REVIEW

Overview

Review of ggplot

Quick review of material covered in the class so far

Questions to prepare for the exam

Announcements

Midterm exam is on Thursday

- Bring a pen and a pencil
- One page (single sided) with code and equations only!
  - You will turn in this page of notes with your exam (put your name on it)
  - Recommend including equations for SEs, etc.

Office hours this week

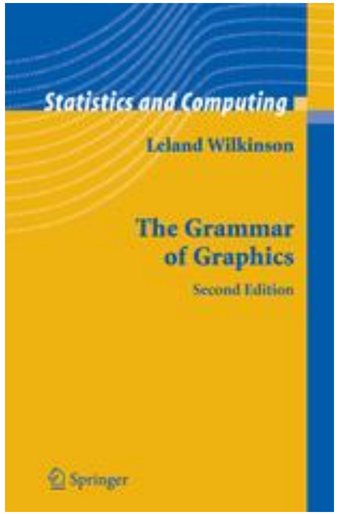
- No TA office hours this week since there is no homework

Review of the grammar of graphics and ggplot

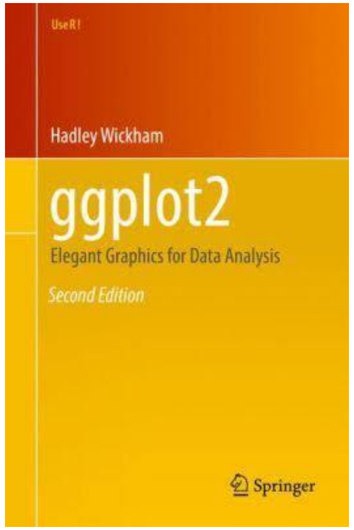
The grammar of graphics

Leland Wilkinson noticed similarities between many graphs and tried to generate a ‘grammar’ that could be used to express a graph

- i.e., a list elements that can be combined together to create a graph



Hadley Wickham implemented these ideas in R in the ggplot2 package



Graphs are composed of…

A Frame: Coordinate system on which data is placed

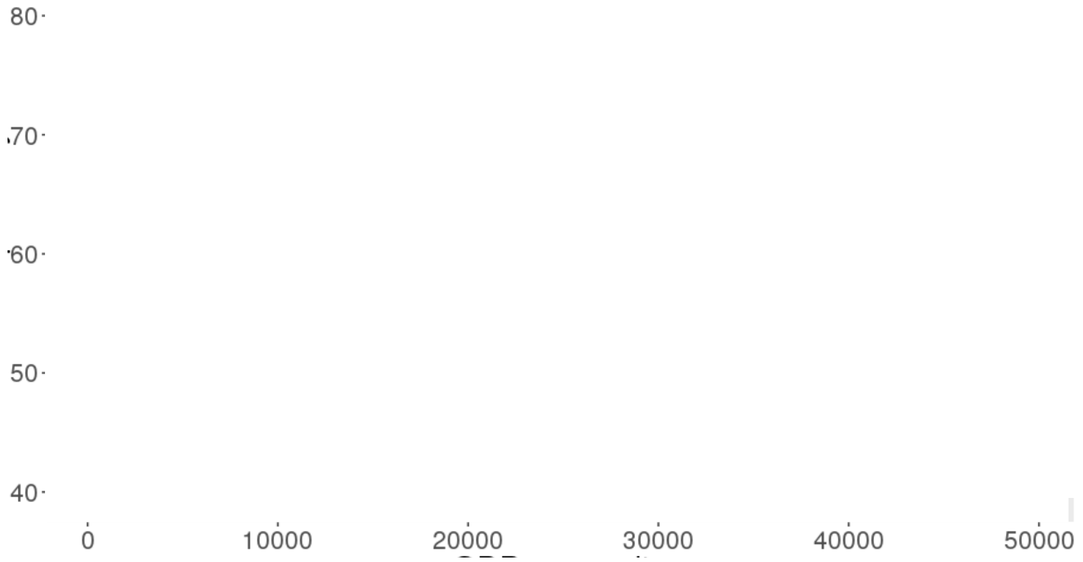
- ggplot() +

Glyphs: basic graphic unit representing cases or statistics

- Data is **mapped** onto these aesthetics such as: shape, color, size, etc. and/or aesthetics can be set to a fixed value
  - geom_point(aes(x = gdpPercap, y = lifeExp, color = continent)) geom_point(aes(x = gdpPercap, y = lifeExp), color = "red")

Scales and guides: shows how to interpret axes and other properties of the glyphs

- scale_x_continuous(trans = "log10") scale_color_brewer(type = "qua", palette = 2)



Plots can also contain…

Facets: allows for multiple side-by-side graphs based on a categorical variable

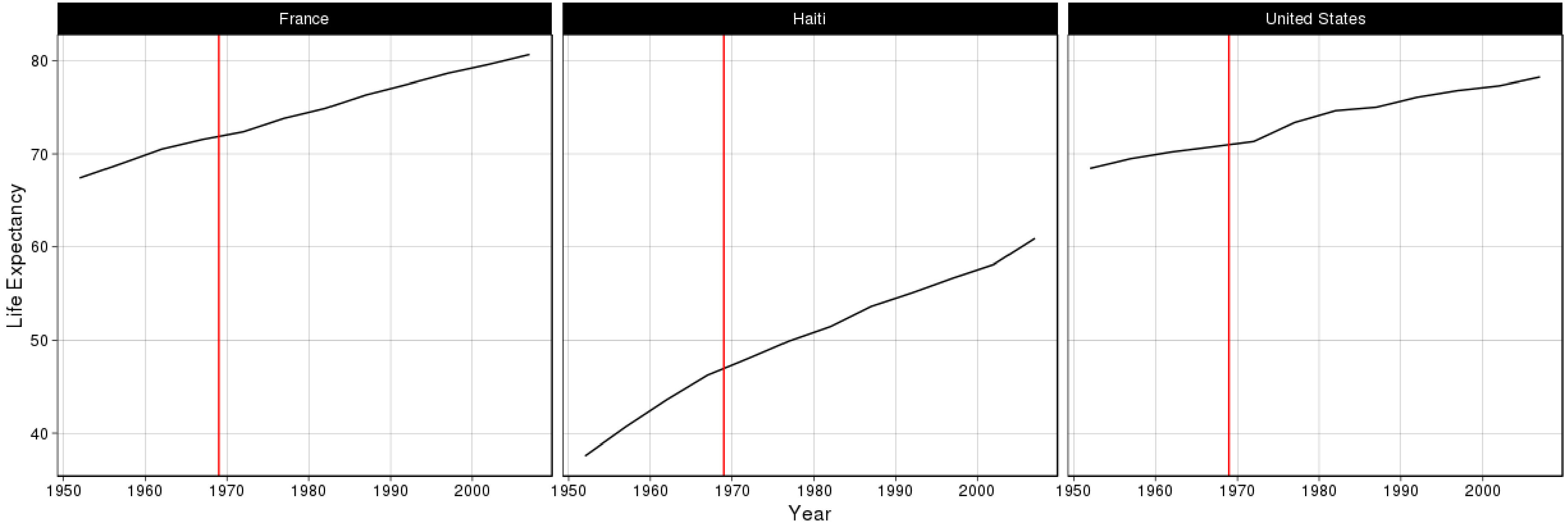
- facet_wrap(~country)

Layers: allows for more than one types of data to be mapped onto the same figure

- geom_vline(xintercept = 1969, col = "red")

