Data Science and R: Base-R

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1. First Encounter
    - First Steps
    - Vectors and Indices
    - Data Frame
    - Extracting Rows / Columns from Data Frames
    - List
    - Graphics
    - Programming
    - Misc: Linear Regression, Help Functions
2. Operators
3. Functions
4. Vectors
5. Common Tasks
6. Programming
7. References

First Encounter

First Steps

- R as a calculator — show the numerical result of $1 + 2 \times \frac{3}{4} - 5 + 6 \sin \frac{\pi}{2} - \sqrt[8]{7}$

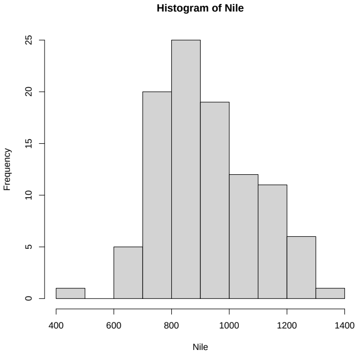
```
1 + 2 * (3 / 4) - 5 + 6 * sin(pi / 2) - 7^(1/8)
# [1] 2.224627
```

- Print the content of the built-in dataset Nile

```
Nile
# Time Series:
# Start = 1871
# End = 1970
# Frequency = 1
#   [1] 1120 1160  963 1210 1160 1160  813 1230 1370 1140  995  935 1110  994 1020
#  [16]  960 1180  799  958 1140 1100 1210 1150 1250 1260 1220 1030 1100  774  840
#  [31]  874  694  940  833  701  916  692 1020 1050  969  831  726  456  824  702
#  [46] 1120 1100  832  764  821  768  845  864  862  698  845  744  796 1040  759
#  [61]  781  865  845  944  984  897  822 1010  771  676  649  846  812  742  801
#  [76] 1040  860  874  848  890  744  749  838 1050  918  986  797  923  975  815
#  [91] 1020  906  901 1170  912  746  919  718  714  740
```

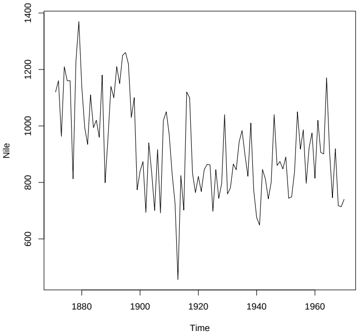
- Show the histogram of Nile

```
hist(Nile)
```



- Show the plot of Nile

```
plot(Nile)
```



Vectors and Indices

- The 2nd item of the `Nile` dataset

```
Nile[2]
# [1] 1160
```

- Subsequence taken from 2nd to 5th item of `Nile`

```
Nile[2:5]
# [1] 1160  963 1210 1160
```

- Subsequence taken from 2nd to 5th item of `Nile`: using the concatenate function `c`

```
Nile[c(2, 3, 4, 5)]
# [1] 1160  963 1210 1160
```

- Subsequence taken from 10th, 3rd, 15th item of `Nile`

```
Nile[c(10, 3, 15)]
# [1] 1140  963 1020
```

- Let x be a vector (10, 20, -1, 3, 5, 6, 30, 9)

```
(x <- c(10, 20, -1, 3, 5, 6, 30, 9))
# [1] 10 20 -1  3  5  6 30  9
```

- Let y be a vector formed by taking the 2nd element out of x

```
(y <- x[-2])
# [1] 10 -1  3  5  6 30  9
```

- Let z be a vector formed by taking the 2nd, 3rd, 6th element out of x

```
(z <- x[c(-2, -3, -6)])
# [1] 10  3  5 30  9
```

- Let w be the vector formed by combining x, y, z

```
(w <- c(x, y, z))
#  [1] 10 20 -1  3  5  6 30  9 10 -1  3  5  6 30  9 10  3  5 30  9
```

- Subsequence taken from 81th to 95th item of `Nile`:

```
Nile[81:95]
#  [1]  744  749  838 1050  918  986  797  923  975  815 1020  906  901 1170  912
```

- Lengths of the subsequence `Nile[81:95]`

```
length(Nile[81:95])
# [1] 15
```

- Let the subsequence `Nile[81:95]` be `v8195`; Compute its mean and standard deviation

```
v8195 <- Nile[81:95]; mean(v8195); sd(v8195)
# [1] 913.6
# [1] 116.4645
```

- Let the vector `x <- c(20, 1, 15, 13, 12)`. Print `x > 14`:

```
x <- c(20, 1, 15, 13, 12); x > 14
# [1]  TRUE FALSE  TRUE FALSE FALSE
```

- How many items in `x` that > 14 ?

```
sum(x > 14)
# [1] 2
```

- Which of the items in `Nile` are > 1200 ?

```
which(Nile > 1200)
# [1]  4  8  9 22 24 25 26
```

- Print out the items in `Nile` that > 1200.

```
Nile[Nile > 1200]
# [1] 1210 1230 1370 1210 1250 1260 1220
```

Data Frame

- data frame: a rectangular table consisting of one row for each data point. Built-in data frame `ToothGrowth`, assigned `tg`.

