UCLA QCBio Collaboratory

Introduction to R and data visualization

Wenbin Guo
Bioinformatics IDP, UCLA
wbguo@ucla.edu
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

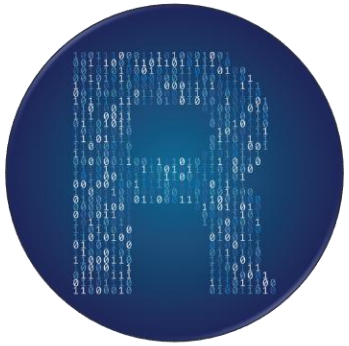
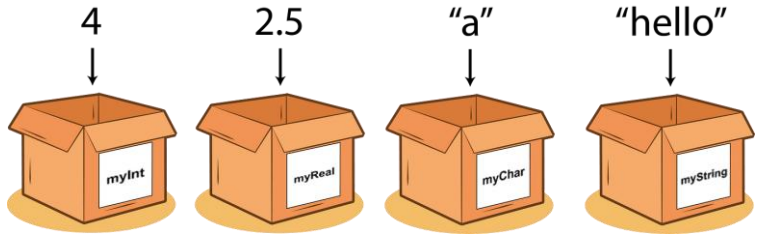


Image from internet

Summary – Day1

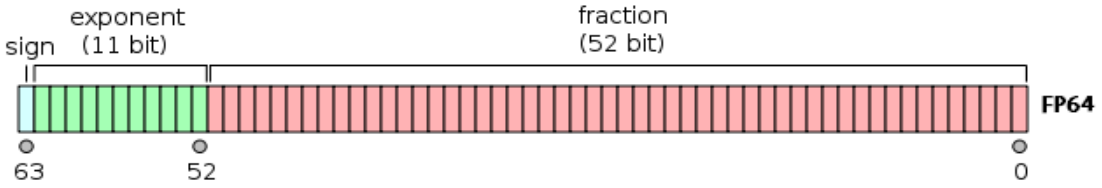


Variables: the container of data

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

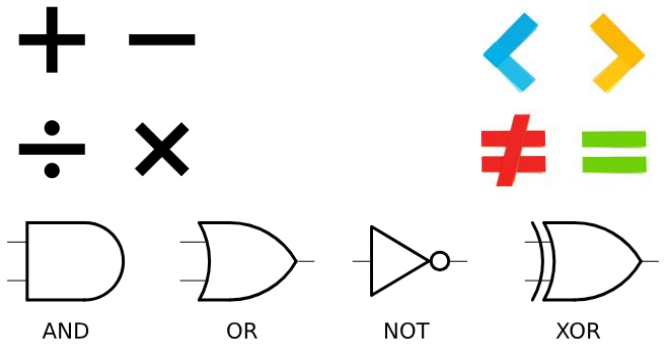
Numbers

- ❑ 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

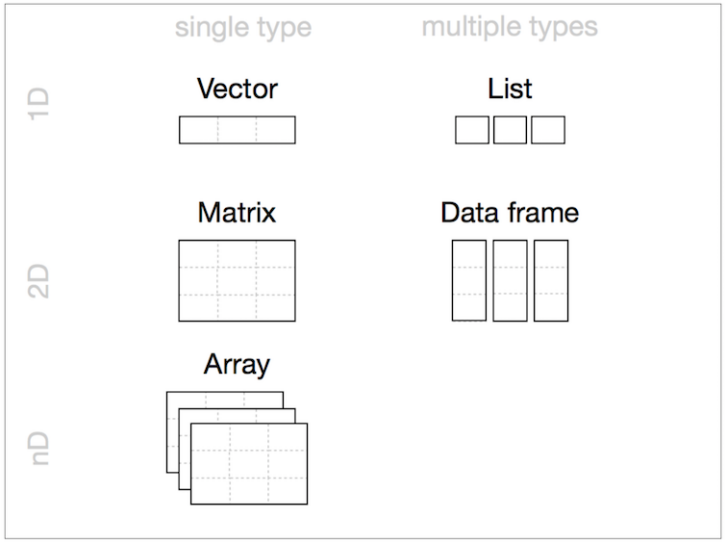
Operator	Description
+	addition
-	subtraction
*	multiplication
/	division
^ or **	exponentiation
x %% y	modulus (x mod y) 5%%2 is 1
x %/% y	integer division 5%/%2 is 2

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
- ❑ …

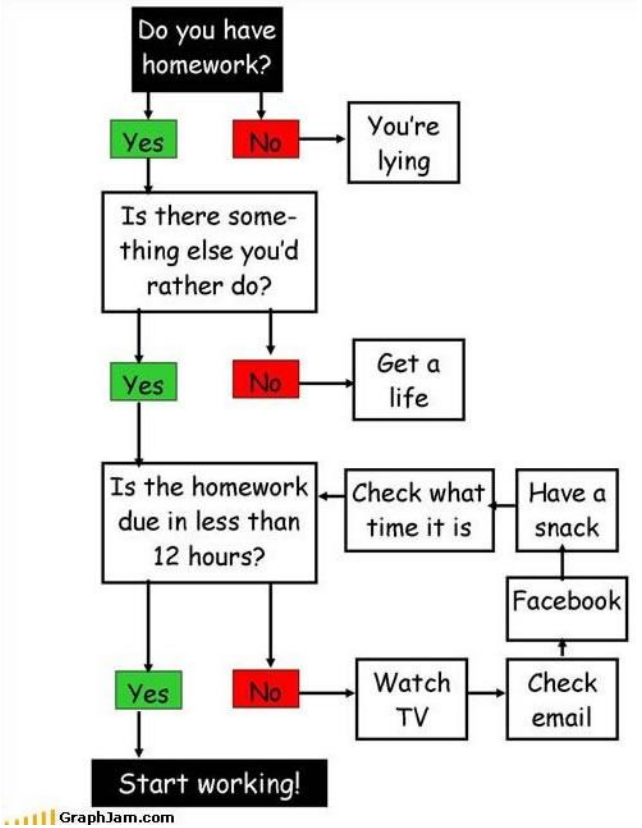
R as a scientific calculator

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

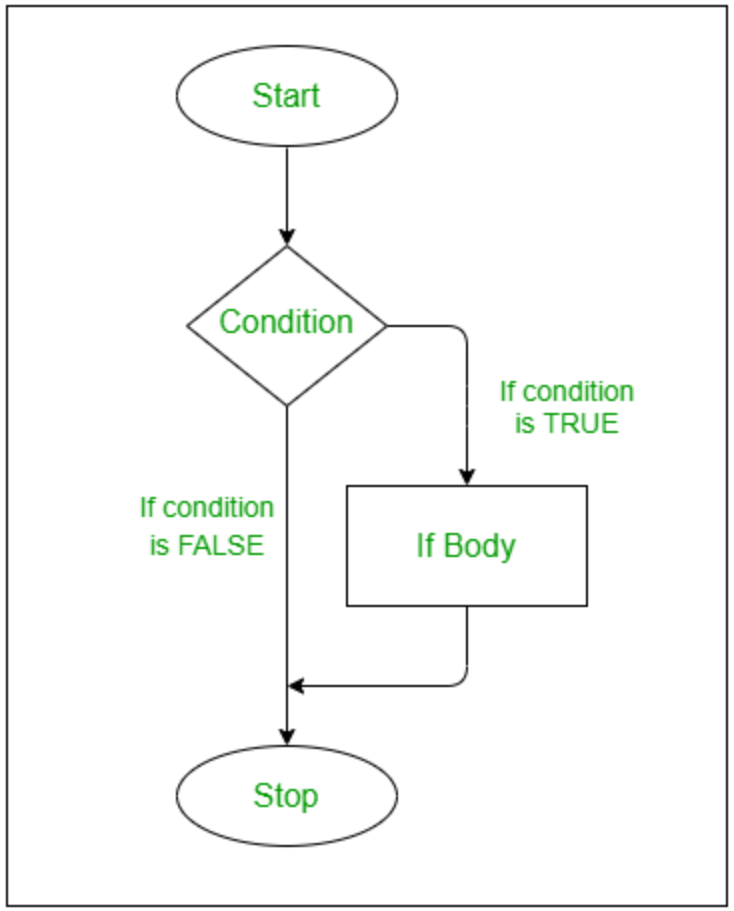
https://rstudio-education.github.io/hopr/r-objects.html

Flow control

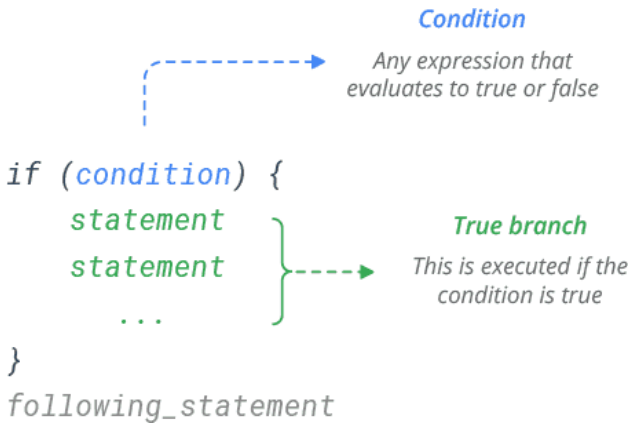
“When in Rome, do as the Romans do.”



