Programming Basics: Conditions, Loops

Stats 102A

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Section 1

Operators that produce logical values

Vectorized Logical Operators

R has the following logical operators. Use of a logical operator will coerce non-logical types to logical type. (e.g. 0 becomes FALSE, all other numeric values become TRUE.)

- or: `x | y`
- and: `x & y`
- not: `!x`
- exclusive or: `xor(x,y)`

The above logical operators are vectorized and will perform element-wise comparison as well as recycling. The vectorized operations will return a vector of logical values.

Non-Vectorized Logical operators

Non-Vectorized operators will return only one logical value. If a vector with length $>$ one is provided on either side of the operator, only the first element of the vector will be used.

- non-vector or: `x || y`
- non-vector and: `x && y`

The 'non-vector' `||` and `&&` evaluates left to right examining only the first element of each vector. This longer form is appropriate for programming control-flow and typically preferred in if clauses.

See `?base::Logic`

Vectorized vs Non-Vectorized

```
x <- c(TRUE,  TRUE, FALSE, FALSE)
y <- c(FALSE, TRUE, FALSE,  TRUE)
x | y
```

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

```
x & y
```

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

```
x || y  # only looks at first element
```

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

```
x && y
```

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

Logical operators with NA

What is `TRUE | NA`?

What is `TRUE & NA`?

What is `FALSE | NA`?

What is `FALSE & NA`?

Solutions:

```
TRUE | NA
```

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

```
TRUE & NA
```

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

```
FALSE | NA
```

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

```
FALSE & NA
```

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

Exclusive Or

`xor()` indicates elementwise exclusive OR (True if x *or* y is true, but not if both are true). That is, `xor(TRUE, TRUE)` is `FALSE`

```
x <- c(TRUE,  TRUE, FALSE, FALSE,   NA,    NA,  NA)
y <- c(FALSE, TRUE, FALSE,  TRUE, TRUE, FALSE,  NA)
xor(x, y)
```

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

any() and all()

any() and all() are generalizations of OR and AND for more than 2 values.

```
u <- c( TRUE,  TRUE,  TRUE)
c(any(u), all(u))
```

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

```
v <- c( TRUE,  TRUE, FALSE)
c(any(v), all(v))
```

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

```
w <- c(FALSE, FALSE, FALSE)
c(any(w), all(w))
```

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

Question

If we add a 0-length vector (like `logical(0)` or `NULL`) to a vector of logical values `v`, it should not affect the result of `any()` or `all()` applied to `v`.

That is:

- `any(logical(0), v)` should produce the same result as `any(v)`
- `all(logical(0), v)` should produce the same result as `all(v)`

With these rules in mind:

- What does `any(logical(0))` return?
- What does `all(logical(0))` return?

any(logical(0)) is FALSE

```
x <- logical(0)
any(x)
```

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

```
u <- c( TRUE,  TRUE,  TRUE)
c(any(u), any(x, u))
```

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

```
v <- c( TRUE,  TRUE, FALSE)
c(any(v), any(x, v))
```

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

```
w <- c(FALSE, FALSE, FALSE) # if any(logical(0)) were TRUE, this would change
c(any(w), any(x, w))
```

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

all(logical(0)) is TRUE

```
x <- logical(0)
all(x)
```

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

```
u <- c( TRUE,  TRUE,  TRUE) # if all(logical(0)) were FALSE, this would change
c(all(u), all(x, u))
```

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

```
v <- c( TRUE,  TRUE, FALSE)
c(all(v), all(x, v))
```

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

```
w <- c(FALSE, FALSE, FALSE)
c(all(w), all(x, w))
```

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

Comparison operators

Comparison operators produce logical values. They are vectorized and perform recycling.

