# Lec 09 - Functional programming & purrr

## Statistical Programming

### Sta 323 | Spring 2022

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# Functional Programming

# Functions as objects

We have mentioned in passing that functions in R are treated as 1st class objects (like vectors), meaning they can be assigned names, stored in lists, etc.

```
f = function(x) {
  x*x
}

f(2)
```

```
## [1] 4
```

```
g = f

g(2)
```

```
## [1] 4
```

```
l = list(f = f, g = g)

l$f(3)
```

```
## [1] 9
```

```
l[[2]](4)
```

```
## [1] 16
```

```
l[1](3)
```

```
## Error in eval(expr, envir, enclos): attempt to apply non-function
```

# Functions as arguments

We can pass in functions as arguments to other functions,

```
do_calc = function(v, func) {
  func(v)
}
```

```
do_calc(1:3, sum)
```

```
## [1] 6
```

```
do_calc(1:3, mean)
```

```
## [1] 2
```

```
do_calc(1:3, sd)
```

```
## [1] 1
```

# Anonymous functions

These are short functions that are created without ever assigning a name,

```
function(x) {x+1}
```

```
## function(x) {x+1}
```

```
(function(y) {y-1})(10)
```

```
## [1] 9
```

this can be particularly helpful for implementing certain types of tasks,

```
integrate(function(x) x, 0, 1)
```

```
## 0.5 with absolute error < 5.6e-15
```

```
integrate(function(x) x^2-2*x+1, 0, 1)
```

```
## 0.3333333 with absolute error < 3.7e-15
```

# Base R anonymous function (lambda) shorthand

Along with the base pipe (`|>`), R v4.1.0 introduced a shortcut for anonymous functions using `\()`, we won't be using this for the same reason but it is useful to know that it exists.

```
f = \(x) {1+x}
f(1:5)
```

```
## [1] 2 3 4 5 6
```

```
(\(x) x^2)(10)
```

```
## [1] 100
```

```
integrate(\(x) sin(x)^2, 0, 1)
```

```
## 0.2726756 with absolute error < 3e-15
```

Use of this with the base pipe is meant avoid the need for `.`, e.g.

```
data.frame(x = runif(10), y = runif(10)) |>
  {\(d) lm(y~x, data = d)}()
```

# apply (base R)

# Apply functions

The apply functions are a collection of tools for functional programming in base R, they are variations of the `map` function found in many other languages and apply a function over the elements of the input (vector).

```
??base::apply
---

##
## Help files with alias or concept or title matching ‘apply’ using fuzzy
## matching:
##
## base::apply             Apply Functions Over Array Margins
## base::.subset           Internal Objects in Package 'base'
## base::by                Apply a Function to a Data Frame Split by Factors
## base::eapply            Apply a Function Over Values in an Environment
## base::lapply            Apply a Function over a List or Vector
## base::mapply            Apply a Function to Multiple List or Vector Arguments
## base::rapply            Recursively Apply a Function to a List
## base::tapply            Apply a Function Over a Ragged Array
```

# lapply

Usage: `lapply(X, FUN, ...)`

`lapply` returns a list of the same length as `X`, each element of which is the result of applying `FUN` to the corresponding element of `X`.

```
lapply(1:8, sqrt) %>% str()
```

```
## List of 8
##  $ : num 1
##  $ : num 1.41
##  $ : num 1.73
##  $ : num 2
##  $ : num 2.24
##  $ : num 2.45
##  $ : num 2.65
##  $ : num 2.83
```

```
lapply(1:8, function(x) (x+1)^2) %>% str()
```

```
## List of 8
##  $ : num 4
##  $ : num 9
##  $ : num 16
##  $ : num 25
##  $ : num 36
##  $ : num 49
##  $ : num 64
##  $ : num 81
```

```
lapply(1:8, function(x, pow) x^pow, pow=3) %>% str()
```

```
## List of 8
##  $ : num 1
##  $ : num 8
##  $ : num 27
##  $ : num 64
##  $ : num 125
##  $ : num 216
##  $ : num 343
##  $ : num 512
```

```
lapply(1:8, function(x, pow) x^pow, x=2) %>% str()
```

```
## List of 8
##  $ : num 2
##  $ : num 4
##  $ : num 8
##  $ : num 16
##  $ : num 32
##  $ : num 64
##  $ : num 128
##  $ : num 256
```