`if` statement



Syntax:



Example:

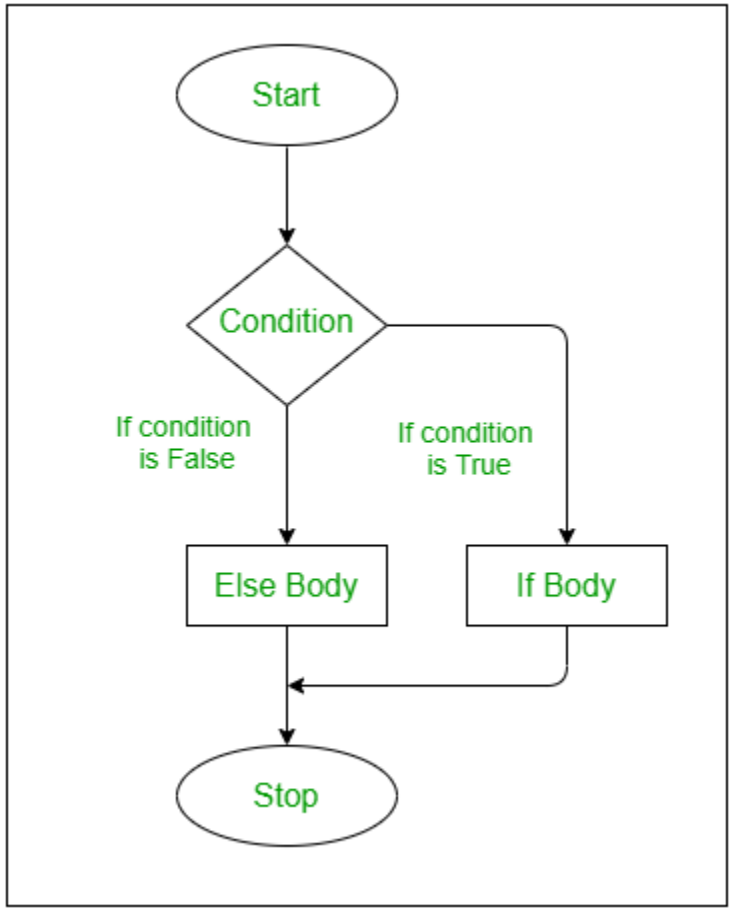
```
x <- 3
if(x > 2)
{
  y <- 2 * x
  z <- 3 * y
}
```

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
```

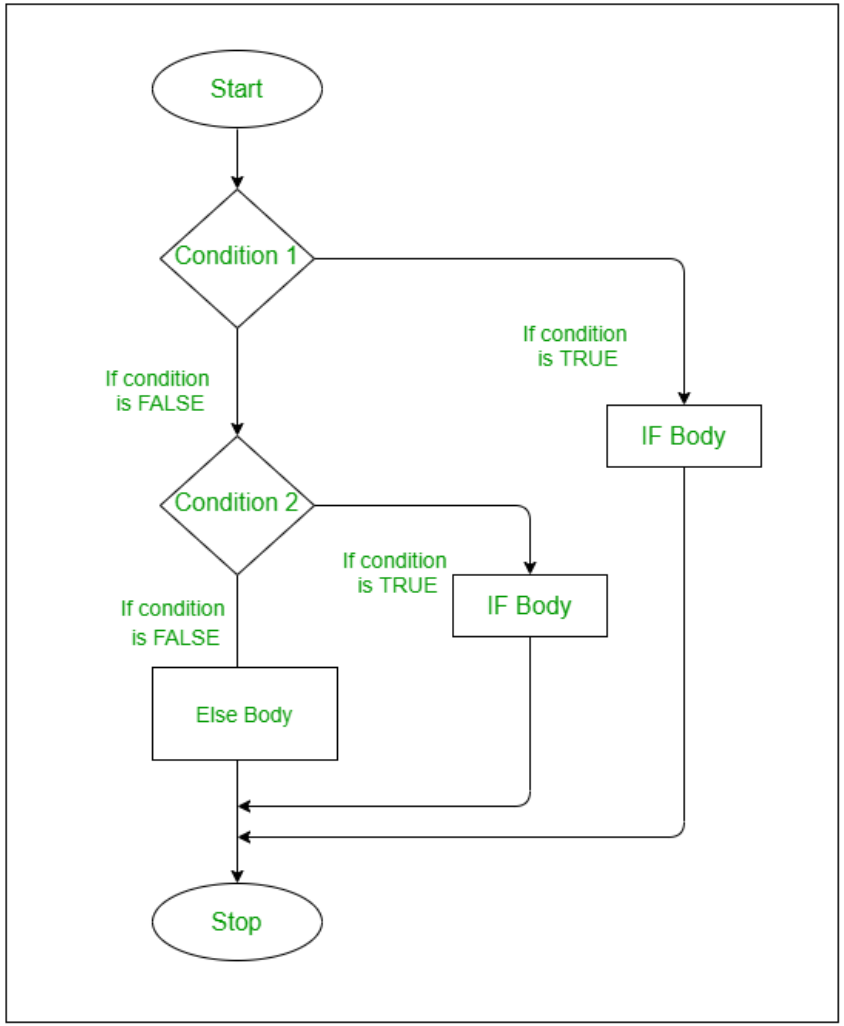
True branch: *This is executed if the condition is true*

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

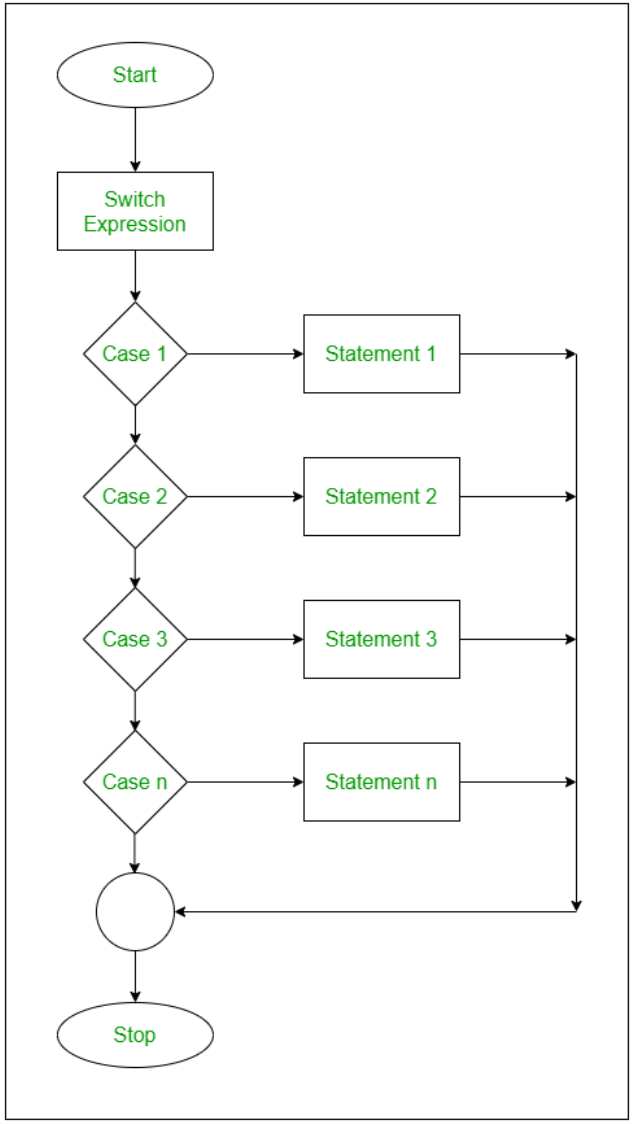
False branch
This is executed if none of the conditions are true

Example:

```
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")
}
```

Stacking **if/else** statements be like

`switch` statement



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:

```
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)
}
```

```
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

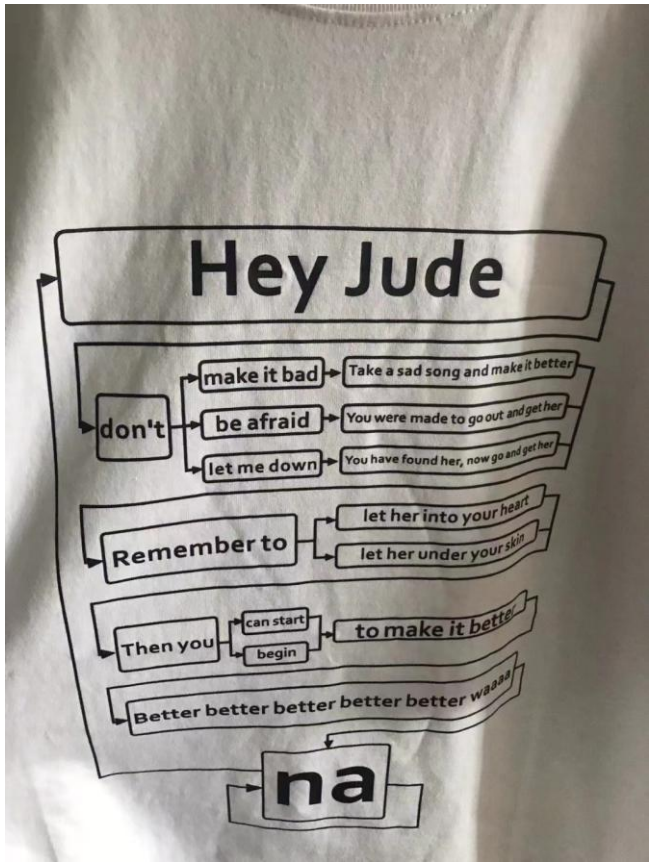
False branch
Select element from this if the condition is false

Let’s do some practice!

