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.
[illegible]	[illegible]	[illegible]	[illegible]

— A —

— B —

— D —

— F —

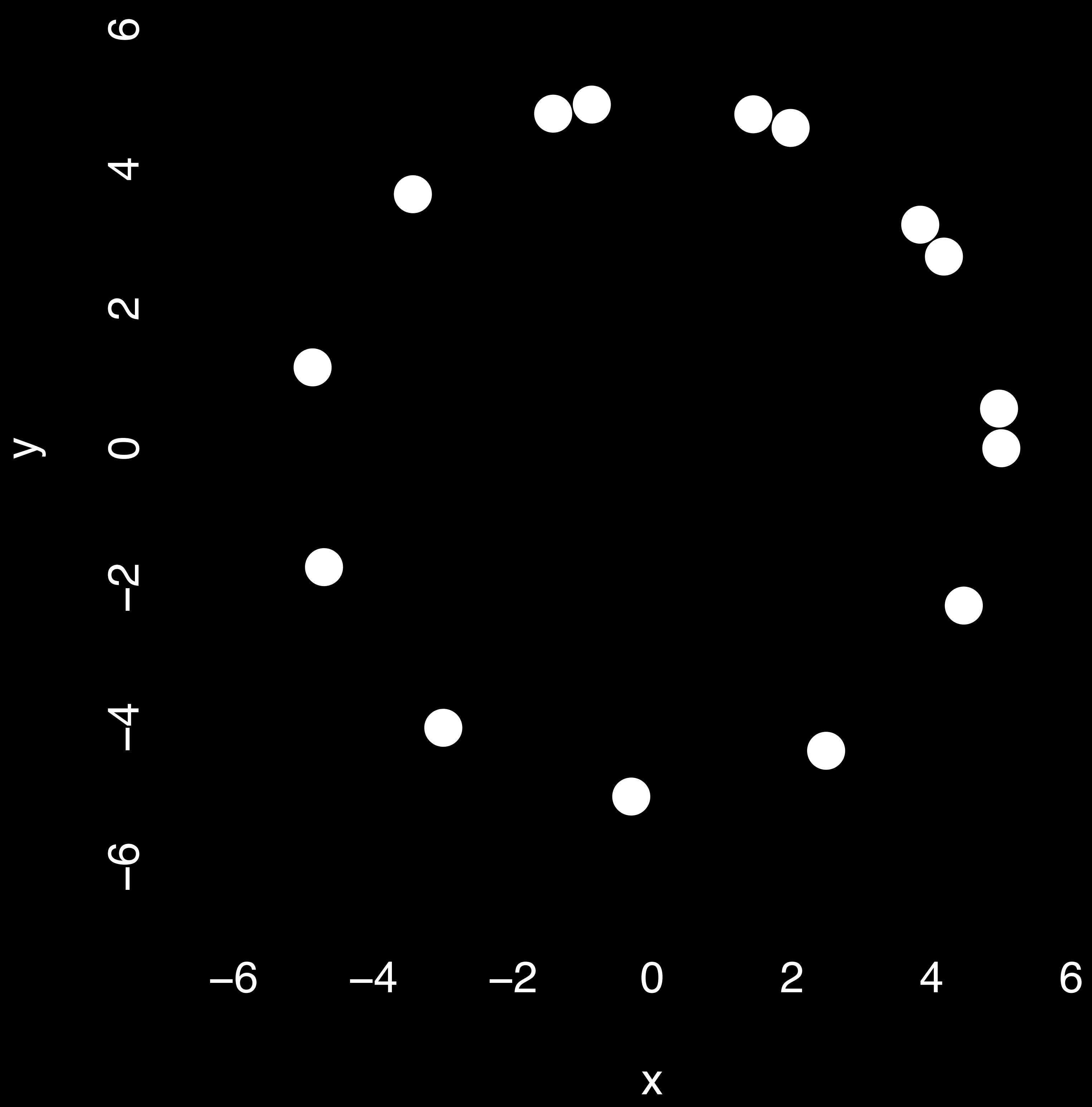
— H —

— J-K —

— O-P —

	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



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2
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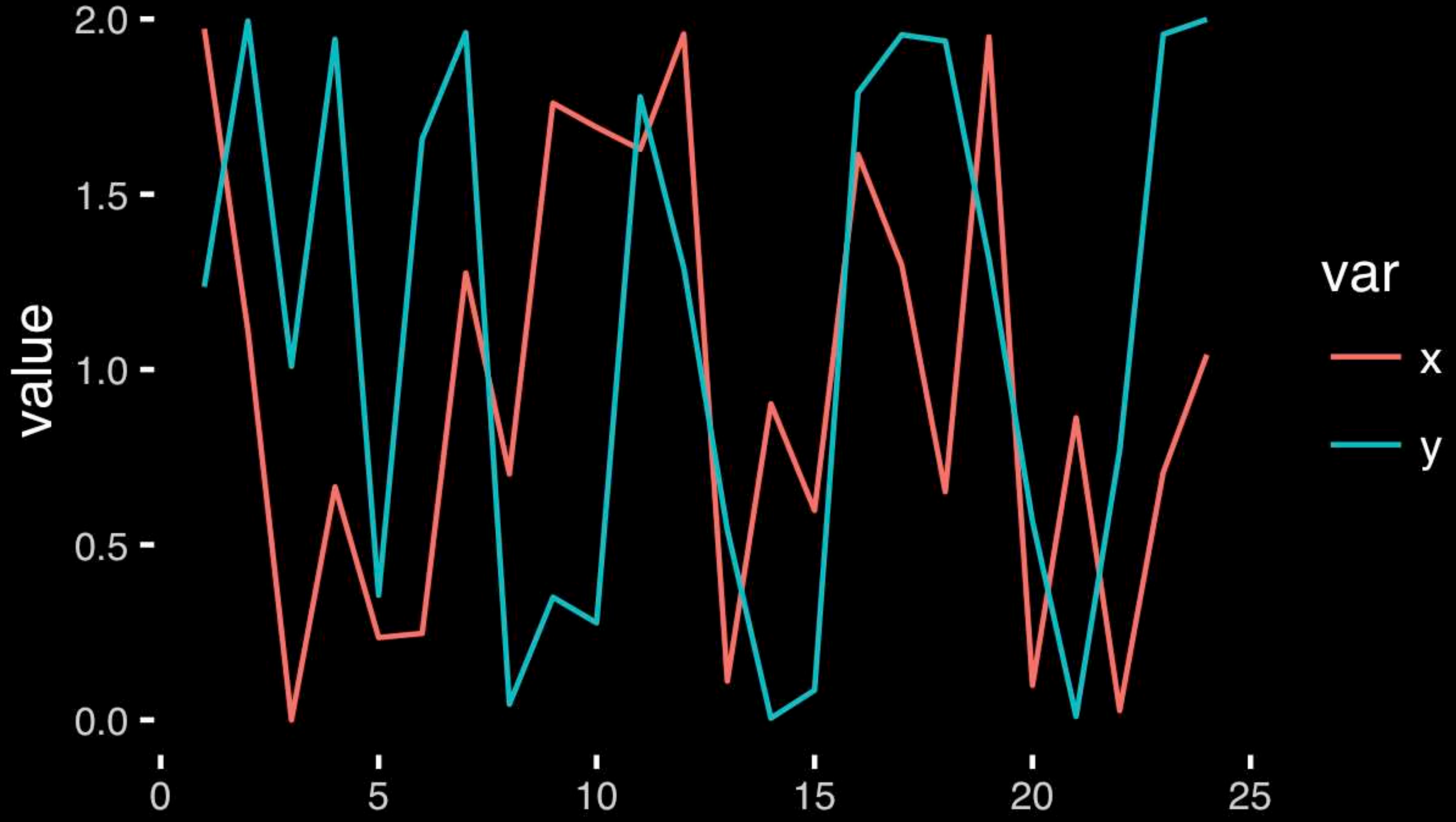
6
x



value
2.0
1.5
1.0
0.5
0.0
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25
var
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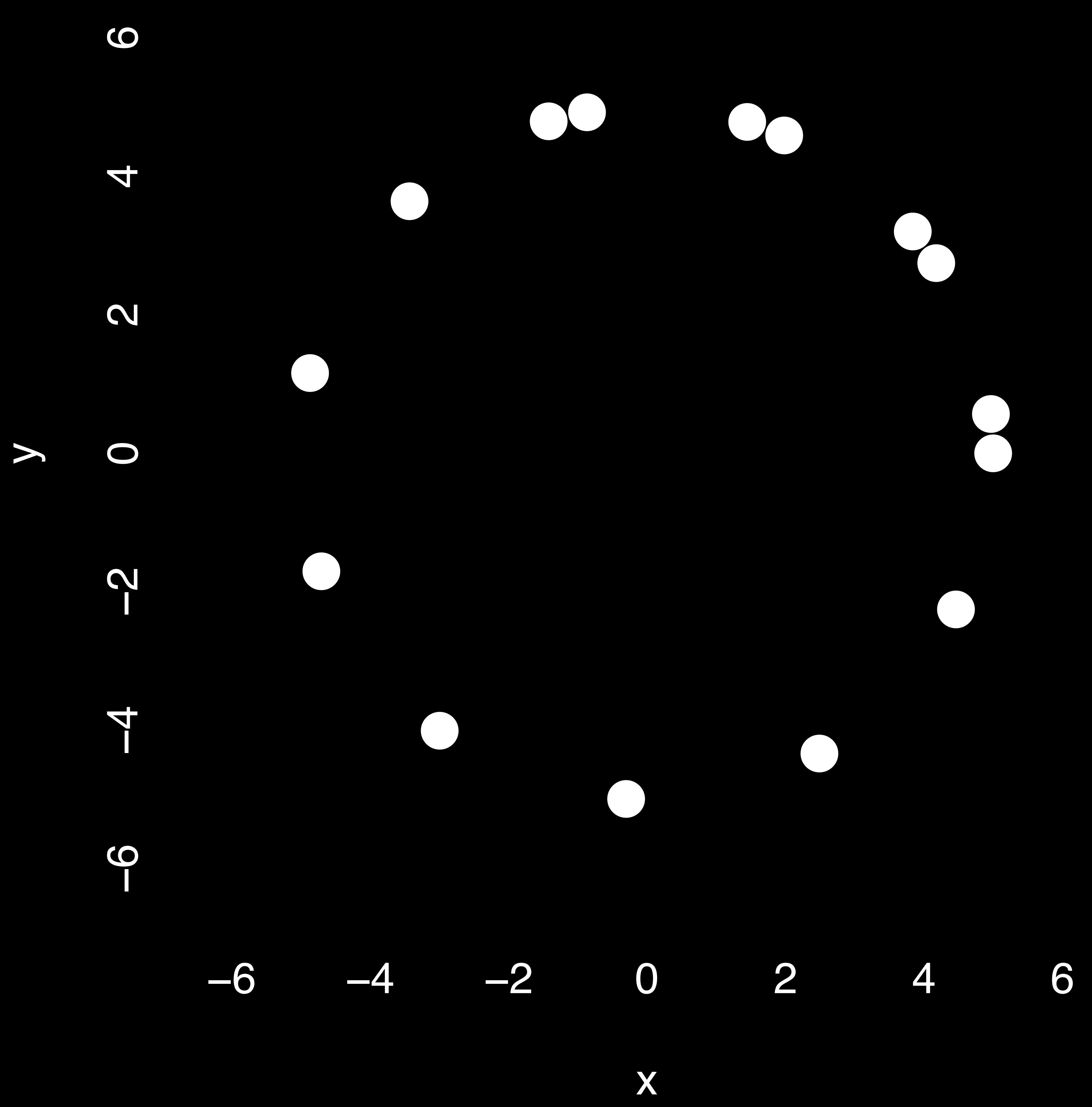
https://bioboot.github.io/bimm143_S18/class-material/05_draw_circle_points/

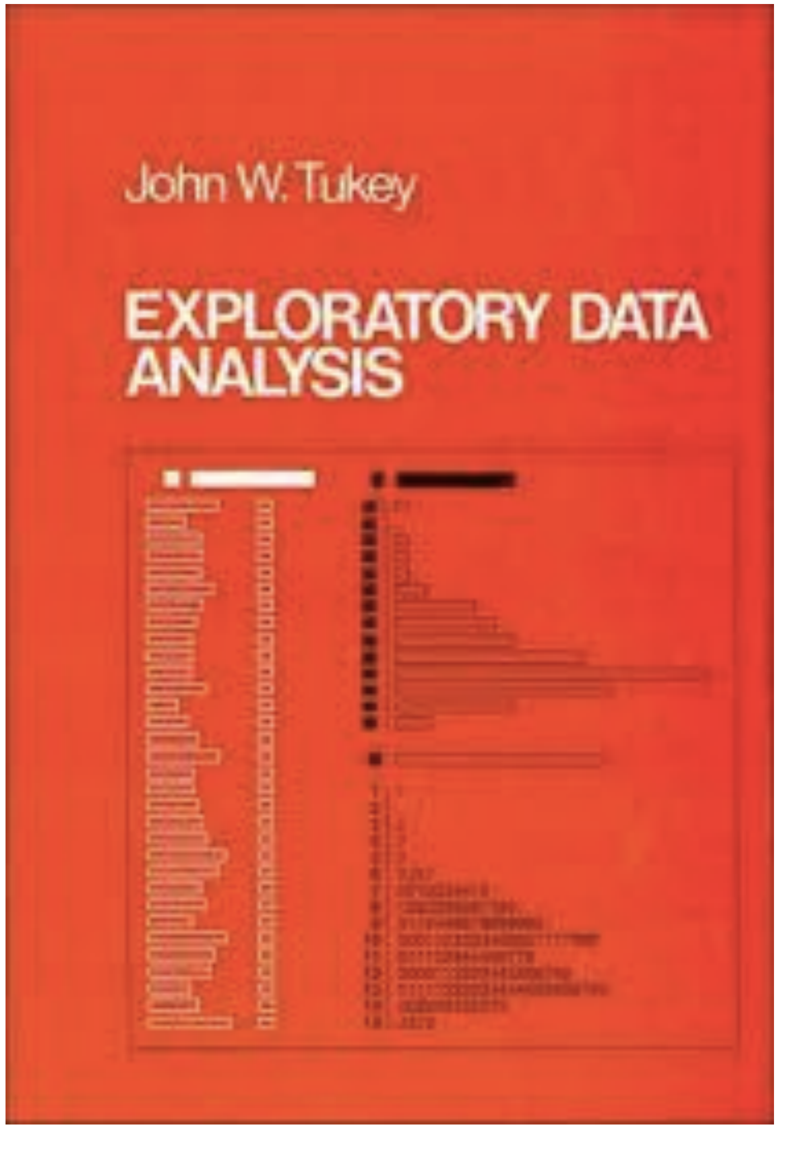


Exploratory Data Analysis

- 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!

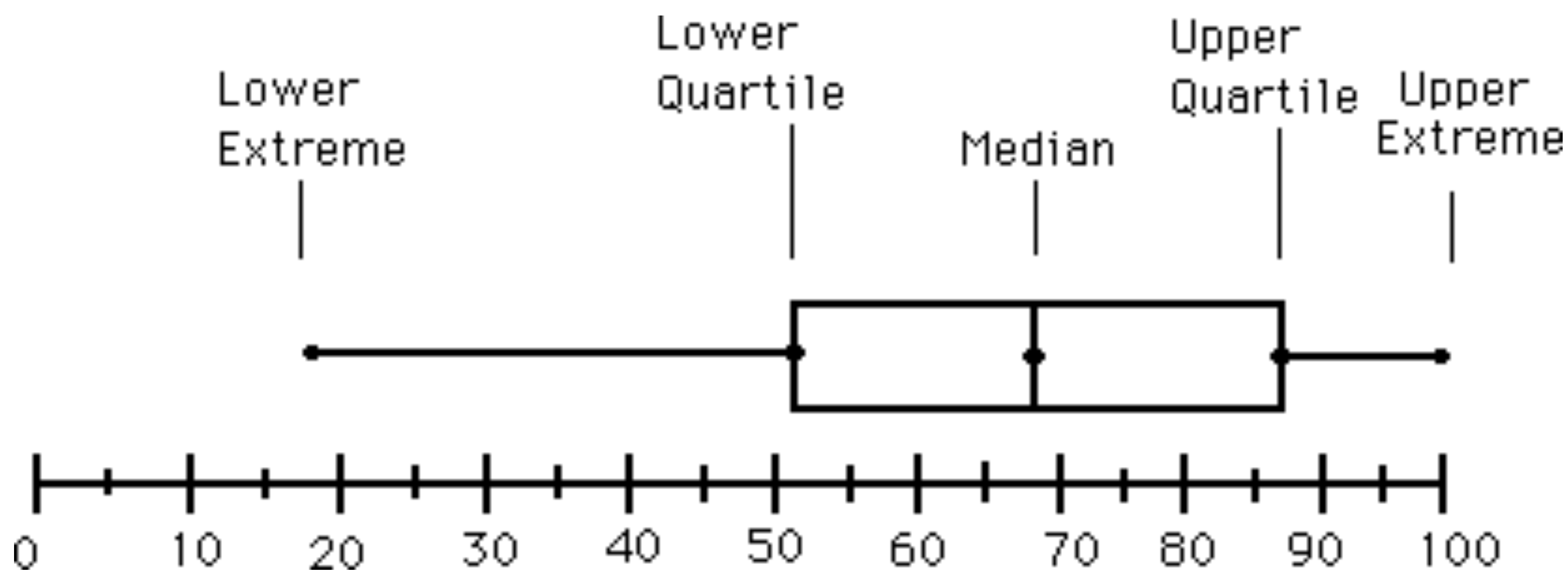
Exploratory Data Analysis 1977

- 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: boxplots

- **Box-and-whisker plot** : a graphical form of 5-number summary (Tukey)



boxplot(rnorm(1000,0))

summary(); hist()

The Trouble with Summary Stats

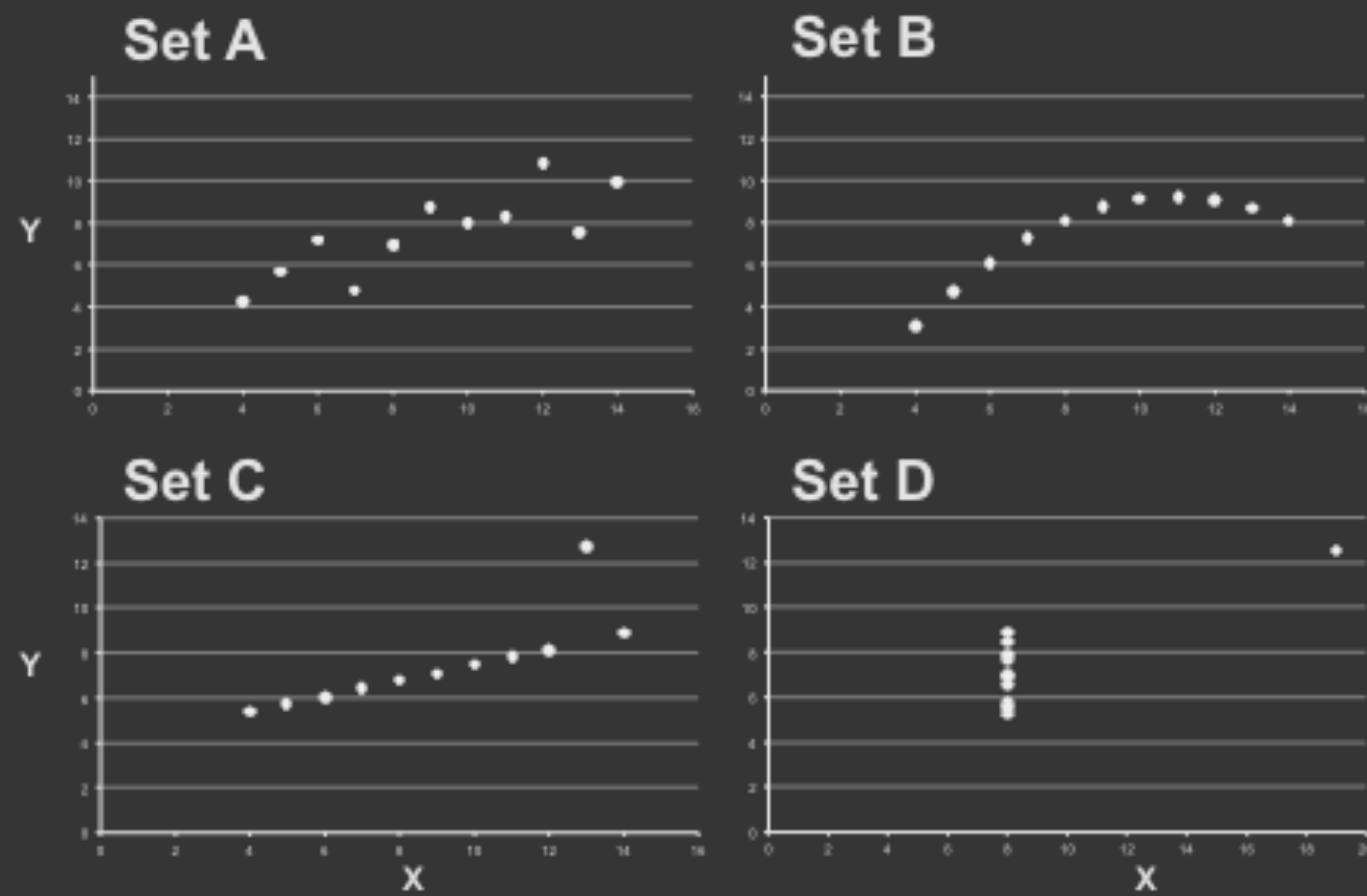
Set A X	Set A Y	Set B X	Set B Y	Set C X	Set C Y	Set D X	Set D Y
10	8.04	10	9.14	10	7.46	8	6.58
8	6.95	8	8.14	8	6.77	8	5.76
13	7.58	13	8.74	13	12.74	8	7.71
9	8.81	9	8.77	9	7.11	8	8.84
11	8.33	11	9.26	11	7.81	8	8.47
14	9.96	14	8.1	14	8.84	8	7.04
6	7.24	6	6.13	6	6.08	8	5.25
4	4.26	4	3.1	4	5.39	19	12.5
12	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

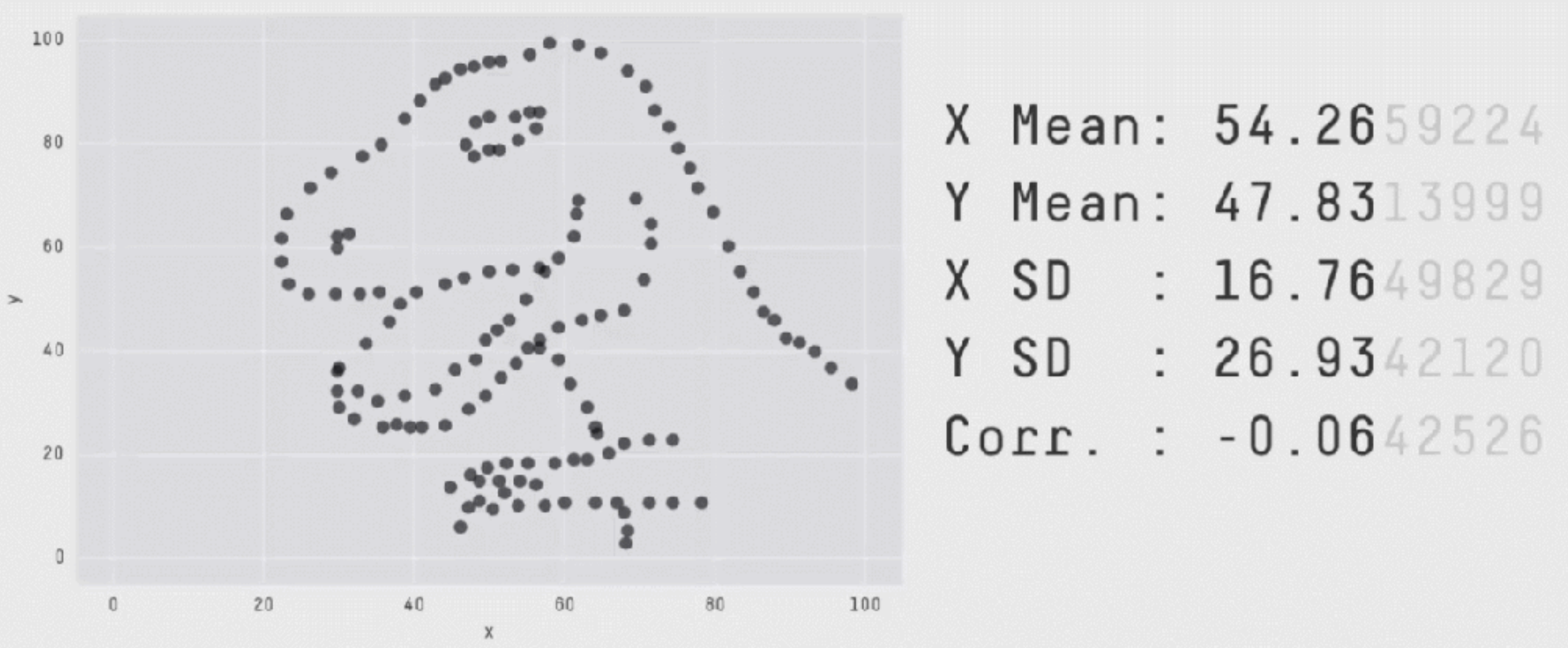
$u_X = 9.0$ $\sigma_X = 3.317$ $Y = 3 + 0.5\,X$
$u_Y = 7.5$ $\sigma_Y = 2.03$ $R^2 = 0.67$

[Anscombe 73]

Looking at Data



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



Key point: You need to visualize your data!

