

# Regular Expression

## Admin Stuff

- assignment 2 is due today
- introduce `styler`

```
library(tidyverse)
```

## Regular Expression

### Introduction

A regular expression, **regex** or **regexp** is a sequence of characters that define a search pattern.

There exists any versions of regular expressions. **stringr** of tidyverse follows the ICU standard while base R follows the PCRE standard. See Comparison of regular-expression engines

We again prefer the tidyverse packages over base functions.

### Basic concepts

We will use <https://regex101.com/> to illustrate the following. (Choose the Python engine to best mimic ICU standard)

- Boolean “or” - `gray|grey` can match `gray` or `grey`
- Grouping - Parentheses are used to define the scope and precedence of the operators - `gr(a|e)y` can match `gray` and `grey`.
- A quantifier after a token, character or group specifies how often that a preceding element is allowed to occur.

| quantifier |                                     |
|------------|-------------------------------------|
| ?          | zero or one occurrences             |
| *          | zero or more occurrences            |
| +          | one or more occurrences             |
| {n}        | exactly n occurrences               |
| {n,}       | n or more times                     |
| {m, n}     | m or more times but not more than n |

Examples:

- `colou?r` matches both “color” and “colour”.

- `ab*c` matches “ac”, “abc”, “abbc”, “abbbc”, and so on
- `ab+c` matches “abc”, “abbc”, “abbbc”, and so on, but not “ac”
- Wildcard - The wildcard `.` matches any character except a new line.  
Examples:
  - `a.c` matches “aac”, “abc” and so on.
- Anchors - `^` matches the beginning of a string and `$` matches the end of a string  
Examples:
  - `^abc` matches “abc” but not “cabc”
  - `abc$` matches “abc” but not “abcd”
- Bracket expression `[...]` matches a single character that is contained within the brackets  
Examples:
  - `[abc]` matches “a”, “b”, or “c”
  - `[abc123]` matches “a”, “b”, “c”, “1”, “2” or “3”
  - `[a-z]` specifies a range which matches any lowercase letter from “a” to “z”.
  - `[a-zA-Z0-9]` matches all alphanumerics
  - `[\[]` matches `[` or `]`
  - `[\]` matches `\`
- Bracket expression `[^...]` matches a single character that is not contained within the brackets  
Examples:
  - `[^abc]` matches any character other than “a”, “b”, or “c”
  - `[^\]]` matches any `]` character which is not `]`.

#### Special characters

Honorable mentions | Pattern | matches | `—|—|` | `|\.` | `|\!` | `|\?` | `|\[` | `|\]` | `|\{` | `|\}` | `|\[` | `|\]` | `|\n` | a new line | `|\s` | a space or a tab | `|\S` | not a space nor a tab | `|\d` | a digit | `|\D` | a non digit | `|\w` | a word character (includes for example CJK chars) | `|\W` | a non word character | `|\b` | word boundaries |

## Escaping characters

In R, these two characters need to be specially treated in double quotes.

- `"\"` means a single backslash
- `"\"` means a double quote

## Package stringr

### Manage Strings

```
fruit <- c("apple", "banana", "pear", "pinapple")
str_length(fruit)
```

```
## [1] 5 6 4 8
```

```
# add leading white spaces
str_pad(fruit, 10)
```

```
## [1] "      apple" "      banana" "      pear" "      pineapple"
```

```
# remove white spaces
str_trim(str_pad(fruit, 10))
```

```
## [1] "apple" "banana" "pear" "pineapple"
```

```
# ...
str_trunc(fruit, 5)
```

```
## [1] "apple" "ba..." "pear" "pi..."
```

## Detect Matches

```
fruit <- c("apple", "banana", "pear", "pineapple")
# contains a?
str_detect(fruit, "a")
```

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

```
# starts with a
str_detect(fruit, "^a")
```

```
## [1] TRUE FALSE FALSE FALSE
```

```
str_starts(fruit, "a")
```

```
## [1] TRUE FALSE FALSE FALSE
```

```
# ends with a
str_detect(fruit, "a$")
```

```
## [1] FALSE TRUE FALSE FALSE
```

```
str_ends(fruit, "a")
```

```
## [1] FALSE TRUE FALSE FALSE
```

```
# contains a, e, i, o or u
str_detect(fruit, "[aeiou]")
```