- `x == y`
- `x != y`
- `x < y`
- `x > y`
- `x <= y`
- `x >= y`
- `x %in% y` (vectorized for `x` only)

see `help(Comparison)`

Comparison operators

For character strings, comparison operations are based on alphabetical order, with the following general arrangement:

```
symbols < "0" < .. < "9" < "a" < "A" < "b" ... < "Z"
```

```
"10" < "2" # with characters, 10 is alphabetized before 2
```

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

```
10 < 2 # of course, numerically 10 is not less than 2
```

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

Just for reference, R arranges the ASCII symbols as follows:

```
"-"  "!"  "#"  "$"  "%"  "&"  "("  ")"  "*"  ","  "."  "/"  ":"  ";"  "?"  "@"  "["  "\\"  "]"  "^"  "_"  "(back-tick)"  "{"  "|"  "}"
"~"  "+"  "<"  "="  ">"
```

is functions

The `is.____()` family of functions return logical values that can be used in conditional statements.

- `is.na()`
- `is.null()`
- `is.atomic()`
- `is.logical()`
- `is.integer()`
- `is.double()`
- `is.numeric()`
- `is.character()`
- `is.list()`
- `is.matrix()`
- `is.array()`
- `is.data.frame()`
- `is.factor()`
- `is.function()`

Section 2

Condtional statements

Conditional statement - `if`

Conditional execution of code blocks is achieved via `if()` statements.

`if(cond)` The condition in an `if()` statement must be a **length-one logical vector that is not `NA`**.

Conditions of length greater than one are accepted with a warning, but only the first element is used. Other types are coerced to logical if possible.

If the condition results in `NA`, you will get an error: `missing value where TRUE/FALSE needed`

If the condition is length 0, you will get an error: `argument is of length zero`

Curly braces `{ }` are used to group the expressions that will run when the condition inside the `if` statement is `TRUE`. If there is only one expression to execute, the curly braces are optional.

Using if()

```
x <- c(1, 3)
1 %in% x
```

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

```
if (1 %in% x) {
    print("Hello!")
}
```

```
## [1] "Hello!"
```

Using if()

```
x <- c(1, 3)
x >= 2
```

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

```
if (x >= 2) {  # sees only the first value, FALSE, and does not execute
  # we get a warning because the length of the logical vector > 1
    print("Hello again!")
}
```

```
## Warning in if (x >= 2) {: the condition has length > 1 and only the
## first element will be used
```

Using if()

```
x <- c(1, 3)
x <= 2
```

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

```
if (x <= 2){ # sees only the first value, TRUE
  # executes with a warning because length > 1
    print("Hello again!")
}
```

```
## Warning in if (x <= 2) {: the condition has length > 1 and only the
## first element will be used
```

```
## [1] "Hello again!"
```

Using if()

```
x <- c(1, 3)
any(x >= 2)  # if your logical vector has length > 1, you might use any/all
```

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

```
if (any(x >= 2)) {
    print("Can you hear me now?")
}
```

```
## [1] "Can you hear me now?"
```

if() errors on NA

```
x <- 1:3
if (x[5] >= 2){
    print("Will this work?")
}
```

```
## Error in if (x[5] >= 2) {: missing value where TRUE/FALSE needed
```

`missing value where TRUE/FALSE needed` is a very common error that you will run into. You'll need to go through your code and see why something inside your if statement is producing an NA value.

if() errors on logical(0)

```
x <- 1:3
which(x == 4)
```

```
## integer(0)
```

```
if (which(x == 4) == 4){
    print("Will this work?")
}
```

```
## Error in if (which(x == 4) == 4) {: argument is of length zero
```

Nesting Conditionals - `if`, `else if`, and `else`

If you want to use an `else` statements, there must be a preceding `if` statement and you must use curly braces. The conditional inside an `else if` statement will only be evaluated if the starting `if` statement is `FALSE`. Make sure you put the `else` on the same line as the closing curly brace of the `if` statement, otherwise R will believe the `if` statement is complete.

```
x <- 3
if (x < 0) {
   print("Negative")
} else if (x > 0) {
   print("Positive")
} else {
   print("Zero")
}
```

```
## [1] "Positive"
```

Nested conditionals

```
x <- 0
if (x < 0) {
   print("Negative")
} else if (x > 0) {
   print("Positive")
} else {
   print("Zero")
}
```

```
## [1] "Zero"
```

Nested conditionals

```
x <- 3
if (x > 0) {
   print("Positive")
} else if (x > 1) {   # will not be evaluated because the first if is TRUE
   print("Bigger than 1")
} else {
   print("Not Positive")
}
```

```
## [1] "Positive"
```

`if()` is not vectorized, `ifelse()` is vectorized

`if()` requires a logical vector of length-one. It is not vectorized. Functions that use an `if()` statement cannot be given a vector of values.

