
# 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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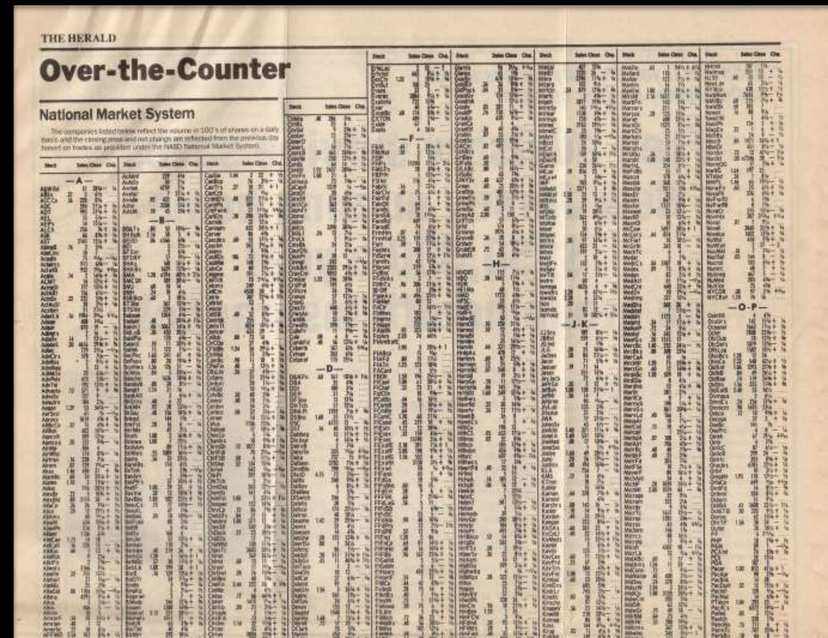
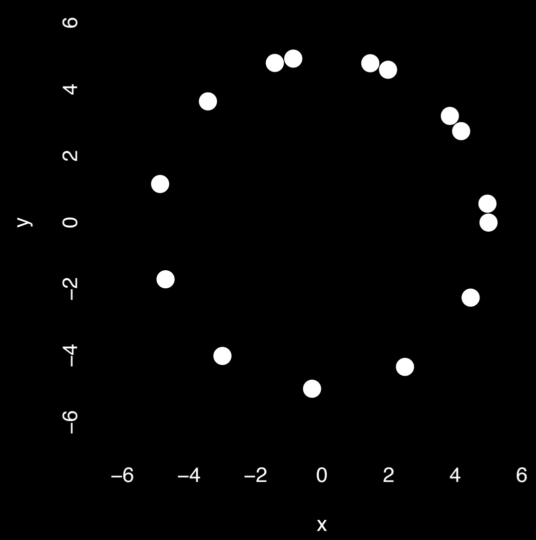
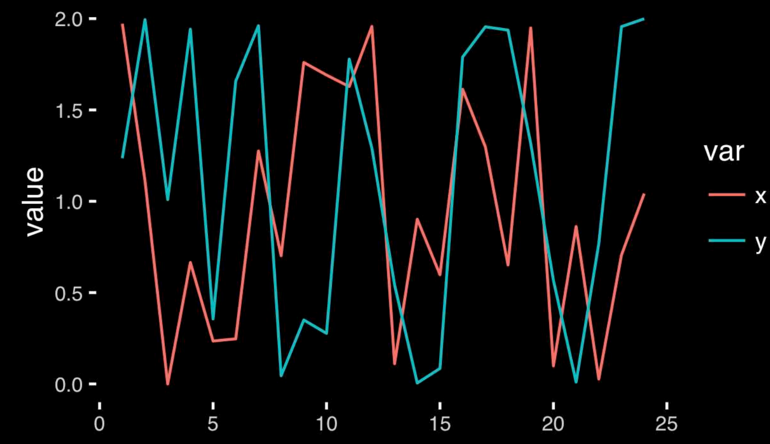
# Why visualize at all?



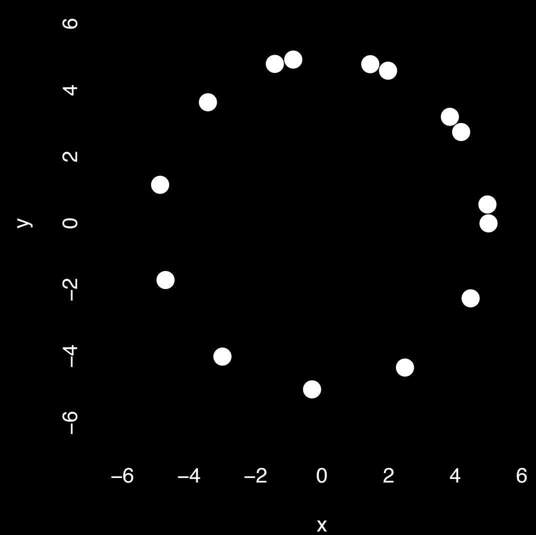

| | x | y |
|---|---|---|
| **1** | 5.00 | 0.00 |
| **2** | 4.18 | 2.75 |
| **3** | 1.98 | 4.59 |
| **4** | -0.86 | 4.92 |
| **5** | -3.43 | 3.64 |
| **6** | -4.86 | 1.16 |
| **7** | -4.70 | -1.70 |
| **8** | -2.99 | -4.01 |
| **9** | -0.30 | -4.99 |
| **10** | 2.49 | -4.34 |
| **11** | 4.46 | -2.25 |
| **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 |



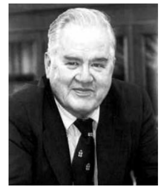

https://bioboot.github.io/bggn213_S18/class-material/05_draw_circle_points/



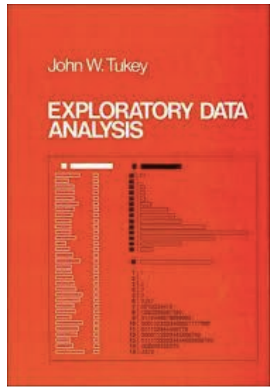

# Exploratory Data Analysis

- 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

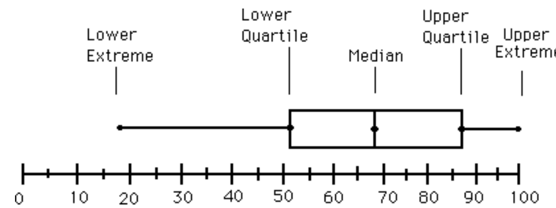


- Based on insights developed at Bell Labs in the 60’s
- Techniques for visualizing and summarizing data
- What can the data tell us? (in contrast to “confirmatory” data analysis)
- Introduced many basic techniques:
  - 5-number summary, box plots, stem and leaf diagrams,…
- 5 Number summary:
  - extremes (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 |

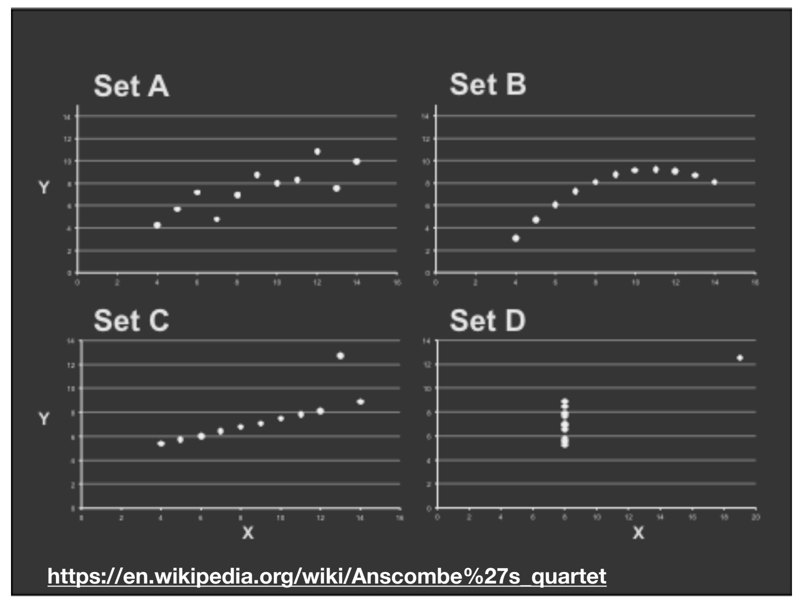
**Summary Statistics Linear Regression**

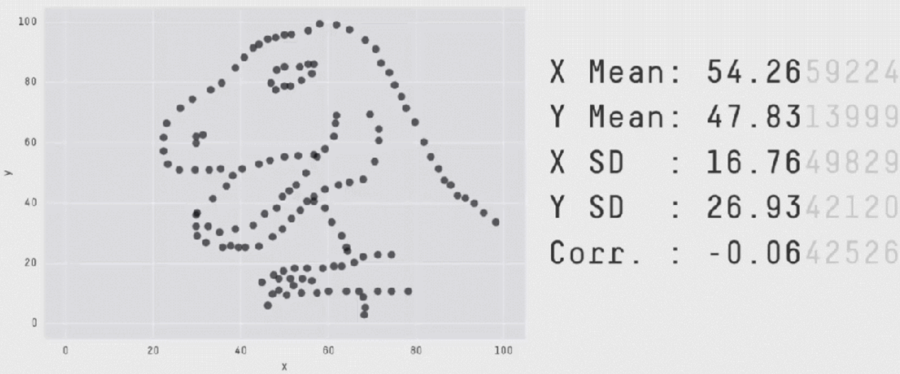
$u_X = 9.0$ $\sigma_X = 3.317$ $Y = 3 + 0.5\,X$

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

[Anscombe 73]