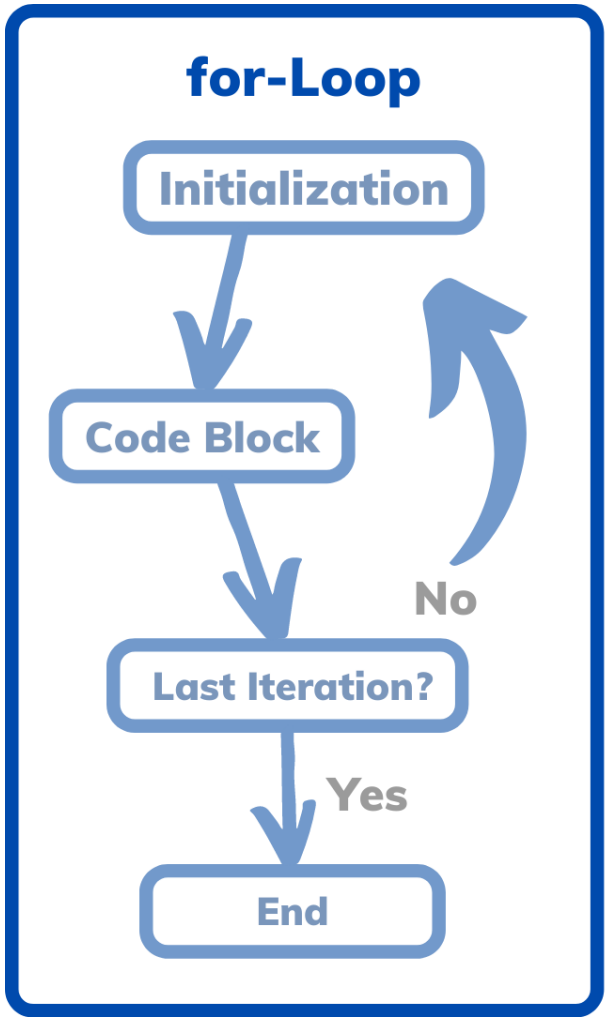
- `git clone https://github.com/wbvguo/qcbio-Intro2R.git`

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

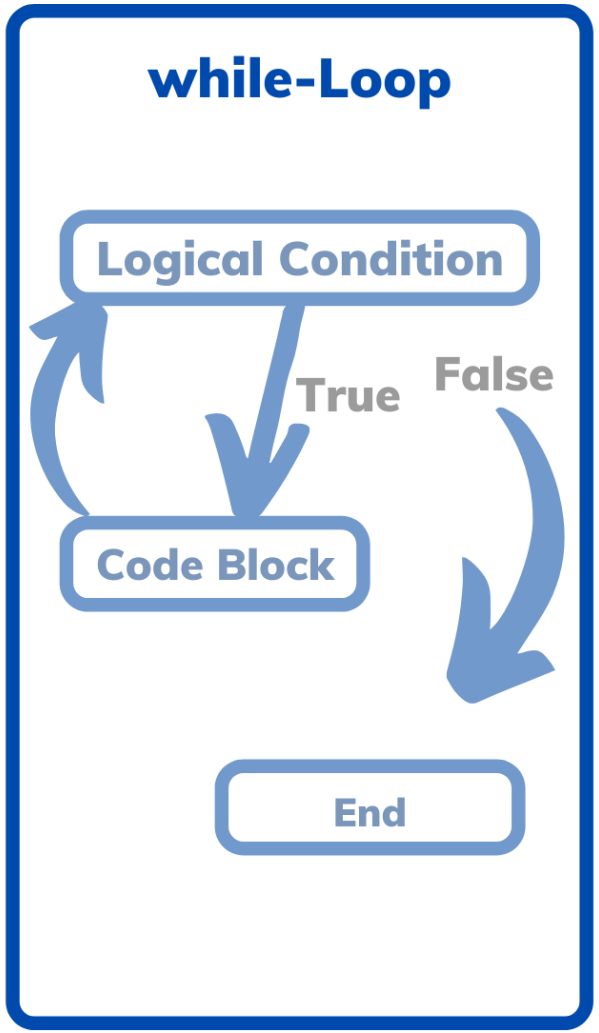
Example:

```
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

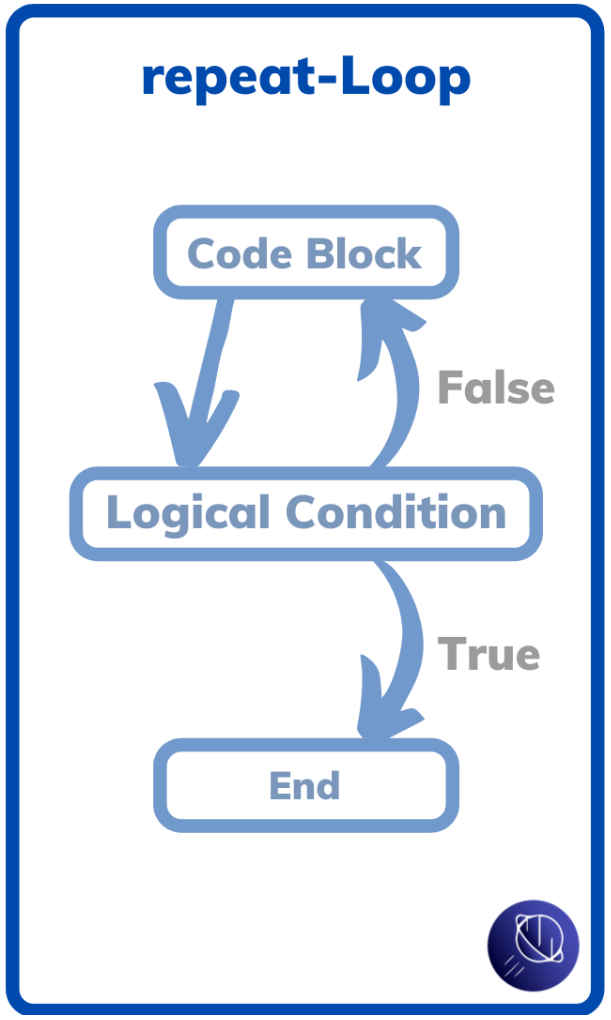
Example:

```
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 repeat 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

```
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