The function `ifelse` is vectorized. It requires three arguments:

- a condition to test
- the result if the condition is true
- the result if the condition is false

```
if(x == 5) {
    n <- "yes"
} else {
    n <- "no"
}
```

is reduced to:

```
n <- ifelse(x == 5, "yes", "no")
```

Section 3

Loops

for Loops

The simplest and most common type of loop in R is the `for` loop. Given a vector (including lists), it iterates through the elements and evaluates the code block for each element.

```
for(x in 1:10) {
  cat(x ^ 2, " ", sep = "")
}
```

```
## 1 4 9 16 25 36 49 64 81 100
```

for loops can iterate through any vector

```
l <- list(1:3, LETTERS[1:7], c(TRUE, FALSE)) # l is a list of three elements
l
```

```
## [[1]]
## [1] 1 2 3
##
## [[2]]
## [1] "A" "B" "C" "D" "E" "F" "G"
##
## [[3]]
## [1]  TRUE FALSE
```

```
for(y in l) {
  print(length(y))
}
```

```
## [1] 3
## [1] 7
## [1] 2
```

for loops

```
library(datasets)
state.name[1:5]
```

```
## [1] "Alabama"    "Alaska"     "Arizona"    "Arkansas"   "California"
```

```
for(state in state.name[1:5]) {
  cat(state, "has", nchar(state),"letters in its name.\n")
}
```

```
## Alabama has 7 letters in its name.
## Alaska has 6 letters in its name.
## Arizona has 7 letters in its name.
## Arkansas has 8 letters in its name.
## California has 10 letters in its name.
```

Loops - Storing results

It is almost always better to create an object to store your results first, rather than growing the object as you go.

```
# Good
res <- rep(NA, 10^7) # create an object to store results.
system.time(
  for(x in seq_along(res)){
    res[x] <- x ^ 2
  }
)
```

```
##   user  system elapsed
##   0.64    0.00    0.64
```

For loops

```
# slower
res <- 0
system.time(
  for (x in 1:10^7){
    res[x] <- x ^ 2  # each iteration requires that res be resized
  }
)
```

```
##    user  system elapsed
##    2.56    0.26    2.83
```

For loops

```
# Slowest
res <- c()
system.time(
  for (x in 1:10^5) {    # we are only doing 1/100 of the work, but it is slow
    res <- c(res, x ^ 2) # each iteration copies res into a redefined res object
  }
)
```

```
##    user  system elapsed
##   13.55    0.09   13.64
```

while loops

Repeat until the given condition is not met (condition is FALSE)

```
i <- 1
res <- rep(NA, 10)
while (i <= 10) {
  res[i] <- i ^ 2
  i <- i + 1
}
res
```

```
##  [1]   1   4   9  16  25  36  49  64  81 100
```

Question: what is the value of `i` when the code finishes?

Answer

```
i <- 1
res <- rep(NA, 10)
while (i <= 10) {
  res[i] <- i ^ 2
  i <- i + 1
}
i
```

```
## [1] 11
```

repeat loops

Repeat until `break` is executed

```
i <- 1
res <- rep(NA, 10)
repeat {
  res[i] <- i ^ 2
  i <- i + 1
  if (i > 10){
    break
  }
}
res
```

```
##  [1]   1   4   9  16  25  36  49  64  81 100
```

Special keywords - `break` and `next`

These are special actions that only work inside of a loop

- `break` - ends the current (inner-most) loop
- `next` - ends the current iteration and starts the next iteration

```
for(i in 1:10) {
    if (i %% 2 == 0){
        break
    }
  cat(i,"")
}
```

Question: What will this output?