https://github.com/stephlocke/datasauRus

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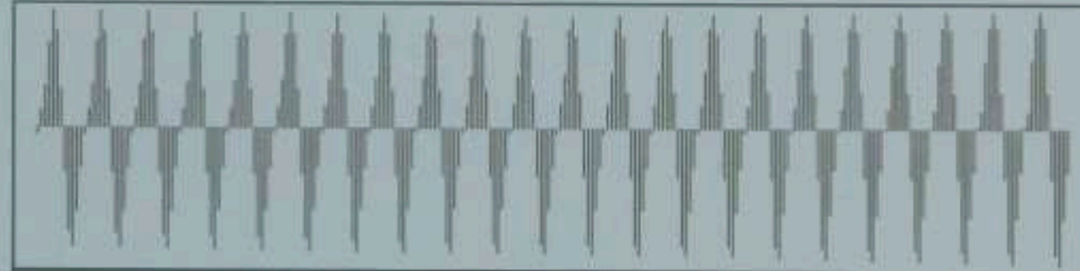
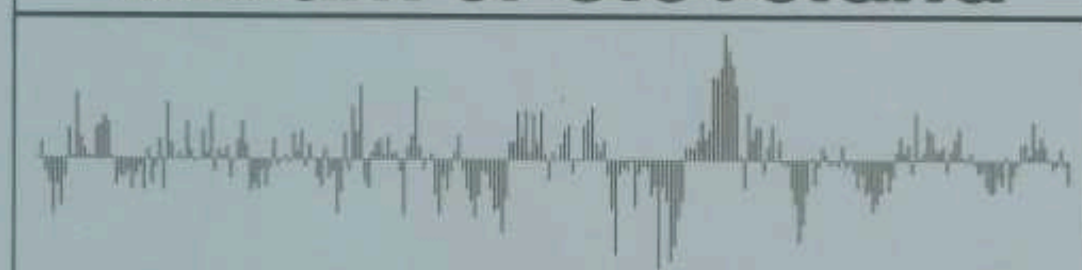
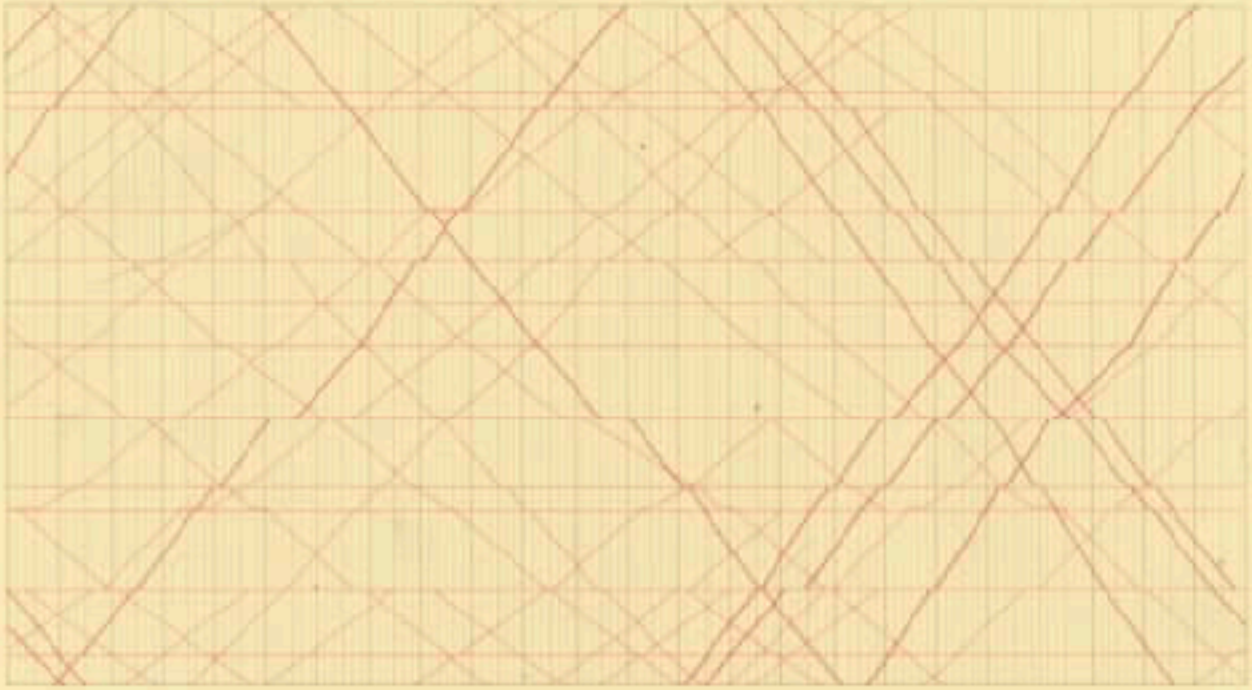


The Elements of Graphing Data

William S. Cleveland





The Visual Display of Quantitative Information

EDWARD R. TUFTE

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

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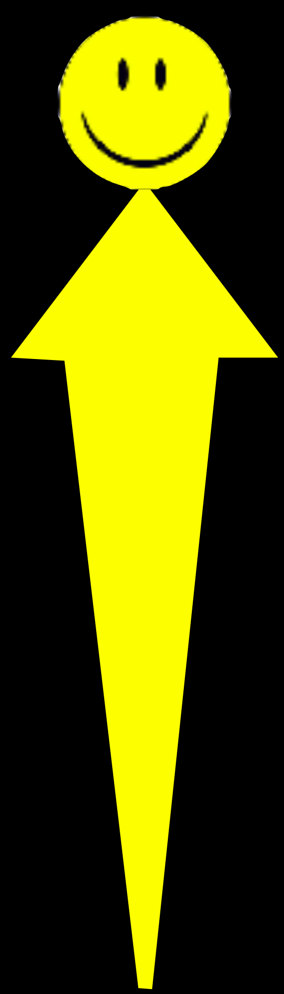

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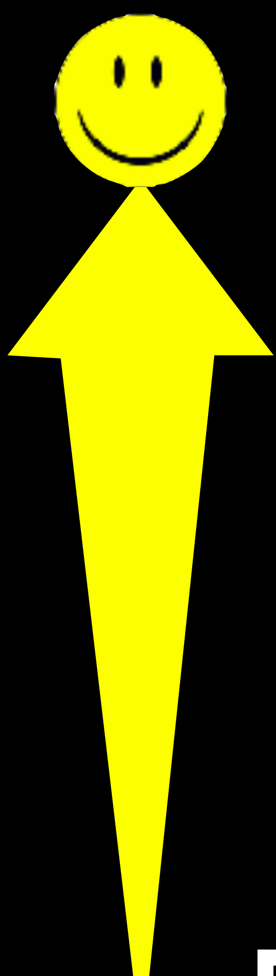

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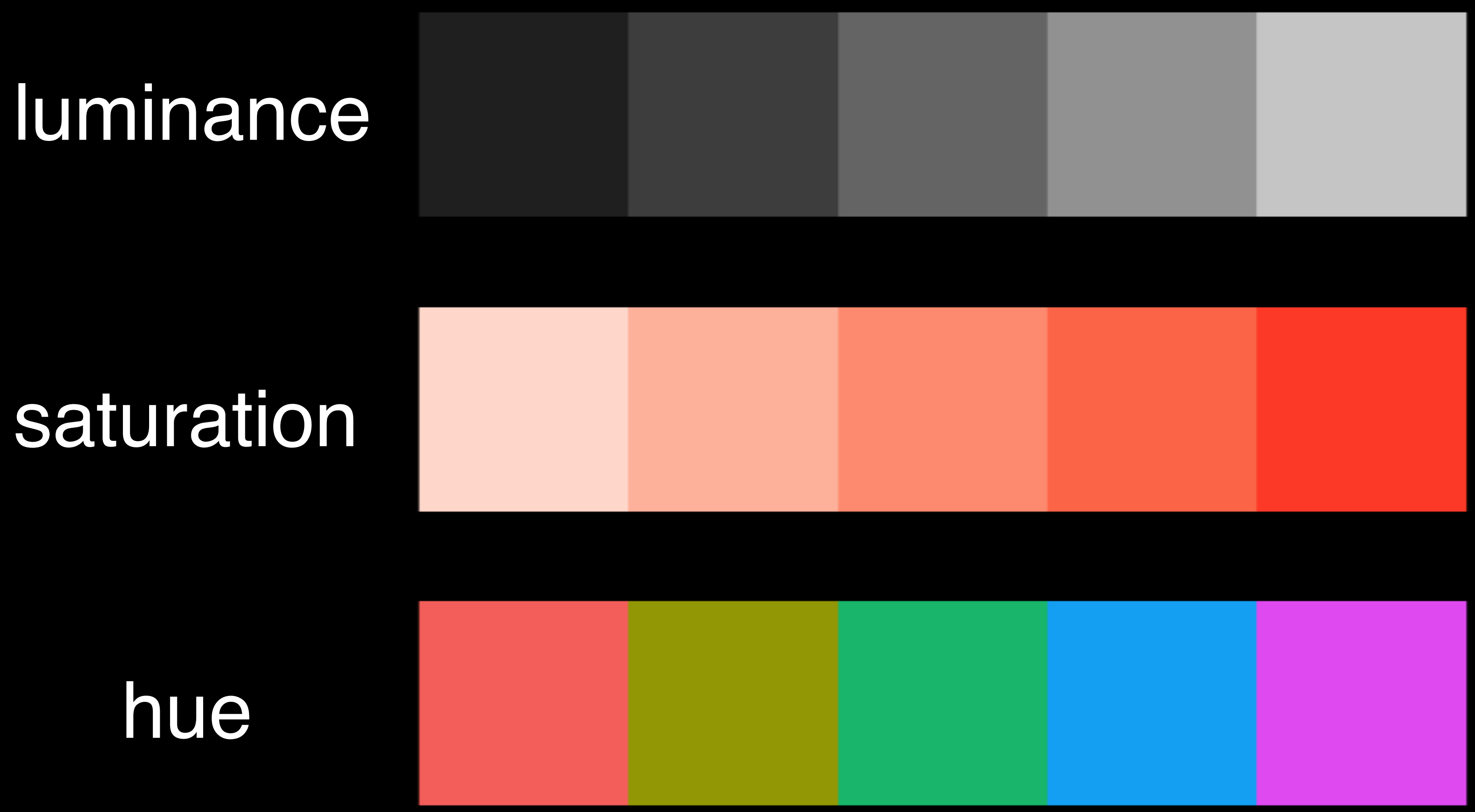
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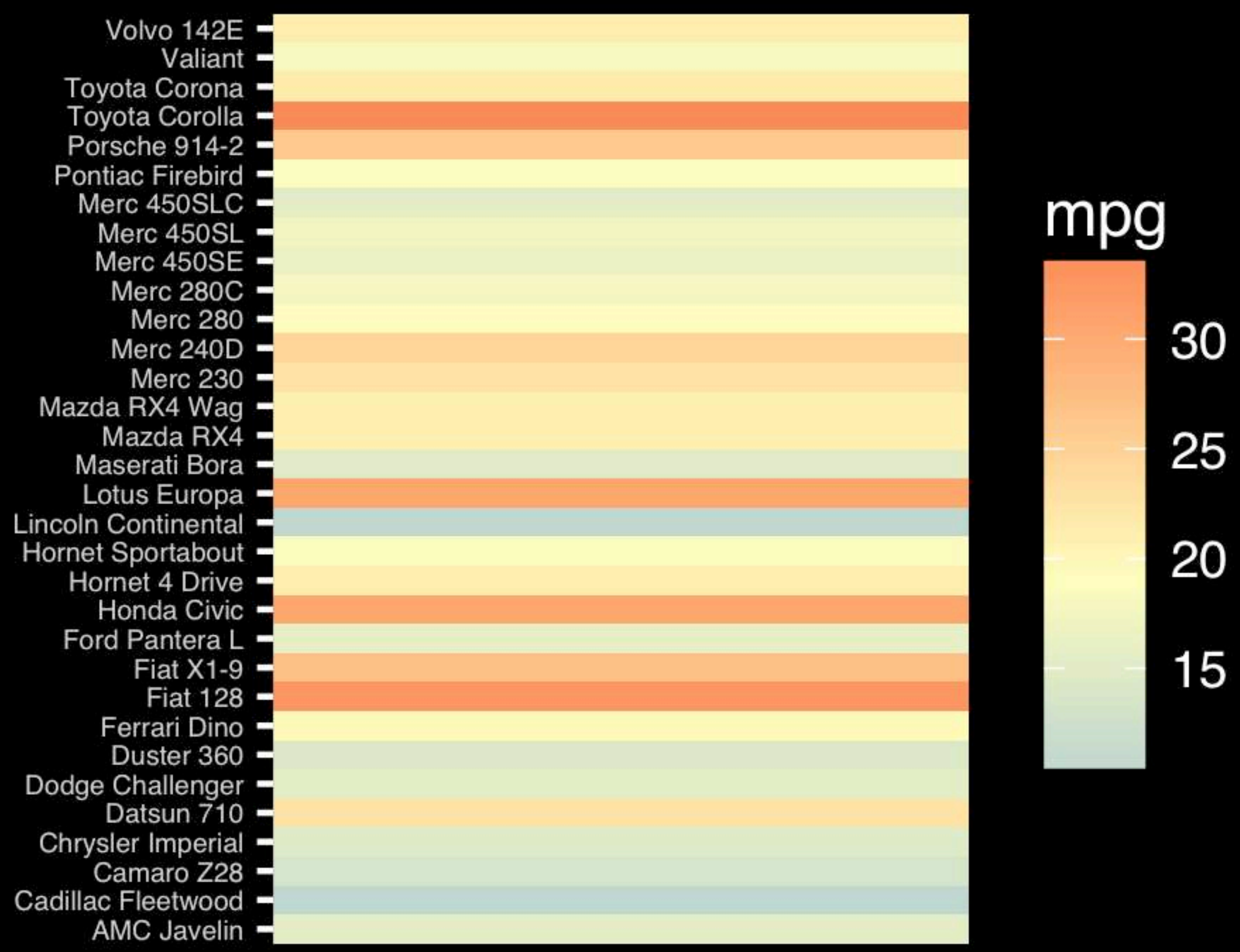
Volvo 142E
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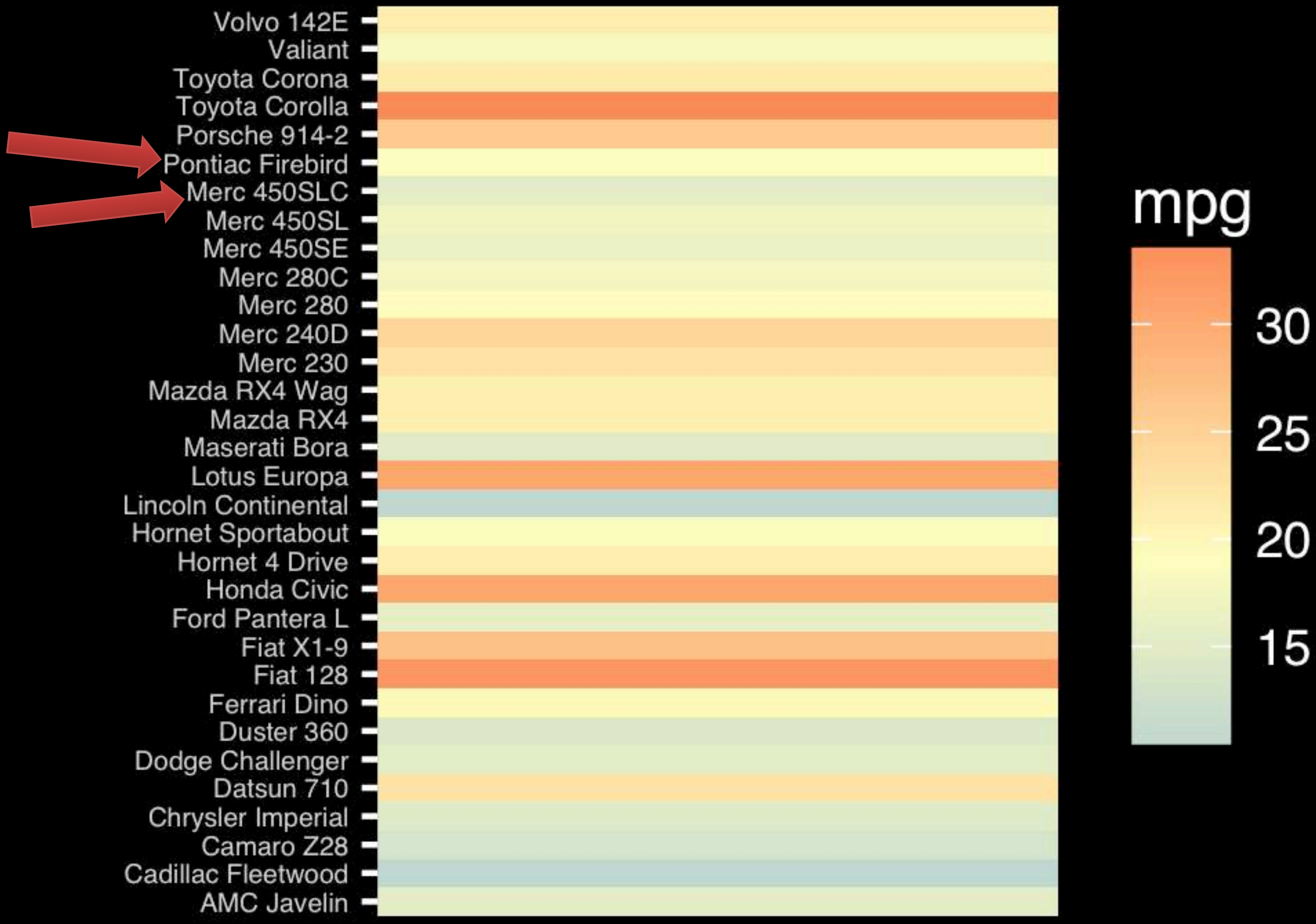

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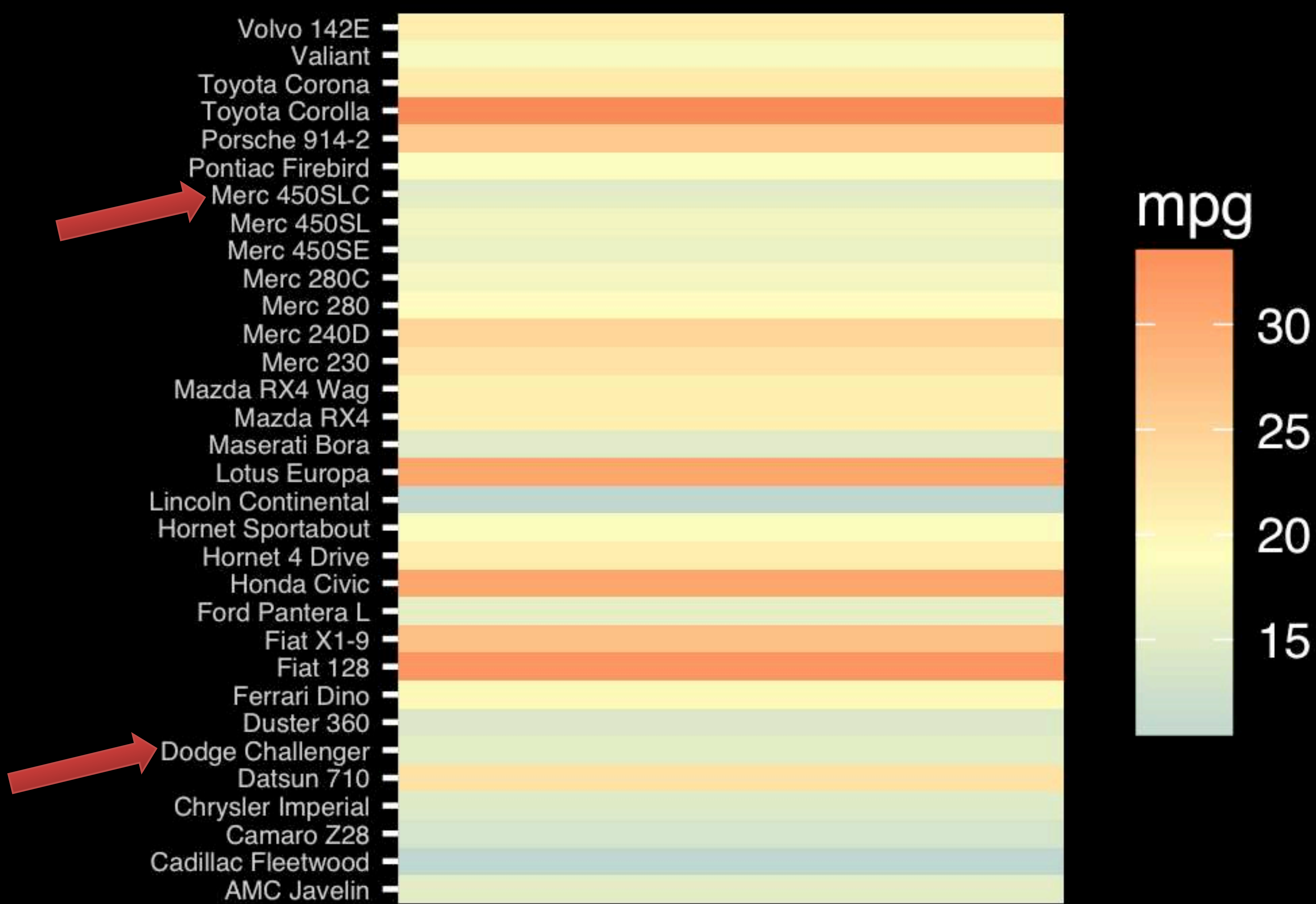

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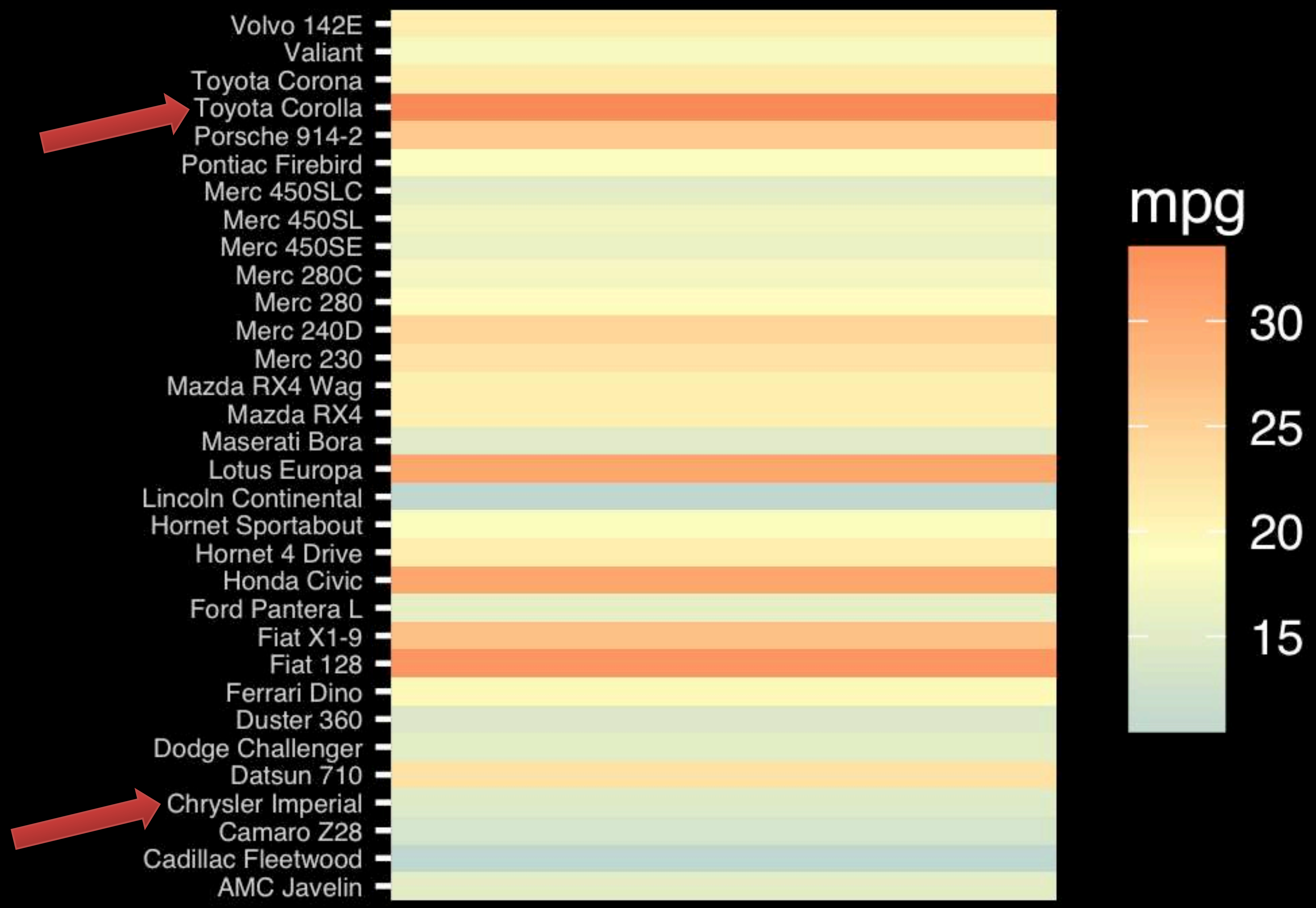

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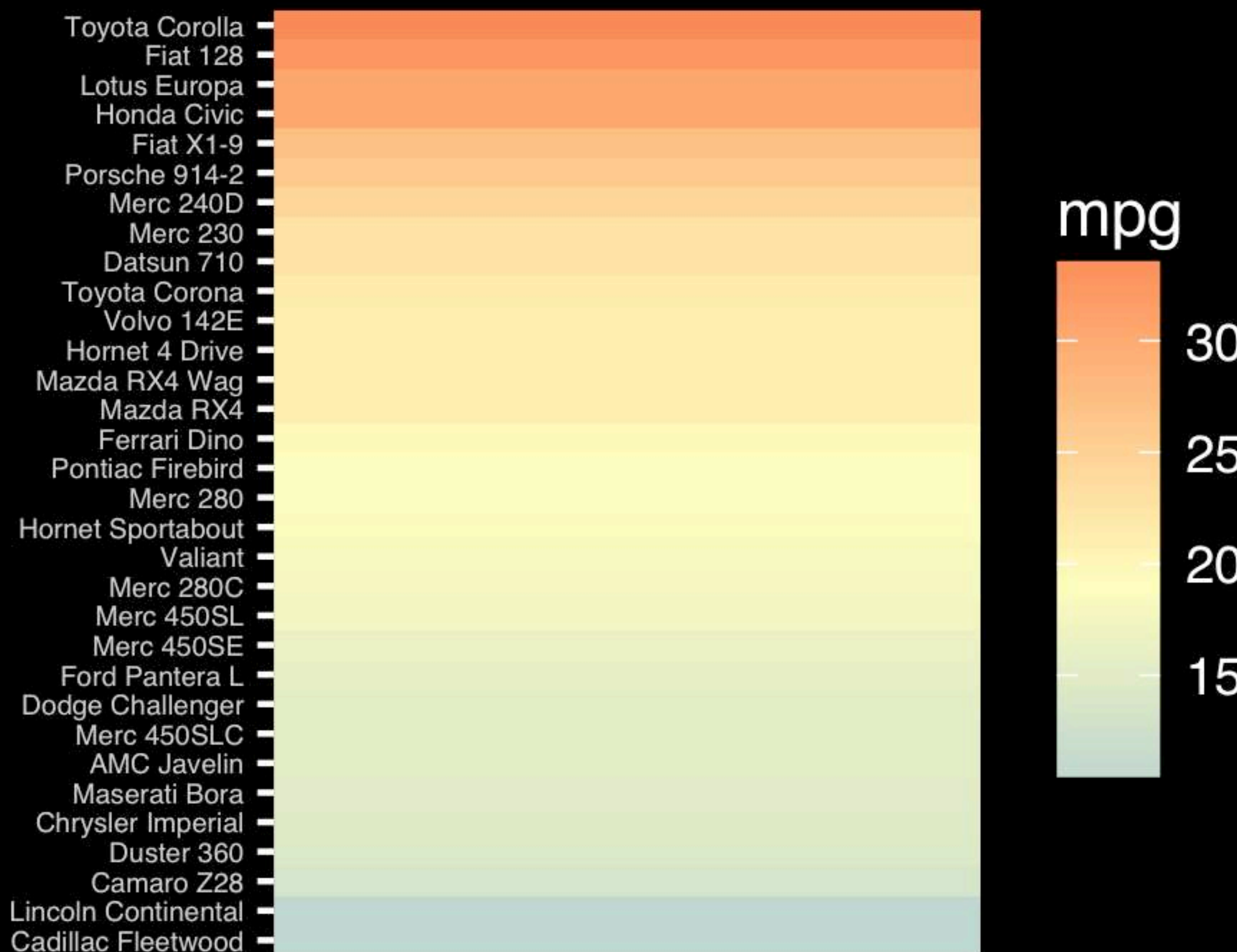
Observation: Alphabetical is almost never the correct ordering of a categorical variable.