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

```
# negate the result
str_detect(fruit, "^p", negate = TRUE)
```

```
## [1] TRUE TRUE FALSE FALSE
```

```
fruit <- c("apple", "banana", "pear", "pinapple")
# count the number of matches
str_count(fruit, "p")
```

```
## [1] 2 0 1 3
```

```
str_count(fruit, "p{1,}")
```

```
## [1] 1 0 1 2
```

```
# get locations
str_locate(fruit, "a")
```

```
##      start end
## [1,]     1   1
## [2,]     2   2
## [3,]     3   3
## [4,]     4   4
```

```
str_locate_all(fruit, "a")
```

```
## [[1]]
##      start end
## [1,]     1   1
##
## [[2]]
##      start end
## [1,]     2   2
## [2,]     4   4
## [3,]     6   6
##
## [[3]]
##      start end
## [1,]     3   3
##
## [[4]]
##      start end
## [1,]     4   4
```

```
# The pattern variable can also be vectorized
str_locate_all(fruit, c("a", "b", "p", "p"))
```

```
## [[1]]
##      start end
```

```
## [1,]      1      1
##
## [[2]]
##      start end
## [1,]      1      1
##
## [[3]]
##      start end
## [1,]      1      1
##
## [[4]]
##      start end
## [1,]      1      1
## [2,]      5      5
## [3,]      6      6
```

## Subset Strings

```
fruit <- c("apple", "banana", "pear", "pinapple")
# exact substring from start to end
str_sub(fruit, 1, 3)
```

```
## [1] "app" "ban" "pea" "pin"
```

```
str_sub(fruit, -3, -2)
```

```
## [1] "pl" "an" "ea" "pl"
```

```
# only select the elements that match
str_subset(fruit, "a")
```

```
## [1] "apple"      "banana"      "pear"         "pinapple"
```

```
# indexes that have matches
str_which(fruit, "^a")
```

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

```
shopping_list <- c("apples x4", "bag of flour", "bag of sugar", "milk x2")
# numbers
str_extract(shopping_list, "\\d")
```

```
## [1] "4" NA  NA  "2"
```

```
# lower case chars
str_extract(shopping_list, "[a-z]+")
```

```
## [1] "apples" "bag"      "bag"      "milk"
```

```
# lower case chars of length 1 to 4
str_extract(shopping_list, "[a-z]{1,4}")
```

```
## [1] "appl" "bag" "bag" "milk"
```

```
# lower case chars of length 1 to 4 with word boundary
str_extract(shopping_list, "\\b[a-z]{1,4}\\b")
```

```
## [1] NA      "bag" "bag" "milk"
```

```
str_extract_all(shopping_list, "[a-z]+")
```

```
## [[1]]
## [1] "apples" "x"
##
## [[2]]
## [1] "bag" "of" "flour"
##
## [[3]]
## [1] "bag" "of" "sugar"
##
## [[4]]
## [1] "milk" "x"
```

```
str_extract_all(shopping_list, "[a-z]+", simplify = TRUE)
```

```
##      [,1]      [,2] [,3]
## [1,] "apples" "x"   ""
## [2,] "bag"    "of"  "flour"
## [3,] "bag"    "of"  "sugar"
## [4,] "milk"   "x"   ""
```

```
strings <- c(
  " 219 733 8965",
  "329-293-8753 ",
  "banana",
  "239 923 8115 and 842 566 4692",
  "Work: 579-499-7527",
  "$1000",
  "Home: 543.355.3679"
)
```

```
phone <- "([2-9][0-9]{2})[-.]( [0-9]{3})[-.]( [0-9]{4})"
```

```
# only the matched pattern
str_extract(strings, phone)
```

```
## [1] "219 733 8965" "329-293-8753" NA      "239 923 8115" "579-499-7527"
## [6] NA              "543.355.3679"
```

```
str_extract_all(strings, phone)
```

```
## [[1]]  
## [1] "219 733 8965"  
##  
## [[2]]  
## [1] "329-293-8753"  
##  
## [[3]]  
## character(0)  
##  
## [[4]]  
## [1] "239 923 8115" "842 566 4692"  
##  
## [[5]]  
## [1] "579-499-7527"  
##  
## [[6]]  
## character(0)  
##  
## [[7]]  
## [1] "543.355.3679"
```

```
# with subgroups
```

```
str_match(strings, phone)
```

```
##      [,1]      [,2] [,3] [,4]  
## [1,] "219 733 8965" "219" "733" "8965"  
## [2,] "329-293-8753" "329" "293" "8753"  
## [3,] NA           NA    NA    NA  
## [4,] "239 923 8115" "239" "923" "8115"  
## [5,] "579-499-7527" "579" "499" "7527"  
## [6,] NA           NA    NA    NA  
## [7,] "543.355.3679" "543" "355" "3679"
```

```
str_match_all(strings, phone)
```

```
## [[1]]  
##      [,1]      [,2] [,3] [,4]  
## [1,] "219 733 8965" "219" "733" "8965"  
##  
## [[2]]  
##      [,1]      [,2] [,3] [,4]  
## [1,] "329-293-8753" "329" "293" "8753"  
##  
## [[3]]  
##      [,1] [,2] [,3] [,4]  
##  
## [[4]]  
##      [,1]      [,2] [,3] [,4]  
## [1,] "239 923 8115" "239" "923" "8115"  
## [2,] "842 566 4692" "842" "566" "4692"
```

```
##
## [[5]]
##      [,1]      [,2] [,3] [,4]
## [1,] "579-499-7527" "579" "499" "7527"
##
## [[6]]
##      [,1] [,2] [,3] [,4]
##
## [[7]]
##      [,1]      [,2] [,3] [,4]
## [1,] "543.355.3679" "543" "355" "3679"
```