Answer:

```
for(i in 1:10) {
    if (i %% 2 == 0){
        break
    }
  cat(i,"")
}
```

```
## 1
```

Keyword: next

```
for(i in 1:10) {
    if (i %% 2 == 0){
        next
    }
  cat(i,"")
}
```

Question: What will this output?

Answer

```
for(i in 1:10) {
    if (i %% 2 == 0){
        next
    }
  cat(i,"")
}
```

```
## 1 3 5 7 9
```

seq_len(), seq_along()

Often we want to use a loop across the indexes of an object and not the elements themselves. There are several useful functions to help you do this: `:`, `seq`, `seq_along`, `seq_len`, etc.

```
l = list(1:3, LETTERS[1:7], c(TRUE,FALSE))
res = rep(NA, length(l))
for(x in seq_along(l)) {
  res[x] = length(l[[x]])
}
res
```

```
## [1] 3 7 2
```

seq_len(), seq_along() produce similar results

```
1:length(l)
```

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

```
seq_along(l)
```

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

```
seq_len(length(l))
```

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

Using 1:length(l) can cause problems for length-0 vectors

```
l <- list() # l is an empty 0-length list
1:length(l) # creates a length-2 vector that counts down
```

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

```
res <- rep(NA, length(l))
for(x in 1:length(l)) {
  res[x] <- length(l[[x]]) # l[[1]] doesn't exist
}
```

```
## Error in l[[x]]: subscript out of bounds
```

seq_len(), seq_along() avoids those issues

```
l <- list()
seq_along(l)
```

```
## integer(0)
```

```
res <- rep(NA, length(l))
for(x in seq_along(l)) { # nothing gets executed
  res[x] <- length(l[[x]])
}

seq_len(length(l)) # similarly seq_len produces a 0-length integer vector
```

```
## integer(0)
```

Section 4

Vectorizing Code

Vectorizing Code

The performance of R code can be frequently improved if we think of ways to vectorize it.

It is not always possible to vectorize code and it is not always worth the effort. In some cases, it is better to write inefficient code that takes 20 seconds to run than getting stuck for a few hours trying to write more efficient code.

If you are aware of some of R's vectorized operations, you can write your code to be vectorized from the start.

> *"We should forget about small efficiencies, say about 97% of the time:* ***premature optimization is the root of all evil****. Yet we should not pass up our opportunities in that critical 3%" - Donald Knuth (Computer science legend, and creator of TeX typesetting)*

if vs ifelse for vectorization

Example from *Scientific Programming and Simulation Using R*. Pg. 43. Section 3.9. Exercise 1.

Consider the function $y = f(x)$ defined by:

$$f(x) = \begin{cases} -x^3, & \text{for } x \leq 0 \\ x^2, & \text{for } 0 < x \leq 1 \\ \sqrt{x}, & \text{for } 1 < x \end{cases}$$

Here is a function that uses `if()`. It works but is not vectorized.

```
f <- function(x) {
  if (x <= 0) {
    value <- -x ^ 3
  } else if (x <= 1) { # note: I do not need to check if x > 0
    value <- x ^ 2
  } else {
    value <- sqrt(x)
  }
  return(value)
}
```

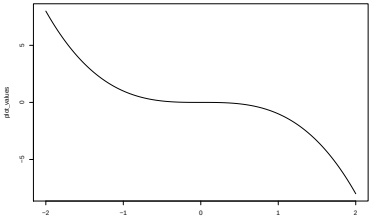
Using a non-vector function

If you try to use `f()` as-is, it will not have the desired effect. It evaluates the first value of `x` which is negative. It then evaluates `-x^3` and returns that. Note that the power operation `^3` is vectorized, so it returns all of `-x^3`

```
x <- seq(-2, 2, by = .01)
plot_values <- f(x) # doesn't work because f is not vectorized
```

```
## Warning in if (x <= 0) {: the condition has length > 1 and only the
## first element will be used
```