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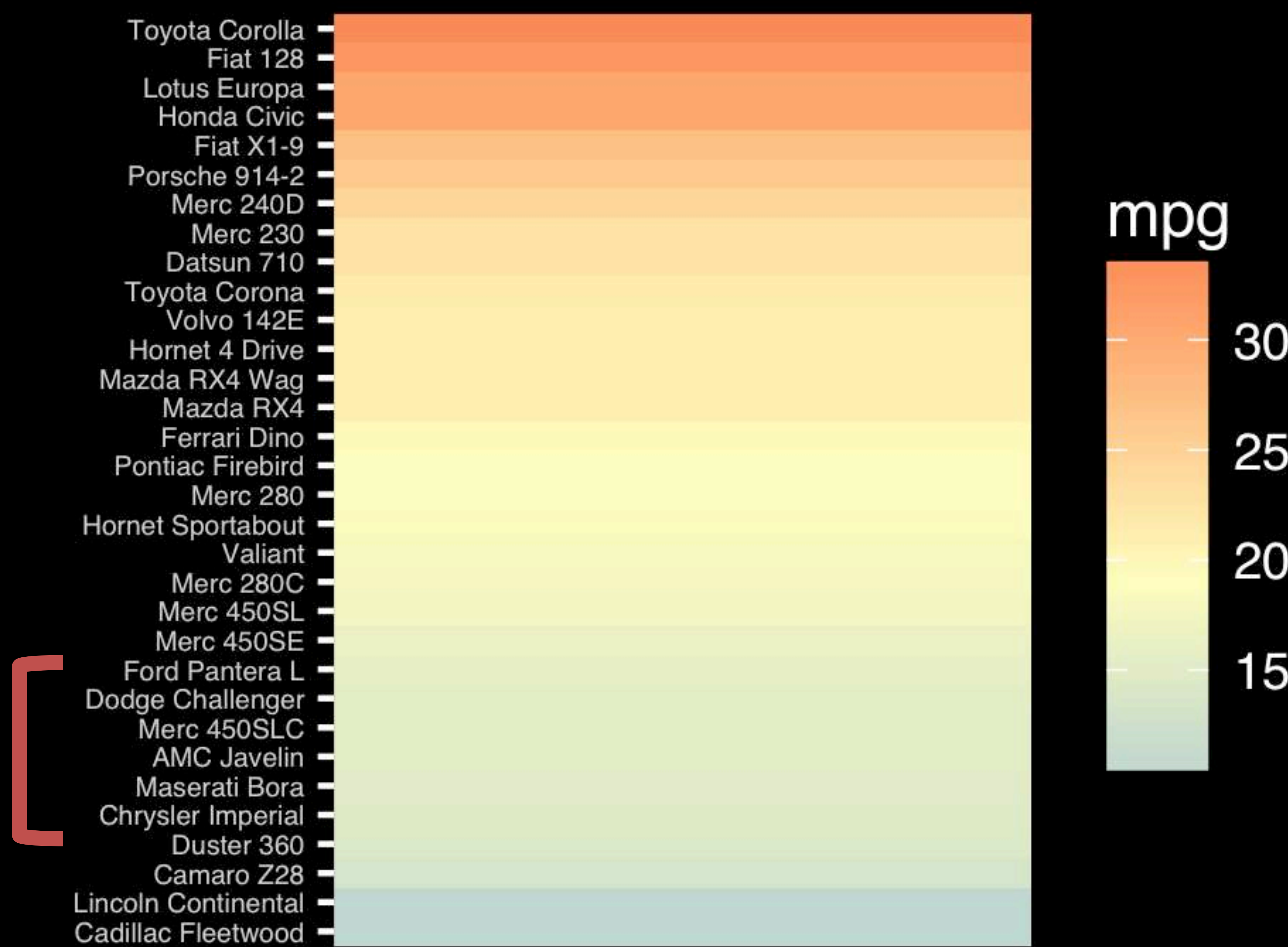
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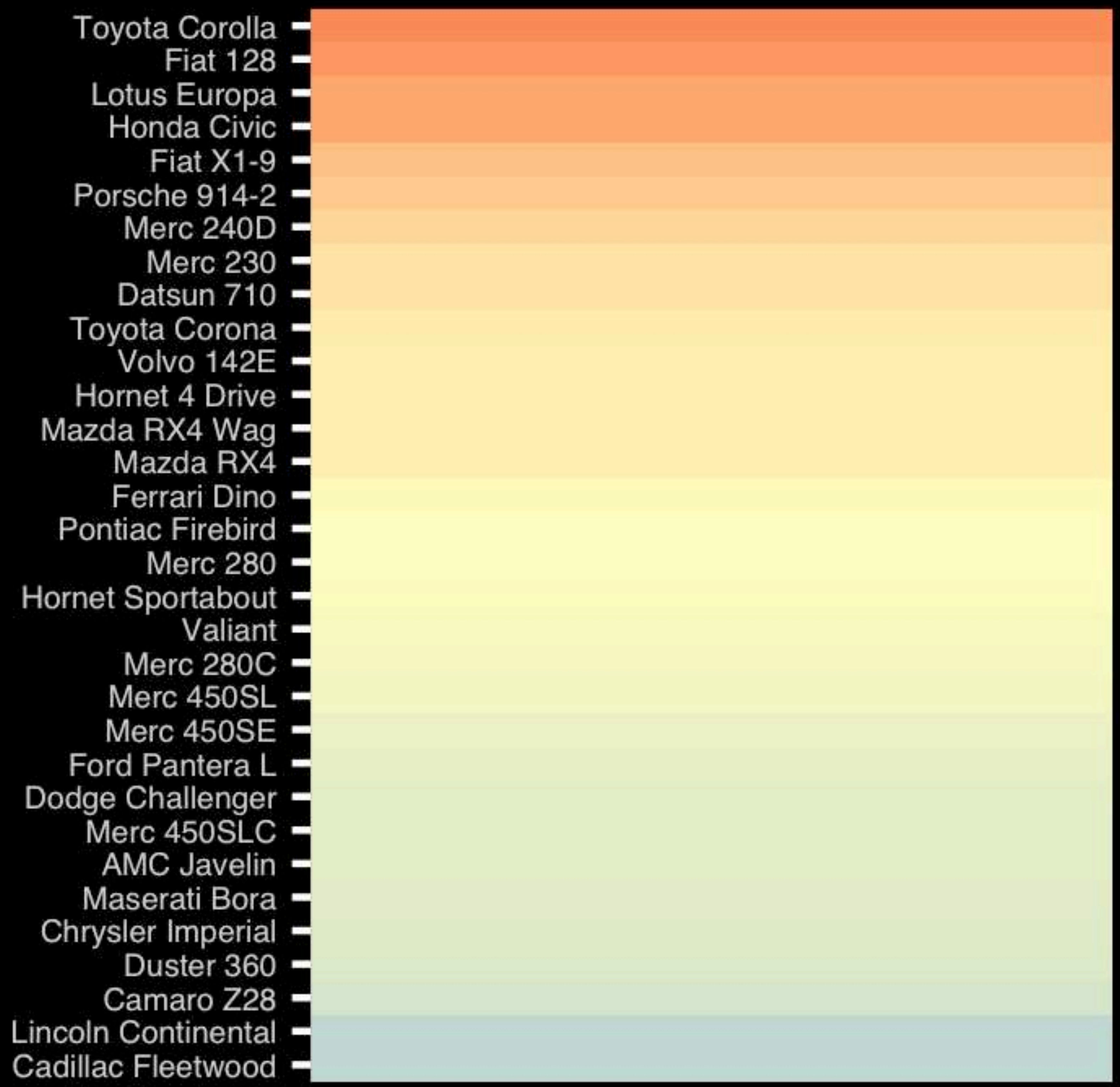
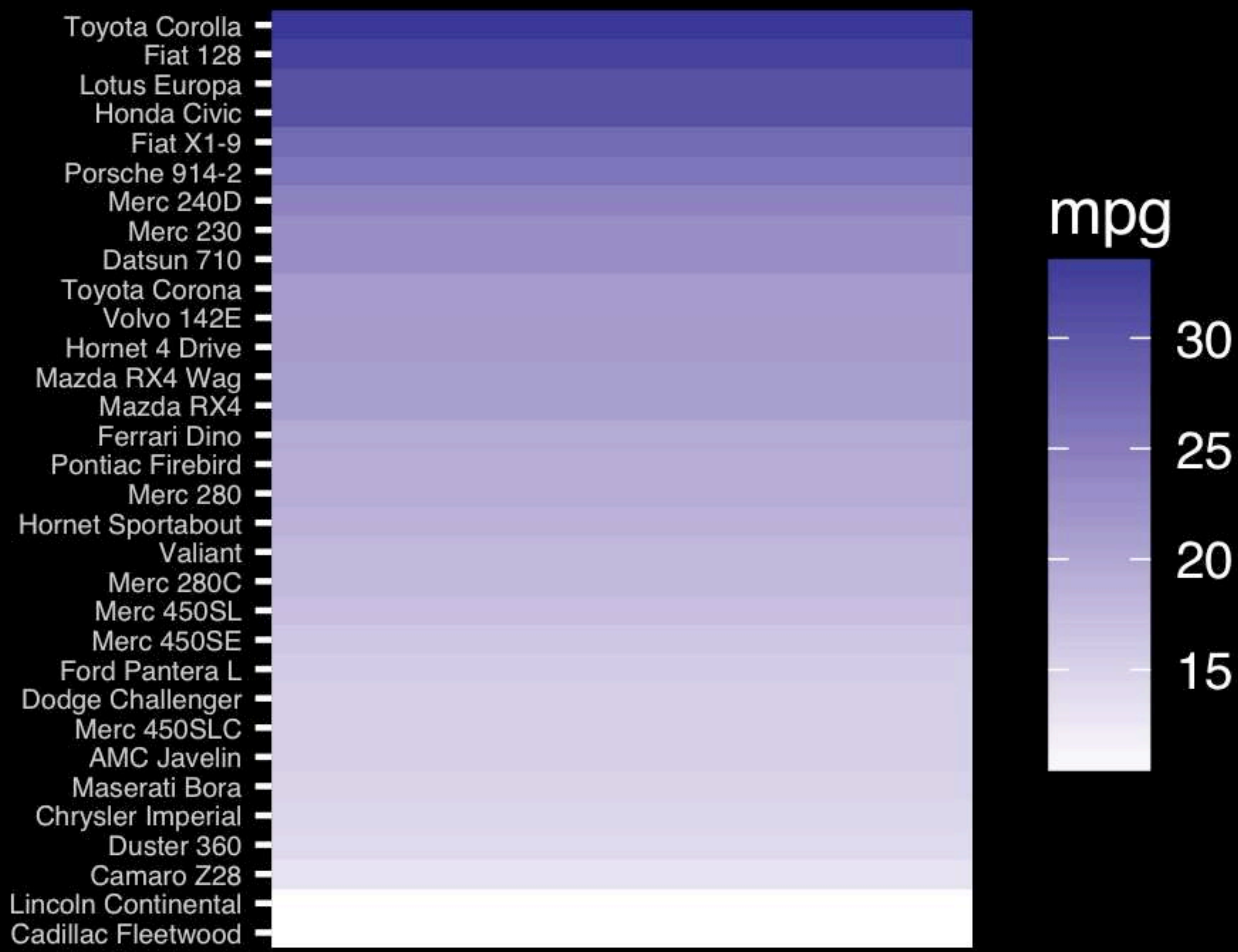


If we did not have the legend would you know which was low or high mpg?



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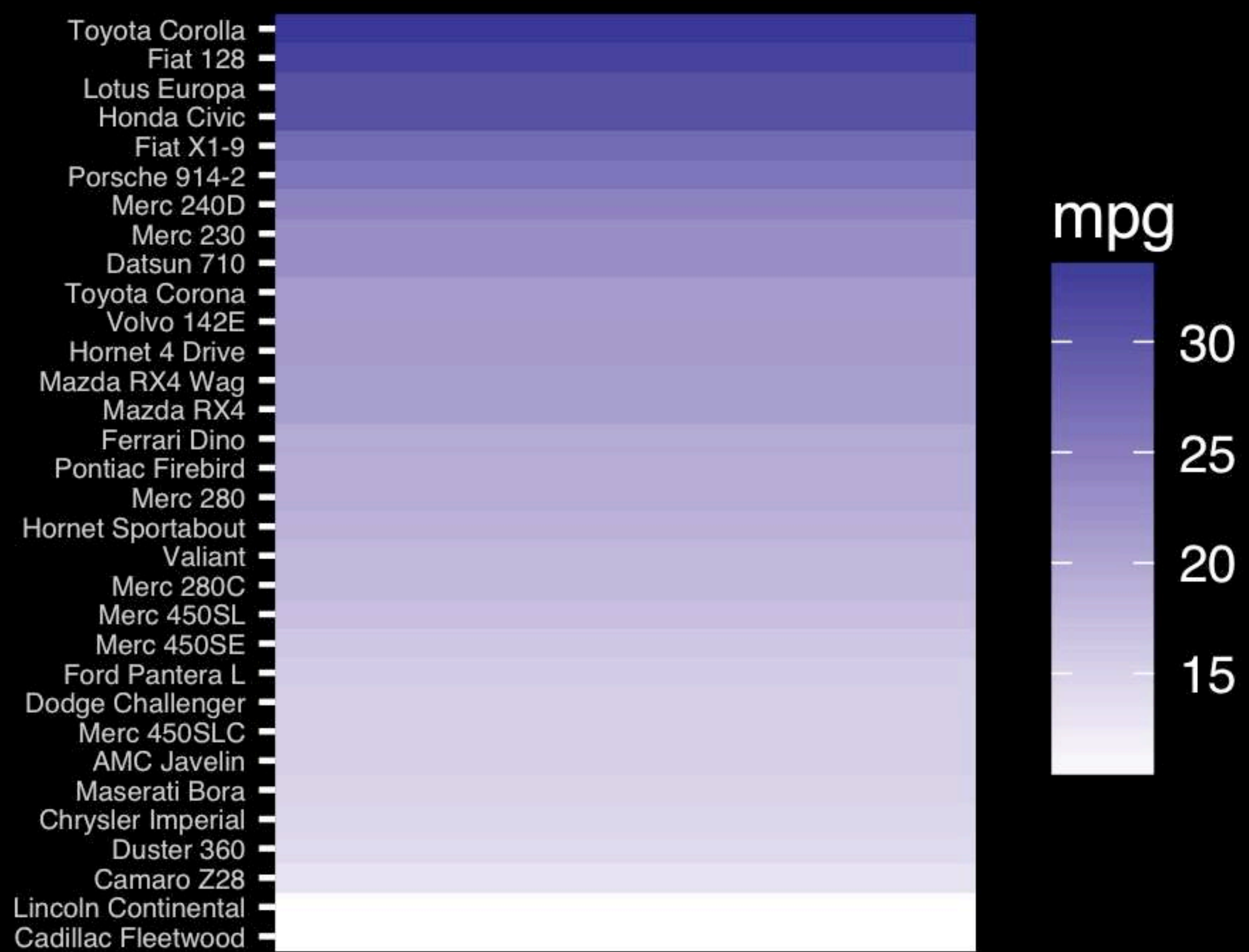

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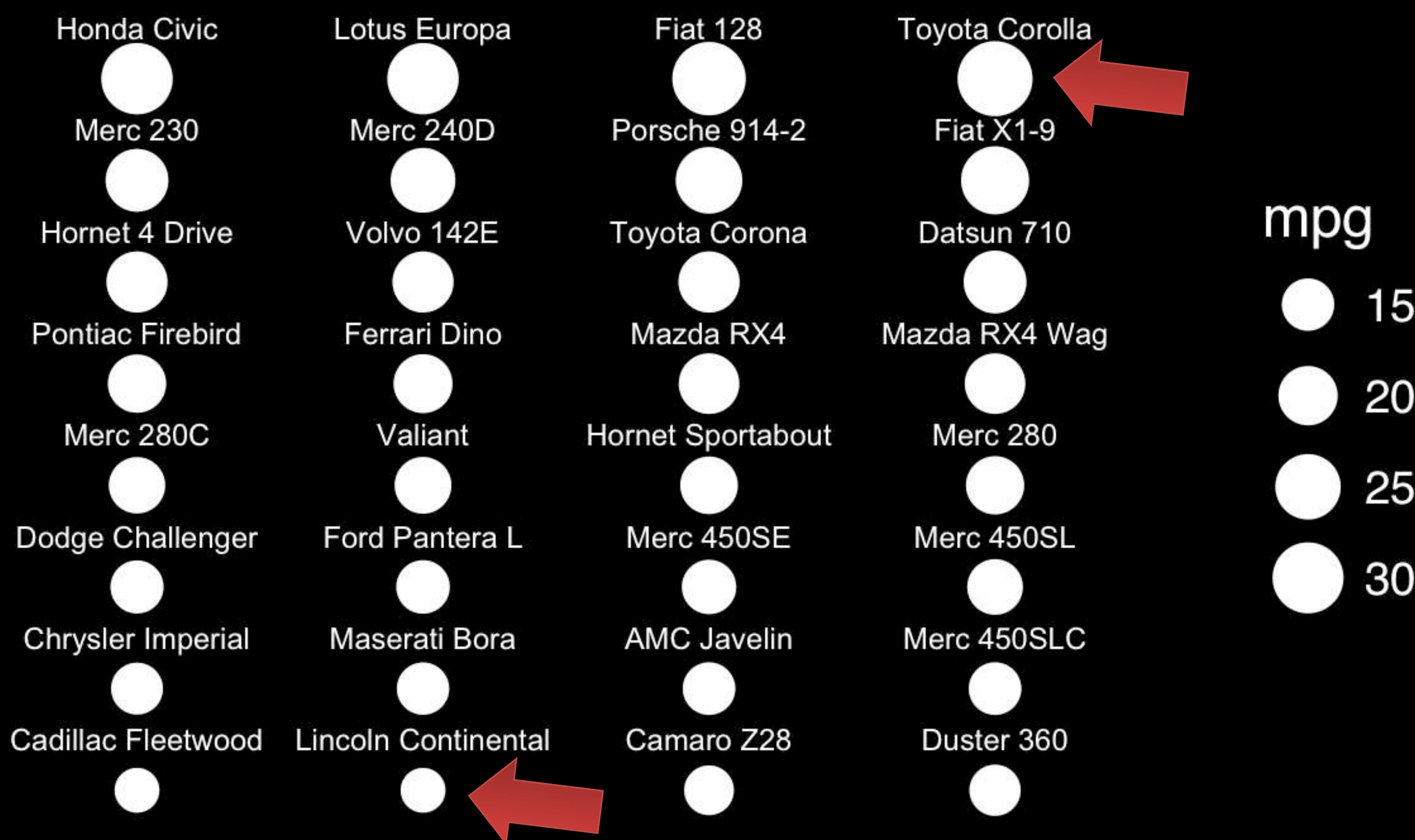
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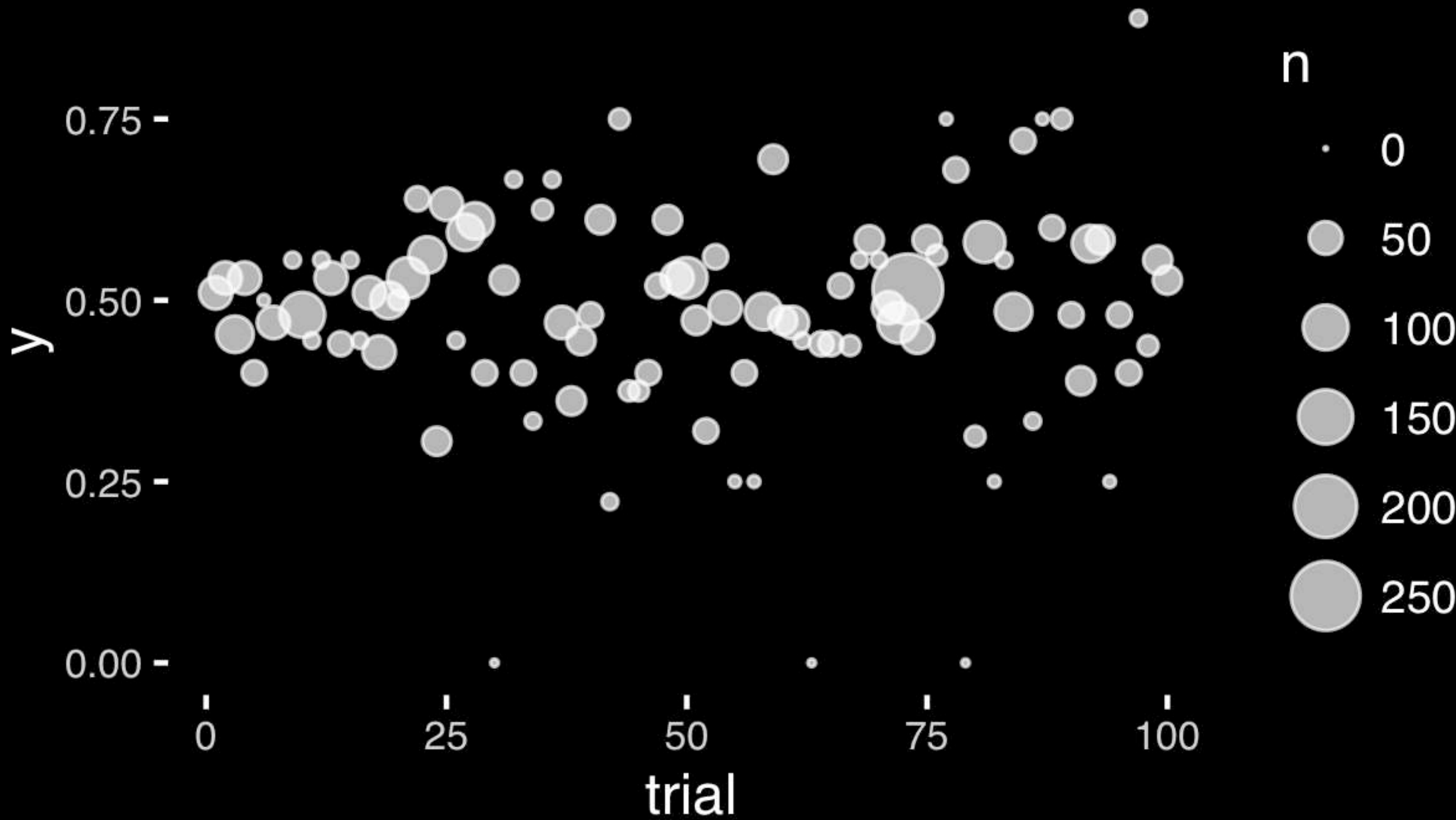