## Mutate Strings

```
fruit <- c("apple", "banana", "pear", "pinapple")
str_sub(fruit, 1, 5) <- "APPLE"
fruit
```

```
## [1] "APPLE"      "APPLEa"      "APPLE"      "APPLEple"
```

```
fruits <- c("one apple", "two pears", "three bananas")
# change the first a, e, i, o and u to -
str_replace(fruits, "[aeiou]", "-")
```

```
## [1] "-ne apple"      "tw- pears"      "thr-e bananas"
```

```
# change all a, e, i, o and u to -
str_replace_all(fruits, "[aeiou]", "-")
```

```
## [1] "-n- -ppl-"      "tw- p--rs"      "thr-- b-n-n-s"
```

```
# apply a function to the matches
str_replace_all(fruits, "[aeiou]", toupper)
```

```
## [1] "OnE AppLe"      "twO pEARs"      "thrEE bAnAnAs"
```

```
# remove all a, e, i, o and u
str_replace_all(fruits, "[aeiou]", "")
```

```
## [1] "n ppl"      "tw prs"      "thr bnns"
```

```
str_remove_all(fruits, "[aeiou]")
```

```
## [1] "n ppl"      "tw prs"      "thr bnns"
```

References of the form \1, \2, etc will be replaced with the contents of the respective matched group



```
fruits <- c("one apple", "two pears", "three bananas")
str_match_all(fruits, "([aeiou])")
```

```
## [[1]]
##      [,1] [,2]
## [1,] "o"  "o"
## [2,] "e"  "e"
## [3,] "a"  "a"
## [4,] "e"  "e"
##
## [[2]]
##      [,1] [,2]
## [1,] "o"  "o"
## [2,] "e"  "e"
## [3,] "a"  "a"
##
## [[3]]
##      [,1] [,2]
## [1,] "e"  "e"
## [2,] "e"  "e"
## [3,] "a"  "a"
## [4,] "a"  "a"
## [5,] "a"  "a"
```

```
str_replace_all(fruits, "([aeiou])", "\\1")
```

```
## [1] "[o]n[e] [a]ppl[e]"      "tw[o] p[e][a]rs"
## [3] "thr[e][e] b[a]n[a]n[a]s"
```

```
strings <- c(
  "Work: 219 733 8965",
  "Mobile: 579-499-7527",
  "Home: 543.355.3679"
)
```

```
phone <- "([2-9][0-9]{2})[-.]( [0-9]{3})[-.]( [0-9]{4})"
```

```
str_match_all(strings, phone)
```

```
## [[1]]
##      [,1]      [,2] [,3] [,4]
## [1,] "219 733 8965" "219" "733" "8965"
##
## [[2]]
##      [,1]      [,2] [,3] [,4]
## [1,] "579-499-7527" "579" "499" "7527"
##
## [[3]]
##      [,1]      [,2] [,3] [,4]
## [1,] "543.355.3679" "543" "355" "3679"
```

```
str_replace_all(strings, phone, "(\\1)-\\2-\\3")
```

```
## [1] "Work: (219)-733-8965" "Mobile: (579)-499-7527" "Home: (543)-355-3679"
```

```
# apply replacement multiple times
```

```
str_replace_all("foobar", c("foo" = "hello", "bar" = "world"))
```

```
## [1] "helloworld"
```