- len: tooth length; supp: supplement VC (vitamin c) or OJ (orange juice); dose

```
head(ToothGrowth)

#    len supp dose
# 1  4.2   VC  0.5
# 2 11.5   VC  0.5
# 3  7.3   VC  0.5
# 4  5.8   VC  0.5
# 5  6.4   VC  0.5
# 6 10.0   VC  0.5
```

- Each column is a vector; use `$` to extract

```
tg <- ToothGrowth; tg$len

#  [1]  4.2 11.5  7.3  5.8  6.4 10.0 11.2 11.2  5.2  7.0 16.5 16.5 15.2 17.3 22.5
# [16] 17.3 13.6 14.5 18.8 15.5 23.6 18.5 33.9 25.5 26.4 32.5 26.7 21.5 23.3 29.5
# [31] 15.2 21.5 17.6  9.7 14.5 10.0  8.2  9.4 16.5  9.7 19.7 23.3 23.6 26.4 20.0
# [46] 25.2 25.8 21.2 14.5 27.3 25.5 26.4 22.4 24.5 24.8 30.9 26.4 27.3 29.4 23.0
```

- To get the item of tg in row 3, column 1

```
tg[3, 1]
# [1] 7.3
```

- To get the item of tg in row 3, column 1: using that tg$len is a vector

```
tg$len[3]
# [1] 7.3
```

- Extract rows 2 through 5, and columns 1 and 3, assigning the result to z

```
(z <- tg[2:5, c(1, 3)])
#    len dose
# 2 11.5  0.5
# 3  7.3  0.5
# 4  5.8  0.5
# 5  6.4  0.5
```

- To get the items of tg in columns 1, 3

```r
head(tg[, c(1, 3)])
```

```
#    len dose
# 1  4.2  0.5
# 2 11.5  0.5
# 3  7.3  0.5
# 4  5.8  0.5
# 5  6.4  0.5
# 6 10.0  0.5
```

- To get the items of tg in columns 1, 3: remove column 2

```r
head(tg[, -2])
```

```
#    len dose
# 1  4.2  0.5
# 2 11.5  0.5
# 3  7.3  0.5
# 4  5.8  0.5
# 5  6.4  0.5
# 6 10.0  0.5
```

- Create your own data frame from vectors of same lengths

```r
age <- c(55, 58, 45)
name <- c('Alice', 'Bill', 'Cathy')
(d <- data.frame(age, name))
```

```
#   age  name
# 1  55 Alice
# 2  58  Bill
# 3  45 Cathy
```

- Note that vector of different lengths are not allowed !

```r
blood <- c('O', 'B', 'A', 'AB')
data.frame(age, name, blood)
```

```
# Error in data.frame(age, name,
blood): arguments imply differing
number of rows: 3, 4
```

Extracting Rows / Columns from Data Frames

- In tg, compute mean tooth length for supplement VC and OJ

```
tg_vc <- tg[tg$supp == 'VC',]
tg_oj <- tg[tg$supp == 'OJ',]
mean(tg_vc$len)

# [1] 16.96333

mean(tg_oj$len)

# [1] 20.66333
```

- Extract the sub data frame from tg with supplement OJ and length < 8.8

```
tg[tg$supp == 'OJ' & tg$len < 8.8,]

#    len supp dose
# 37 8.2   OJ  0.5
```

- Note the existence and the postion of the comma (,) and the use of == !

- Extract the sub data frame from tg with length > 28 or dose $= 1.0$

```
w <- tg[tg$len == 28 | tg$dose == 1.0,]
head(w, 13)

#     len supp dose
# 11 16.5   VC    1
# 12 16.5   VC    1
# 13 15.2   VC    1
# 14 17.3   VC    1
# 15 22.5   VC    1
# 16 17.3   VC    1
# 17 13.6   VC    1
# 18 14.5   VC    1
# 19 18.8   VC    1
# 20 15.5   VC    1
# 41 19.7   OJ    1
# 42 23.3   OJ    1
# 43 23.6   OJ    1
```

List

- In `mtcars`, split the miles-per-gallon (mpg) data according to the number of cylinders (cyl):

```
(mtl <- split(mtcars$mpg, mtcars$cyl))
```

```
# $`4`
#  [1] 22.8 24.4 22.8 32.4 30.4 33.9 21.5 27.3 26.0 30.4 21.4
#
# $`6`
# [1] 21.0 21.0 21.4 18.1 19.2 17.8 19.7
#
# $`8`
#  [1] 18.7 14.3 16.4 17.3 15.2 10.4 10.4 14.7 15.5 15.2 13.3 19.2 15.8 15.0
```

```
class(mtl)
```

```
# [1] "list"
```

- Now vectors in `mtl`, a list, can be accessed individually with `` $` ` `` and `[[ ]]`:

```
mtl$`6`; mtl[[2]]
```

```
# [1] 21.0 21.0 21.4 18.1 19.2 17.8 19.7
# [1] 21.0 21.0 21.4 18.1 19.2 17.8 19.7
```

- In R, data frames can't hold vectors of different lengths, but lists can.

```r
vn <- c(1, 1.2, 2.3, 3.4, 4.5)
vb <- c(TRUE, TRUE, FALSE)
vc <- c('limestone', 'marl', 'oolite', 'CaCO3')
```

```r
data.frame(vn, vb, vc)
```

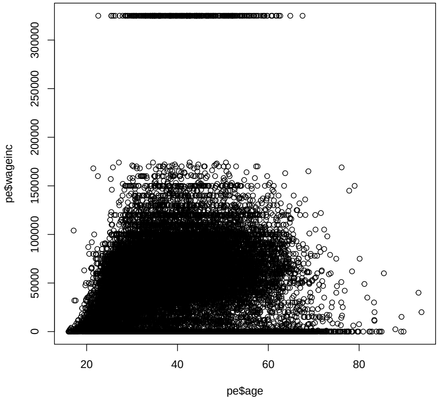
```
# Error in data.frame(vn, vb, vc): arguments imply differing number of rows:
5, 3, 4
```

```r
list(vn, vb, vc)
```