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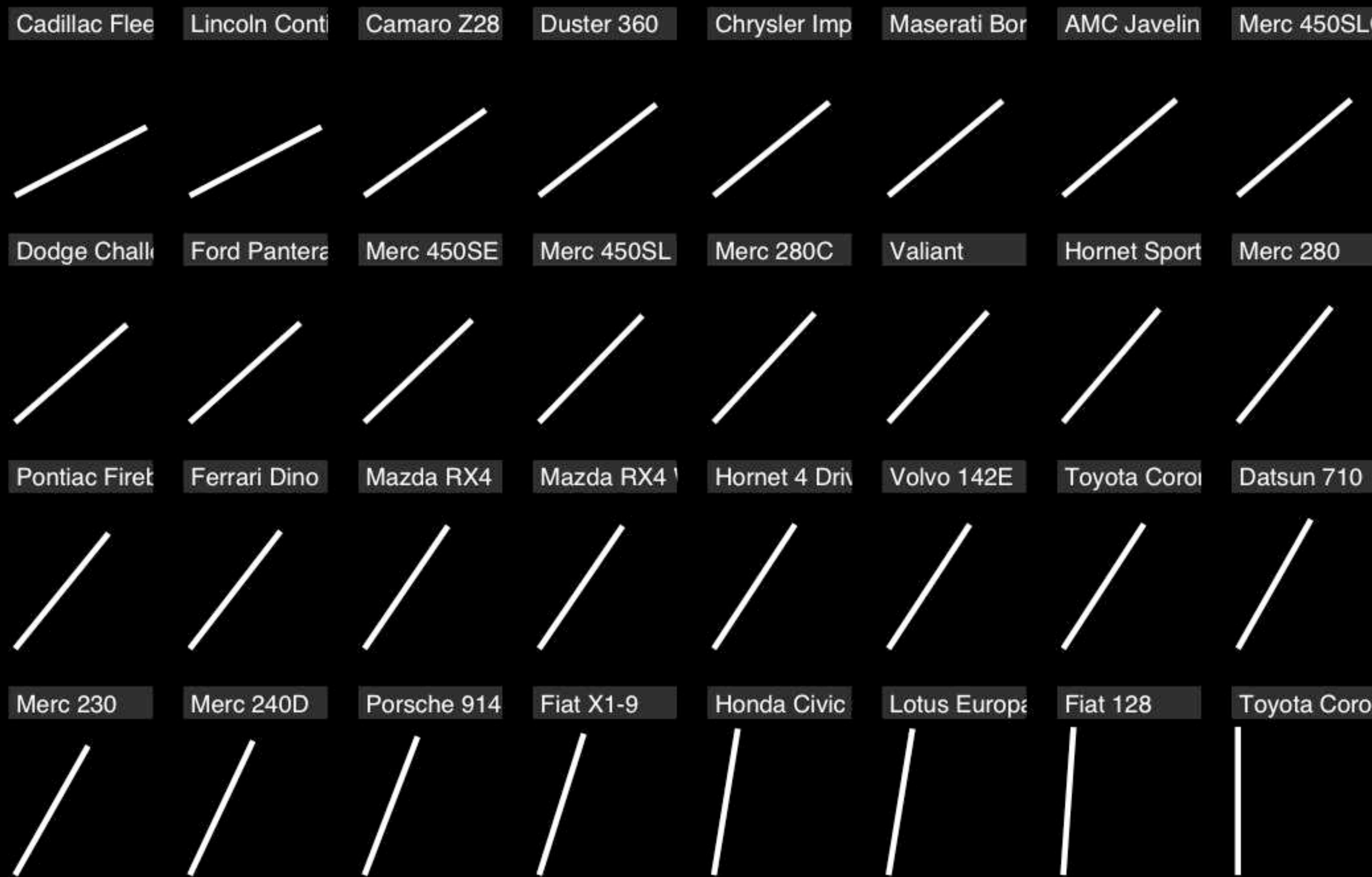
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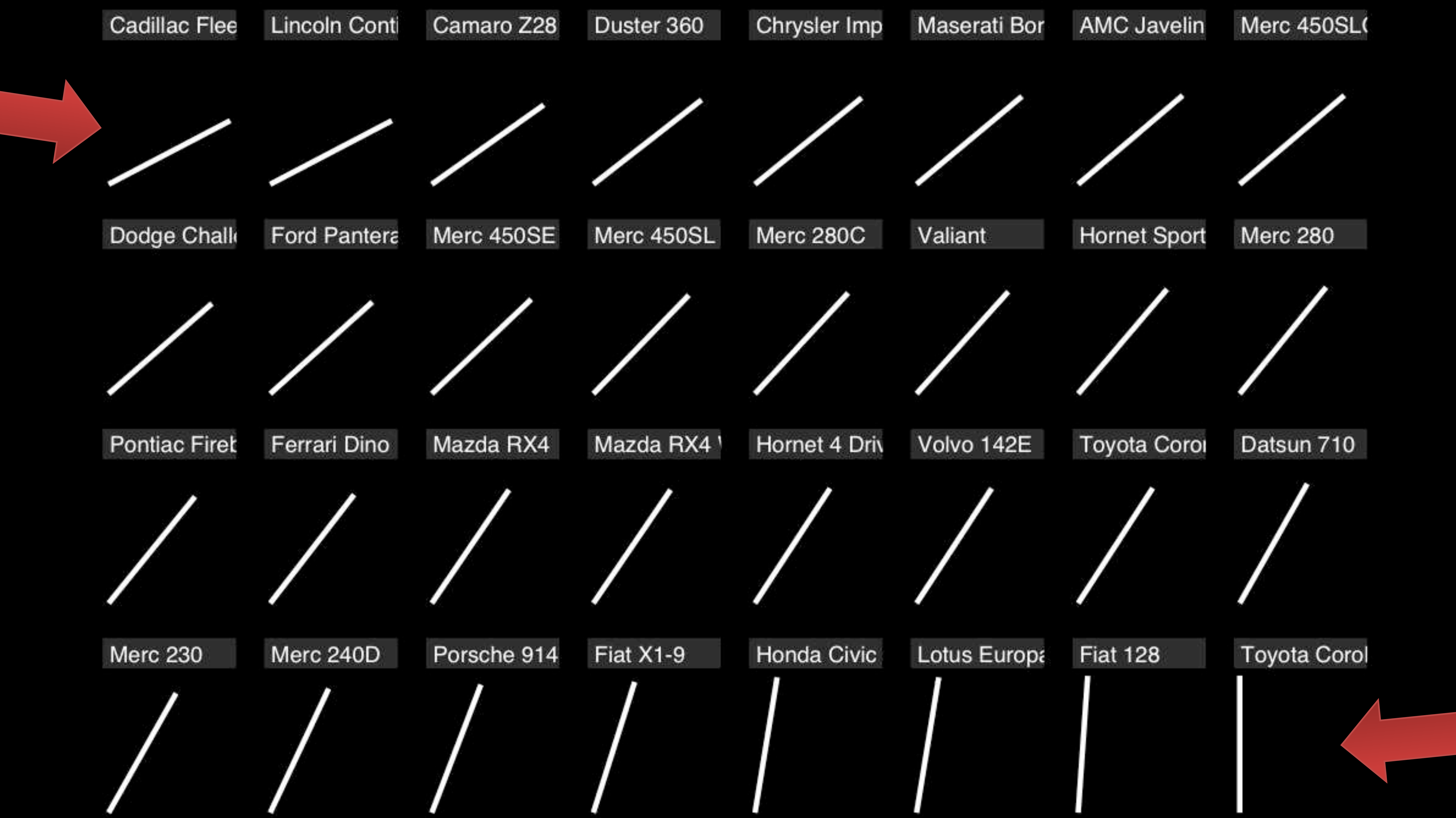
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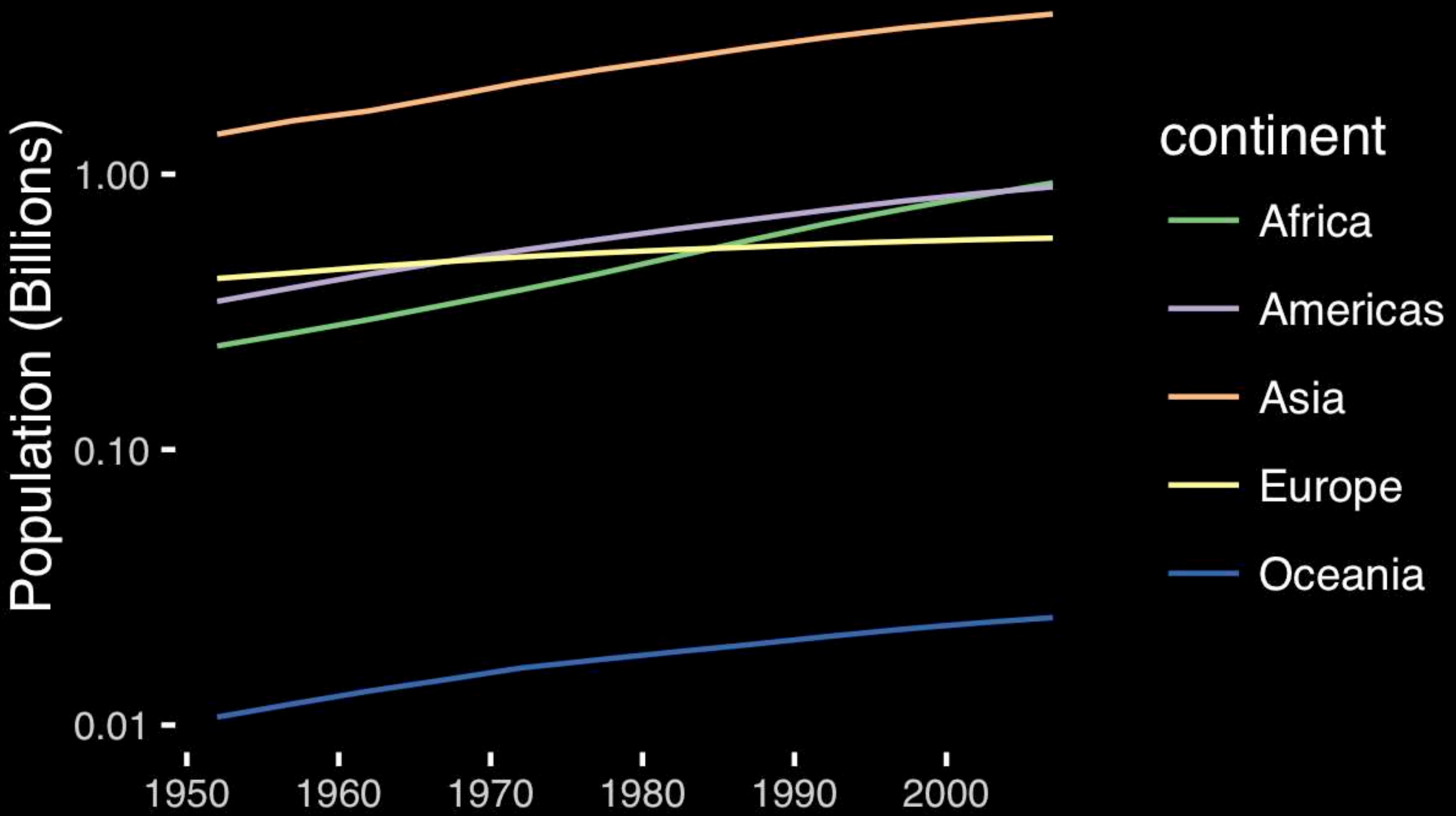
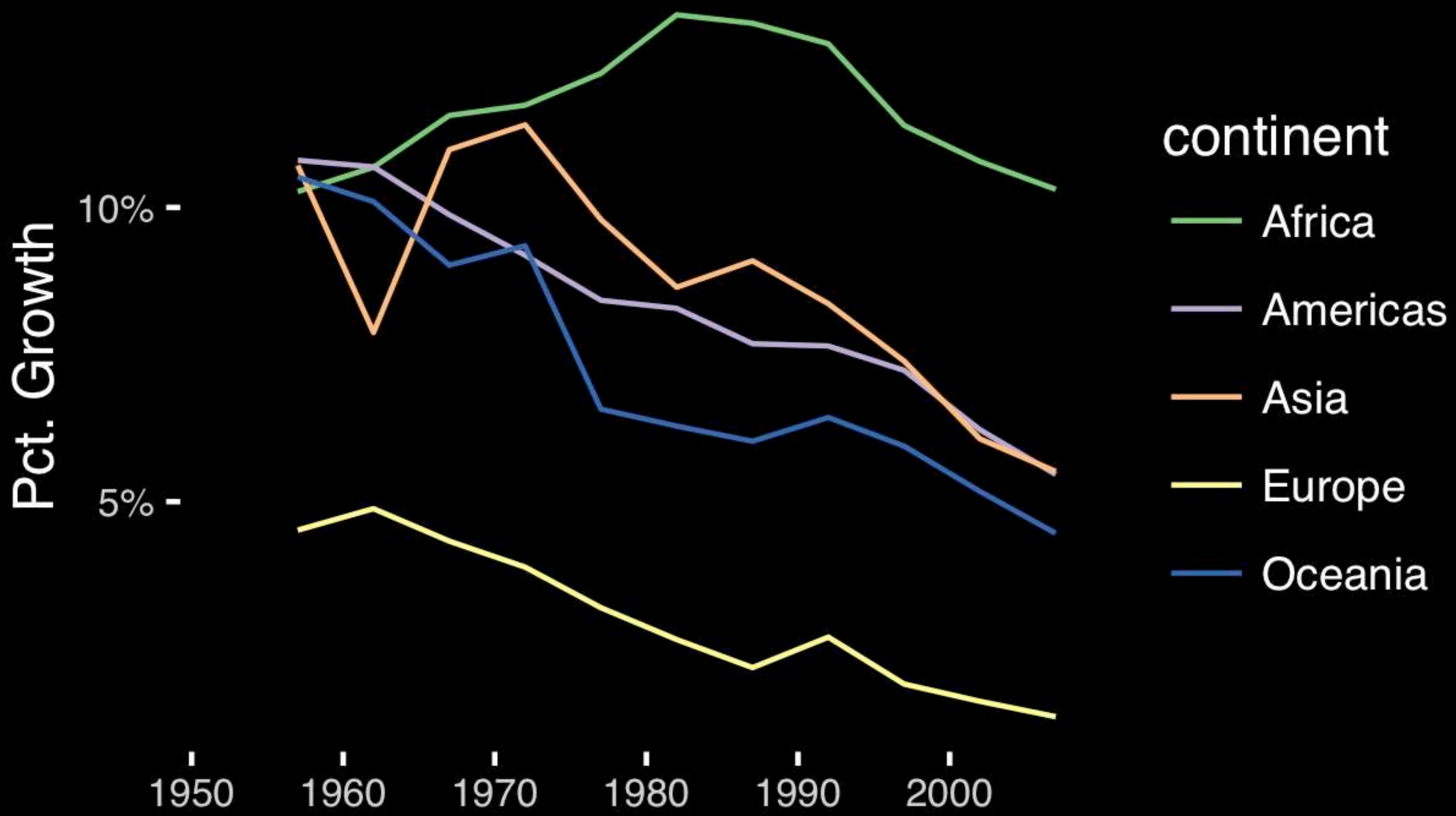


Population (Billions)
1.00
0.10
0.01
1950
1960
1970
1980
1990
2000
continent
Africa
Americas
Asia
Europe
Oceania

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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Observation: Pie charts are <u>ALWAYS</u> 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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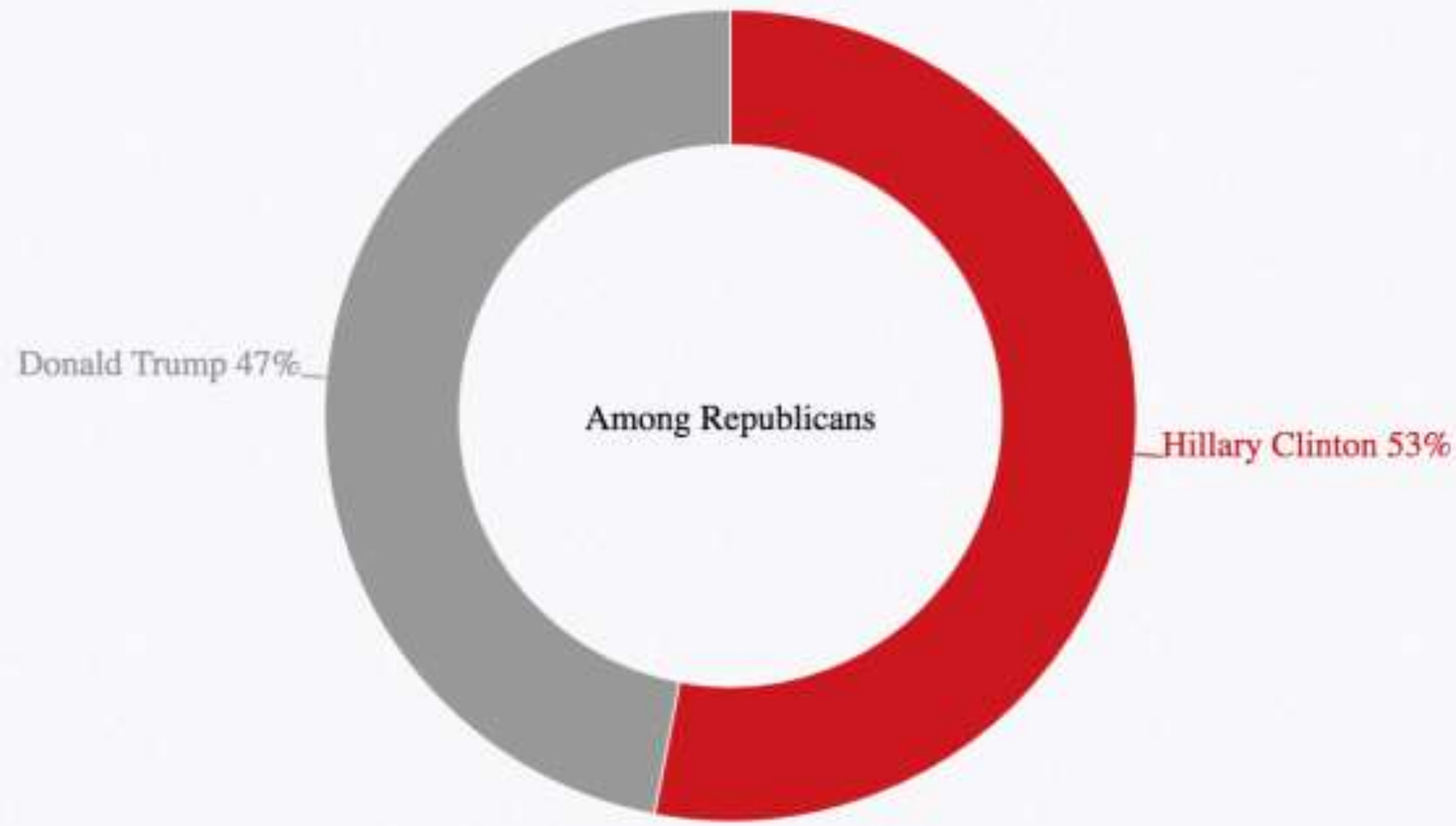
Who do you think did a better job in tonight's debate?

Among Republicans | Among Democrats



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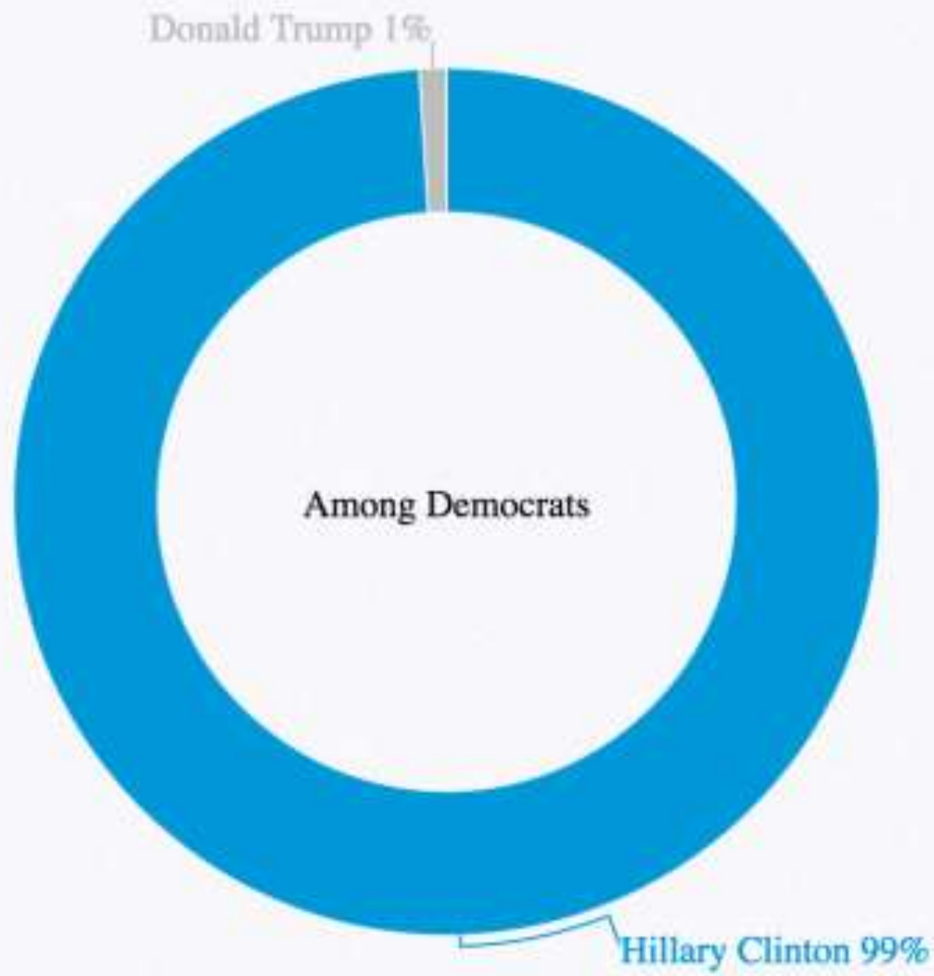
POLITICO

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

Among Republicans | Among Democrats



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POLITICO

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.**

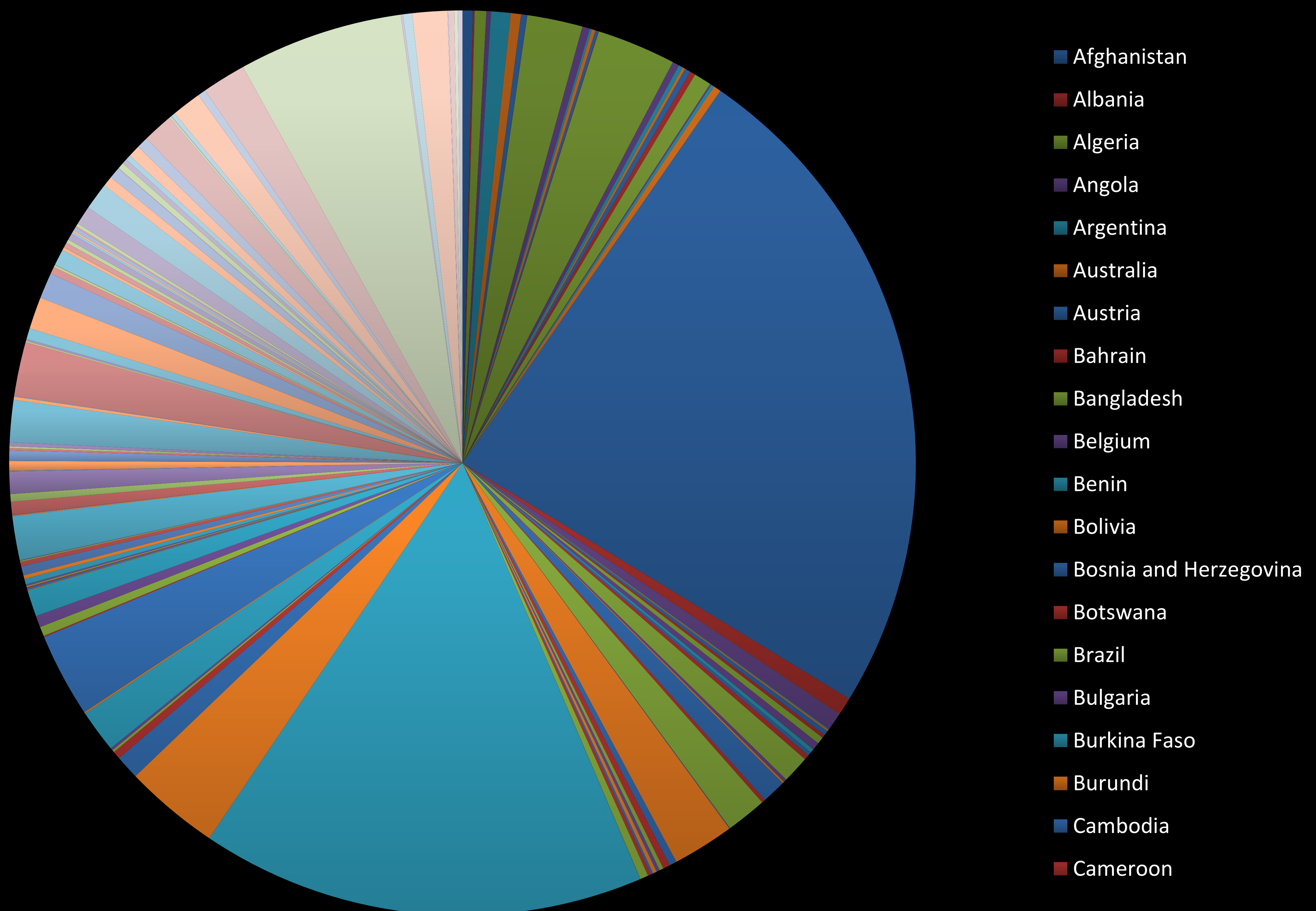
-Edward Tufte, The Visual Display of Quantitative Information

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.