# Looking at Data






**Key point**: You need to visualize your data!

https://github.com/stephlocke/datasauRus

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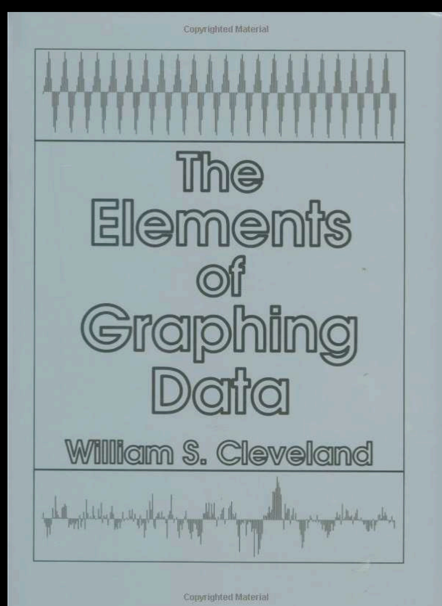
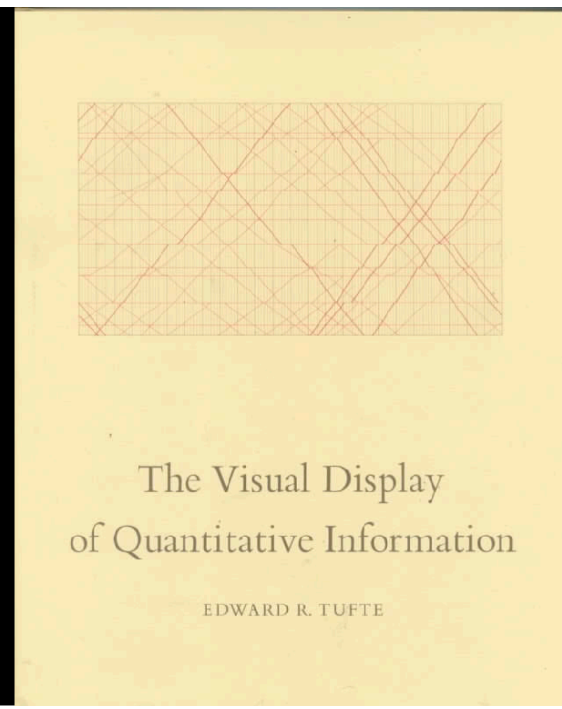


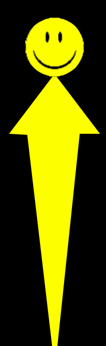
**Key Point:**

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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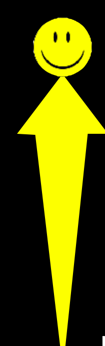

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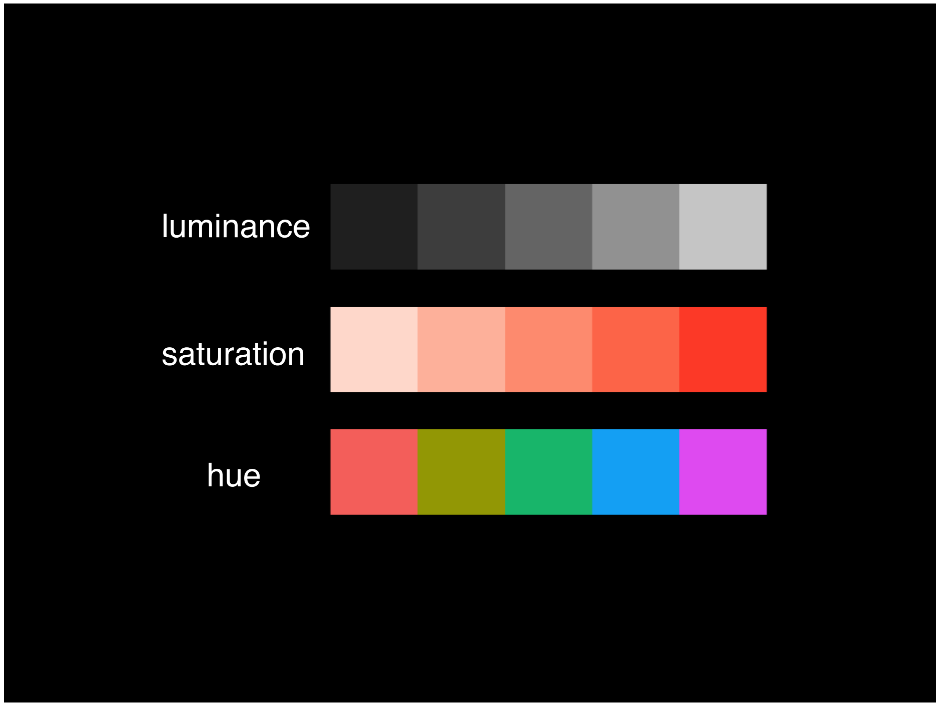
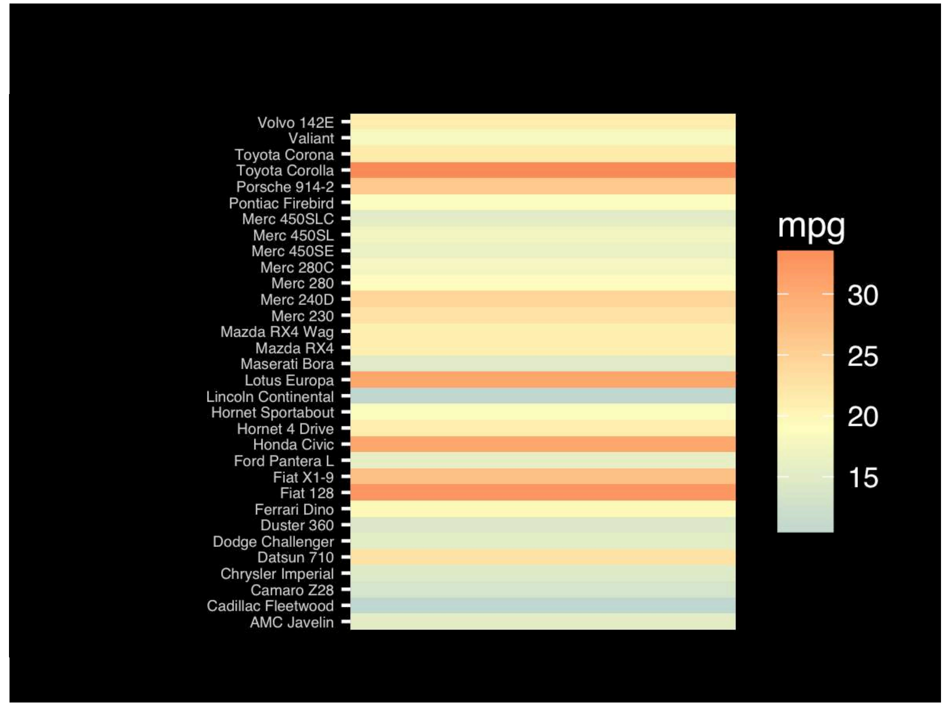

