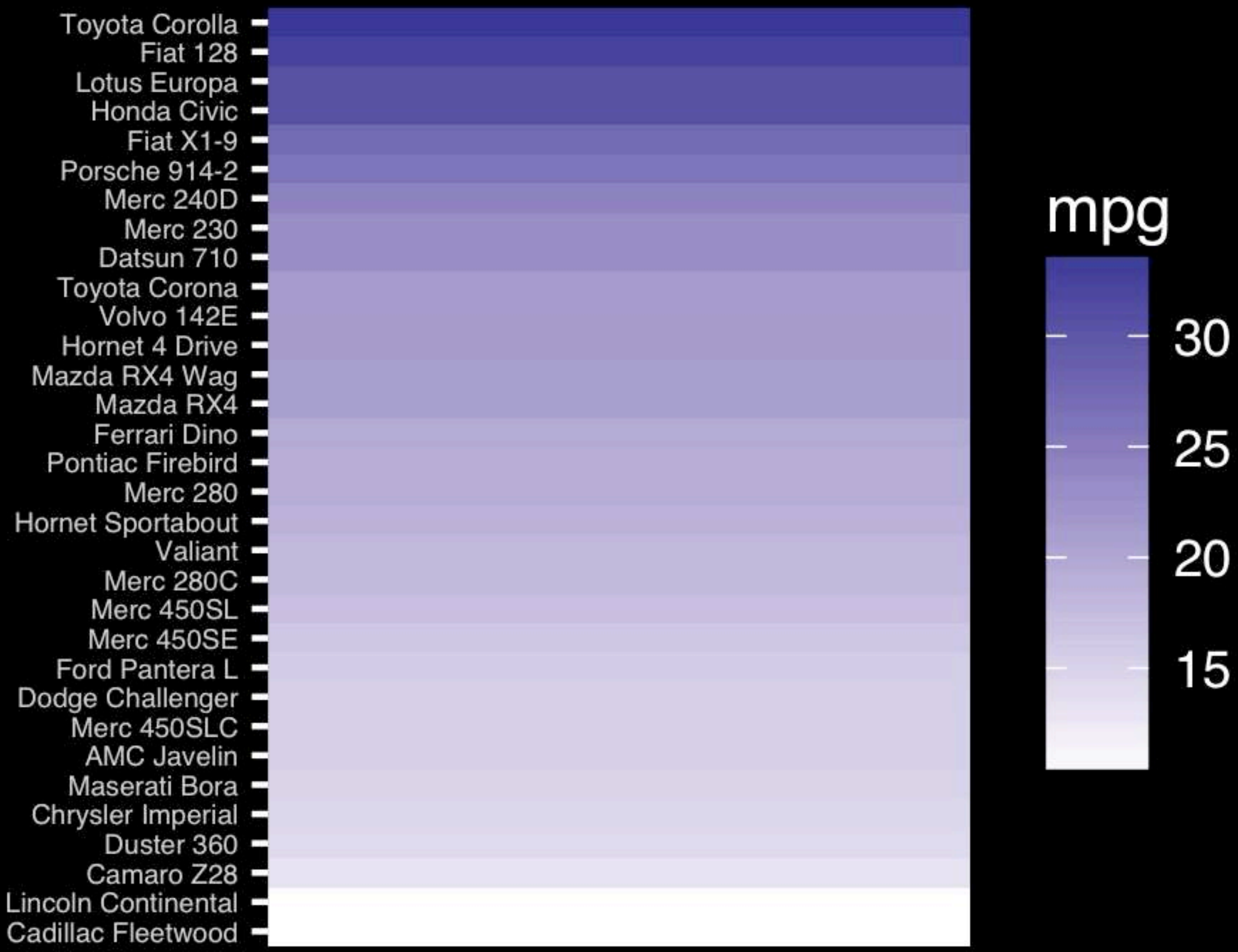
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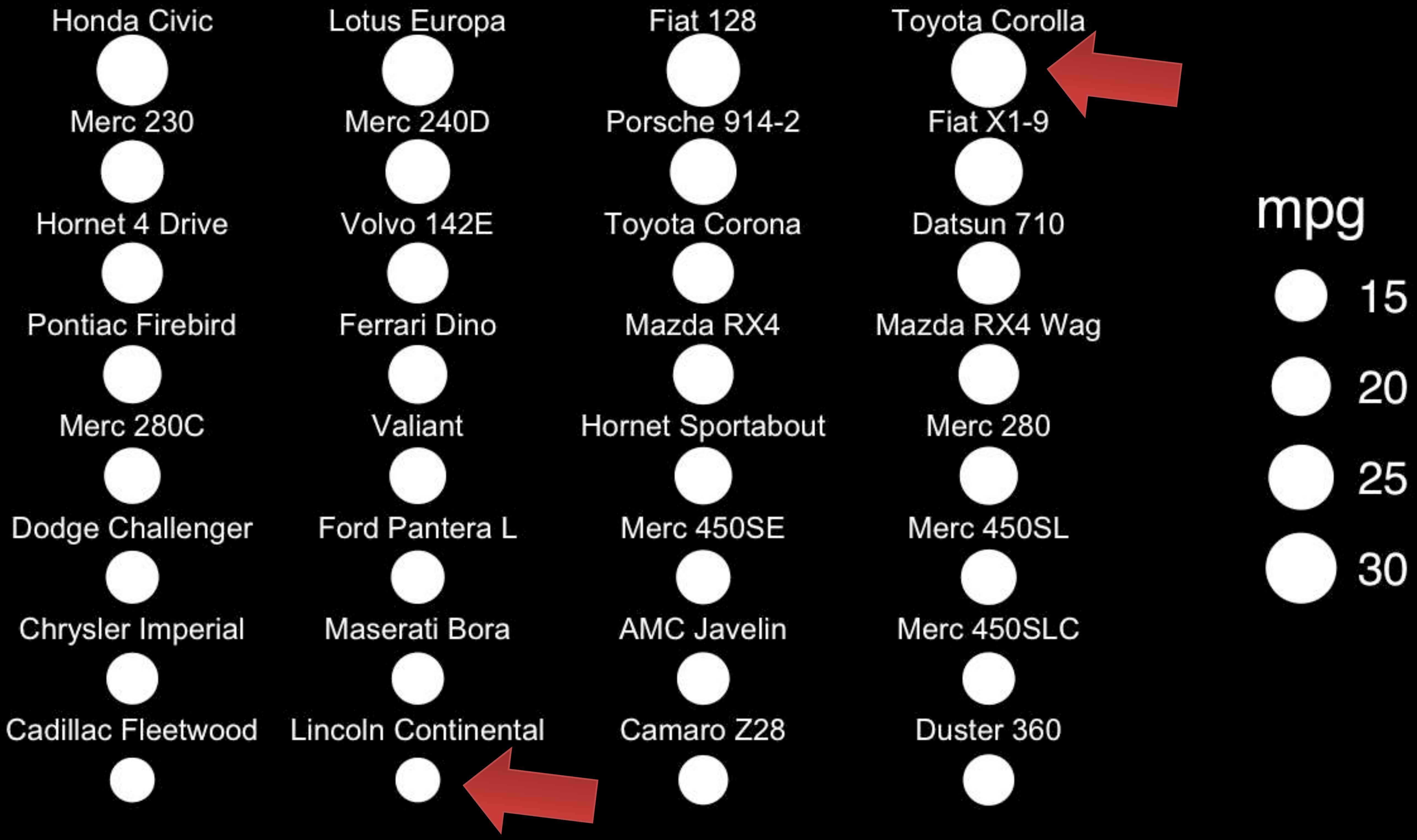
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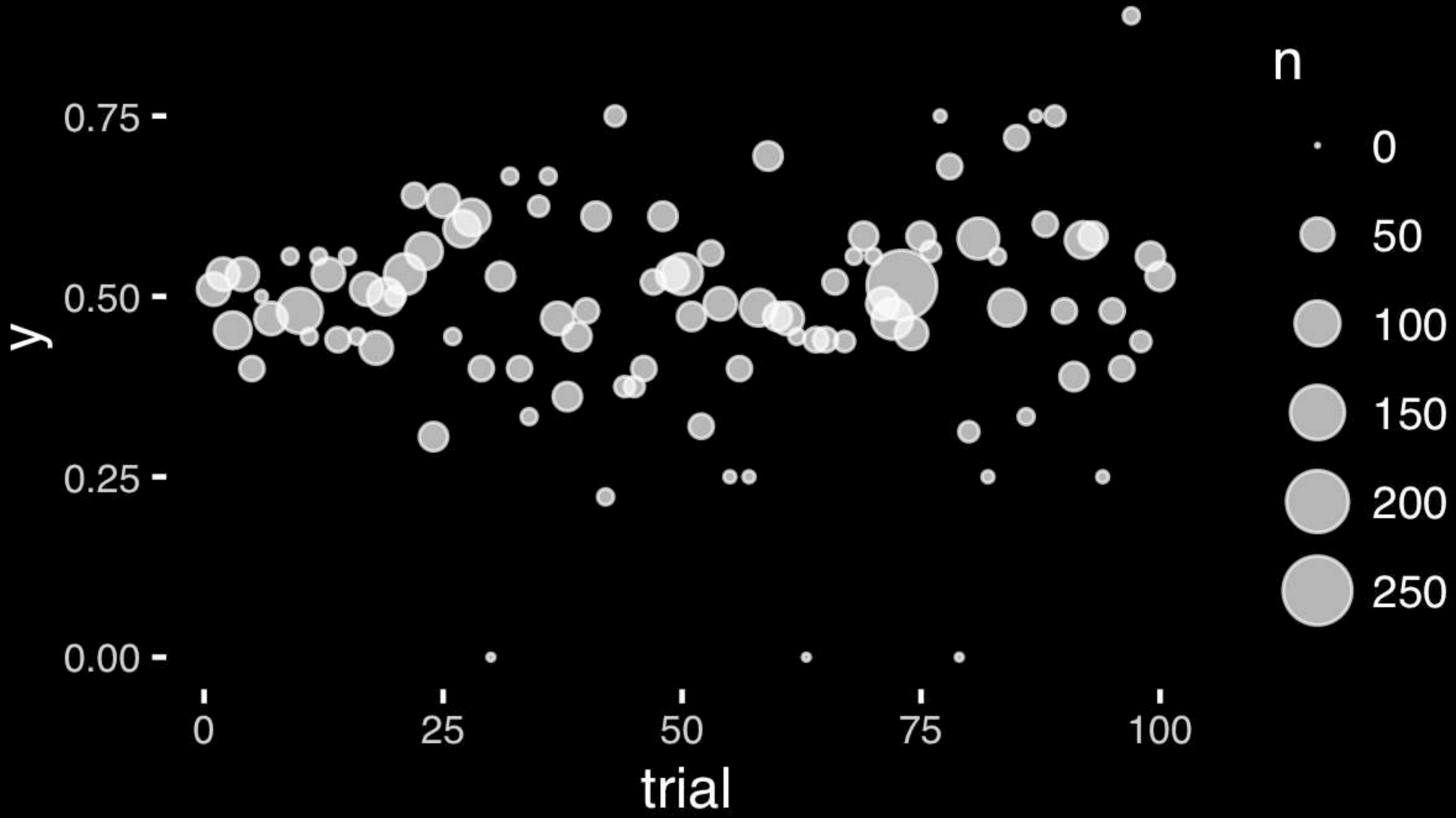
25
30


0.75
0.50
0.25
0.00
y
0
25
50
75
100
trial
n
0
50
100
150
200
250

The most important measurement should exploit the highest ranked encoding possible.

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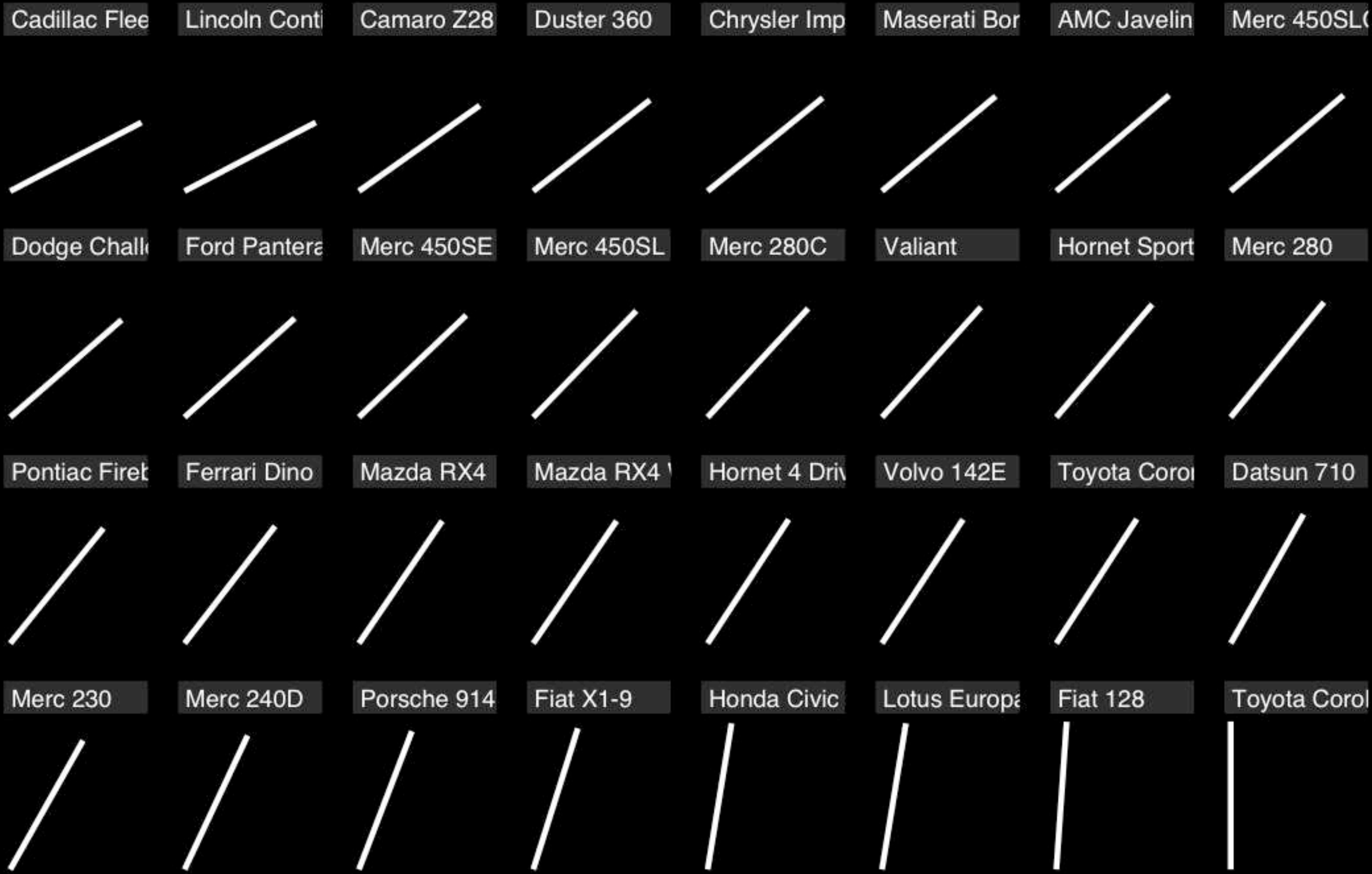
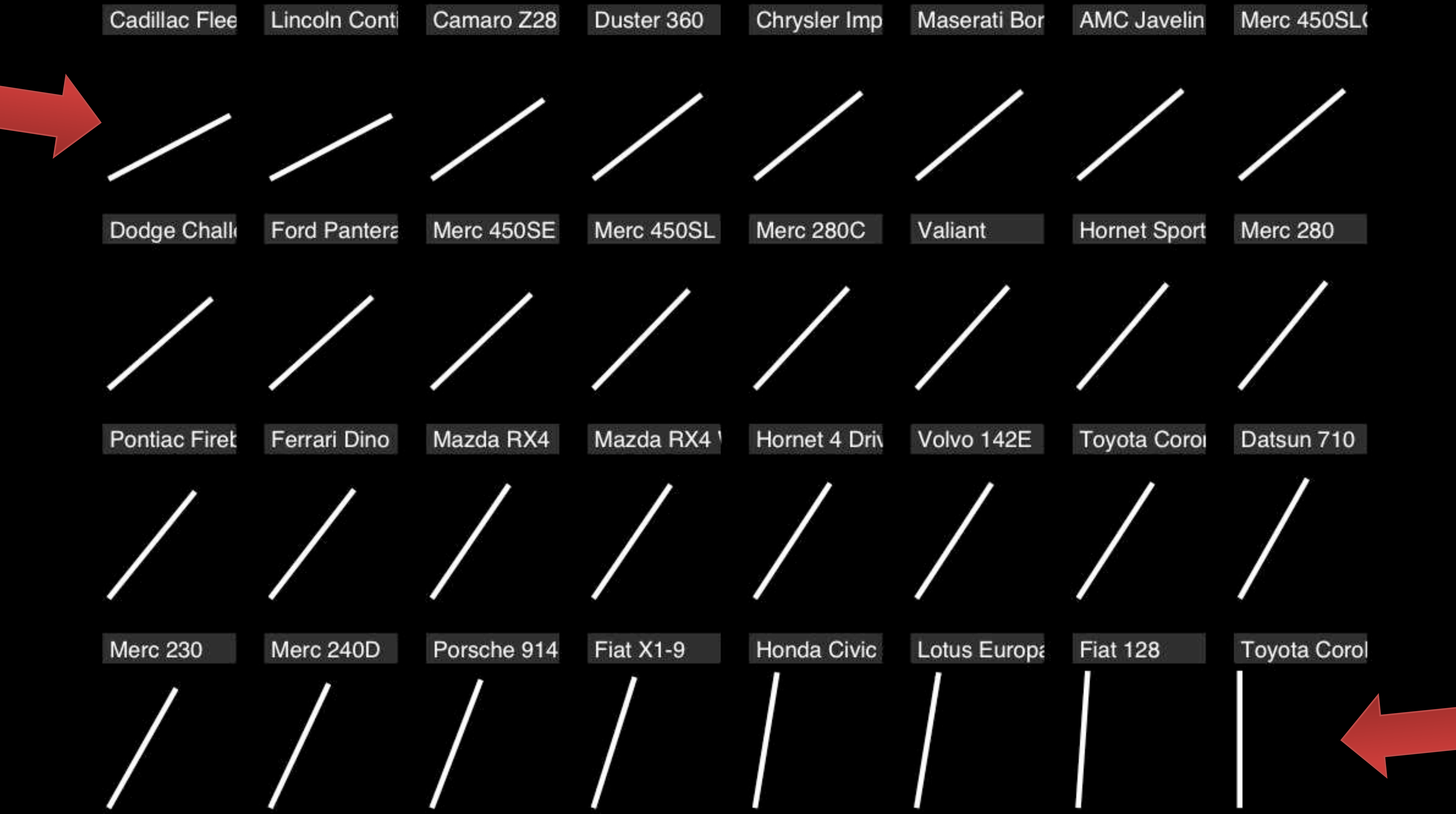
- Position on identical but nonaligned scales
- Length
- **Angle or Slope**
- Area
- Volume or Density or Color saturation/hue