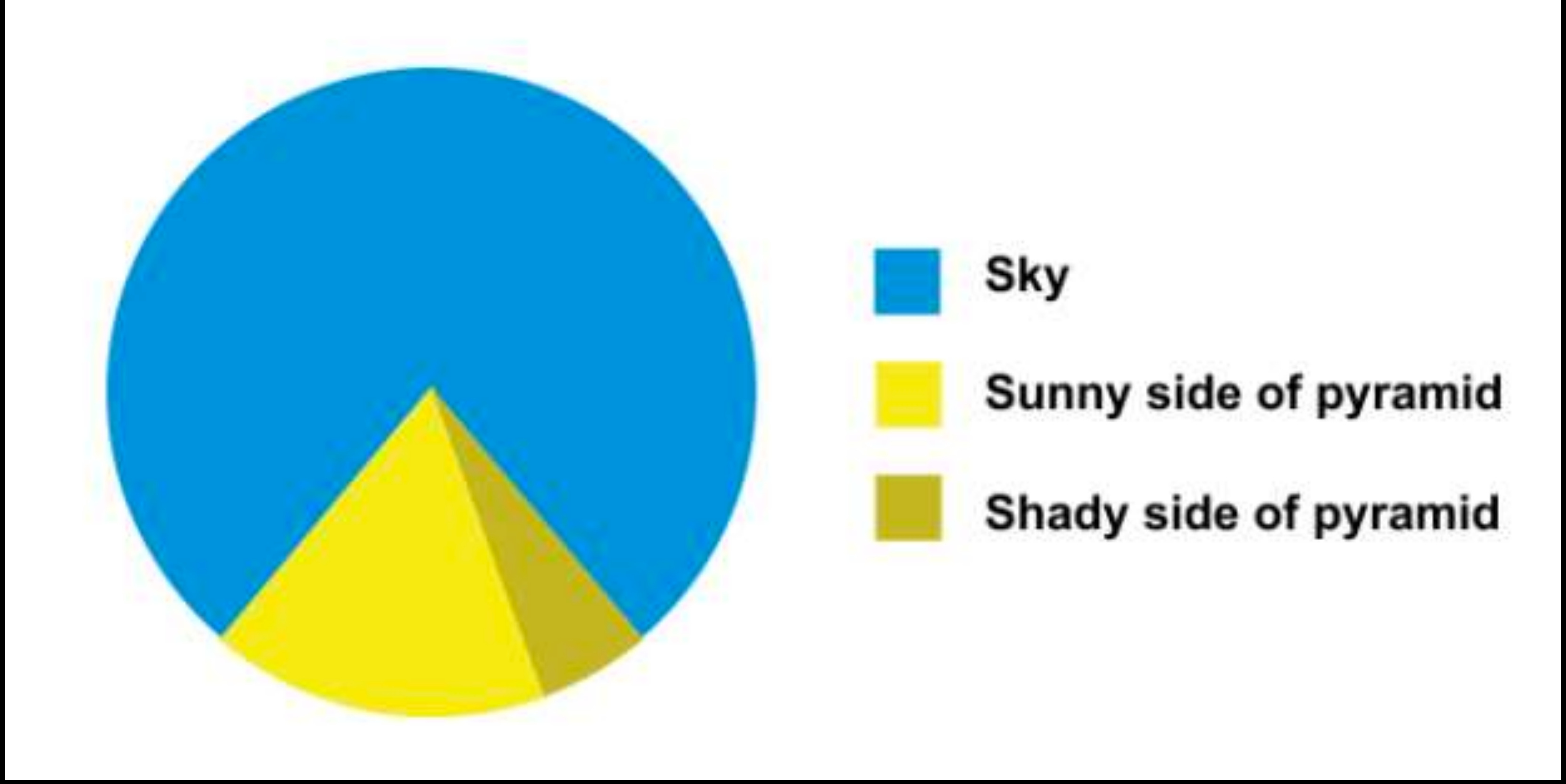
-Edward Tufte, The Visual Display of Quantitative Information

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

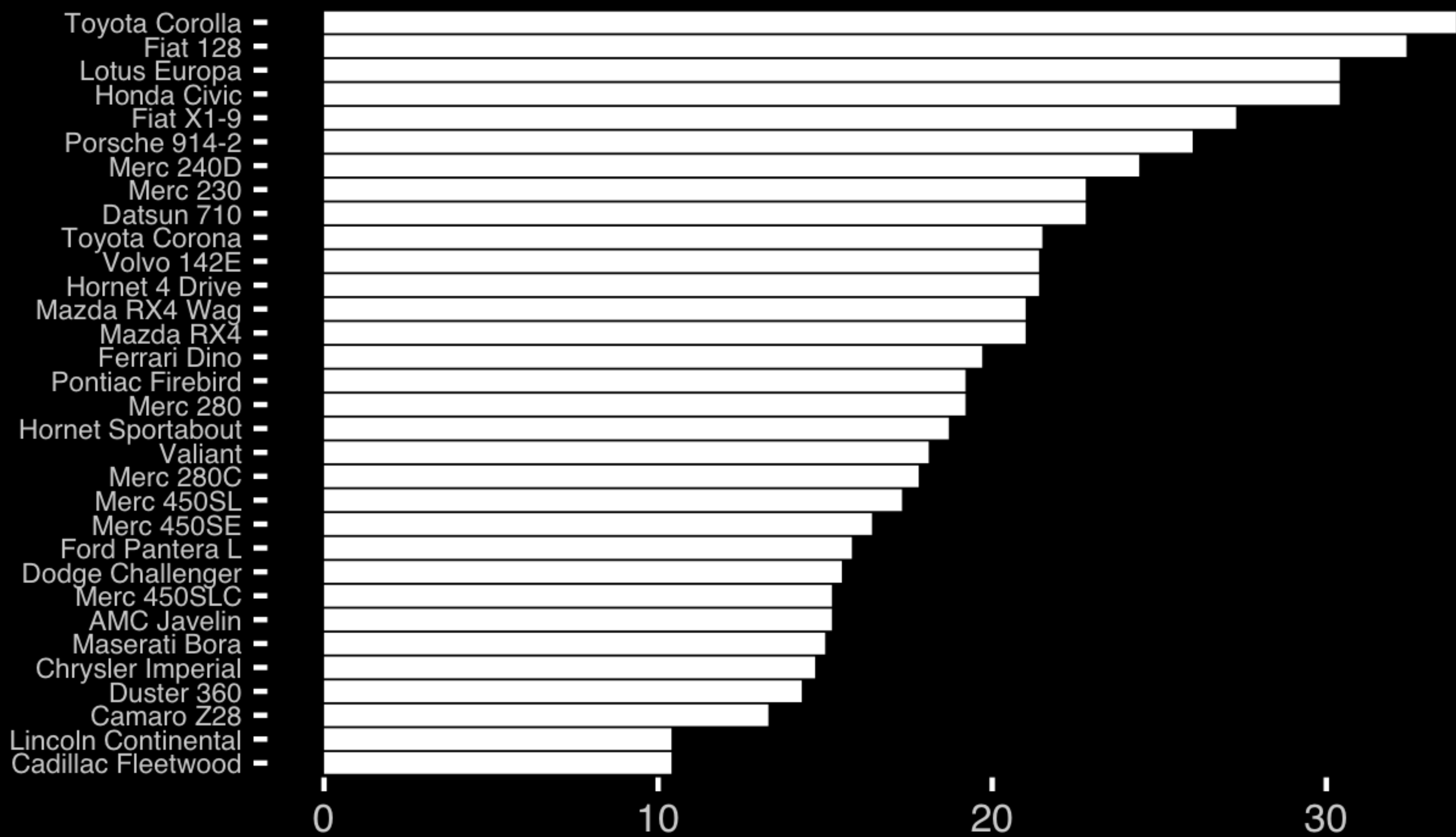
All good pie charts are jokes…



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

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



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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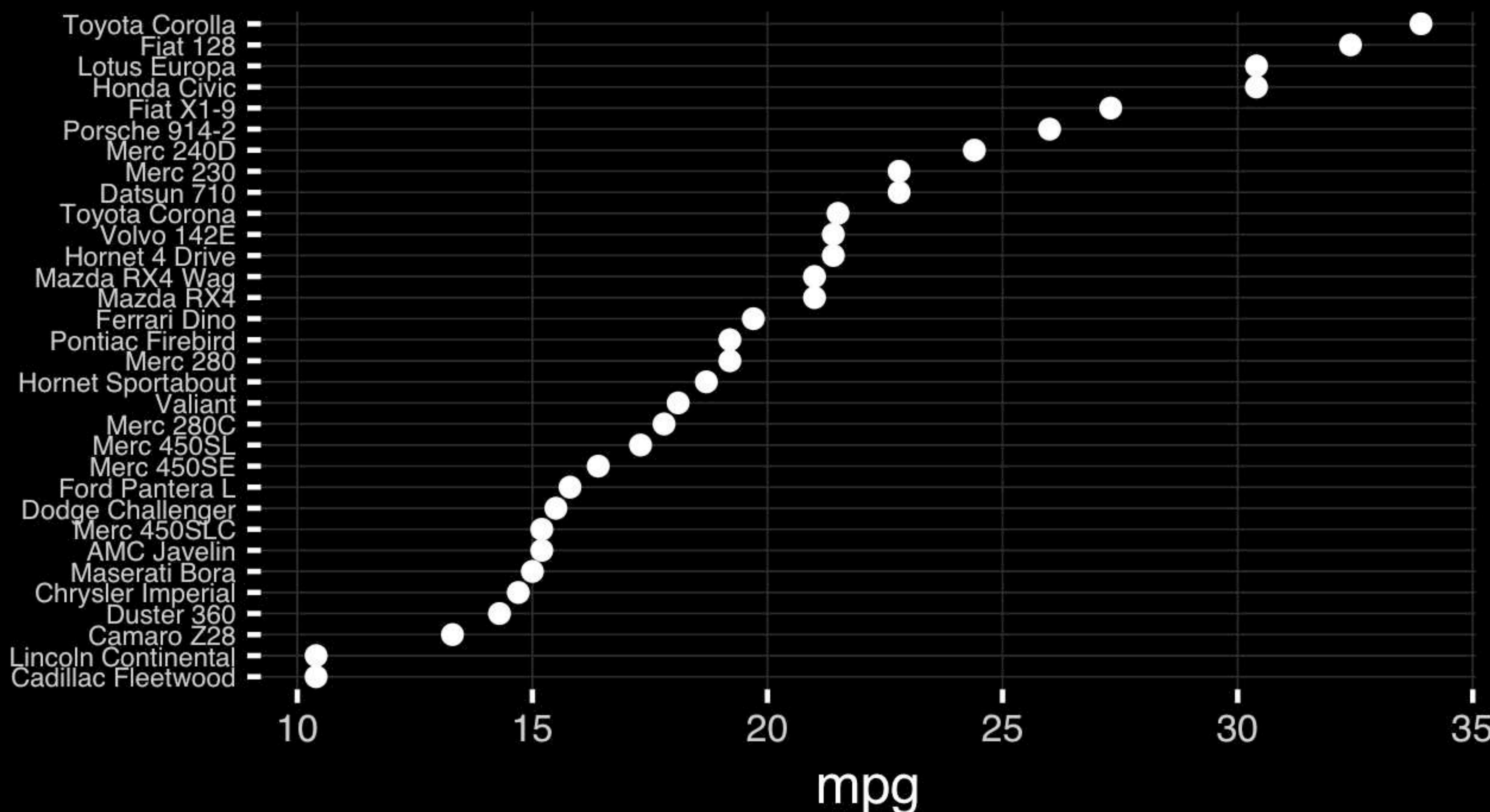
Pontiac Firebird
Merc 280
Hornet Sportabout
Valiant
Merc 280C
Merc 450SL
Merc 450SE
Ford Pantera L
Dodge Challenger
Merc 450SLC
AMC Javelin
Maserati Bora
Chrysler Imperial
Duster 360
Camaro Z28
Lincoln Continental
Cadillac Fleetwood
0
10
20
30



Toyota Corolla
Fiat 128
Lotus Europa
Honda Civic
Fiat X1-9
Porsche 914-2
Merc 240D
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Datsun 710
Toyota Corona
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Merc 450SLC
AMC Javelin
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Cadillac Fleetwood
10
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25
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35
mpg

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

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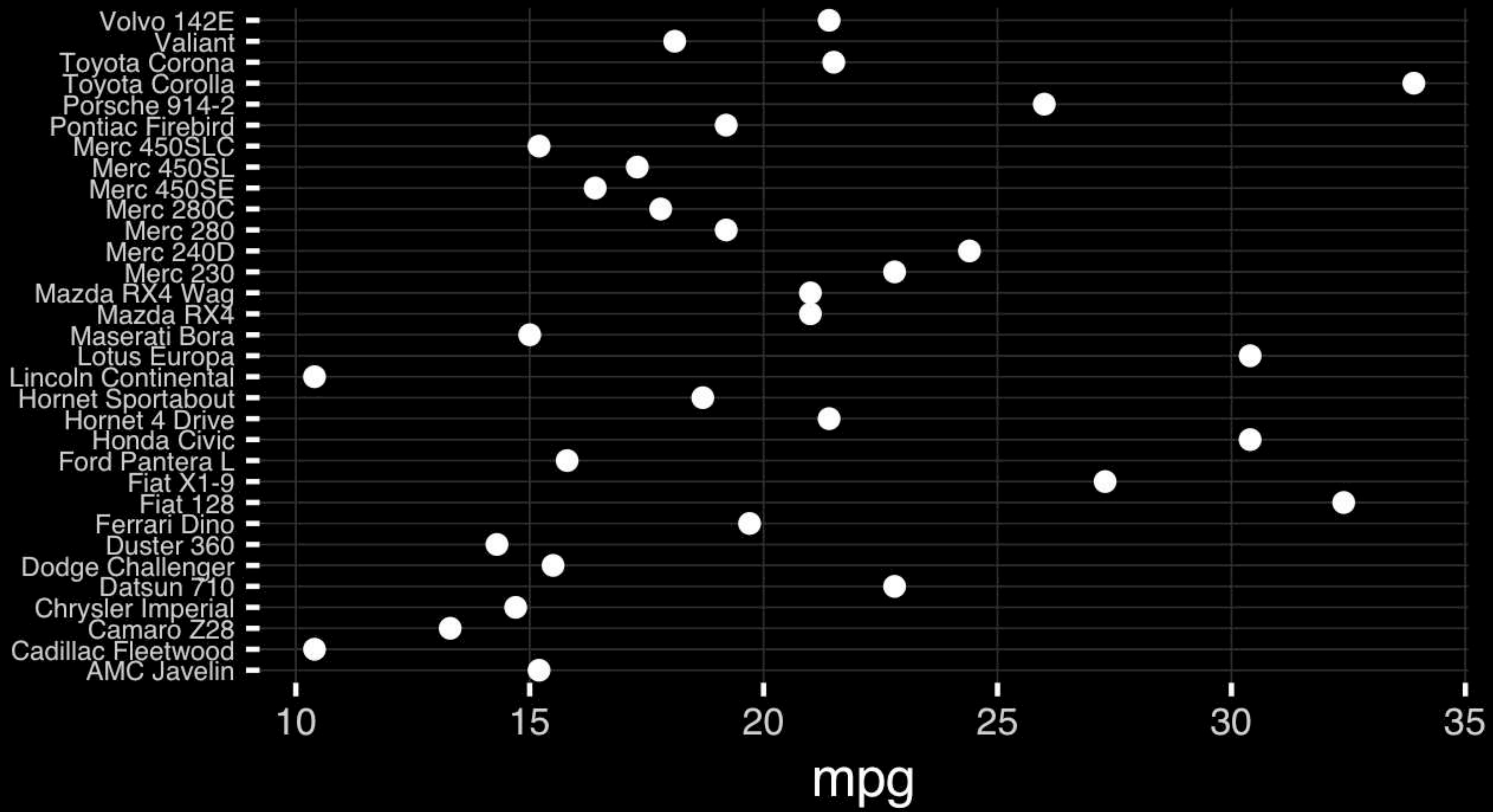

Volvo 142E
Valiant
Toyota Corona
Toyota Corolla
Porsche 914-2
Pontiac Firebird
Merc 450SLC
Merc 450SL
Merc 450SE
Merc 280C
Merc 280
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Chrysler Imperial
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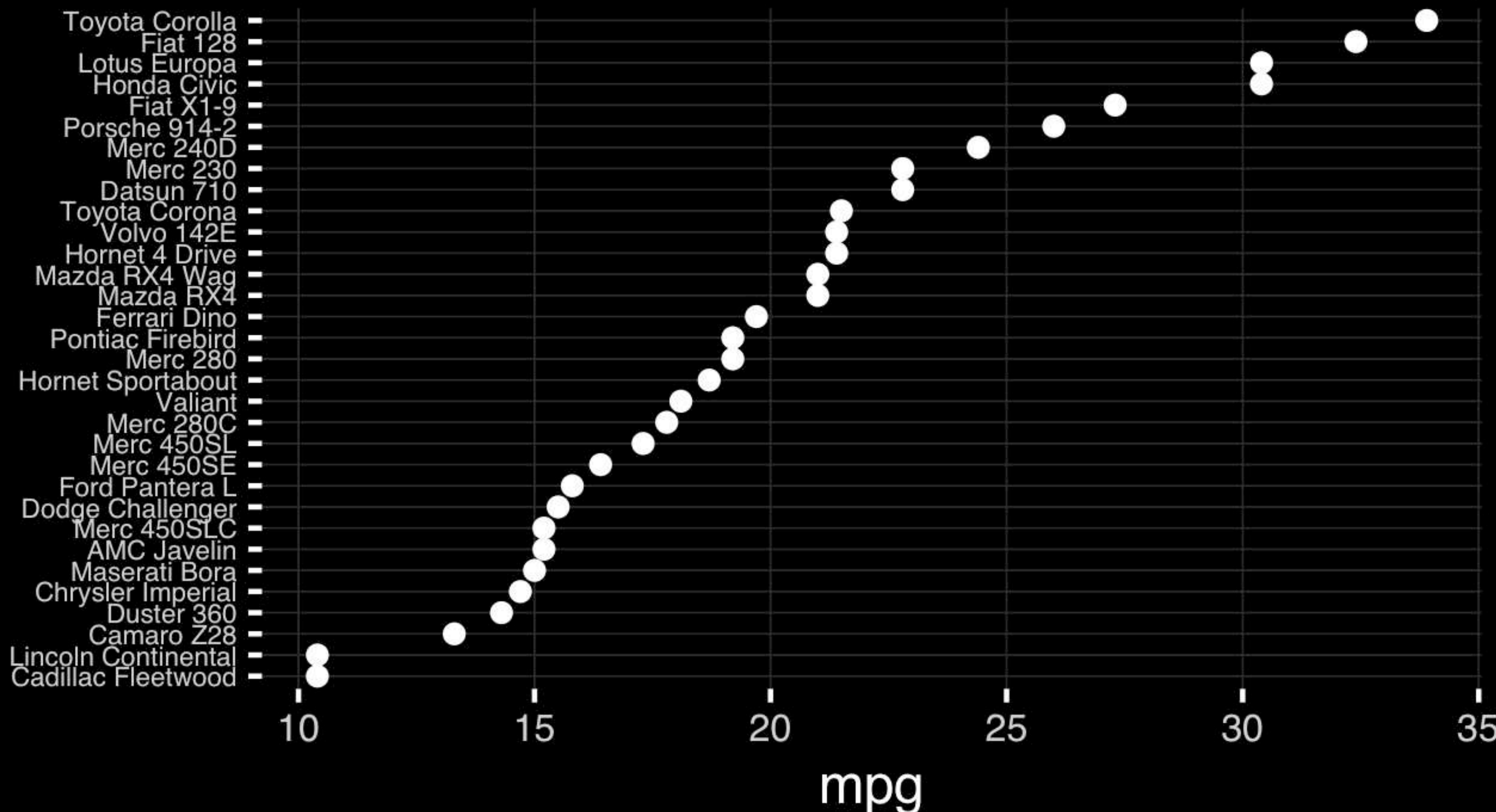
mpg


Toyota Corolla
Fiat 128
Lotus Europa
Honda Civic
Fiat X1-9
Porsche 914-2
Merc 240D
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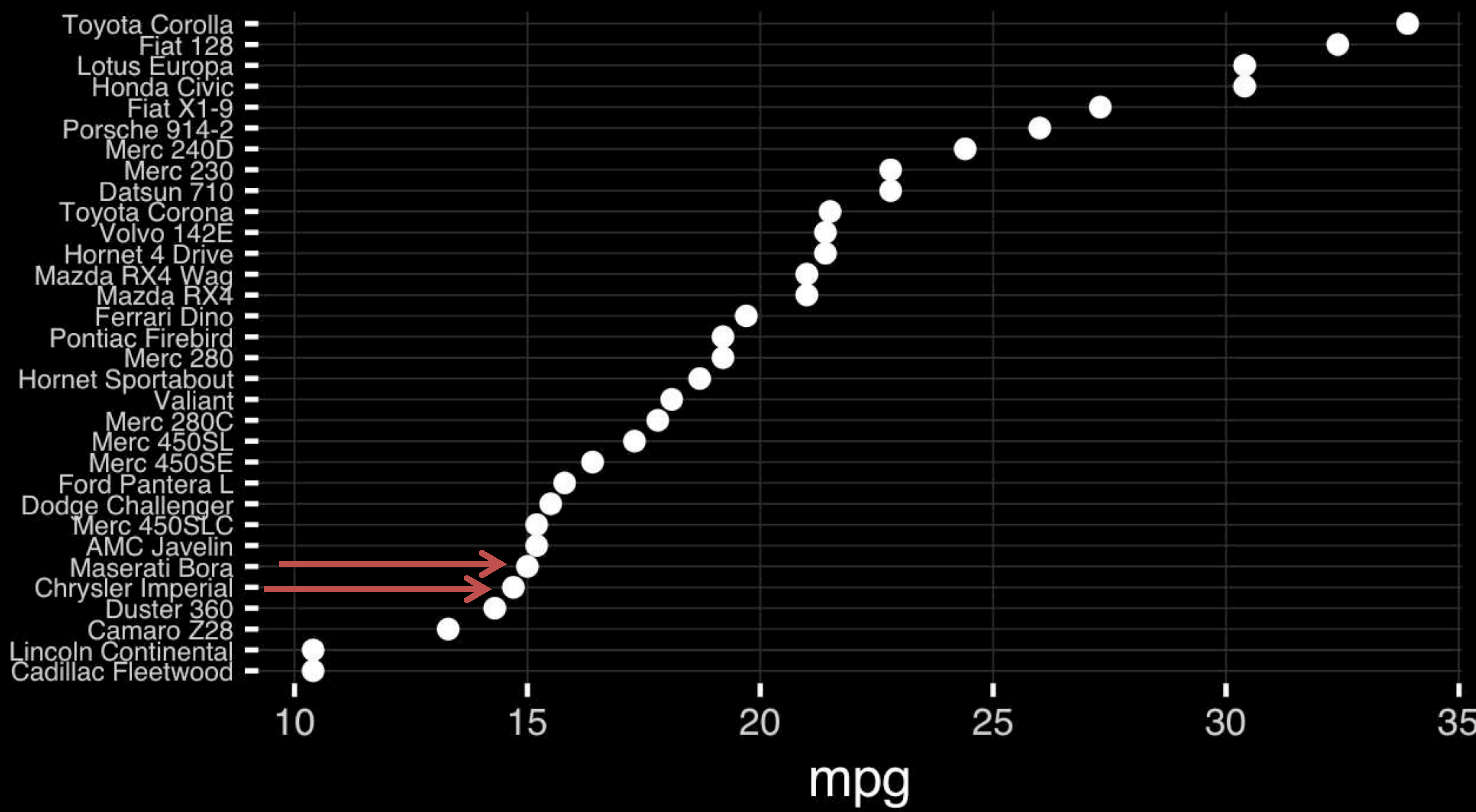

Toyota Corolla
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Porsche 914-2
Merc 240D
Merc 230
Datsun 710
Toyota Corona
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AMC Javelin
Maserati Bora
Chrysler Imperial
Duster 360
Camaro Z28
Lincoln Continental
Cadillac Fleetwood
10
15
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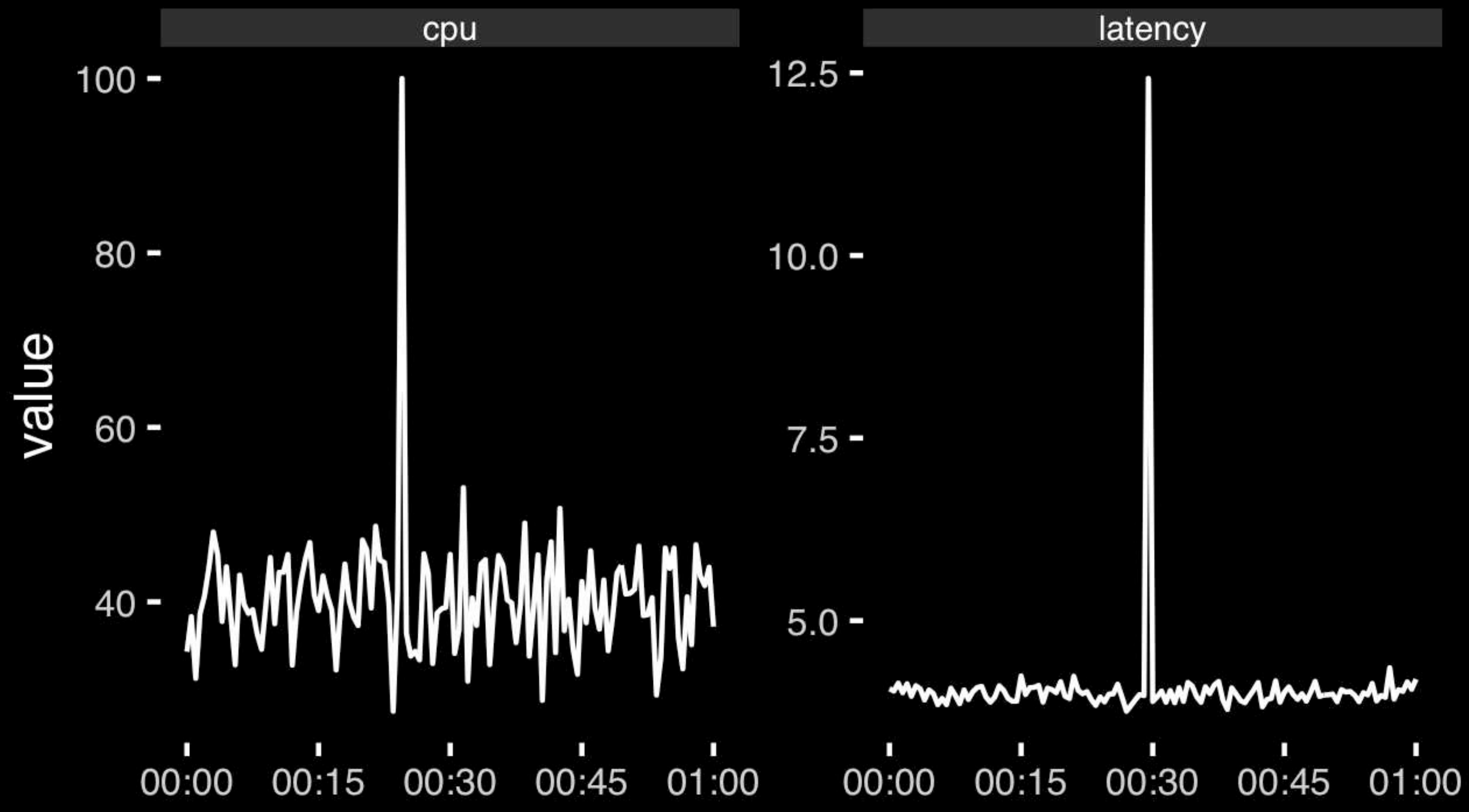
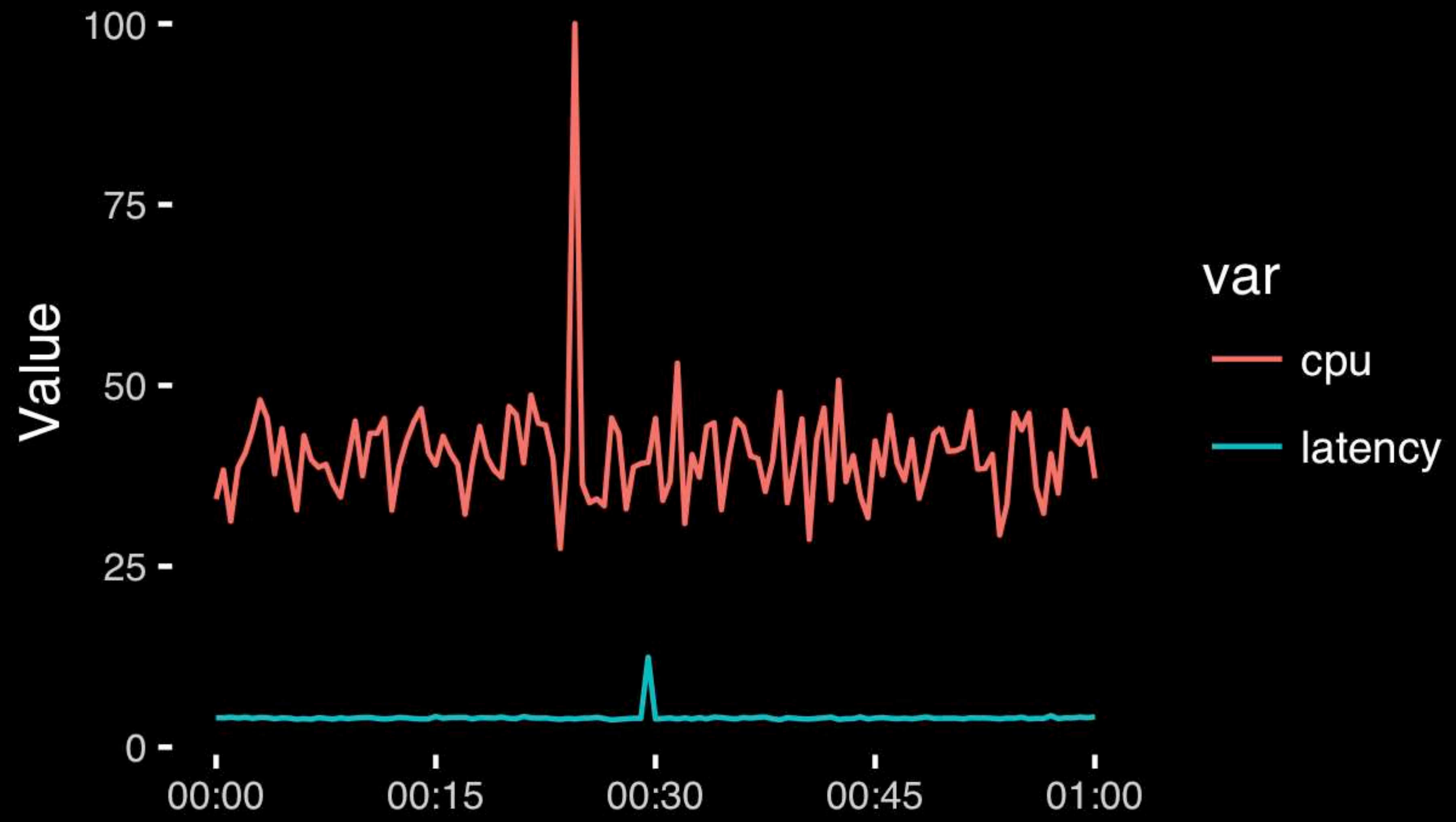
mpg