# sapply

Usage: `sapply(X, FUN, ..., simplify = TRUE, USE.NAMES = TRUE)`

`sapply` is a user-friendly version and wrapper of `lapply`, it is a simplifying version of lapply. Whenever possible it will return a vector, matrix, or an array.

```
sapply(1:8, sqrt)
```

```
## [1] 1.000000 1.414214 1.732051 2.000000 2.236068 2.449490 2.645751 2.828427
```

```
sapply(1:8, function(x) (x+1)^2)
```

```
## [1]  4  9 16 25 36 49 64 81
```

```
sapply(1:8, function(x) c(x, x^2, x^3))
```

```
##      [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8]
## [1,]    1    2    3    4    5    6    7    8
## [2,]    1    4    9   16   25   36   49   64
## [3,]    1    8   27   64  125  216  343  512
```

What happens if the returned lengths don't match?

```
sapply(1:6, seq)
```

```
## [[1]]
## [1] 1
##
## [[2]]
## [1] 1 2
##
## [[3]]
## [1] 1 2 3
##
## [[4]]
## [1] 1 2 3 4
##
## [[5]]
## [1] 1 2 3 4 5
##
## [[6]]
## [1] 1 2 3 4 5 6
```

```
lapply(1:6, seq)
```

```
## [[1]]
## [1] 1
##
## [[2]]
## [1] 1 2
##
## [[3]]
## [1] 1 2 3
##
## [[4]]
## [1] 1 2 3 4
##
## [[5]]
## [1] 1 2 3 4 5
##
## [[6]]
## [1] 1 2 3 4 5 6
```

## What happens if the types don't match?

```
l = list(a = 1:3, b = 4:6, c = 7:9, d = list(10, 11, "A"))
```

```
sapply(l, function(x) x[1])
```

```
## $a
## [1] 1
##
## $b
## [1] 4
##
## $c
## [1] 7
##
## $d
## [1] 10
```

```
sapply(l, function(x) x[[1]])
```

```
##  a  b  c  d
##  1  4  7 10
```

```
sapply(l, function(x) x[[3]])
```

```
##   a   b   c   d
```

# *apply and data frames

We can use these functions with data frames, the key is to remember that a data frame is just a fancy list.

```
df = data.frame(
  a = 1:6,
  b = letters[1:6],
  c = c(TRUE,FALSE)
)
```

```
lapply(df, class) %>% str()
```

```
## List of 3
##  $ a: chr "integer"
##  $ b: chr "character"
##  $ c: chr "logical"
```

```
sapply(df, class)
```

```
##           a           b           c
##   "integer" "character"   "logical"
```

# A more useful example

Some sources of data (e.g. the US government) will encode missing values with `-999`, if want to replace these with `NA`s lapply is not a bad choice.

```
d = data.frame(
  patient_id = c(1, 2, 3, 4, 5),
  age = c(32, 27, 56, 19, 65),
  bp = c(110, 100, 125, -999, -999),
  o2 = c(97, 95, -999, -999, 99)
)
```

```
fix_missing = function(x) {
  x[x == -999] = NA
  x
}
lapply(d, fix_missing)
```

```
## $patient_id
## [1] 1 2 3 4 5
##
## $age
## [1] 32 27 56 19 65
##
```

```
lapply(d, fix_missing) %>%
  as.data.frame()
```

```
##   patient_id age  bp o2
## 1          1  32 110 97
## 2          2  27 100 95
## 3          3  56 125 NA
## 4          4  19  NA NA
## 5          5  65  NA 99
```

# dplyr alternative

dplyr is also a viable option here using the `across()` helper,

```
d %>%
  mutate(
    across(bp:o2, fix_missing)
  )
```