Cadillac Flee
Lincoln Conti
Camaro Z28
Duster 360
Chrysler Imp
Maserati Bor
AMC Javelin
Merc 450SL
Dodge Chall
Ford Panter
Merc 450SE
Merc 450SL
Merc 280C
Valiant
Hornet Sport
Merc 280
Pontiac Fireb
Ferrari Dino
Mazda RX4
Mazda RX4
Hornet 4 Driv
Volvo 142E
Toyota Coro
Datsun 710
Merc 230
Merc 240D
Porsche 914
Fiat X1-9
Honda Civic
Lotus Europ
Fiat 128
Toyota Corol


Cadillac Flee
Lincoln Conti
Camaro Z28
Duster 360
Chrysler Imp
Maserati Bor
AMC Javelin
Merc 450SL
Dodge Chall
Ford Panter
Merc 450SE
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Merc 280C
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Mazda RX4
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Volvo 142E
Toyota Coron
Datsun 710
Merc 230
Merc 240D
Porsche 914
Fiat X1-9
Honda Civic
Lotus Europa
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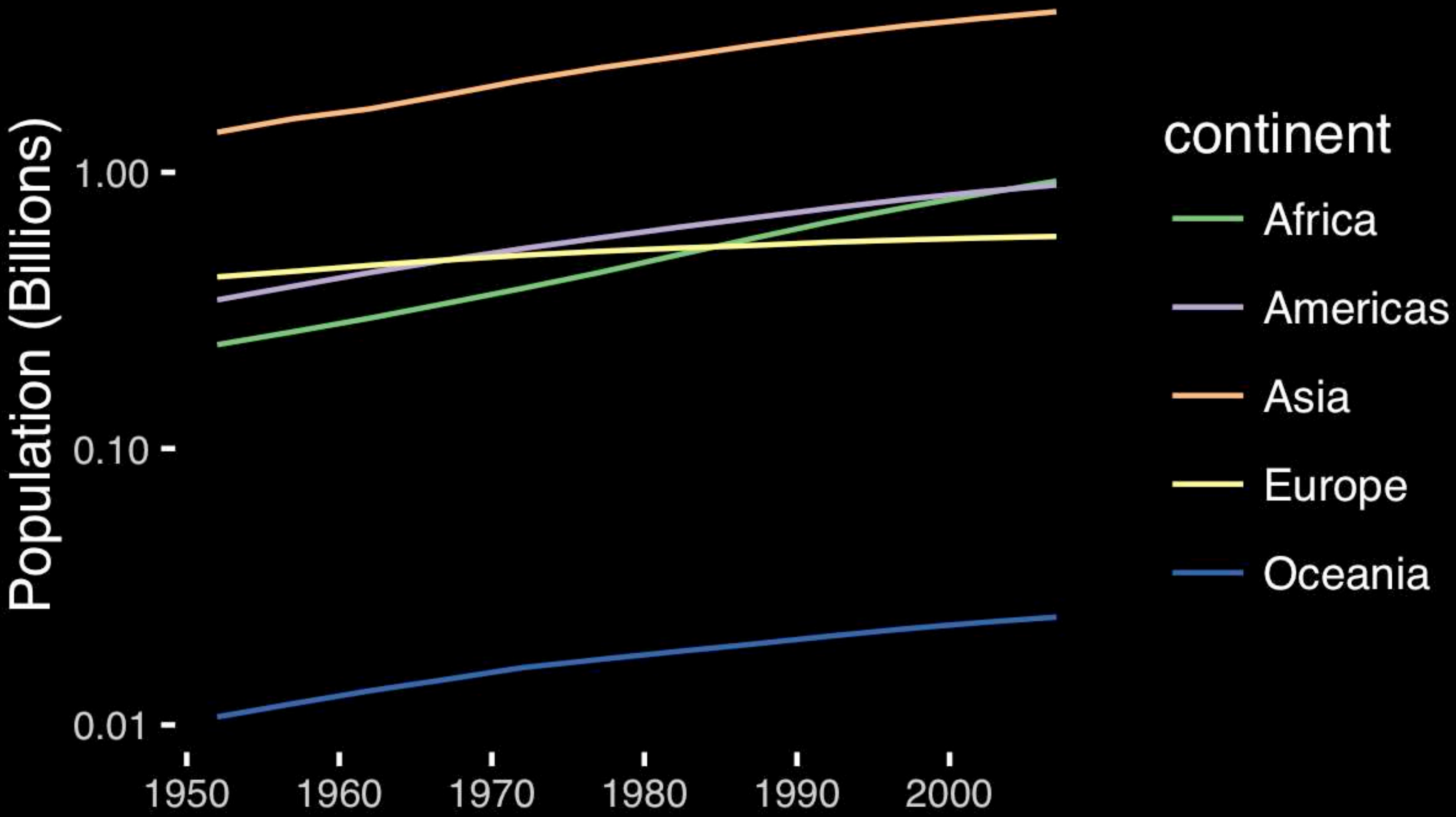
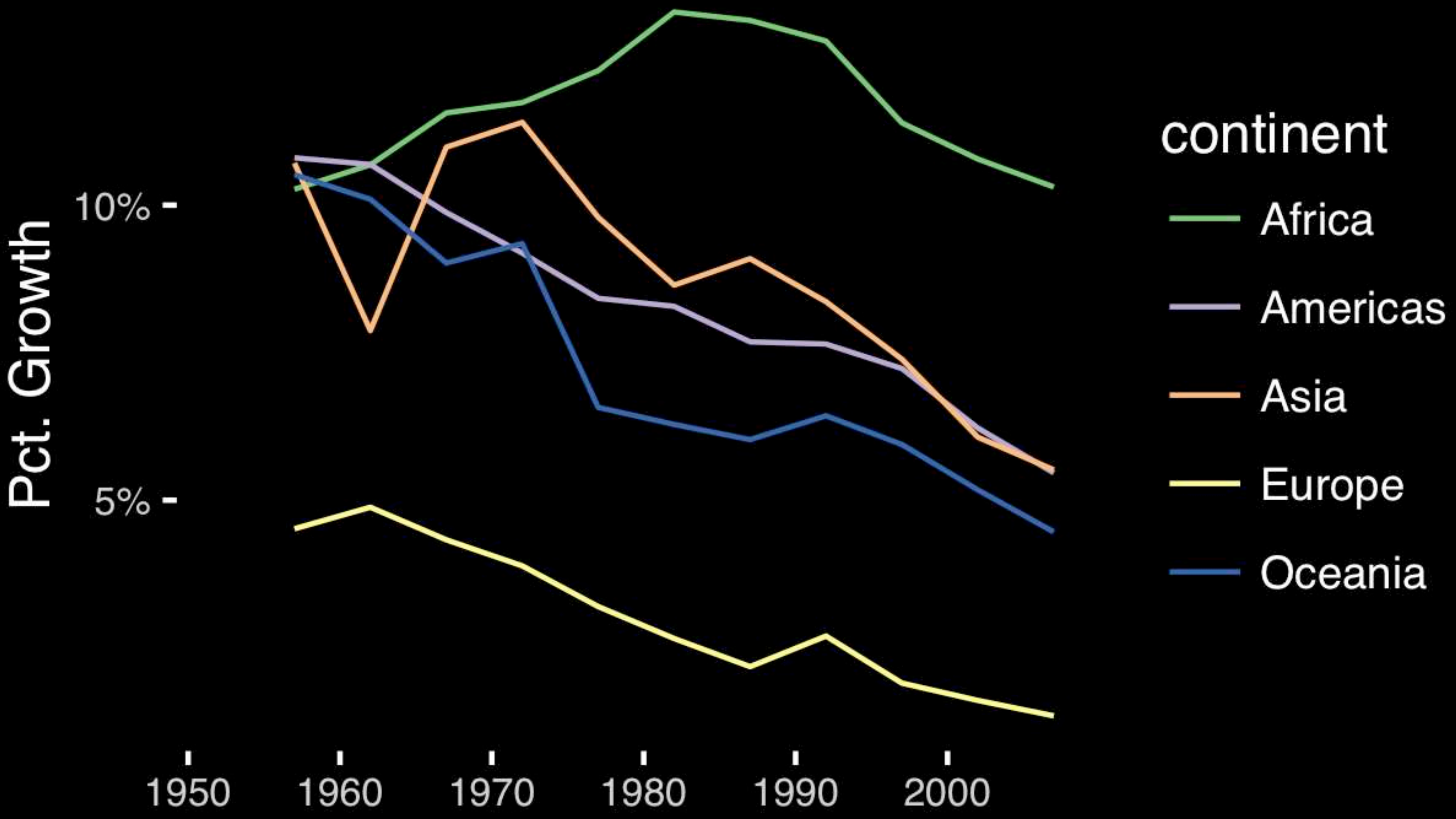
Toyota Corol


Population (Billions)
1.00
0.10
0.01
1950
1960
1970
1980
1990
2000
continent
Africa
Americas
Asia
Europe
Oceania

If growth (slope) is important, plot it directly.


Pct. Growth
10%
5%
1950
1960
1970
1980
1990
2000
continent
Africa
Americas
Asia
Europe
Oceania

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- Length
- **Angle or Slope**
- Area
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Observation: Pie charts are ALWAYS a mistake.

Apart from MPAs :-)

Piecharts are the information visualization equivalent of a roofing hammer to the frontal lobe. They have no place in the world of grownups, and occupy the same semiotic space as short pants, a runny nose, and chocolate smeared on one’s face. They are as professional as a pair of assless chaps.

http://blog.codahale.com/2006/04/29/google-analytics-the-goggles-they-do-nothing/

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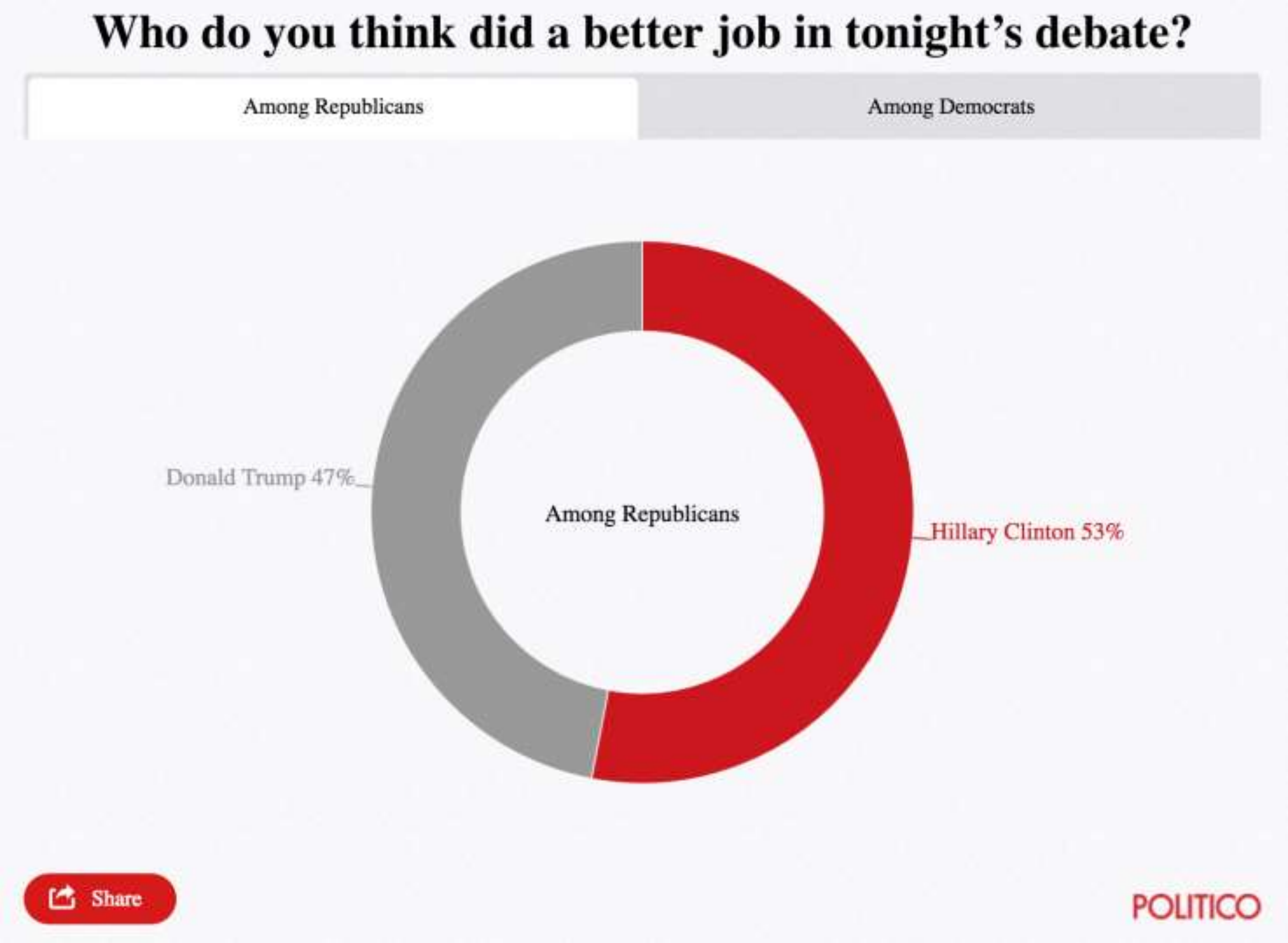
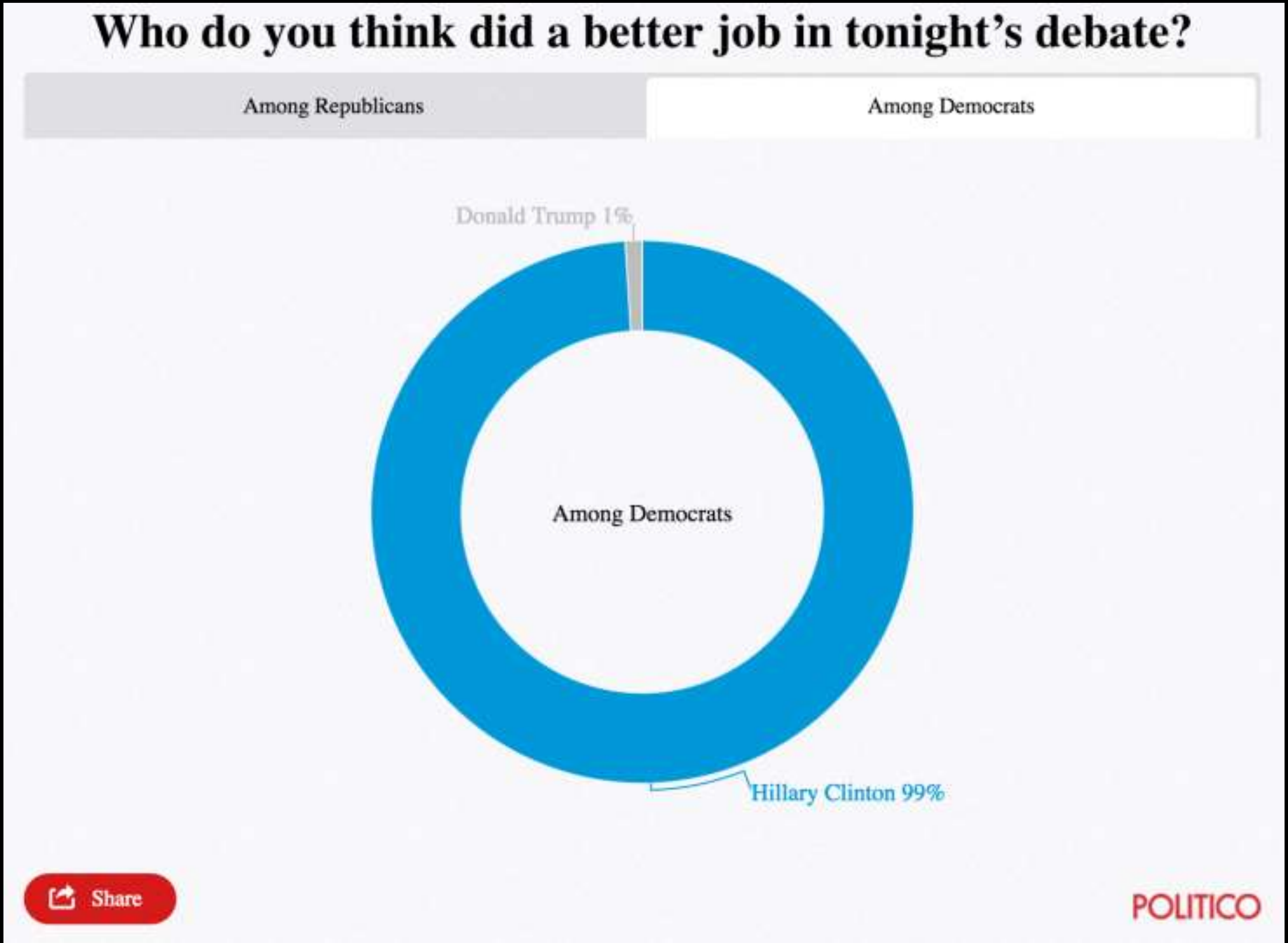


Who do you think did a better job in tonight's debate?