```
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

```
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. 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. 1 indicates rows 2 indicates columns 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)

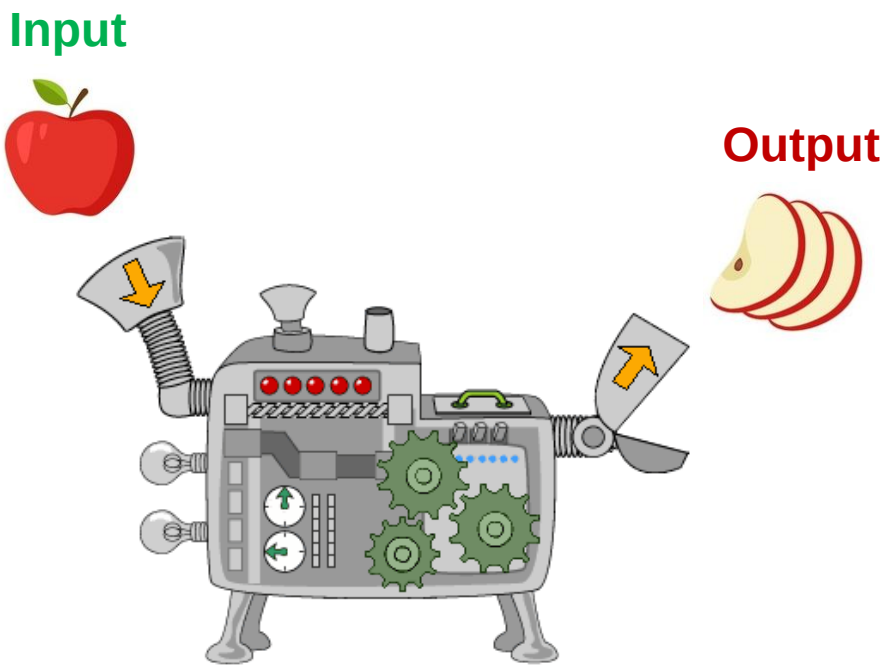
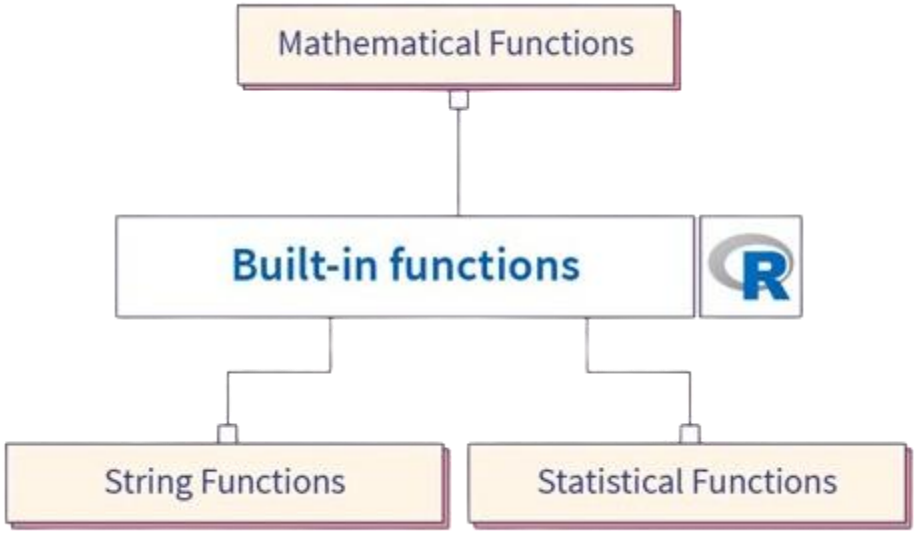


Image from Internet

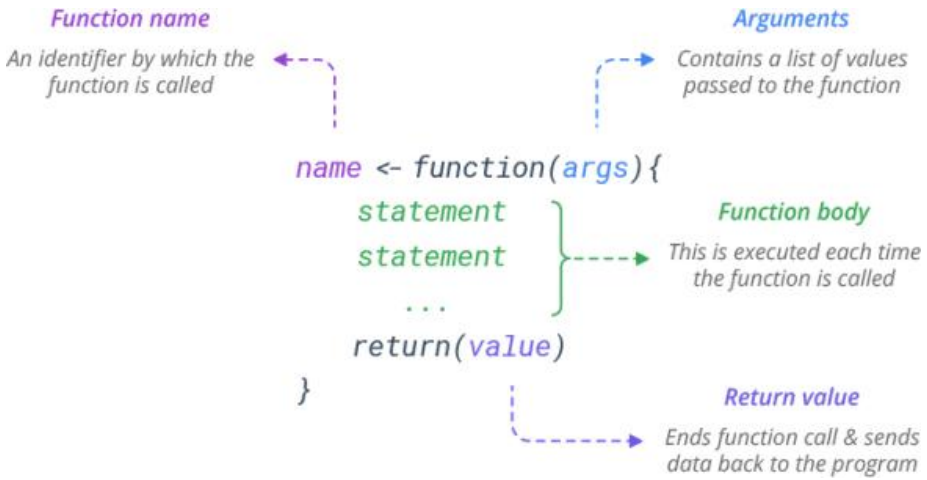
Built-in functions



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.
	prod()	Computes the product of the elements in 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 or a p x p sample covariance matrix got if the input is a n x p matrix.
	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

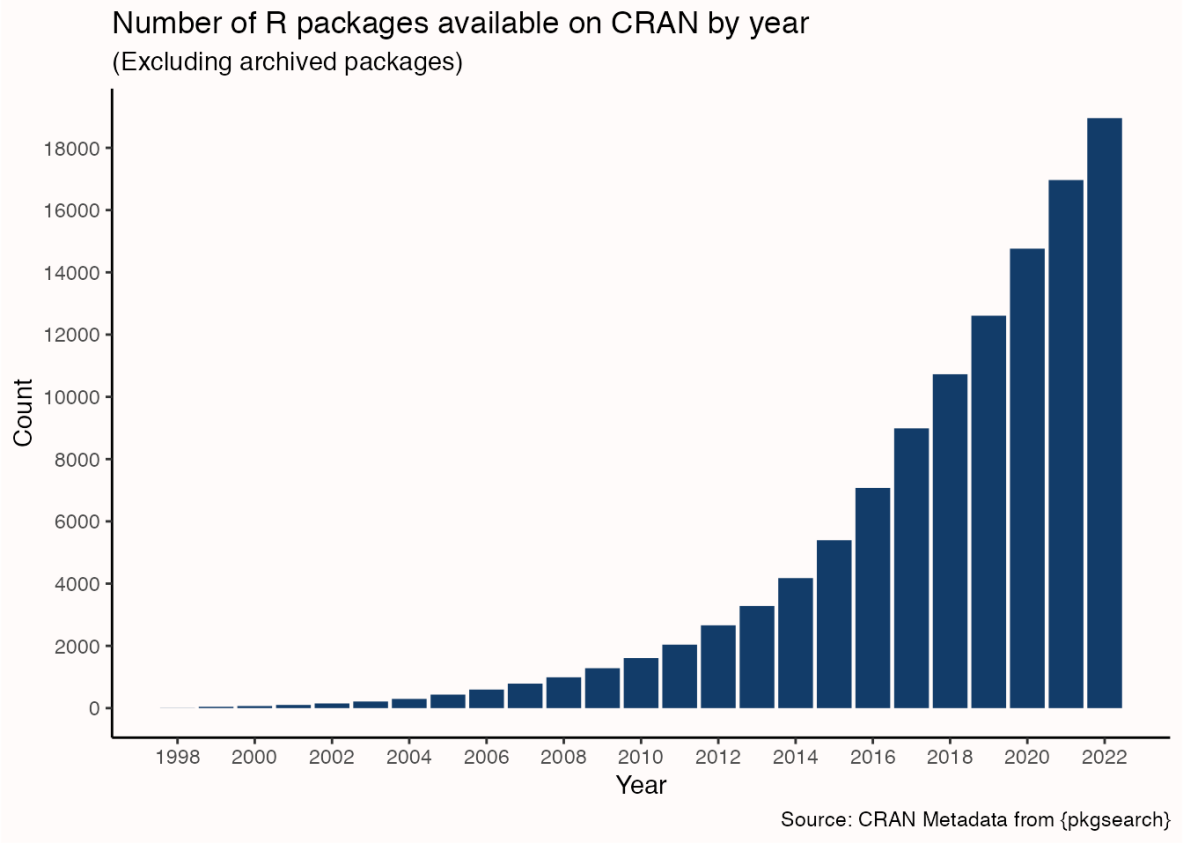
Question: can the global environment access the local variable defined in a function?

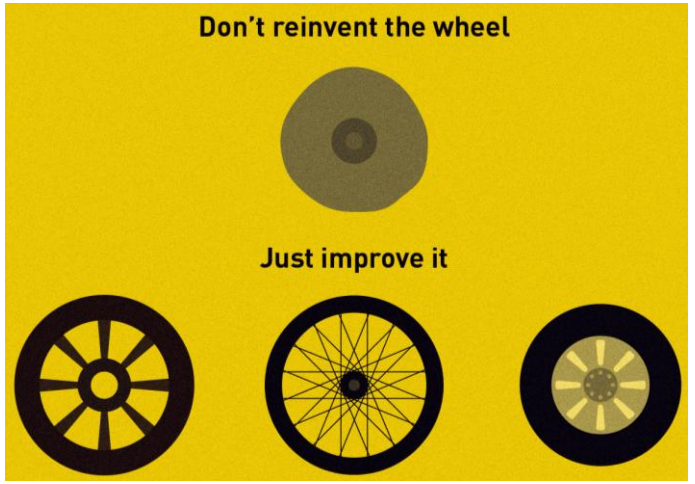
Packages

“Code reuse is the Holy Grail of Software Engineering.”