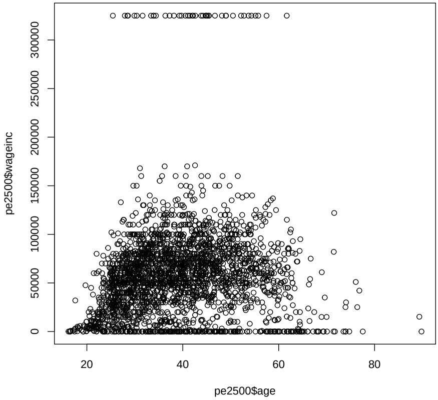
```
# [[1]]
# [1] 1.0 1.2 2.3 3.4 4.5
#
# [[2]]
# [1]  TRUE  TRUE FALSE
#
# [[3]]
# [1] "limestone" "marl"      "oolite"    "CaCO3"
```

Graphics

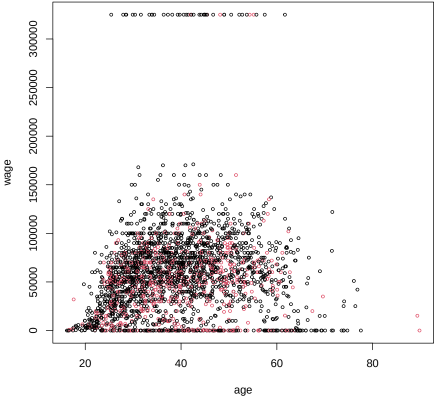
```r
pe <- read.table(
    'https://raw.githubusercontent.com/matloff/fasteR/master/data/prgeng.txt',
    header=TRUE)
plot(pe$age, pe$wageinc)
```



```r
pe2500 <- pe[sample(1:nrow(pe), 2500),]
plot(pe2500$age, pe2500$wageinc)
```



```
plot(pe2500$age, pe2500$wageinc,
     col=as.factor(pe2500$sex), xlab='age', ylab='wage', cex=0.6)
```



Programming

- We have been using built-in functions such as mean, var.

```
v <- c(1, 1.2, 2.3, 3.4, 4.5, 5.6, 6.7, 7.8)
cat('mean: ', mean(v), 'var: ', var(v))

# mean:  4.0625 var:  6.37125
```

- Now write our own:

```
my_mean <- function(x) {
    return(sum(x) / length(x))
}
my_mean(v)

# [1] 4.0625
```

```
my_var <- function(x) {
    m <- my_mean(x)
    return(sum((x - m)^2 / (length(x) - 1)))
}
my_var(v)

# [1] 6.37125
```

- How to sum 1 to 10000 if we don't use built-in functions?

```
ans <- 0
for (i in 1:10000) {
    ans <- ans + i
}
ans
# [1] 50005000
```

- How to sum $\sum_{k=1}^{100} \min\{2^k, k^4\}$?

```
ans <- 0
for (k in 1:100) {
    ans <- ans + min(2^k, k^4)
}
ans
# [1] 2050220551
```

- Bonus: Do you know how to do $\sum_{k=1}^{100} \min\{2^k, k^4\}$ quickly without loops?

```
v = 100; sum(pmin(2^v, v^4))
```

- How to sum a vector `x` if we don't use built-in functions?

```r
my_sum <- function(x) {
    ans <- 0
    for (i in 1:length(x)) {
        ans <- ans + x[i]
    }
    ans
}
my_sum(1:100)
# [1] 5050
```

- But it's SOOOO inefficient comparing to built-in functions …

```r
v <- 1:1000000; system.time(my_sum(v)); system.time(sum(v))
#    user  system elapsed
#   0.026   0.000   0.025
#    user  system elapsed
#       0       0       0
```

- Your Turn: Write a function `myprod` to replicate the built-in function `prod`.

- conditional: if, else

```
v <- c(20, 18, 45, 33, 25, 9, 17, 55, 69, 81, 44, 32); nv <- length(v)
w <- vector(length = nv)
for (i in 1:nv) {
    if (v[i] >= 20 & v[i] < 40) {
        w[i] <- 0
    } else if (v[i] >= 40 & v[i] < 60) {
        w[i] <- -1
    } else {
        w[i] <- v[i]
    }
}
v; w
#  [1] 20 18 45 33 25  9 17 55 69 81 44 32
#  [1]  0 18 -1  0  0  9 17 -1 69 81 -1  0
```

- vector version: ifelse

```
ww <- ifelse(v >= 20 & v < 40, 0, v)
ww <- ifelse(ww >= 40 & ww < 60, -1, ww); ww
#  [1]  0 18 -1  0  0  9 17 -1 69 81 -1  0
```

Misc: Linear Regression, Help Functions

- Linear regression model

```r
head(cars)
model <- lm(dist ~ speed, data = cars)
print(model)
summary(model)
plot(model)
abline(model)
```

- built-in help mechanisms; functions source lookup

```r
?prod
example(cumsum)
example(persp)
help.search('multivariate normal')
help(mgcv::rmvn)
help(rmvn)
rmvn
mgcv::rmvn
prod
var
sd
```

Operators

Operators	Definition
`+ - * /`	plus, minus, times, divide
`%/% %% ^`	integer quotient, modulo, power
`> >= < <=`	greater than, greater than or equals, less than, less than or equals
`== !=`	equals, not equals
`! & |`	not, and, or
`<- ->`	assignment (gets)
`$`	list indexing ('the element name' operator)
`:`	sequence creation
`~`	model formulae ('is modelled as a function of')
`%x%`	special binary operators: `x` can be set by any valid name
`%*%`	special binary operator: matrix product
`%in%`	special binary operator: test matching
`&& ||`	vector and, or
`::`	namespace assignment
`xor(a, b)`	elementwise exclusive OR
`<<-`	global assignment

