UCLA QCBio Collaboratory

# Introduction to R and data visualization

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2024 Spring

UCLA Bioinformatics

# Notation of the slides

- `Code` or `Pseudo-Code` chunk starts with " ➢ ", e.g.
  - `print("Hello world!")`

- Link is underlined

- Important terminology is in **bold** font

- Practice comes with

# Agenda

- Day 1: R basics
  - Environment setup
  - Variable, Operators
  - Data structure: Vector, Matrix, List, Data frame

- Day 2: R advanced topics
  - Flow control, Loops
  - Function, Packages, File Input/Output
  - Data wrangling with tidyverse toolkit

- Day 3: Data visualization with ggplot2
  - ggplot2 syntax, grammar, and elements
  - Basic plot types and customization


Image from internet

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# Day 2: R advanced topics

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# Overview

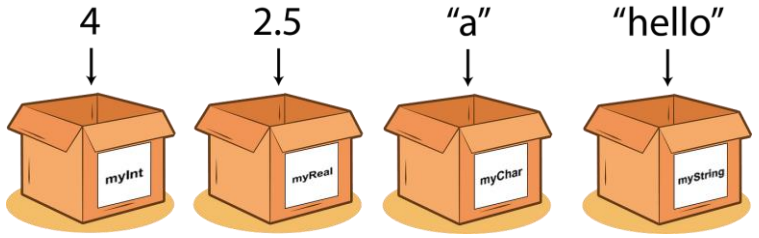
## Time

- 3-hour workshop (45min + 45min + 30min + practice/Q&A)

## Topics

- ❑Flow control, Loops
- ❑Function, Packages, File Input/Output
- ❑Data Wrangling with tidyverse toolkit

# Summary – Day1

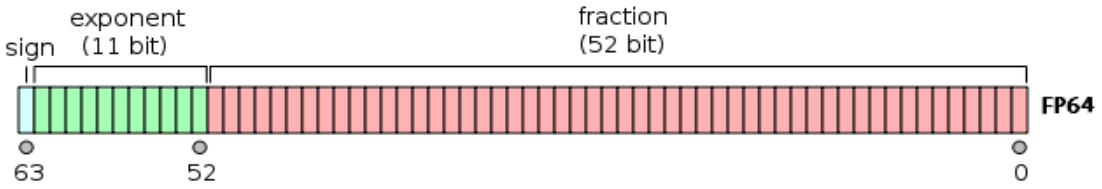



**Variables**: the container of data

- ❑ Naming rules
- ❑ Value assignment
- ❑ Variable classes
- ❑ Inspecting the variable
- ❑ Inspecting the workspace

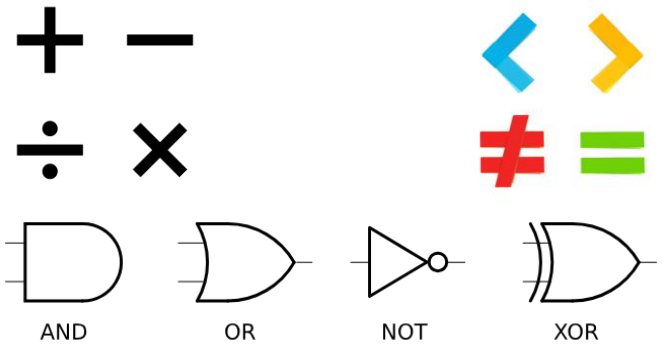
Numbers

- ❑ Number representation
- ❑ Special numbers




$$\pm d_0 . d_1 d_2 \cdots d_p \times b^e$$

# Summary – Day1




## **Operators**: the actions on variables

- ❑ Arithmetic
- ❑ Relational
- ❑ Logical
- ❑ Operator's precedence

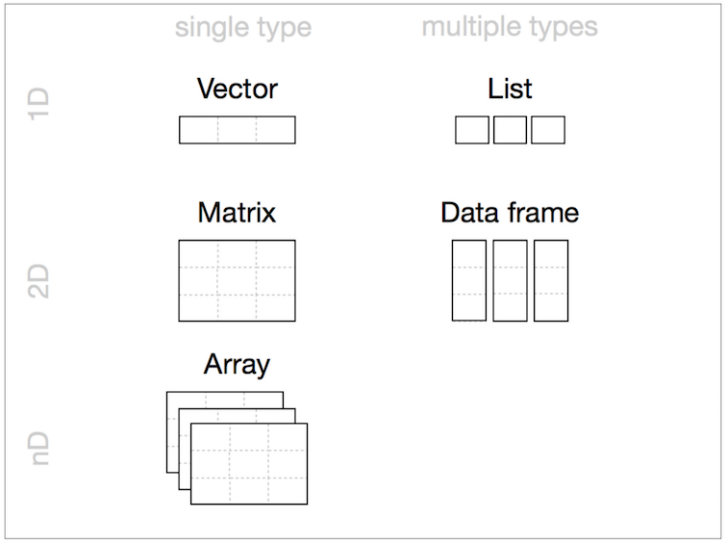
| Operator | Description |
|---|---|
| + | addition |
| - | subtraction |
| * | multiplication |
| / | division |
| ^ or ** | exponentiation |
| x %% y | modulus (x mod y) 5%%2 is 1 |
| x %/% y | integer division 5%/%2 is 2 |

| Operator | Description |
|---|---|
| < | less than |
| <= | less than or equal to |
| > | greater than |
| >= | greater than or equal to |
| == | exactly equal to |
| != | not equal to |
| !x | Not x |
| x \| y | x OR y |
| x & y | x AND y |
| isTRUE(x) | test if X is TRUE |

| Precedence | Operator | Description |
|---|---|---|
| 18 | :: ::: | access variables in a namespace |
| 17 | $ @ | component / slot extraction |
| 16 | [ ] [[ ]] | indexing |
| 15 | ^ | Exponentiation operator (Right to Left) |
| 14 | +a -a | Unary plus, Unary minus |
| 13 | : | Sequence operator |
| 12 | %% %*% %/% %in% %o% %x% | Special operators |
| 11 | * / | Multiplication, Division |
| 10 | + - | Addition, Subtraction |
| 9 | < <= > >= | Less than, Less than or equal, Greater than, and Greater than or equal |
| | == != | Equality and Inequality |
| 8 | ! | Logical NOT |
| 7 | & && | Logical AND |
| 6 | \| \|\| | Logical OR |
| 5 | ~ | as in formulae |
| 4 | -> ->> | Right assignment operator, Global right assignment operator |
| 3 | <- <<- | Left assignment operator, Global left assignment operator (Right to Left) |
| 2 | = | Left assignment operator (Right to Left) |
| 1 | ? | help (unary and binary) |

Top to bottom in **descending precedence**

# Summary – Day1




**R objects**: data container

- ❑ Vectors
- ❑ String and Factor
- ❑ Matrix
- ❑ List
- ❑ Data frame

Operations on the R objects

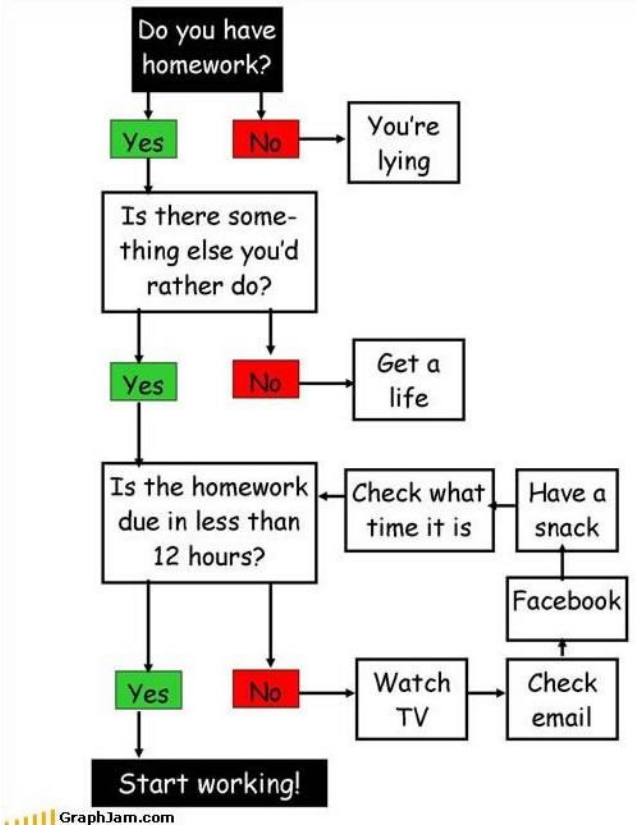
- ❑ Create
- ❑ Indexing
- ❑ Update
- ❑ …

R as a scientific calculator

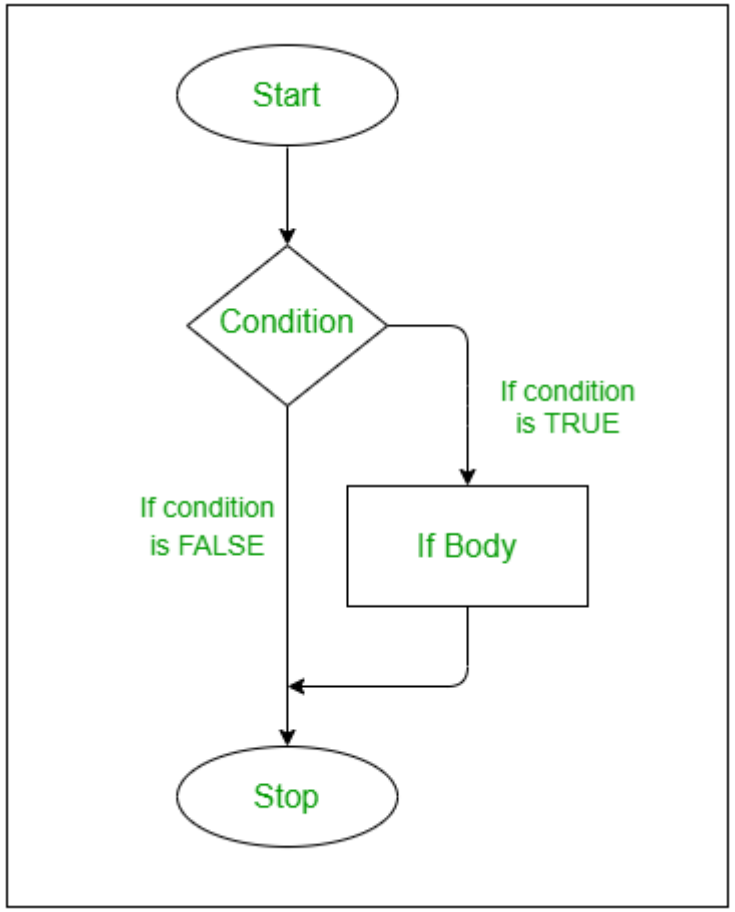
- ❑ R/RStudio environment setup
- ❑ Get help in R
- ❑ Interesting examples

# Flow control

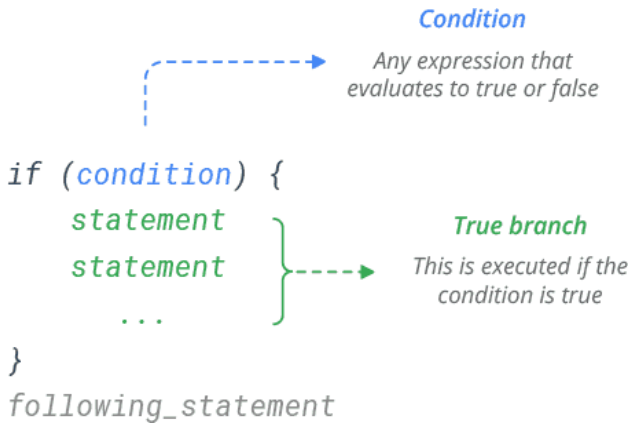
"When in Rome, do as the Romans do."