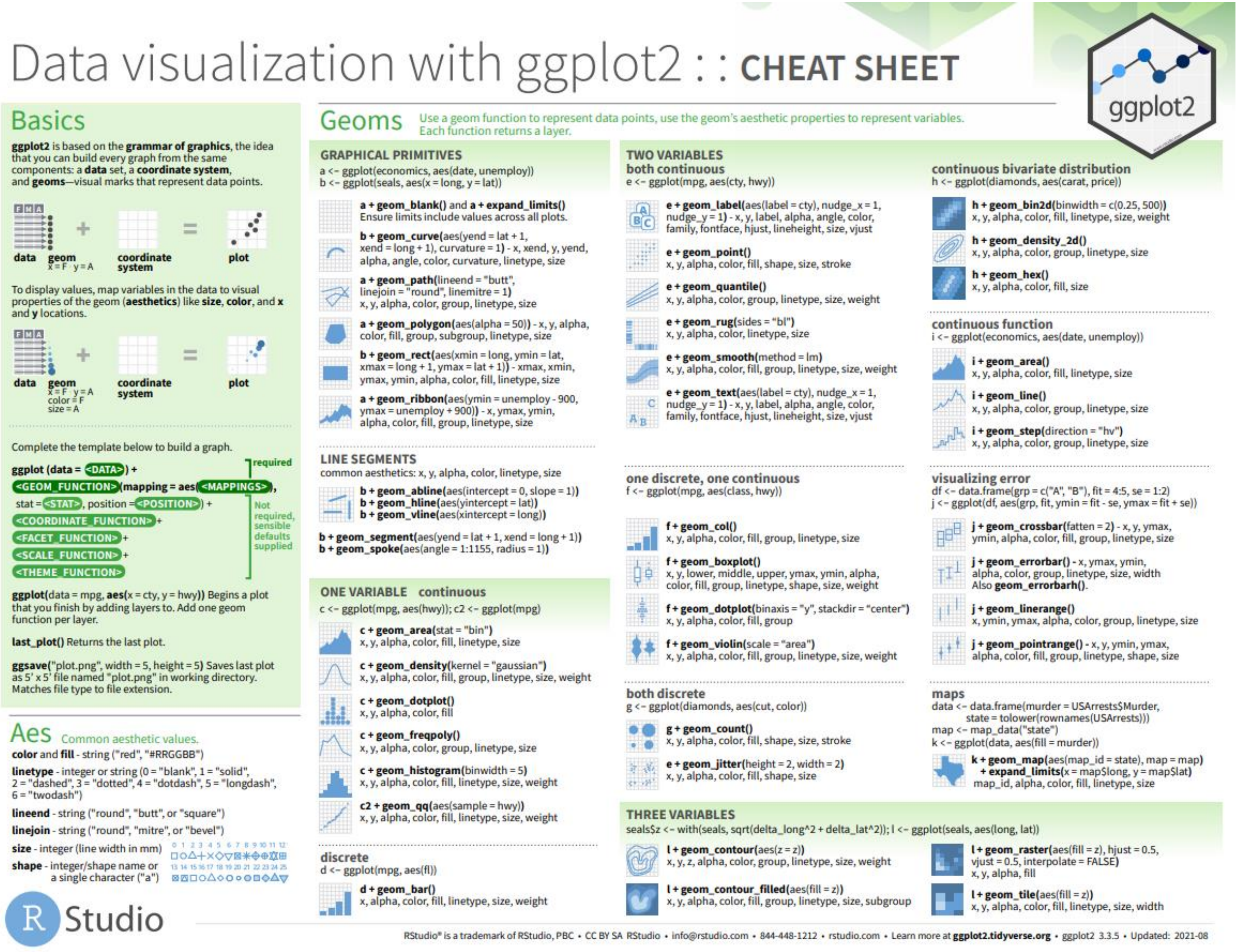
Theme: contains finer points of display (e.g., font size, background color, etc.)

- theme_wsj()



Questions?

ggplot2 cheat sheet



Data visualization with ggplot2 : : CHEAT SHEET

ggplot2

Basics

ggplot2 is based on the **grammar of graphics**, the idea that you can build every graph from the same components: a **data** set, a **coordinate system**, and **geoms**—visual marks that represent data points.

data **geom** x = F y = A **coordinate system** **plot**

To display values, map variables in the data to visual properties of the geom (**aesthetics**) like **size**, **color**, and **x** and **y** locations.

data **geom** x = F y = A color = F size = A **coordinate system** **plot**

Complete the template below to build a graph.

```
ggplot (data = <DATA>) +                                        required
<GEOM_FUNCTION>(mapping = aes(<MAPPINGS>),
 stat = <STAT>, position = <POSITION>) +                        Not
<COORDINATE_FUNCTION> +                                         required,
<FACET_FUNCTION> +                                              sensible
<SCALE_FUNCTION> +                                              defaults
<THEME_FUNCTION>                                                supplied
```

ggplot(data = mpg, **aes**(x = cty, y = hwy)) Begins a plot that you finish by adding layers to. Add one geom function per layer.

last_plot() Returns the last plot.

ggsave("plot.png", width = 5, height = 5) Saves last plot as 5' x 5' file named "plot.png" in working directory. Matches file type to file extension.

Aes

Common aesthetic values.

color and **fill** - string ("red", "#RRGGBB")

linetype - integer or string (0 = "blank", 1 = "solid", 2 = "dashed", 3 = "dotted", 4 = "dotdash", 5 = "longdash", 6 = "twodash")

lineend - string ("round", "butt", or "square")

linejoin - string ("round", "mitre", or "bevel")

size - integer (line width in mm)

shape - integer/shape name or a single character ("a")

0	1	2	3	4	5	6	7	8	9	10	11	12
□	○	△	+	×	◇	▽	⊠	✳	⊕	⊕	✡	⊞

13	14	15	16	17	18	19	20	21	22	23	24	25
⊠	⊠	□	○	△	◇	○	∘	○	□	◇	△	▽

RStudio

Geoms

Use a geom function to represent data points, use the geom's aesthetic properties to represent variables. Each function returns a layer.

GRAPHICAL PRIMITIVES

a <- ggplot(economics, aes(date, unemploy))
b <- ggplot(seals, aes(x = long, y = lat))

a + geom_blank() and **a + expand_limits()**
Ensure limits include values across all plots.

b + geom_curve(aes(yend = lat + 1, xend = long + 1), curvature = 1**)** - x, xend, y, yend, alpha, angle, color, curvature, linetype, size

a + geom_path(lineend = "butt", linejoin = "round", linemitre = 1**)**
x, y, alpha, color, group, linetype, size

a + geom_polygon(aes(alpha = 50)**)** - x, y, alpha, color, fill, group, subgroup, linetype, size

b + geom_rect(aes(xmin = long, ymin = lat, xmax = long + 1, ymax = lat + 1)**)** - xmax, xmin, ymax, ymin, alpha, color, fill, linetype, size

a + geom_ribbon(aes(ymin = unemploy - 900, ymax = unemploy + 900)**)** - x, ymax, ymin, alpha, color, fill, group, linetype, size

LINE SEGMENTS

common aesthetics: x, y, alpha, color, linetype, size

b + geom_abline(aes(intercept = 0, slope = 1)**)**
b + geom_hline(aes(yintercept = lat)**)**
b + geom_vline(aes(xintercept = long)**)**

b + geom_segment(aes(yend = lat + 1, xend = long + 1)**)**
b + geom_spoke(aes(angle = 1:1155, radius = 1)**)**