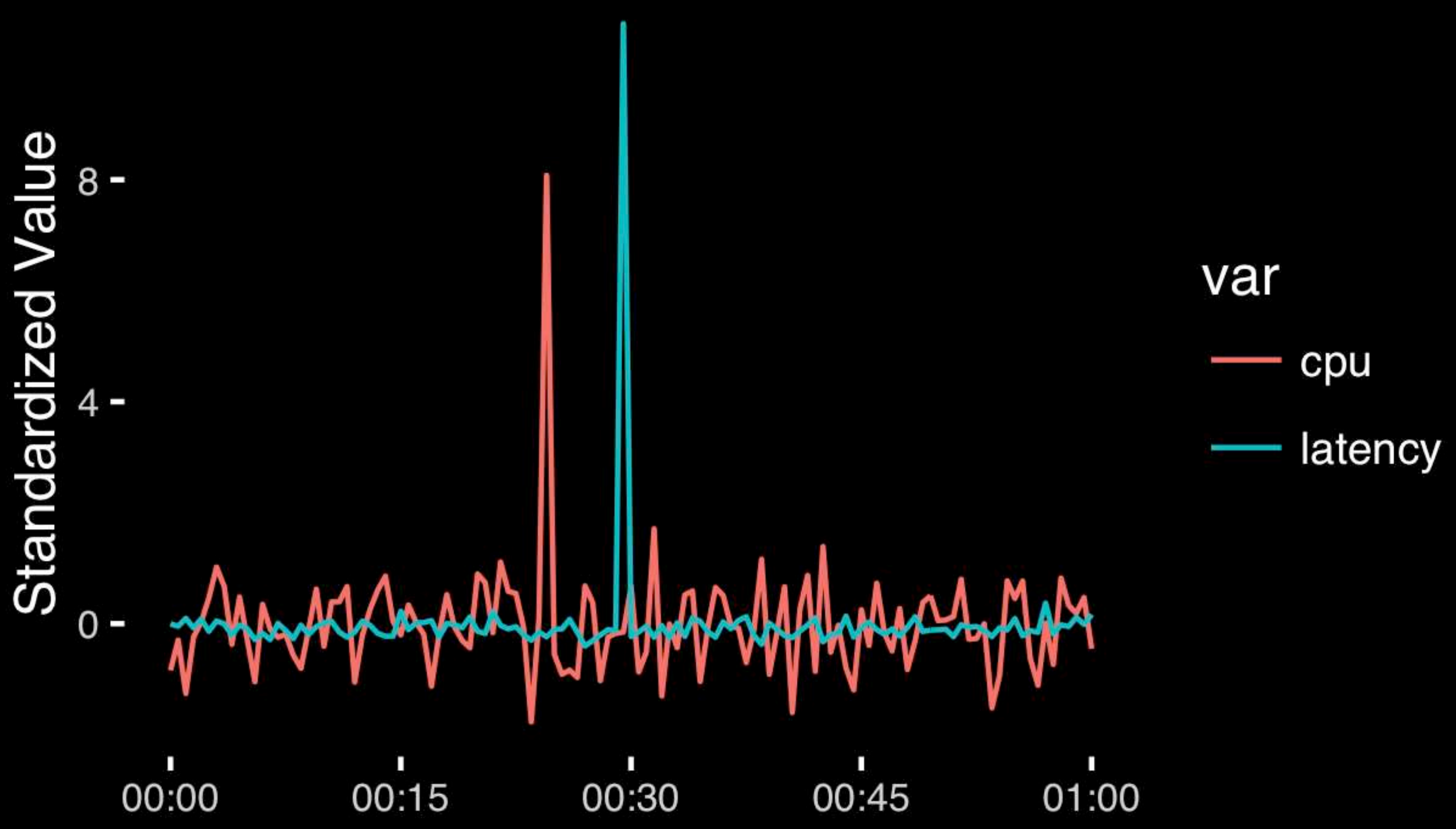
Observation: Comparison is trivial on a common scale.



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



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.

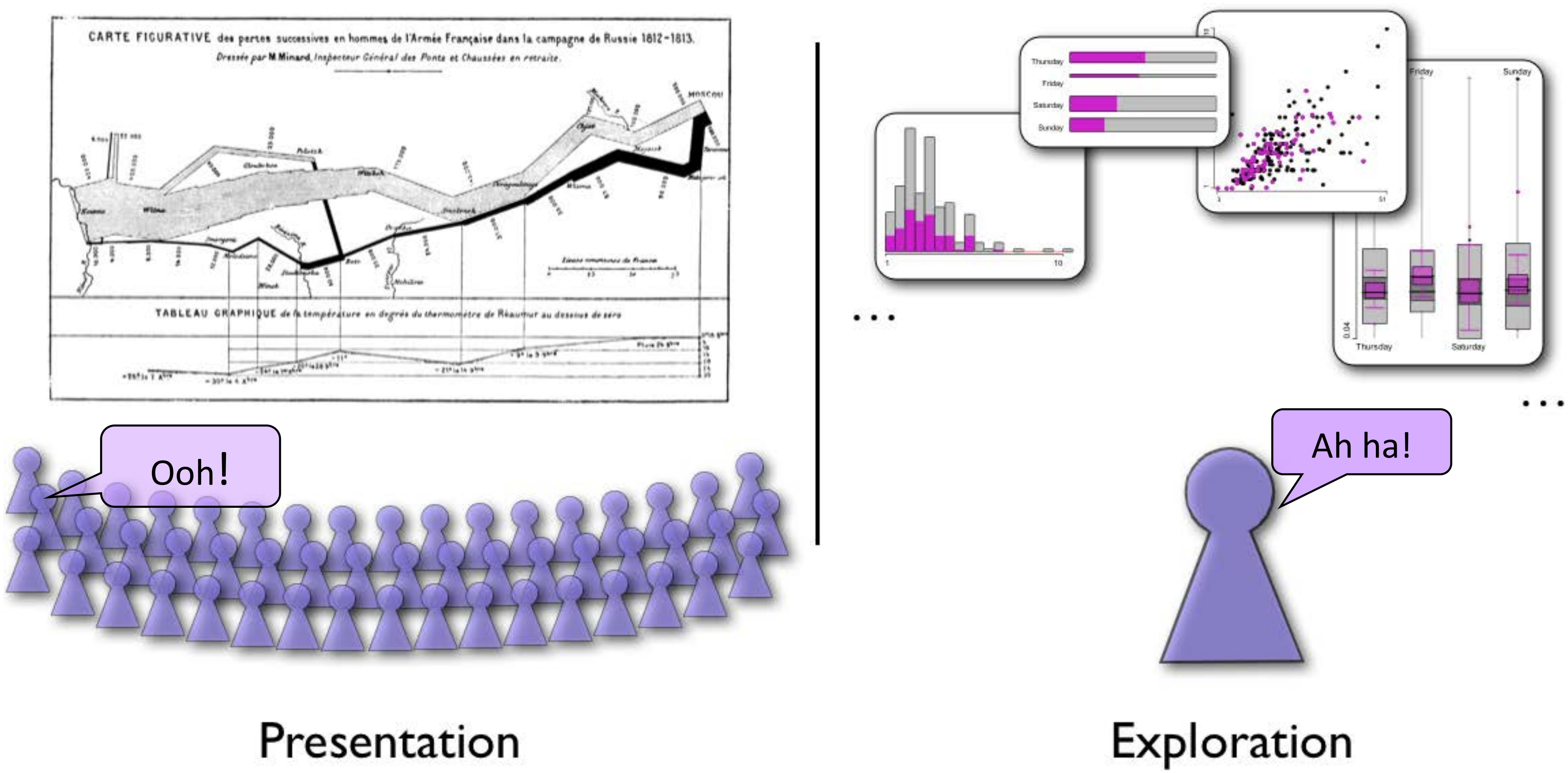
- Be conversant with **data visualization best practices** and understand how good visualizations optimize for the human visual system.

- 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



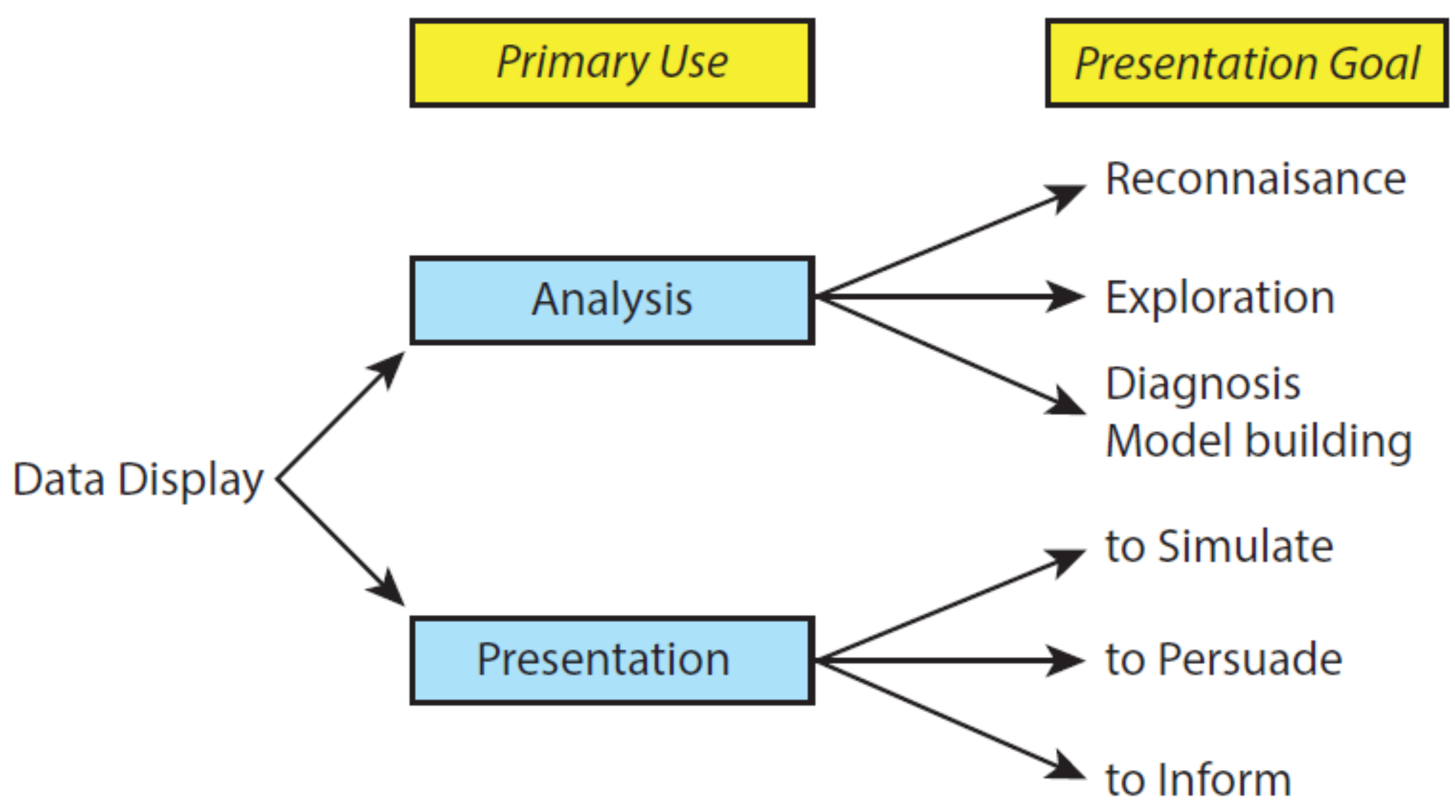
Roles of graphics in data analysis

- Graphs (& tables) are forms of communication:
  - What is the audience?
  - What is the message?

Analysis graphs: design to see patterns, trends, aid the process of data description, interpretation

Presentation graphs: design to attract attention, make a point, illustrate a conclusion

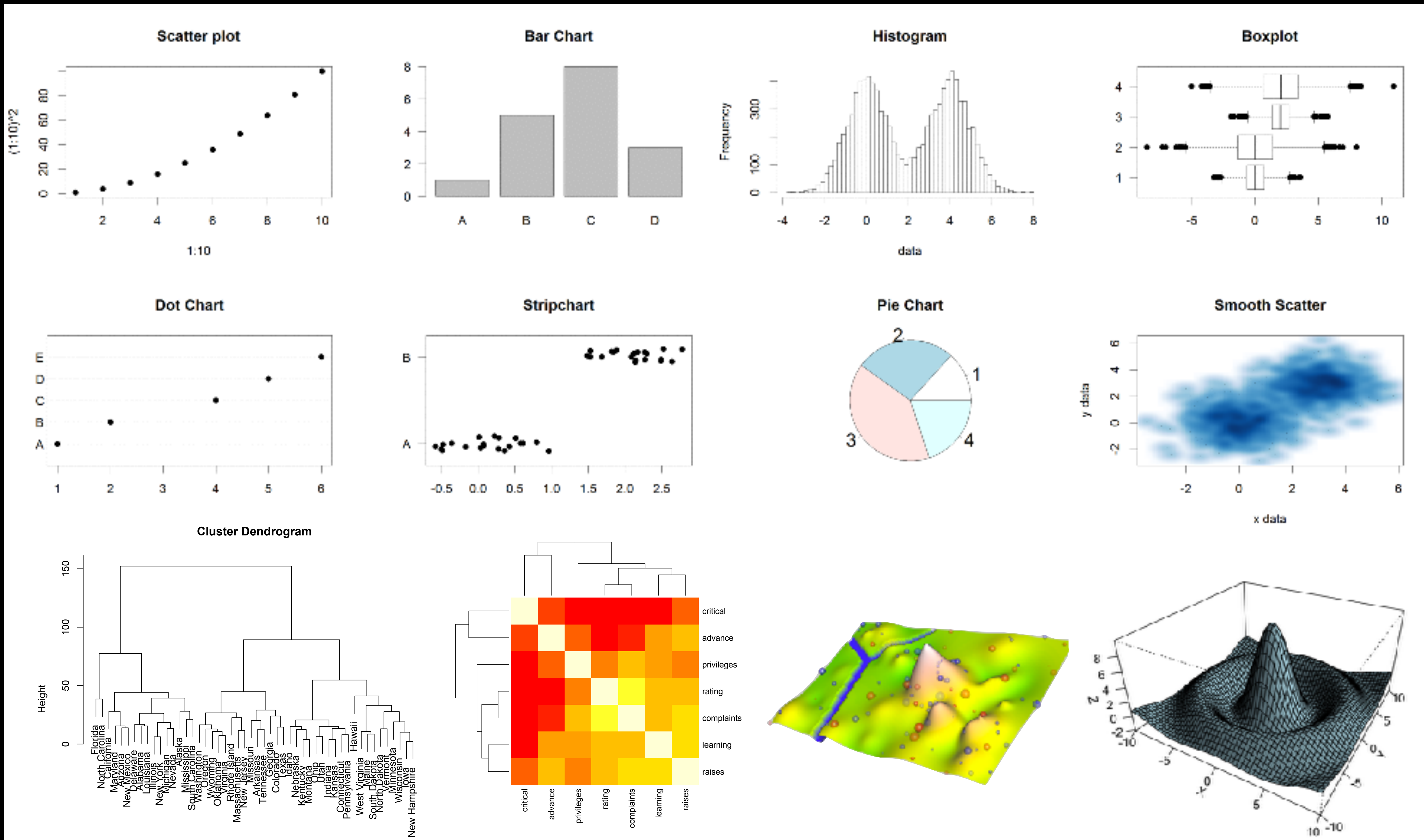
Basic functions of data display



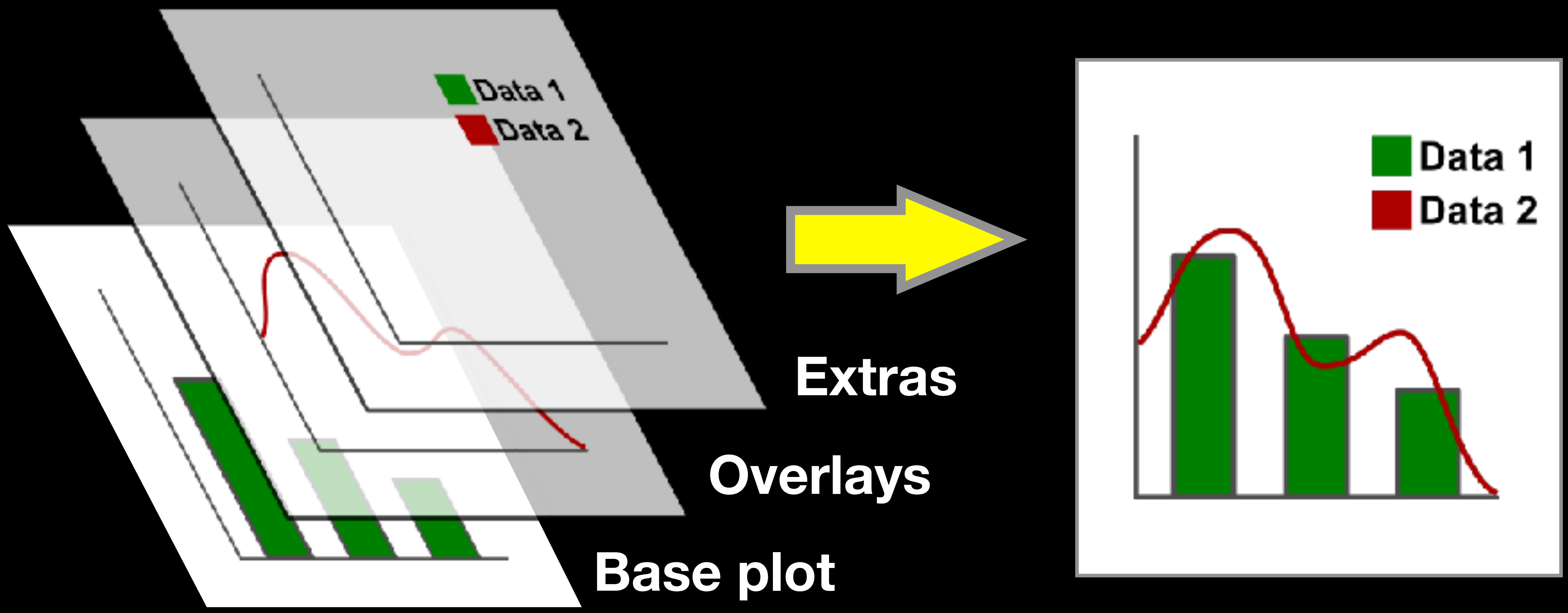
Exploratory (for you!)

Info for others, publications & sharing etc.

Core R Graph Types

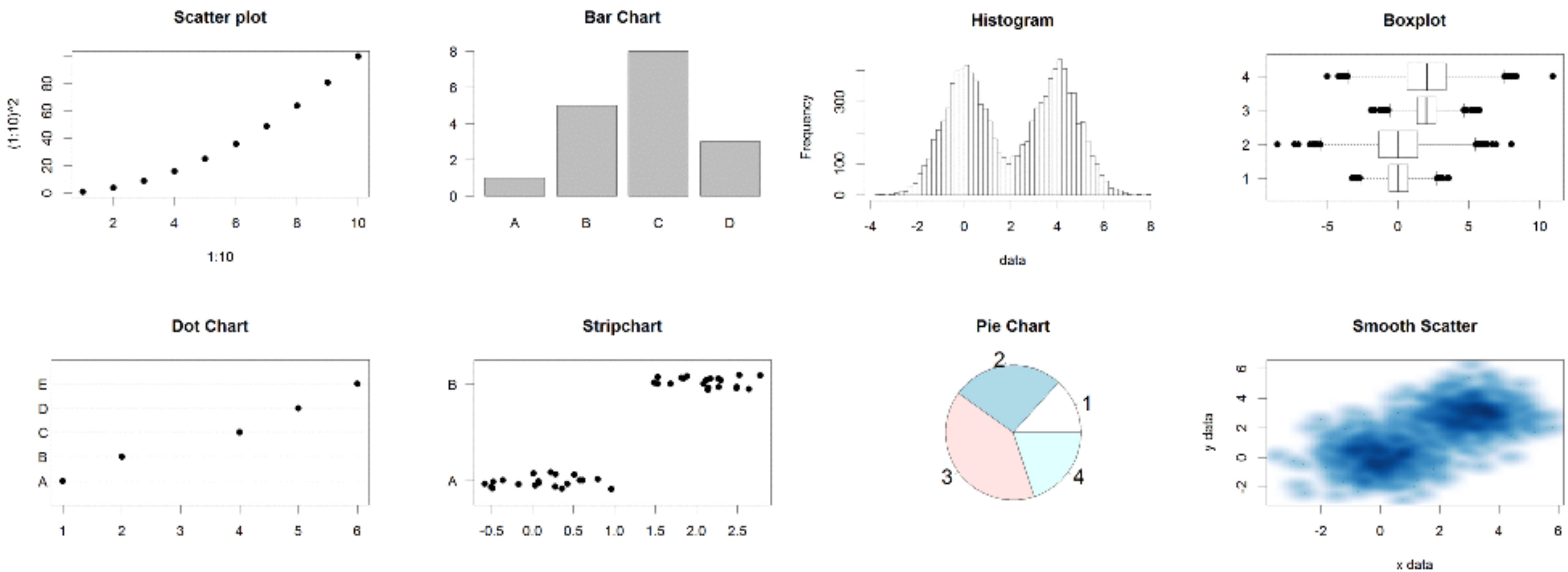


The R Painters Model



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

Core Graph Types



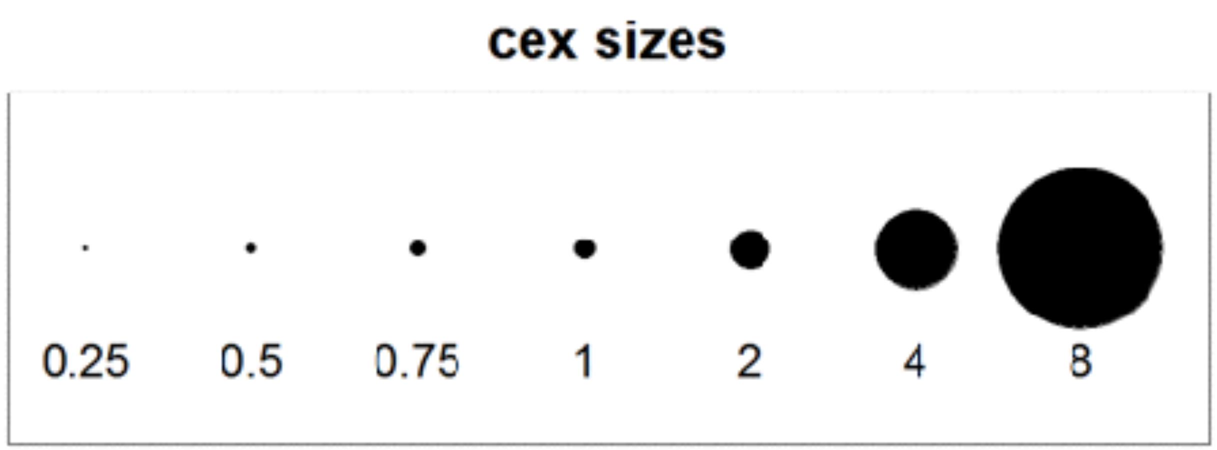
- Local options to change a specific plot
- Global options to affect all graphs