# `if` statement




**Syntax:**




**Example:**

```r
x <- 3
if(x > 2)
{
  y <- 2 * x
  z <- 3 * y
}
```

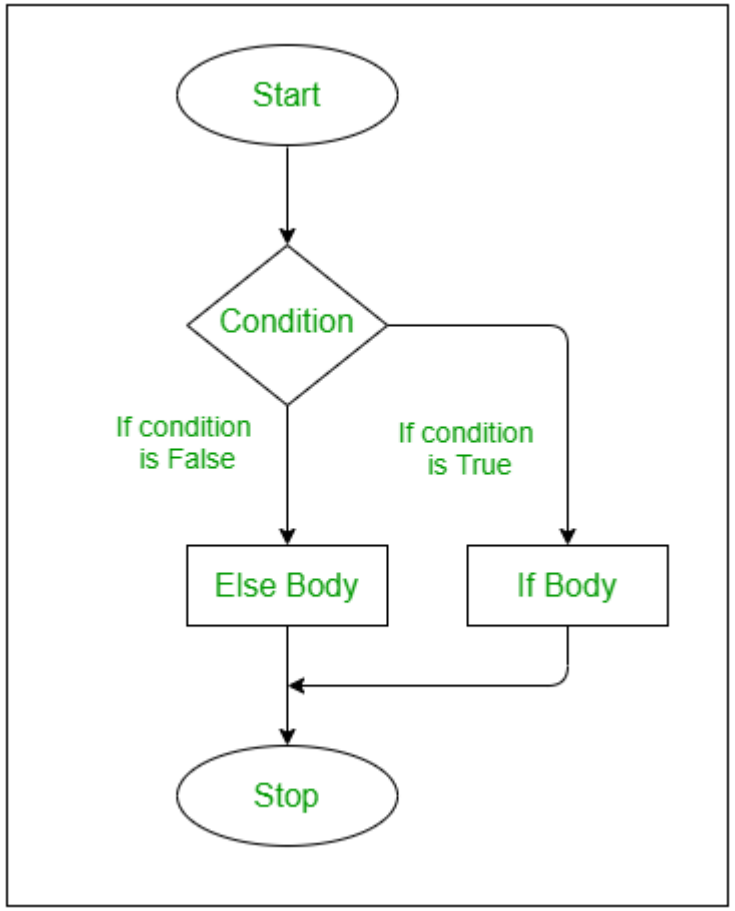
Note:

- Condition is a logical value (a logical vector of length one)
- Passing missing value to `if()` is not allowed



Image from internet

# `if-else` statement




**Syntax:**

```
if (condition) {
   statement
   statement
      ...
} else {
   statement
   statement
      ...
}
following_statement
```

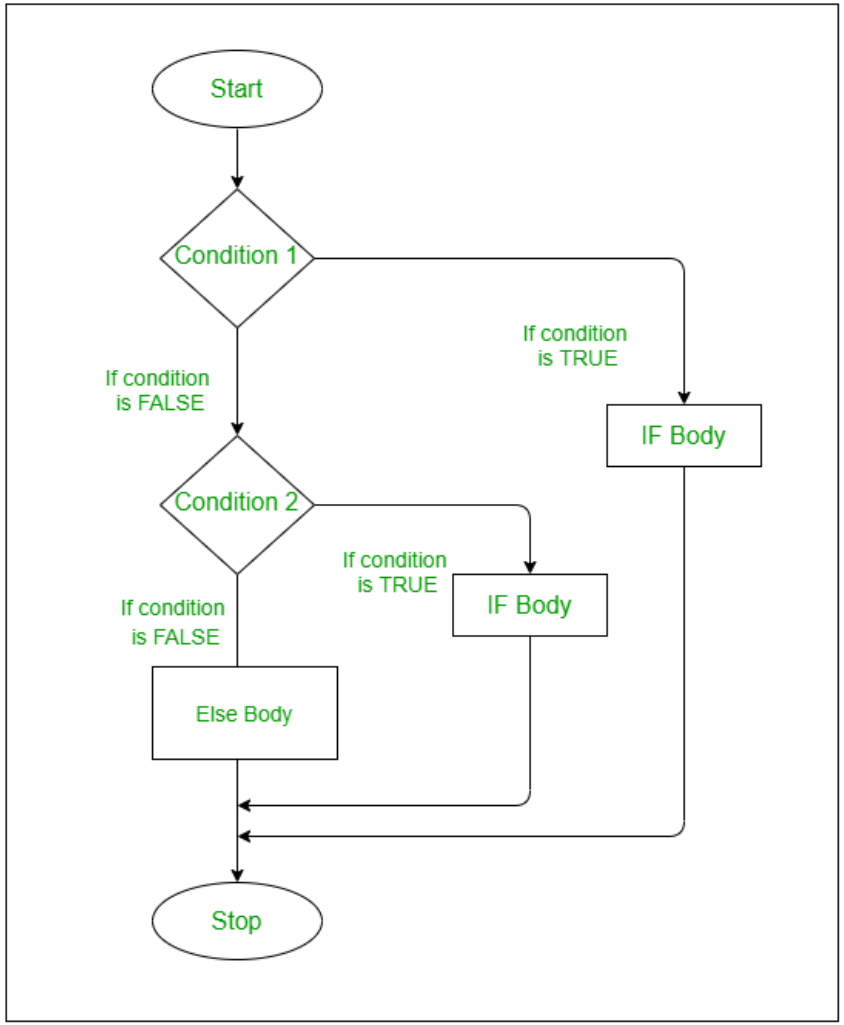
*True branch*: *This is executed if the condition is true*

*False branch*: *This is executed if the condition is false*

Note:

- Condition is a logical value (a logical vector of length one)
- Passing missing value to `if()` is not allowed
- `else` statement must occur on the same line as the closing curly brace from the if clause

# if-else if-else statement




**Syntax:**

```
if (condition) {
    statement
    statement
      ...
} else if (condition) {
    statement
    statement
      ...
} else {
    statement
    statement
      ...
}
following_statement
```

*First condition*
*This is executed if the first condition is true*

*New condition*
*A new condition to test if previous condition isn't true*

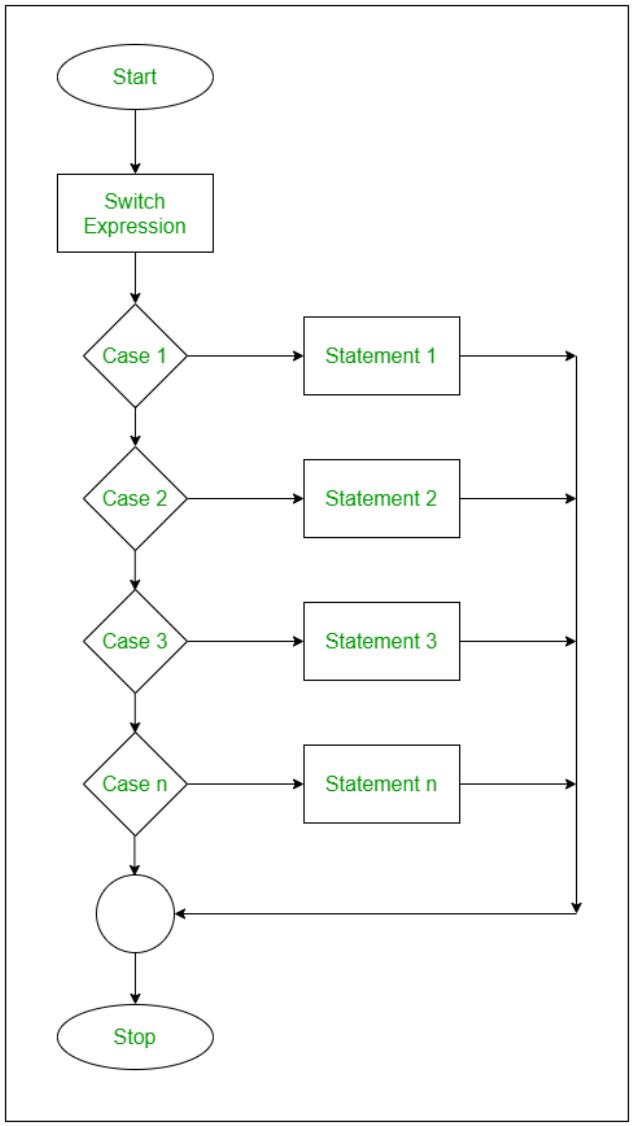
*False branch*
*This is executed if none of the conditions are true*

**Example:**

Stacking **if/else** statements be like

```
if(is.nan(x))
{
  message("x is missing")
} else if(is.infinite(x))
{
  message("x is infinite")
} else if(x > 0)
{
  message("x is positive")
} else if(x < 0)
{
  message("x is negative")
} else
{
  message("x is zero")
}
```

# `switch` staement




**Syntax:**

```
variable <- switch(expression, val1, val2, ...)
```

*Expression*

*It can be either a number or a character*

*List of values*

*Value is selected based on the name or position*

**Example:**

```r
day_of_week_if_else <- function(day) {
  if (day == 1) {
    result <- "Monday"
  } else if (day == 2) {
    result <- "Tuesday"
  } else if (day == 3) {
    result <- "Wednesday"
  } else if (day == 4) {
    result <- "Thursday"
  } else if (day == 5) {
    result <- "Friday"
  } else if (day == 6) {
    result <- "Saturday"
  } else if (day == 7) {
    result <- "Sunday"
  } else {
    result <- "Invalid day"
  }
  return(result)
}
```

```r
day_of_week_switch <- function(day) {
  result <- switch(as.character(day),
                   "1" = "Monday",
                   "2" = "Tuesday",
                   "3" = "Wednesday",
                   "4" = "Thursday",
                   "5" = "Friday",
                   "6" = "Saturday",
                   "7" = "Sunday",
                   "Invalid day")
  return(result)
}
```

# Other usage

- `if-else` assignment in one line

```
variable <- if (condition) Statement else Statement;
```

**True branch**
*Execute this if the condition is true*

**False branch**
*Execute this if the condition is false*

- Vectorized `if-esle`

```
ifelse (condition, TrueVector, FalseVector)
```

**Condition**
*Condition is checked for every element of a vector*

**True branch**
*Select element from this if the condition is true*

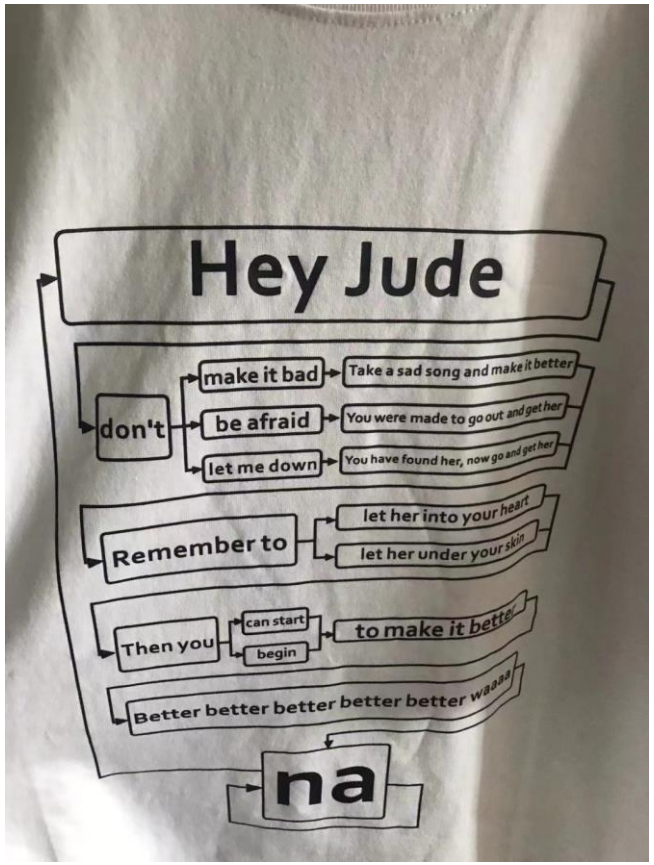
**False branch**
*Select element from this if the condition is false*