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

Tables are preferable to graphics for many small data sets. A table is nearly always better than a dumb pie chart; the only thing worse than a pie chart is several of them, for then the viewer is asked to compare quantities located in spatial disarray both within and between pies... Given their low data-density and failure to order numbers along a visual dimension, **pie charts should never be used.**

-Edward Tufte, The Visual Display of Quantitative Information

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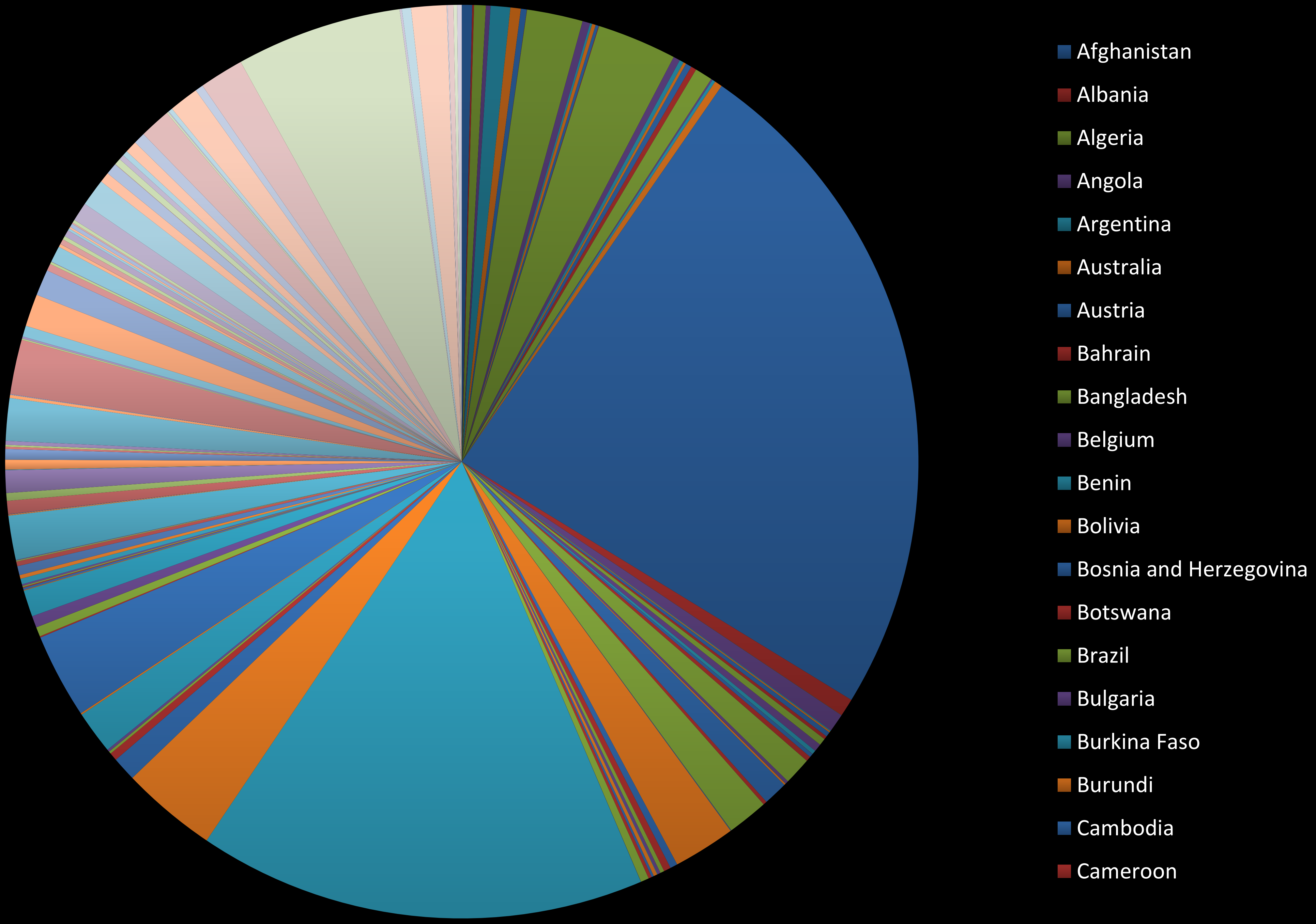
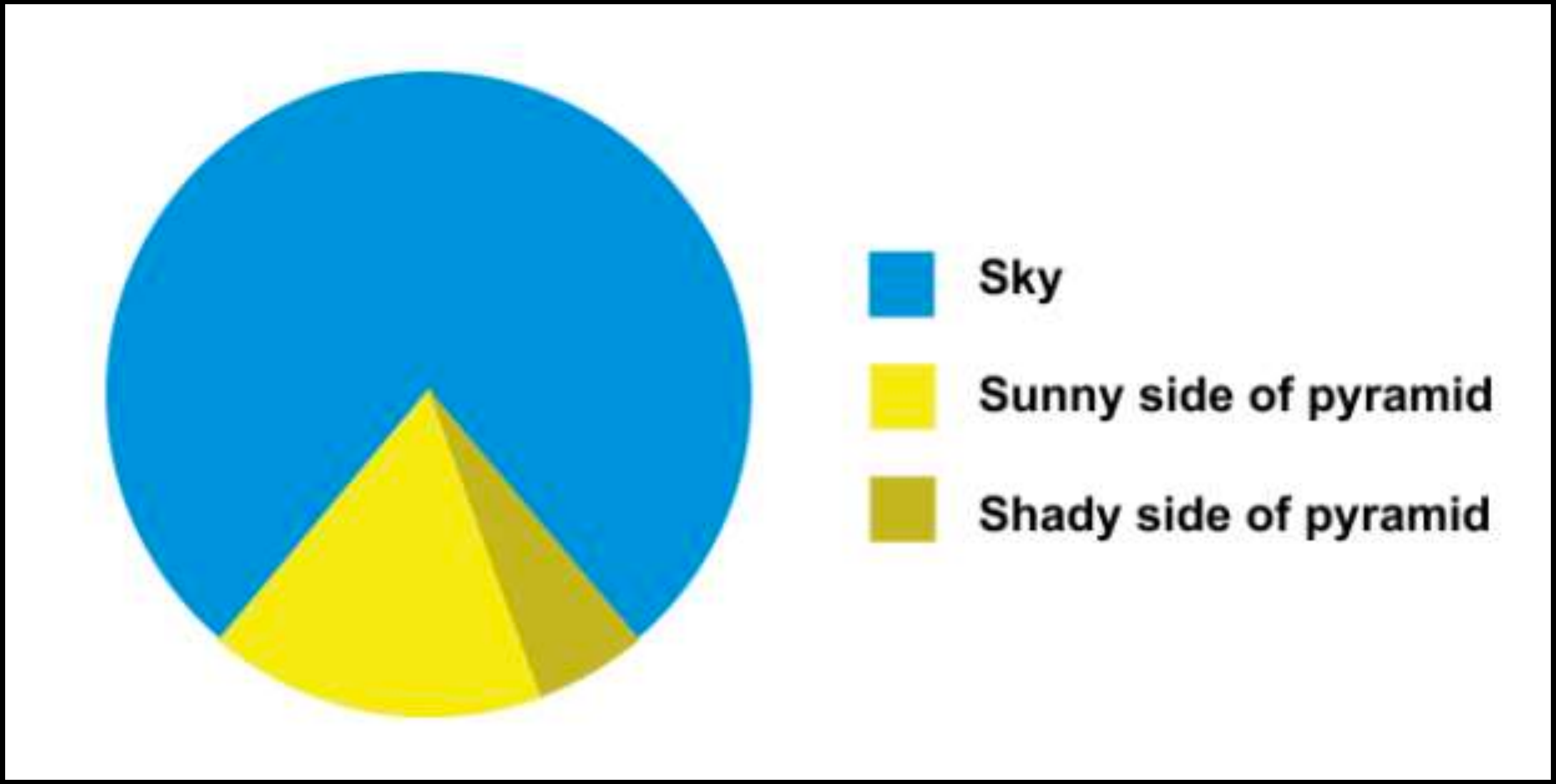
-Edward Tufte, The Visual Display of Quantitative Information

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

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


Afghanistan
Albania
Algeria
Angola
Argentina
Australia
Austria
Bahrain
Bangladesh
Belgium
Benin
Bolivia
Bosnia and Herzegovina
Botswana
Brazil
Bulgaria
Burkina Faso
Burundi
Cambodia
Cameroon

All good pie charts are jokes…



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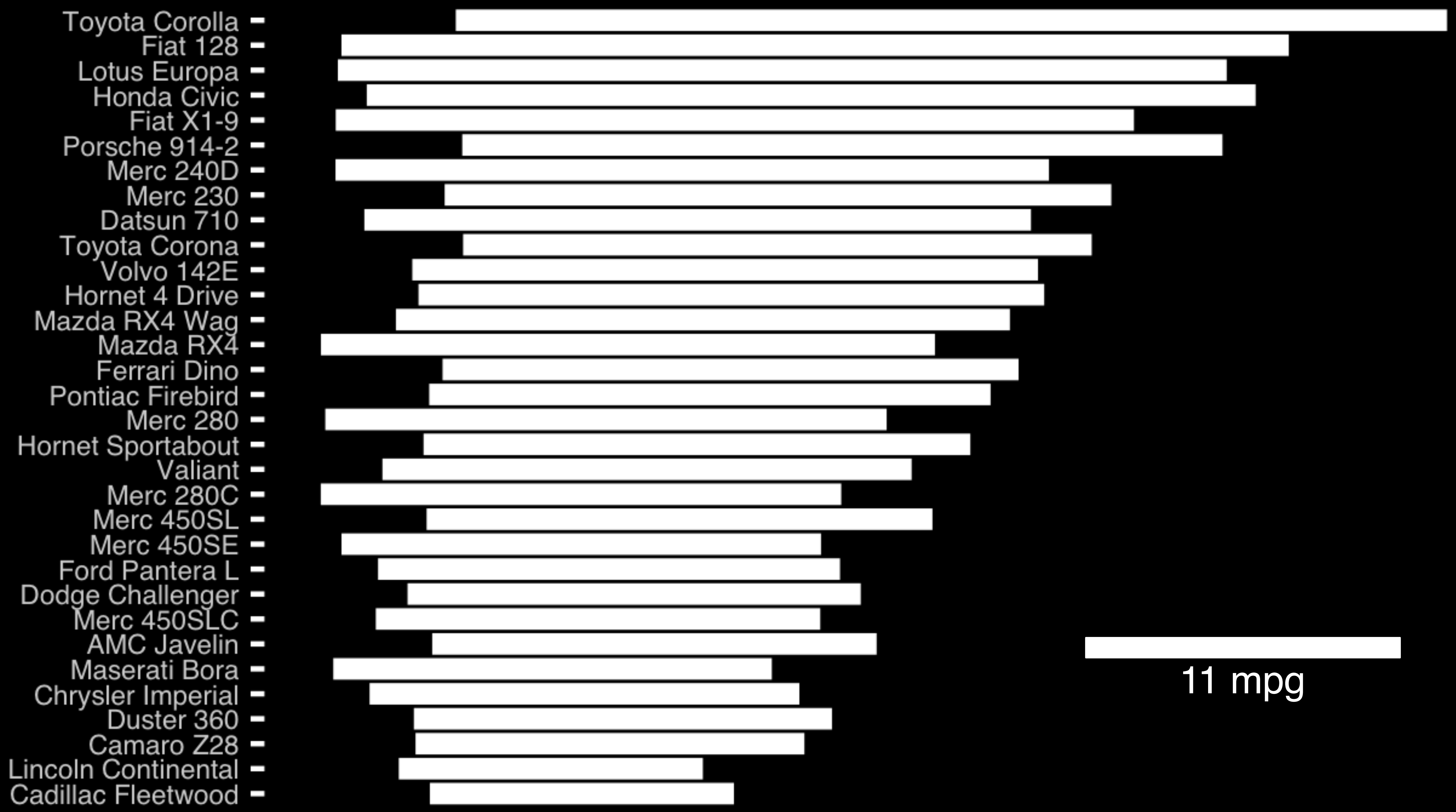
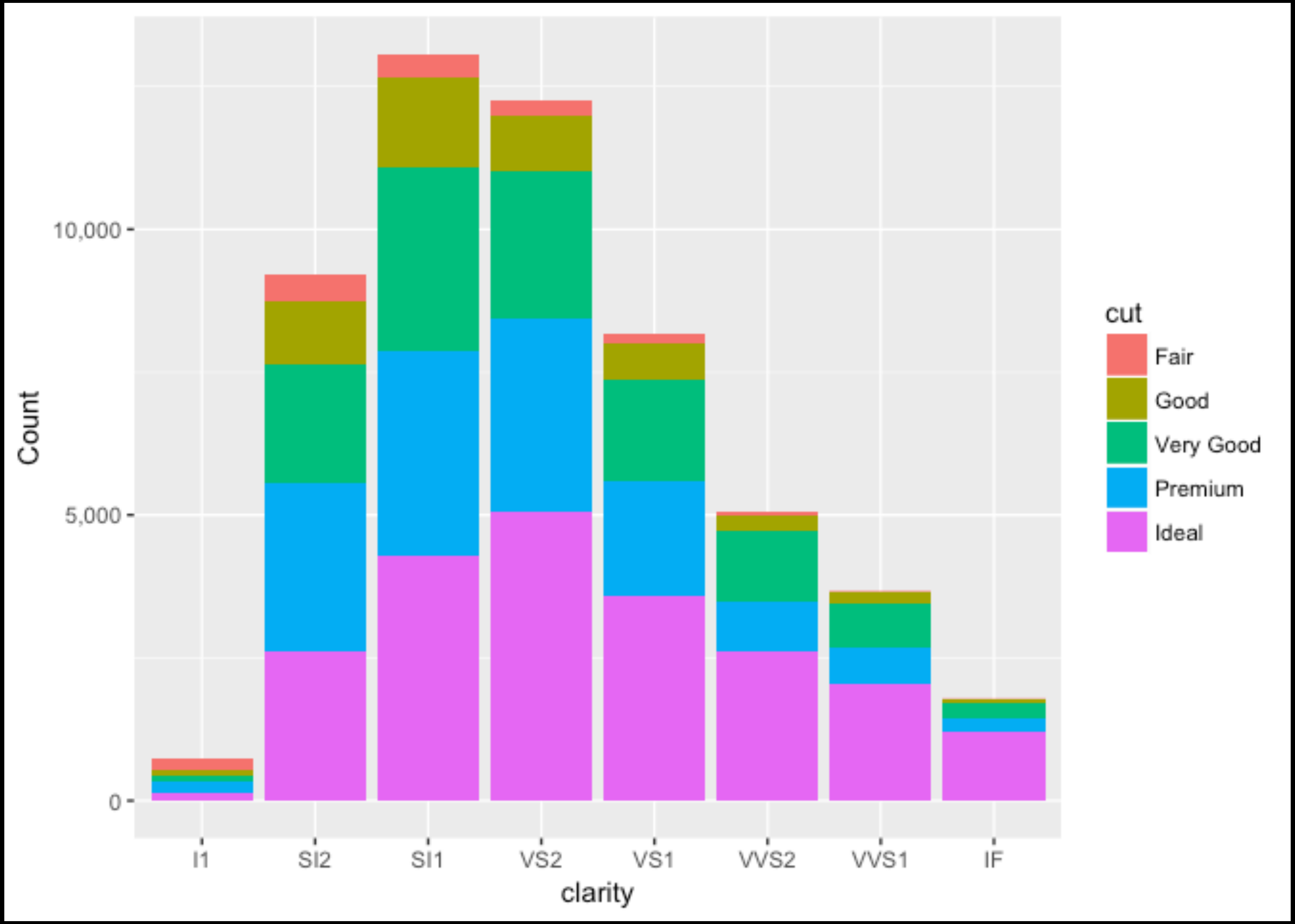
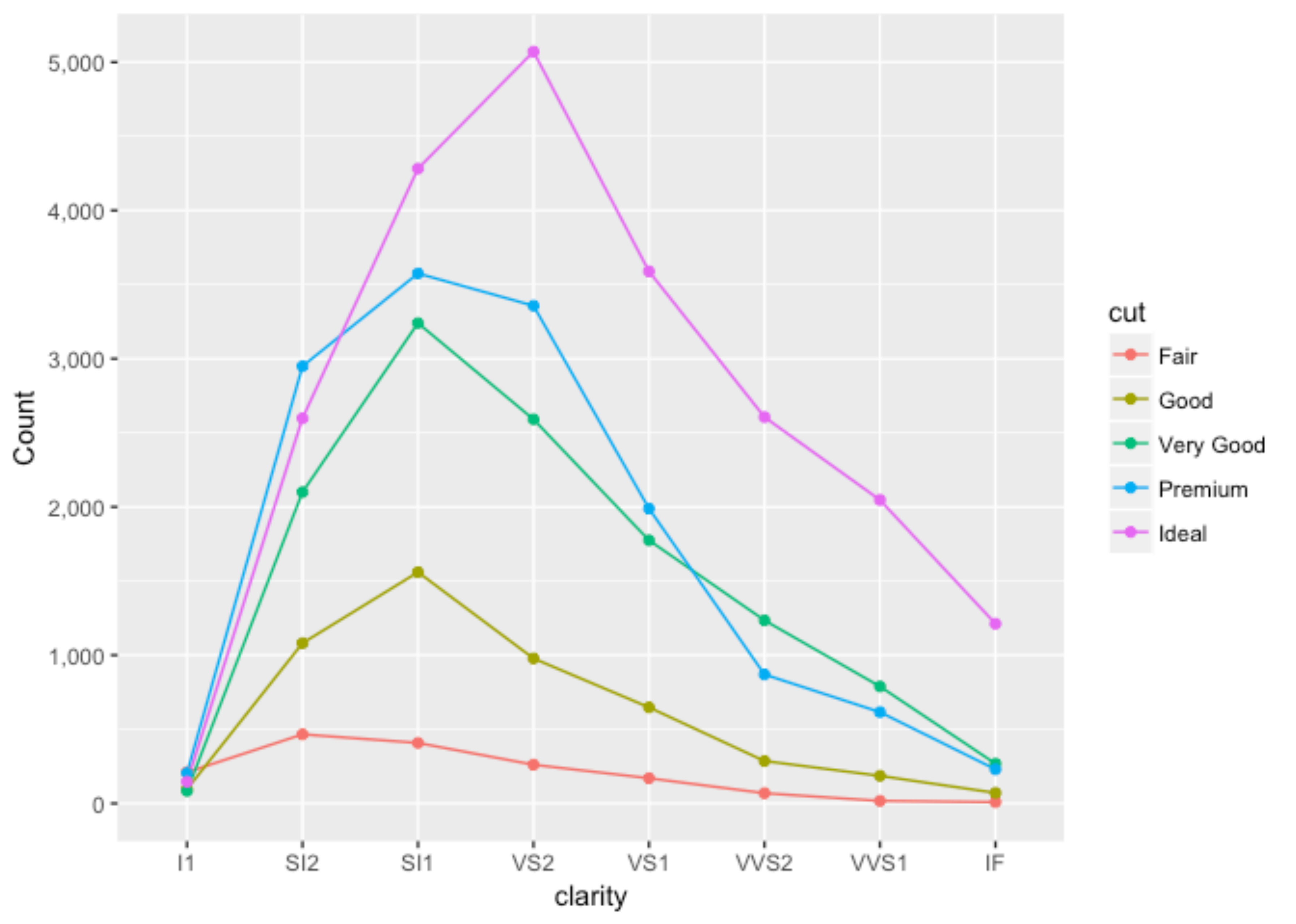
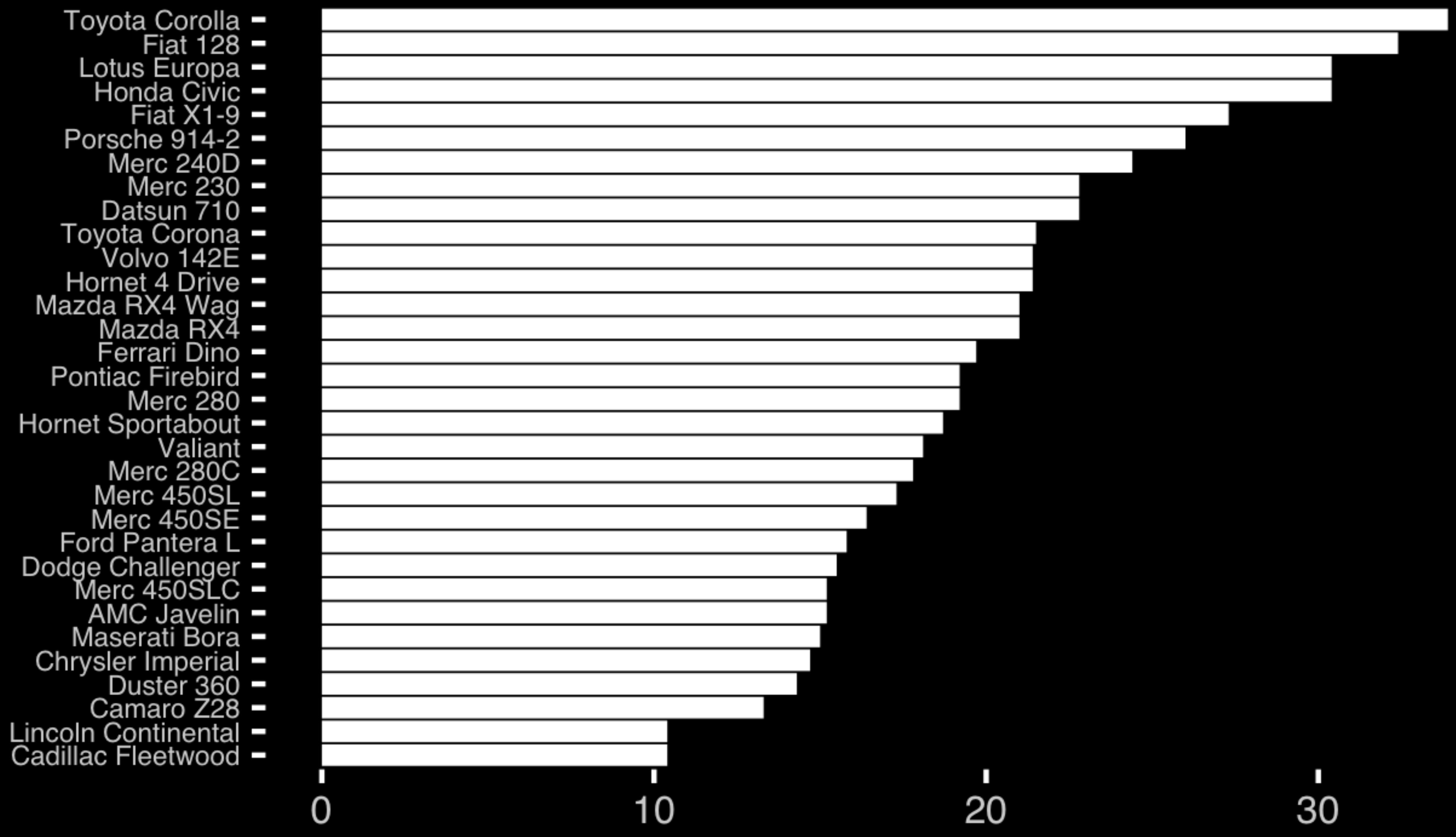