ONE VARIABLE continuous

c <- ggplot(mpg, aes(hwy)); c2 <- ggplot(mpg)

c + geom_area(stat = "bin"**)**
x, y, alpha, color, fill, linetype, size

c + geom_density(kernel = "gaussian"**)**
x, y, alpha, color, fill, group, linetype, size, weight

c + geom_dotplot()
x, y, alpha, color, fill

c + geom_freqpoly()
x, y, alpha, color, group, linetype, size

c + geom_histogram(binwidth = 5**)**
x, y, alpha, color, fill, linetype, size, weight

c2 + geom_qq(aes(sample = hwy)**)**
x, y, alpha, color, fill, linetype, size, weight

discrete

d <- ggplot(mpg, aes(fl))

d + geom_bar()
x, alpha, color, fill, linetype, size, weight

TWO VARIABLES

both continuous

e <- ggplot(mpg, aes(cty, hwy))

e + geom_label(aes(label = cty), nudge_x = 1, nudge_y = 1**)** - x, y, label, alpha, angle, color, family, fontface, hjust, lineheight, size, vjust

e + geom_point()
x, y, alpha, color, fill, shape, size, stroke

e + geom_quantile()
x, y, alpha, color, group, linetype, size, weight

e + geom_rug(sides = "bl"**)**
x, y, alpha, color, linetype, size

e + geom_smooth(method = lm**)**
x, y, alpha, color, fill, group, linetype, size, weight

e + geom_text(aes(label = cty), nudge_x = 1, nudge_y = 1**)** - x, y, label, alpha, angle, color, family, fontface, hjust, lineheight, size, vjust

one discrete, one continuous

f <- ggplot(mpg, aes(class, hwy))

f + geom_col()
x, y, alpha, color, fill, group, linetype, size

f + geom_boxplot()
x, y, lower, middle, upper, ymax, ymin, alpha, color, fill, group, linetype, shape, size, weight

f + geom_dotplot(binaxis = "y", stackdir = "center"**)**
x, y, alpha, color, fill, group

f + geom_violin(scale = "area"**)**
x, y, alpha, color, fill, group, linetype, size, weight

both discrete

g <- ggplot(diamonds, aes(cut, color))

g + geom_count()
x, y, alpha, color, fill, shape, size, stroke

e + geom_jitter(height = 2, width = 2**)**
x, y, alpha, color, fill, shape, size

continuous bivariate distribution

h <- ggplot(diamonds, aes(carat, price))

h + geom_bin2d(binwidth = c(0.25, 500)**)**
x, y, alpha, color, fill, linetype, size, weight

h + geom_density_2d()
x, y, alpha, color, group, linetype, size

h + geom_hex()
x, y, alpha, color, fill, size

continuous function

i <- ggplot(economics, aes(date, unemploy))

i + geom_area()
x, y, alpha, color, fill, linetype, size

i + geom_line()
x, y, alpha, color, group, linetype, size

i + geom_step(direction = "hv"**)**
x, y, alpha, color, group, linetype, size

visualizing error

df <- data.frame(grp = c("A", "B"), fit = 4:5, se = 1:2)
j <- ggplot(df, aes(grp, fit, ymin = fit - se, ymax = fit + se))

j + geom_crossbar(fatten = 2**)** - x, y, ymax, ymin, alpha, color, fill, group, linetype, size

j + geom_errorbar() - x, ymax, ymin, alpha, color, group, linetype, size, width
Also **geom_errorbarh()**.

j + geom_linerange()
x, ymin, ymax, alpha, color, group, linetype, size

j + geom_pointrange() - x, y, ymin, ymax, alpha, color, fill, group, linetype, shape, size

maps

```
data <- data.frame(murder = USArrests$Murder,
        state = tolower(rownames(USArrests)))
map <- map_data("state")
k <- ggplot(data, aes(fill = murder))
```

k + geom_map(aes(map_id = state), map = map**)**
+ expand_limits(x = map$long, y = map$lat**)**
map_id, alpha, color, fill, linetype, size

THREE VARIABLES

seals$z <- with(seals, sqrt(delta_long^2 + delta_lat^2)); l <- ggplot(seals, aes(long, lat))

l + geom_contour(aes(z = z)**)**
x, y, z, alpha, color, group, linetype, size, weight

l + geom_contour_filled(aes(fill = z)**)**
x, y, alpha, color, fill, group, linetype, size, subgroup

l + geom_raster(aes(fill = z), hjust = 0.5, vjust = 0.5, interpolate = FALSE**)**
x, y, alpha, fill

l + geom_tile(aes(fill = z)**)**
x, y, alpha, color, fill, linetype, size, width

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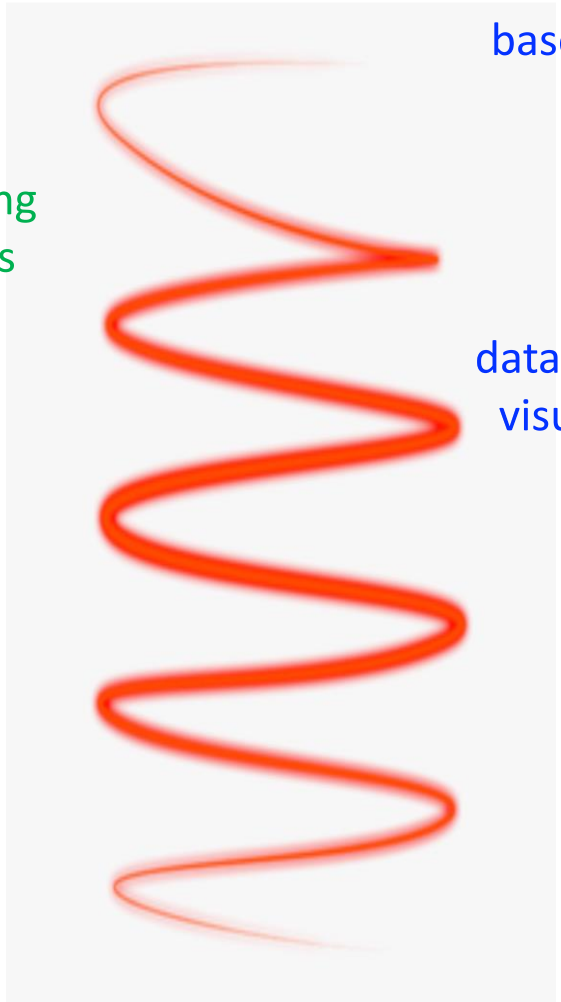
TiME FOR REViEW

What we have covered so far…

1	Aug 31	Course overview, introduction to R, descriptive statistics
2	Sep 5-7	Review of central statistical concepts and exploratory analysis using R
3	Sep 12-14	Confidence Intervals and the bootstrap
4	Sep 19-21	Review of hypothesis tests and permutation tests in R
5	Sep 26-28	Parametric, non-parametric and theories of hypothesis testing
6	Oct 3-5	Data manipulation and visualization
7	Oct 10-12	Review and midterm exam
8	Oct 17-21	Odds and ends, October break