# Let’s do some practice!

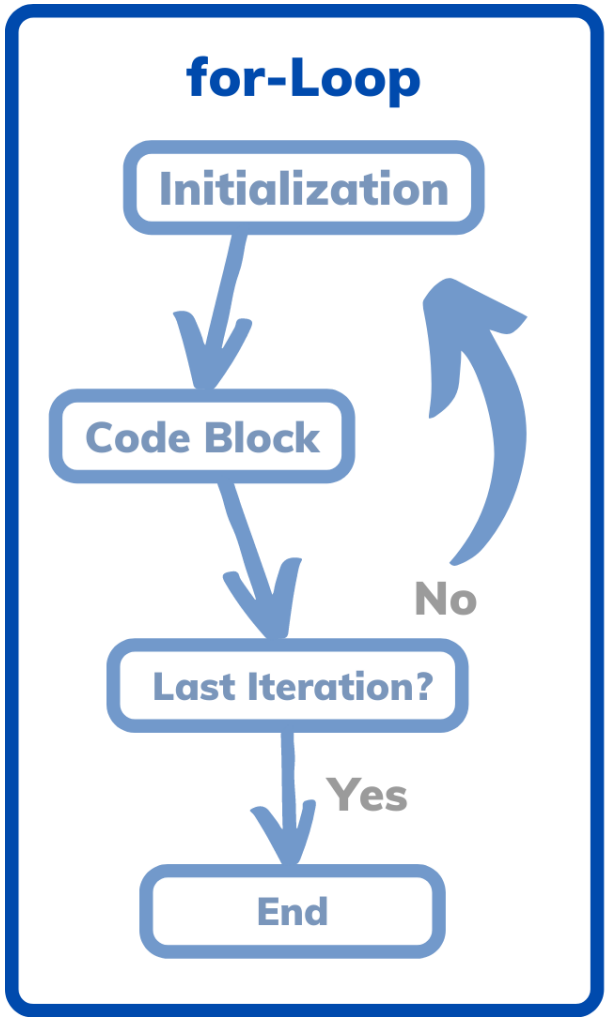
- `git clone https://github.com/wbvguo/qcbio-Intro2R.git`

# Loops

"History repeats itself"



# for loop




**Syntax:**

*Var*
*It takes items from iterable one by one*

*Iterable*
*It's a collection of objects (like a vector, list etc.)*

```
for (var in iterable) {
    statement
    statement
       ...
}
following_statement
```

*Loop body*
*It is executed once for each item in iterable*

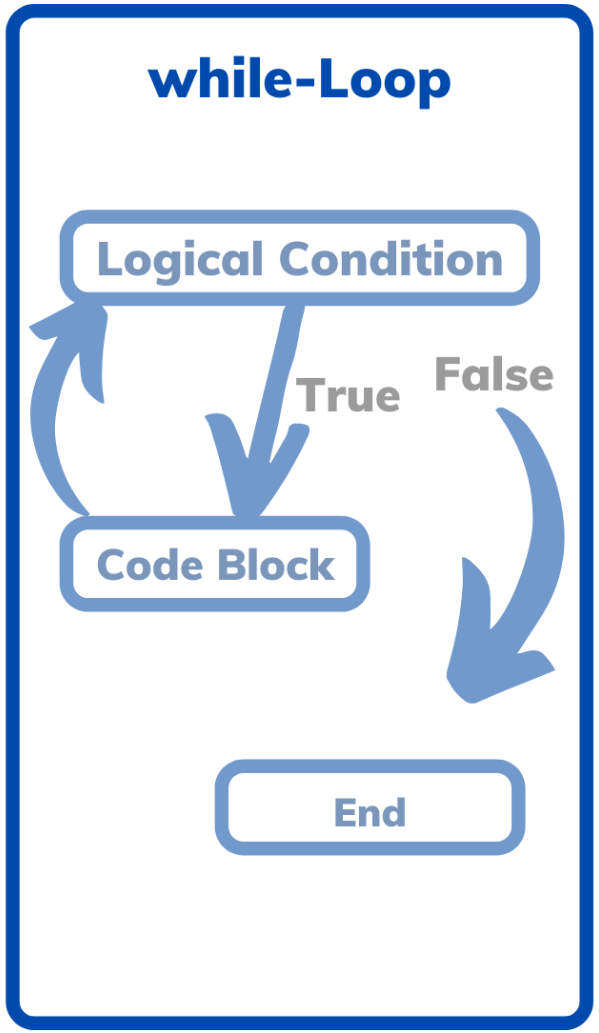
**Example:**

```
for(i in 1:5)
{
  j <- i ^ 2
  message("j = ", j)
}
```

```
## j = 1
## j = 4
## j = 9
## j = 16
## j = 25
```

https://universeofdatascience.com/loops-in-r-for-while-repeat/

# `while` loop




**Syntax:**

```
while (condition) {
    statement
    statement
       ...
}
following_statement
```

*Condition*
*Any expression that evaluates to true or false*

*Loop body*
*It is executed as long as the condition is true*

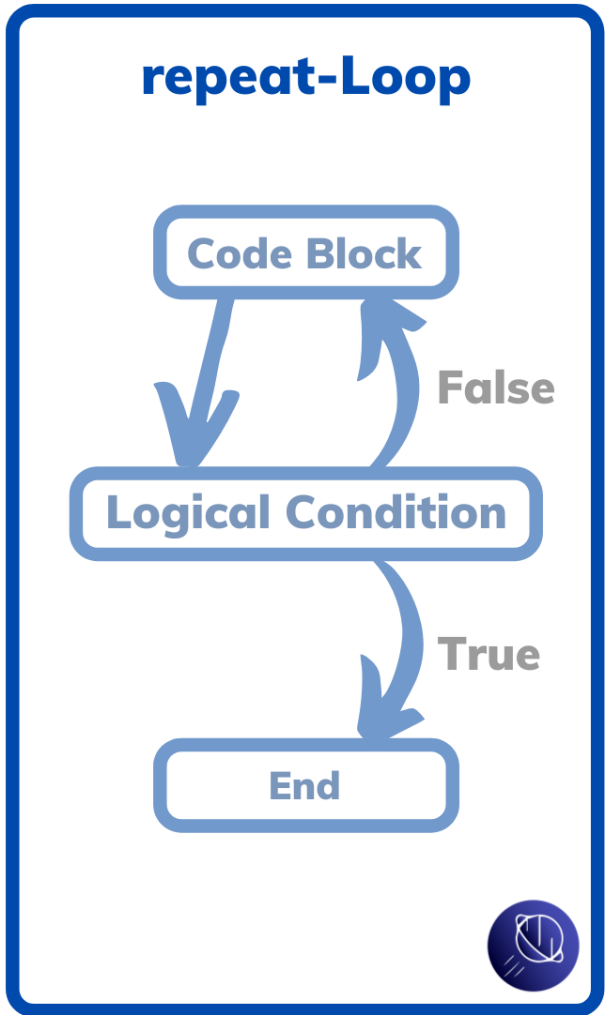
**Example:**

```
while(alive)
{
   eat();
   sleep();
   code();
}
```

## Try it out

- Implement previous example using while loop

# Repeat




**Syntax:**

```
repeat {
    statement
    statement
       ...
}
following_statement
```

*Loop body*
*Repeat this block of code indefinitely*

## Try it out

- Implement previous example using while loop

# The apply family


"There is more than one ways to do it"

- `lapply()`: list apply
- `sapply()`: simplifying list apply
- `tapply()`: table apply
- `apply()`: data frame/matrix apply

```r
prime_factors <- list(
  two   = 2,
  three = 3,
  four  = c(2, 2),
  five  = 5,
  six   = c(2, 3),
  seven = 7,
  eight = c(2, 2, 2),
  nine  = c(3, 3),
  ten   = c(2, 5)
)
```

for

```r
unique_primes <- vector("list", length(prime_factors))
for(i in seq_along(prime_factors))
{
  unique_primes[[i]] <- unique(prime_factors[[i]])
}
names(unique_primes) <- names(prime_factors)
```

apply

```r
lapply(prime_factors, unique)
```

There are other functions `mapply()`, `vapply()`...check them out with `?fun_name`



Image from Internet

# lapply

`lapply()` takes a list and a function as inputs, applies the function to each element of the list in turn, and returns another list of results

```
lapply(x,FUN,…)
```

## Parameters

| Parameter | Condition | Description |
|---|---|---|
| x | Required | A list |
| FUN | Required | The function to be applied |
| ... | Optional | Any other arguments to be passed to the FUN function |

# sapply

`sapply()` basically works the same as `lapply()`, but tries to simplify the result as vector or matrix

- if return value is the same length across elements (if length is 1, return vector, else matrix)
- If the return value is not always the same length, return list

```
sapply(x,FUN,…)
```

Parameters

| Parameter | Condition | Description |
|---|---|---|
| x | Required | A list |
| FUN | Required | The function to be applied |
| ... | Optional | Any other arguments to be passed to the FUN function |

# tapply

`tapply()` breaks the data set up into groups and applies a function to each group

```
tapply(x,INDEX,FUN,…,simplify)
```

## Parameters

| Parameter | Condition | Description |
|---|---|---|
| x | Required | A vector |
| INDEX | Required | A grouping factor or a list of factors |
| FUN | Required | The function to be applied |
| … | Optional | Any other arguments to be passed to the FUN function |
| simplify | Optional | Returns simplified result if set to TRUE.<br>Default is TRUE. |

# apply

The `apply` function provides the row/column-wise equivalent of `lapply()`

```
apply(x,MARGIN,FUN,…)
```

Parameters

| Parameter | Condition | Description |
|---|---|---|
| x | Required | A matrix , data frame or array |
| MARGIN | Required | A vector giving the subscripts which the function will be applied over.<br>1 indicates rows<br>2 indicates columns<br>c(1, 2) indicates rows and columns |
| FUN | Required | The function to be applied |
| ... | Optional | Any other arguments to be passed to the FUN function |

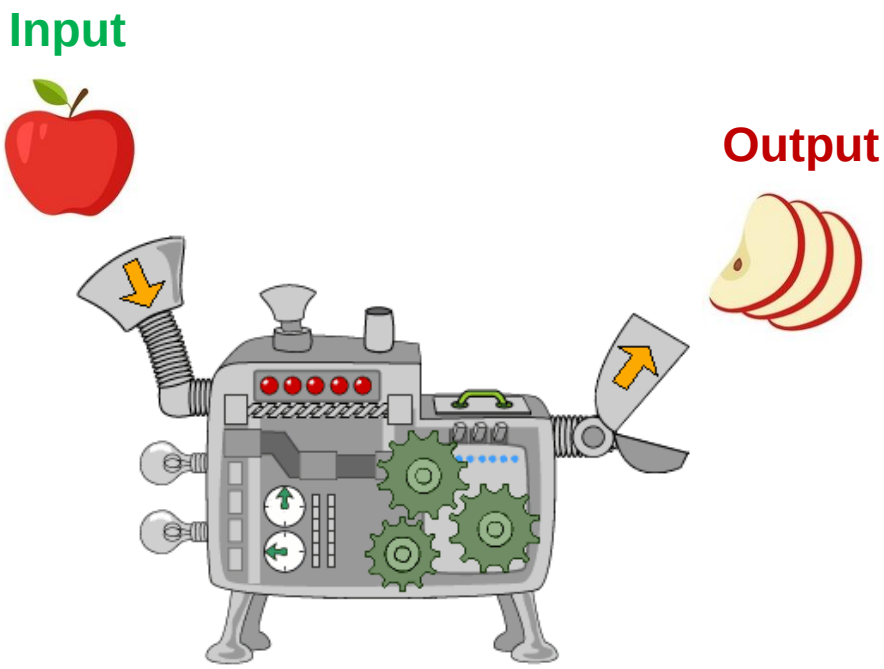
## Question:

1. how to calculate the row sum of a matrix using apply?
2. How to standardize the rows of a matrix? (mean 0, standard deviation 1)