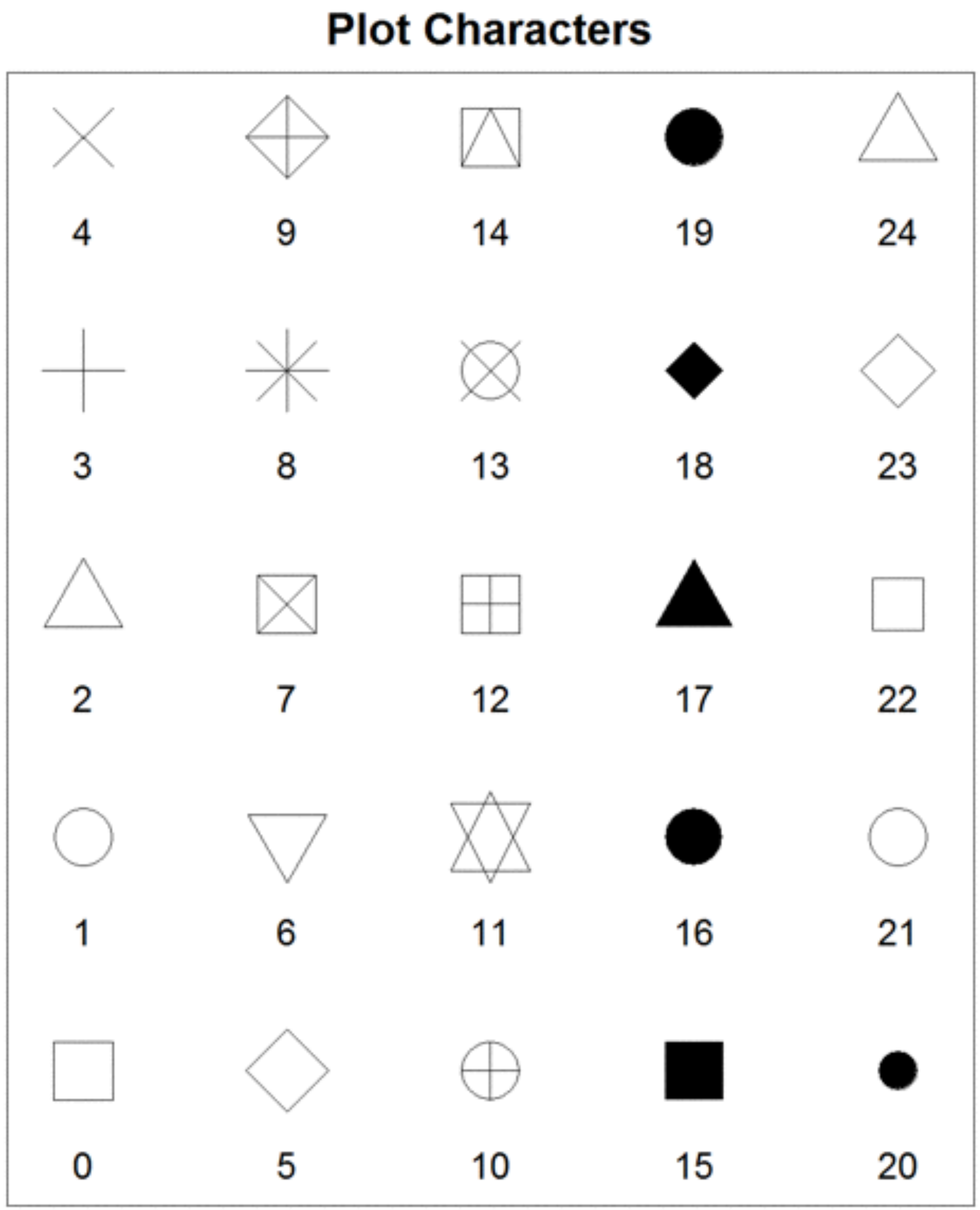
Common Options

- 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

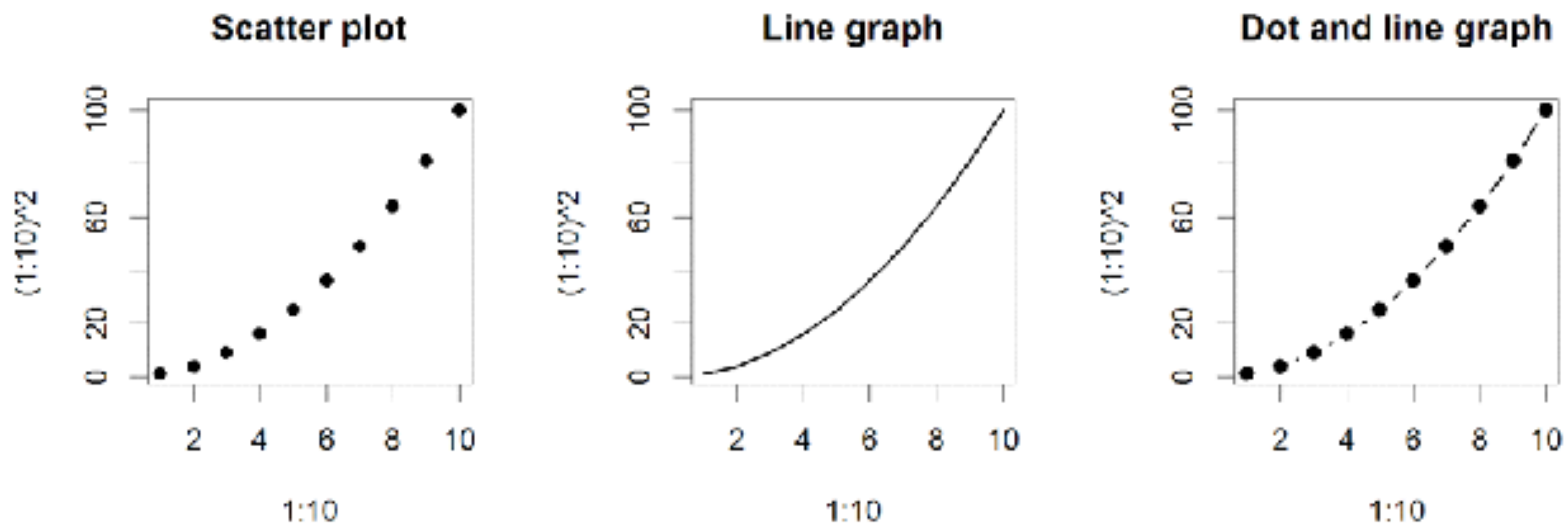




`plot( 1:5, pch=1:5, cex=1:5 )`

Plot Type Specific Options

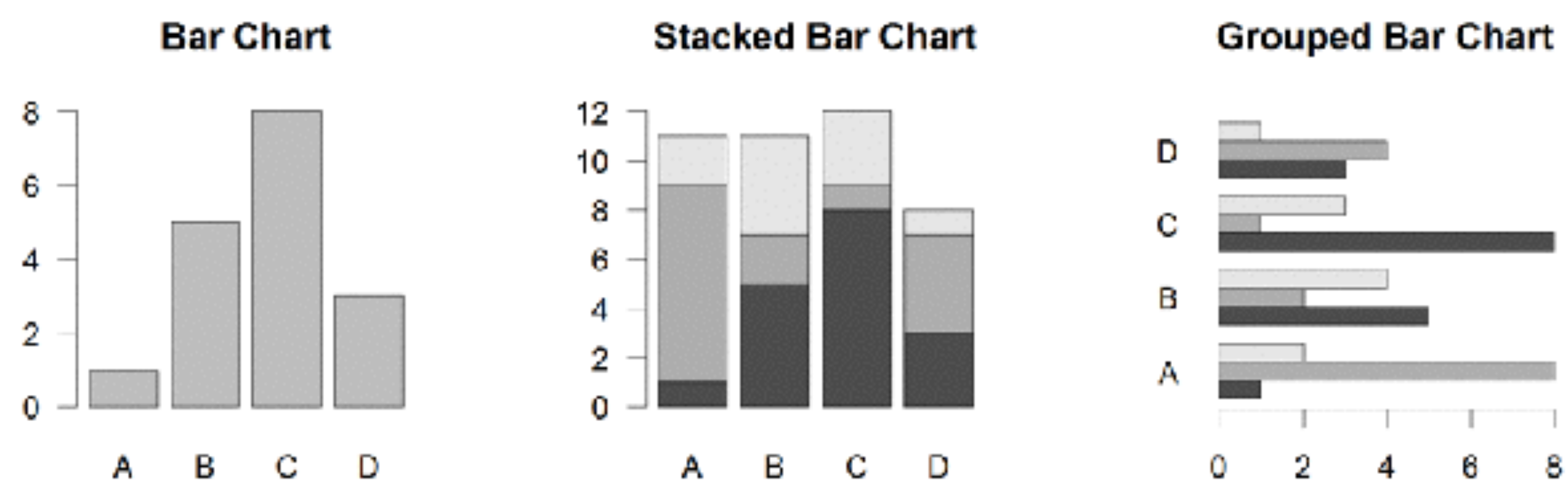
Plot (scatterplots and line graphs)



- 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 )
```

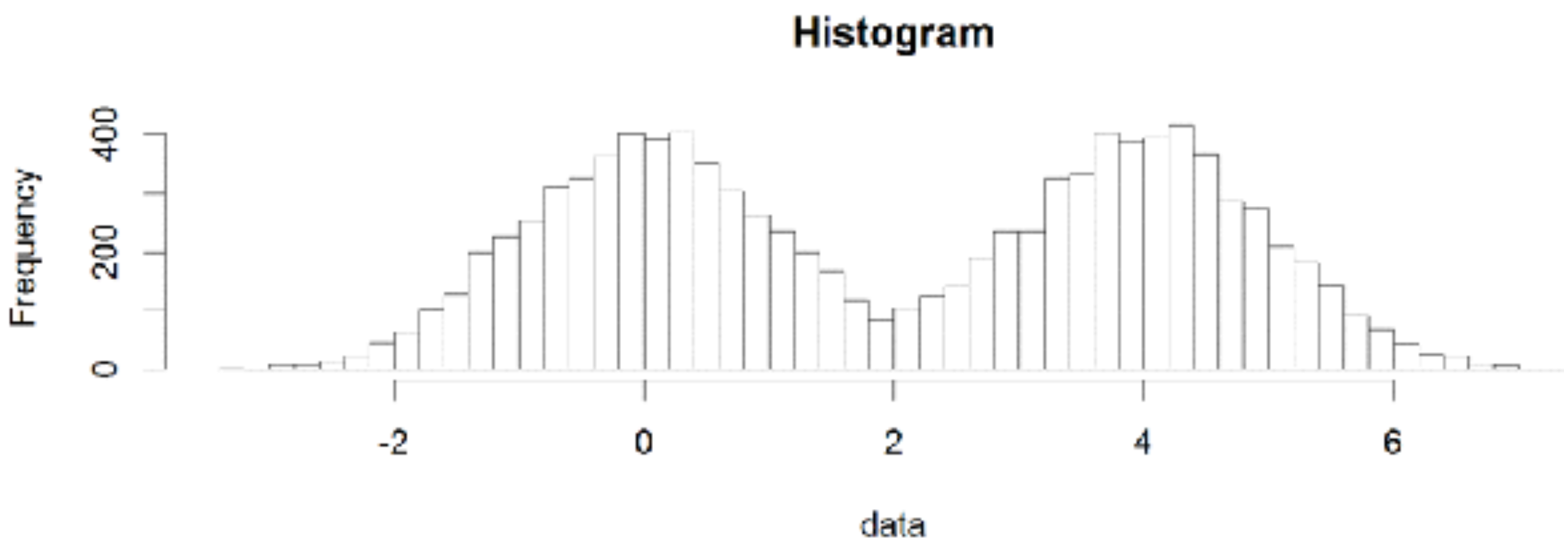
Barplot (bar graphs)



- 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)
```

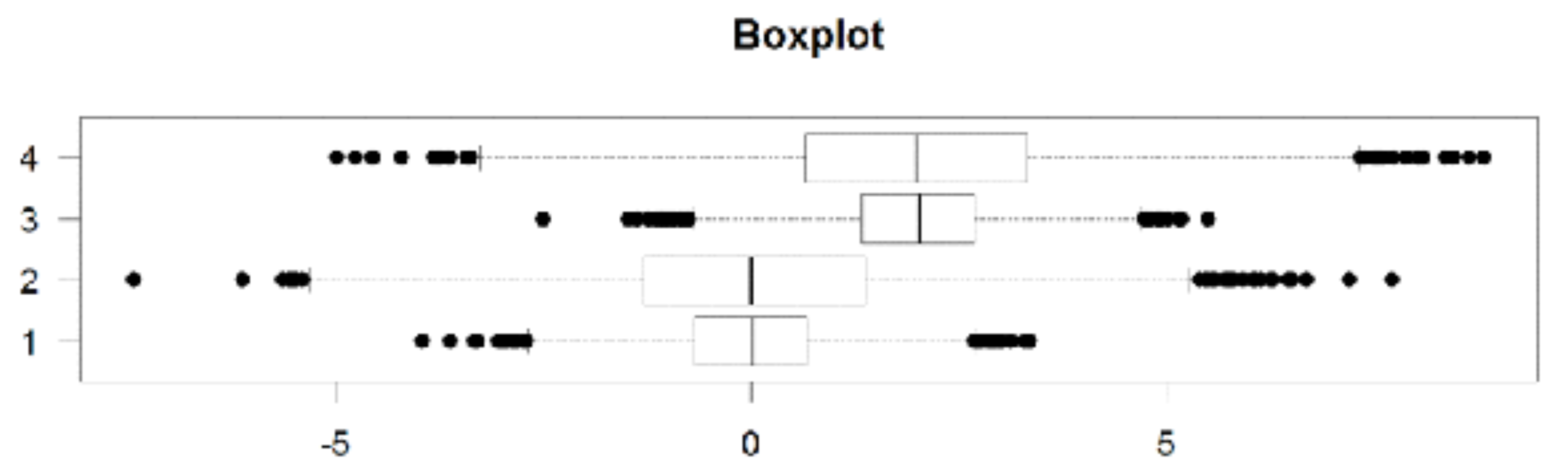
Hist (histograms)



- Input: Vector
- Output: Summary of binned data
- Options:
  - `breaks` Number or limits of bins
  - `probability` Y axis is probability, not freq
  - `labels` Per bin text labels

```
hist( c( rnorm(1000,0), rnorm(1000,4) ), breaks=20 )
```

Boxplot



- Input: Vector, List or formula (`data~factor`)
- Output: Summary of the boxplot parameters
- Options:
  - `range` Sensitivity of whiskers
  - `varwidth` Width represents total observations
  - `horizontal` Plot horizontally

```
boxplot( cbind( rnorm(1000,0), rnorm(1000,4) ) )
```

