Non-Numeric Values

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Introduction to R

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Introduction

- Statistical programming sometimes requires non-numeric values.
- Examples of non numerical values in R: characters and logical values.

What are logical values?

- Logical values can only have two values: TRUE or FALSE.
- Logical values in R can be abbreviated as T or F.

```
> foo <- TRUE
> foo
[1] TRUE

> bar <- F
> bar
[1] FALSE
```

Logical vectors and matrices

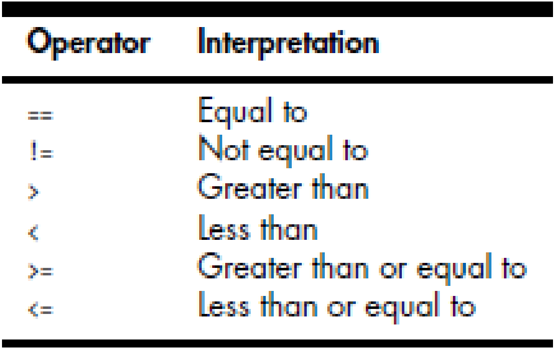
- A logical vector:

```
> baz <- c(TRUE, FALSE, FALSE, FALSE, TRUE, FALSE)
> baz
[1]  TRUE FALSE FALSE FALSE  TRUE FALSE
```

- A logical matrix:

```
> qux <- matrix(data = baz, nrow = 3, ncol = 2)
> qux
      [,1]  [,2]
[1,]  TRUE FALSE
[2,] FALSE  TRUE
[3,] FALSE FALSE
```

Basic logical operators



Operator	Interpretation
==	Equal to
!=	Not equal to
>	Greater than
<	Less than
>=	Greater than or equal to
<=	Less than or equal to

Figure 1: Basic logical operators in R

Logical comparisons

- Logicals can be used to check relationships between values:

```
> 1 == 2
[1] FALSE

> 1>2
[1] FALSE

> (2-1) <= 2
[1] TRUE

> 1 != (2+3)
[1] TRUE
```

Logical comparisons

- Logicals can be used to check relationships between variables:

```
> x <- log(5, base = 10)
> y <- log(5, base = exp(1))

> y == x
[1] FALSE
> y >= x
[1] TRUE

> c(x, y)
[1] 0.698970 1.609438
```

Vectorized logical comparison

```
> vec_x <- c(1, 5, 6, 7, 3)
> vec_y <- c(1, 6, 8, 2, 1)

> vec_x == 5
[1] FALSE  TRUE FALSE FALSE FALSE
> vec_x != 5
[1]  TRUE FALSE  TRUE  TRUE  TRUE
> vec_x >= vec_y
[1]  TRUE FALSE FALSE  TRUE  TRUE
```

The ! operator

- "!" is the negation (NOT) operator

```
> !TRUE
[1] FALSE

> !FALSE
[1] TRUE

> !c(TRUE, FALSE, TRUE, TRUE, FALSE)
[1] FALSE  TRUE FALSE FALSE  TRUE
```

The ! operator

```
> x <- c(FALSE, TRUE)
> !x
[1]  TRUE FALSE
```

The ! operator

```
> vec_x <- c(1, 5, 6, 7, 3)
> vec_y <- c(1, 6, 8, 2, 1)

> vec_x >= vec_y
[1]  TRUE FALSE FALSE  TRUE  TRUE

> !(vec_x >= vec_y)
[1] FALSE  TRUE  TRUE FALSE FALSE
```

The ! operator

```
> vec_x <- c(1, 5, 6, 7, 3)
> vec_y <- c(1, 6, 8, 2, 1)

> vec_x == 5
[1] FALSE  TRUE FALSE FALSE FALSE
> !(vec_x == 5)
[1]  TRUE FALSE  TRUE  TRUE  TRUE

> vec_x == vec_y
[1]  TRUE FALSE FALSE FALSE FALSE
```

! vs *Factorial*

- Do not confuse ”!” with the factorial function
- In R, the factorial function is *factorial*:

```
> factorial(5)
[1] 120
> 5 * 4 * 3 * 2 * 1
[1] 120
```

- Alternatively, can use the product function:

```
> prod(5:1)
[1] 120
> prod(5, 4, 3, 2, 1)
[1] 120
```

Subset with logicals

```
> myvec <- c(5, -2.3, 4, 4, 1)

> myvec[c(TRUE, FALSE, TRUE, FALSE, FALSE)]
[1] 5 4
```