Toyota Corolla
Fiat 128
Lotus Europa
Honda Civic
Fiat X1-9
Porsche 914-2
Merc 240D
Merc 230
Datsun 710
Toyota Corona
Volvo 142E
Hornet 4 Drive
Mazda RX4 Wag
Mazda RX4
Ferrari Dino
Pontiac Firebird
Merc 280
Hornet Sportabout
Valiant
Merc 280C
Merc 450SL
Merc 450SE
Ford Pantera L
Dodge Challenger
Merc 450SLC
AMC Javelin
Maserati Bora
Chrysler Imperial
Duster 360
Camaro Z28
Lincoln Continental
Cadillac Fleetwood
11 mpg

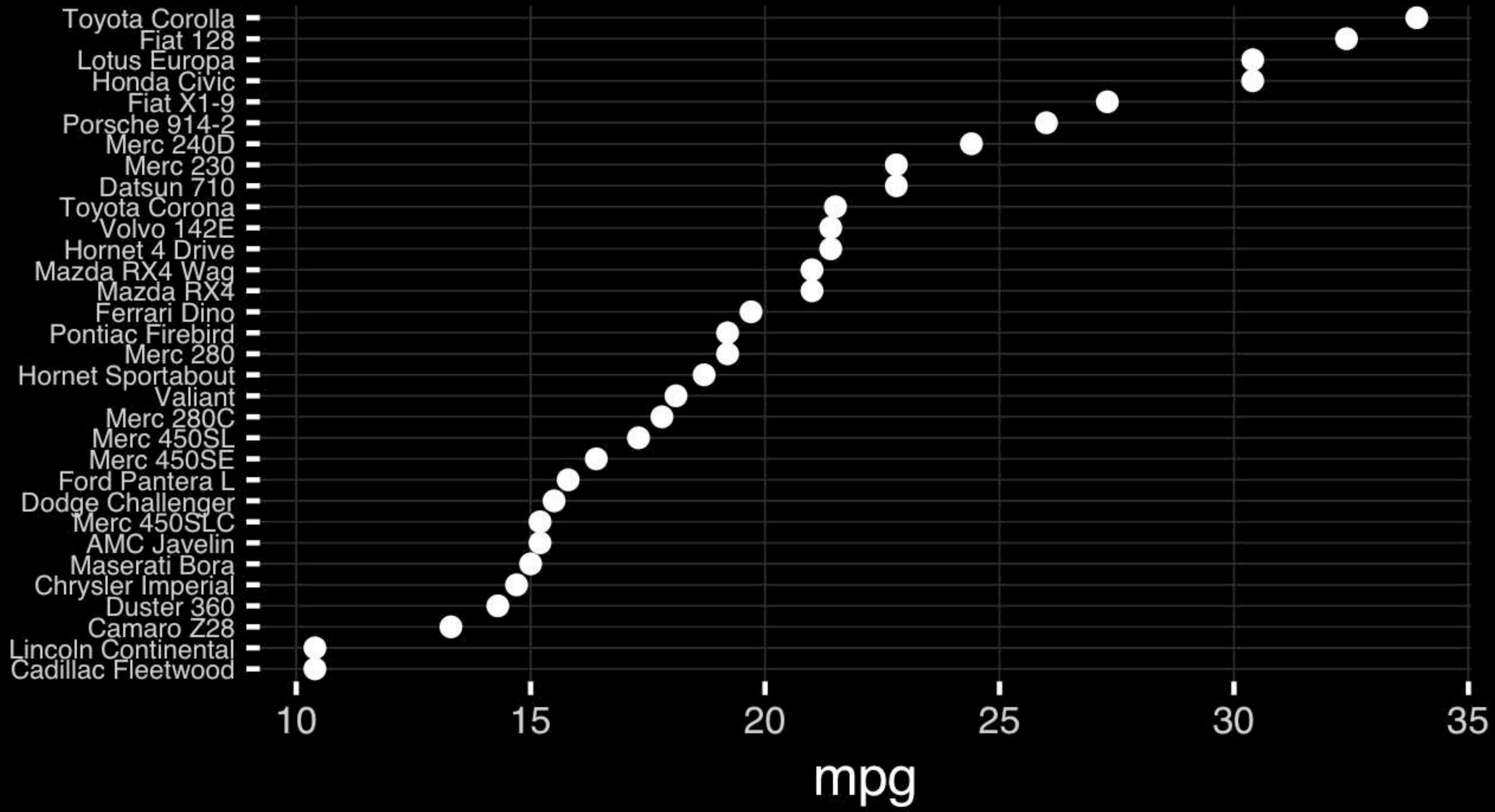
Stacked anything is nearly always a mistake



This is much better...




Toyota Corolla
Fiat 128
Lotus Europa
Honda Civic
Fiat X1-9
Porsche 914-2
Merc 240D
Merc 230
Datsun 710
Toyota Corona
Volvo 142E
Hornet 4 Drive
Mazda RX4 Wag
Mazda RX4
Ferrari Dino
Pontiac Firebird
Merc 280
Hornet Sportabout
Valiant
Merc 280C
Merc 450SL
Merc 450SE
Ford Pantera L
Dodge Challenger
Merc 450SLC
AMC Javelin
Maserati Bora
Chrysler Imperial
Duster 360
Camaro Z28
Lincoln Continental
Cadillac Fleetwood
0
10
20
30


Toyota Corolla
Fiat 128
Lotus Europa
Honda Civic
Fiat X1-9
Porsche 914-2
Merc 240D
Merc 230
Datsun 710
Toyota Corona
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Ferrari Dino
Pontiac Firebird
Merc 280
Hornet Sportabout
Valiant
Merc 280C
Merc 450SL
Merc 450SE
Ford Pantera L
Dodge Challenger
Merc 450SLC
AMC Javelin
Maserati Bora
Chrysler Imperial
Duster 360
Camaro Z28
Lincoln Continental
Cadillac Fleetwood
10
15
20
25
30
35
mpg

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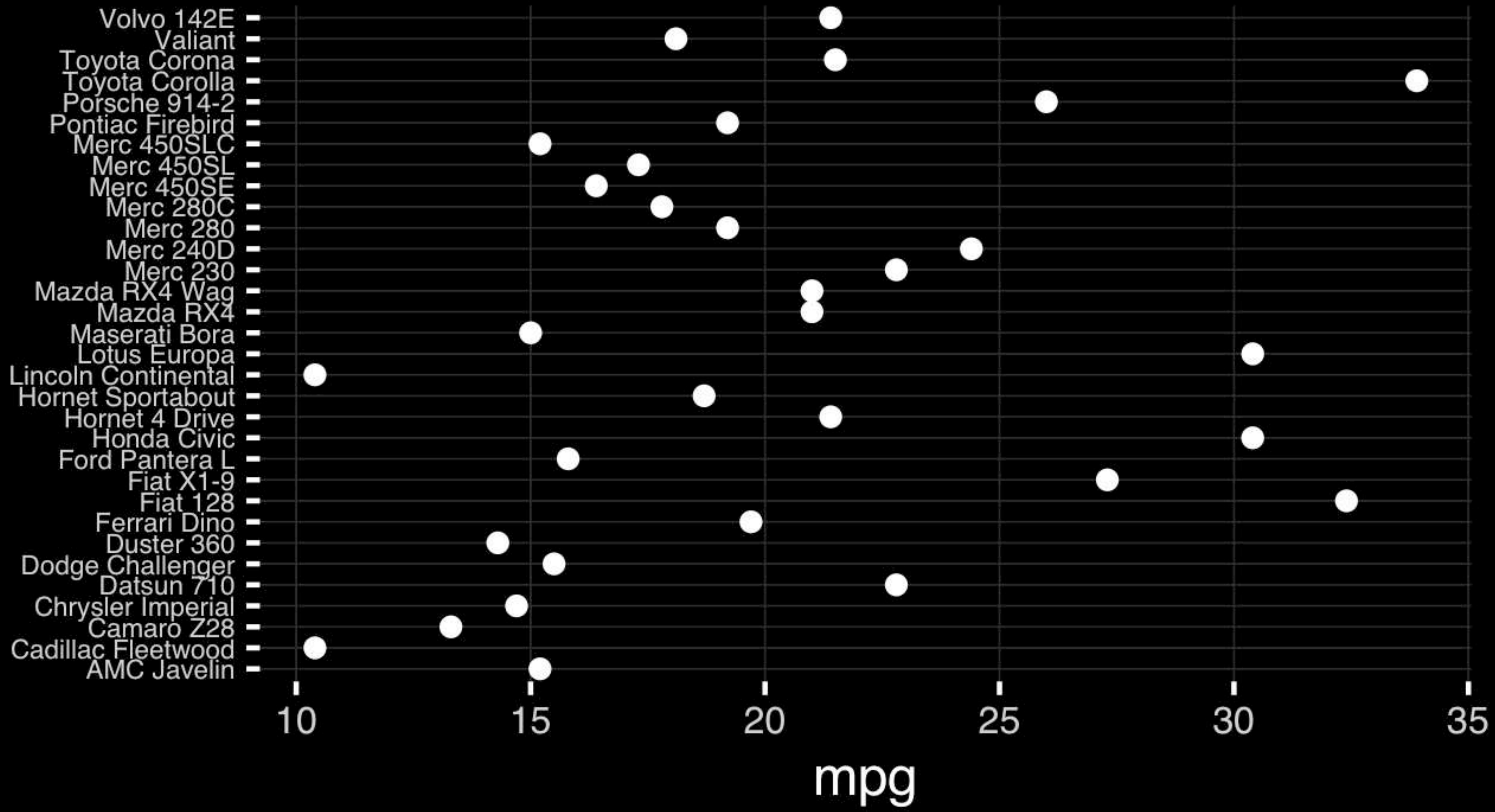
Volvo 142E
Valiant
Toyota Corona
Toyota Corolla
Porsche 914-2
Pontiac Firebird
Merc 450SLC
Merc 450SL
Merc 450SE
Merc 280C
Merc 280
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Fiat X1-9
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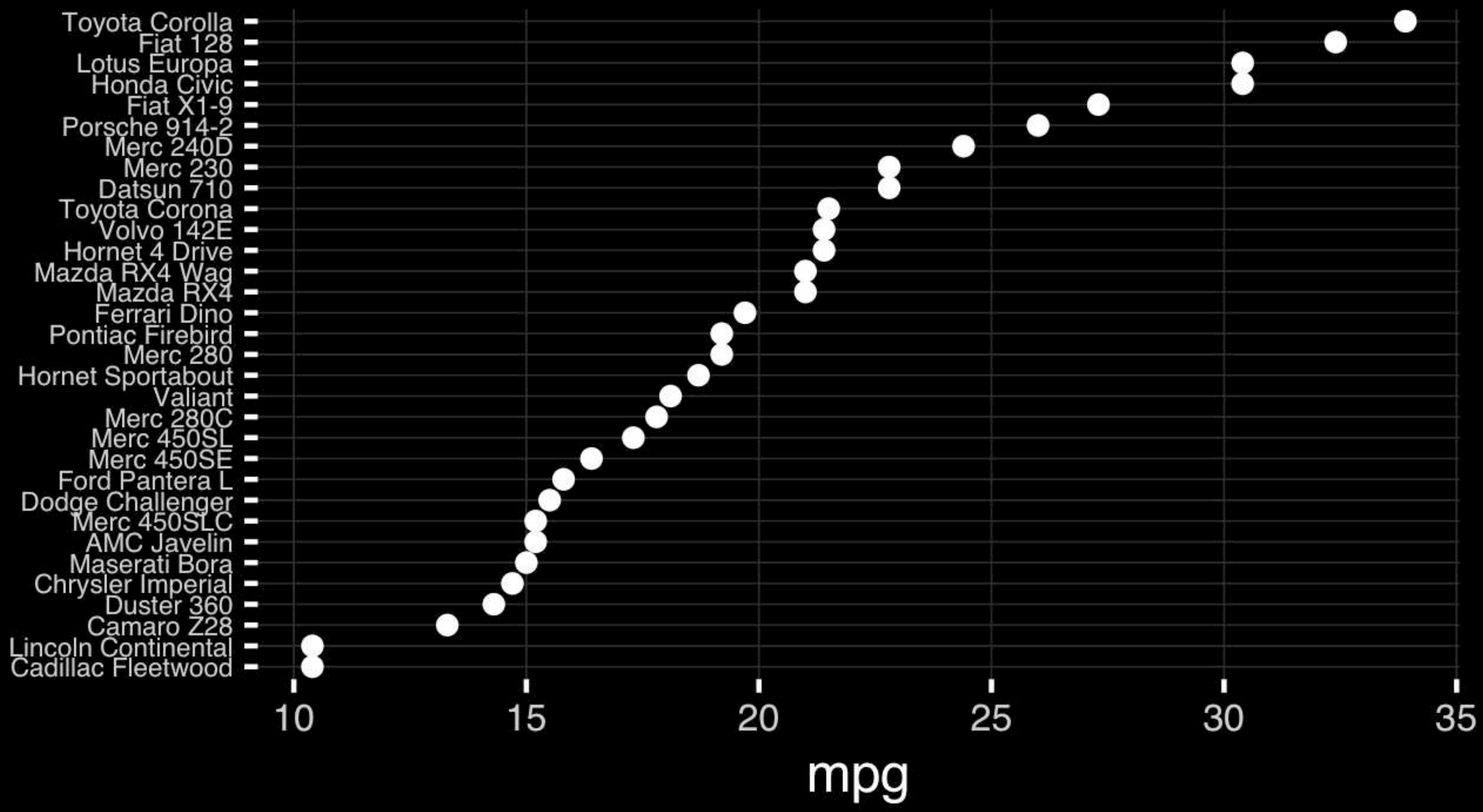
Ferrari Dino
Duster 360
Dodge Challenger
Datsun 710
Chrysler Imperial
Camaro Z28
Cadillac Fleetwood
AMC Javelin
10
15
20
25
30
35
mpg