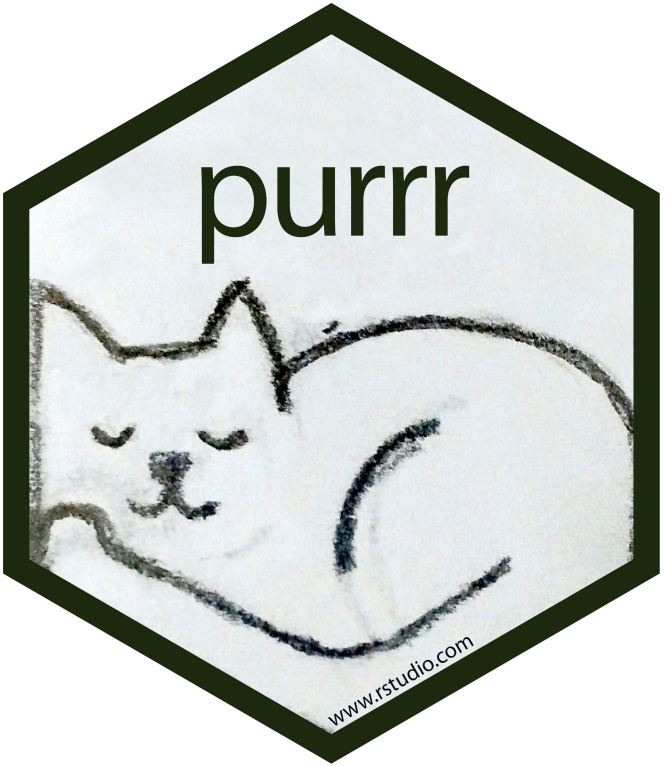
```
##   patient_id age  bp o2
## 1          1  32 110 97
## 2          2  27 100 95
## 3          3  56 125 NA
## 4          4  19  NA NA
## 5          5  65  NA 99
```

```
d %>%
  mutate(
    across(where(is.numeric), fix_missing)
  )
```

```
##   patient_id age  bp o2
## 1          1  32 110 97
## 2          2  27 100 95
## 3          3  56 125 NA
## 4          4  19  NA NA
## 5          5  65  NA 99
```

# other less common apply functions

- `apply()` - applies a function over the rows or columns of a data frame, matrix or array
- `vapply()` - is similar to `sapply`, but has a enforced return type and size
- `mapply()` - like `sapply` but will iterate over multiple vectors at the same time.
- `rapply()` - a recursive version of `lapply`, behavior depends largely on the `how` argument
- `eapply()` - apply a function over an environment.


purrr
www.rstudio.com

# Map functions

Basic functions for looping over objects and returning a value (of a specific type) - replacement for `lapply`/`sapply`/`vapply`.

- `map()` - returns a list, equivalent to `lapply()`
- `map_lgl()` - returns a logical vector.
- `map_int()` - returns a integer vector.
- `map_dbl()` - returns a double vector.
- `map_chr()` - returns a character vector.
- `map_dfr()` - returns a data frame by row binding.
- `map_dfc()` - returns a data frame by column binding.
- `walk()` - returns nothing, used exclusively for function side effects

# Type Consistency

R is a weakly / dynamically typed language which means there is no syntactic way to define a function which enforces argument or return types. This flexibility can be useful at times, but often it makes it hard to reason about your code and requires more verbose code to handle edge cases.

```
x = list(rnorm(1e3), rnorm(1e3), rnorm(1e3))
```

```
map_dbl(x, mean)
```

```
## [1] -0.044745835  0.009868732 -0.011927102
```

```
map_chr(x, mean)
```

```
## [1] "-0.044746" "0.009869"  "-0.011927"
```

```
map_int(x, mean)
```

```
## Error: Can't coerce element 1 from a double to a integer
```

```
map(x, mean) %>% str()
```

```
lapply(x, mean) %>% str()
```

# Working with Data Frames

`map_dfr` and `map_dfc` are particularly useful when working with and/or creating data frames.