- Recycling rules apply as usual:

  ```
  > myvec[c(TRUE, FALSE)]
  [1] 5 4 1
  ```

Subset with logicals

```
> mymat <- matrix(1:9, nrow = 3)
> mymat
     [,1] [,2] [,3]
[1,]    1    4    7
[2,]    2    5    8
[3,]    3    6    9

> mymat[, c(TRUE, FALSE, TRUE)]
     [,1] [,2]
[1,]    1    7
[2,]    2    8
[3,]    3    9
```

Subset with logicals

```
> mymat[c(TRUE, TRUE, FALSE), ]
     [,1] [,2] [,3]
[1,]    1    4    7
[2,]    2    5    8

> mymat[c(TRUE, TRUE, FALSE), c(TRUE, TRUE, FALSE)]
     [,1] [,2]
[1,]    1    4
[2,]    2    5
```

Subset with logicals

```
> myvec <- c(5, -2.3, 4, 4, -1)

> myvec < 0
[1] FALSE  TRUE FALSE FALSE  TRUE
> myvec[myvec < 0]
[1] -2.3 -1.0

> myvec != 4
[1]  TRUE  TRUE FALSE FALSE  TRUE
> myvec[myvec != 4]
[1]  5.0 -2.3 -1.0
```

Overwriting with logicals

```
> mymat <- matrix(1:9, nrow = 3, byrow = TRUE)
> mymat
     [,1] [,2] [,3]
[1,]    1    2    3
[2,]    4    5    6
[3,]    7    8    9

> mymat < 5
      [,1]  [,2]  [,3]
[1,]  TRUE  TRUE  TRUE
[2,]  TRUE FALSE FALSE
[3,] FALSE FALSE FALSE
```

Overwriting with logicals

```
> mymat[mymat < 5]
[1] 1 4 2 3

> mymat[mymat < 5] <- 0
> mymat
     [,1] [,2] [,3]
[1,]    0    0    0
[2,]    0    5    6
[3,]    7    8    9
```

Overwriting with logicals

```
> mymat <- matrix(1:9, nrow = 3, byrow = TRUE)
> mymat
     [,1] [,2] [,3]
[1,]    1    2    3
[2,]    4    5    6
[3,]    7    8    9

> which(mymat < 5)
[1] 1 2 4 7

> mymat[which(mymat < 5)] <- 0 # same result as the
>       # previous slide
```

Introduction

- In R, missing values are represented by NA (not available)
- NAs are exceptional logical values.
- The *is.logical* testes whether or not values are logic:

```
> is.logical(54)
[1] FALSE
> is.logical(myvec)
[1] FALSE
> is.logical(TRUE)
[1] TRUE
> is.logical(FALSE)
[1] TRUE
> is.logical(NA)
[1] TRUE
```

Introduction

- In the previous lesson, we dealt with numerical values
- There is also a test function for numerics:

```
> is.numeric(54)
[1] TRUE
> is.numeric(myvec)
[1] TRUE
> is.numeric(TRUE)
[1] FALSE
> is.numeric(FALSE)
[1] FALSE
> is.numeric(NA)
[1] FALSE
```

Operations with NAs

- When NAs are present, caution is required!

```
> y <- c(1, 2, 3, NA)

> NA + 5
[1] NA
 > (NA + 3) > 0
[1] NA

> sum(1, 5, 6, NA, 7)
[1] NA
> mean(y)
[1] NA
```

Dealing with missing values

- Many functions have a *na.rm* argument. It is set to FALSE by default.

```
> y <- c(1, 2, 3, 7, 0.5, NA)
> y_without_nas <- y[-6]

> mean(y, na.rm = TRUE)
[1] 2.7
> mean(y_without_nas)
[1] 2.7
> sum(1, 5, 6, NA, 7, na.rm = TRUE)
[1] 19
> sum(1, 5, 6, 7)
[1] 19
```

Dealing with missing values

- Other option: *na.omit*

```
> y <- c(1, 2, 3, 7, 0.5, NA)
> na.omit(y)
[1] 1.0 2.0 3.0 7.0 0.5

> y_new <- na.omit(y)
> y_new
[1] 1.0 2.0 3.0 7.0 0.5
```