luminance
saturation
hue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Porsche 914-2
Pontiac Firebird
Merc 450SLC
Merc 450SL
Merc 450SE
Merc 280C
Merc 280
Merc 240D
Merc 230
Mazda RX4 Wag
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Lotus Europa
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Fiat X1-9
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Duster 360
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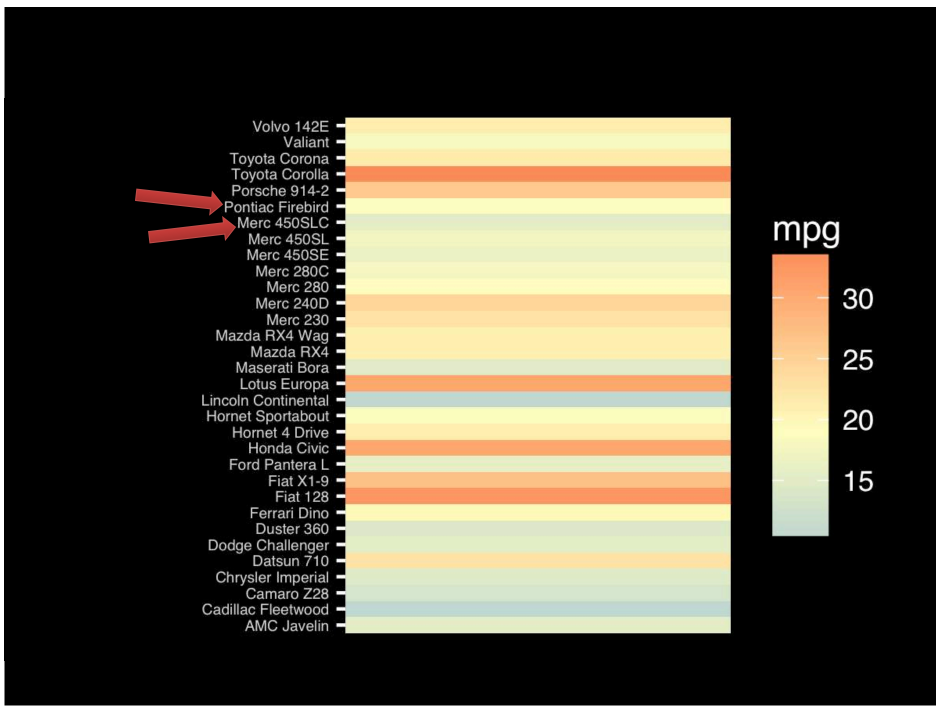
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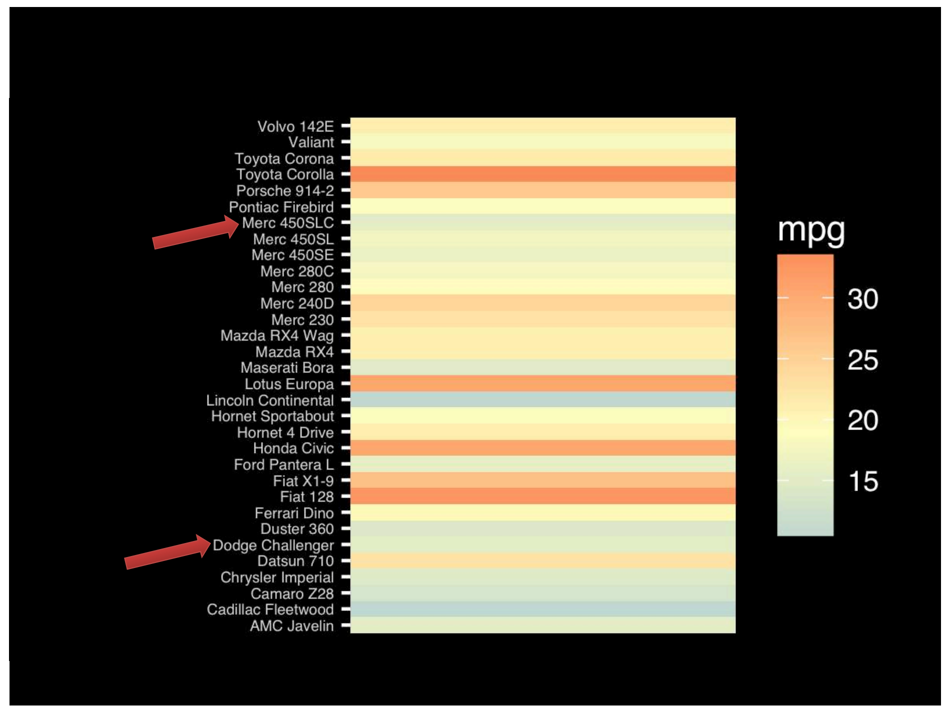
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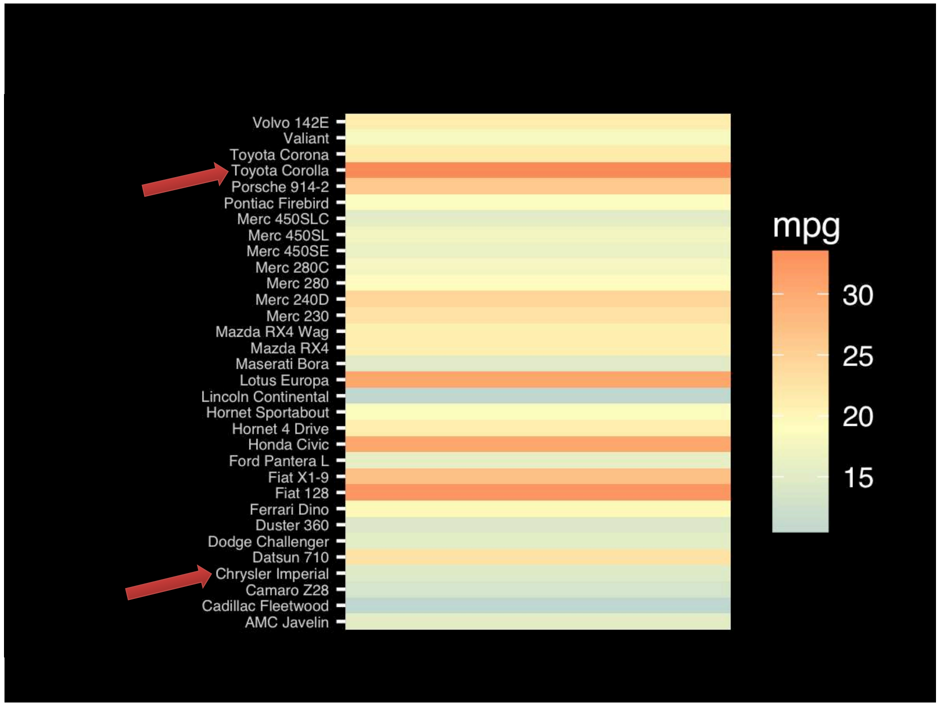
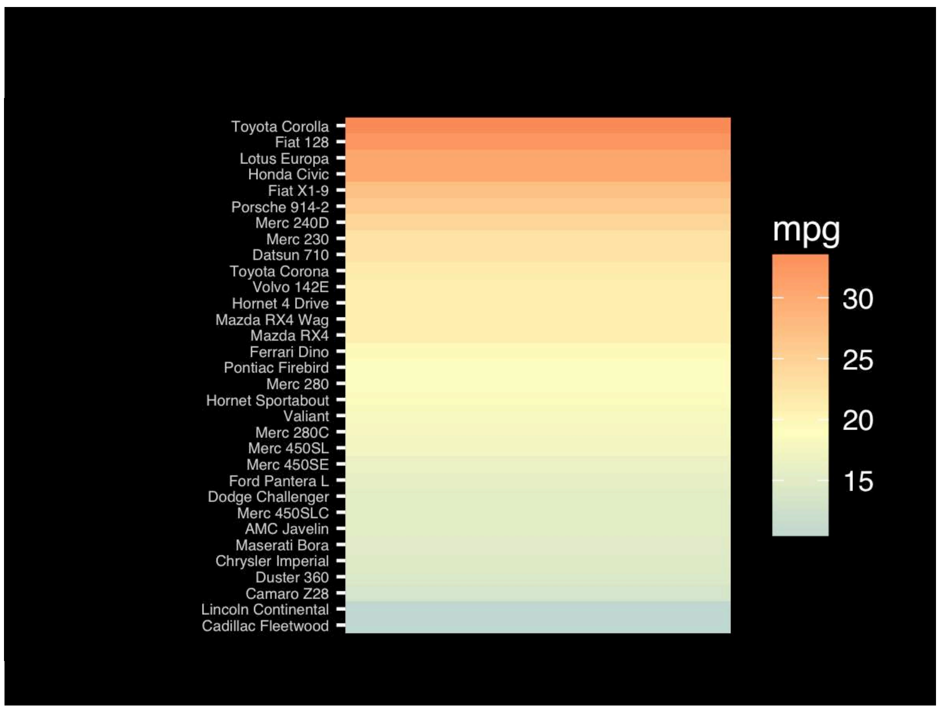
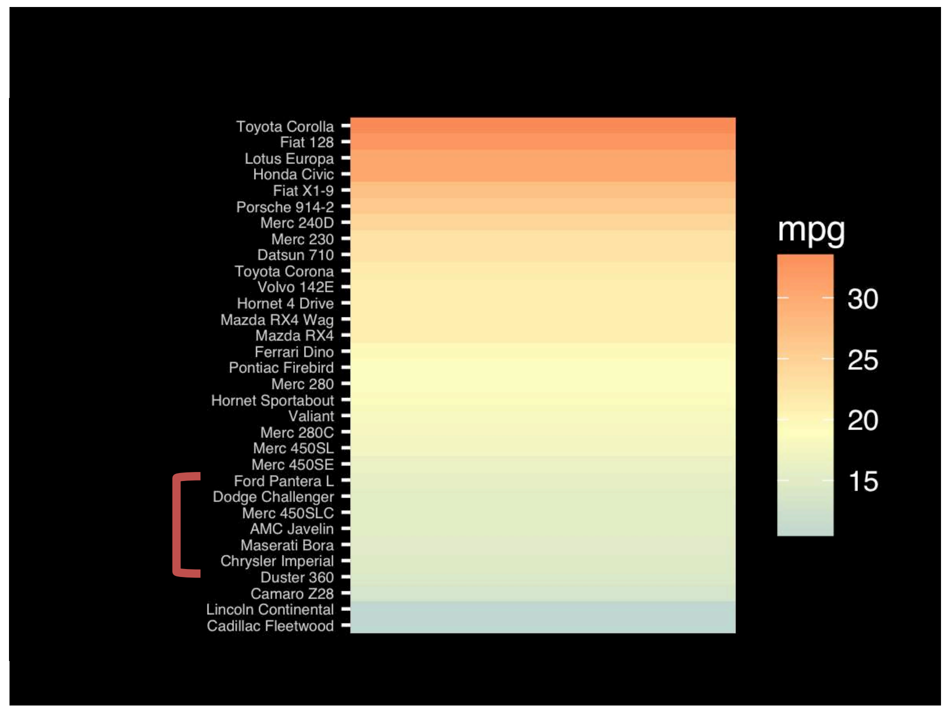
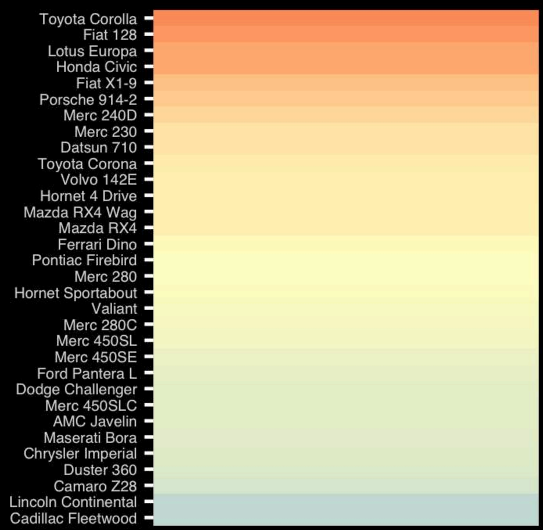


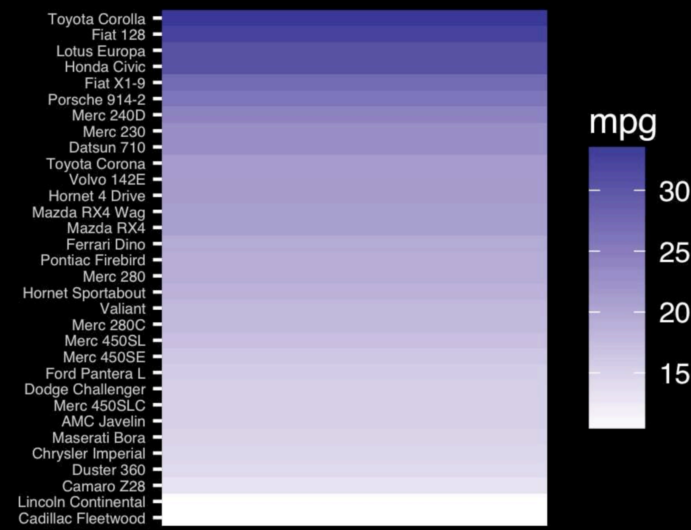

**Observation:** Alphabetical is almost never the correct ordering of a categorical variable.






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

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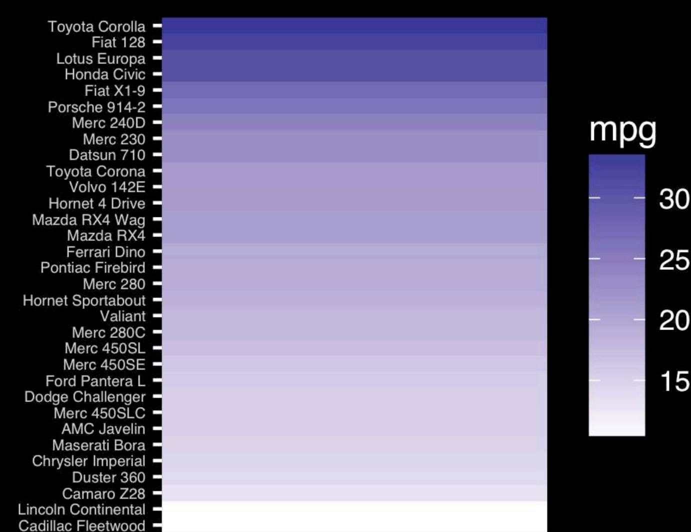