Take for example the Lecture 5 Exercise 2 example from above,

```
d = data.frame(
  patient_id = c(1, 2, 3, 4, 5),
  age = c(32, 27, 56, 19, 65),
  bp = c(110, 100, 125, -999, -999),
  o2 = c(97, 95, -999, -999, 99)
)
```

```
fix_missing = function(x) {
  x[x == -999] = NA
  x
}
```

```
purrr::map_dfc(d, fix_missing)
```

```
## # A tibble: 5 × 4
##   patient_id   age    bp    o2
##        <dbl> <dbl> <dbl> <dbl>
## 1          1    32   110    97
## 2          2    27   100    95
## 3          3    56   125    NA
## 4          4    19    NA    NA
```

```r
map_dfr(sw_people, function(x) x[1:5])
```

```
## # A tibble: 87 × 5
##    name               height mass  hair_color    skin_color
##    <chr>              <chr>  <chr> <chr>         <chr>
##  1 Luke Skywalker     172    77    blond         fair
##  2 C-3PO              167    75    n/a           gold
##  3 R2-D2              96     32    n/a           white, blue
##  4 Darth Vader        202    136   none          white
##  5 Leia Organa        150    49    brown         light
##  6 Owen Lars          178    120   brown, grey   light
##  7 Beru Whitesun lars 165    75    brown         light
##  8 R5-D4              97     32    n/a           white, red
##  9 Biggs Darklighter  183    84    black         light
## 10 Obi-Wan Kenobi     182    77    auburn, white fair
## # … with 77 more rows
```

```r
map_dfr(sw_people, function(x) x)
```

```
## Error in `stop_vctrs()`:
## ! Can't recycle `name` (size 5) to match `vehicles` (size 2).
```

# purrr style anonymous functions

purrr lets us write anonymous functions using one sided formulas where the argument is given by `.` or `.x` for `map` and related functions.

```
map_dbl(1:5, function(x) x/(x+1))
```

```
## [1] 0.5000000 0.6666667 0.7500000 0.8000000 0.8333333
```

```
map_dbl(1:5, ~ ./(.+1))
```

```
## [1] 0.5000000 0.6666667 0.7500000 0.8000000 0.8333333
```

```
map_dbl(1:5, ~ .x/(.x+1))
```

```
## [1] 0.5000000 0.6666667 0.7500000 0.8000000 0.8333333
```

Generally, the latter option is preferred to avoid confusion with magrittr.

# Multiargument anonymous functions

Functions with the `map2` prefix work the same as the `map` functions but they iterate over two objects instead of one. Arguments in an anonymous function are given by `.x` and `.y` (or `..1` and `..2`) respectively.

```
map2_dbl(1:5, 1:5, function(x,y) x / (y+1))
```

```
## [1] 0.5000000 0.6666667 0.7500000 0.8000000 0.8333333
```

```
map2_dbl(1:5, 1:5, ~ .x/(.y+1))
```

```
## [1] 0.5000000 0.6666667 0.7500000 0.8000000 0.8333333
```

```
map2_dbl(1:5, 1:5, ~ ..1/(..2+1))
```

```
## [1] 0.5000000 0.6666667 0.7500000 0.8000000 0.8333333
```

```
map2_chr(LETTERS[1:5], letters[1:5], paste0)
```

```
## [1] "Aa" "Bb" "Cc" "Dd" "Ee"
```

# Lookups

Very often we want to extract only certain (named) values from a list, `purrr` provides a shortcut for this operation - if instead of a function you provide either a character or numeric vector, those values will be used to sequentially subset the elements being iterated.

```
purrr::map_chr(sw_people, "name") %>% head()
```

```
## [1] "Luke Skywalker" "C-3PO"          "R2-D2"          "Darth Vader"
## [5] "Leia Organa"    "Owen Lars"
```

```
purrr::map_chr(sw_people, 1) %>% head()
```

```
## [1] "Luke Skywalker" "C-3PO"          "R2-D2"          "Darth Vader"
## [5] "Leia Organa"    "Owen Lars"
```

```
purrr::map_chr(sw_people, list("films", 1)) %>% head(n=10)
```

```
##  [1] "http://swapi.co/api/films/6/" "http://swapi.co/api/films/5/"
##  [3] "http://swapi.co/api/films/5/" "http://swapi.co/api/films/6/"
##  [5] "http://swapi.co/api/films/6/" "http://swapi.co/api/films/5/"
##  [7] "http://swapi.co/api/films/5/" "http://swapi.co/api/films/1/"
##  [9] "http://swapi.co/api/films/1/" "http://swapi.co/api/films/5/"
```