Toyota Corolla
Fiat 128
Lotus Europa
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Fiat X1-9
Porsche 914-2
Merc 240D
Merc 230
Datsun 710
Toyota Corona
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Maserati Bora
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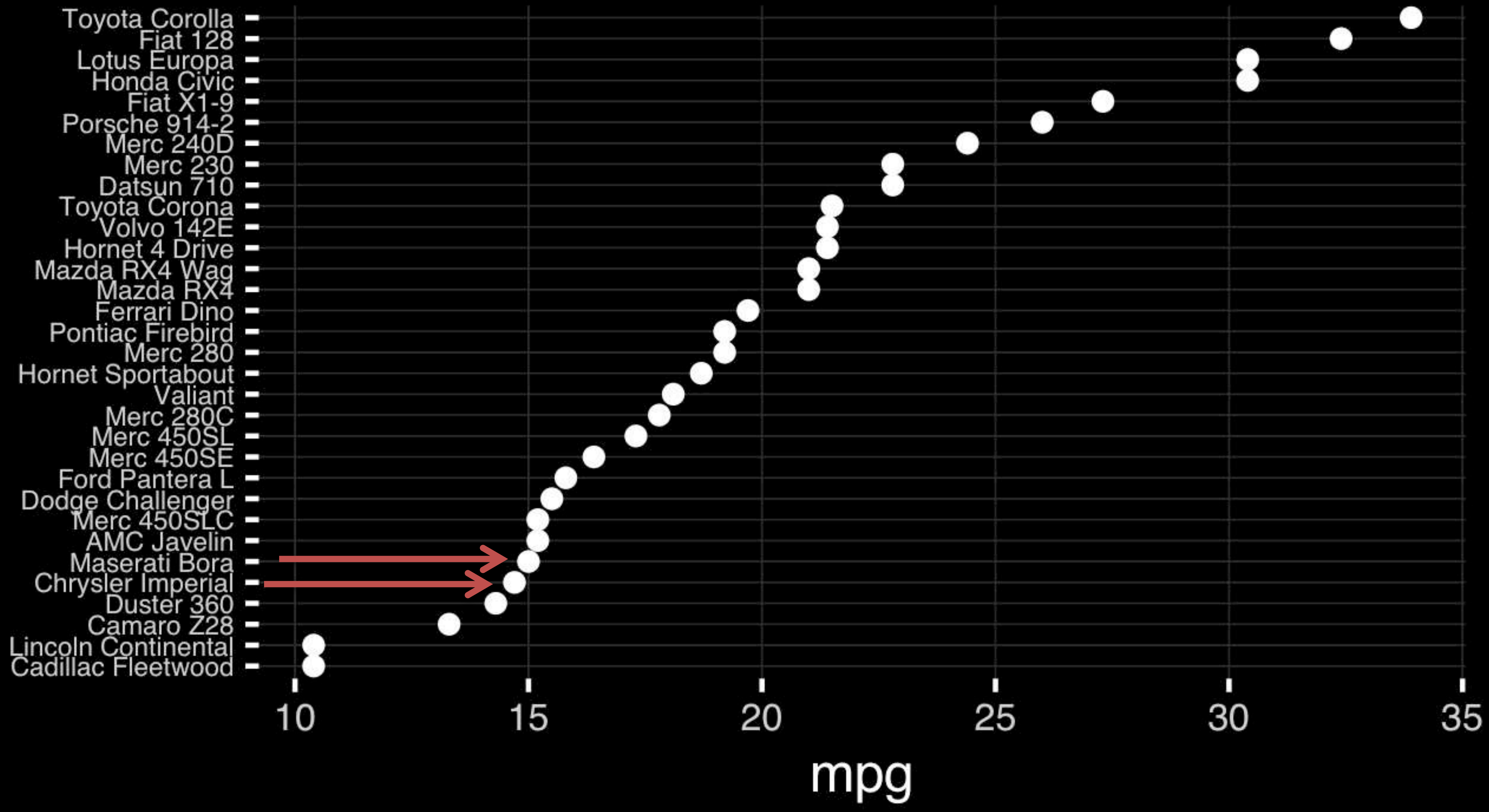
Camaro Z28
Lincoln Continental
Cadillac Fleetwood
10
15
20
25
30
35
mpg


Toyota Corolla
Fiat 128
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Honda Civic
Fiat X1-9
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Ford Pantera L
Dodge Challenger
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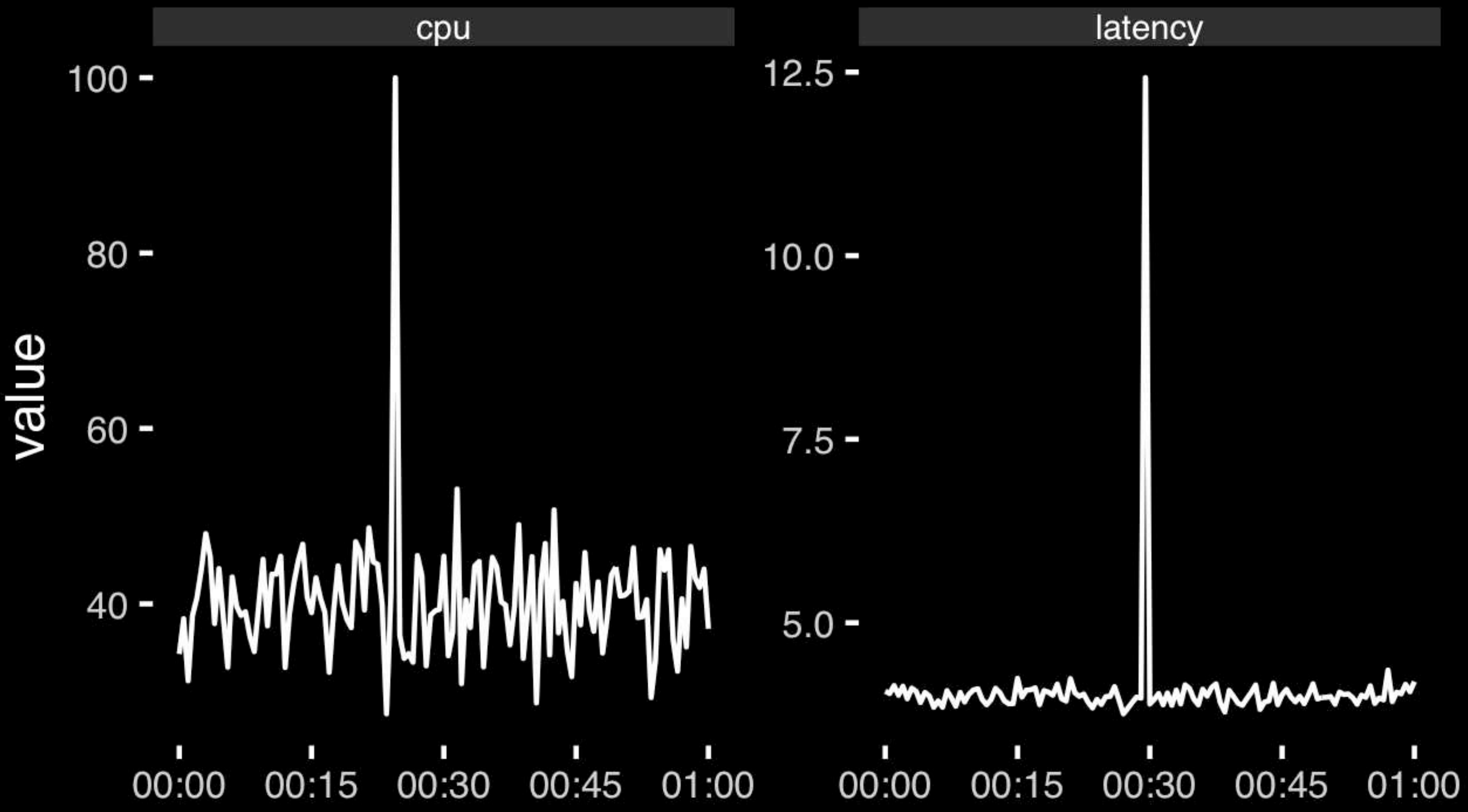
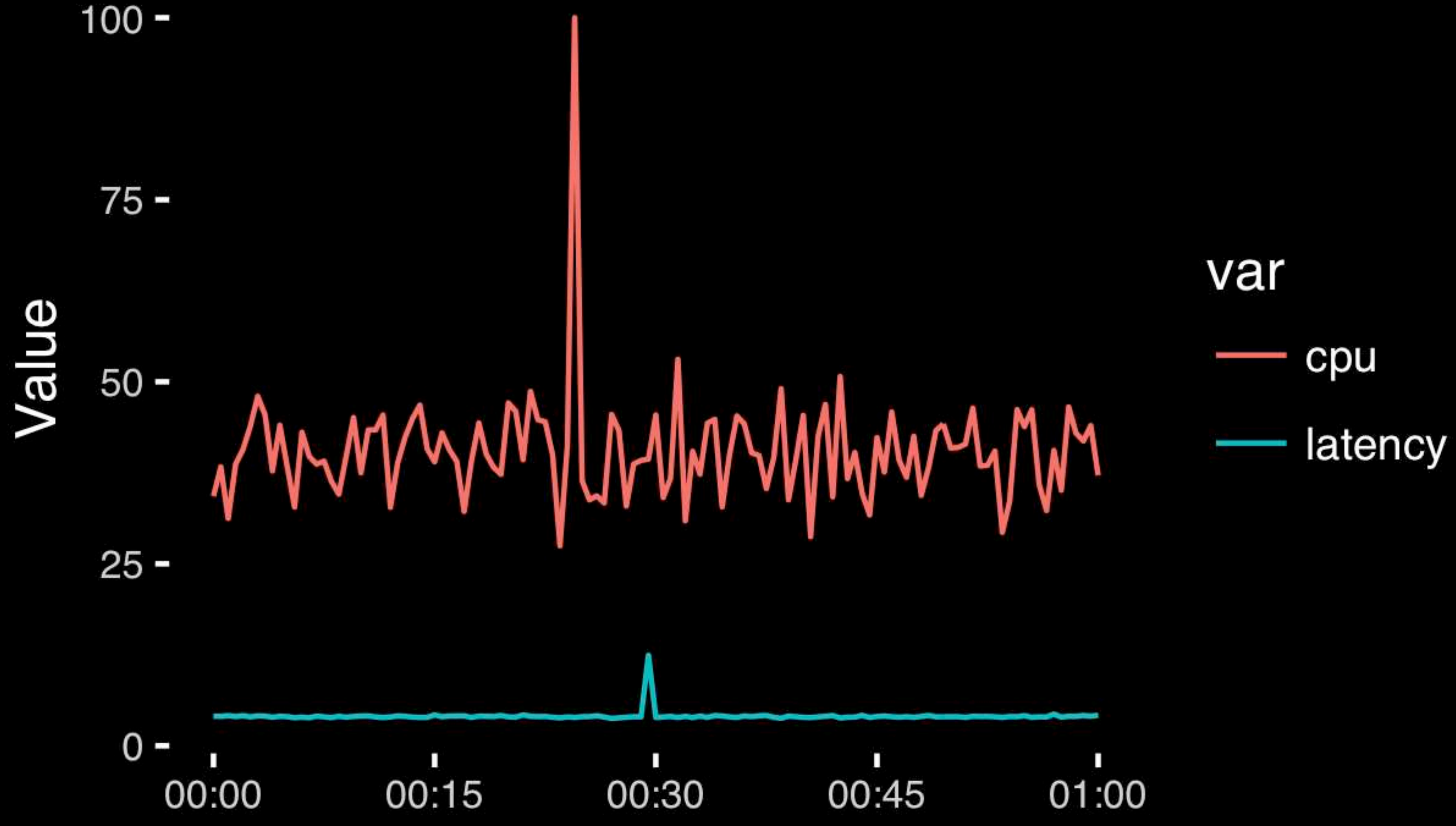
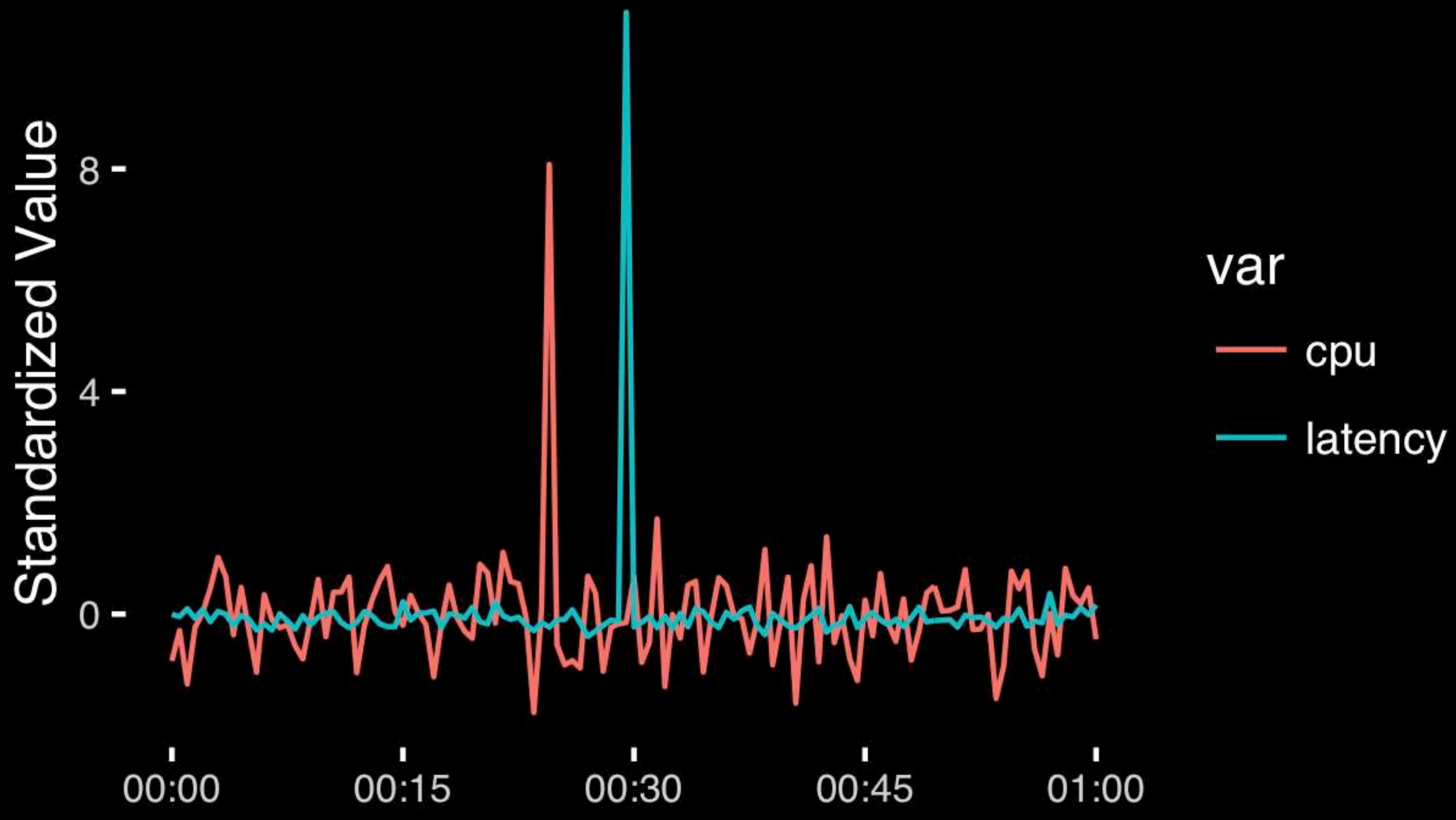
AMC Javelin
Maserati Bora
Chrysler Imperial
Duster 360
Camaro Z28
Lincoln Continental
Cadillac Fleetwood
10
15
20
25
30
35
mpg

Observation: Comparison is trivial on a common scale.


cpu
latency
value
100
80
60
40
12.5
10.0
7.5
5.0
00:00
00:15
00:30
00:45
01:00
00:00
00:15
00:30
00:45
01:00


Value
100
75
50
25
0
00:00
00:15
00:30
00:45
01:00
var
cpu
latency



Standardized Value
8
4
0
00:00
00:15
00:30
00:45
01:00
var
cpu
latency

Today's Learning Goals

- Appreciate the major elements of **exploratory data analysis** and why it is important to visualize data.

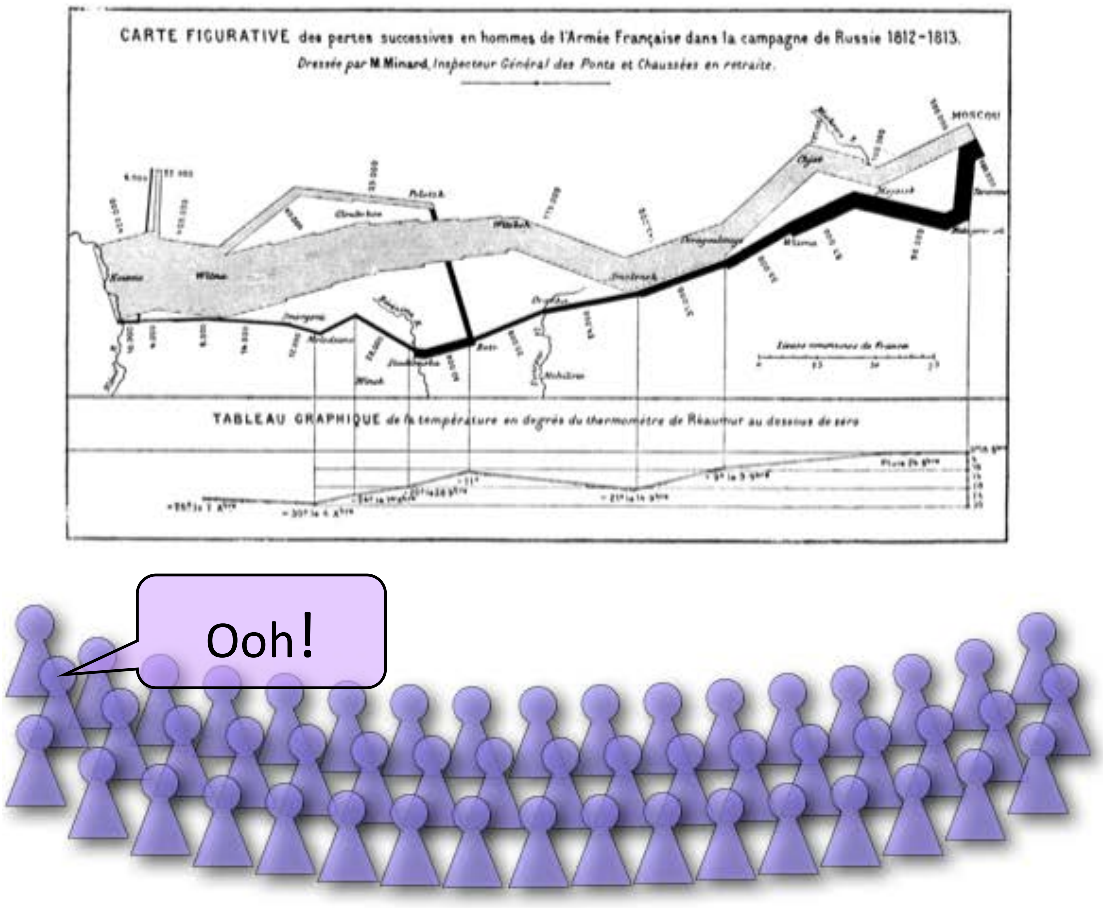
- Be conversant with **data visualization best practices** and understand how good visualizations optimize for the human visual system.

- Be able to generate informative graphical displays including **scatterplots**, **histograms**, **bar graphs**, **boxplots**, **dendrograms** and **heatmaps** and thereby gain exposure to the extensive graphical capabilities of R.