Changes cases

```
str_to_lower(c("one Apple", "tWo BANANAs", "THREE orangeS"))
```

```
## [1] "one apple" "two bananas" "three oranges"
```

```
str_to_upper(c("one Apple", "tWo BANANAs", "THREE orangeS"))
```

```
## [1] "ONE APPLE" "TWO BANANAS" "THREE ORANGES"
```

```
str_to_title(c("one Apple", "tWo BANANAs", "THREE orangeS"))
```

```
## [1] "One Apple" "Two Bananas" "Three Oranges"
```

## Join and split

```
str_c("apple", "pie")
```

```
## [1] "applepie"
```

```
str_c(letters, LETTERS)
```

```
## [1] "aA" "bB" "cC" "dD" "eE" "fF" "gG" "hH" "iI" "jJ" "kK" "lL" "mM" "nN" "oO"  
## [16] "pP" "qQ" "rR" "sS" "tT" "uU" "vV" "wW" "xX" "yY" "zZ"
```

```
str_c(letters, collapse = "")
```

```
## [1] "abcdefghijklmnopqrstuvwxyz"
```

```
str_c(letters, LETTERS, collapse = "")
```

```
## [1] "aAbBcCdDeEfFgGhHiIjJkKlLmMnNoOpPqQrRsStTuUvVwWxXyYzZ"
```

```
str_flatten(letters) # faster than str_c(letters, collapse = "") marginally
```

```
## [1] "abcdefghijklmnopqrstuvwxyz"
```

```
fruits <- c(
  "apples and oranges and pears and bananas",
  "pineapples and mangos and guavas"
)

str_split(fruits, " and ")
```

```
## [[1]]
## [1] "apples" "oranges" "pears" "bananas"
##
## [[2]]
## [1] "pineapples" "mangos" "guavas"
```

```
str_split(fruits, " and ", simplify = TRUE)
```

```
##      [,1]      [,2]      [,3]      [,4]
## [1,] "apples"  "oranges" "pears"  "bananas"
## [2,] "pineapples" "mangos" "guavas" ""
```

```
str_split(fruits, " and ", n = 2)
```

```
## [[1]]
## [1] "apples"                "oranges and pears and bananas"
##
## [[2]]
## [1] "pineapples"            "mangos and guavas"
```

```
str_split(fruits, " and ", n = 3, simplify = TRUE)
```

```
##      [,1]      [,2]      [,3]
## [1,] "apples"  "oranges" "pears and bananas"
## [2,] "pineapples" "mangos" "guavas"
```

```
# a shorthand for str_split(..., n, simplify = TRUE)
str_split_fixed(fruits, " and ", n = 3)
```

```
##      [,1]      [,2]      [,3]
## [1,] "apples"  "oranges" "pears and bananas"
## [2,] "pineapples" "mangos" "guavas"
```

## Glue String

```
name <- c("John", "Peter")
age <- c(23, 17)
# get variables from globals
str_glue("{name} is {age}")
```

```
## John is 23
## Peter is 17
```

```
# get variables from arguments
str_glue("{name} is {age}", name = "Anna", age = 43)
```

```
## Anna is 43
```

```
mtcars %>%
  group_by(cyl) %>%
  summarize(m = mean(mpg)) %>%
  str_glue_data("A {cyl}-cylinder car has an average mpg of {round(m, 2)}.")
```

```
## A 4-cylinder car has an average mpg of 26.66.
## A 6-cylinder car has an average mpg of 19.74.
## A 8-cylinder car has an average mpg of 15.1.
```