Functions

Function	Definition
`abs(x)`	absolute value of `x`
`floor(x)`	greatest integer less than `x`
`ceiling(x)`	smallest integer greater than `x`
`trunc(x)`	closest integer to `x` between `x` and `0`
`round(x, digits = 0)`	round the value of `x` into integer
`signif(x, digits = 6)`	give `x` to 6 significant digits in scientific notation
`runif(n)`	generate `n` random numbers from uniform$(0, 1)$
`choose(n, m)`	binomial coefficient $\binom{n}{m}$
`log(x)`	log to base e of `x`
`log(x, n)`	log to base `n` of `x`
`log10(x)`	log to base 10 of `x`
`exp(x)`	$\exp(x)$
`sqrt(x)`	$\sqrt{x}$
`factorial(x)`	$x! = x \times (x-1) \times (x-2) \times \cdots \times 2 \times 1$
`sin(x), cos(x), tan(x)`	$\sin x$, $\cos x$, $\tan x$

Function	Definition
max(x)	maximum value in x
min(x)	mininum value in x
sum(x)	sum of all the values in x
mean(x)	arithmetic average of the values in x
median(x)	median value in x
quantile(x, p)	vector corresponding to the given probability p of x
range(x)	vector of min(x) and max(x)
rank(x)	vector of the ranks of the values in x
order(x)	an integer vector containing the permutation to sort x into asc order
var(x)	sample variance of x
cor(x, y)	correlation between vectors x and y.
sort(x)	a sorted copy of x
cumsum(x)	vector containing the sum of all the elements up to that point
cumprod(x)	vector containing the product of all the elements up to that point
pmax(x, y, z)	vector containing the maximum of x, y, z at each position
pmin(x, y, z)	vector containing the minimum of x, y, z at each position
colMeans(x)	column means of dataframe or matrix x
colSums(x)	column totals of dataframe or matrix x
rowMeans(x)	row means of dataframe or matrix x
rowSums(x)	row totals of dataframe or matrix x

Vectors

- flavors: atomic, generic (lists)
- primary types of atomic vector: logical, integer, double, character; integer + double = numeric
- esoteric types of atomic vector: complex, raw
- scalars: vectors of length 1
  - logical: `TRUE`, `FALSE`, `T`, `F`
  - double: `0.1234`, `1.23e4`, `0xcafe`, `NaN`, `-Inf`, `Inf`
  - integer: `1234L`, `1e4L`, `0xcafeL`
  - character: `"hi"`, `'bye'`, special characters escaped with `\`; see `?Quotes` for details.
- demonstrations

```r
v_logical <- c(TRUE, FALSE) # atomic vector: logical
v_integer <- c(1L, 6L, 10L) # atomic vector: integer
v_double <- c(1, 2.5, 4.5)  # atomic vector: double
v_character <- c('these', 'are', 'characters') # atomic vector: character
# concatenation of atomic vectors yield atomic vectors
(v <- c(c(1, 2), c(3, 4)))
```

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

```r
typeof(v_logical); typeof(v_integer); typeof(v_double); typeof(v_character)
```

```
# [1] "logical"
# [1] "integer"
# [1] "double"
# [1] "character"
```

- missing values: NA (Not Applicable); be existent but unknown.

```
NA > 5; 20 * NA; !NA  # NA tend to be infectious!
# [1] NA
# [1] NA
# [1] NA
NA ^ 0; NA | TRUE; NA & FALSE  # some exceptions
# [1] 1
# [1] TRUE
# [1] FALSE
x <- c(NA, 5, NA, 10); x == NA; is.na(x) # using is.na() to test
# [1] NA NA NA NA
# [1]  TRUE FALSE  TRUE FALSE
```

- NULL: nonexistent value

```
u <- NULL; length(u)
# [1] 0
v <- NA; length(v)
# [1] 1
```

- useful tests: `is.null()`, `is.na()`
- testing vector type: use `is.logical()`, `is.integer()`, `is.double()`, `is.character()`
- testing vector type: avoid `is.vector()`, `is.atomic()`, `is.numeric()`

- R feature: automatic coercion of vector elements; `as.*()` to coerce

```
typeof(c('a', 1))
# [1] "character"
x <- c(TRUE, FALSE, TRUE, TRUE); as.numeric(x)
# [1] 1 0 1 1
as.integer(c('1', '1.5', 'a'))
# Warning: NAs introduced by coercion
# [1]  1  1 NA
```

- type coercion hierarchy: character > double > integer > logical

```
c(1, FALSE); c(TRUE, 1L); 1 == '1'; -1 < FALSE; 'one' < 2
# [1] 1 0
# [1] 1 1
# [1] TRUE
# [1] TRUE
# [1] FALSE
```

- `:` generating consecutive sequence

```
5:10; 5:1; i <- 5; 1:i-1; 1:(i-1)
# [1]  5  6  7  8  9 10
# [1] 5 4 3 2 1
# [1] 0 1 2 3 4
# [1] 1 2 3 4
```

- seq — generalized :

```
seq(from = 11, to = 30, by = 3); seq(from = 1.1, to = 2, length = 10)
# [1] 11 14 17 20 23 26 29
#  [1] 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0
```

- using seq in for-loops

```
for (i in 1:length(x)) {}  # What if length(x) == 0 ?
for (i in seq(x)) {}       # Use this instead !
(x <- c(9, 5, 17)); seq(x); (x <- NULL); seq(x)
```