# Let’s do some practice!

- `git clone https://github.com/wbvguo/qcbio-Intro2R.git`

# Function

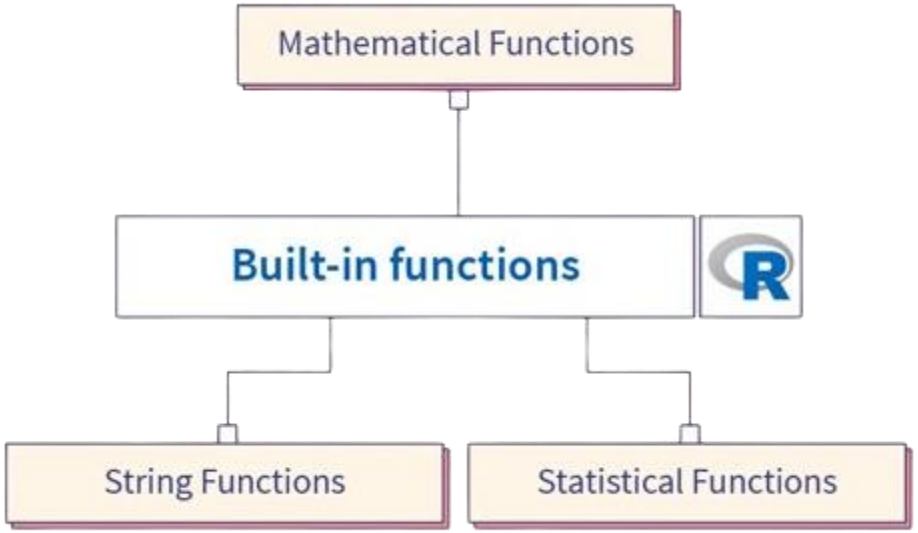



Variables stores data (nouns), functions let us do things with data (verbs)



Image from Internet

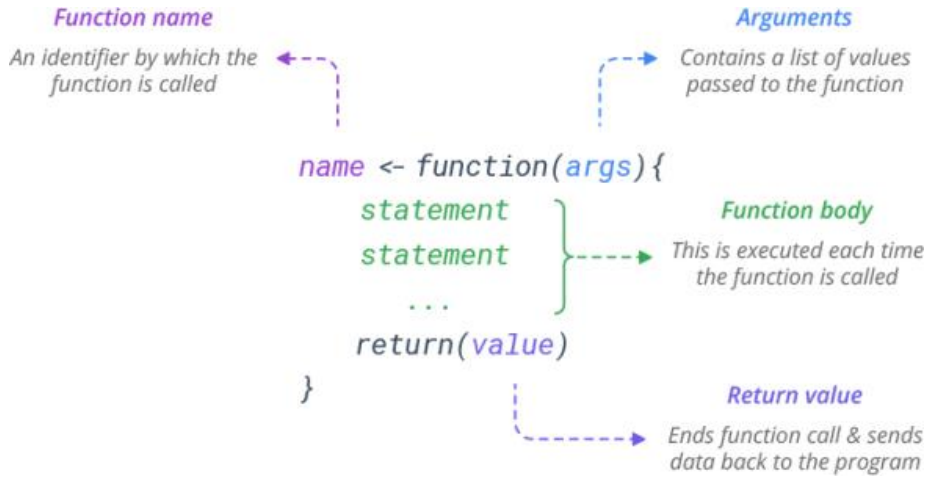
# Built-in functions




| Category | Function Name | Description |
|---|---|---|
| **Math** | abs() | Calculates the absolute value of a numeric vector. |
| | sqrt() | Computes the square root of each element in a numeric vector. |
| | sum() | Computes the sum of the vector. |
| | exp() | Computes the exponential of each element in a numeric vector. |
| | log() | Computes the natural logarithm of each element in a numeric vector. |
| **Statistical** | min() | Calculates the minimum of a numeric vector. |
| | max() | Calculates the minimum of a numeric vector. |
| | mean() | Calculates the mean of a numeric vector. |
| | sd() | Calculates the standard deviation of a numeric vector. |
| | var() | Computes the sample variance of a given vector. |
| | cor() | Computes the correlation matrix for numeric variables. |
| | median() | Computes the median of a numeric vector. |
| | quantile() | Computes the quantiles of a numeric vector |
| | rank() | Computes the rank of elements in a numeric vector. |
| **String** | paste() | Concatenates strings together. |
| | toupper() | Converts a character vector to uppercase. |
| | grep() | Searches for a pattern in a character vector. |
| | nchar() | Counts the number of characters in each element in a string object. |
| **Other** | unique() | Extracts unique elements from a vector. |
| | sort() | Sorts the elements of a vector in ascending or descending order. |
| | sample() | Selects random sample elements from a vector. |

Image from Internet

# Customized functions




**Example:**

```
hypotenuse <- function(x, y)
{
  sqrt(x ^ 2 + y ^ 2)
}
```

## Function arguments

- Default values can be supplied in function definition: `function(var_name = value){…}`
- Input values are matched to arguments by positions when calling a function without argument name
- R has a special argument ..., that contains all the arguments that aren't matched by position or name

## Return

- Without return statement, the last value calculated in the function is automatically returned

# Variable scope (local/global)

A variable's scope is the set of places from which you can see the variable

- when you define a variable inside a function (local variable), the rest of the statements in that function will have access to that variable
- Variables defined in the global environment (global variable) can be seen from anywhere

```
h <- function(x)
{
  x * y
}
```

When R tries to find variables

- find variables in the current environment
- if it doesn't find them, it will look in the parent environment, then that environment's parent, and so on recursively until it reaches the global environment

Question: can the global environment access the local variable defined in a function?

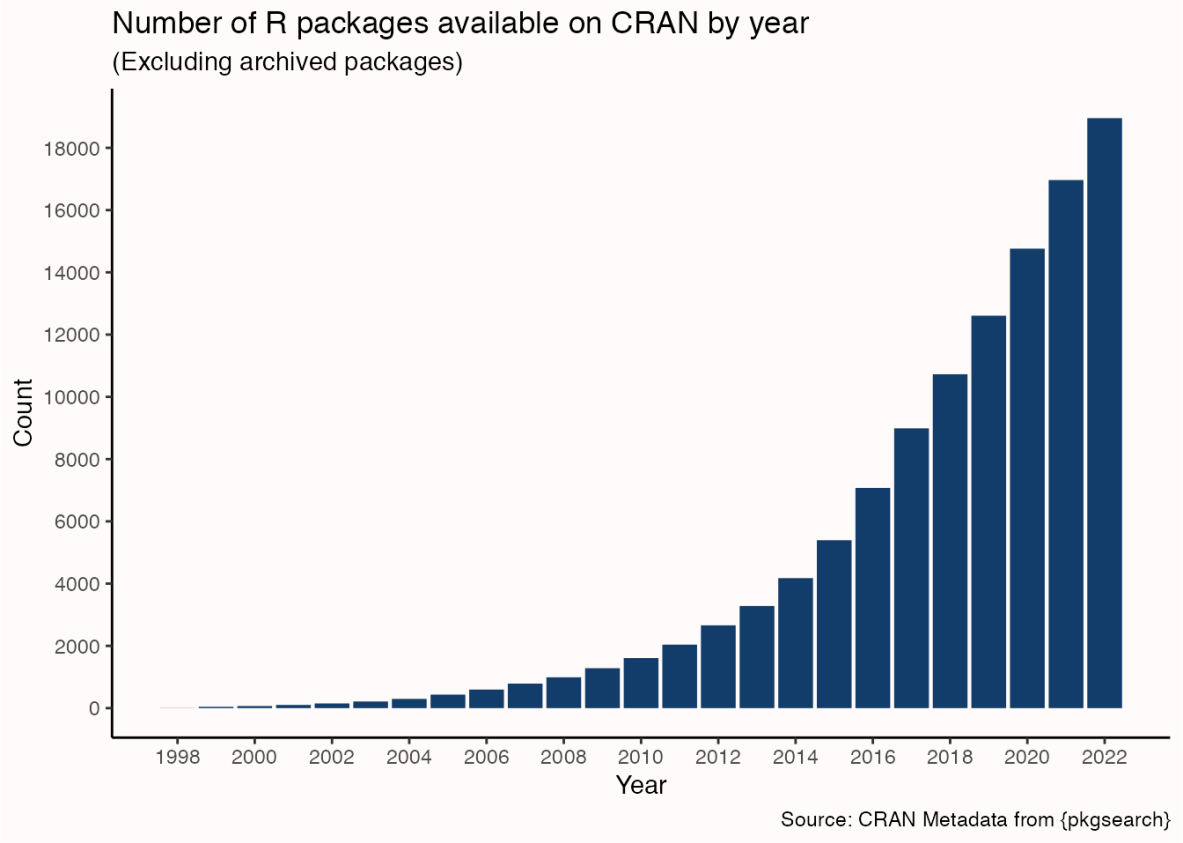
# Packages

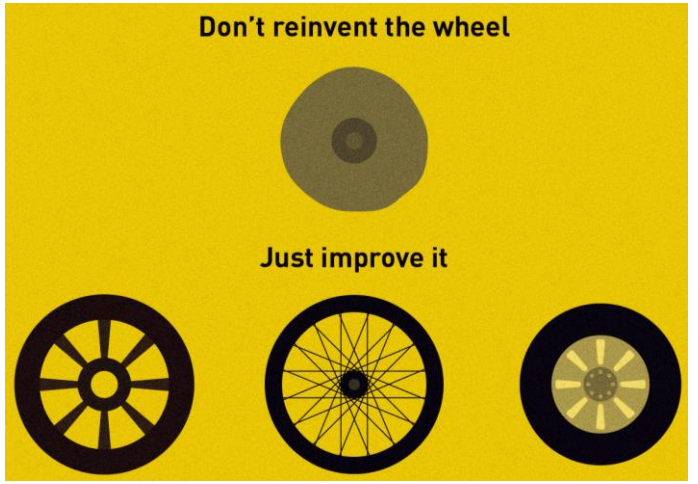
Code reuses



Image from Internet

# R packages: the shoulder of giants




Typically, there is no need to reinvent the wheels…Just realign or improve it if needed



Image from Internet

# Install / load packages

- Install, update, remove packages
  - `install.packages("tidyverse")`
  - `update.packages("tidyverse")`
  - `remove.packages("tidyverse")`

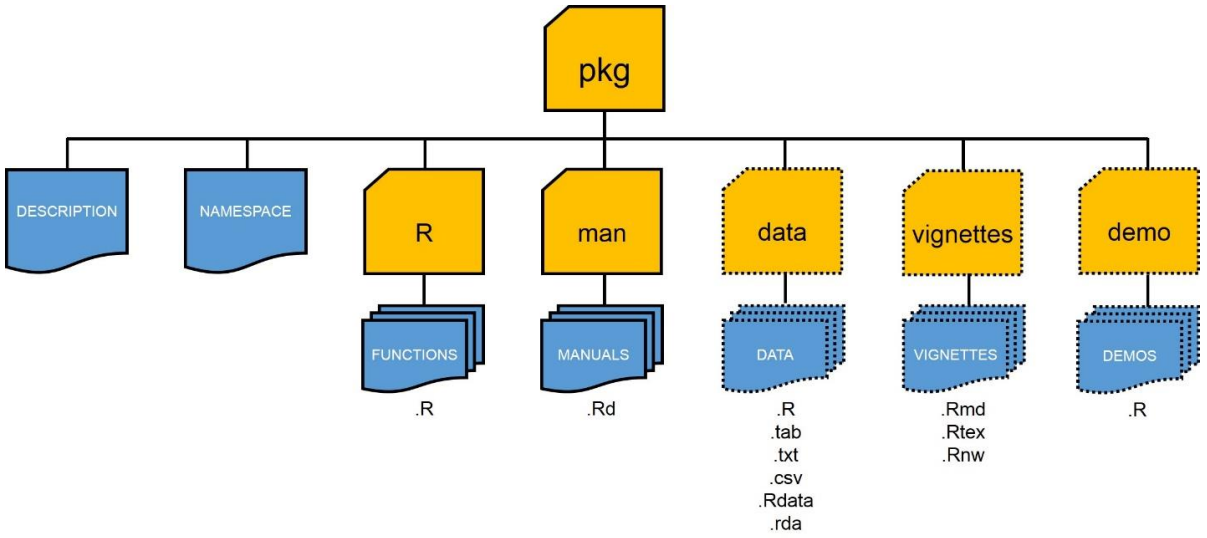
Images sourced from https://www.wikihow.com/Change-a-Light-Bulb

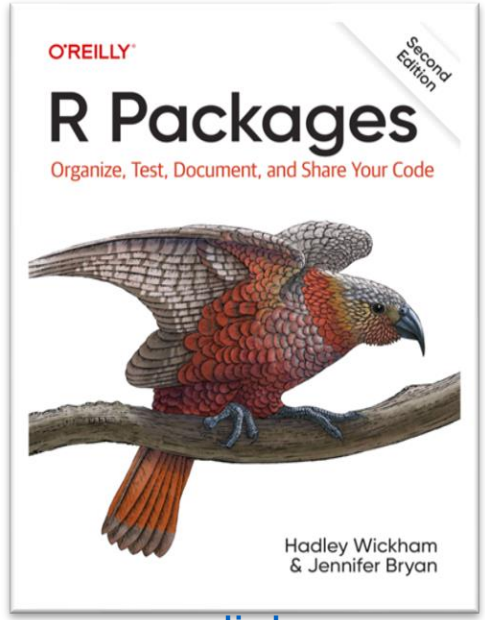
- Load, unload package
  - `library(tidyverse)`
  - `unloadNamespace("tidyverse")`

- Check package's version
  - `packageVersion("tidyverse")`
  - `sessionInfo() # print session information and package versions`

# Write your own package

- Bundles together code, data, documentation, and tests, in a way that is easy to share.



