Functional programming & purrr

Lecture 08

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Functional Programming

Functions as objects

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

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

f(2)
```

```
[1] 4
```

```r
g = f

g(2)
```

```
[1] 4
```

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

l$f(3)
```

```
[1] 9
```

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

```
[1] 16
```

```r
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,

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

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

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

```
[1] 9
```

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

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

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

```
1 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 `\()`,

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

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

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

```
[1] 100
```

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

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

```
1 (function(x) {1+x})(1:5)
```

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

```
1 (function(x) x^2)(10)
```

```
[1] 100
```

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

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

Use of this with the base pipe helps avoid the need for `_`,

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

```
Call:
lm(formula = y ~ x, data = d)

Coefficients:
(Intercept)            x
    0.54501      0.09595
```

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 an input (vector).

```
??base::apply

## Help files with alias or concept or title matching ‘apply’ using
## 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
## base::eapply               Apply a Function Over Values in an Enviro
## base::lapply               Apply a Function over a List or Vector (A
## base::mapply               Apply a Function to Multiple List or Vect
## 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`.

```
1 lapply(1:8, sqrt) |>
2   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
```

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

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

Argument matching

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

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

```
1 lapply(1:8, function(x, pow) x^pow, x=2)
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.

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

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

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

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

```
1 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
```

Length mismatch?

```
1 sapply(1:6, seq) |> str()
```

```
List of 6
 $ : int 1
 $ : int [1:2] 1 2
 $ : int [1:3] 1 2 3
 $ : int [1:4] 1 2 3 4
 $ : int [1:5] 1 2 3 4 5
 $ : int [1:6] 1 2 3 4 5 6
```

```
1 lapply(1:6, seq) |> str()
```

```
List of 6
 $ : int 1
 $ : int [1:2] 1 2
 $ : int [1:3] 1 2 3
 $ : int [1:4] 1 2 3 4
 $ : int [1:5] 1 2 3 4 5
 $ : int [1:6] 1 2 3 4 5 6
```

Type mismatch?

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

```
1 sapply(l, function(x) x[1]) |> str()
```

```
List of 4
 $ a: int 1
 $ b: int 4
 $ c: int 7
 $ d: num 10
```

```
1 sapply(l, function(x) x[[1]]) |> str()
```

```
 Named num [1:4] 1 4 7 10
 - attr(*, "names")= chr [1:4] "a" "b" "c" "d"
```

```
1 sapply(l, function(x) x[[3]]) |> str()
```

```
 Named chr [1:4] "3" "6" "9" "A"
 - attr(*, "names")= chr [1:4] "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.

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

```r
lapply(df, class) |> str()
```

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

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

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

A more useful example

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

```
d = tibble::tribble(
  ~patient_id, ~age,  ~bp,  ~o2,
             1,   32,  110,   97,
             2,   27,  100,   95,
             3,   56,  125, -999,
             4,   19, -999, -999,
             5,   65, -999,   99
)
```

```r
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

$bp
[1] 110 100 125  NA  NA

$o2
[1] 97 95 NA NA 99
```

```r
lapply(d, fix_missing) |>
  as_tibble()
```

```
# 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
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
    )
  )
```

```
# 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
5          5    65    NA    99
```

```
d |>
  mutate(
    across(
      where(is.numeric),
      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
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.
- `walk()` - returns nothing, used for 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]  0.01186377 -0.01026577 -0.02440657
```

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

```
[1] "0.011864"  "-0.010266" "-0.024407"
```

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

```
List of 3
 $ : num 0.0119
 $ : num -0.0103
 $ : num -0.0244
```

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

```
Error in `map_int()`:
ℹ In index: 1.
Caused by error:
! Can't coerce from a number to an integer.
```

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

```
List of 3
 $ : num 0.0119
 $ : num -0.0103
 $ : num -0.0244
```

Working with Data Frames

purrr offers the functions `map_dfr` and `map_dfc` (which were superseded as of v1.0.0) - these allow for the construction of a data frame by row or by column respectively.

```
d = tibble::tribble(
  ~patient_id, ~age,  ~bp,  ~o2,
             1,   32,  110,   97,
             2,   27,  100,   95,
             3,   56,  125, -999,
             4,   19, -999, -999,
             5,   65, -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
5          5    65    NA    99
```

```
purrr::map(d, fix_missing) |>
  bind_cols()
```

```
# 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
5          5    65    NA    99
```

Building by row

```
map(sw_people, function(x) x[1:5]) |> bind_rows()
```

```
# 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
# ℹ 77 more rows
```

```
map(sw_people, function(x) x) |> bind_rows()
```

```
Error in `vctrs::data_frame()`:
! 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` prefixed functions but they iterate over two objects instead of one. Arguments for 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"
```

imap functions

purrr also contains a collection of `imap` prefixed functions which are short hand for mapping over an object and the indexes of that object (i.e. `seq_along(obj)`).

```
iwalk(
  letters[1:5],
  ~cat("index: ", .y, ", value: ", .x, "\n", sep="")
)
```

```
index: 1, value: a
index: 2, value: b
index: 3, value: c
index: 4, value: d
index: 5, value: e
```

Lookups

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

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

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

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

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

```
1 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 `purrr::map_chr()`:
ℹ In index: 2.
Caused by error:
! Result must be length 1, not 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() |> str()
```

```
List of 6
 $ : chr "http://swapi.co/api/starships/12/"
 $ : NULL
 $ : NULL
 $ : chr "http://swapi.co/api/starships/13/"
 $ : NULL
 $ : 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]>
# ℹ 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
# ℹ 77 more rows
```

Example

List columns and approximating pi

Example

`discog` - purrr vs tidyr

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.

```
1 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.jpg():format(jpeg):mode.rgb()"|   truncated
```