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

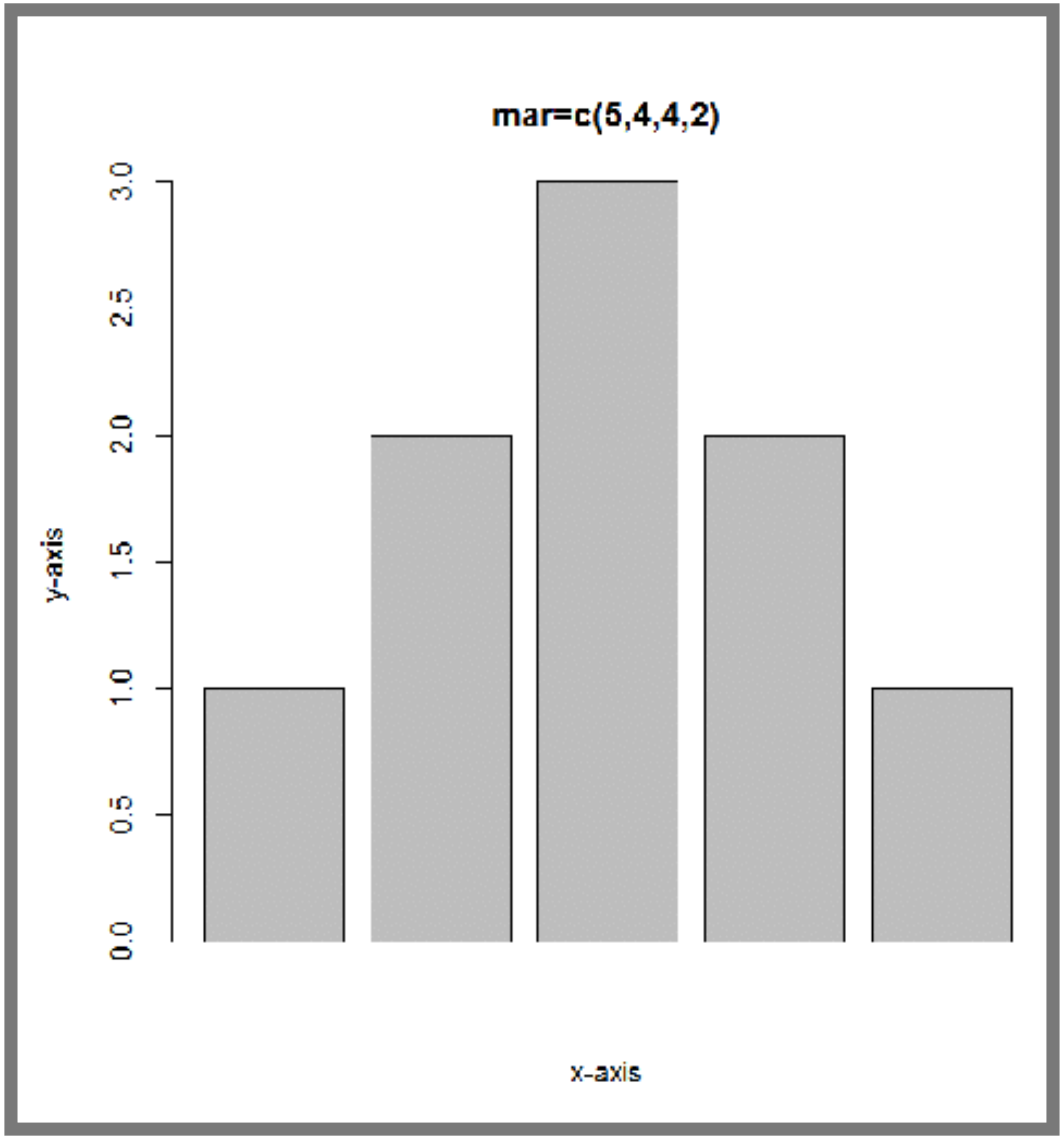
Par examples

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

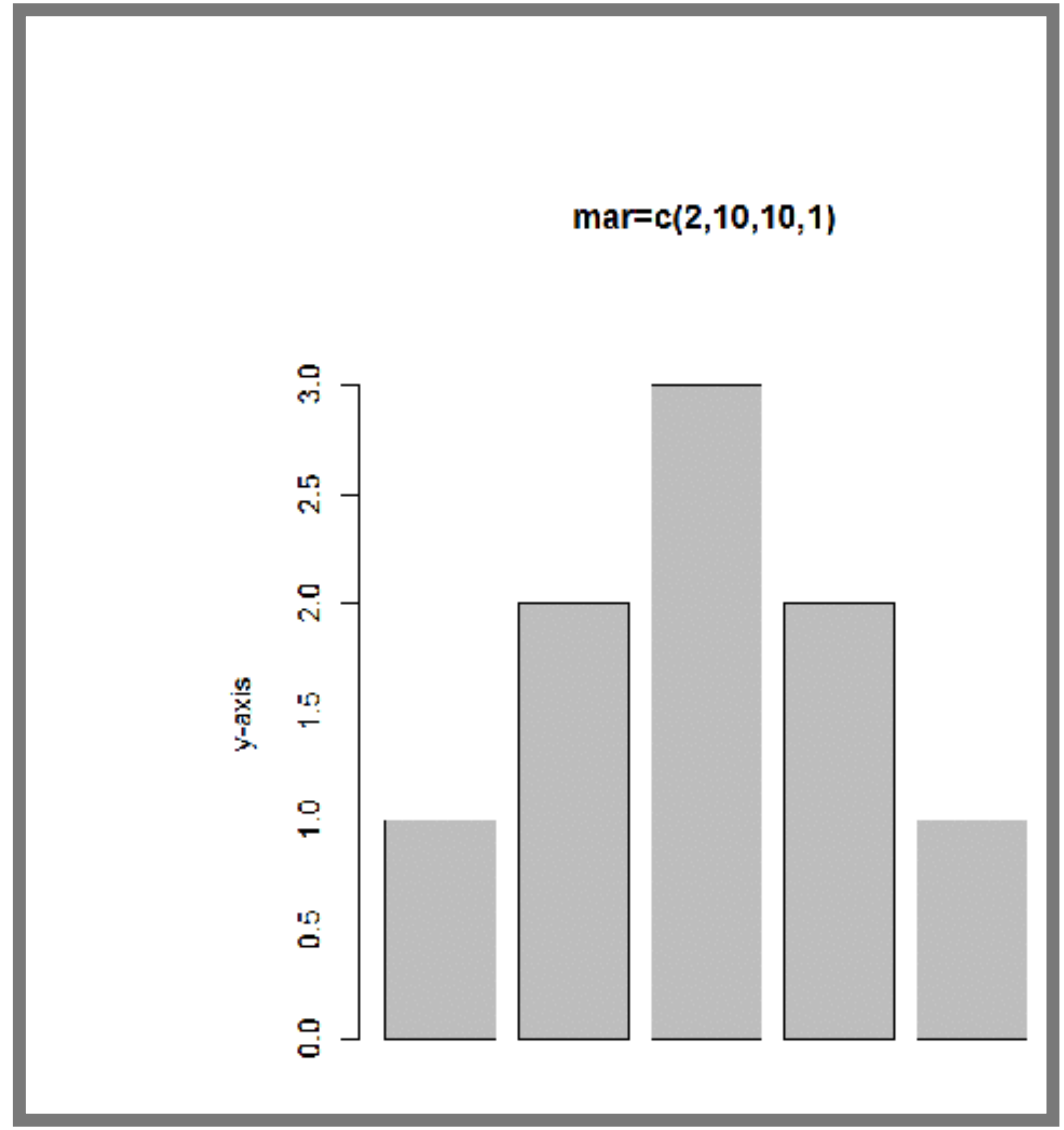
Par options

- 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) )
```



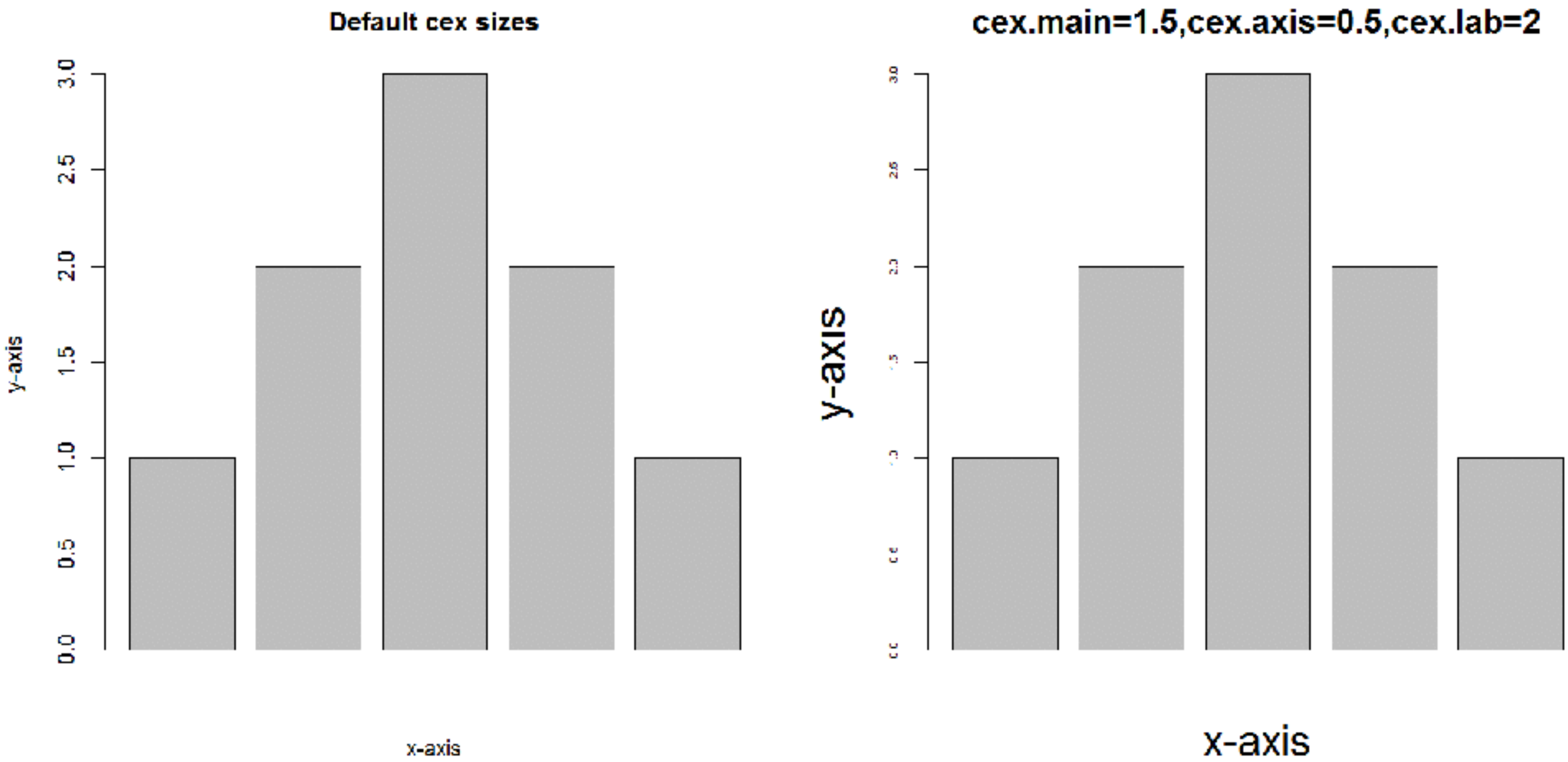
mar=c(5,4,4,2)
y-axis
0.0
0.5
1.0
1.5
2.0
2.5
3.0
x-axis



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

Par options

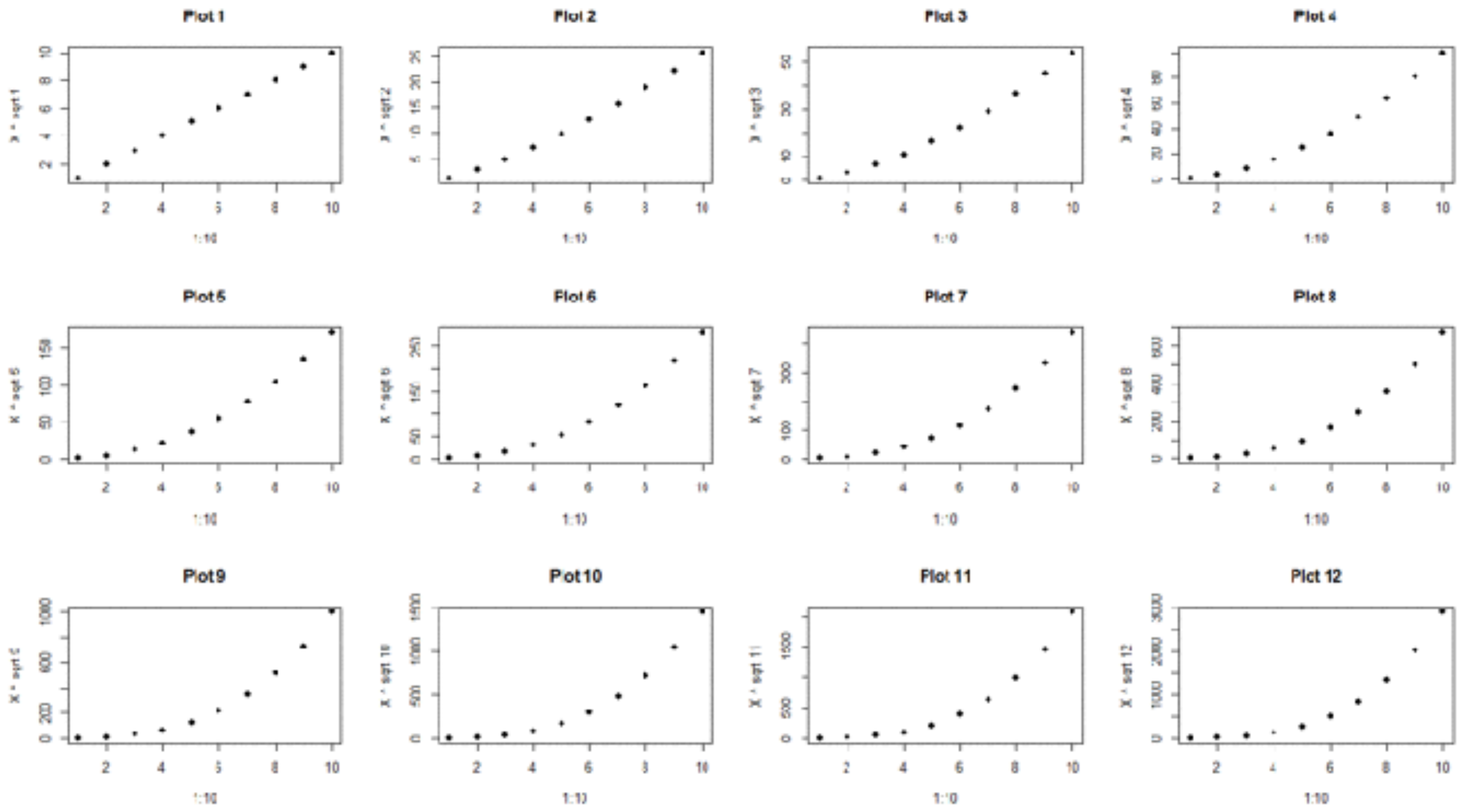
- Fonts and labels
  - `cex` - global char expansion
    - `cex.axis`
    - `cex.lab`
    - `cex.main`
    - `cex.sub`



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

Par options

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



par(mfrow(3 , 4))

Exercise 1

Using Color

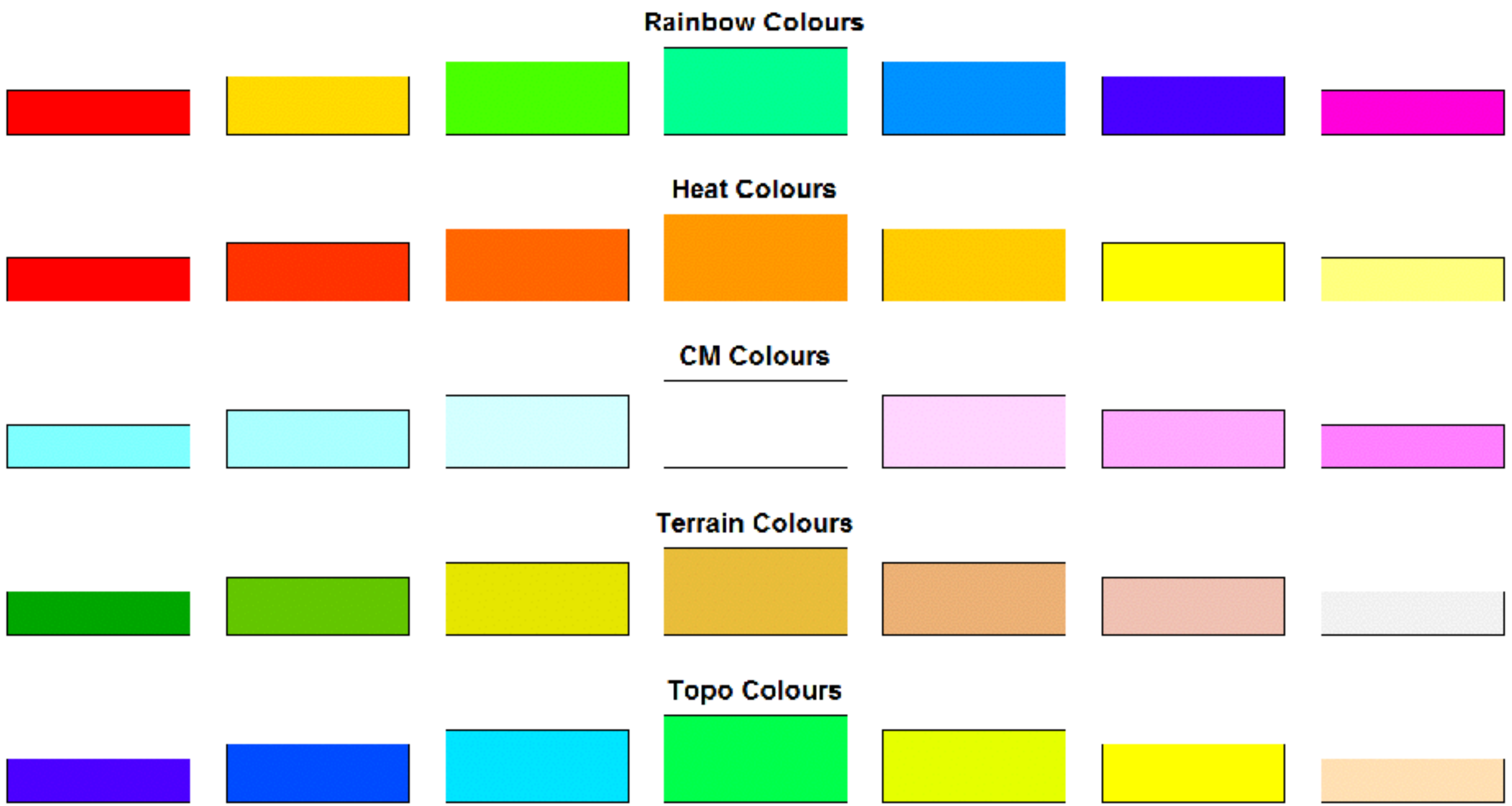
Specifying colors

- Hexadecimal strings
  - `#FF0000` (red)
  - `#0000FF` (blue)
  - `#CC00CC` (purple)
- Controlled names
  - `“red” “green”` etc.
  - `colors()`

Built in color schemes

- Functions to generate colors
- Pass in number of colors to make
- 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 **pallete** 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

- Coloring by value
  - Need function to map values to colors

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

Exercise 2

Q: 2B. stringsAsFactors = TRUE vs stringsAsFactors = FALSE

Exercise 2C Revisited

- Open your previous Lecture5 RStudio **project** (and your saved **R script**)

- Locate and open in RStudio the downloaded file color_to_value_map.r

- This is an example of a poorly written function typical of something you might get from a lab mate that knows some R…

(POOR!) Color Mapping Function

```
map.colors <- function (value,high.low,palette) {
  proportion <- ((value-high.low[1])/(high.low[2]-high.low[1]))
  index <- round ((length(palette)-1)*proportion)+1
  return (palette[index])
}
```

Talking point:

- Can you figure out what this function it is supposed to do?
- What format should the inputs be in order to work?
- How could we improve this function?

1. What are the function inputs?

```
map.colors2 <- function(x, high.low, palette) {

  proportion <- ((x - high.low[1])/(high.low[2] - high.low[1]))

  index <- round( (length(palette)-1) * proportion )+1

  return(palette[index])
}
```

Let’s first space things out so it is easier for us to read and then change to use **x** as our numeric input vector.

1. What are the function inputs?

```
map.colors2 <- function(x, high.low, palette) {

  proportion <- ((x - high.low[1])/(high.low[2] - high.low[1]))

  index <- round( (length(palette)-1) * proportion )+1

  return(palette[index])
}
```

Let's first space things out so it is easier for us to read and then change to use **x** as our numeric input vector.

We can guess that `high.low` is a two element numeric vector and `palette` is probably a vector of colors

2. What is the function doing?

```
map.colors2 <- function(x, high.low, palette) {

  # Determine precent values of the 'high.low' range
  proportion <- ((x - high.low[1])/(high.low[2] - high.low[1]))

  index <- round( (length(palette)-1) * proportion )+1

  return(palette[index])
}
```

Let’s add a comment to explain the logic of the first line

2. What is the function doing?

```
map.colors2 <- function(x, high.low, palette) {

  # Determine precent values of the 'high.low' range
  precent <- ((x - high.low[1])/(high.low[2] - high.low[1]))

  index <- round( (length(palette)-1) * precent )+1

  return(palette[index])
}
```

Let's change the object name from `proportion` to **`precent`** so it is more meaningful for us. Remember to change it everywhere ;-)

2. What is the function doing?

```
map.colors2 <- function(x, high.low, palette) {

  # Determine precent values of the 'high.low' range
  precent <- ((x - high.low[1])/(high.low[2] - high.low[1]))

  #index <- round( (length(palette)-1) * precent )+1
  index <- round( length(palette) * precent )

  return(palette[index])
}
```

Perhaps we can simplify the next line, which determines the corresponding index position in the color '`palette`' vector?

2. What is the function doing?

```
map.colors2 <- function(x, high.low, palette) {

  # Determine precent values of the 'high.low' range
  precent <- ((x - high.low[1])/(high.low[2] - high.low[1]))

  #index <- round( (length(palette)-1) * precent )+1
  index <- round( length(palette) * precent )

  return(palette[index])
}
```

Doh! What happens if our `precent` value is zero or very small?

We will get an **`index`** value of zero, will cause a problem when accessing `palette[`**`index`**`]` in the last line

2. What is the function doing?

```
map.colors2 <- function(x, high.low, palette) {

  # Determine precent values of the 'high.low' range
  precent <- ((x - high.low[1])/(high.low[2] - high.low[1]))

  # Find corresponding index position in the color 'palette'
  #   note catch for 0 precent values to 1
  index <- round( (length(palette)-1) * precent )+1

  return(palette[index])
}
```

Add a comment again to describe the logic of what our code is doing

3. How could we improve this function?

```
map.colors2 <- function(x, high.low, palette) {

  ## Description: Map the values of the input vector 'x'
  ##  to the input colors vector 'palette'

  # Determine precent values of the 'high.low' range
  precent <- ((x - high.low[1])/(high.low[2] - high.low[1]))

  # Find corresponding index position in the color 'palette'
  #   note catch for 0 precent values to 1
  index <- round( (length(palette)-1) * precent )+1

  return(palette[index])
}
```

Make more user friendly in lots of ways including adding **more description**, input argument defaults, error checking of inputs etc.

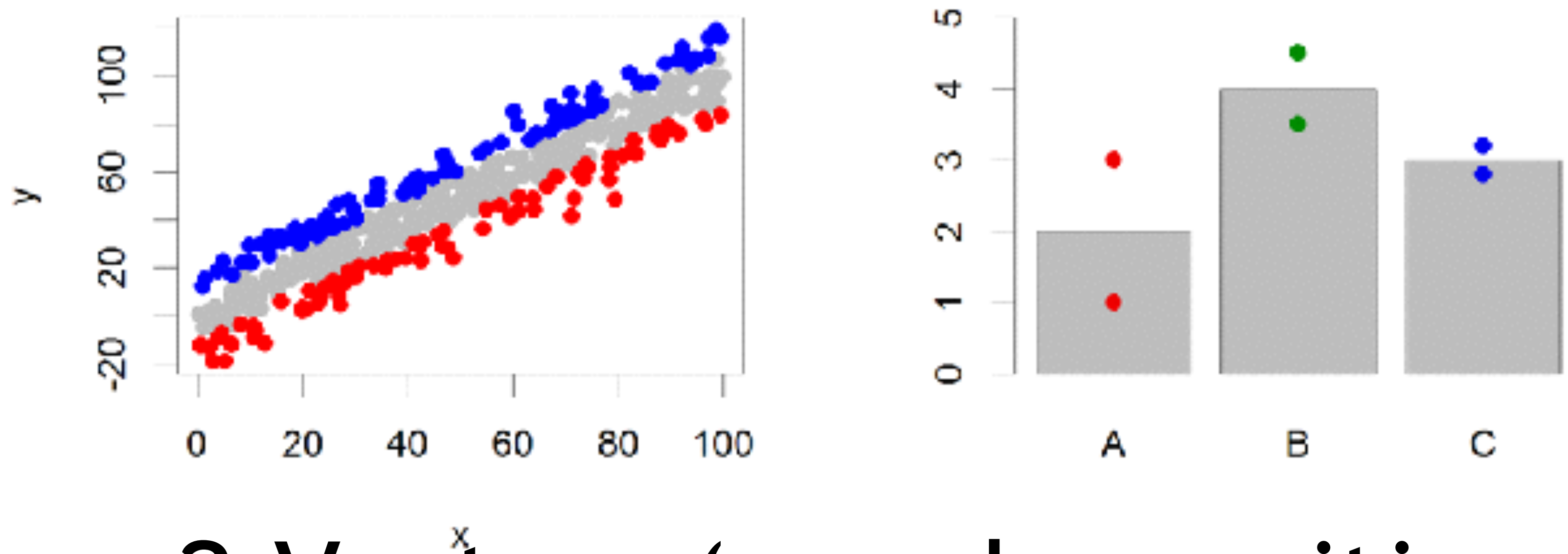
3. How could we improve this function?

```
map.colors3 <- function(x,
                        low.high = range(x),
                        palette  = cm.colors(100)) {

  ## Description: Map the values of the input vector 'x'
  ##  to the input colors vector 'palette'

  # Determine precent values of the 'high.low' range
  precent <- ((x - low.high[2])/(low.high[1] - low.high[2]))

  # Find corresponding index position in the color 'palette'
  #   note catch for 0 precent values to 1
  index <- round( (length(palette)-1) * precent )+1

  return(palette[index])
}
```

Make more user friendly in lots of ways including adding more description, input argument defaults, error checking of inputs etc.

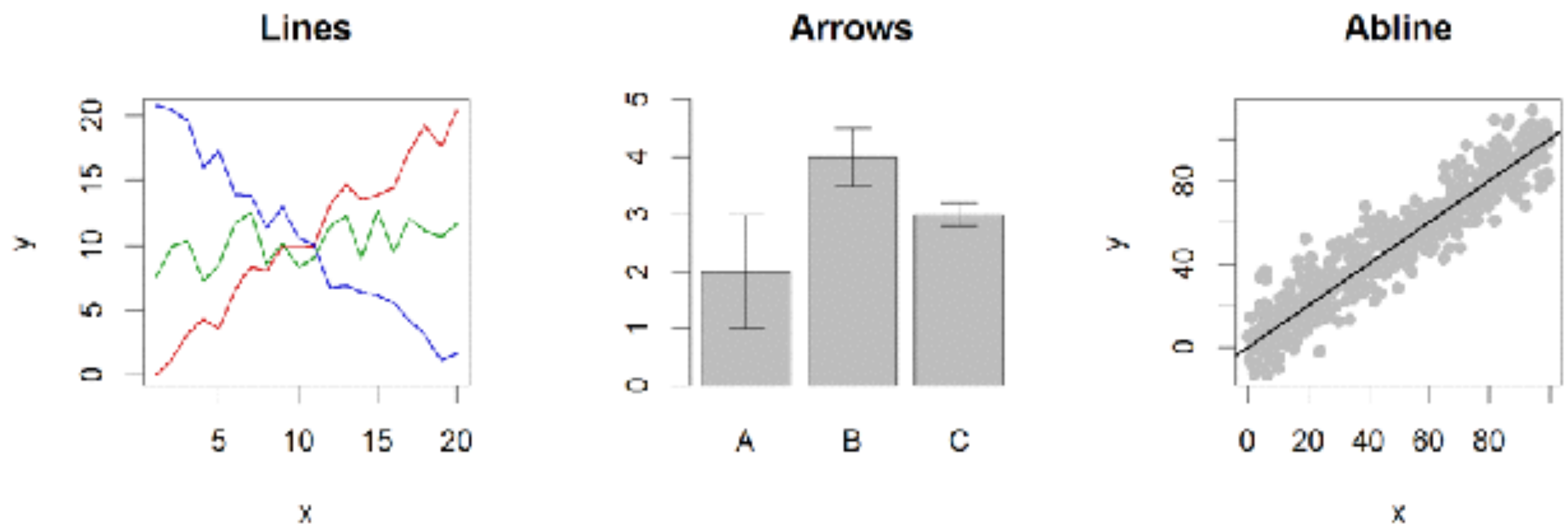
Plot Overlays
Exercise 3

Points



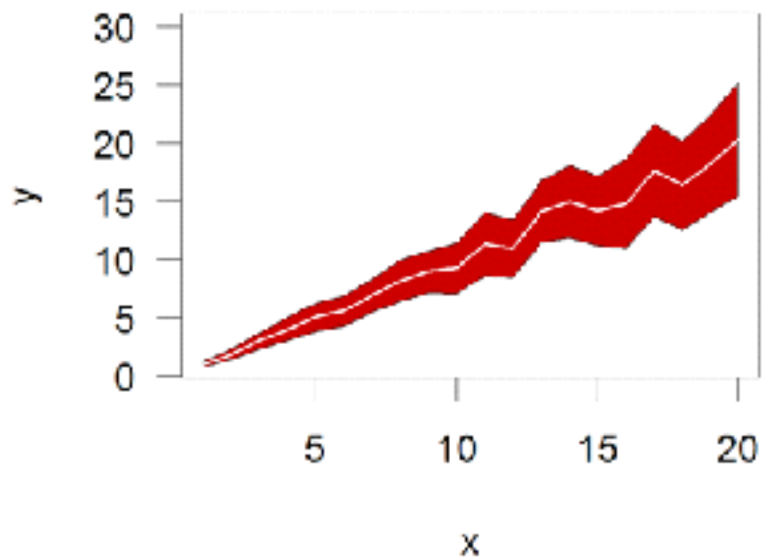
- Input: 2 Vectors (x and y positions)
- Options:
  - `pch`
  - `cex`

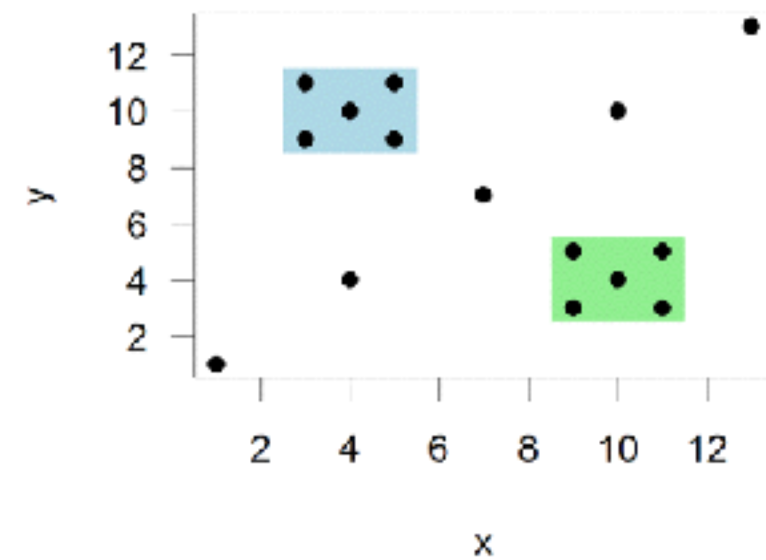
Lines / Arrows / Abline



- Input:
  - Lines 2 vectors (x and y)
  - Arrows 4 vectors (x0,x1,y0,y1)
  - Abline Intercept and slope (or correlation object)
- Options:
  - `lwd`
  - `angle` (arrows)

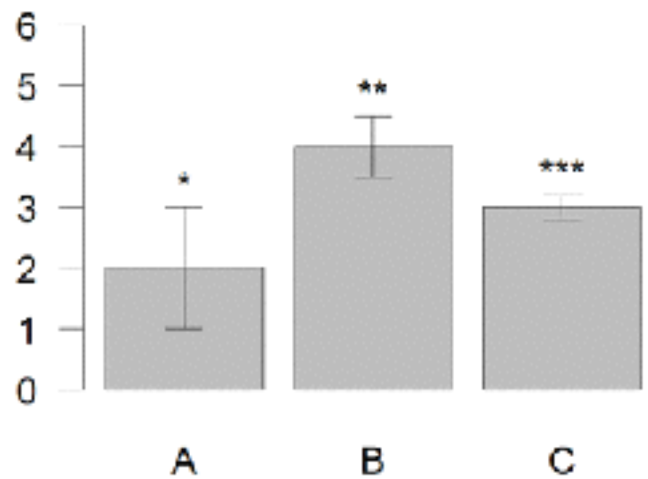
Polygon (shaded areas)

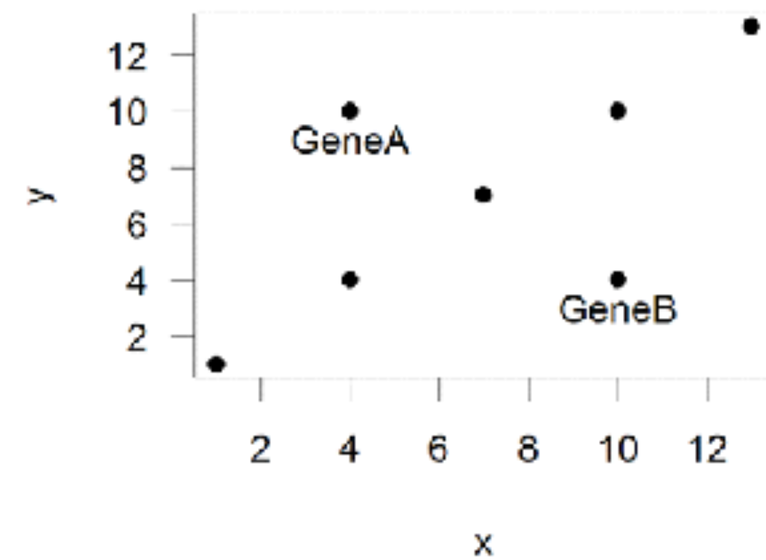




- Input:
  - 2 vectors (x and y) for bounding region
- Options:
  - `col`

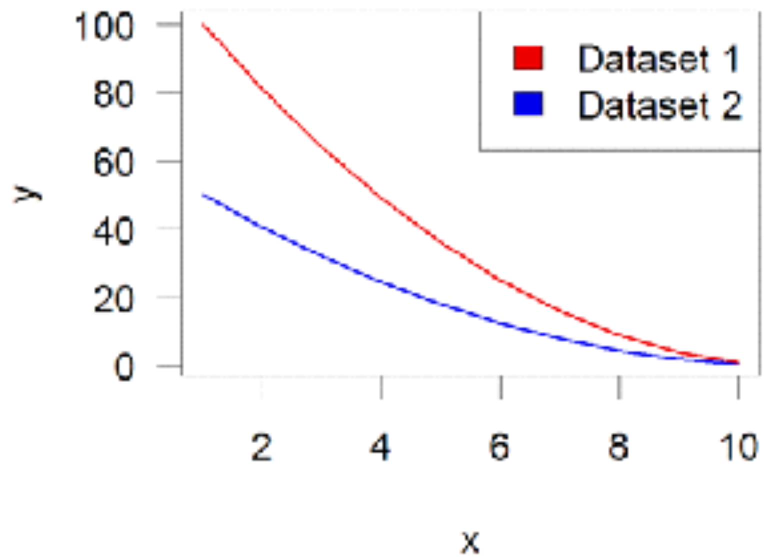
Text (in plot text)

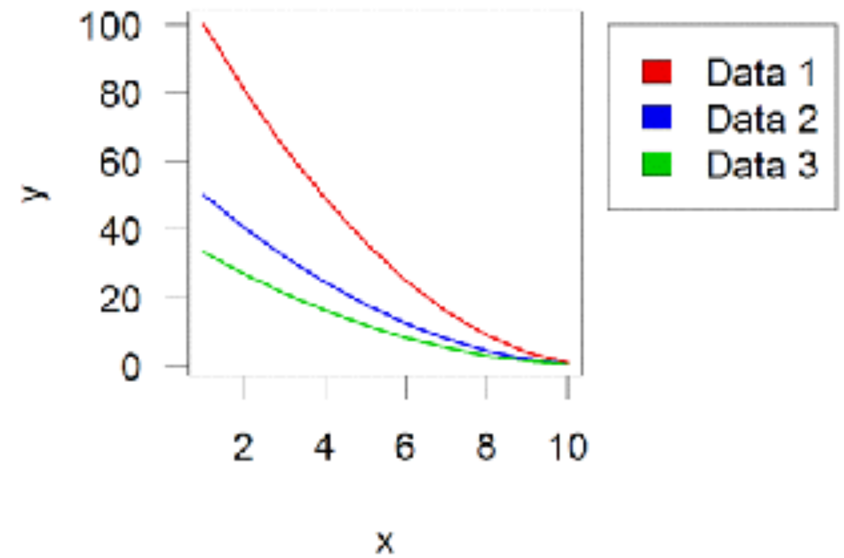




- Input:
  - Text, x, y
- Options:
  - `adj` (x and y offsets)
  - `pos` (auto offset 1=below,2=left,3=above, 4=right)

Legend





- Input:
  - Position (x,y or “topright”,”bottomleft” etc)
  - Text labels
- Options:
  - `fill` (colours for shaded boxes)
  - `xpd=NA` (draw outside plot area)

Exercise 3

[**Muddy Point Assessment Form Link**]

Homework!

New **DataCamp** Assignments

- Introduction to R Markdown
- Functions
- Loops

Muddy Point Assessment Form Link