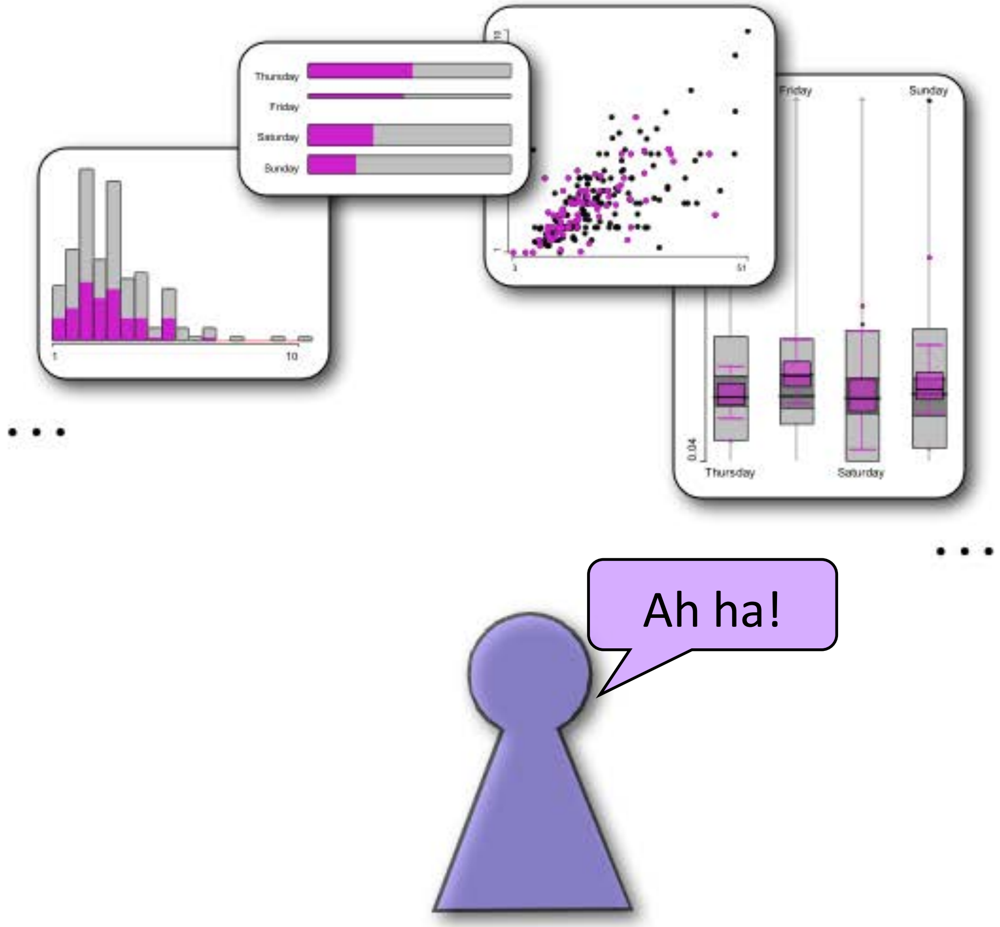
- Appreciate that you can build even more complex charts with **ggplot** and additional R packages such as **rgl**.

Different graphs for different purposes

Exploratory graphs: many images for a narrow audience (you!)
Presentation graphs: single image for a large audience

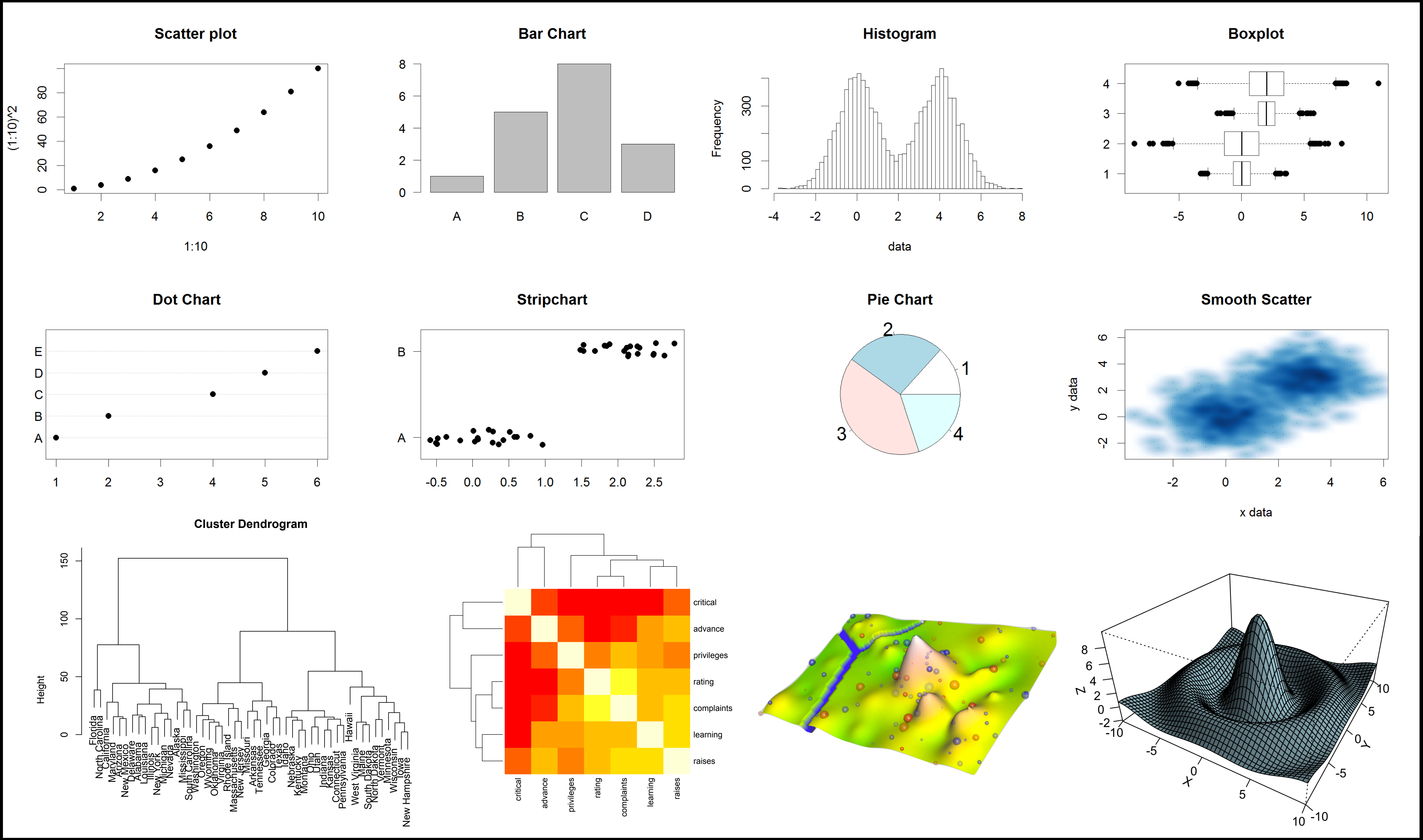

CARTE FIGURATIVE des pertes successives en hommes de l'Armée Française dans la campagne de Russie 1812-1813.
Dressée par M. Minard, Inspecteur Général des Ponts et Chaussées en retraite.
MOSCOU
TABLEAU GRAPHIQUE de la température en degrés du thermomètre de Réaumur au dessous de zero
Ooh!

Presentation

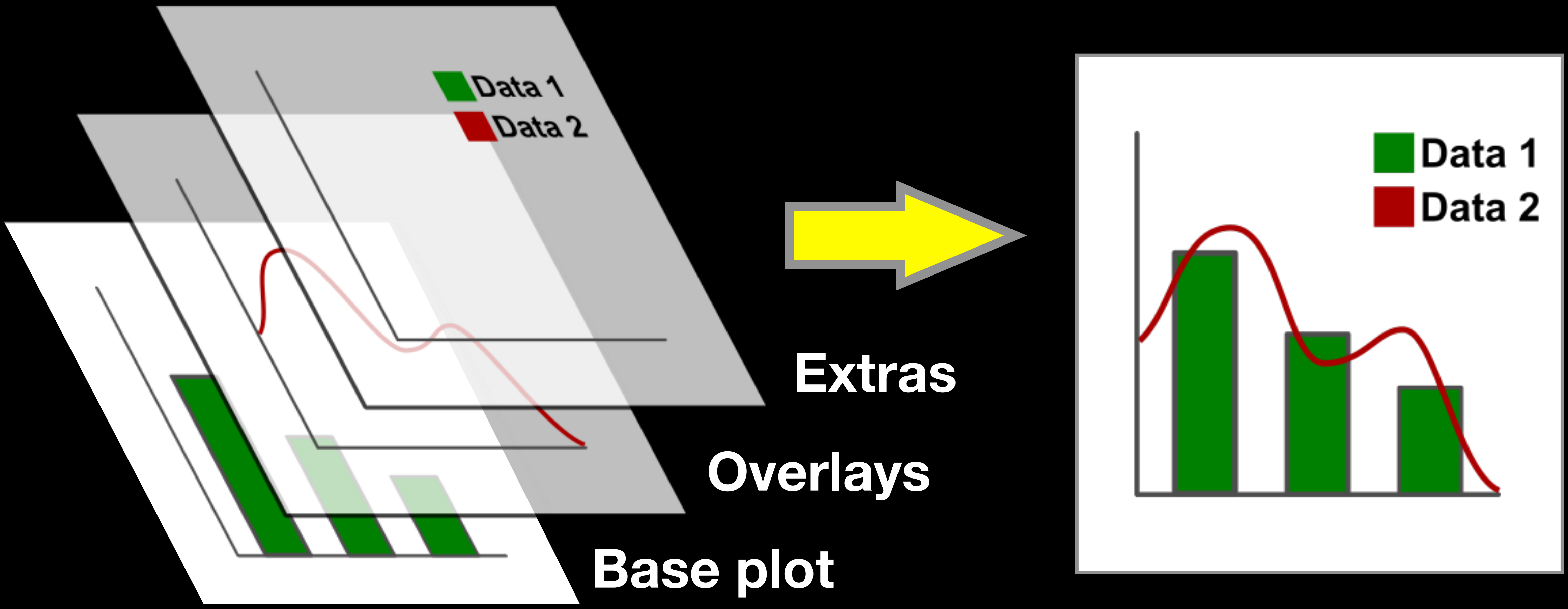


Exploration

Core R Graph Types



The R Painters Model



Extras

Overlays

Base plot

Side-Note: “Red and green should never be seen”

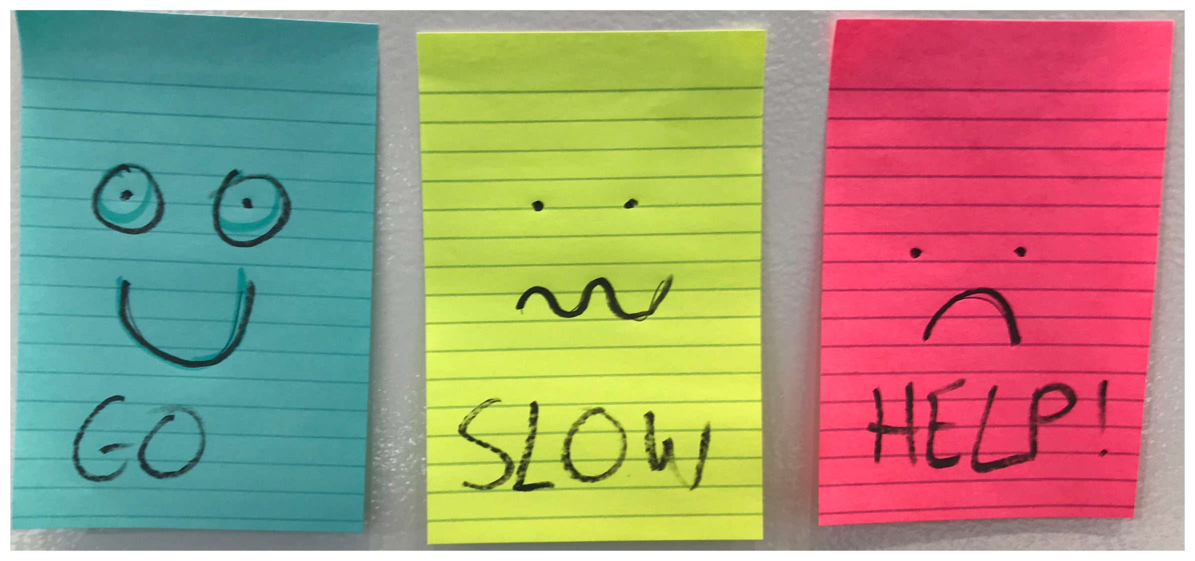
Do it Yourself!

Hands-on

Section 1 only please

- ➡ Create a new **RStudio Project** for this class,
- ➡ **Download** the example data files and move them to your project directory,
- ➡ Focus on **Sections 1A & 1B** in the **handout**.

Do it Yourself!



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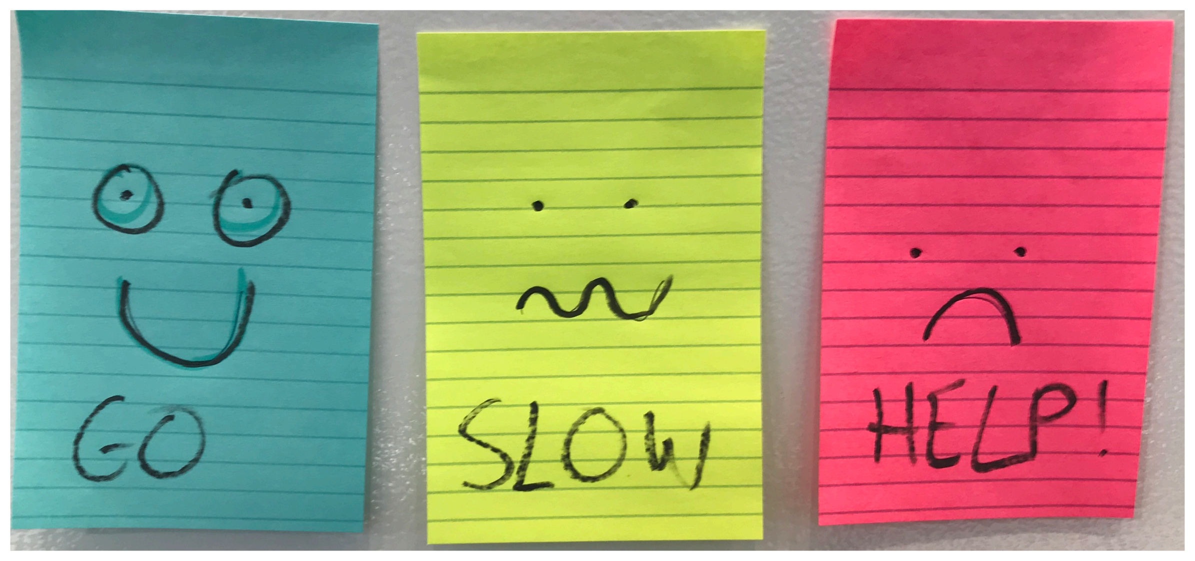


Hands-on

Section 2 Notes

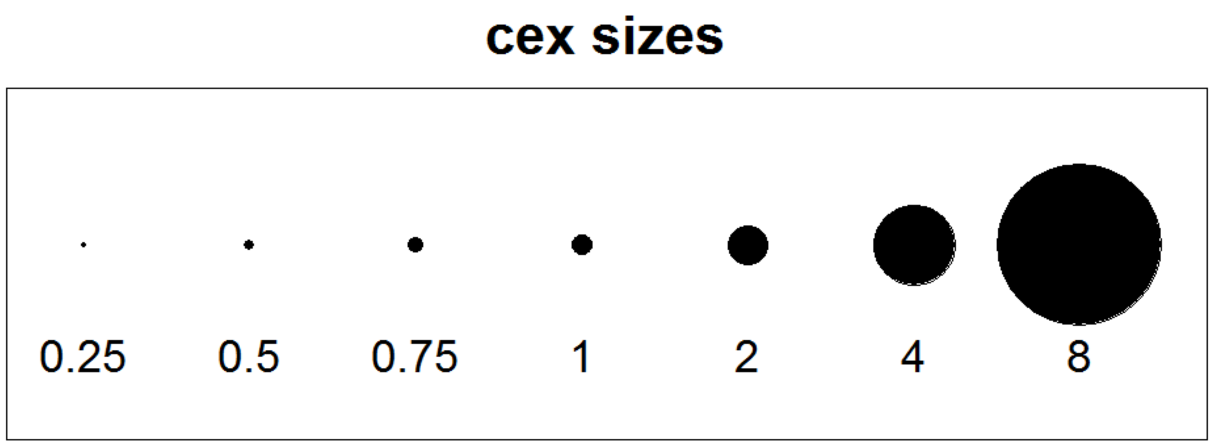
- ➡ Focus on Sections 2A & 2B in the lab **handout**.
- ➡ Try Section 2C if you have time.
- ➡ See notes on the following slides...