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")`

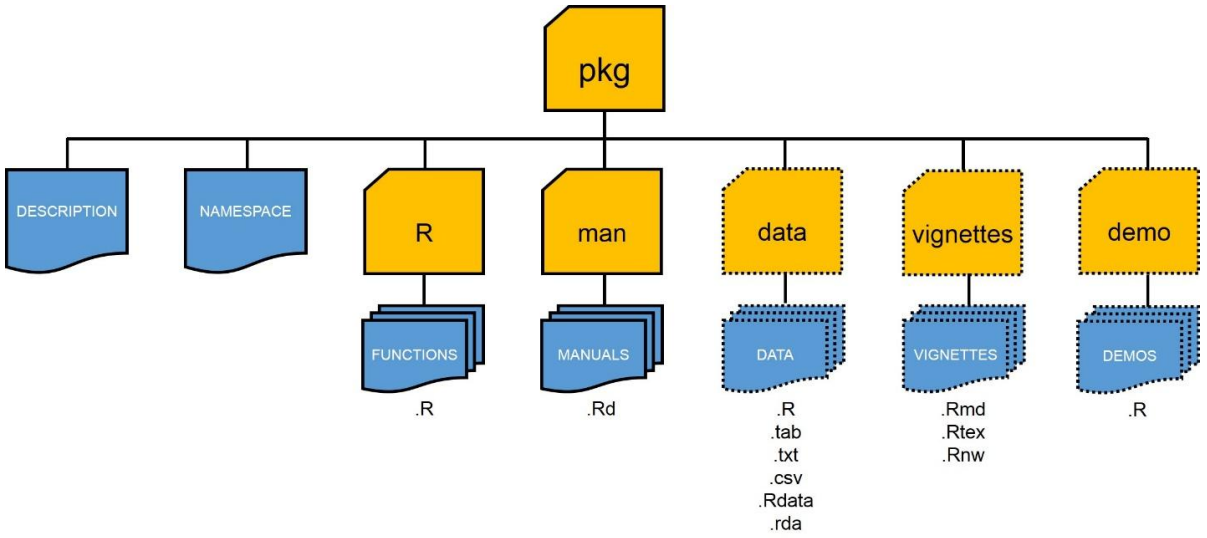
Images sourced from https://www.wikihow.com/Change-a-Light-Bulb

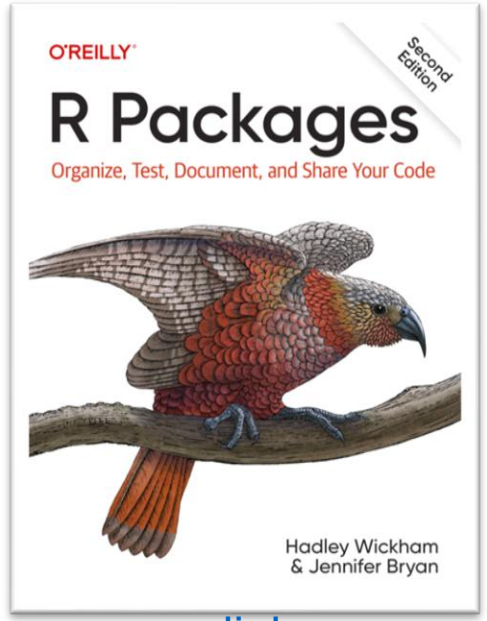
- Load, unload package
  - `library(tidyverse)`
  - `unloadNamespace("tidyverse")`

- 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.

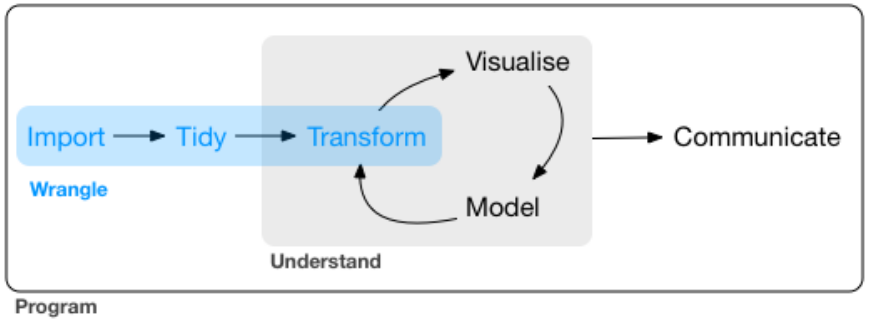




link

Image from Internet

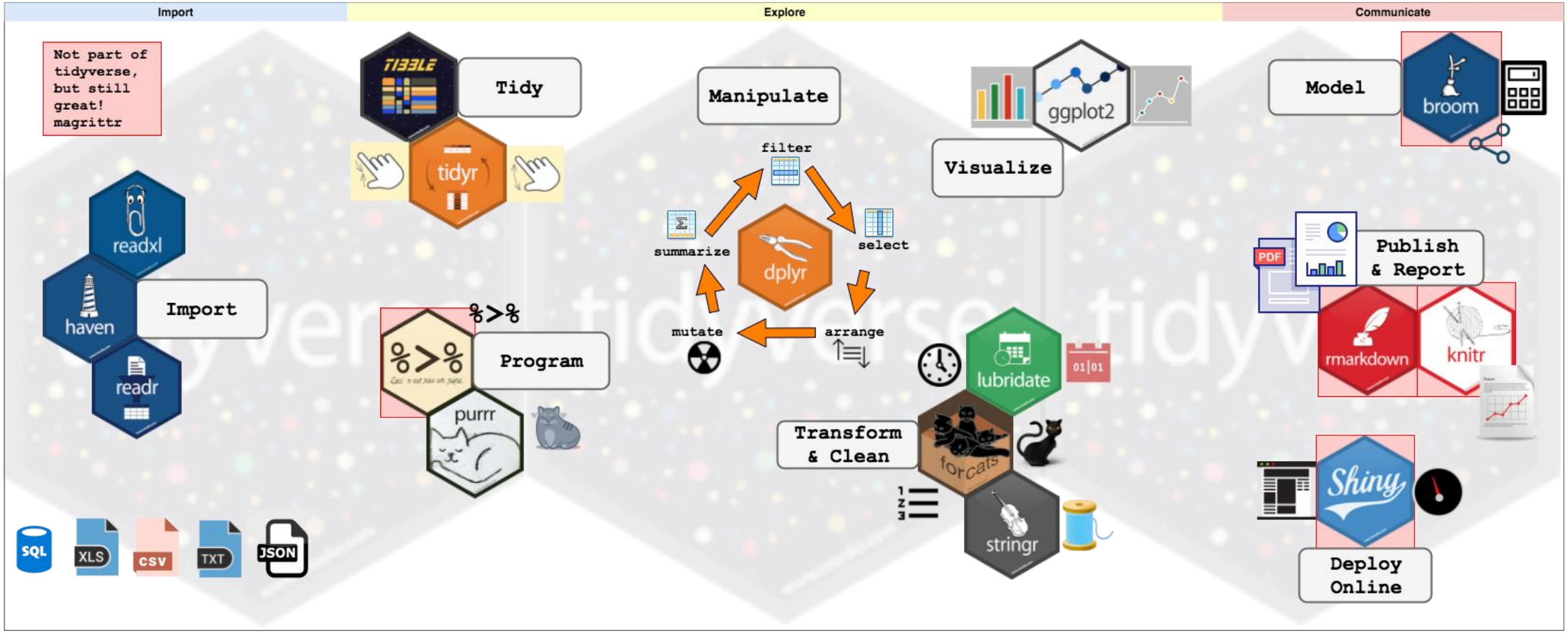
Data wrangling



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

Image from Internet

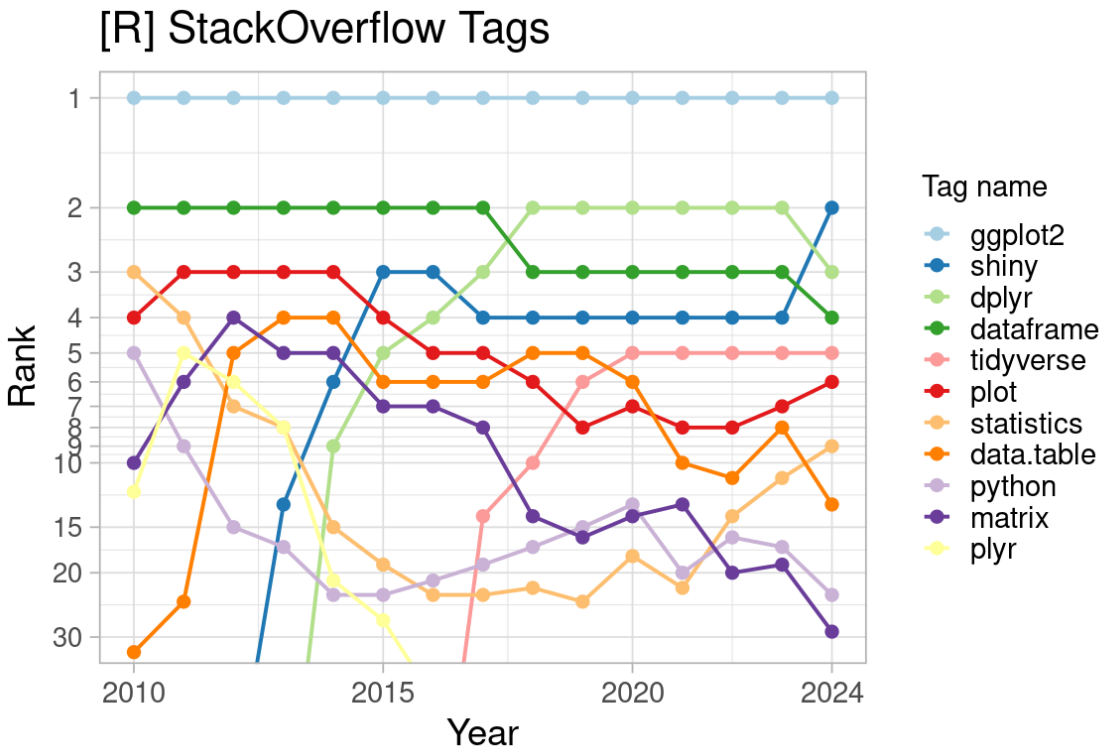
tidyverse for data wrangling

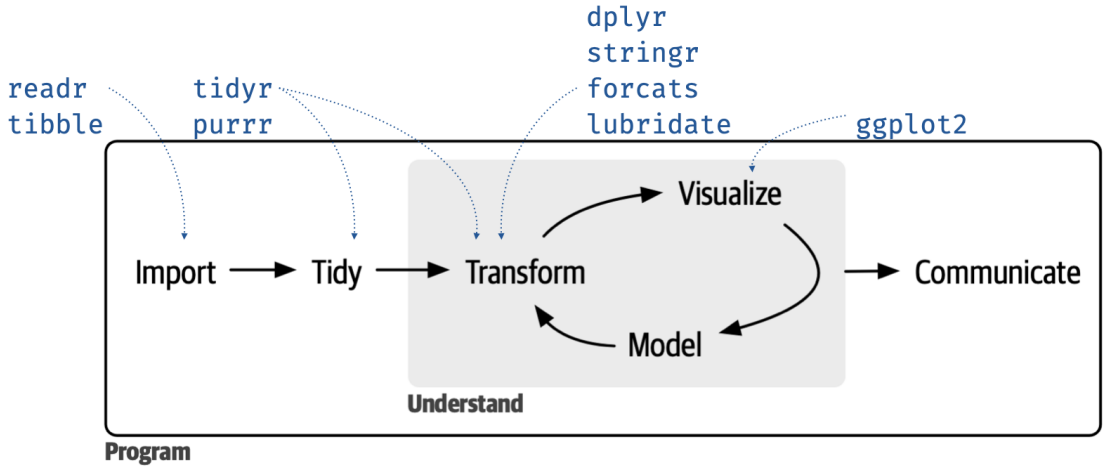


https://www.storybench.org/getting-started-with-tidyverse-in-r/

tidyverse for data wrangling

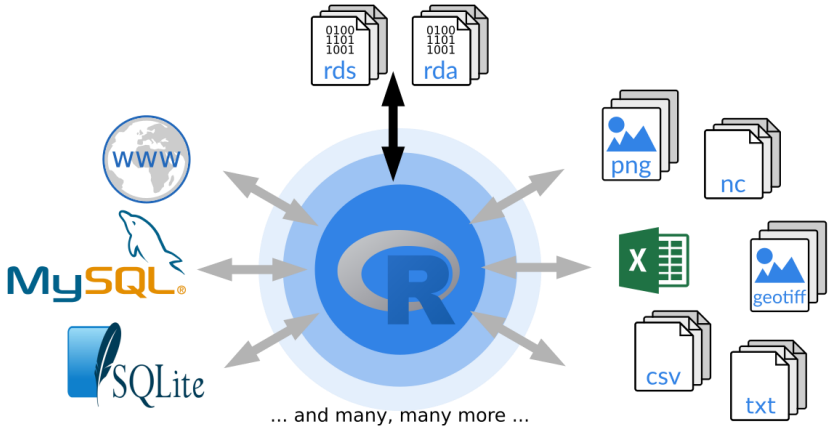
Stackoverflow topics for R





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

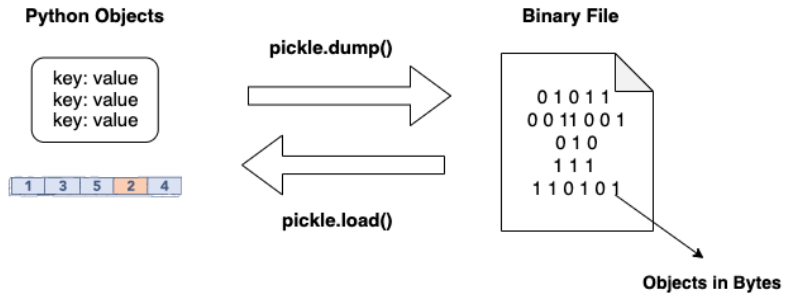


Image from Internet

Manipulate Data

“Once you have