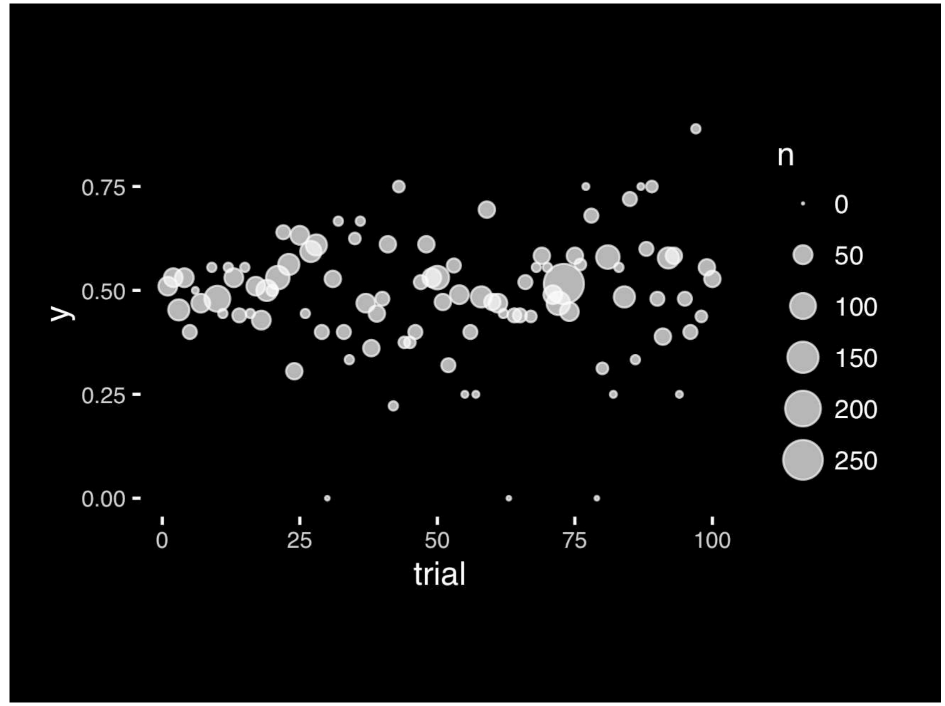


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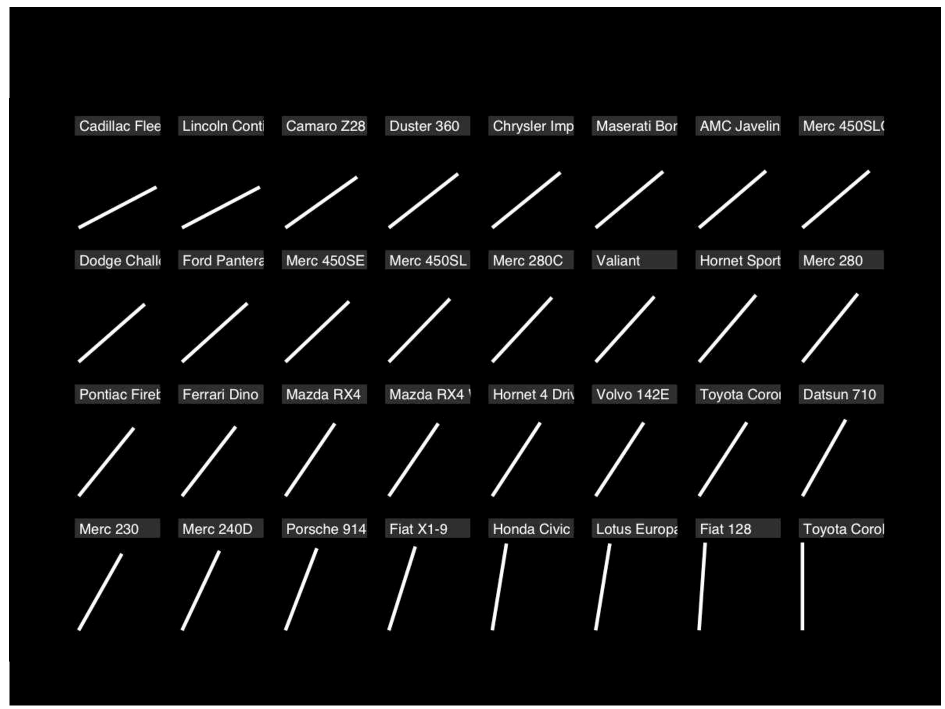
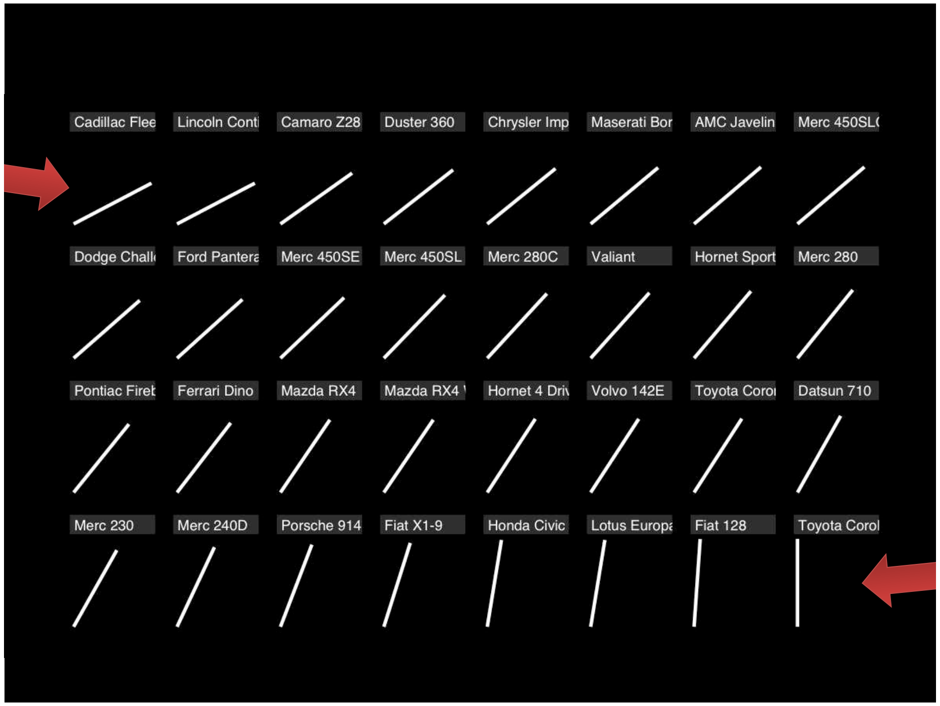
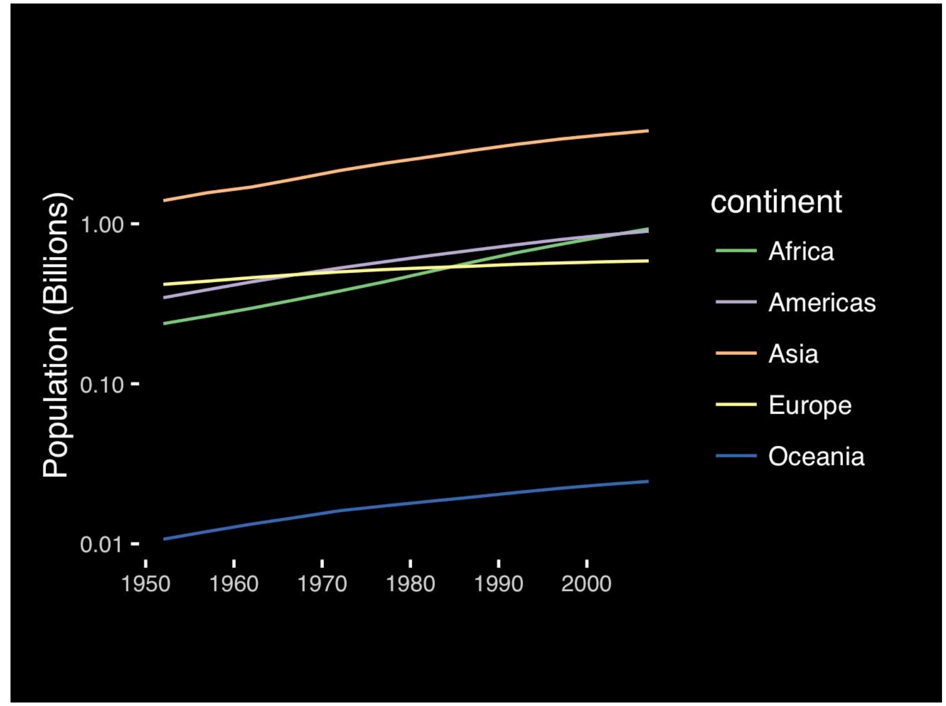
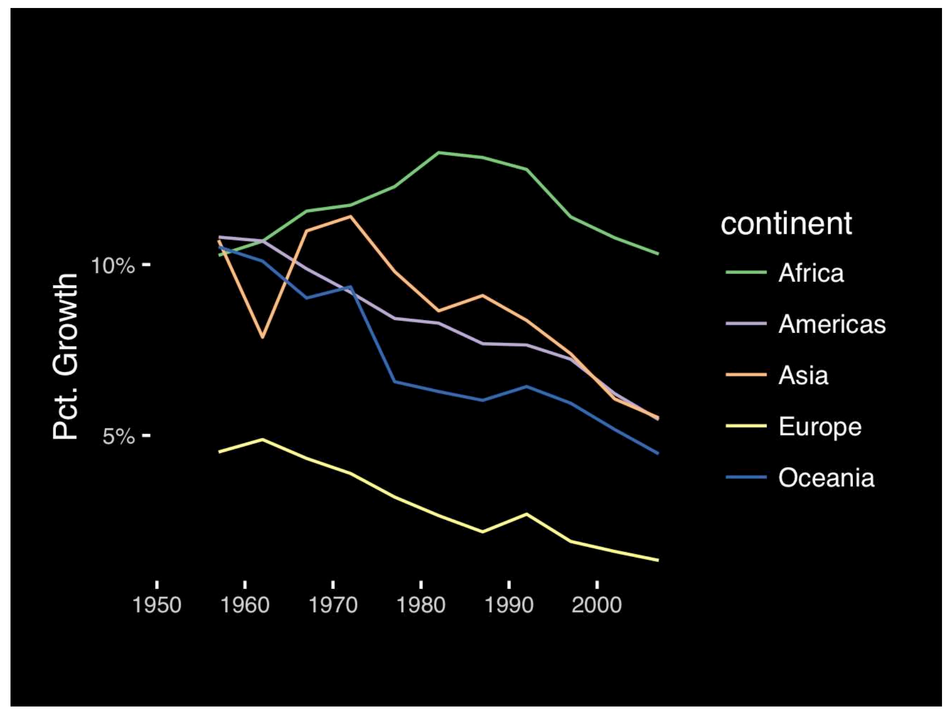