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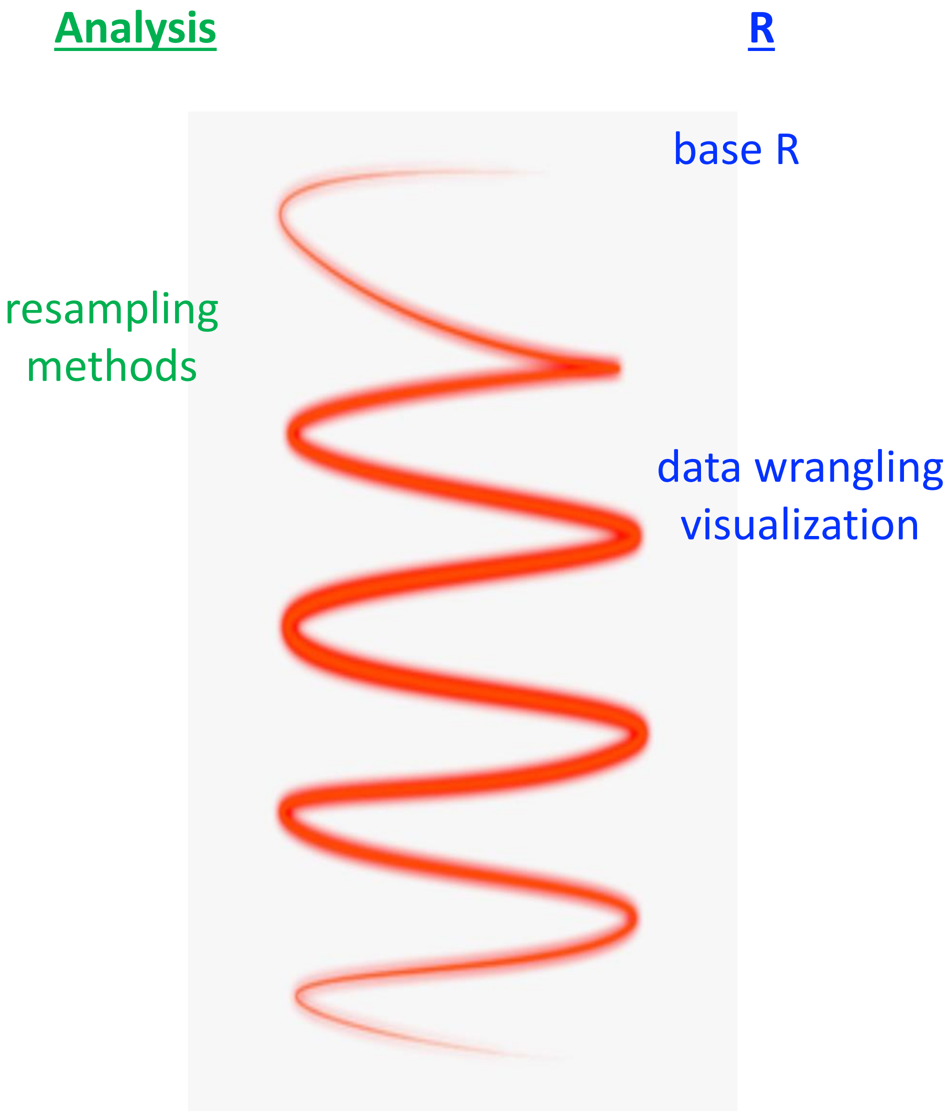


Analysis

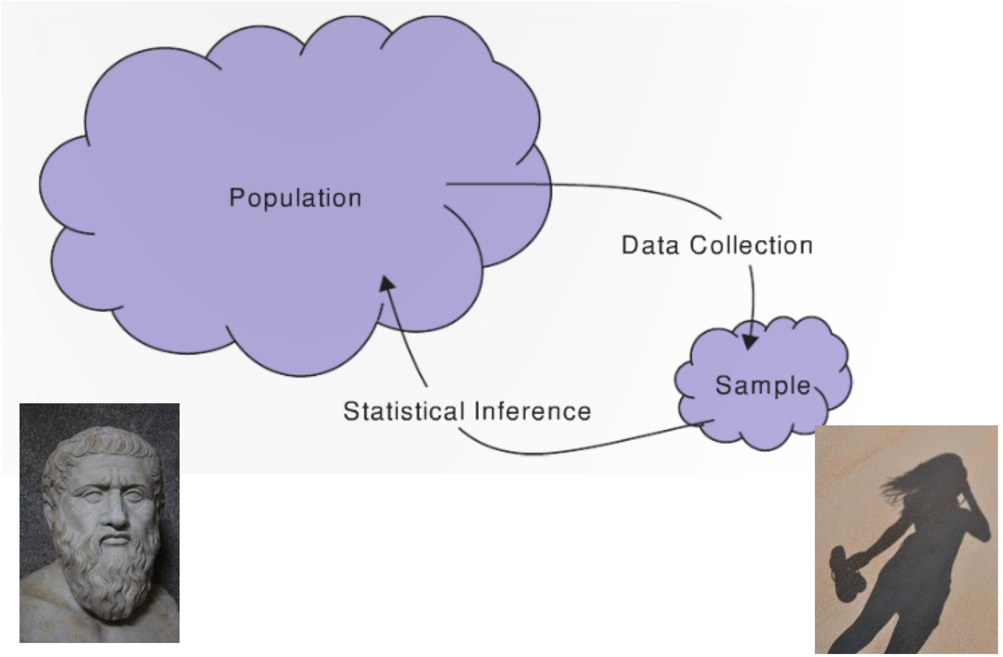
R

base R

resampling methods

data wrangling
visualization

Parameters and statistics commonly used symbols



$$\bar{x} = \frac{\Sigma_i^n x_i}{n}$$

	Population parameter (Plato)	**Sample statistic (shadow)**
Mean	μ	x̄
Standard deviation	σ	s
Proportion	π	p̂
Correlation	ρ	r
Regression slope	β	b

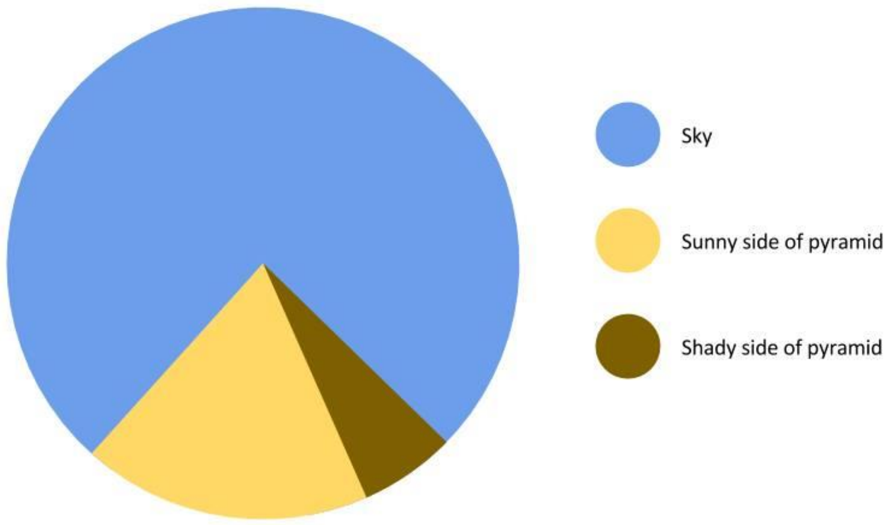
Base R

Basics of R

```
> my_vec <- c(5, 28, 19)
> inds_less_than_10 <- my_vec < 10
```

How to plot data in base R

```
> drinks_table <- table(profiles$drinks)
> barplot(drinks_table)
> pie(drinks_table)
> hist(profiles$height)
```



For loops

```
my_results <- NULL
for (i in 1:100) {
        my_results[i] <- i^2
}
```

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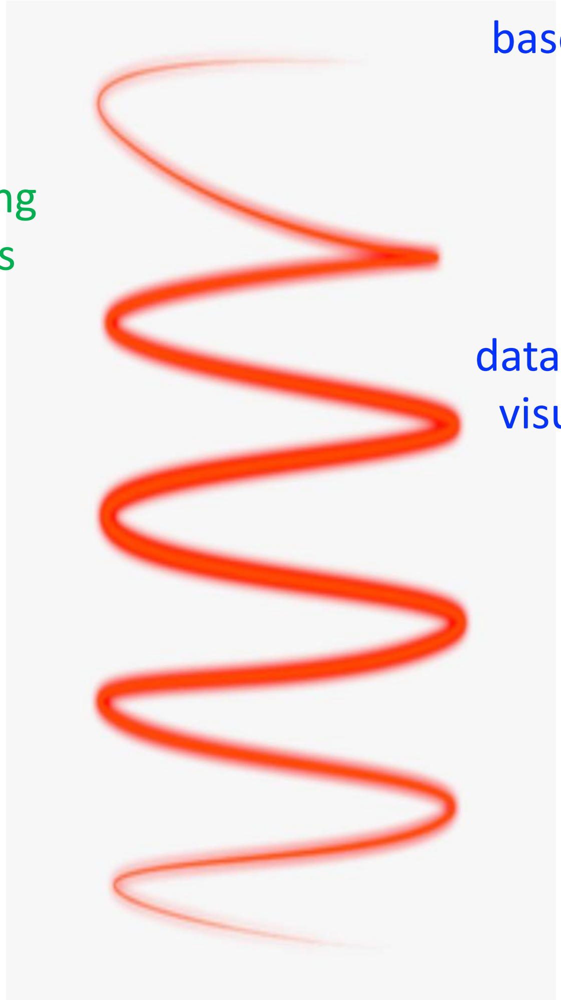
Analysis