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

the right visualization is often obvious”

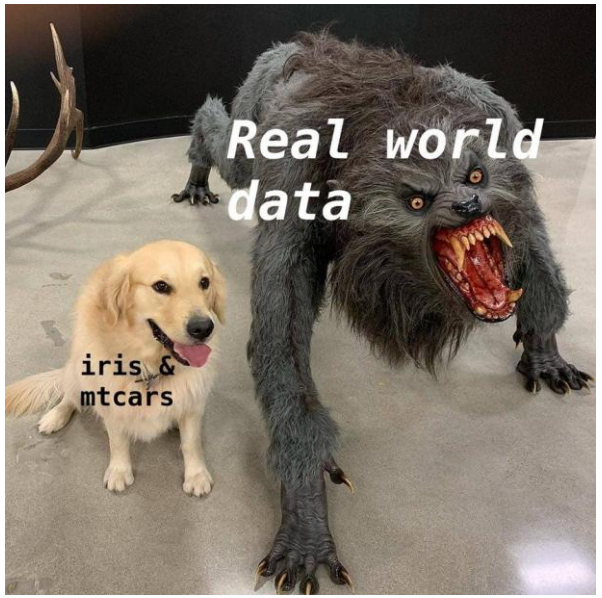


Image from Internet

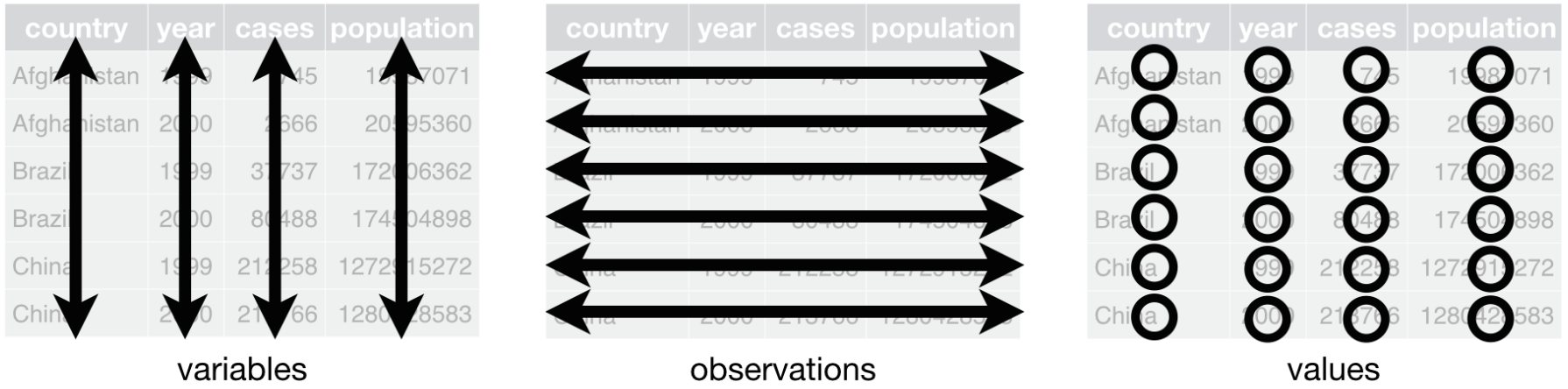
Recap: Variables

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

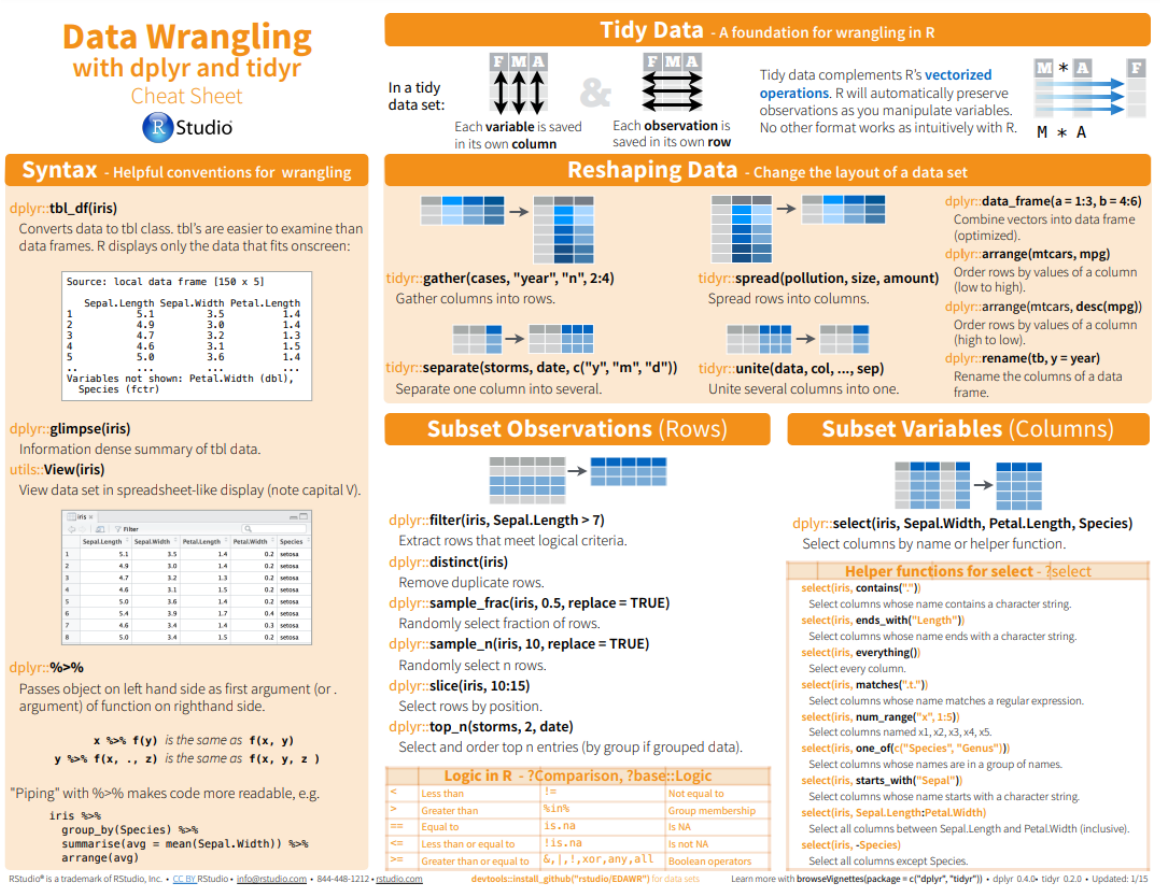
A generic data object that are used to store tabular data



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

Data wrangling functions

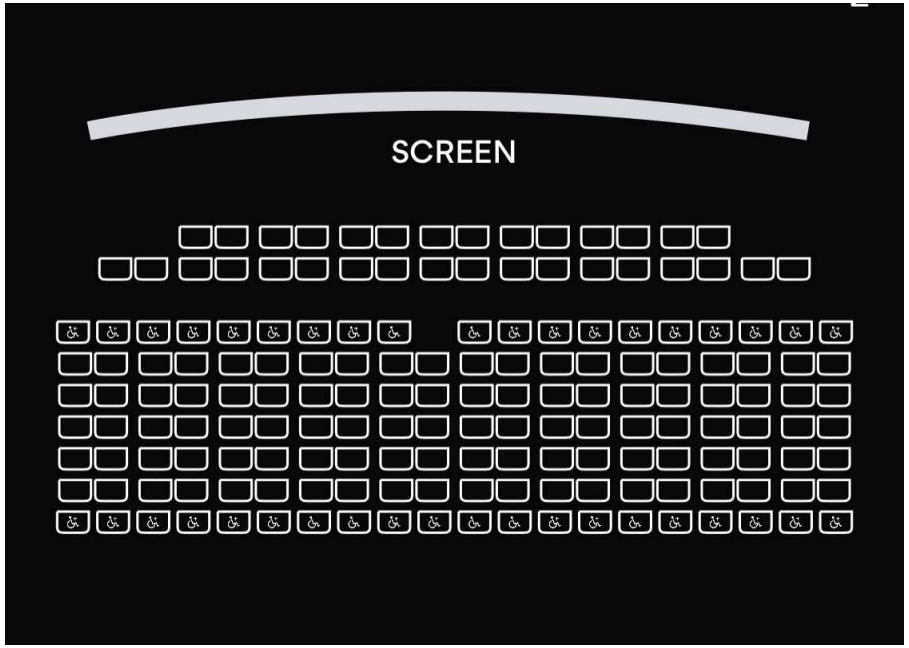
- Manipulate observations (rows)
  - `filter()`
  - `arrange()`
  - `bind_rows()`
- Manipulate variables (columns)
  - `select()`
  - `mutate()`
  - `left_join(), right_join()` …
- Reshape the data
  - `pivot_longer(), pivot_wider()`
- Group and summarize
  - `group_by()`
  - `summarize()`



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

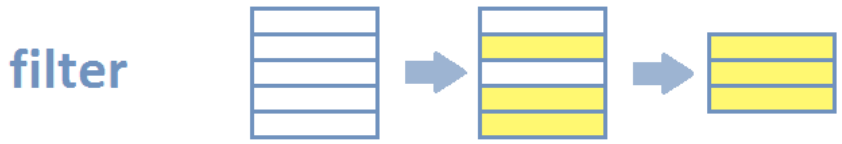
Create logical vectors:

❑ 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