# If growth (slope) is important, plot it directly.



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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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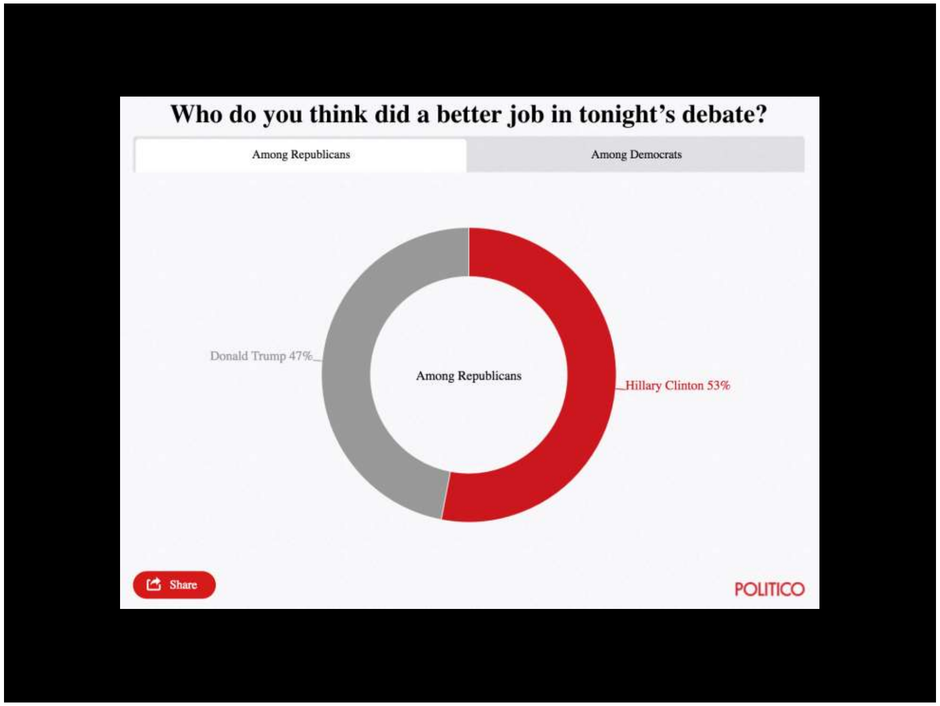


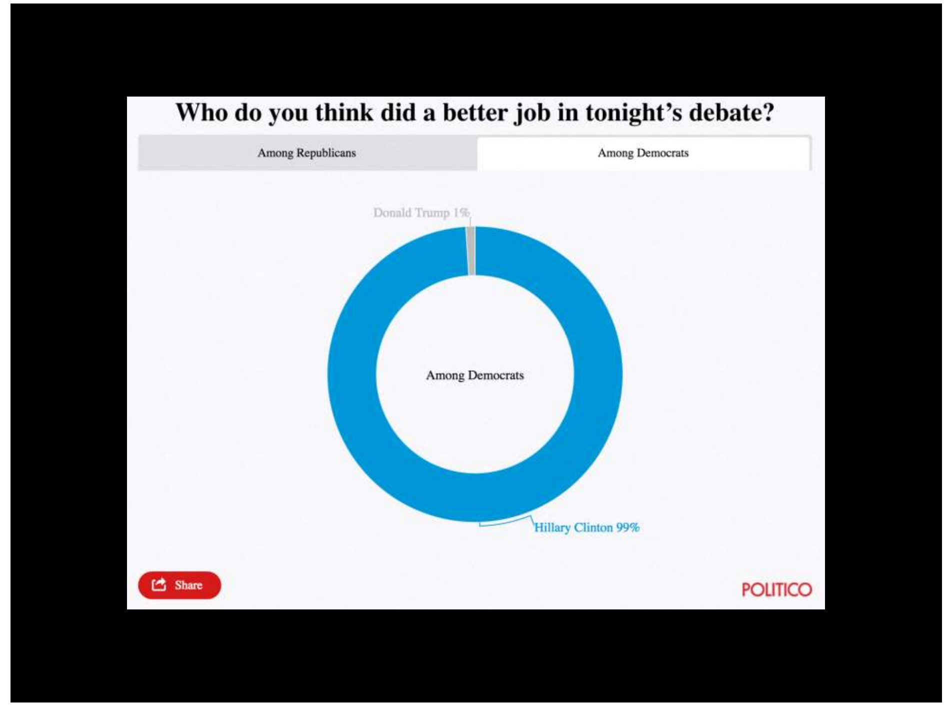


Tables are preferable to graphics for many small data sets. A table is nearly always better than a dumb pie chart; the only thing worse than a pie chart is several of them, for then the viewer is asked to compare quantities located in spatial disarray both within and between pies... Given their low data-density 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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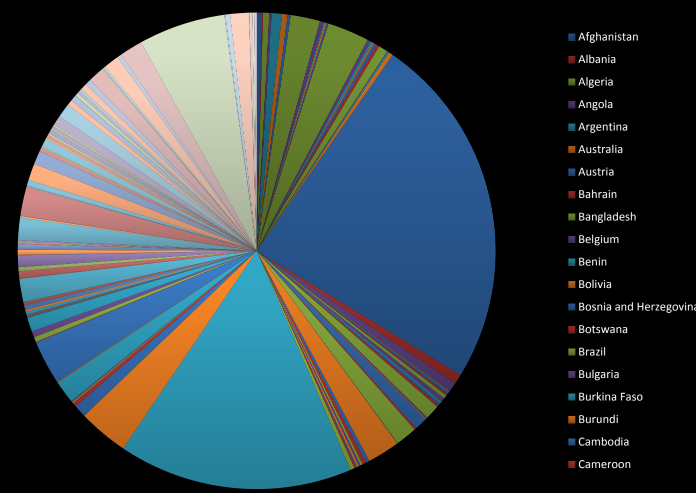
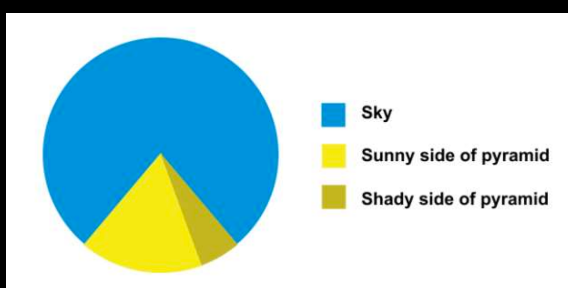
Who do you think did a better job in tonight's debate?

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




All good pie charts are jokes…

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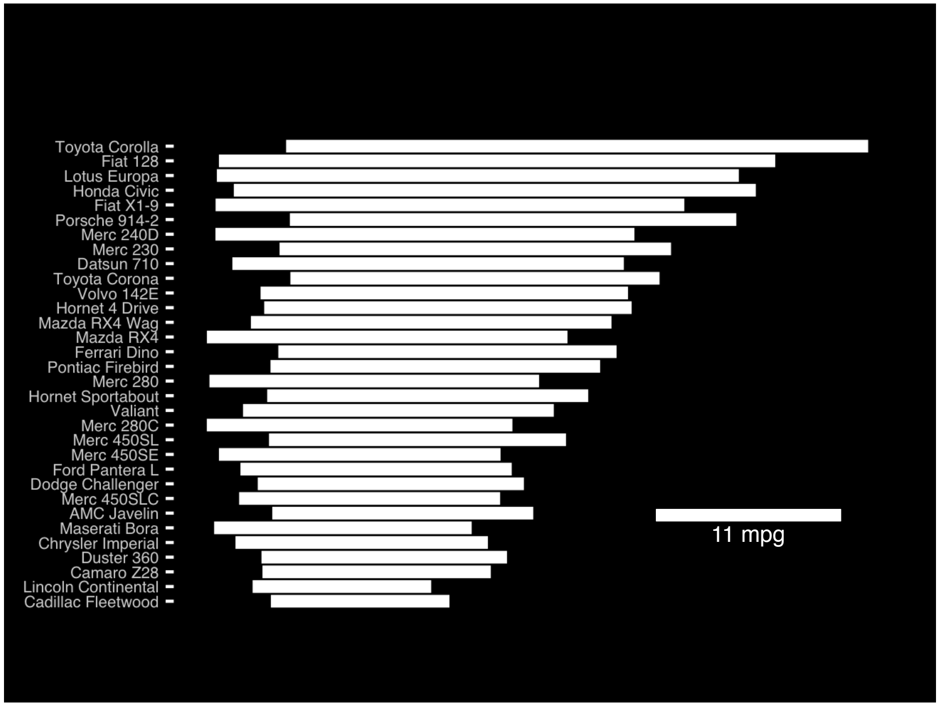