R



base R

resampling methods

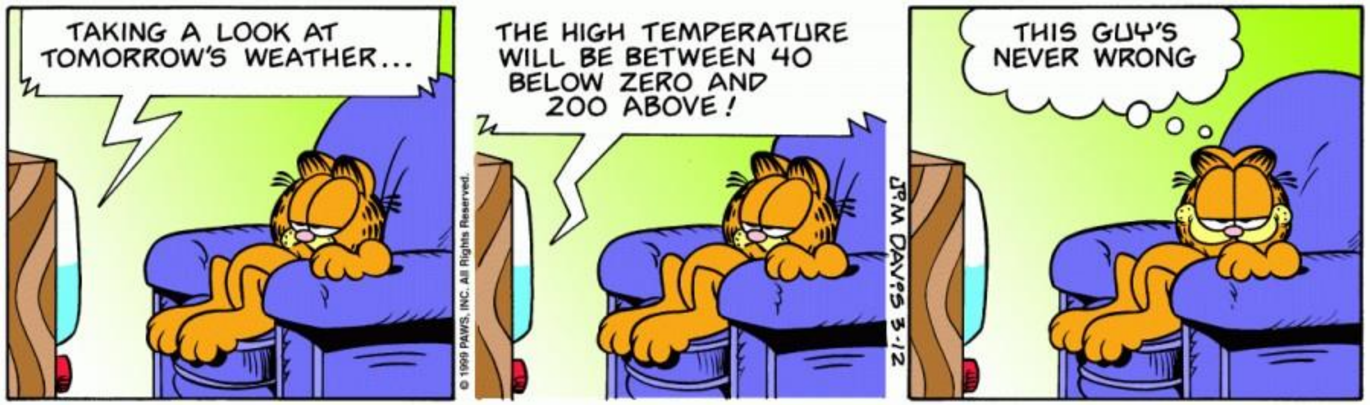
data wrangling visualization

Probability and confidence intervals

Probability functions; e.g.,   rnorm, pnorm, dnorm, qnorm

Confidence intervals:

$$CI_{95} \;=\; \text{stat} \;\pm\; 2 \cdot SE$$


TAKING A LOOK AT TOMORROW'S WEATHER...
THE HIGH TEMPERATURE WILL BE BETWEEN 40 BELOW ZERO AND 200 ABOVE!
THIS GUY'S NEVER WRONG
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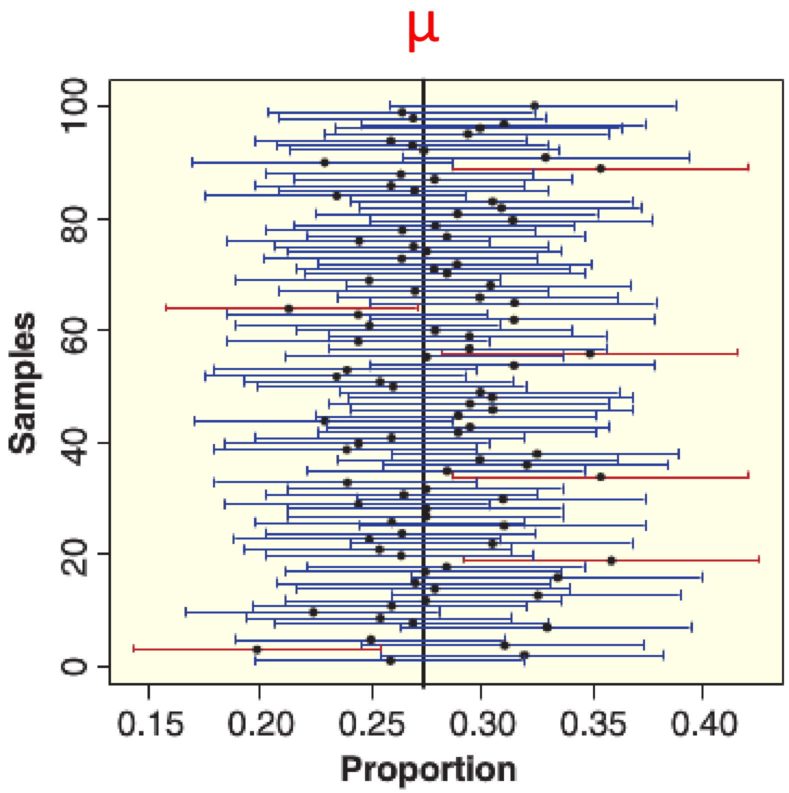
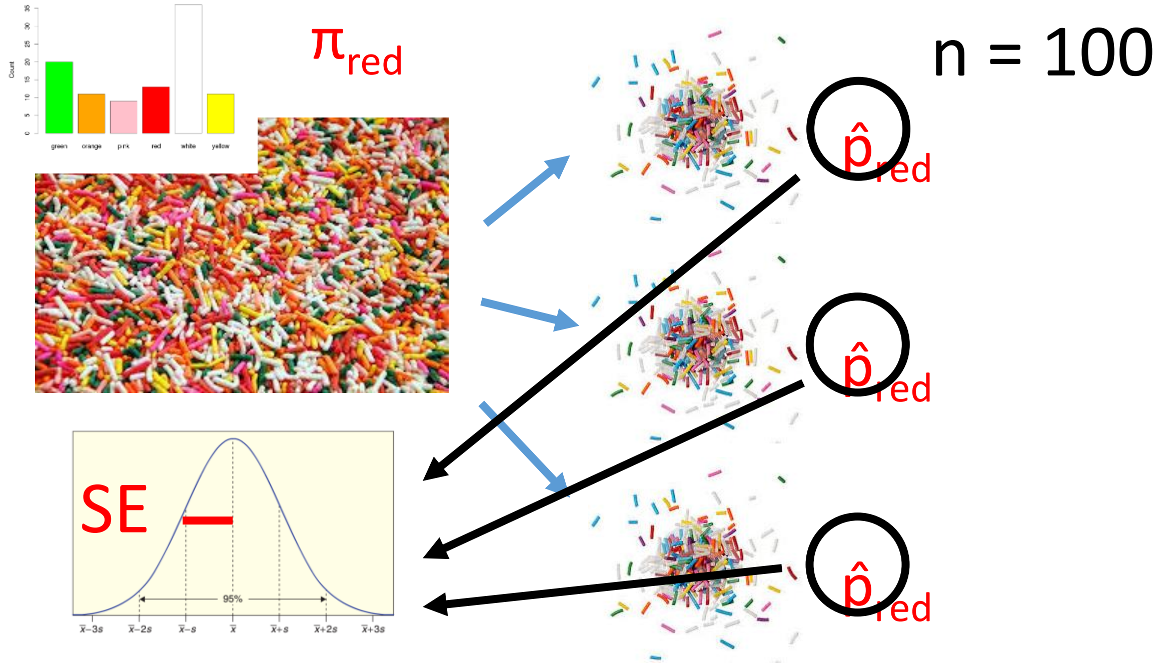
JPM DAVIS 3-12



Sampling and bootstrap distributions

Sampling distribution



π_{red}

n = 100

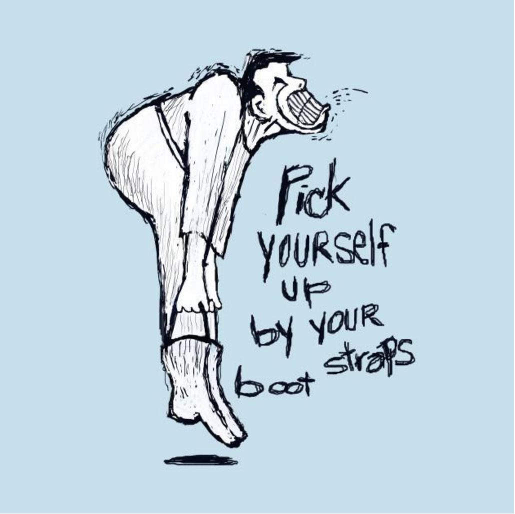
$\hat{p}_{red}$

$\hat{p}_{red}$

$\hat{p}_{red}$

Sampling distribution!