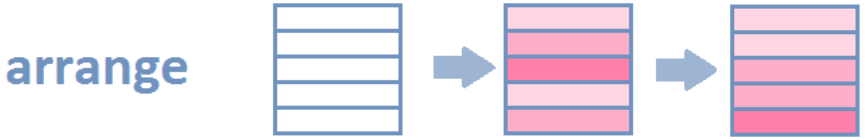
- `!x` (pronounced "not x"), flips `TRUE` and `FALSE` so it keeps all the values where x is `FALSE`.
- `x & y`: `TRUE` if both x and y are `TRUE`.
- `x | y`: `TRUE` if either x or y (or both) are `TRUE`.
- `xor(x, y)`: `TRUE` if either x or y are `TRUE`, but not both (exclusive or).



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



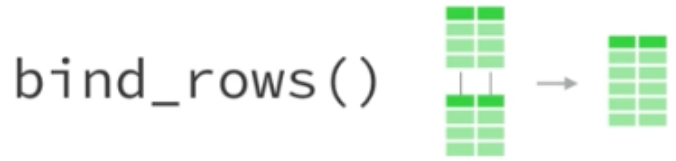
Note:

- 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

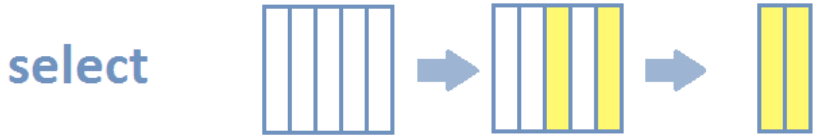
Variables

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

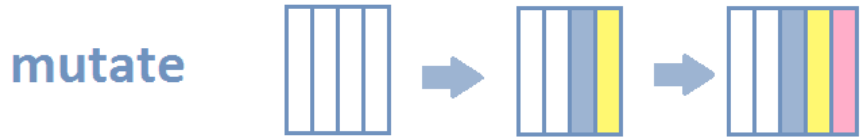
Useful Operators

- `!`: 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)

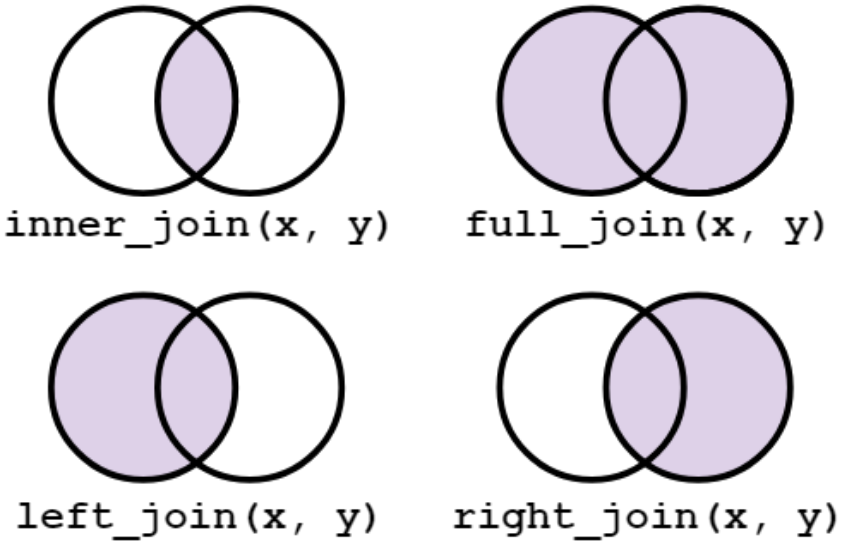


The values can be

- 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()`:



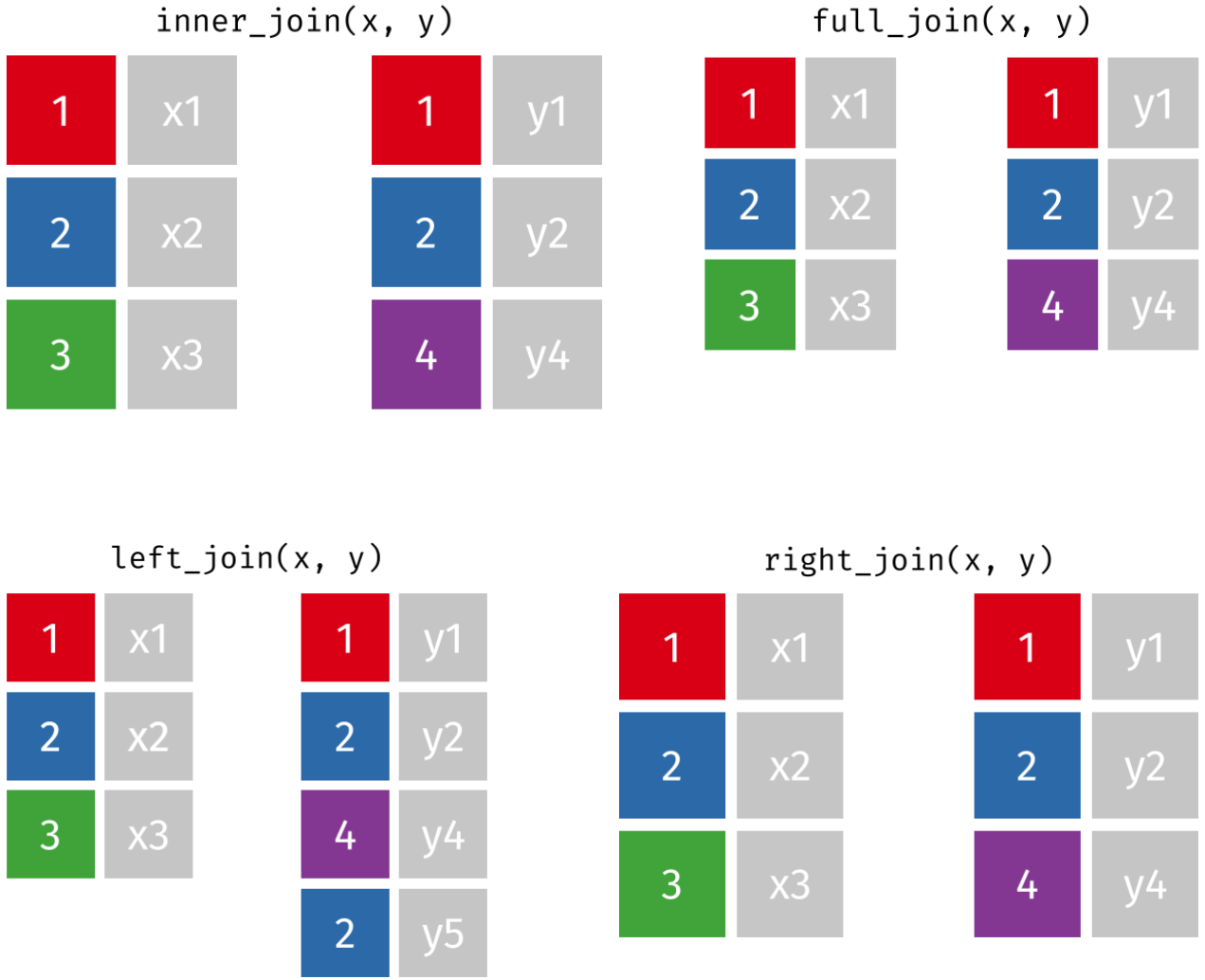
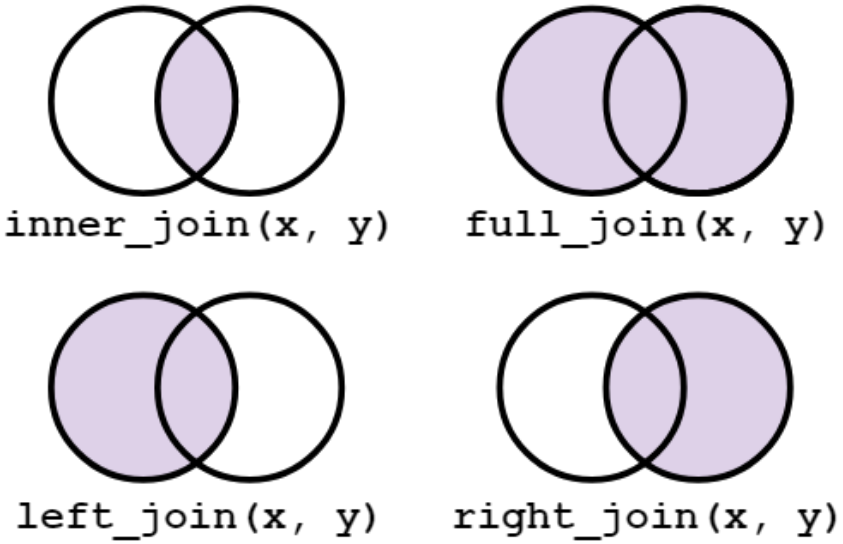
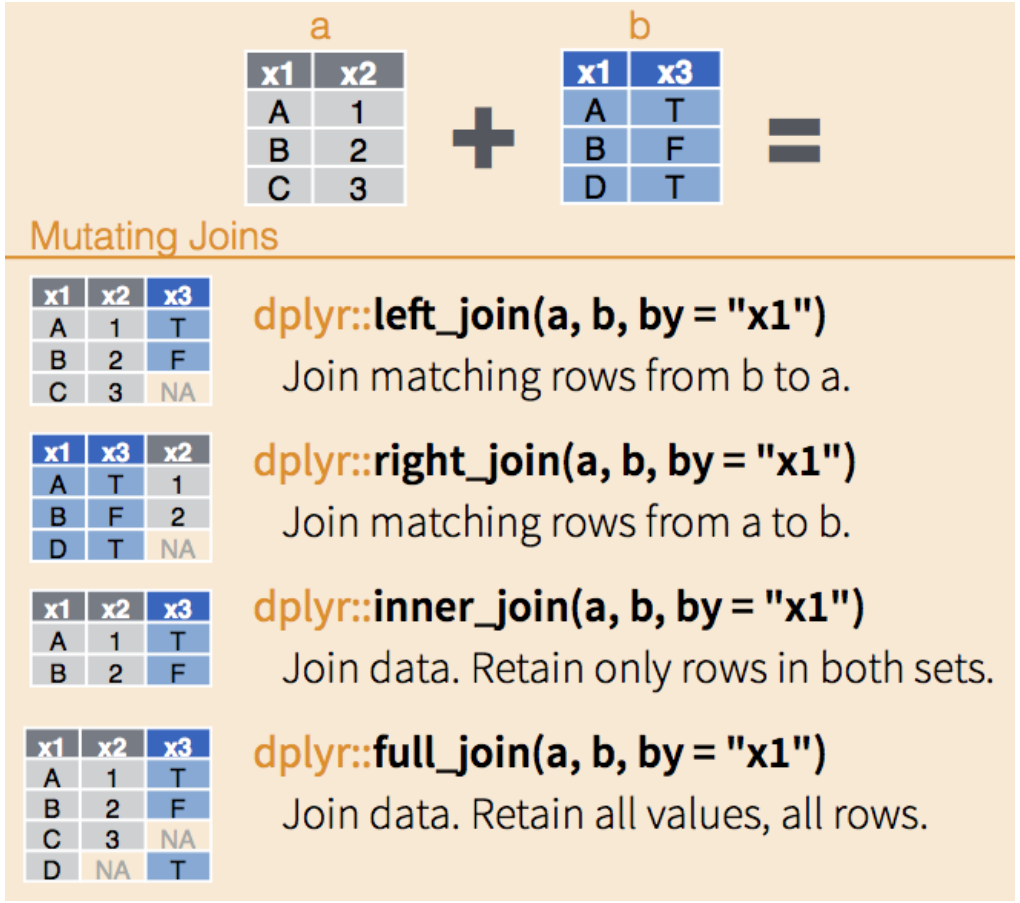