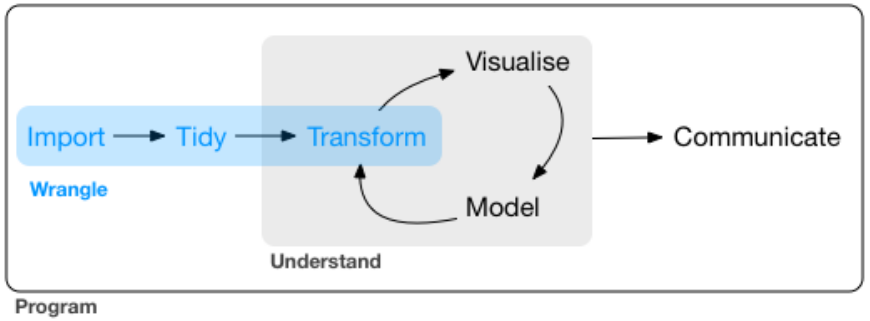




link



Image from Internet


# Data wrangling

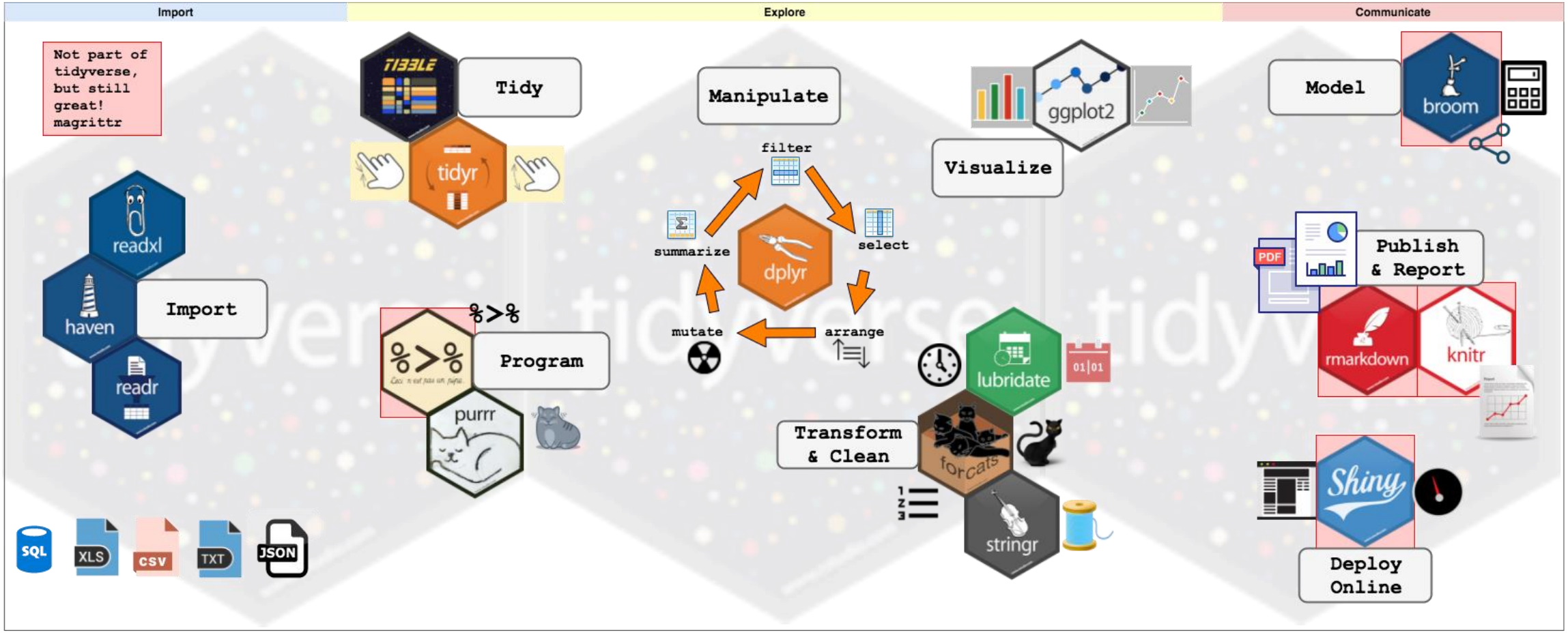



The process of converting raw data into a usable form for modeling/visualization



Image from Internet

# tidyverse for data wrangling

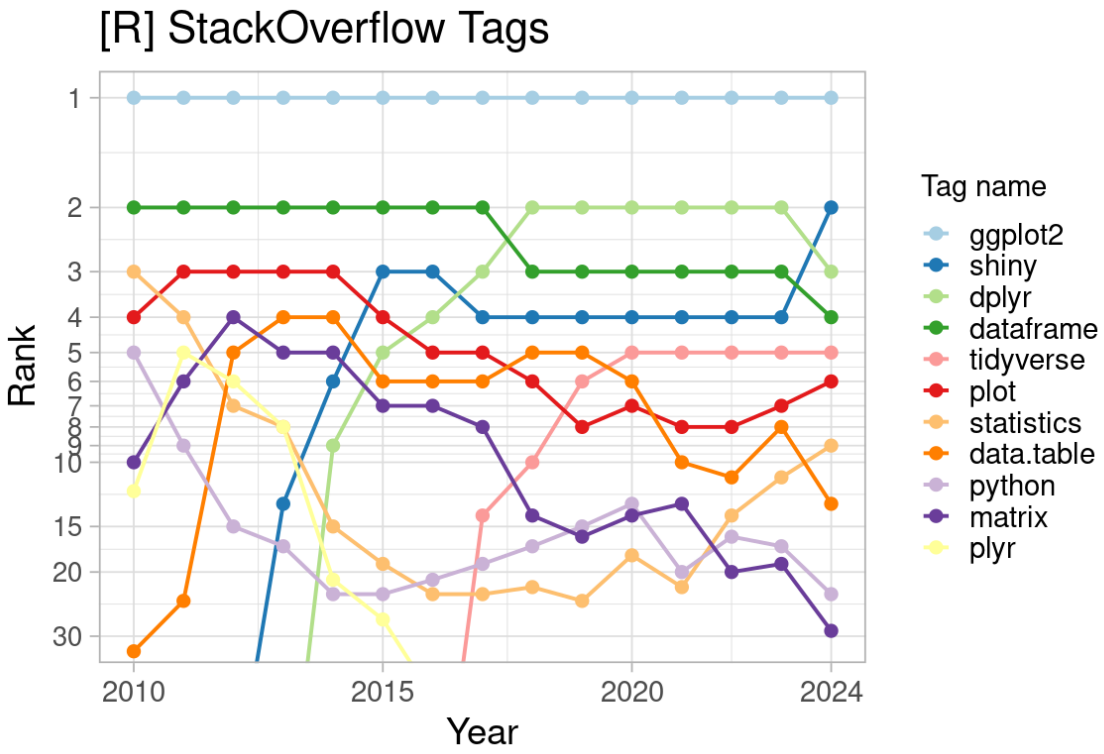


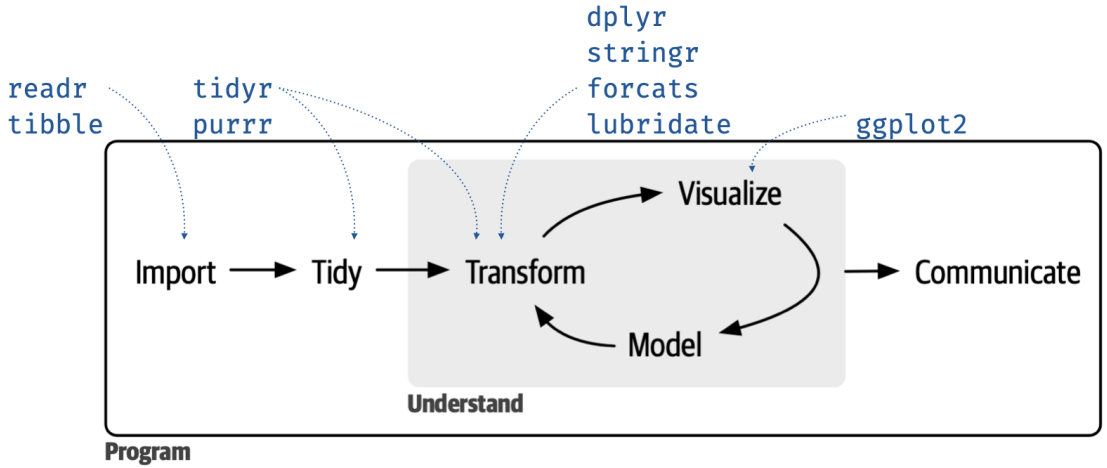



https://www.storybench.org/getting-started-with-tidyverse-in-r/

# tidyverse for data wrangling

## Stackoverflow topics for R






https://www.tidyverse.org/blog/2023/08/teach-tidyverse-23/

# File I/O (.txt/.tsv/.csv)

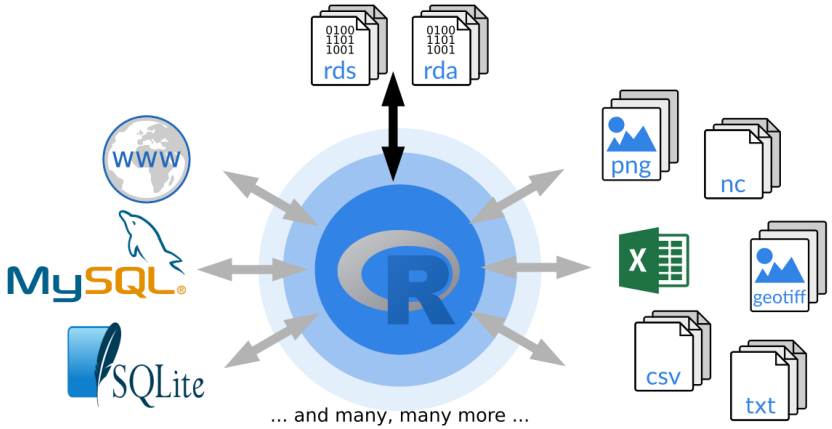
## Read

- `utils::read.table()/read.csv()` (base R)
- `readr::read_table()/read_csv()` (tidyverse)

```
read.table(file, header = FALSE, sep = "", quote = "\"'",
           dec = ".", numerals = c("allow.loss", "warn.loss", "no.loss"),
           row.names, col.names, as.is = !stringsAsFactors,
           na.strings = "NA", colClasses = NA, nrows = -1,
           skip = 0, check.names = TRUE, fill = !blank.lines.skip,
           strip.white = FALSE, blank.lines.skip = TRUE,
           comment.char = "#",
           allowEscapes = FALSE, flush = FALSE,
           stringsAsFactors = default.stringsAsFactors(),
           fileEncoding = "", encoding = "unknown", text, skipNul = FALSE)
```

**Some important arguments**

- `nrows` : Read only `N` lines (default `-1` ; all).
- `skip` : Skip the first `N` lines (default `0` ).
- `strip.white` : Remove leading/trailing white spaces from characters.
- `blank.lines.skip` : Ignore blank lines.
- `fileEncoding` : Character set used for encoding (e.g., `"UTF-8"` , `"latin1"` , ...).
- `text` : Read from a character string rather than a file.