- The recycling rule: in operations involving two vectors, R repeats the shorter one

```
c(2, 4, 3) + c(6, 10, -1, 3, 5)
# Warning in c(2, 4, 3) + c(6, 10, -1, 3, 5): longer object length is not a multiple of shorter object length
# [1]  8 14  2  5  9
c(2, 4, 3, 2, 4) + c(6, 10, -1, 3, 5)
# [1]  8 14  2  5  9
c(2, 4, 3) * c(6, 10, -1, 3, 5)
# Warning in c(2, 4, 3) * c(6, 10, -1, 3, 5): longer object length is not a multiple of shorter object length
# [1] 12 40 -3  6 20
c(2, 4, 3, 2, 4) * c(6, 10, -1, 3, 5)
# [1] 12 40 -3  6 20
```

- example: how to select even terms in a vector?

```
x <- 1:10; x[x %% 2 == 0]
# [1]  2  4  6  8 10
x <- sin(1:10); x[seq(x) %% 2 == 0]; x[c(F, T)]
# [1]  0.9092974 -0.7568025 -0.2794155  0.9893582 -0.5440211
# [1]  0.9092974 -0.7568025 -0.2794155  0.9893582 -0.5440211
```

- `rep`: repeating vector constants

```
(x <- rep(3, 5)); rep(c(10, 15, 3), 4); rep(5:1, 3)
# [1] 3 3 3 3 3
#  [1] 10 15  3 10 15  3 10 15  3 10 15  3
#  [1] 5 4 3 2 1 5 4 3 2 1 5 4 3 2 1
```

- some other examples

```
rep(c(10, 15, 3), each = 4) # interleave the copies with `each`
#  [1] 10 10 10 10 15 15 15 15  3  3  3  3
rep(1:4, each = 2, times = 3); rep(1:4, 1:4); rep(1:4, c(4, 1, 4, 2))
#  [1] 1 1 2 2 3 3 4 4 1 1 2 2 3 3 4 4 1 1 2 2 3 3 4 4
#  [1] 1 2 2 3 3 3 4 4 4 4
#  [1] 1 1 1 1 2 3 3 3 3 4 4
rep(c('C', 'G', 'H'), c(4, 5, 2))
#  [1] "C" "C" "C" "C" "G" "G" "G" "G" "G" "H" "H"
```

-
  ```
  rep(1:4, each = c(4, 3, 2))
  # Warning in rep(1:4, each = c(4, 3, 2)): first element used of 'each'
  argument
  
  #  [1] 1 1 1 1 2 2 2 2 3 3 3 3 4 4 4 4
  ```
- `all` and `any`

```
x <- 1:100; any(x > 200); all(x > 0)

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

- testing vector equality: not `==`

```
x <- 1:3; y0 <- c(1, 2, 3); y1 <- c(1, 3, 4); x == y0; x == y1

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

- consider `identical` and `all.equal` — use `isTRUE(all.equal(…))` in `if` expr !

```
identical(x, y0); typeof(x); typeof(y0)

# [1] FALSE
# [1] "integer"
# [1] "double"

all.equal(x, y0); all.equal(x, y1)

# [1] TRUE
# [1] "Mean relative difference: 0.4"
```

- attr(), attributes(), structure(): make other data structures from atomic vectors by adding attributes

```
a <- 1:3; attr(a, 'x') <- 'ab'; attr(a, 'x')
# [1] "ab"
attr(a, 'y') <- 4:6; str(attributes(a))
# List of 2
#  $ x: chr "ab"
#  $ y: int [1:3] 4 5 6
a <- structure(1:3, x = 'ab', y = 4:6); str(attributes(a))
# List of 2
#  $ x: chr "ab"
#  $ y: int [1:3] 4 5 6
```

- 3 ways to name a vector x

```
x <- c(a = 1, b = 2, c = 3)
x <- 1:3; names(x) <- c('a', 'b', 'c')
x <- setNames(1:3, c('a', 'b', 'c'))
```

- adding a dim attribute to vectors make 2d matrices and nd arrays

```
x <- matrix(1:6, nrow = 2, ncol = 3)  # 2d matrix
x1 <- 1:6; dim(x1) <- c(2, 3); x1
y <- array(1:12, c(2, 3, 2))  # 3d array
y1 <- 1:12; dim(y1) <- c(2, 3, 2); y1
```

- S3 atomic vectors in Base-R
  - categorical data: fixed set of levels in `factor` vectors
  - date (with day resolution): recorded in `Date` vectors
  - date-time (with second / subsecond resolution): recorded in `POSIXct` vectors
  - durations: stored in `difftime` vectors

- factors are used when we have categorical variables.

```
(x <- factor(c('a', 'b', 'b', 'a'))); str(x); typeof(x); attributes(x);
```

- `tapply`: simple example

```
ages <- c(25, 26, 55, 37, 21, 42); affils <- c('R', 'D', 'D', 'R', 'U', 'D')
tapply(ages, affils, mean)
```

- `tapply`: further example

```
d <- data.frame(list(gender = c('M', 'M', 'F', 'M', 'F', 'F'),
                     age = c(47, 59, 21, 32, 33, 24),
                     income = c(55000, 88000, 32450, 76500, 123000, 45650)))
d$over25 <- ifelse(d$age > 25, 1, 0)
tapply(d$income, list(d$gender, d$over25), mean)
```

Common Tasks

- create a vector from given values: c

```
# Note the coercion hierarchy: character, double, integer, logical
v1 <- c(1, 2, 3); v2 <- c('a', 'b', 'c'); (v3 <- c(v1, v2))
[1] "1" "2" "3" "a" "b" "c"
```

- comparison of two vectors: element-by-element

```
# Note the vector recycling (and scalars are vectors of length 1)!
v <- c(4, pi); w <- c(pi, pi, pi, 3);
v == w; v != w; v < w; v <= w; v > w; v >= w; w != pi
[1] FALSE  TRUE FALSE FALSE
[1]  TRUE FALSE  TRUE  TRUE
[1] FALSE FALSE FALSE FALSE
[1] FALSE  TRUE FALSE FALSE
[1]  TRUE FALSE  TRUE  TRUE
[1] TRUE TRUE TRUE TRUE
[1] FALSE FALSE FALSE  TRUE
```