Image from internet

Combine datasets

`*_join()`:





Exercise: let's do some practice

Image from internet

Reshape

Landscape ↔ Portrait

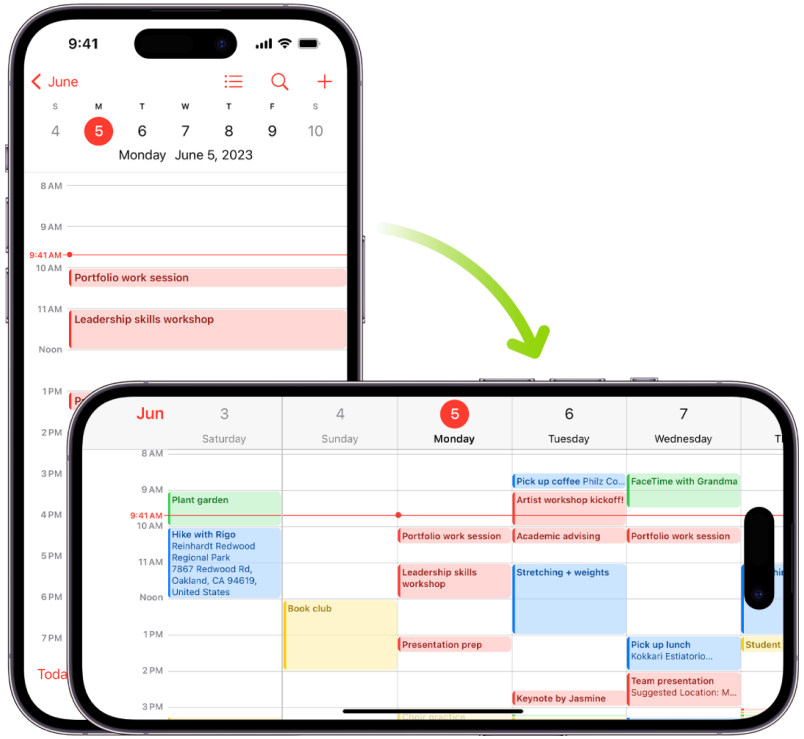


Image from internet

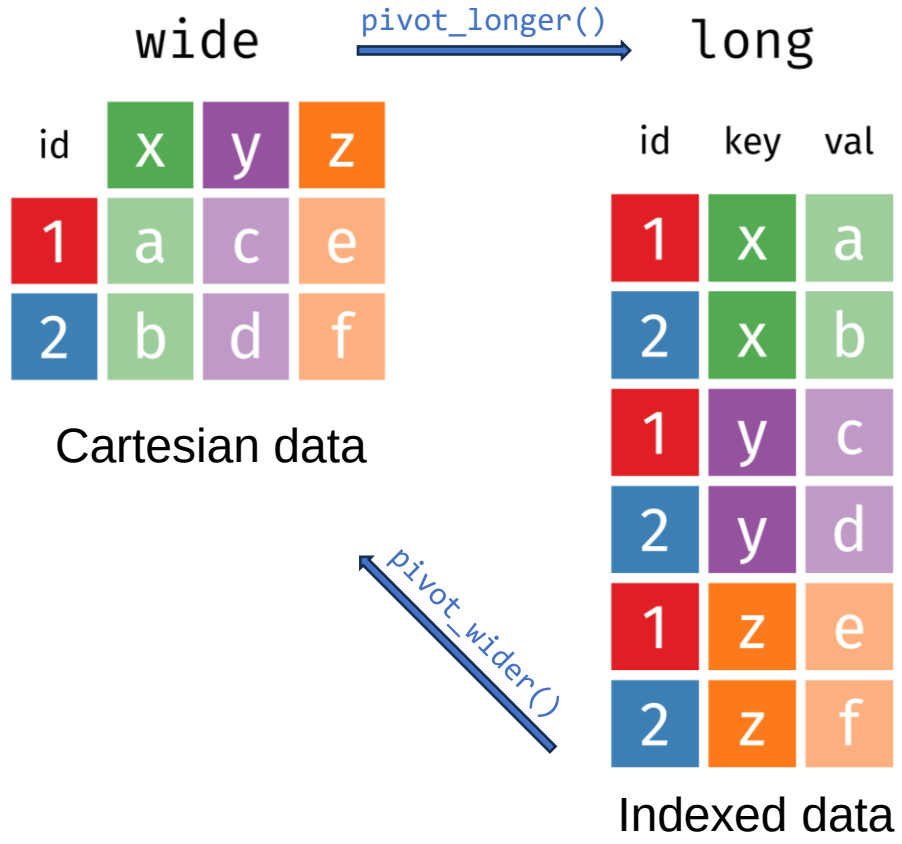
Reshape data frame

`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

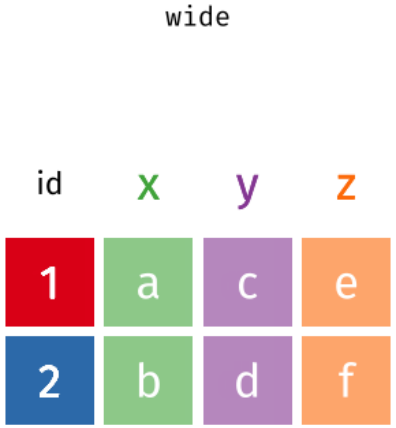


https://bookdown.org/Maxine/r4ds/pivoting.html

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

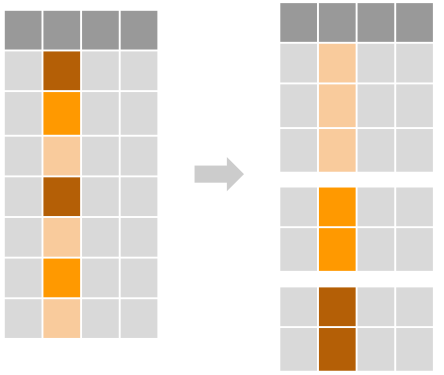
Group

“Birds of a feather flock together.”

Image from Internet

Group and summarize

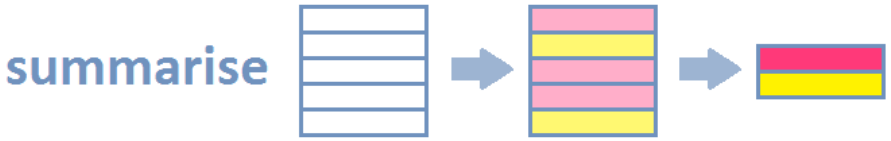
`group_by(dat, vars)`



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

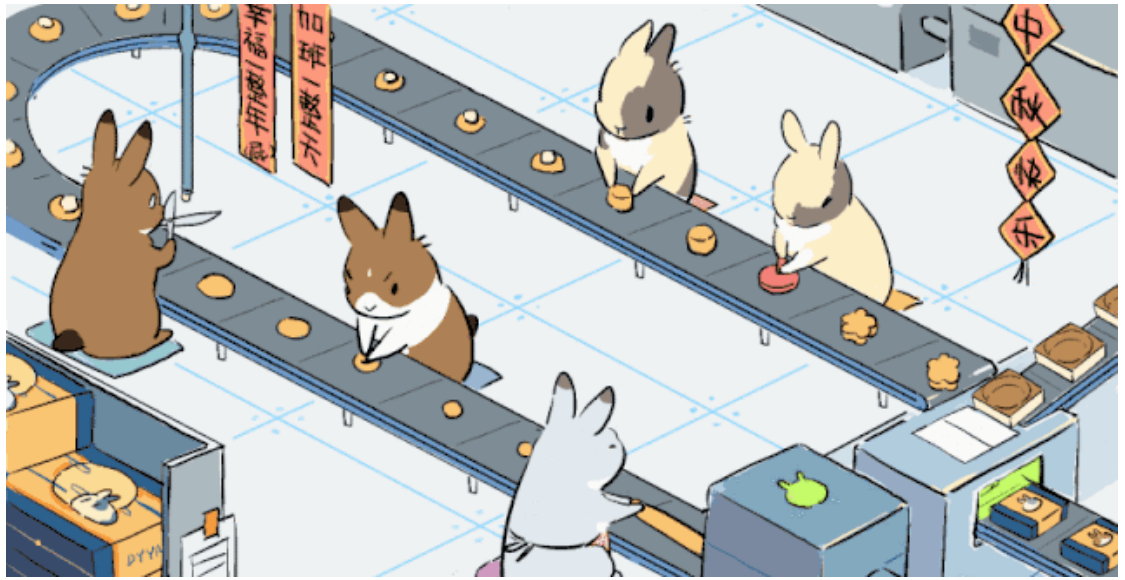


`summarise()`/`summarize()`:

- 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)
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))
```

%>% 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`