Check out how to write file using `?` mark

- `write.table()/write.csv()`
- `write_table()/write_csv()`



https://discdown.org/rprogramming/reading-writing.html

# File I/O (.rds)

Load data

- `obj = readRDS("/path/to/file.rds")`

Output data

- `saveRDS(obj, "/path/to/file.rds")`

Similar to the `pickle` module in Python

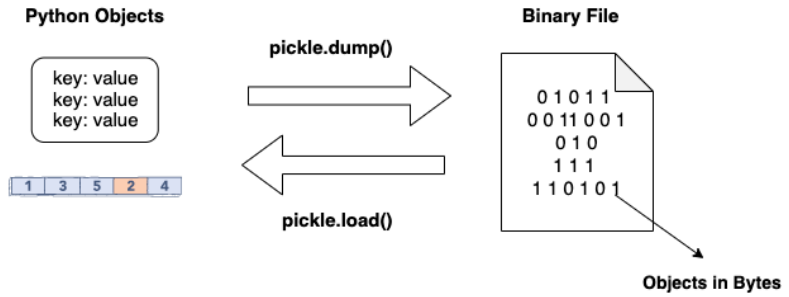





Image from Internet

# Manipulate Data

“Once you have

- ❑ the right data,
- ❑ in the right format,
- ❑ aggregated in the right way,

the right visualization is often obvious”

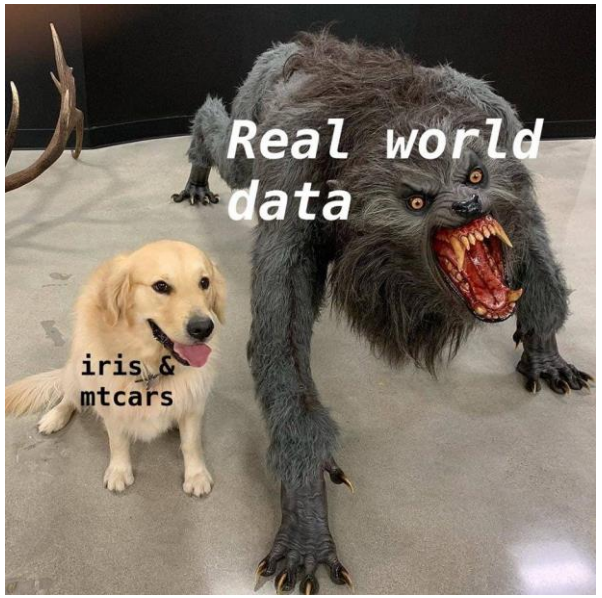



Image from Internet

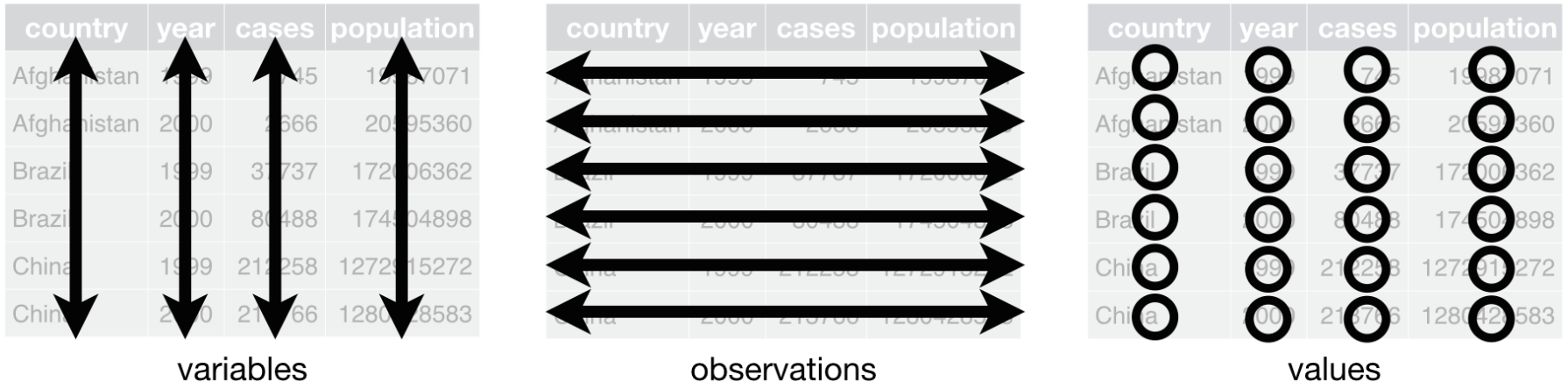
# Recap: Variables

The container for storing values

- **Categorical variables**: take discrete values
  - `x = c("apple", "banana")` # nominal variables: without an order
  - `y = c("low", "medium", "high")` # ordinal variables: with an order
- **Continuous variables**: take any values within a range
  - `z = c(0.05, 1, -2)`

# Recap: Data Frame

A generic data object that are used to store tabular data

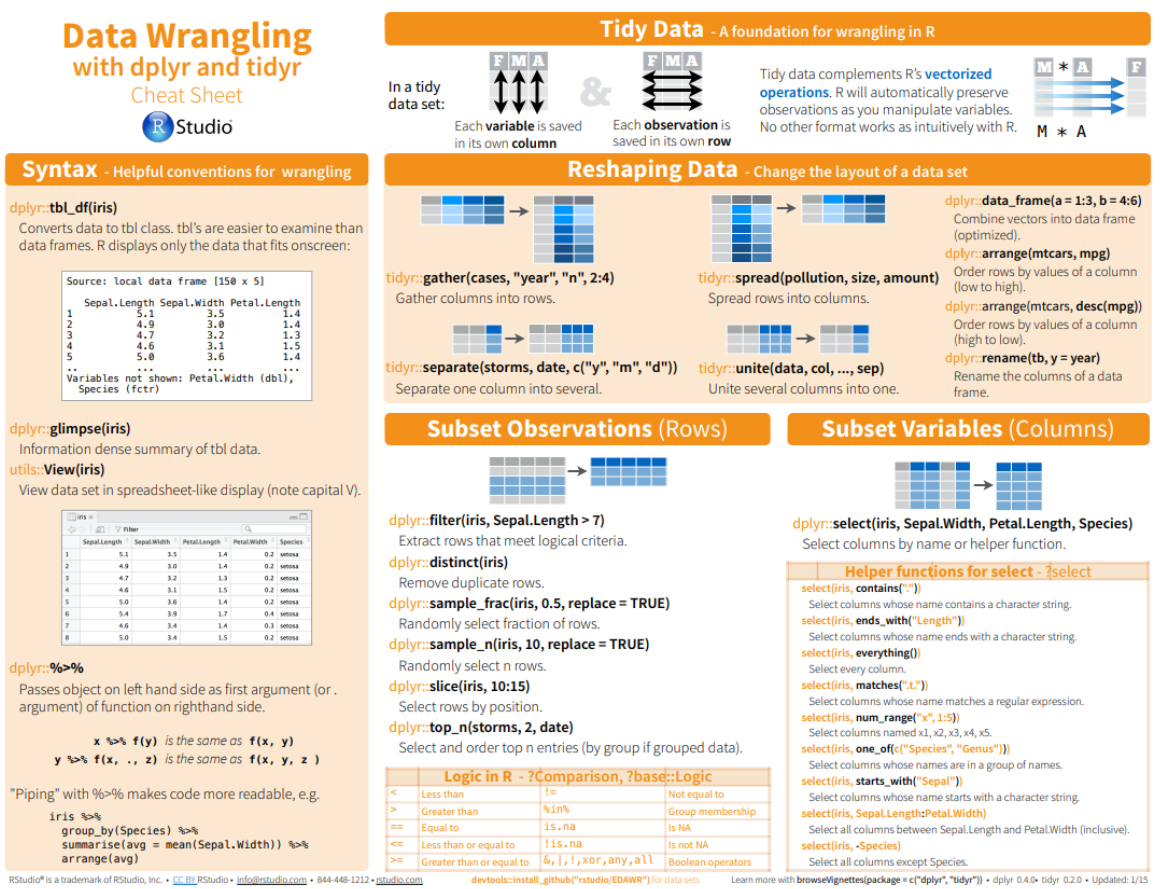





https://ismayc.github.io/moderndiver-book/4-tidy.html

# Data wrangling functions

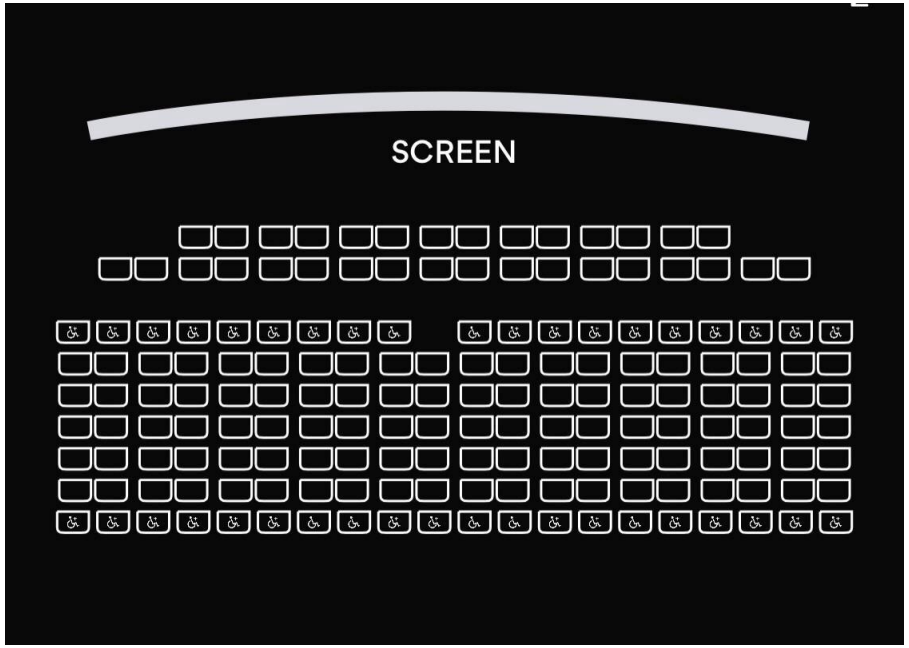
- Manipulate observations (rows)
  - `filter()`
  - `arrange()`
  - `bind_rows()`
- Manipulate variables (columns)
  - `select()`
  - `mutate()`
  - `left_join(), right_join()` …
- Reshape the data
  - `pivot_longer(), pivot_wider()`
- Group and summarize
  - `group_by()`
  - `summarize()`




For more information, check the [cheatsheet]

# Rows

Observations




AMC seats

# Manipulate observations

`filter()`: keep rows that satisfy certain conditions

- The first argument is a data frame
- The second and subsequent arguments must be logical vectors

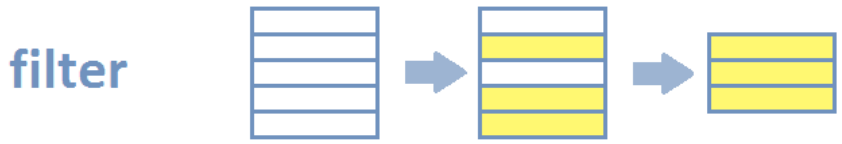
Create logical vectors:

❑ Comparison operators

- `x == y`: x and y are equal.
- `x != y`: x and y are not equal.
- `x %in% c("a", "b", "c")`: x is one of the values in the right hand side.
- `x > y`, `x >= y`, `x < y`, `x <= y`: greater than, greater than or equal to, less than, less than or equal to.

