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
1  f = function(x) {
2    x*x
3  }
4  f(2)
```

```
[1] 4
```

```r
1  g = f
2  g(2)
```

```
[1] 4
```

```r
1  l = list(f = f, g = g)
2  l$f(3)
```

```
[1] 9
```

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

```
[1] 16
```

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

```
Error: attempt to apply non-function
```

3

Functions as arguments

We can pass in functions as arguments to other functions,

```
1  do_calc = function(v, func) {
2    func(v)
3  }
```

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

```
[1] 6
```

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

```
[1] 2
```

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

```
[1] 1
```

4

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 `\()`,

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

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

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

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

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

```
[1] 100
```

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

```
[1] 100
```

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

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

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

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

We can use this with the base pipe to avoid using `_`,

```r
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
     0.3813      -0.2679
```

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).

```
1  ??base::apply
2
3  ## Help files with alias or concept or title matching 'apply' using fuzzy
4  ## matching:
5  ##
6  ## base::apply            Apply Functions Over Array Margins
7  ## base::.subset          Internal Objects in Package 'base'
8  ## base::by               Apply a Function to a Data Frame Split by Factors
9  ## base::eapply           Apply a Function Over Values in an Environment
10 ## base::lapply           Apply a Function over a List or Vector (Aliases:
11 ## base::mapply           Apply a Function to Multiple List or Vector Argum
12 ## base::rapply           Recursively Apply a Function to a List
13 ## 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

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

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

```r
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
```

11

Length mismatch?

```r
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
```

```r
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
1  df = data.frame(
2    a = 1:6,
3    b = letters[1:6],
4    c = c(TRUE,FALSE)
5  )
```

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

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

```r
1  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 NAs lapply is not a bad choice.

```r
1  d = tibble::tribble(
2    ~patient_id, ~age,  ~bp,   ~o2,
3             1,   32,  110,    97,
4             2,   27,  100,    95,
5             3,   56,  125,  −999,
6             4,   19, −999,  −999,
7             5,   65, −999,    99
8  )
```

```r
1  fix_missing = function(x) {
2    x[x == −999] = NA
3    x
4  }
5  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
1  lapply(d, fix_missing) |>
2    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,

```
1  d |>
2    mutate(
3      across(
4        bp:o2,
5        fix_missing
6      )
7    )
```

```
1  d |>
2    mutate(
3      across(
4        where(is.numeric),
5        fix_missing
6      )
7    )
```

```
# 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
```

```
# 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 matrix or array (data frames also work but are bad idea)

- `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.

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.

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

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

```
[1]  0.07395152 -0.03673950  0.02590063
```

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

Warning: Automatic coercion from double to
character was deprecated in purrr 1.0.0.
ℹ Please use an explicit call to `as.character()`
within `map_chr()` instead.

```
[1] "0.073952"  "-0.036740" "0.025901"
```

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

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

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

```
List of 3
 $ : num 0.074
 $ : num -0.0367
 $ : num 0.0259
```

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

```
List of 3
 $ : num 0.074
 $ : num -0.0367
 $ : num 0.0259
```

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.

```r
1  d = tibble::tribble(
2    ~patient_id, ~age,  ~bp,   ~o2,
3             1,   32,  110,    97,
4             2,   27,  100,    95,
5             3,   56,  125,  -999,
6             4,   19, -999,  -999,
7             5,   65, -999,    99
8  )
```

```r
1  fix_missing = function(x) {
2    x[x == -999] = NA
3    x
4  }
```

```r
1  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
```

```r
1  purrr::map(d, fix_missing) |>
2    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

```
1 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
```

```
1 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.

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

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

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

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

```
1  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.

23

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.

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

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

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

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

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

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

```r
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)`).

```
1  iwalk(
2    letters[1:5],
3    ~cat("index: ", .y, ", value: ", .x, "\n", sep="")
4  )
```

```
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/"
```

26

Length coercion?