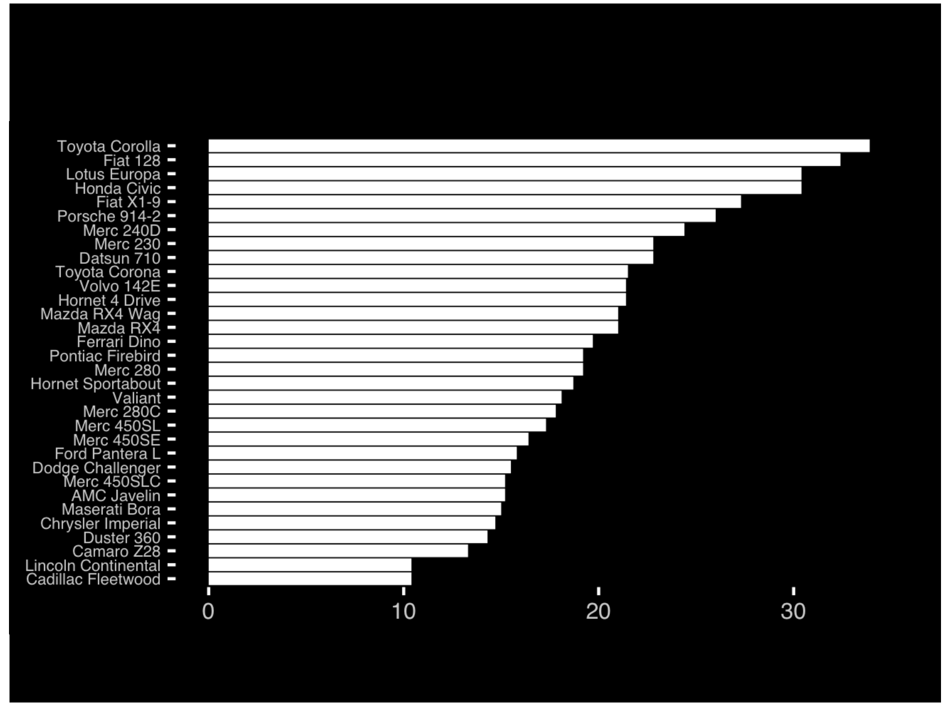


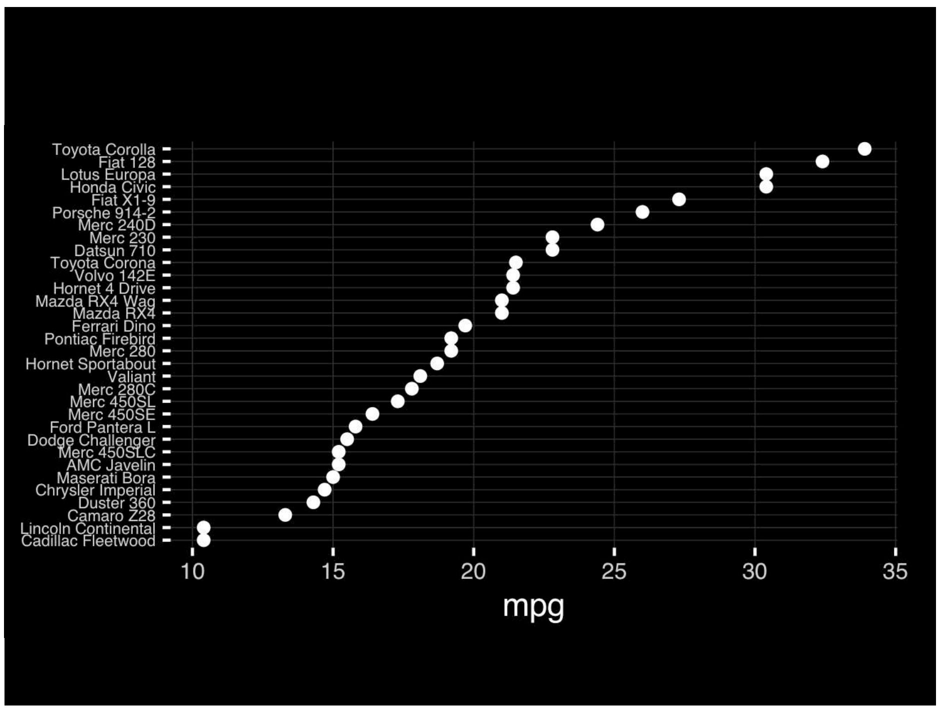


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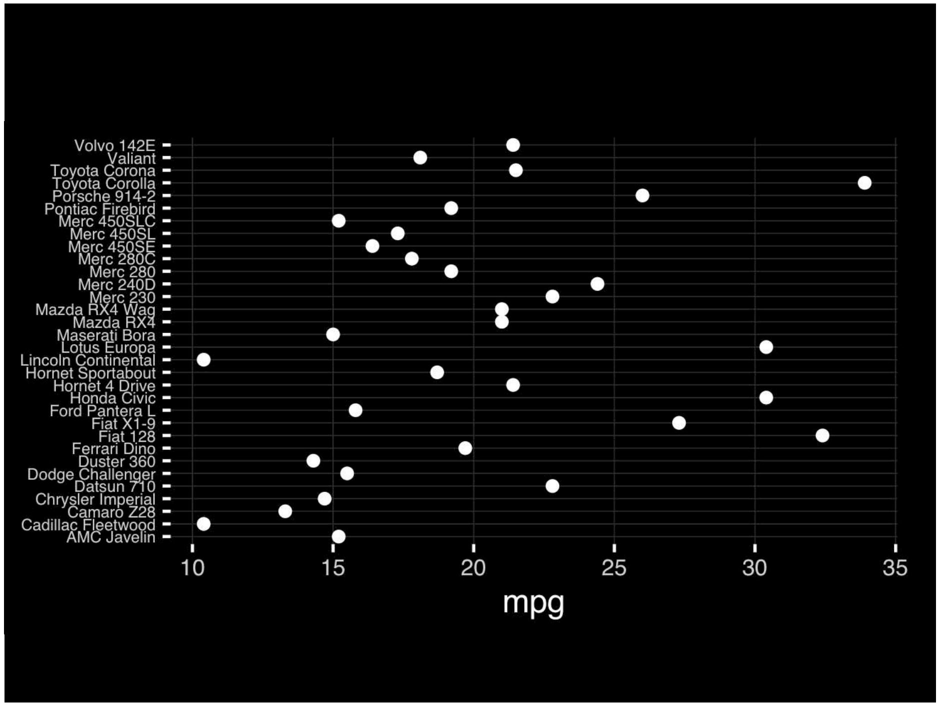
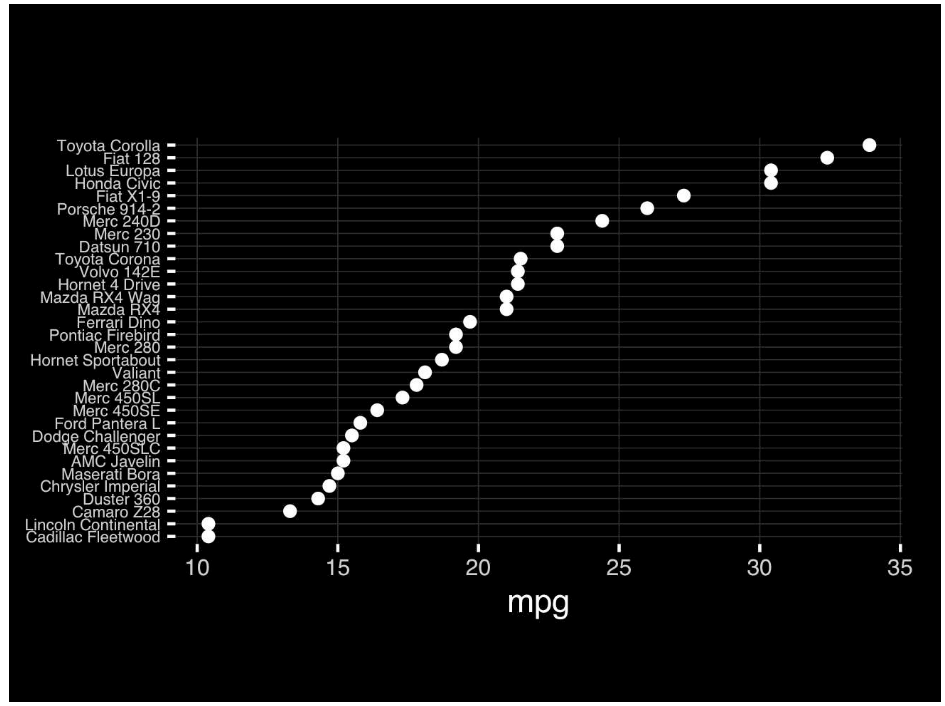
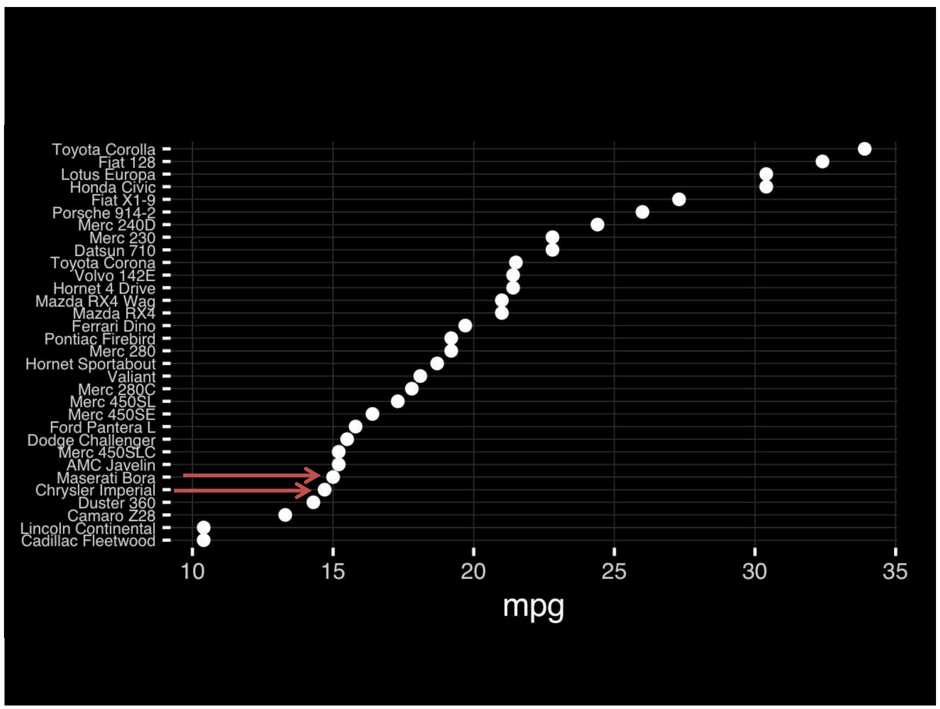
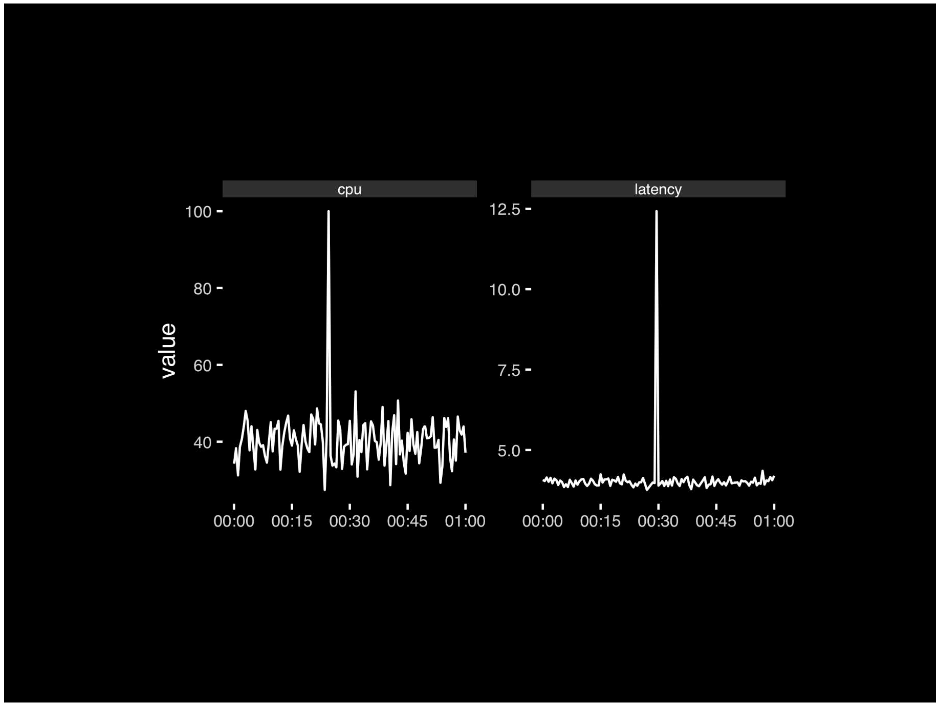
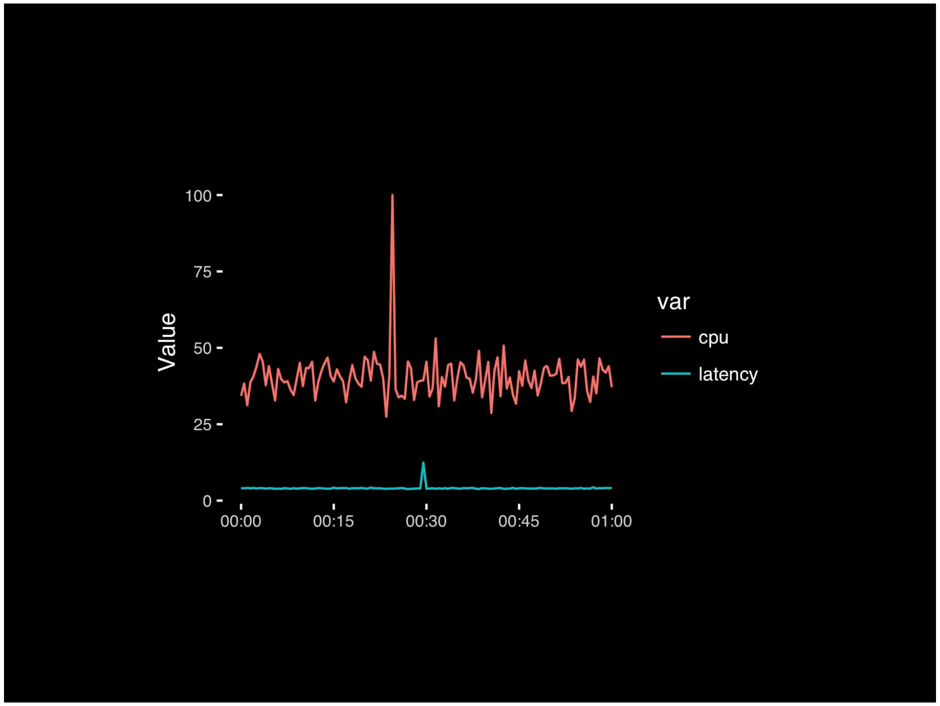