❑ Logical operators

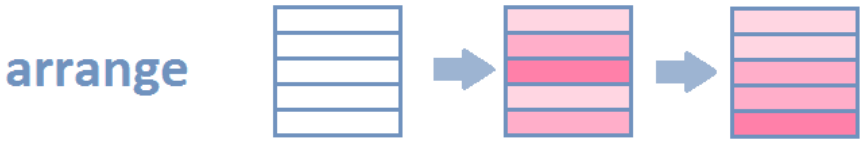
- `!x` (pronounced "not x"), flips `TRUE` and `FALSE` so it keeps all the values where x is `FALSE`.
- `x & y`: `TRUE` if both x and y are `TRUE`.
- `x | y`: `TRUE` if either x or y (or both) are `TRUE`.
- `xor(x, y)`: `TRUE` if either x or y are `TRUE`, but not both (exclusive or).



# Manipulate observations

## `arrange()`: orders observations according to variables

- The first argument is a data frame
- The second and subsequent arguments are variables or function of variables
- `.by_group`: If `TRUE`, will sort first by grouping variable. Applies to grouped data frames only



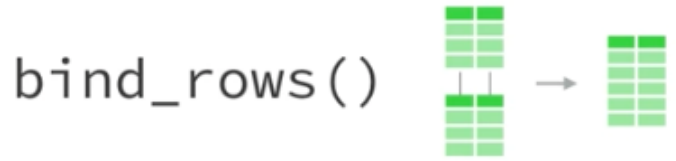

## Note:

- the default sorting order is ascending
- use `desc()` to sort a variable in descending order

# Manipulate observations

`bind_rows()`: Bind any number of data frames by row

- The first and subsequent arguments are data frames to combine
- Columns are matched by name, and missing columns will be filled with `NA`




Exercise: let's do some practice

# Columns

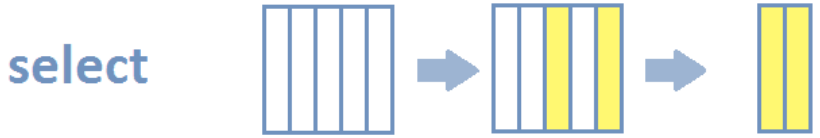
Variables


LACMA lights

# Manipulate variables

`select()`: keep or drop variables using their names and types

- The first argument is a data frame
- The second and subsequent arguments are unquoted expressions separated by comma




Useful functions

- `all_of()`: Matches variable names in a character vector
- `starts_with()/ends_with()`: Starts/ends with a substring
- `where()`: Applies a function to all variables and selects those for which the function returns TRUE

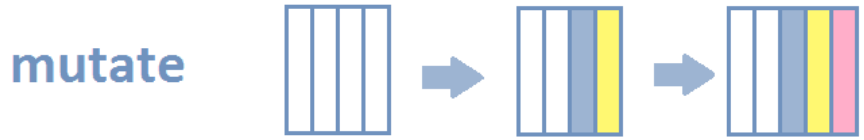
Useful Operators

- `!`: take the complement of a set of variables
- `&` or `|`: select the intersection or union of two sets of variables
- `c()` : combine selections

# Manipulate variables

## `mutate()`: create new variables

- The first argument is a data frame.
- The second and subsequent arguments are name-value pairs (named expression that generate the new variables)

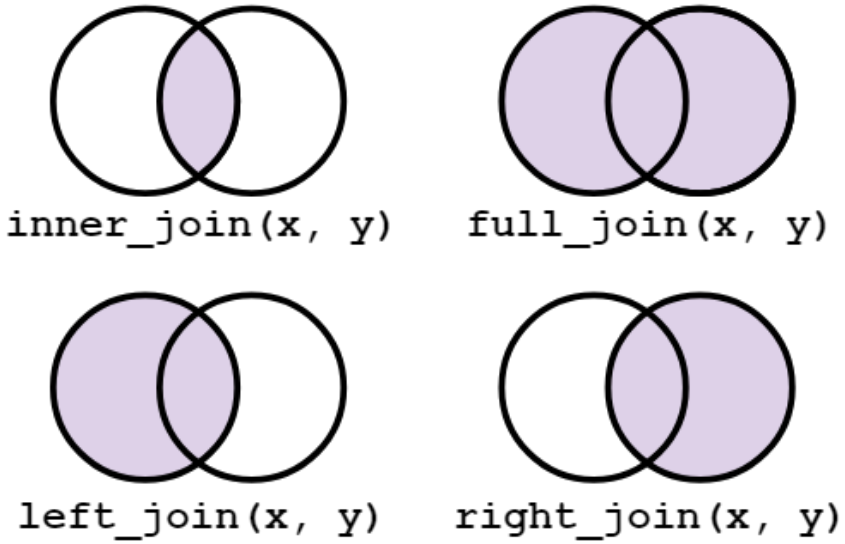



## The values can be

- Vector of length 1
- Vector of the same length as whole data frame or current group (for grouped data frame)
- `NULL` to remove the column

# Combine datasets

`*_join()`:



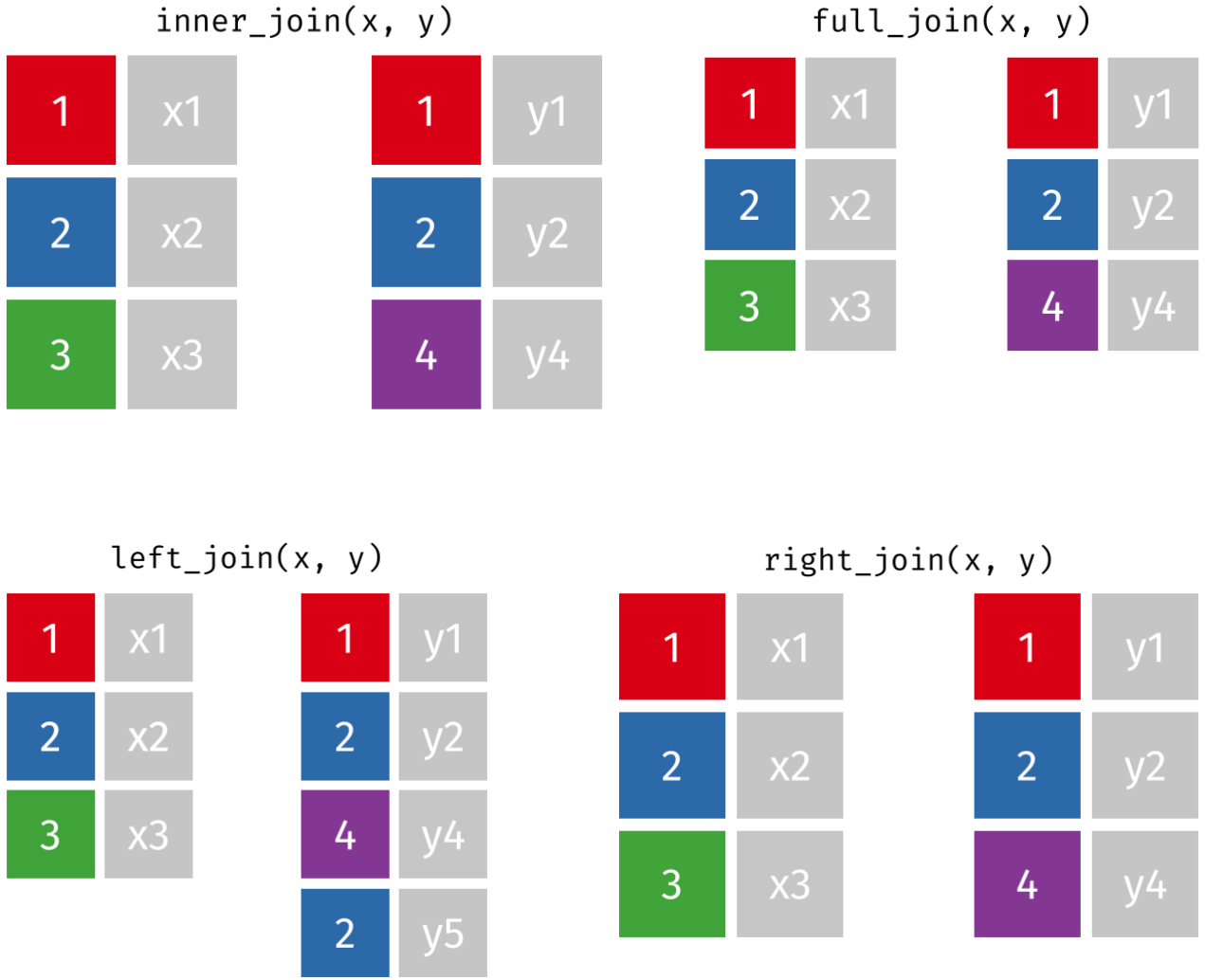
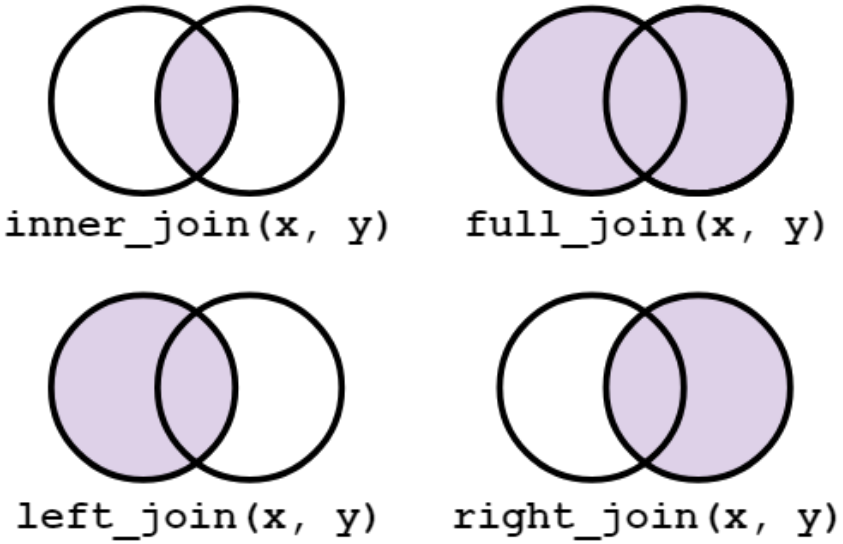



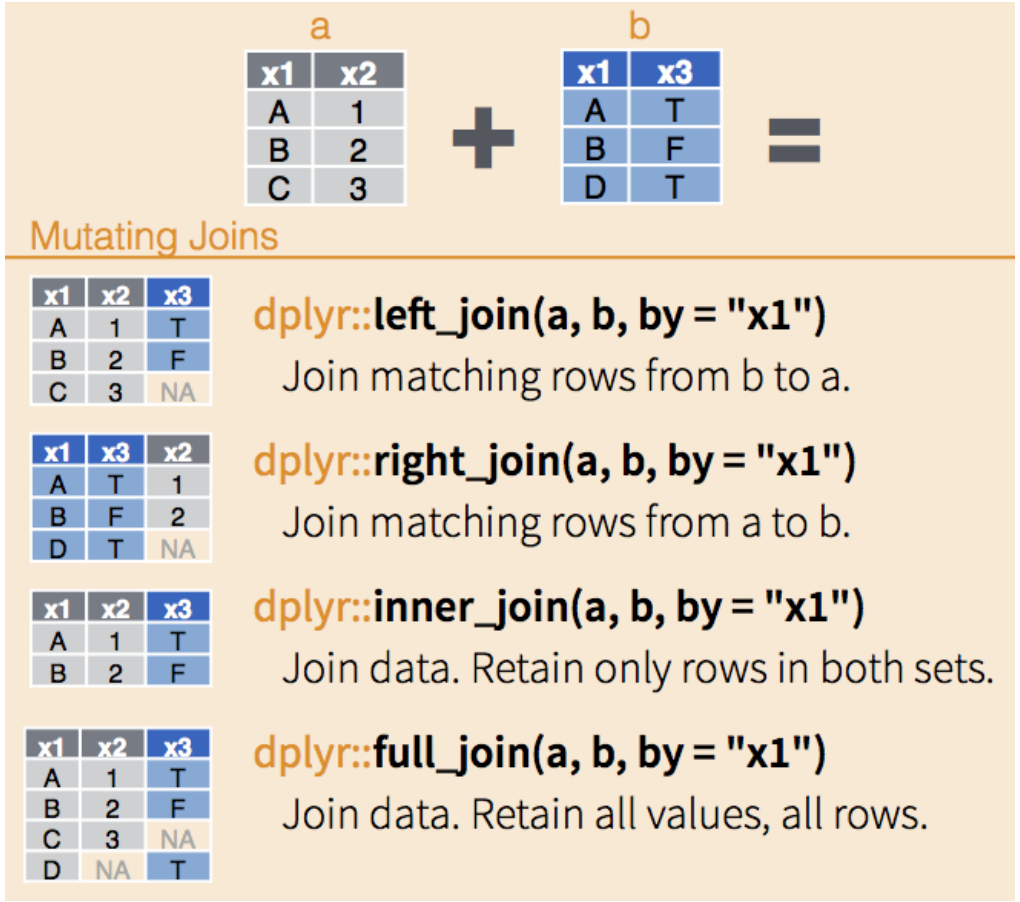



Image from internet

# Combine datasets

`*_join()`:



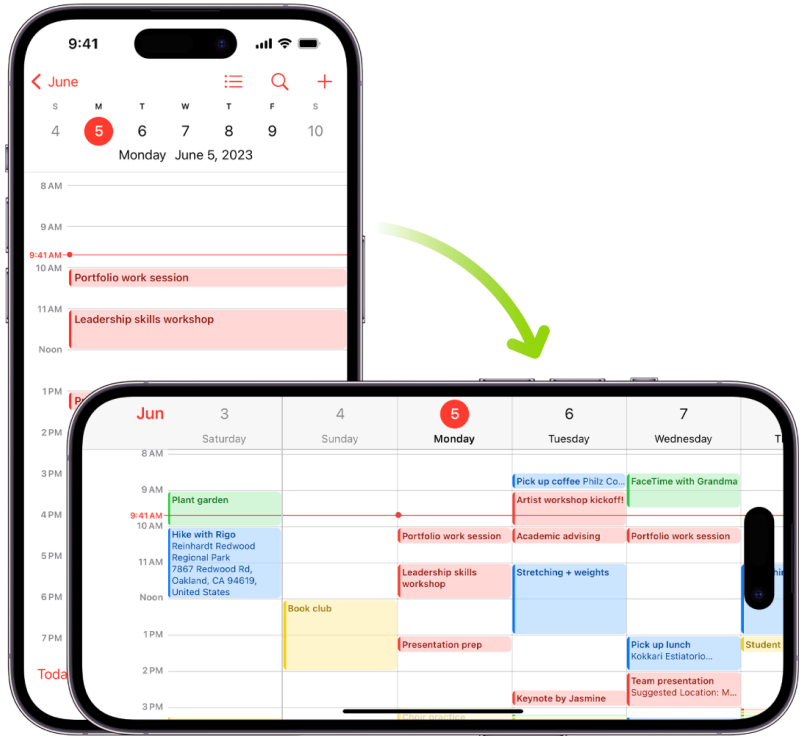




Exercise: let's do some practice

Image from internet

# Reshape

Landscape ↔ Portrait



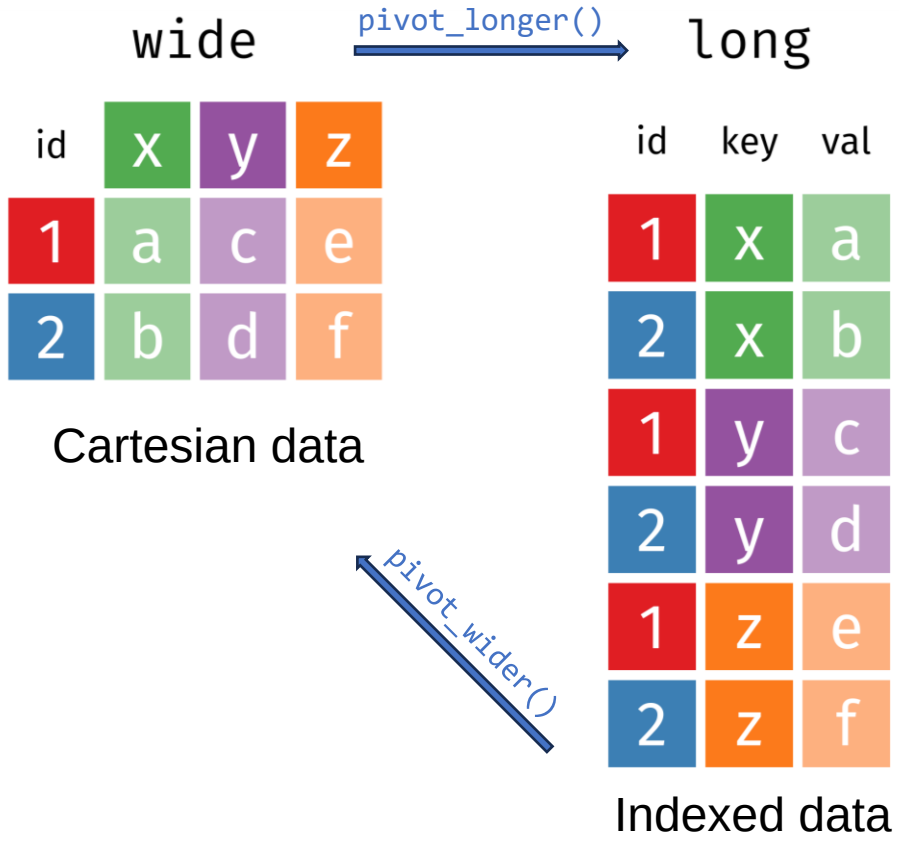
# Reshape data frame

## `pivot_longer()`: pivot into long format

- The first argument is a data frame
- The second argument is columns to pivot into longer format
- `names_to:` new column name for column names
- `values_to:` new column name for cell values

## `pivot_wider()`: pivot into wide format

- The first argument is a data frame
- `names_from:` column to get the names of output column
- `values_from:` column to get the cell values



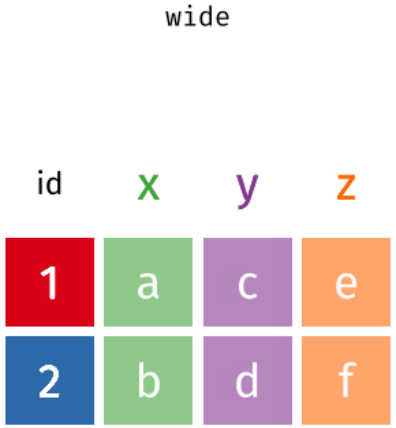



https://bookdown.org/Maxine/r4ds/pivoting.html

# Reshape data frame

## `pivot_longer()`: pivot into long format

- The first argument is a data frame
- The second argument is columns to pivot into longer format
- `names_to:` new column name for column names
- `values_to:` new column name for cell values




## `pivot_wider()`: pivot into wide format

- The first argument is a data frame
- `names_from:` column to get the names of output column
- `values_from:` column to get the cell values

# Group

“Birds of a feather flock together”



Image from Internet

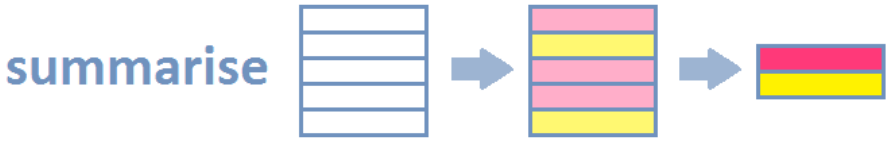
# Group and summarize

`group_by(dat, vars)`

Returns copy of dat, grouped by vars

## `group_by()`: Define the grouping variables

- The first argument is a data frame
- The second and subsequent arguments are variables used for grouping

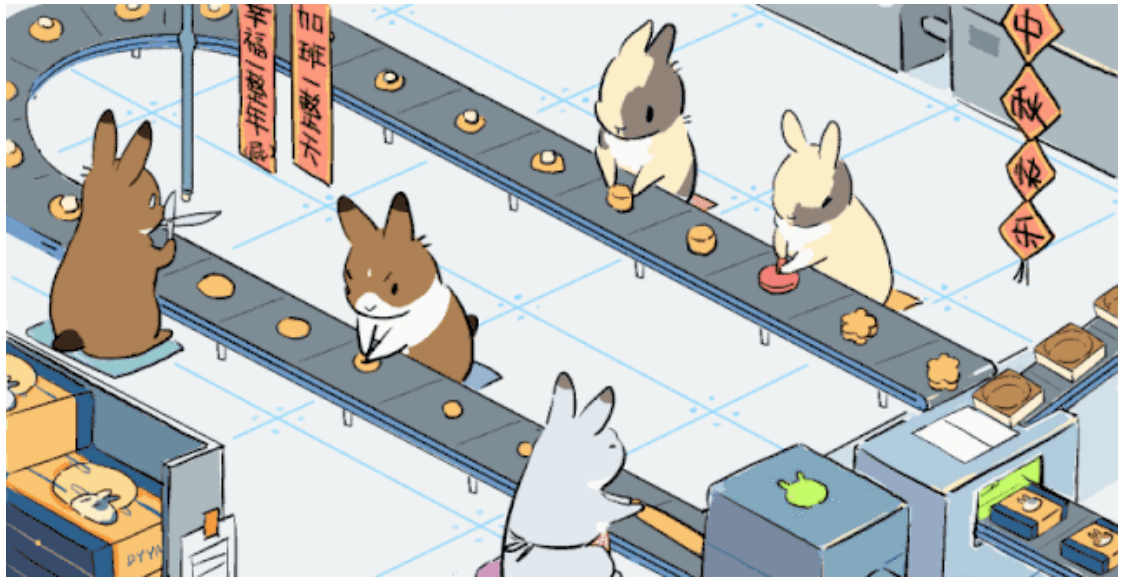



## `summarise()`/`summarize()`:

- The first argument is a data frame
- The second and subsequent arguments are name-value pairs for summary function
  - Counts: `n()`, `n_distinct(x)`.
  - Middle: `mean(x)`, `median(x)`.
  - Spread: `sd(x)`, `mad(x)`, `IQR(x)`.
  - Extremes: `quartile(x)`, `min(x)`, `max(x)`.
  - Positions: `first(x)`, `last(x)`, `nth(x, 2)`.

## `ungroup()`: takes a data frame and removes the grouping

# Pipes



“Coming together is a beginning, working together is success” – Henry Ford



Image from Internet

# Chain the functions together using pipe (%>%)

```r
# By using intermediate values
cut_depth <- group_by(diamonds, cut, depth)
cut_depth <- summarise(cut_depth, n = n())
cut_depth <- filter(cut_depth, depth > 55, depth < 70)
cut_depth <- mutate(cut_depth, prop = n / sum(n))
```

```r
# By "composing" functions
mutate(
  filter(
    summarise(
      group_by(
        diamonds,
        cut,
        depth
      ),
      n = n()
    ),
    depth > 55,
    depth < 70
  ),
  prop = n / sum(n)
)
```

```r
cut_depth <- diamonds %>%
  group_by(cut, depth) %>%
  summarise(n = n()) %>%
  filter(depth > 55, depth < 70) %>%
  mutate(prop = n / sum(n))
```

Question: Which one do you think is the most elegant?

# Chain the functions together using pipe (%>%)

```r
# By using intermediate values
cut_depth <- group_by(diamonds, cut, depth)
cut_depth <- summarise(cut_depth, n = n())
cut_depth <- filter(cut_depth, depth > 55, depth < 70)
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```r
# By "composing" functions
mutate(
  filter(
    summarise(
      group_by(
        diamonds,
        cut,
        depth
      ),
      n = n()
    ),
    depth > 55,
    depth < 70
  ),
  prop = n / sum(n)
)
```

```r
cut_depth <- diamonds %>%
  group_by(cut, depth) %>%
  summarise(n = n()) %>%
  filter(depth > 55, depth < 70) %>%
  mutate(prop = n / sum(n))
```

%>% works by taking the object on the left hand side (LHS) and using it as the first argument to the function on the right hand side (RHS)

- `f(x,y)  <=>  x %>% f(y)`

Question: how to rewrite `g(f(x, y), z)` using pipe?

# Let’s do some practice!

- `git clone https://github.com/wbvguo/qcbio-Intro2R.git`