Dealing with missing values

- *na.omit* with matrices:

```
> (M <- matrix(c(1:3, NA, c(5, 9)), nrow = 3,
 byrow = TRUE))
     [,1] [,2]
[1,]    1    2
[2,]    3   NA
[3,]    5    9
>
> na.omit(M)
     [,1] [,2]
[1,]    1    2
[2,]    5    9
```

Dealing with missing values

- In matrices (and data frames) *na.omit* returns only complete rows!
- This can be useful in data analysis when only complete cases are to be considered.
- However, sometimes we have small samples and can't afford to throw away incomplete observations.
  - Solution: imputation

Testing for missing values

```
> y <- c(1, 2 , 3, NA)

> is.na(y)
[1] FALSE FALSE FALSE  TRUE

> !is.na(y)
[1]  TRUE  TRUE  TRUE FALSE
```

Testing for missing values

```
> M <- matrix(c(1:3, NA, c(5, 9)), 3, 2, TRUE)
> M
     [,1] [,2]
[1,]    1    2
[2,]    3   NA
[3,]    5    9

> is.na(M)
      [,1]  [,2]
[1,] FALSE FALSE
[2,] FALSE  TRUE
[3,] FALSE FALSE
```

Imputation of missing values

```
> M <- matrix(c(1:3, NA, c(5, NA)), 2, 3, TRUE)
> M
     [,1] [,2] [,3]
[1,]    1    2    3
[2,]   NA    5   NA

> is.na(M)
      [,1]  [,2]  [,3]
[1,] FALSE FALSE FALSE
[2,]  TRUE FALSE  TRUE
```

Imputation of missing values

```
> M[is.na(M)] <- 0
> M

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

- Replacing missing values with zeros can result in severe underestimation of the actual values. Sometimes it better to replace NAs with an estimate of its value.

Imputation of missing values

```
> M <- cbind(
   y  = c(3, NA, 7, 1),
   x1 = c(1, 7,  9, 6),
   x2 = c(6, 7,  9, NA)
 )

> M
      y x1 x2
[1,]  3  1  6
[2,] NA  7  7
[3,]  7  9  9
[4,]  1  6 NA
```

Imputation of missing values

```
> M[, "y"]
[1]  3 NA  7  1

> is.na(M[, "y"])
[1] FALSE  TRUE FALSE FALSE

> M[is.na(M[, "y"]), "y"] <- median(M[, "y"],
 na.rm = TRUE)

> M[is.na(M[, "x2"]), "x2"] <- median(M[, "x2"],
 na.rm = TRUE)
```

Imputation of missing values

```
> M
     y x1 x2
[1,] 3  1  6
[2,] 3  7  7
[3,] 7  9  9
[4,] 1  6  7
```

Counting missing values

- The *table* function is useful here:

```
> y <- c(1, 2 , 3, NA, 6, NA, 9, NA)

> is.na(y)
[1] FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE  TRUE

> table(is.na(y))
FALSE  TRUE
    5     3
```

Counting missing values

- *table* also works with matrices:

```
> M <- rbind(
   col1 <- c(2, 5, 7),
   col2 <- c(NA, 5, 7),
   col3 <- c(2, 5, NA)
  )

> table(is.na(M))

FALSE  TRUE
    7     2
```

Counting missing values

- Alternative:

```
> y <- c(1, 2 , 3, NA, 6, NA, 9, NA)
> sum(is.na(y))
[1] 3

> M <- rbind(
    col1 <- c(2, 5, 7),
    col2 <- c(NA, 5, 7),
    col3 <- c(2, 5, NA)
  )
> sum(is.na(M))
[1] 2
```

Coercion of logical values

- Why does *sum(is.na())* Work? R coerces logical values to numerical values if you use them in a context where numeric values are expected.
- How?

```
> as.numeric(TRUE)
[1] 1
> as.numeric(FALSE)
[1] 0
```

- The *as.numeric* function forces the coercion to numeric.

Coercion of logical values

```
> y <- c(1, 2 , 3, NA, 6, NA, 9, NA)
> is.na(y)
[1] FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE  TRUE
> as.numeric(is.na(y))
[1] 0 0 0 1 0 1 0 1
> sum(as.numeric(is.na(y)))
[1] 3
```

- The *as.numeric* function here is redundant since R coerces the inputs of *sum* to numerical if possible.
- The same happens with matrices.

Removing NAs with the *which* function

```
> y <- c(1, 2 , 3, NA, 6, NA, 9, NA)
```

- How many NAs in y?