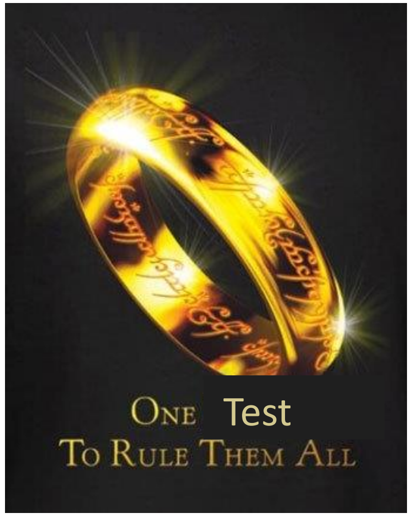
Bootstrap distribution

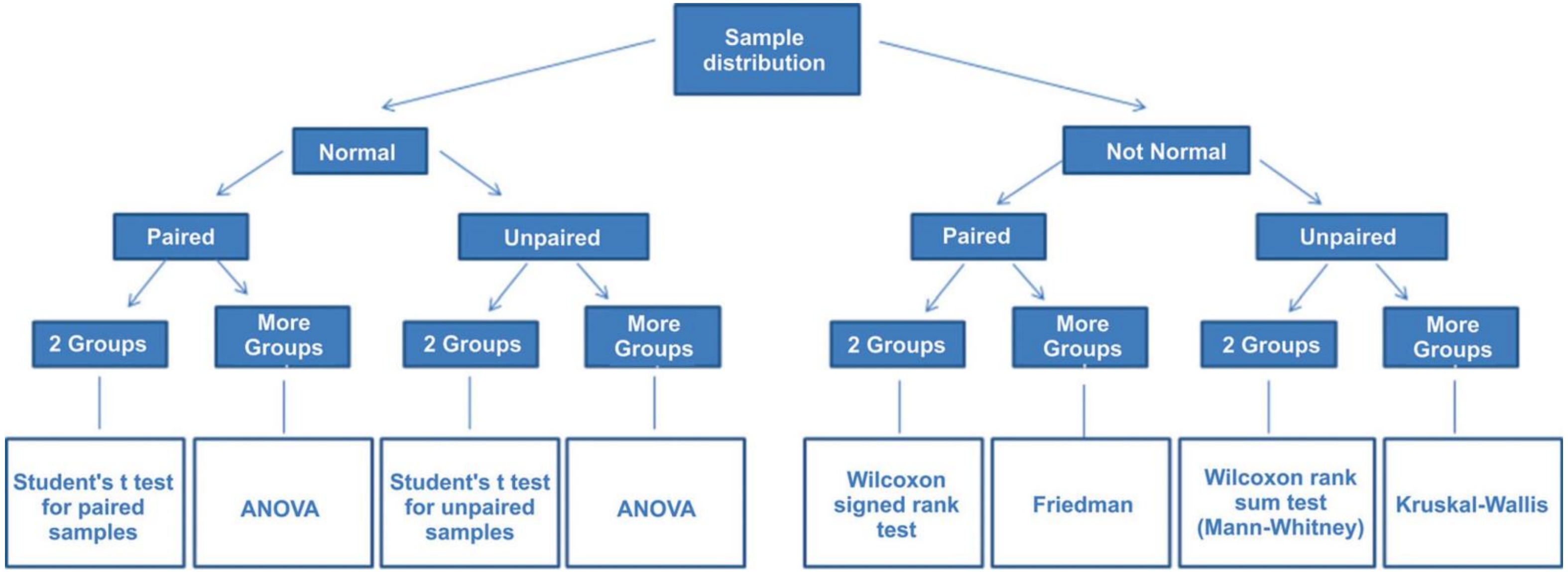


Sample with replacement from our original sample to mimic a sampling distribution

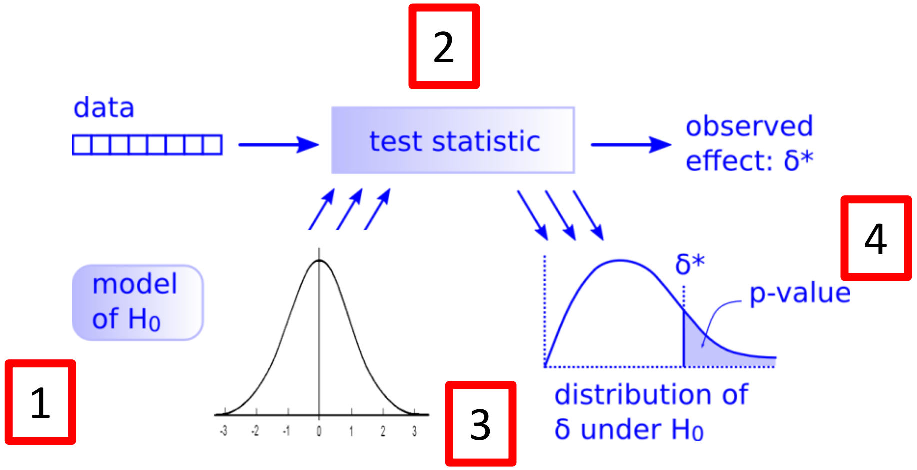
$$CI_{95} = \text{stat} \pm 2 \cdot SE^*$$

Hypothesis tests




- Sample distribution
  - Normal
    - Paired
      - 2 Groups: Student's t test for paired samples
      - More Groups: ANOVA
    - Unpaired
      - 2 Groups: Student's t test for unpaired samples
      - More Groups: ANOVA
  - Not Normal
    - Paired
      - 2 Groups: Wilcoxon signed rank test
      - More Groups: Friedman
    - Unpaired
      - 2 Groups: Wilcoxon rank sum test (Mann-Whitney)
      - More Groups: Kruskal-Wallis

Just need to follow 5 steps!


2

data

test statistic

observed effect: δ*

model of H₀

1

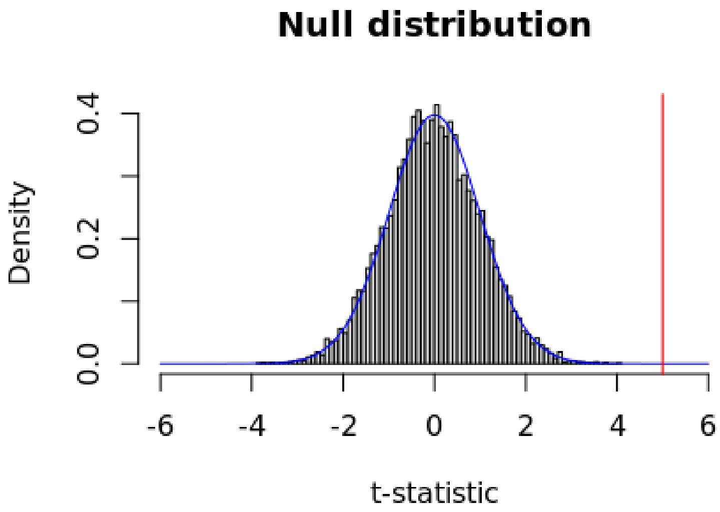
3

δ*

p-value

4

distribution of δ under H₀



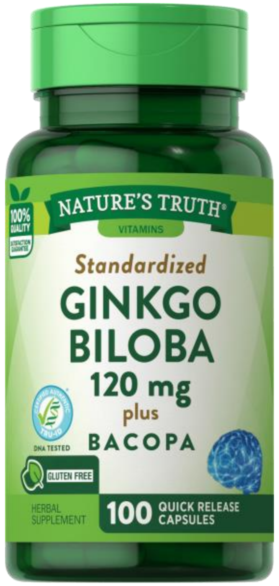
Randomization/permutation tests

Create a null distribution through computational simulations/shuffling

- rbinom(), sample(), etc.