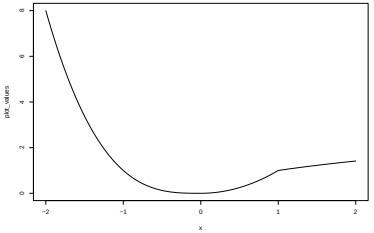
```
plot(x, plot_values, type = "l")
```



Using a non-vector function

To get the desired result, we have to combine the non-vectorized function with a loop. The loop will subset `x` to `x[i]`. It takes each value `x[i]` and calculates and stores `f(x[i])`. This will produce the desired results.

```
x <- seq(-2, 2, by = .01)
plot_values <- rep(0, length(x))
# f is not vectorized and requires a loop to evaluate each value in x separately
for(i in seq_along(x)) {
  plot_values[i] <- f(x[i])
}
plot(x, plot_values, type = "l")
```



Vectorize with `ifelse`

Instead of using `if()`, we can use `ifelse()` to vectorize the function.

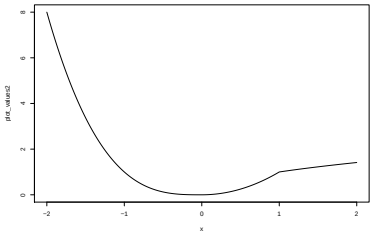
```
f2 <- function(x) {
  ifelse(x <= 0, # check if x <= 0
         -x ^ 3, # if x <= 0 is true, return x ^ 3
         ifelse(x <= 1,  # if x <= 0 is false, check if x <= 1
                x ^ 2,   # if x <= 1 is true, return x ^ 2
                sqrt(x), # otherwise return sqrt(x)
                )
        )
}

# with comments removed, it's compact:
f2 <- function(x) {
  ifelse(x <= 0, -x ^ 3, ifelse(x <= 1, x ^ 2, sqrt(x)))
}
```

Vectorized function `f2()` does not require a loop

```
x <- seq(-2, 2, by = .01)
plot_values2 <-  f2(x)
```

```
## Warning in sqrt(x): NaNs produced
```

```
plot(x, plot_values2, type = "l")
```



Note on the warning

In the previous slide, a warning is produced.

The warning is produced because `sqrt(x)` is calculated for all of `x` which contains negative values.

The `ifelse` statement evaluates the entire TRUE-expression and the entire FALSE-expression. It then decides whether to return the values from the TRUE expression or the FALSE expression based on the condition.

The result is that the vector `plot_values2` consists only of real numbers, but because `sqrt(x)` was evaluated for all of `x`, we see the warning about `NaN`s produced when `sqrt()` was evaluated on negative values of `x`.

rowSums() and colSums()

R offers two very fast operations for matrices: `rowSums()` and `colSums()`

If you can think of a way to use these operations, you can save time from your code.

I will perform the same operation in three different ways.

We create a large matrix: 1 million rows x 100 columns. We want to find the mean of each row.

Method 1: Subsetting by row, find the mean

```
x <- matrix(1:10^8, ncol = 100)
results1 <- rep(NA, nrow(x))
system.time(
  for(i in seq_along(results1)){
    results1[i] <- mean(x[i, ])
  }
)
```

```
##   user  system elapsed
##   3.66    0.00    3.67
```

Method 2: apply()

```
system.time(
  results2 <- apply(x, MARGIN = 1, FUN = mean)
)
```

```
##   user  system elapsed
##   6.44    0.05    6.48
```

Method 3: Use `rowSums()` and divide by the number of columns

```
# fastest
system.time(
  results3 <- rowSums(x)/ncol(x)
)
```

```
##   user  system elapsed
##   0.26    0.00    0.27
```

All three methods produce the same results

```
all.equal(results1, results2)
```

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

```
all.equal(results1, results3)
```

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