```
> length(which(is.na(y)))
[1] 3
```

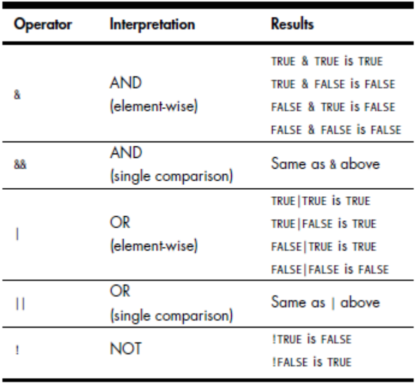
- In which positions are the positions with non-NA values of y?

```
> which(is.na(y))
[1] 4 6 8
```

- Subset y to extract non-missing values only:

```
> y[which(!is.na(y))] # notice the "!"
[1] 1 2 3 6 9
```

Logical comparison with more than one condition



Operator	Interpretation	Results
&	AND (element-wise)	TRUE & TRUE is TRUE TRUE & FALSE is FALSE FALSE & TRUE is FALSE FALSE & FALSE is FALSE
&&	AND (single comparison)	Same as & above
|	OR (element-wise)	TRUE|TRUE is TRUE TRUE|FALSE is TRUE FALSE|TRUE is TRUE FALSE|FALSE is FALSE
||	OR (single comparison)	Same as | above
!	NOT	!TRUE is FALSE !FALSE is TRUE

Figure 2: The ”and”, ”or” and ”not” operators in R

Logical comparison with more than one condition

- Examples:

```
> (6 < 4) || (3 != 1)
[1] TRUE

> (6 < 4) || (3 == 1)
[1] FALSE

> (6 < 4) && (3 != 1)
[1] FALSE

> (6 > 4) && (3 >= 1)
[1] TRUE
```

Logical comparison with more than one condition

- Examples:

```
> y <- c(1, 5 ,3, 1, 2, 9)

> (y > 2) & (y < 6)
[1] FALSE  TRUE  TRUE FALSE FALSE FALSE

> (y > 2) | (y < 6)
[1] TRUE TRUE TRUE TRUE TRUE TRUE
```

Logical comparison with more than one condition

- Examples:

```
> y <- c(1, 5 ,3, 1, 2, 9)

> y[(y > 2) & (y < 6)]
[1] 5 3

> y[(y > 2) | (y < 6)]
[1] 1 5 3 1 2 9
```

Logical comparison with more than one condition

- You can chain as many comparisons as you want:

```
> y[y > 2]
[1] 5 3 9

> y[(y > 2) | (y < 6)]
[1] 1 5 3 1 2 9

> y[((y > 2) | (y < 6)) & (y != 2)]
[1] 1 5 3 1 9
```

- When performing multiple comparisons, parentheses are recommended!

The *any* and *all* functions

- Given a set of logical vectors, is at least one of the values true?
- Given a set of logical vectors, are all of the values true?

```
> y <- c(1, 5 , 3, NA, 2, 9)

> any(y > 2, y < 6, !is.na(y))
[1] TRUE

> all(y > 2, y < 6, !is.na(y))
[1] FALSE
```

Exclusive OR

- *xor* indicates element-wise exclusive OR

```
> y <- c(1, 5 ,3, 1, 2, 9)

> xor(y>2, y<6)
[1]  TRUE FALSE FALSE  TRUE  TRUE  TRUE
```

Logical comparison with more than one condition

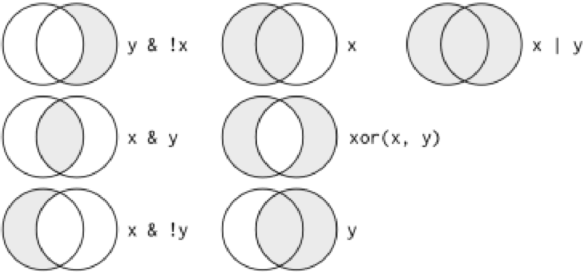


Figure 3: A visual perspective of logical operators

Creating character values

- Character strings are used to represent text, and should be inside single or double quotes:

```
> foo <- "hello world"
> foo
[1] "hello world"

> foo2 <- ’hello world’
> foo2
[1] "hello world"
```

Basic functions for characters

- Character strings are used to represent text, and should be inside single or double quotes:

```
> foo <- "hello world"
> foo
[1] "hello world"