H_0: $\pi = 0.5$
H_A: $\pi > 0.5$

H_0: $\mu_T - \mu_C = 0$
H_A: $\mu_T - \mu_C > 0$



H_0: $\mu_i = \mu_j\ _{...}= ...\ \mu_k$
H_A: $\mu_i \neq \mu_j$ for some i, j

Data	1 Sample	2 Samples	> 2 Samples
Categorical data	H_0: $\pi = p_0$ H_A: $\pi \neq p_0$ Flip "coins" rbinom()	H_0: $\pi_1 = \pi_2$ H_A: $\pi_1 \neq \pi_2$ Flip "coins" rbinom()	H_0: $\pi_1 = p_1$, $\pi_2 = p_2$, … , $\pi_k = p_k$ H_A: At least one p_i is different than specified Flip coins rmultinom()
Quantitative data	H_0: $\mu = v_0$ H_A: $\mu \neq v_0$ resample sample(… , replace = TRUE)	H_0: $\mu_1 = \mu_2$ H_A: $\mu_1 \neq \mu_2$ Shuffle data sample()	H_0: $\mu_1 = \mu_2 = … = \mu_k$ H_A: At least one μ_i is different Shuffle data sample()

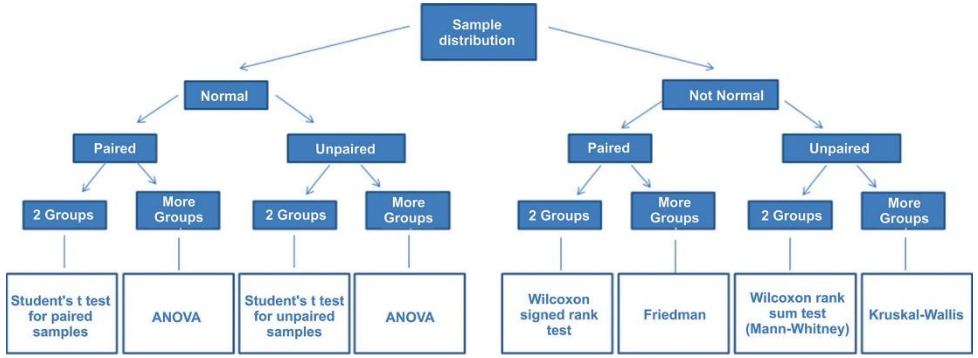
Parametric tests

Use mathematical density functions for the null distribution

H_0: $\mu_T - \mu_C = 0$

H_A: $\mu_T - \mu_C > 0$

$$t = \frac{\bar{x}_t - \bar{x}_c}{\sqrt{\frac{s_t^2}{n_t} + \frac{s_c^2}{n_c}}}$$



Sample distribution

Normal

Paired

2 Groups – Student's t test for paired samples

More Groups – ANOVA

Unpaired

2 Groups – Student's t test for unpaired samples

More Groups – ANOVA

Not Normal

Paired

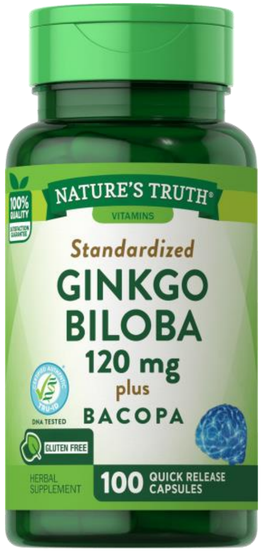
2 Groups – Wilcoxon signed rank test

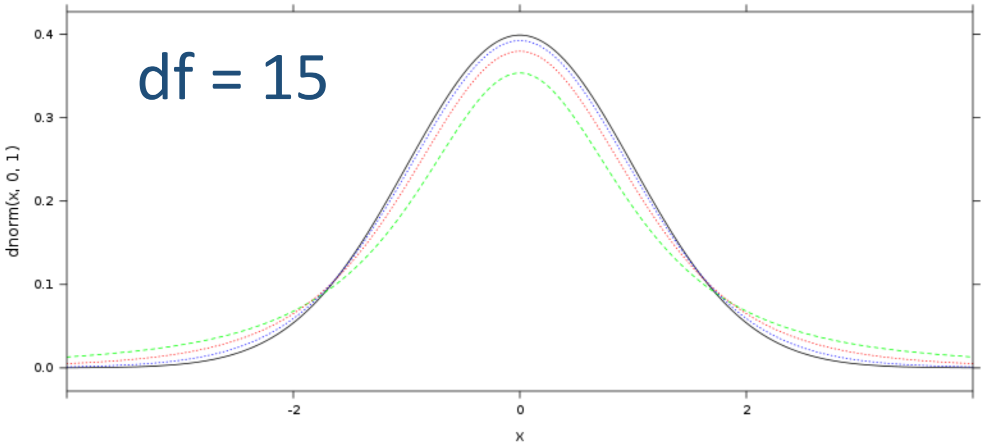
More Groups – Friedman

Unpaired

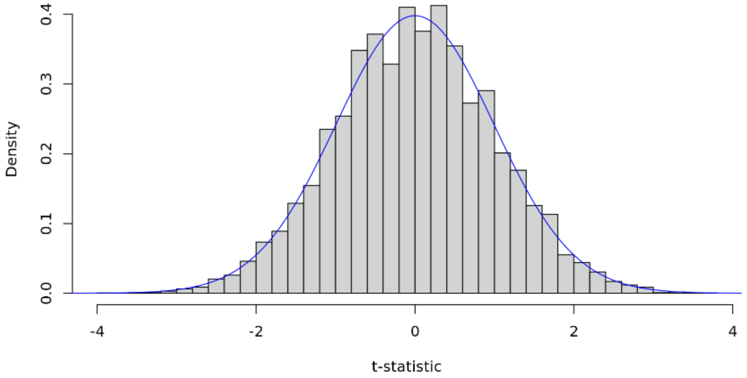
2 Groups – Wilcoxon rank sum test (Mann-Whitney)

More Groups – Kruskal-Wallis





df = 15



Data	1 Sample	2 Samples	> 2 Samples
Categorical data	H_0: π = p_0 H_A: π ≠ p_0 z-test $z = \frac{\hat{p}-p_0}{\sqrt{\frac{p_0(1-p_0)}{n}}}$	H_0: π_1 = π_2 H_A: π_1 ≠ π_2 z-test or a chi-square $z = \frac{\hat{p_1} - \hat{p_2}}{\sqrt{\frac{\hat{p_1}(1-\hat{p_1})}{n_1} + \frac{\hat{p_2}(1-\hat{p_2})}{n_2}}}$	H_0: $\pi_1 = p_1$, $\pi_2 = p_2$, … , $\pi_k = p_k$ H_A: At least one p_i is different than specified chi-square test $\chi^2 = \sum_{i=1}^{k} \frac{(Observed_i - Expected_i)^2}{Expected_i}$ df = k - 1
Quantitative data	H_0: μ = v_0 H_A: μ ≠ v_0 One sample t-test $t = \frac{\bar{x}-v_0}{s/\sqrt{n}}$ df = n - 1	H_0: μ_1 = μ_2 H_A: μ_1 ≠ μ_2 Two sample t-test $t = \frac{\bar{x}_1-\bar{x}_2}{\sqrt{\frac{s_1^2}{n_1}+\frac{s_2^2}{n_2}}}$ df = min n_1 - 1, n_2 - 1	H_0: μ_1 = μ_2 = … = μ_k H_A: At least one μ_i is different Analysis of Variance $F = \frac{\frac{1}{K-1}\sum_{i=1}^{K} n_i(\bar{x}_i - \bar{x}_{tot})^2}{\frac{1}{N-K}\sum_{i=1}^{K}\sum_{j=1}^{n_i}(x_{ij} - \bar{x}_i)^2}$ df_1 = k, df_2 = n - k