## Order Strings

```
names <- c("John", "Albert", "Peter", "Charles")
str_order(names)
```

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

```
str_sort(names)
```

```
## [1] "Albert" "Charles" "John" "Peter"
```

```
str_sort(names, decreasing = TRUE)
```

```
## [1] "Peter" "John" "Charles" "Albert"
```

```
files <- c("file10", "file2", "file5", "file1")
str_sort(files)
```

```
## [1] "file1" "file10" "file2" "file5"
```

```
# more natural order
str_sort(files, numeric = TRUE)
```

```
## [1] "file1" "file2" "file5" "file10"
```

```
str_order(files, numeric = TRUE)
```

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

## Pattern interpretation

Patterns in stringr functions are interpreted as regex in default, you could use `fixed` or `regex` to change the default behavior.

```
strings <- c("abb", "a.b")
```

```
str_detect(strings, "a.b")
```

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

```
str_detect(strings, fixed("a.b"))
```

```
## [1] FALSE TRUE
```

```
str_detect(strings, fixed("A.B", ignore_case = TRUE))
```

```
## [1] FALSE TRUE
```

```
str_match_all("abaa\na", "^a")
```

```
## [[1]]  
##      [,1]  
## [1,] "a"
```

```
str_match_all("abaa\na", regex("^a", multiline = TRUE))
```

```
## [[1]]  
##      [,1]  
## [1,] "a"  
## [2,] "a"
```

```
str_match_all("abaa\na", regex("^A", ignore_case = TRUE, multiline = TRUE))
```

```
## [[1]]  
##      [,1]  
## [1,] "a"  
## [2,] "a"
```

## An exercise

```
# we need some string
calculus_url <- "https://en.wikipedia.org/wiki/Calculus"
calculus <- read_lines(calculus_url) %>%
  str_flatten()
```

```
calculus %>%
  str_extract_all("<p>.*?</p>") %>%
  unlist() %>%
  str_remove_all("</?\\w+[^>]*>") %>%
  str_extract_all("[a-zA-Z]+") %>%
  unlist() %>%
  str_to_lower() %>%
  tibble(word = .) %>%
  count(word) %>%
  arrange(desc(n))
```

```
## # A tibble: 1,140 x 2
##   word      n
##   <chr>   <int>
## 1 the      424
## 2 of       290
## 3 a        162
## 4 and      156
## 5 is       133
## 6 to       126
## 7 in       121
## 8 calculus   87
## 9 function   64
## 10 as        52
## # ... with 1,130 more rows
```

## More advanced topics of regex

I assume that you are now comfortable with the basic regex. Let's talk about some more advanced topics.

- non-capturing groups  
a capturing group could be created by using a pair of parentheses (**<regex>**) and a non-capturing group can be created by using (**?:<regex>**).

```
# with captureing groups
str_match("12mb", "([0-9]+)([a-z]+)")
```

```
##      [,1]    [,2] [,3]
## [1,] "12mb" "12"  "mb"
```

```
# with non-capturing groups
str_match("12mb", "(?:[0-9]+)(?:[a-z]+)")
```

```
##      [,1]
## [1,] "12mb"
```

- atomic groups  
an atomic group prevents the regex engine from backtracking back into the group

```
strings <- c("abc", "abcc")
str_extract(strings, "a(?:bc|b)c")
```

```
## [1] NA      "abcc"
```

- lazy quantifier

| quantifier |   |
|------------|---|
| ??         | zero or one occurrence, lazy              |
| ?          | zero or more occurrences, lazy            |
| +?         | one or more occurrences, lazy             |
| {n,}       | n or more times, lazy                     |
| {m, n}     | m or more times but not more than n, lazy |

```
strings <- c("abc", "acb")
# it is greedy
str_extract(strings, "ab?c?")
```

```
## [1] "abc" "ac"
```

```
# it is lazy
str_extract(strings, "ab??c?")
```

```
## [1] "a"  "ac"
```

```
strings <- "acbcbbc"
# it is greedy, longest match
str_extract(strings, "a.*c")
```

```
## [1] "acbcbbc"
```

```
# it is lazy, shortest match
str_extract(strings, "a.*?c")
```

```
## [1] "ac"
```

```
strings <- "acbcbbc"
# it is greedy, longest match
str_extract(strings, "a.+c")
```

```
## [1] "acbcbbc"
```

```
# it is lazy, shortest match
str_extract(strings, "a.+?c")
```

```
## [1] "acbc"
```

```
strings <- "acbcbbc"
str_extract(strings, "a.{2,}c")
```

```
## [1] "acbcbbc"
```

```
str_extract(strings, "a.{2,}?c")
```

```
## [1] "acbc"
```