> length(foo)
[1] 1

> nchar(foo)
[1] 11
```

Common use of characters in R

- Provide arguments to functions
- Directories
- Create factors
- Create names (vectors, matrices, lists, data frames)

Introduction

- When writing strings, you can insert single quotes in a string with double quotes, and vice versa:

```
# single quotes within double quotes
ex1 <- "The ’R’ project for statistical computing"

# double quotes within single quotes
ex2 <- ’The "R" project for statistical computing’
```

- You cannot directly insert single quotes in a string with single quotes, neither you can insert double quotes in a string with double quotes

Introduction

- If you really want to include a double quote as part of the string, you need to escape the double quote using a backslash before it:

  ```
  "The \"R\" project for statistical computing"
  ```

The *paste* and *paste0* functions

```
PI <- paste("The life of", pi)
PI
> [1] "The life of 3.14159265358979"
```

The *paste* and *paste0* functions

```
# paste with objects of the same lengths
IloveR <- paste("I", "love", "R", sep = "-")
IloveR
> [1] "I-love-R"

> paste(c(3, 2, 1), c("a", "b", "c"), sep = "_")
[1] "3_a" "2_b" "1_c"

# paste with objects of different lengths
paste("X", 1:5, sep = ".")
> [1] "X.1" "X.2" "X.3" "X.4" "X.5"
```

The *paste* and *paste0* functions

```
# paste with collapsing
paste(1:3, c("!","?","+"), sep = "", collapse = "")
> [1] "1!2?3+"

> paste(1:3, c("!","?","+"), sep = "$", collapse = "")
[1] "1$!2$?3$+"

# paste without collapsing
paste(1:3, c("!","?","+"), sep = "")
> [1] "1!" "2?" "3+"
```

The *paste* and *paste0* functions

- One of the potential problems with *paste* is that it coerces NAs into the character ”NA”

```
# with NA
evalue <- paste("the value of 'e' is", exp(1), NA)

evalue
> [1] "the value of 'e' is 2.71828182845905 NA"
```

The *paste* and *paste0* functions

- In addition to paste(), there’s also the function *paste0* which is the equivalent of *paste*(..., sep = ””)

```
# collapsing with paste0
paste0("let’s", "collapse", "all", "these", "words")
> [1] "let’scollapseallthesewords"

> paste("let’s", "collapse", "all", "these", "words")
[1] "let’s collapse all these words"
```

The *paste* and *paste0* functions

- *paste* and *paste0* can be useful to generate vector names:

```
> paste("y", 1:length(y), sep = "")
[1] "y1" "y2" "y3"

> paste("name", 1:length(y), sep = "_")
[1] "name_1" "name_2" "name_3"

> paste("year", 1990:1993, sep = "-")
[1] "year-1990" "year-1991" "year-1992" "year-1993"

> paste0("X", 1:5)
[1] "X1" "X2" "X3" "X4" "X5"
```

The *paste* and *paste0* functions

```
> vec <- c("awesome","R","is")
>
> my_opinion <- paste(vec[2],vec[3],"totally",vec[1],"!")
> my_opinion
[1] "R is totally awesome !"
```

The *cat* function

```
> vec <- c("awesome","R","is")

> cat(vec[2],vec[3],"totally",vec[1],"!")
R is totally awesome !
```

- *cat* outputs the object but does not store it nor does it return anything
- Useful to print objects in functions

Operations with characters

- It is not possible to make operations with characters:

```
> zag <- c("23", "4")
> zag * 5
Error in zag * 5 : non-numeric argument to binary operator

> bar <- c("23", "4", "some-random-string")
> length(bar)
[1] 3
> nchar(bar) # number of characters
[1]  2  1 18
> zag[2] # subsetting works as usual
[1] "4"
```

Equality test

```
> "alpha"=="alpha"
[1] TRUE

> "alpha"!="beta"
[1] TRUE

> c("alpha","beta","gamma") == "beta"
[1] FALSE TRUE FALSE

> "beta" %in% c("alpha","beta","gamma")
[1] TRUE
```

Logical comparisons

- Alphabetical order matters:

```
> "alpha"<="beta"
[1] TRUE
> "gamma">"Alpha"
[1] TRUE
```

- Uppercase letters also matters:

```
> "Alpha">"alpha"
[1] TRUE
> "beta">="bEtA"
[1] FALSE
```