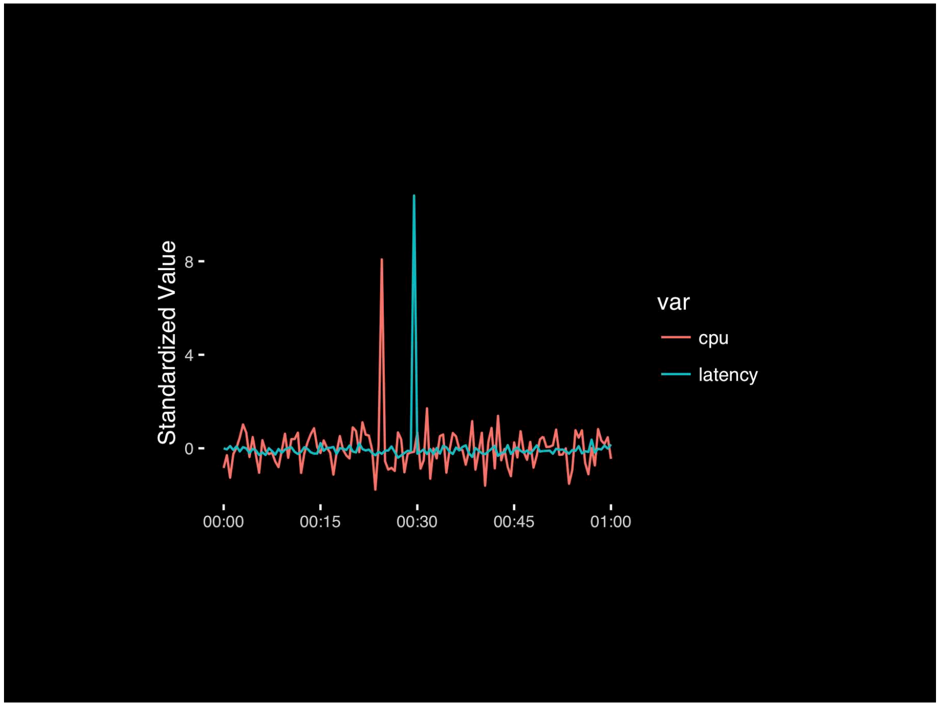




**Observation:** Comparison is trivial on a common scale.

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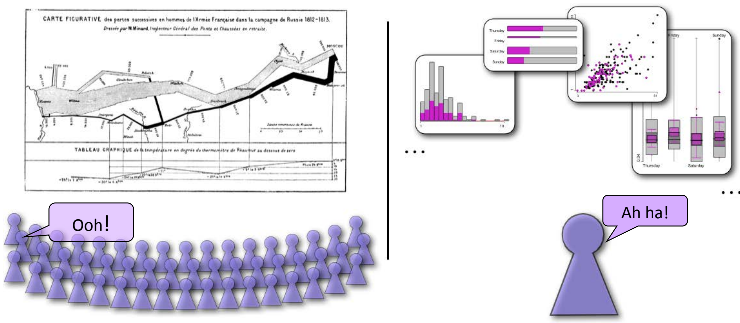
# Different graphs for different purposes

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




Presentation

Exploration



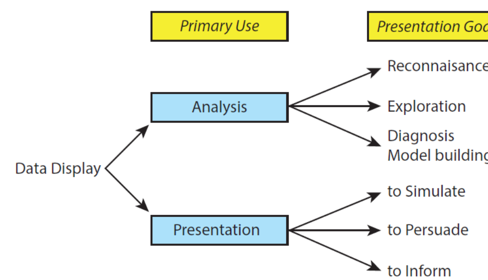
# Roles of graphics in data analysis

- 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

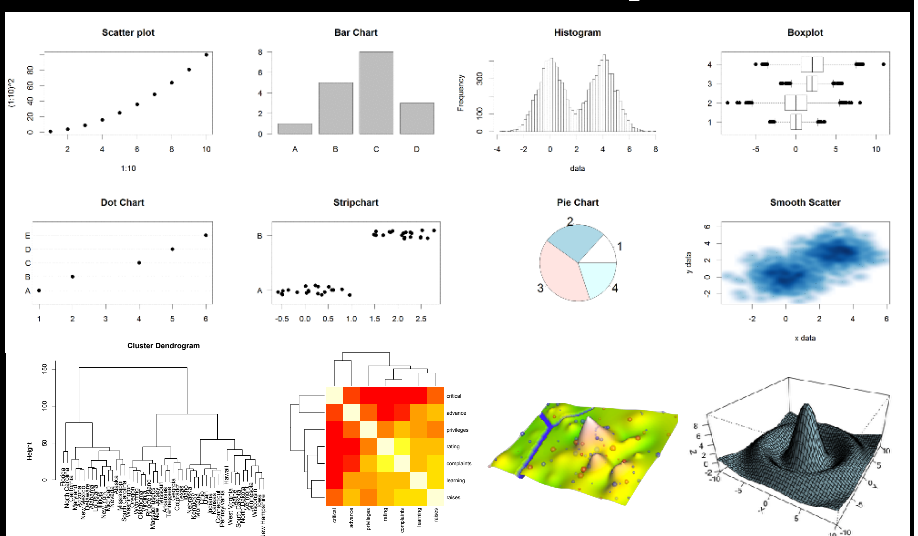
***Basic functions of data display***



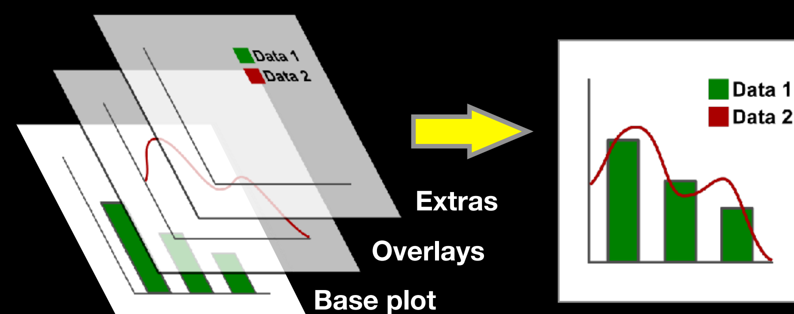

Exploratory (for you!)

Info for others, publications & sharing etc.