```
1  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.
```

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

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

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

```
NULL
```

```
1  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
```

```
1  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

```
1  (chars = tibble(
2    name = purrr::map_chr(
3      sw_people, "name"
4    ),
5    starships = purrr::map(
6      sw_people, "starships"
7    )
8  ))
```

```
# 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
```

```
1  chars |>
2    mutate(
3      n_starships = map_int(
4        starships, length
5      )
6    )
```

```
# 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
```

28

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_icc():format(jpeg):mode_rgb()"|   truncated
```

Partial vs complete rectangling

In the case of `discog` we may want to rectangle the `id`, `year`, `title`, `artist`, and `label` fields but leave the rest of the data as is.

In cases like this using tidyr's `unnest_wider()` and `unnest_long()` is not ideal as they will attempt to rectangle the entire data set when we only want a subset. There is no need to do the expensive work of unnesting columns we will never use.

purrr's `map_*()` functions and tidyr's `hoist()` function are useful for targeting specific columns to rectangle.

purrr

```r
1  tibble(disc = repurrrsive::discog) |>
2    mutate(
3      id    = purrr::map_int(disc, "id"),
4      year  = purrr::map_int(disc, c("basic_information", "year")),
5      title = purrr::map_chr(disc, c("basic_information", "title")),
6      artist = purrr::map_chr(disc, list("basic_information", "artists", 1, "name")),
7      label  = purrr::map_chr(disc, list("basic_information", "labels", 1, "name"))
8    )
```

```
# A tibble: 155 × 6
   disc                   id  year title                          artist label
   <list>              <int> <int> <chr>                          <chr>  <chr>
 1 <named list [5]>  7496378  2015 Demo                           Mollot Tobi…
 2 <named list [5]>  4490852  2013 Observant Com El Mon Es Destrue… Una B… La V…
 3 <named list [5]>  9827276  2017 I                              S.H.I… La V…
 4 <named list [5]>  9769203  2017 Oído Absoluto                  Rata … La V…
 5 <named list [5]>  7237138  2015 A Cat's Cause, No Dogs Problem Ivy (… Kato…
 6 <named list [5]> 13117042  2019 Tashme                         Tashme High…
 7 <named list [5]>  7113575  2014 Demo                           Desgr… Mind…
 8 <named list [5]> 10540713  2015 Let The Miracles Begin         Phant… Not …
 9 <named list [5]> 11260950  2017 Sub Space                      Sub S… Not …
10 <named list [5]> 11726853  2017 Demo                           Small… Pres…
# ℹ 145 more rows
```

hoist()

```
1  tibble(disc = repurrrsive::discog) %>%
2    hoist(
3      disc,
4      id = "id",
5      year = c("basic_information", "year"),
6      title = c("basic_information", "title"),
7      artist = list("basic_information", "artists", 1, "name"),
8      label = list("basic_information", "labels", 1, "name")
9    )
```

```
# A tibble: 155 × 6
        id  year title                                  artist      label disc
     <int> <int> <chr>                                  <chr>       <chr> <list>
 1  7496378  2015 Demo                                   Mollot      Tobi… <named list>
 2  4490852  2013 Observant Com El Mon Es Destrueix Una Bèst… La V… <named list>
 3  9827276  2017 I                                      S.H.I.T.… La V… <named list>
 4  9769203  2017 Oído Absoluto                          Rata Neg… La V… <named list>
 5  7237138  2015 A Cat's Cause, No Dogs Problem         Ivy (18)    Kato… <named list>
 6 13117042  2019 Tashme                                 Tashme      High… <named list>
 7  7113575  2014 Demo                                   Desgraci… Mind… <named list>
 8 10540713  2015 Let The Miracles Begin                 Phantom … Not … <named list>
 9 11260950  2017 Sub Space                              Sub Spac… Not … <named list>
10 11726853  2017 Demo                                   Small Ma… Pres… <named list>
# ℹ 145 more rows
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34