- comparison of two vectors: all at once

```
v <- c(3, pi, 4); any(v == pi); all(v == pi)
[1] TRUE
[1] FALSE
```

- selecting vector elements by numerical vectors (including scalars)

```
fib <- c(0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144);
fib[1]; fib[5]; fib[2:5]; fib[8:4]; fib[c(2, 4, 8, 1)]
```

```
[1] 0
[1] 3
[1] 1 1 2 3
[1] 13  8  5  3  2
[1]  1  2 13  0
```

```
# Note that 'minus' means 'exclude'; no mixing of positive/negative integers!
fib[-3]; fib[-(5:9)]
```

```
 [1]   0   1   2   3   5   8  13  21  34  55  89 144
[1]   0   1   1   2  34  55  89 144
```

- selecting vector elements by logical vectors: the recycling rule is in effect

```
# selecting elements that < 10
fib[fib < 10]
```

```
[1] 0 1 1 2 3 5 8
```

```
# selecting elements that are multiples of 2 and 3
fib[fib %% 2 == 0 | fib %% 3 == 0]
```

```
[1]   0   2   3   8  21  34 144
```

```
# selecting the odd terms: 1st, 3rd, 5th, etc.
fib[c(T, F)]
```

```
[1]   0   1   3   8  21  55 144
```

- selecting vector elements by combinations of functions of logical vectors

```
v <- c(2, 8, 1, 7, -11, 6, 20, 3, 12, 35, 21, 3, 5, 7, -2);
# select all elements greater than the median
v[v > median(v)]
```

```
[1]  8  7 20 12 35 21  7
```

```
# select all elements in the lower and upper 5%
v[v < quantile(v, 0.05) | v > quantile(v, 0.95)]
```

```
[1] -11  35
```

```
# select all elements that exceed ±1 standard deviations from the mean
v[abs(v - mean(v)) > sd(v)]
```

```
[1] -11  20  35  21
```

```
# select all elements that are neither NA nor NULL
v <- c(21, 2, 3, NA, 5, NULL, NA, 32, 55)
v[!is.na(v) & !is.null(v)]
```

```
[1] 21  2  3  5 32 55
```

- generate 1-spaced number sequences — operator :

```
1:5; 0.5:4.5; 4.5:0.5
```

```
[1] 1 2 3 4 5
[1] 0.5 1.5 2.5 3.5 4.5
[1] 4.5 3.5 2.5 1.5 0.5
```

- generate evenly-spaced sequences: `seq`

```
seq(10, 20)
 [1] 10 11 12 13 14 15 16 17 18 19 20
seq(from = 10, to = 20, by = 1.5)
[1] 10.0 11.5 13.0 14.5 16.0 17.5 19.0
seq(from = 10, to = 20, length.out = 6)
[1] 10 12 14 16 18 20
```

- generate repetitive sequences: `rep`

```
rep('A', 5); rep(1:5, c(2, 3, 2, 1, 5))
[1] "A" "A" "A" "A" "A"
 [1] 1 1 2 2 2 3 3 4 5 5 5 5 5
```

- generate random sequences (sampling): `sample`

```
sample(LETTERS[1:5], 15, replace = T); sample(letters[1:20], 15)
 [1] "C" "C" "D" "E" "D" "A" "C" "D" "D" "E" "D" "C" "D" "B" "C"
 [1] "h" "f" "m" "j" "l" "k" "o" "a" "g" "b" "n" "s" "t" "c" "i"
```

- primitive sequences generator: `sequence`

```
cat(sequence(8:5, from = c(1, 2, 1, 3)))
1 2 3 4 5 6 7 8 2 3 4 5 6 7 8 1 2 3 4 5 6 3 4 5 6 7
cat(sequence(8:5, from = c(1, 2, 1)))
1 2 3 4 5 6 7 8 2 3 4 5 6 7 8 1 2 3 4 5 6 1 2 3 4 5
sequence(c(6, 7, 4), from = c(8, 1, 9), by = c(-1, 1, -2))
 [1] 8 7 6 5 4 3 1 2 3 4 5 6 7 9 7 5 3
```

- print concatenated results on screen: `cat`

```
# `cat` puts a space between each item: using '\n' to terminate the line
v <- c(20, 30, 3 * pi); cat("The content of v is:", v, "...\n")
The content of v is: 20 30 9.424778 ...
```

- (old school) string formatting: `sprintf`

```
# %3d: 3 digits; %.6f: floats with 6 decimal places; %s: string
for (i in 50 * (0:2)) {
  cat(sprintf('The %3d-th term of sequence %s(%s(%3d)) is %.6f',
              i, 'exp', 'sin', i, exp(sin(i))), '\n')
}
The   0-th term of sequence exp(sin(  0)) is 1.000000
The  50-th term of sequence exp(sin( 50)) is 0.769223
The 100-th term of sequence exp(sin(100)) is 0.602682
```

- generate concatenate string vectors: paste, paste0

```
(labels <- paste(c('a', 'b'), 1:20, sep = '-'))
```

```
 [1] "a-1"  "b-2"  "a-3"  "b-4"  "a-5"  "b-6"  "a-7"  "b-8"  "a-9"  "b-10"
[11] "a-11" "b-12" "a-13" "b-14" "a-15" "b-16" "a-17" "b-18" "a-19" "b-20"
```

```
(nth <- paste0(1:12, c("st", "nd", "rd", rep("th", 9))))
```

```
 [1] "1st"  "2nd"  "3rd"  "4th"  "5th"  "6th"  "7th"  "8th"  "9th"  "10th"
[11] "11th" "12th"
```