# Core R Graph Types

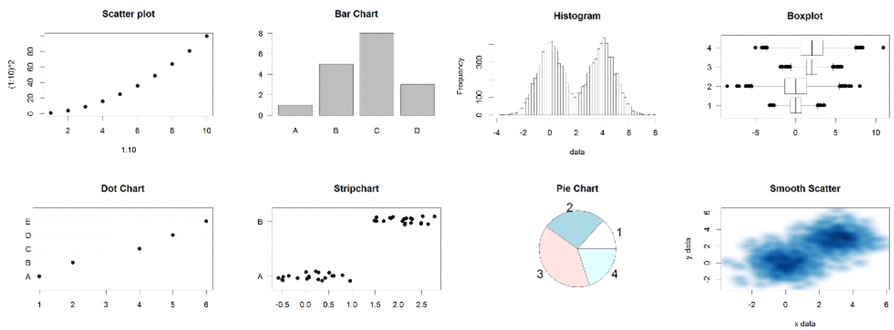



# The R Painters Model




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

# Core Graph Types



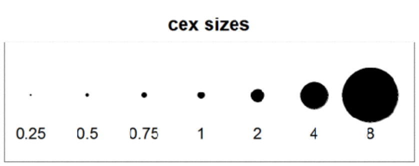

- Local options to change a specific plot
- Global options to affect all graphs

# Common Options

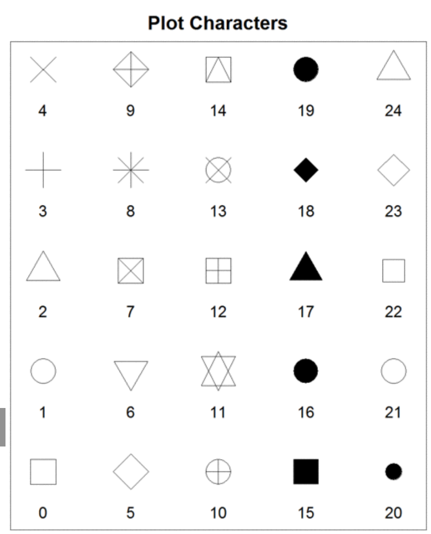
- Axis scales
  - xlim c(min,max)
  - ylim c(min,max)
- Axis labels
  - xlab(text)
  - ylab(text)
- Plot titles
  - main(text)
  - sub(text)
- Plot characters
  - pch(number)
  - cex(number)

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

# Plot Characters

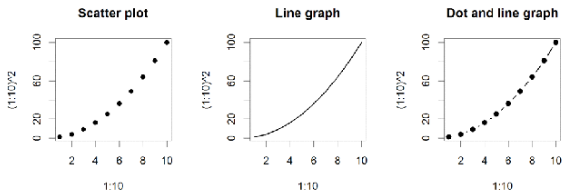



plot( 1:5, pch=1:5, cex=1:5 )




# Plot Type Specific Options

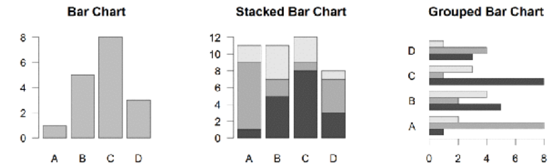
# Plot (scatterplots and line graphs)




- 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 )
```

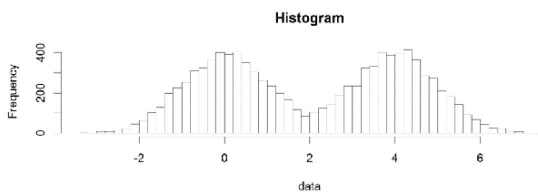
# Barplot (bar graphs)




- 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)
```

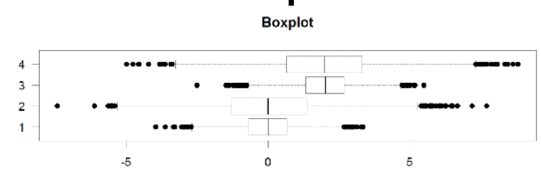
# Hist (histograms)




- 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

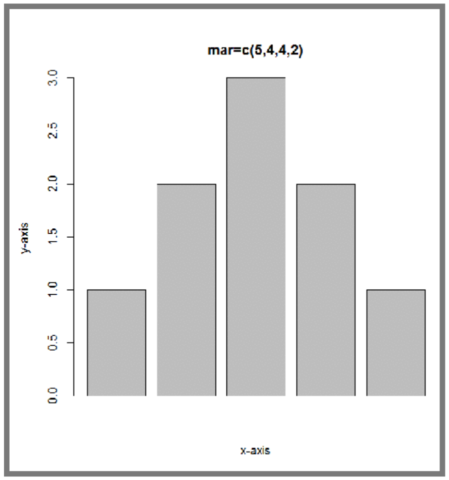
# Par examples

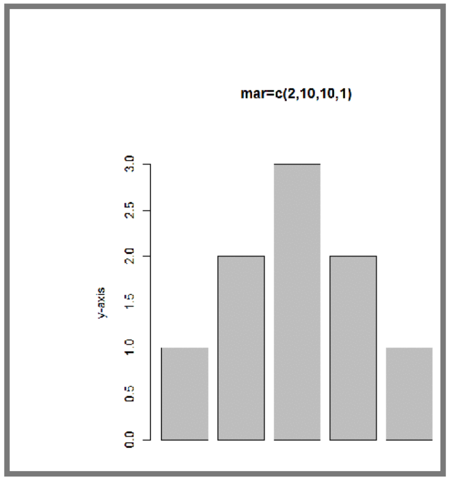
- Reading current value
  - `par()$cex`
- Setting a value
  - `par(cex=1.5) -> old.par`
- Restoring a value
  - `par(old.par)`
  - `dev.off()`

# 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`

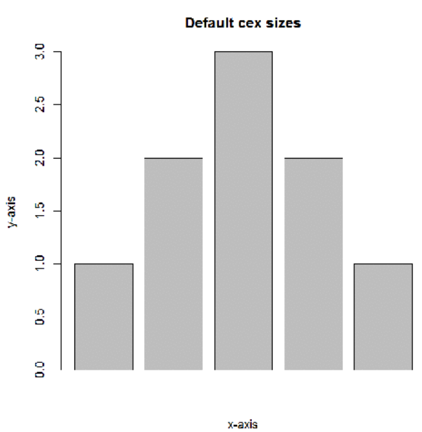
par( mar=c(2, 10, 1, 1) )

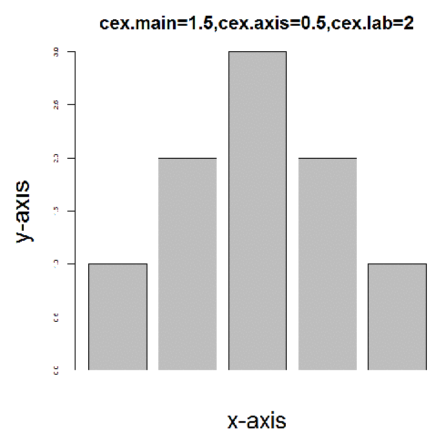



# Par options

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

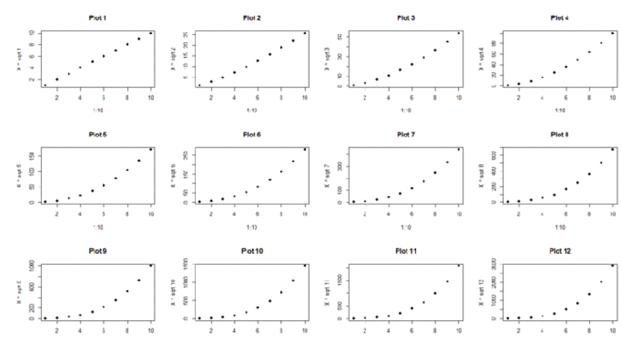



par( cex.main=1.5, cex.axis=0.5, cex.lab=2 )

# Par options

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



par( mfrow(3 , 4 ) )

# Exercise 1

# Using Color

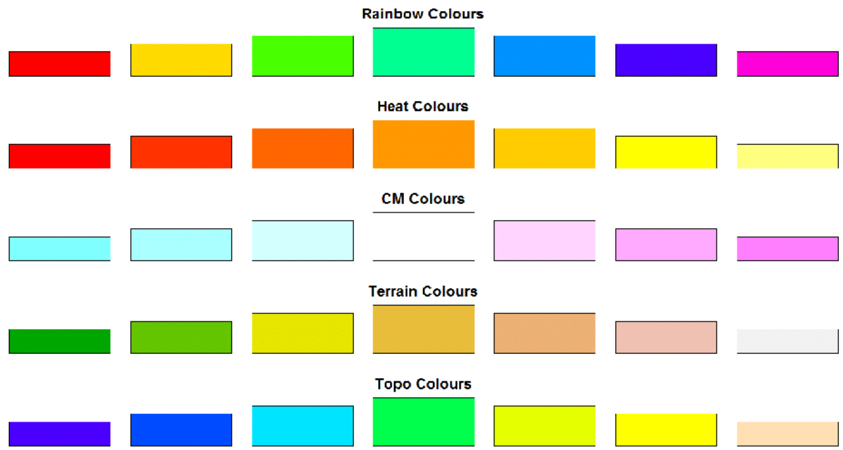
# Specifying colors

- 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( 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.

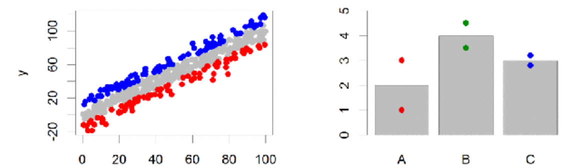
# 3. How could we improve this function?

```
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.

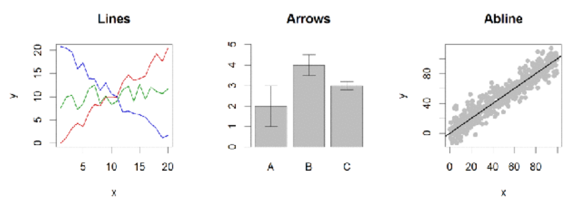
# Plot Overlays
# Exercise 3

# Points



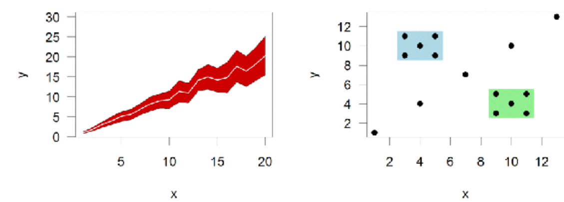
- Input: 2 Vectors (x and y positions)
- Options:
  - `pch`
  - `cex`

# Lines / Arrows / Abline



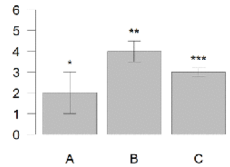

- Input:
  - Lines 2 vectors (x and y)
  - Arrows 4 vectors (x0,x1,y0,y1)
  - Abline Intercept and slope (or correlation object)
- Options:
  - `lwd`
  - `angle` (arrows)

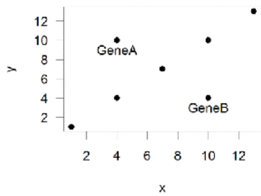
# Polygon (shaded areas)



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

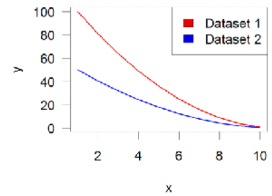
# Text (in plot text)

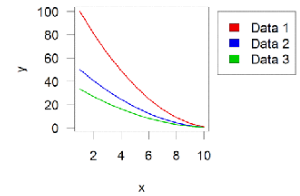



- Input:
  - Text, x, y
- Options:
  - `adj` (x and y offsets)
  - `pos` (auto offset 1=below,2=left,3=above, 4=right)

# 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**