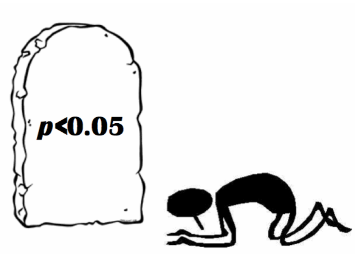
Data	1 Sample	2 Samples
Categorical Data	$SE = \sqrt{\frac{\pi(1-\pi)}{n}}$ $\hat{p} \pm z^* \cdot \sqrt{\frac{\hat{p}(1-\hat{p})}{n}}$	$SE = \sqrt{\frac{\pi_1(1-\pi_1)}{n_1} + \frac{\pi_2(1-\pi_2)}{n_2}}$ $\hat{p_1} - \hat{p_2} \pm z^* \sqrt{\frac{\hat{p_1}(1-\hat{p_1})}{n_1} + \frac{\hat{p_2}(1-\hat{p_2})}{n_2}}$
Quantitative Data	$SE = \frac{s}{\sqrt{n}}$ $\overline{x} \pm t^* \frac{s}{\sqrt{n}}$	$SE = \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$ $(\overline{x_1} - \overline{x_2}) \pm t^* \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$

Theories of hypothesis testing

Fisher (1890-1962)

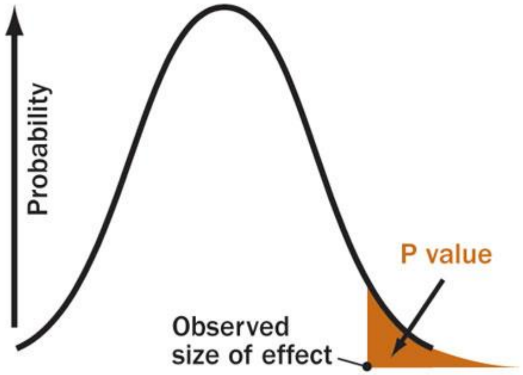
Neyman (1894-1981)

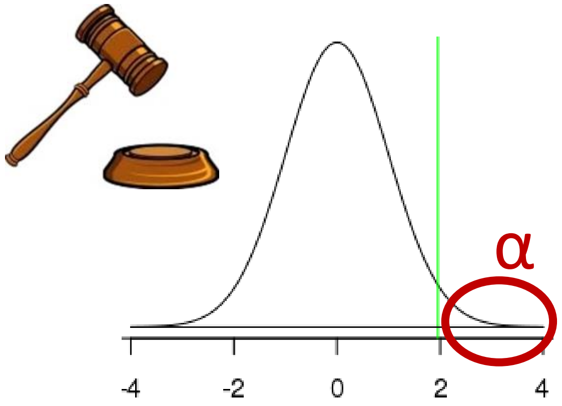
Pearson (1895-1980)

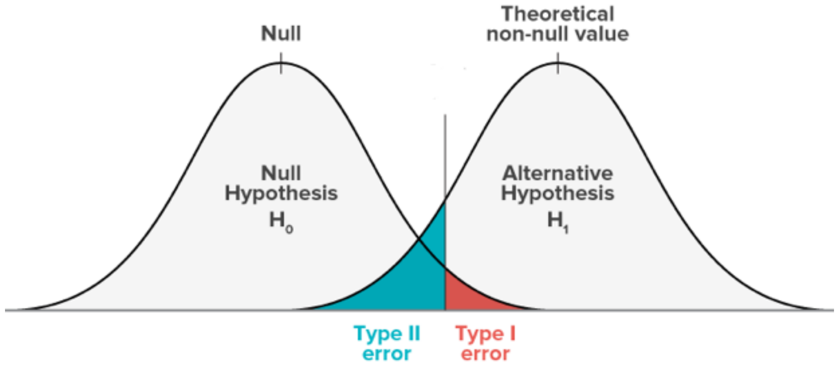


p-value a strength of evidence

Use p-value to make a decision







Data manipulation with dplyr

dplyr is a package that has a set of verbs for transformations data

- All these function **take a data frame** and other arguments and **return a data frame**

1. filter()
2. select()
3. mutate()
4. arrange()
5. summarize()
6. group_by()

```
film_results <- movies |>
    filter(title_type == "Feature Film") |>
    select(critics_score, audience_score, genre) |>
     mutate(audience_prefers =
            audience_score - critics_score) |>
     group_by(genre) |>
      summarize(mean_audience_prefers =
             mean(audience_prefers)) |>
       arrange(desc(mean_audience_prefers))

head(film_results )
```

Grammar of graphics with ggplot

A Frame: Coordinate system on which data is placed

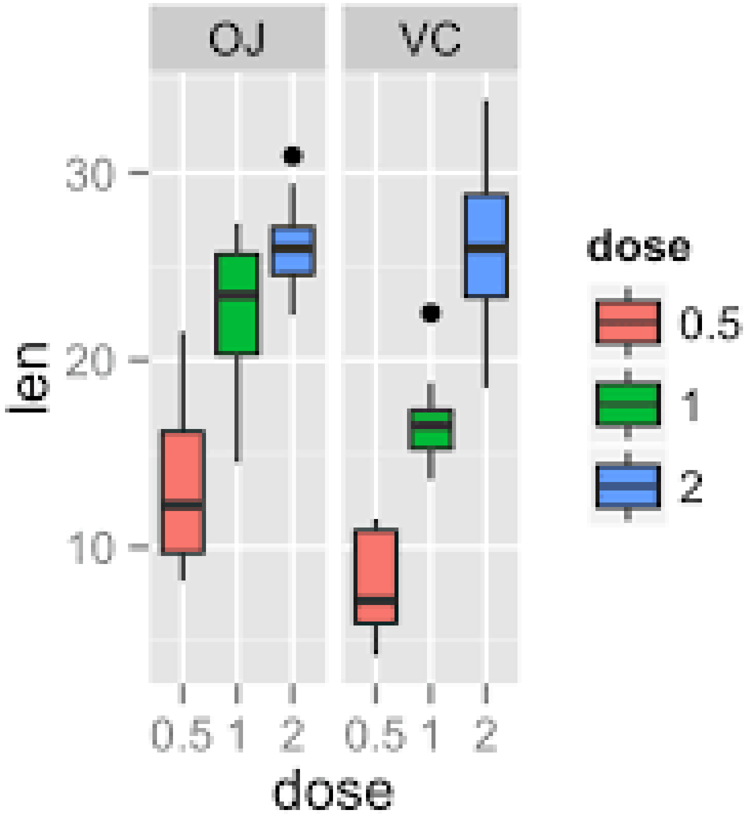
Glyphs: basic graphic unit representing cases or statistics

Scales and guides: shows how to interpret axes and other properties of the glyphs

Facets: allows for multiple side-by-side graphs based on a categorical variable

Layers: allows for more than one types of data to be mapped onto the same figure

Theme: contains finer points of display (e.g., font size, background color, etc.)



Questions