Common Options

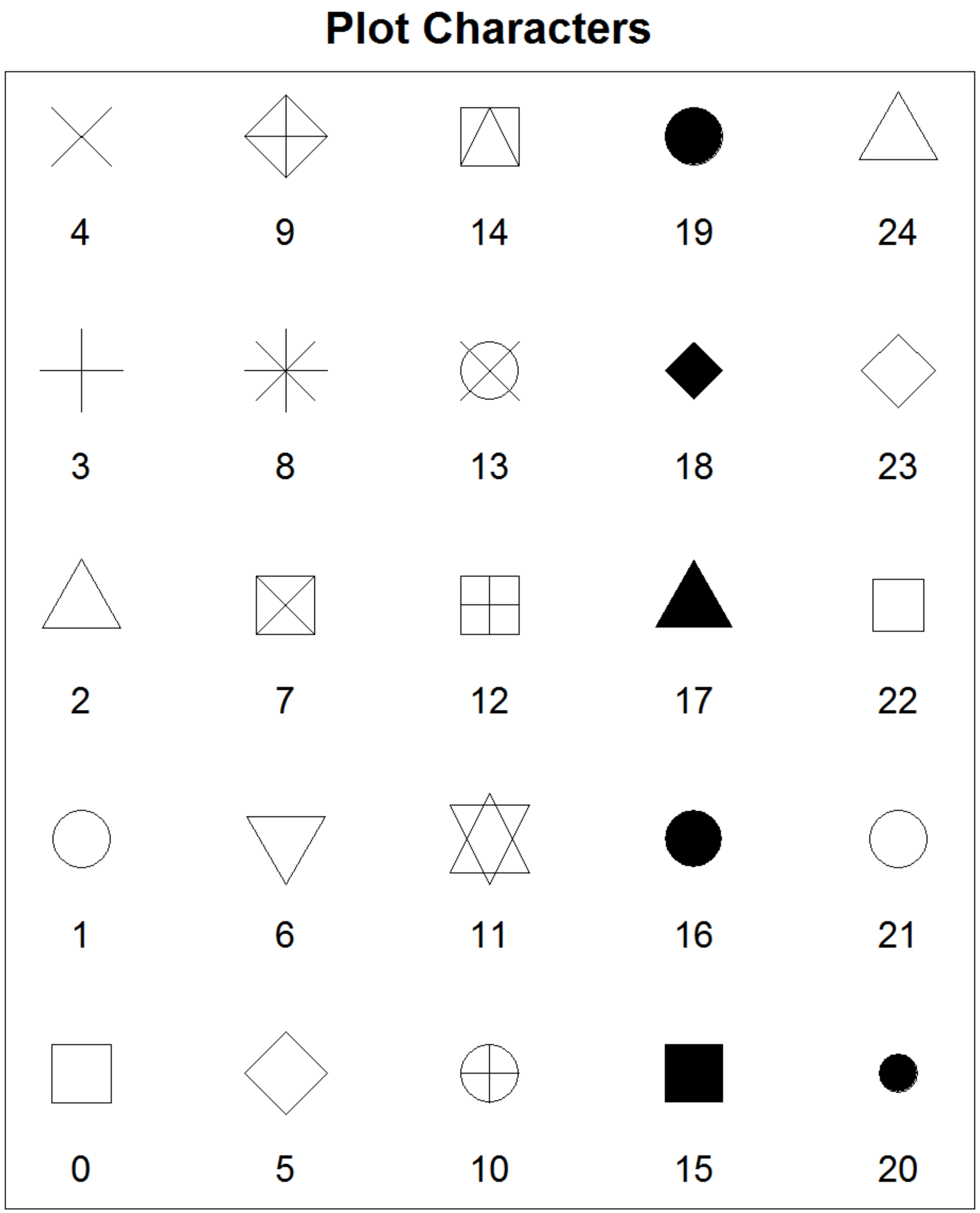
- Axis scales
  - `xlim c(min,max)`
  - `ylim c(min,max)`
- Axis labels
  - `xlab(text)`
  - `ylab(text)`
- Plot titles
  - `main(text)`
  - `sub(text)`
- Plot characters
  - `pch(number)`
  - `cex(number)`

- Local options to change a specific plot
- Global options to affect all graphs

Plot Characters

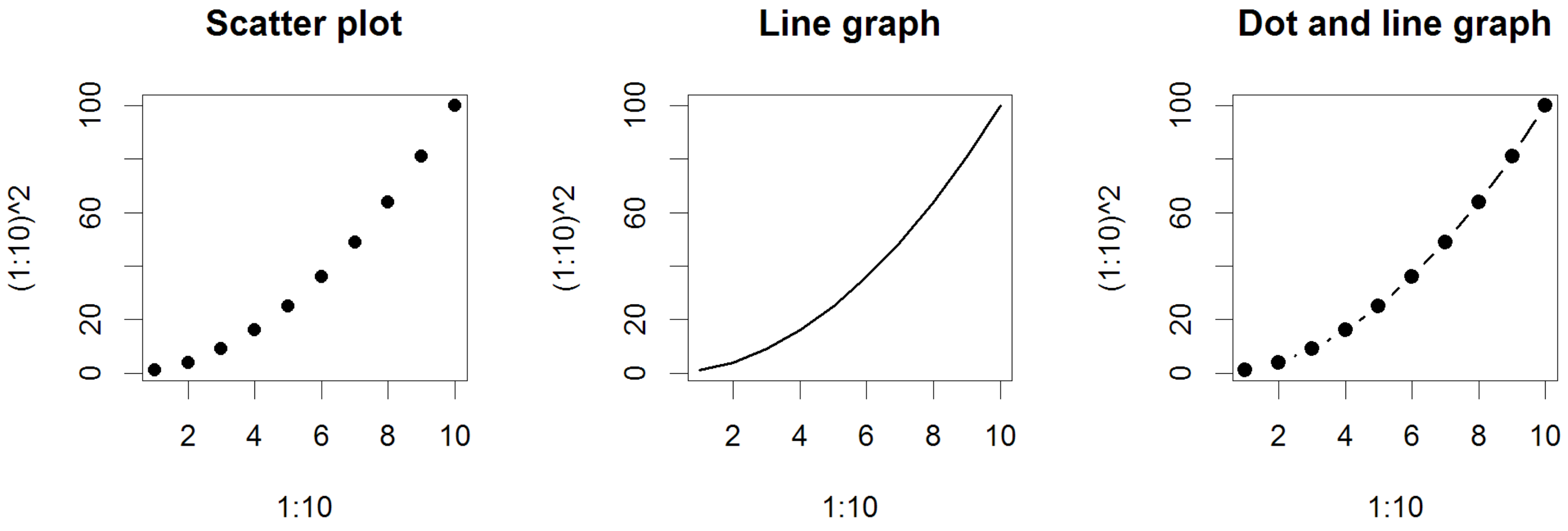


```
plot( 1:5, pch=1:5, cex=1:5 )
```



Plot Type Specific Options

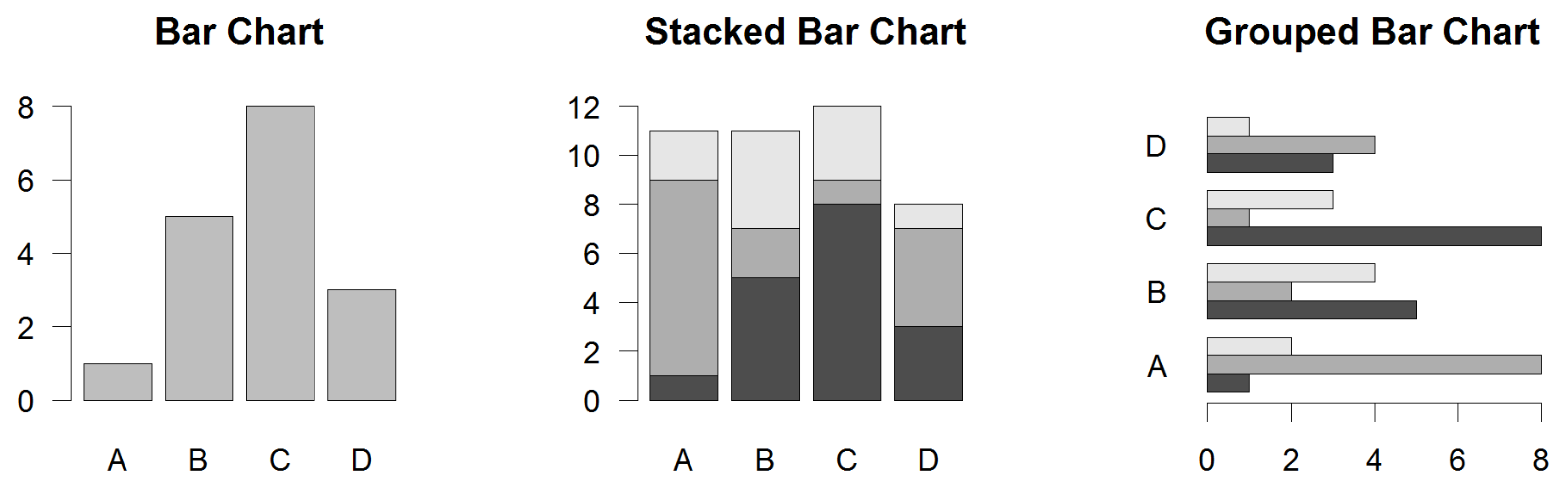
Plot (scatterplots and line graphs)



- Input: Almost anything. 2 x Vectors
- Output: Nothing
- Options:
  - `type` l=line, p=point, b=line+point
  - `lwd` line width (thickness)
  - `lty` line type (1=solid,2=dashed,3=dotted etc.)

```
plot( c(1:10)^2, typ="b", lwd=4, lty=3 )
```

Section 2B: Barplot (a.k.a. bar graphs)



- Input: Vector (single) or Matrix (stack or group)
- Output: Bar centre positions
- Options:
  - `names.arg` Bar labels (if not from data)
  - `horiz=TRUE` Plot horizontally
  - `beside=TRUE` Plot multiple series as a group not stacked

```
barplot(VADeaths, beside = TRUE)
```

Controlling plot area options with `par`

Par

- The `par` function controls global parameters affecting all plots in the current plot area

- Changes affect all subsequent plots

- Many par options can also be passed to individual plots

?par

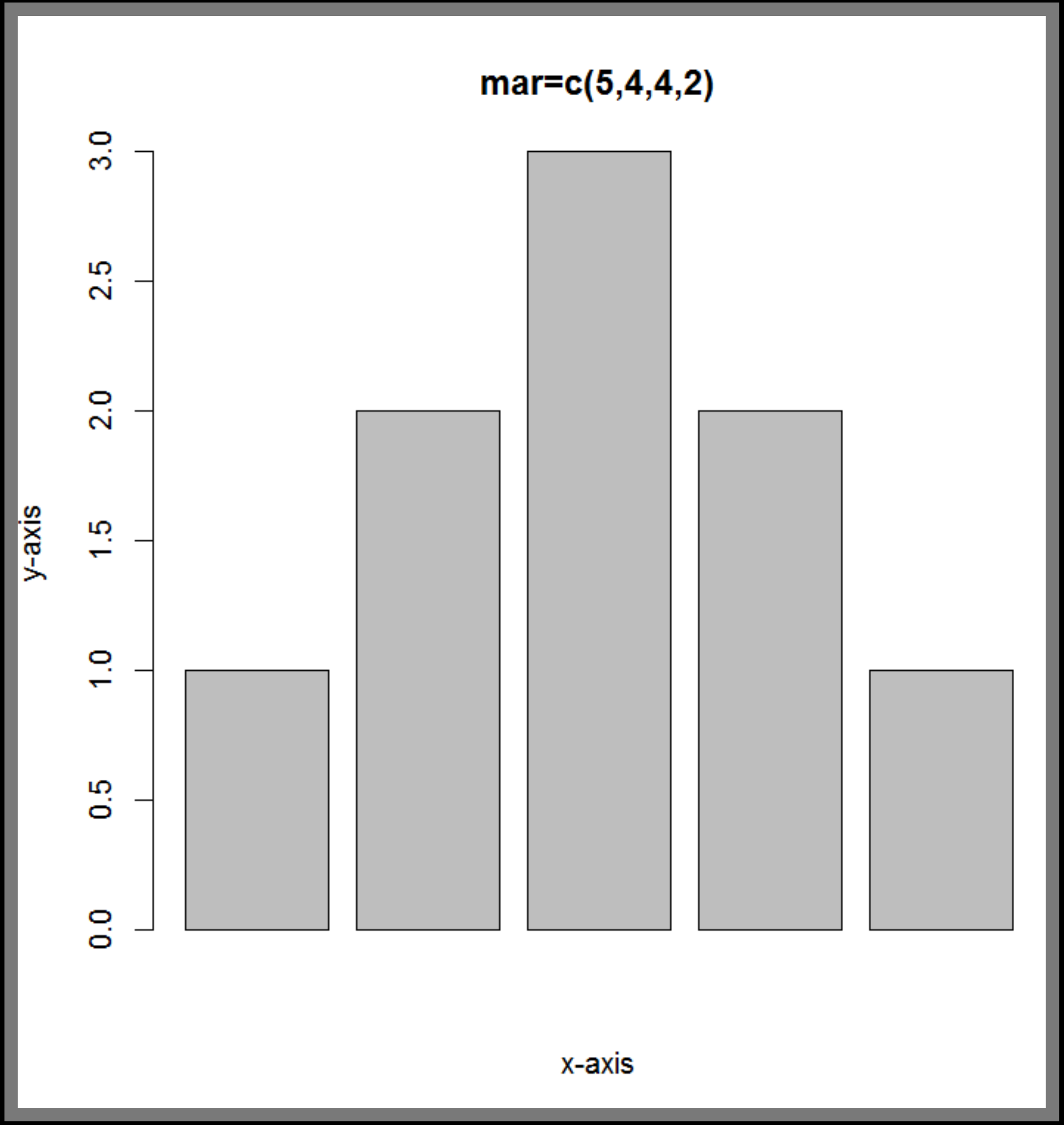
Par examples

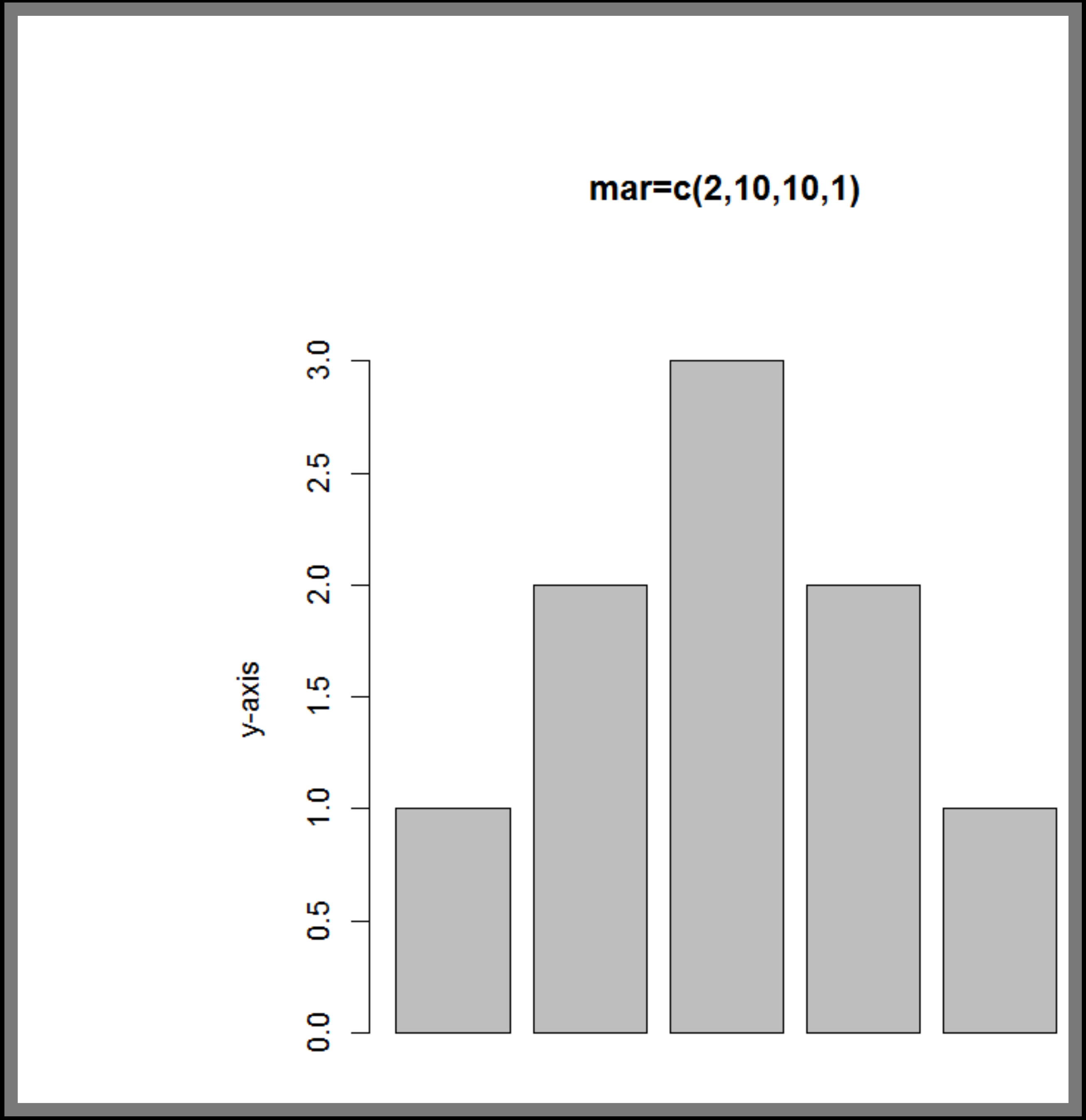
- Reading current value
  - `par()$cex`
- Setting a value
  - `par(cex=1.5) -> old.par`
- Restoring a value
  - `par(old.par)`

Par options

- Margins
  - `mai` (set margins in inches)
  - `mar` (set margins in number of lines)
  - `mex` (set lines per inch)
  - 4 element vector (bottom, left, top, right)
- Warning
  - `Error in plot.new() : figure margins too large`