- appending data to a vector

```
# use c() to concatenate vector
v <- c(1, 2, 3); it <- c(6, 7, 8); c(v, it)
# R will automatically extend the vector
v <- c(1, 2, 3); v[length(v) + 1] <- 42; v
# append an entire vector
w <- c(5, 6, 7, 8); v <- c(v, w); v
v[15] <- 0; v
```

- inserting data to a vector

```
append(1:10, 99, after = 5)
append(1:10, 99, after = 0)
```

- creating a list

```
(l <- list(3.14, 'Moe', c(1, 3, 5, 2), mean))
l <- list(); l[[1]] <- 3.14; l[[2]] <- 'Moe';
l[[3]] <- c(1, 3, 5, 2); l[[4]] <- mean; l
(l <- list(max = 5, right = 0.6, mean = 20))
```

- selecting list elements

```
l[[1]]  # by position
l[['max']]; l$mean; l['max'] # by name; different outcomes
```

- building a name / value association list

```
values <- c(0.1, 0.52, 0.33); names <- c("left", "right", "mid")
l <- list(); l[names] <- values; l
# Note two conventional ways
l <- list(); l$left <- 0.1; l$right <- 0.52; l$mid <- 0.33; l
l <- list(); l[['left']] <- 0.1; l[['right']] <- 0.52; l[['mid']] <- 0.33; l
```

- removing an element from a list

```
(l <- list(date = '2020-01-05', time = '12:50:11', number = 20))
l[c('date', 'time')] <- NULL; l  # remove two elements
```

- flatten a list into a vector

```
iq.scores <- list(100, 120, 140, 112, 105);
mean(iq.scores); mean(unlist(iq.scores))
cat(iq.scores, '\n'); cat('IQ scores:', unlist(iq.scores), '\n')
```

- initializing a matrix

```
v <- 1:6; matrix(v, 2, 3)
```

- giving descriptive names to the rows and columns of a matrix

```
m <- matrix(c(1, 0.556, 0.380, 0.556, 1, 0.444, 0.380, 0.444, 1), 3, 3)
colnames(m) <- c('AAPL', 'MSFT', 'GOOG');
rownames(m) <- c('AAPL', 'MSFT', 'GOOG');
m; m['MSFT', 'GOOG']
```

- selecting one row or column from a matrix

```
m[1,]; m[1,, drop=FALSE]; m[,3]; m[, 3, drop=FALSE]
```

- initializing a data frame from column data

```
pred1 <- c(4.01, 2.64, 6.03, 2.78); pred2 <- c(10.7, 12.2, 12.2, 15.0);
pred3 <- c('AM', 'PM', 'PM', 'AM'); resp <- c(11.5, 10.0, 9.2, 5.1);
data.frame(pred1, pred2, pred3, resp)
data.frame(p1 = pred1, p2 = pred2, p3 = pred3, r = resp)
list.of.vectors <- list(p1 = pred1, p2 = pred2, p3 = pred3, r = resp)
as.data.frame(list.of.vectors)
```

- initializing a data frame from row data

```
r1 <- data.frame(a = 1, b = 2, c = "X");
r2 <- data.frame(a = 3, b = 4, c = "Y");
r3 <- data.frame(a = 5, b = 6, c = "Z");
r <- rbind(r1, r2, r3)
```

- appending rows to a data frame

```
r0 <- rbind(r, data.frame(a = 4, b = 10, c = 'u'),
               data.frame(a = 3, b = -1, c = 'xx'))
```

- removing NAs from a data frame

```
df <- data.frame(x = c(1, NA, 3, 4, 5), y = c(1, 2, NA, 4, 5))
cumsum(na.omit(df))
```

- combining two data frames

```
df1 <- data.frame(a = c(1,2)); df2 <- data.frame(b = c(7,8)); cbind(df1, df2)
df1 <- data.frame(x = c("a", "a"), y = c(5, 6))
df2 <- data.frame(x = c("b", "b"), y = c(9, 10))
rbind(df1, df2)
```

Table 1: From One Data Structure to Another: HowTo

From	To	How	Note
vector	list	`as.list(v)`	1
vector	matrix	`cbind(v)`, `as.matrix(v)`, `rbind(v)`, `matrix(v, n, m)`	
vector	dataframe	`as.data.frame(v)`, `as.data.frame(rbind(v))`	
list	vector	`unlist(v)`	2
list	matrix	`as.matrix(l)`, `as.matrix(rbind(l))`, `matrix(l, n, m)`	
list	dataframe	`as.data.frame(l)`	
matrix	vector	`as.vector(m)`	
matrix	list	`as.list(m)`	
matrix	dataframe	`as.data.frame(m)`	
dataframe	vector	`df[1,]` or `df[,1]`, `df[[1]]`	3
dataframe	list	`as.list(df)`	4
dataframe	matrix	`as.matrix(df)`	5

1. Don't use `list(v)` !
2. Use `unlist` rather than `as.vector`.
3. This makes sense only if `df` contains one row or one column.
4. Using `as.list` removes the `class` attribute `data.frame`.
5. Note the coercion hierarchy: all elements will be coerced into the common denominator type!