# Length coercion?

```
purrr::map_chr(sw_people, list("starships", 1))
```

```
## Error in `stop_bad_type()`:
## ! Result 2 must be a single string, not NULL of length 0
```

```
sw_people[[2]]$name
```

```
## [1] "C-3PO"
```

```
sw_people[[2]]$starships
```

```
## NULL
```

```
purrr::map_chr(sw_people, list("starships", 1), .default = NA) %>% head()
```

```
## [1] "http://swapi.co/api/starships/12/" NA
## [3] NA                                  "http://swapi.co/api/starships/13/"
## [5] NA                                  NA
```

```
purrr::map(sw_people, list("starships", 1)) %>% head()
```

```
## [[1]]
## [1] "http://swapi.co/api/starships/12/"
##
## [[2]]
## NULL
##
## [[3]]
## NULL
##
## [[4]]
## [1] "http://swapi.co/api/starships/13/"
##
## [[5]]
## NULL
##
## [[6]]
## NULL
```

# list columns

```
(chars = tibble(
  name = purrr::map_chr(sw_people, "name"),
  starships = purrr::map(sw_people, "starships")
))
```

```
## # A tibble: 87 × 2
##    name               starships
##    <chr>              <list>
##  1 Luke Skywalker     <chr [2]>
##  2 C-3PO              <NULL>
##  3 R2-D2              <NULL>
##  4 Darth Vader        <chr [1]>
##  5 Leia Organa        <NULL>
##  6 Owen Lars          <NULL>
##  7 Beru Whitesun lars <NULL>
##  8 R5-D4              <NULL>
##  9 Biggs Darklighter  <chr [1]>
## 10 Obi-Wan Kenobi     <chr [5]>
## # … with 77 more rows
```

```
chars %>%
  mutate(
    n_starships = map_int(starships, length)
  )
```

```
## # A tibble: 87 × 3
##    name               starships n_starships
##    <chr>              <list>          <int>
##  1 Luke Skywalker     <chr [2]>           2
##  2 C-3PO              <NULL>              0
##  3 R2-D2              <NULL>              0
##  4 Darth Vader        <chr [1]>           1
##  5 Leia Organa        <NULL>              0
##  6 Owen Lars          <NULL>              0
##  7 Beru Whitesun lars <NULL>              0
##  8 R5-D4              <NULL>              0
##  9 Biggs Darklighter  <chr [1]>           1
## 10 Obi-Wan Kenobi     <chr [5]>           5
## # … with 77 more rows
```

# Example - list columns and approximating pi

# Selective rectangling

# Complex heirarchical data

Often we may encounter complex data structures where our goal is not to rectangle every value (which may not even be possible) but rather to rectangle a small subset of the data.

```
str(repurrrsive::discog, max.level = 3)
```

```
## List of 155
##  $ :List of 5
##   ..$ instance_id      : int 354823933
##   ..$ date_added       : chr "2019-02-16T17:48:59-08:00"
##   ..$ basic_information:List of 11
##   .. ..$ labels      :List of 1
##   .. ..$ year        : int 2015
##   .. ..$ master_url  : NULL
##   .. ..$ artists     :List of 1
##   .. ..$ id          : int 7496378
##   .. ..$ thumb       : chr "https://img.discogs.com/vEVegHrMNTsP6xG_K6OuFXz4h_U=/fit-in/150x150/filters:strip
##   .. ..$ title       : chr "Demo"
##   .. ..$ formats     :List of 1
##   .. ..$ cover_image : chr "https://img.discogs.com/EmbMh7vsElksjRgoXLFSuY1sjRQ=/fit-in/500x499/filters:strip
##   .. ..$ resource_url: chr "https://api.discogs.com/releases/7496378"
##   .. ..$ master_id   : int 0
##   ..$ id               : int 7496378
##   ..$ rating           : int 0
```

# Example - discog - purrr vs tidyr