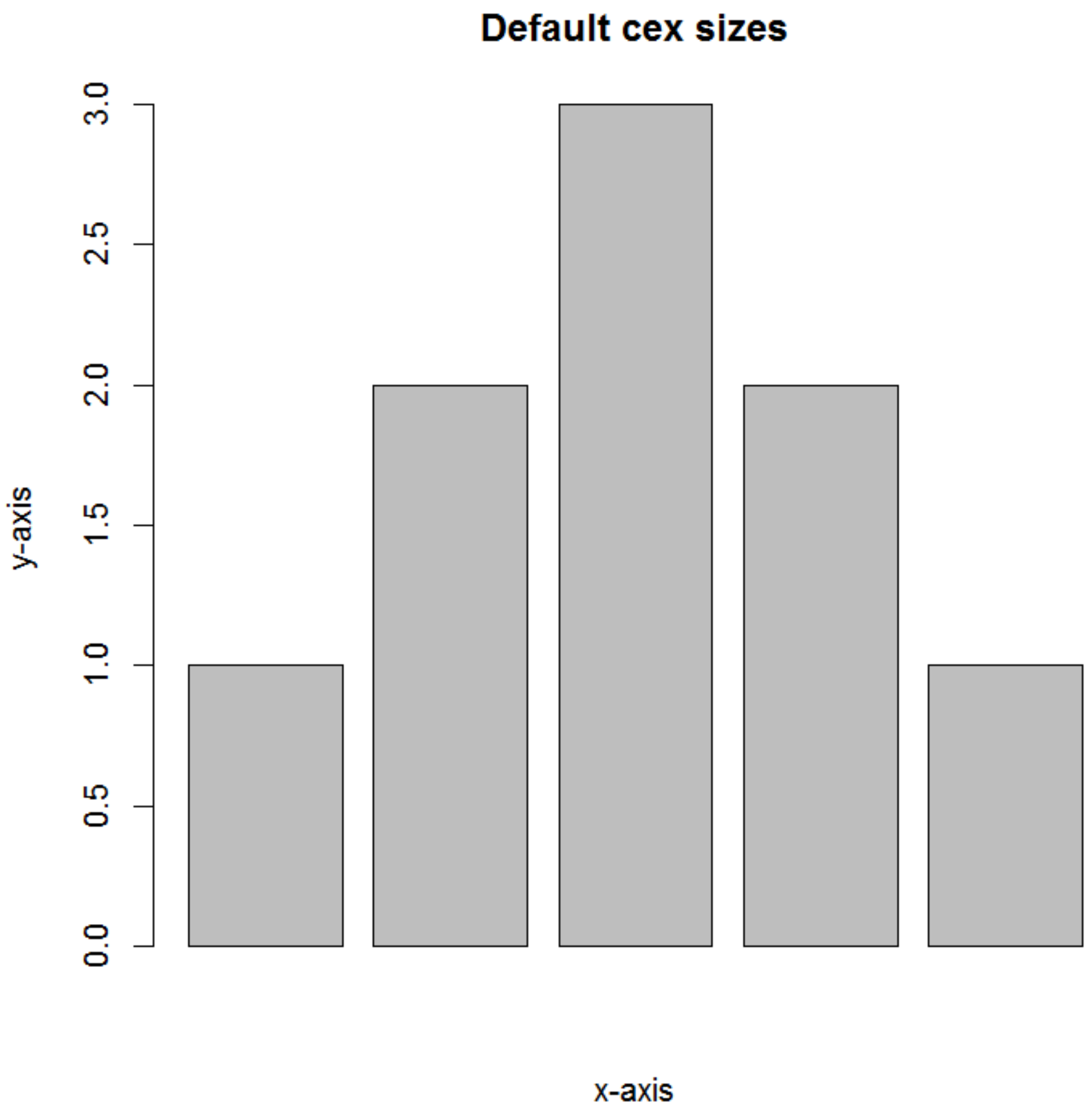
```
par( mar=c(2, 10, 1, 1) )
```

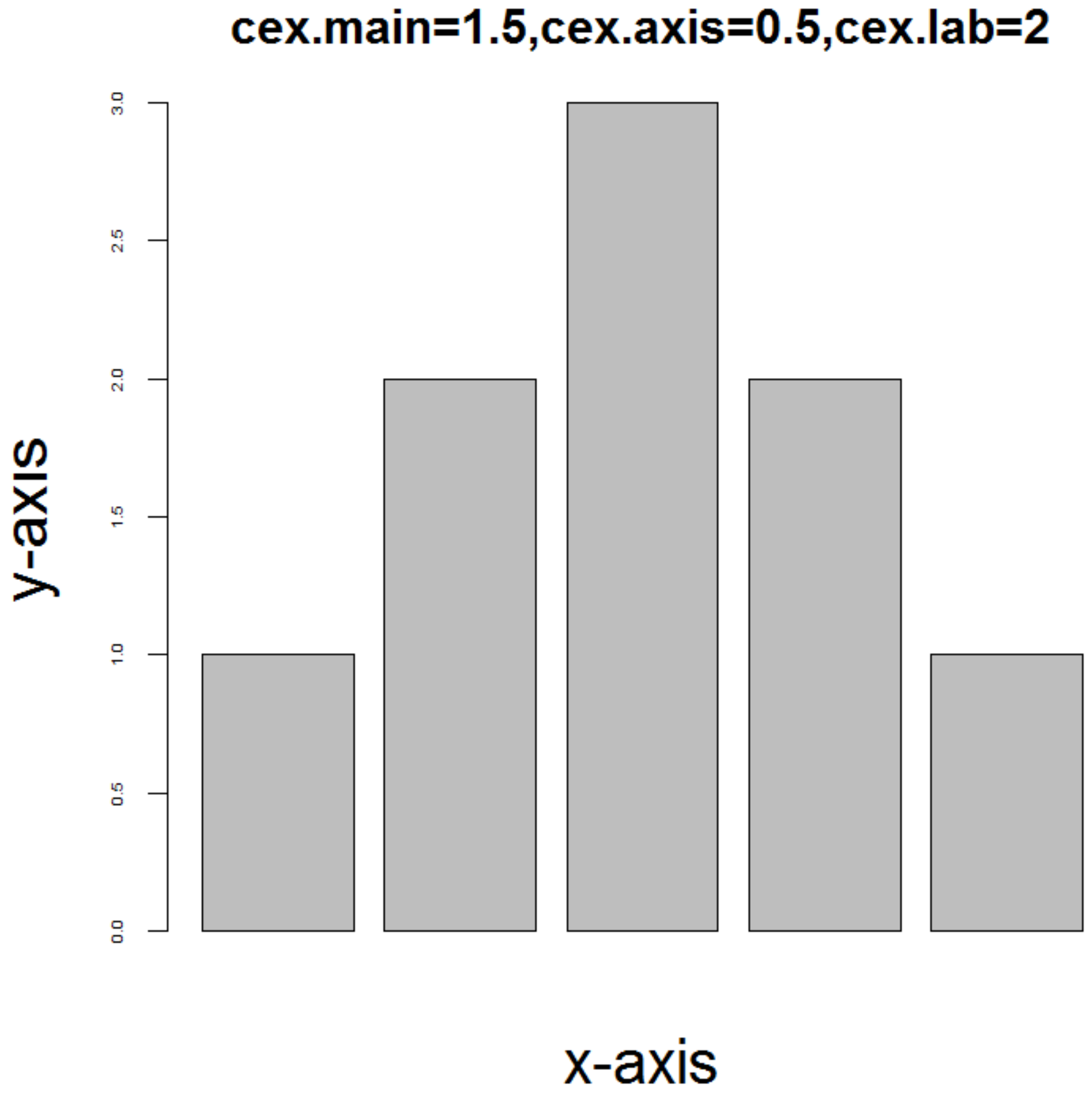

mar=c(5,4,4,2)
y-axis
0.0
0.5
1.0
1.5
2.0
2.5
3.0
x-axis


mar=c(2,10,10,1)
y-axis
0.0
0.5
1.0
1.5
2.0
2.5
3.0

Par options

- Fonts and labels
  - `cex` - global char expansion
    - `cex.axis`
    - `cex.lab`
    - `cex.main`
    - `cex.sub`

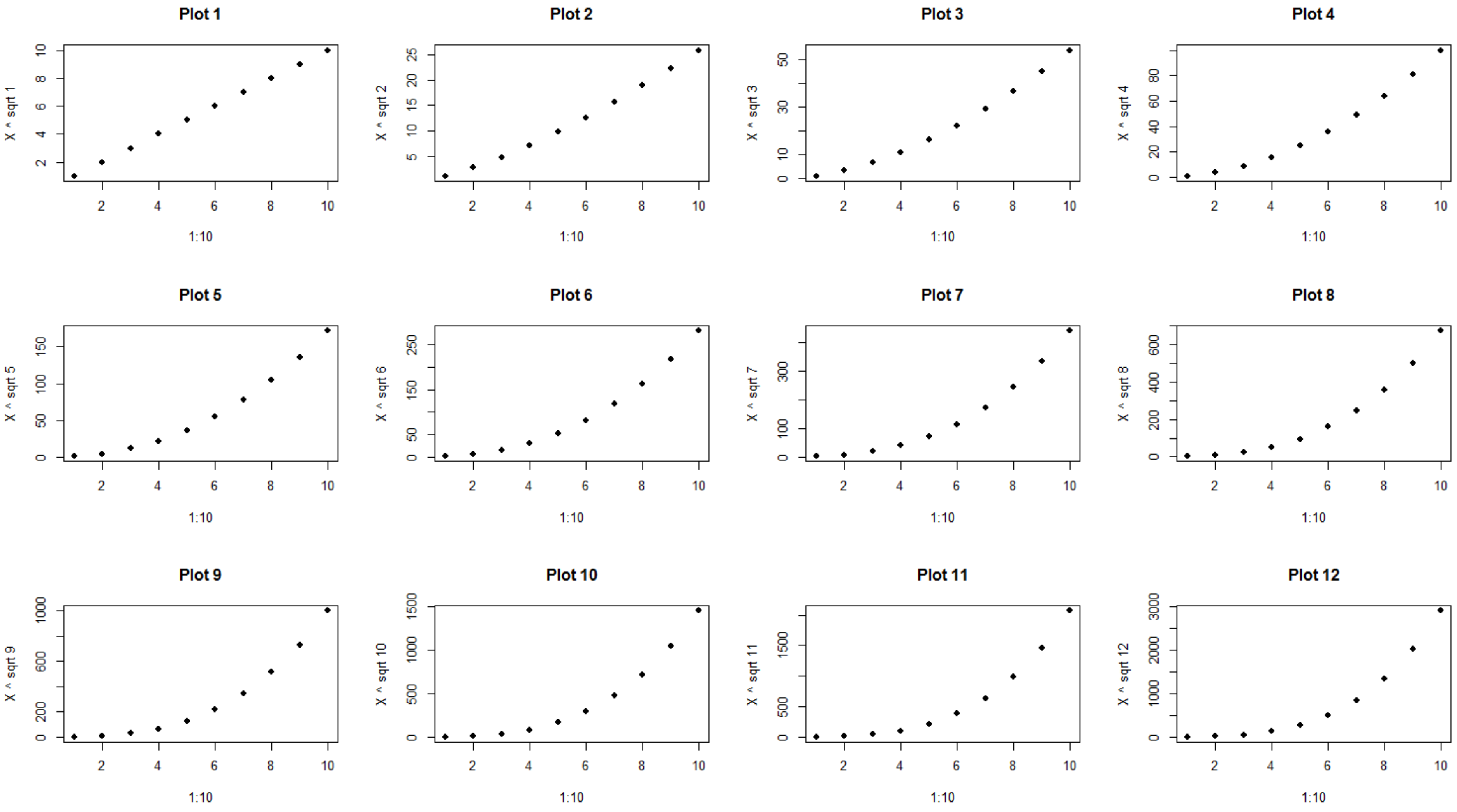




par(cex.main=1.5, cex.axis=0.5, cex.lab=2)

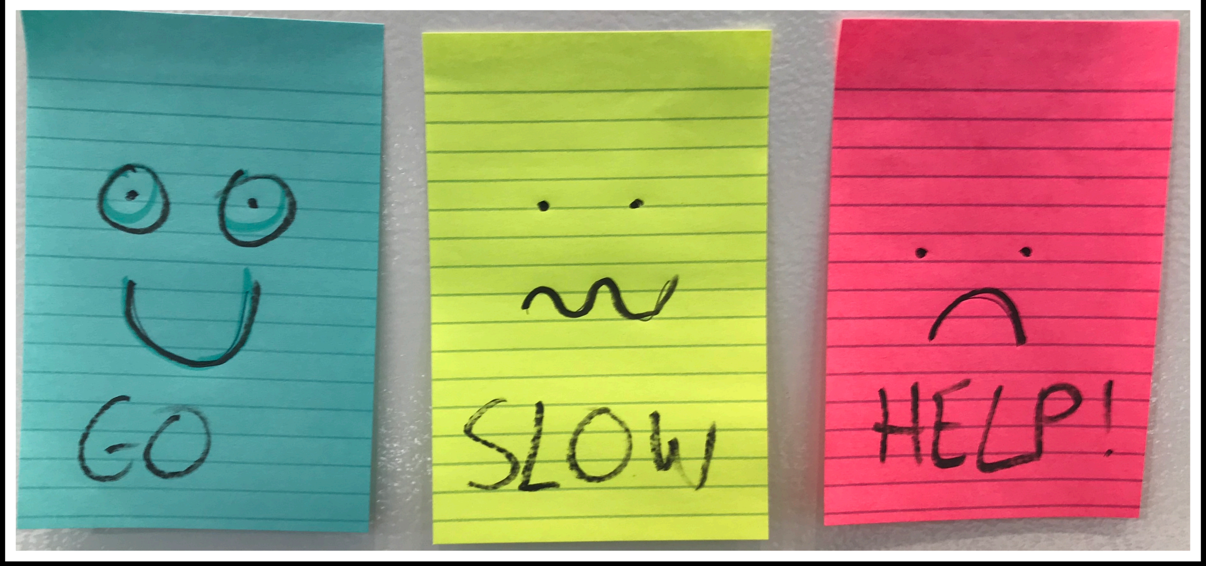
Par options

- Multi-panel
  - `par( mfrow=c(rows,cols) )`



par(mfrow=c(3 , 4))

Do it Yourself!



Hands-on

Section 3 only please

Using Color

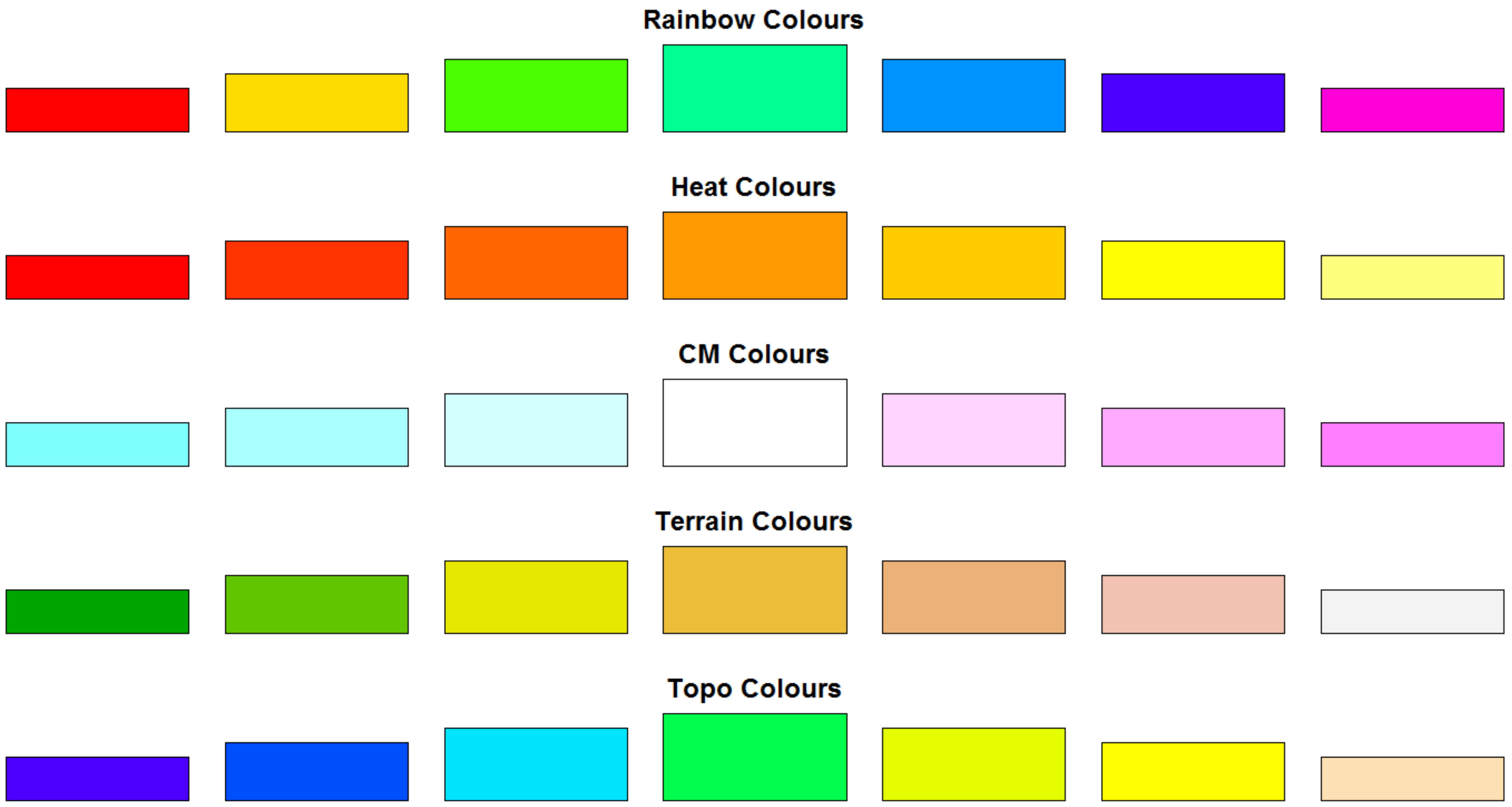
Specifying colors

- Color by number
  - `col=c(1, 2, 3)`
  - Will give `black, red, green` etc.
- Hexadecimal strings
  - `#FF0000` (red)
  - `#0000FF` (blue)
  - `#CC00CC` (purple)
- Controlled names
  - `col=c("red", "green")` etc.
  - see `colors()`
- Also RGB values, HCL values, etc.

Built in color schemes

- Functions to generate colors
- Pass in number of colors you want
- E.G. the functions:
  - `rainbow()`
  - `heat.colors()`
  - `cm.colors()`
  - `terrain.colors()`
  - `topo.colors()`

rainbow(7)


Rainbow Colours
Heat Colours
CM Colours
Terrain Colours
Topo Colours

```
rainbow( 7 )
```

Color Packages

- Color Brewer
  - Set of pre-defined, optimized palettes
  - `library(RColorBrewer)`
  - `brewer.pal(n_colours, palette)`

- ColorRamps
  - Create smooth palettes for ramped color
  - Generates a function to make actual color vectors
  - `colorRampPalette(c(“red”,”white”,”blue”))`
  - `colorRampPalette(c(“red”,”white”,”blue”))(5)`

Applying Color to Plots

- Vector of numbers or specified colors passed to the `col` parameter of a plot function

- Vector of **factors** used to divide the data
  - Colors will be taken from the set color **palette**
  - Can read or set using **pallette()** function
    - `palette()`
    - `palette(brewer.pal(9,”Set1”)`

```
plot( 1:5, col=1:5, pch=15, cex=2)
```

Dynamic use of color

- Coloring by density
  - Pass data and palette to `densCols()`
  - Vector of colors returned

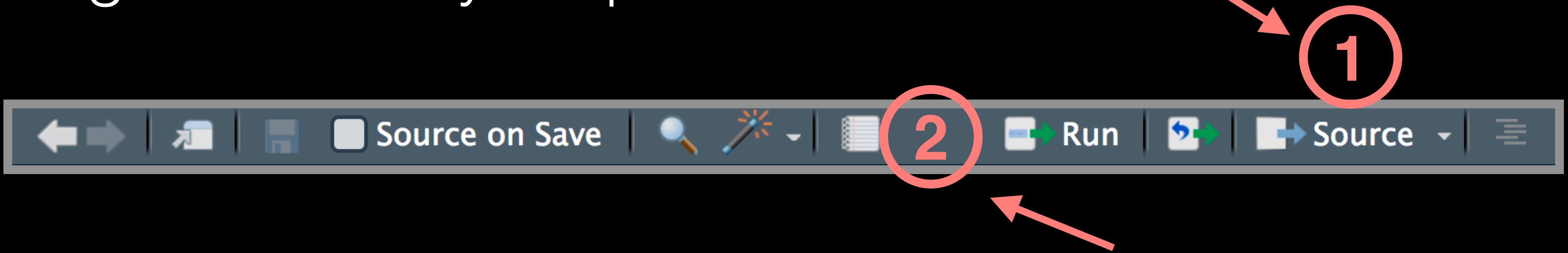
- See **Lab Supplement** (online):
  - Plotting with color in R

https://www.rdocumentation.org/packages/grDevices/versions/3.4.3/topics/densCols

Make a lab report!

- Open your previous class05 RStudio **project** (and your saved **R script**)

- Can you source your class05.R file to re-generate all your plots without error?



- If so you can now generate a nice HTML report of your work to date...

[Take 2-3 minutes]

Homework!

New **DataCamp** Assignments

- **RStudio IDE (Pt 1)**
- **Intermediate R**
  - Conditionals and Control Flow
  - Functions
  - Loops

Muddy Point Assessment Form Link

Useful new website: https://www.data-to-viz.com/