Programming

- format of a function:

```
function_name <- function(argument1, argument2 = default_value2, ...) {
    # ...
    # rows with code to create some_object
    # ...
    return(some_object)
}
```

- functions can access global variables

```
y_squared <- function() {
    return(y^2)
}
y <- 2; y_squared()
# [1] 4
```

- but operations on global variables inside functions won't affect global variables

```
add_to_y <- function(n) {
    y <- y + n
}
y <- 1; add_to_y(2); y
# [1] 1
```

- use <<- operator if you really need to change a global variable inside functions

```
add_to_y_global <- function(n) {
    y <<- y + n
}
y <- 1; add_to_y_global(2); y
# [1] 3
```

- Define function avg(x) to compute the average of x

```r
avg <- function(x) {
    return(sum(x) / length(x))
}
```

- See what happens for various inputs:

```r
avg(c(2, 3, 6)); avg(c(TRUE, FALSE, TRUE, FALSE))
# [1] 3.666667
# [1] 0.5
avg(c('Moon', 'River', 'Wider', 'Than', 'A', 'MILE'))
# Error in sum(x): invalid 'type' (character) of argument
avg(data.frame(x = c(5, 2, 5), y = c(-3, -1, 13)))
# [1] 10.5
avg(data.frame(x = c(5, 2, 5), y = c('A', 'D', 'E')))
# Error in FUN(X[[i]], ...): only defined on a data frame with all numeric-alike variables
```

- Consequences of implicit return

```r
avg_bad <- function(x) {
    avg <- sum(x) / length(x)
}
avg_ok <- function(x) {
    sum(x) / length(x)
}
avg_bad(1:10)  # it's mute!
avg_ok(1:10)
# [1] 5.5
```

- Define function power_n(x, n) to compute x to the power of n

```
power_n <- function(x, n = 2){
    return(x^n)
}
```

- See what happens for various inputs:

```
power_n(3)    # using default  n = 2
# [1] 9
power_n(3, 3) # using supplied n = 3
# [1] 27
power_n(x = 5, n = 2)  # using named arguments
# [1] 25
power_n(n = 2, x = 5)  # ... even in wrong order
# [1] 25
power_n(n = 2)         # this is an error!
# Error in power_n(n = 2):  argument "x" is missing, with no default
```

- It is possible to apply function name as an argument

```
apply_to_first2 <- function(x, func) {
    result <- func(x[1:2])
    return(result)
}
```

-
  ```
  x <- c(1, 2, 3)
  apply_to_first2(x, sqrt)
  # [1] 1.000000 1.414214
  apply_to_first2(x, is.character)
  # [1] FALSE
  apply_to_first2(x, power_n)
  # [1] 1 4
  ```
- But what if we want to supply additional arguments to `func`?

```
x <- c(1, 2, 3); apply_to_first2(x, sum)
# [1] 3
x <- c(NA, 2, 3); apply_to_first2(x, sum) # using sum(x, na.rm = TRUE) ...
# [1] NA
```

- `...` comes to the rescue

```
apply_to_first2 <- function(x, func, ...) {
    result <- func(x[1:2], ...)
    return(result)
}
apply_to_first2(x, sum, na.rm = TRUE)
# [1] 2
```

- An example of typical usage of `if` & `else`

```r
reciprocal <- function(x) {
  if (is.na(x)) {
      cat("Error! Divison by NA.")
  } else if (is.infinite(x)) {
      cat("Error! Divison by infinity.")
  } else if (x == 0) {
      cat("Error! Division by zero.")
  } else {
      1 / x
  }
}
reciprocal(2); reciprocal(0); reciprocal(-Inf); reciprocal(NA)
```

```
# [1] 0.5
# Error! Division by zero.
# Error! Divison by infinity.
# Error! Divison by NA.
```

- `ifelse`: the vector version of `if` & `else`

```r
x <- c(-1, 2, -100, 20, 50)
ifelse(x > 0, 'positive', 'negative')
```

```
# [1] "negative" "positive" "negative" "positive" "positive"
```

- && is the short-circuited &. Note the difference:

```
# aa is a variable that doesn't exist; using && works:
if (exists("aa") && aa > 0) {
    cat("The variable aa exists and is positive.")
} else {
    cat("aa doesn't exist or is negative.")
}

# aa doesn't exist or is negative.

# But using & doesn't, because it attempts to evaluate aa > 0
#     even though aa doesn't exist!
if (exists("aa") & aa > 0) {
    cat("The variable aa exists and is positive.")
} else {
    cat("aa doesn't exist or is negative.")
}

# Error in eval(expr, envir, enclos): object 'aa' not found
```

References

Arnold, J. B. (2020). R for Data Science: Exercises Solutions. https://jrnold.github.io/r4ds-exercise-solutions/.

Braun, J. and Murdoch, D. (2015). *A First Course in Statistical Programming with R*. Cambridge University Press, Cambridge, 2nd edition.

Grolemund, G. and Wickham, H. (2017). *R for Data Science: Import, Tidy, Transform, Visualize, and Model Data*. Sebastopol, CA, O'Reilly Media, Inc. https://r4ds.had.co.nz/.

Grosser, M., Bumann, H., and Wickham, H. (2022). *Advanced R Solutions*. Chapman & Hall/CRC, Boca Raton, FL. https://advanced-r-solutions.rbind.io/.

Ismay, C. and Kim, Y. (2020). *Statistical Inference via Data Science: A ModernDive into R and the Tidyverse*. Chapman & Hall/CRC, Boca Raton, FL. https://moderndive.netlify.app/.

Long, J. D. and Teetor, P. (2019). *R Cookbook*. Sebastopol, CA, O'Reilly Media, Inc., 2nd edition. https://rc2e.com/.

Matloff, N. (2011). *The Art of R Programming: A Tour of Statistical Software Design*. No Starch Press, San Francisco.

Thulin, M. (2021). *Modern Statistics with R*. Eos Chasma Press. http://www.modernstatisticswithr.com/.

Wickham, H. (2019). *Advanced R*. Chapman & Hall/CRC, Boca Raton, FL, 2nd edition. https://adv-r.hadley.nz/.