- Possessive quantifier (does not backtrack)

| quantifier |                                      |
|------------|--------------------------------------|
| ?+         | zero or one occurrence, possessive   |
| +          | zero or more occurrences, possessive |
| ++         | one or more occurrences, possessive  |

```
strings <- c("apple", "pineapple", "pinepineapple")
str_extract(strings, "(pine)?pineapple")
```

```
## [1] NA          "pineapple"  "pinepineapple"
```

```
str_extract(strings, "(pine)?+pineapple")
```

```
## [1] NA          NA           "pinepineapple"
```

```
str_extract(strings, "(pine)*pineapple")
```

```
## [1] NA          "pineapple"  "pinepineapple"
```

```
str_extract(strings, "(pine)*+pineapple")
```

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

- back reference  
back reference is used to reference a previous matched group

```
str_match(":abc:", "( :) [a-z]+\\1")
```

```
##      [,1]      [,2]
## [1,] ":abc:" ":"
```

- look ahead
  - positive look ahead



```
# it matches only the second `t` because the second `t` is followed by `s`
str_locate_all("streets", "t(?=s)")
```

```
## [[1]]
##      start end
## [1,]      6  6
```

- negative look ahead

```
# it matches only the first `t` because the second `t` is followed by `s`
str_locate_all("streets", "t(?!s)")
```

```
## [[1]]
##      start end
## [1,]      2  2
```

- look behind
  - positive look behind

```
# it matches only the first `t` because the second `t` follows `s`
str_locate_all("streets", "(?<=s)t")
```

```
## [[1]]
##      start end
## [1,]      2  2
```

- negative look behind

```
# it matches only the second `t` because the first `t` follows `s`
str_locate_all("streets", "(?<!s)t")
```

```
## [[1]]
##      start end
## [1,]      6  6
```

```
# it also works if the look behind pattern is a (bounded) regex
# (base R functions do not support regex in look behind pattern)
str_locate_all("twisty streets", "(?<![se]{1,100})t")
```

```
## [[1]]
##      start end
## [1,]      1  1
```

- recursion

We try to find the highest level of paranthesse in (((x))), ((x)((y))(z)) (x) (y)

```
# what doesn't work
strings <- c("(((x)))", "(x) (y) (z)", "(x) (y)")
str_extract_all(strings, "\\([^()]*\\)")
```

```
## [[1]]
## [1] "(x)))"
##
## [[2]]
## [1] "(x)" "(y)" "(z)"
##
## [[3]]
## [1] "(x)" "(y)"
```

```
str_extract_all(strings, "\\([^()]*\\)")
```

```
## [[1]]
## [1] "(x)"
##
## [[2]]
## [1] "(x)" "(y)" "(z)"
##
## [[3]]
## [1] "(x)" "(y)"
```

```
# how about back reference the entire group? no, it doesnt work
str_extract_all(strings, "\\((?:\\1*|\\1)*\\)")
```

```
## [[1]]
## [1] "(((x)"
##
## [[2]]
## [1] "(x)" "(y)" "(z)"
##
## [[3]]
## [1] "(x)" "(y)"
```

stringr's functions don't support recursions, we will need to use base R functions (which are difficult to use and slower). Luckily, there is `rematch2` which provides nice wrapping functions to base R functions (still, it is slower).

```
library(rematch2)
re_match_all(strings, "\\((?: (?0)* | \\1)*\\)") %>%
  pull(.match)
```

```
## [[1]]
## [1] "(((x)))"
##
## [[2]]
## [1] "(x) (y) (z)"
##
## [[3]]
## [1] "(x)" "(y)"
```

## Three games to learn regex

- <http://play.infinf.units.it>
- <https://alf.nu/RegexGolf>
- <https://regexcrossword.com/>

## Reference

- Online regex tester <https://regex101.com/>
- R for Data Science <https://r4ds.had.co.nz/strings.html>