

Lecture 7: Midterm Review

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This note is designed to give a brief review on lecture materials [Zhang, 2023] and highlight those important concepts/results in STAT 302 before the midterm exam. The review is by no means comprehensive and in order to excel at the midterm exam, a student is expected to master those R fundamentals in the course instead of simply memorizing the key functions or commands in R.

Disclaimer: Parts of this note are modified from the midterm review of STAT 133 in Fall 2016 at UC Berkeley by Professor Deborah Nolan.

1 R Basics and Syntax

- **Binary arithmetic operators:** `+`, `-`, `*`, `/`, `%%` (for mod), `%/%` (for integer division), and `^` (exponentiation), etc.
- **Comparison operators:** `>`, `<`, `<=`, `>=`, `==`, and `!=`. The returning value of a comparison statement is TRUE or FALSE.
- **Logical operators:** `&`, `|`, and `!`. A logical operator takes one or more comparison statements and return TRUE or FALSE.

★ Notes: Pay attention to the order/priority of operations as well as the difference between simple and compound expressions.

Data Types in R:

- Basic types in R: numeric (and integer), character, logical, factor, etc.
- Factor has a level (string) and is stored internally as an integer.
- Special values include `NA` (not available), `NaN` (not a number), `NULL` (empty vector), and `Inf` (infinity).

We can use the built-in function `class()` to determine the data type of an R object.

★ Note: The function `typeof()` determines the (R internal) type or storage mode of any R object. Its returning value may not be the same as `class()`.

2 Data Structures in R

Vector calculations:

- Vector is an ordered container of primitive elements of the same data type.
- R is vectorized so that we can perform operations on vectors.
- Remember the recycling rule in R when the vectors are of different lengths:

```
> x = rep(c(1,2), times = c(2, 4))
> y = 1:3
> x^y
[1] 1 1 8 2 4 8
```

Matrices and arrays: A matrix or an array is a rectangular collections of primitive elements of the same data type. They are stored in R as a vector with shape information.

Lists: A list is an ordered container of objects, e.g., mixtures of vectors, data frames, lists, functions.

Data frames: A data frame is an ordered container of vectors, where the vectors are of the same length and possibly different data types.

Practice Problem: Describe two important differences between a data frame and a matrix in R.

Answer: Here are some acceptable answers.

- A data frame is essentially a list of vectors of the same length, whereas a matrix is essentially a vector with shape information.
- Data frames can have columns/vectors that are different types, whereas all values in a matrix must be the same primitive element.
- Data frames can be indexed with \$.
- Data frames require variable names.

Subsetting: We use the family.txt data as an example.

```
> head(family)
firstName sex age height weight      bmi overWt
1      Tom  m  77      70     175 25.16239  TRUE
2     Maya  f  33      64     124 21.50106 FALSE
3      Joe  m  79      73     185 24.45884 FALSE
4  Robert  m  47      67     156 24.48414 FALSE
5      Sue  f  27      61      98 18.51492 FALSE
6      Liz  f  33      68     190 28.94981  TRUE
```

```
> sapply(family, class)
firstName      sex      age      height      weight      bmi      overWt
"character" "character" "integer" "integer" "integer" "numeric" "logical"
```

- Position – using the indices of elements, rows, columns that we want.

```
> family[,1]
[1] "Tom"      "Maya"      "Joe"      "Robert" "Sue"      "Liz"      "Jon"      "Sally"      "Tim"
[10] "Tom"      "Ann"      "Dan"      "Art"      "Zoe"

> family[c(1, 3, 6), ]
firstName sex age height weight      bmi overWt
1      Tom  m  77      70     175 25.16239  TRUE
3      Joe  m  79      73     185 24.45884 FALSE
6      Liz  f  33      68     190 28.94981  TRUE
```

- Exclusion – using the indices of elements to exclude.

```
> family[-(2:12), ]
  firstName sex age height weight      bmi overWt
1      Tom   m  77     70    175 25.16239   TRUE
13     Art   m  46     66    150 24.26126  FALSE
14     Zoe   f  48     62    125 22.91060  FALSE
```

- Logical – using a logical vector of the same length as the vector/rows/columns being subsetted. It will keep the elements corresponding to TRUE.

```
> family[(family$overWt) & (family$age > 60), ]
  firstName sex age height weight      bmi overWt
1      Tom   m  77     70    175 25.16239   TRUE
7      Jon   m  67     68    185 28.18797   TRUE
```

- Name – using a character vector of names of elements/rows/columns to keep.

```
> family[, "age"]
[1] 77 33 79 47 27 33 67 52 59 27 55 24 46 48
```

★ Note: Subsetting a list or data frame via a double-square bracket returns the element or column within the list or data frame, but not a list or data frame of one element.

```
> class(family[["age"]])
[1] "integer"
> class(family["age"])
[1] "data.frame"
```

Practice Problem: Write down what the value of x will contain after each line of R code, if the commands are executed sequentially.

```
> x = seq(0, 8, length = 5)
> x
[1] 0 2 4 6 8

> x[x<4] = NA
> x
[1] NA NA 4 6 8

> x[5] = 10
> x
[1] NA NA 4 6 10

> x[] = 0
> x
[1] 0 0 0 0 0

> x = 12
> x
[1] 12
```

Practice Problem: Data on 37 parents of babies born at Kaiser Hospital in the 1960s is available in a data frame called `parents`. The variables `age`, `ed`, `ht`, and `wt` are the mother's age, education level, height and weight. The variables that start with the letter `d` are corresponding variables for the fathers.

```
> head(parents)
  age ed      ht wt dage ded      dht dwt marital inc
1  27 College  62 100 31 College  65 110 Married [2500, 5000)
2  33 College  64 135 38 College  70 148 Married [7000, 8000)
3  28 High School 64 115 32 Some High School NA NA Married [5000, 6000)
4  36 College  69 190 43 Some College  68 197 Married [12500, 15000)
5  23 College  67 125 24 College  NA NA Married [2500, 5000)
6  25 High School 62 93 28 High School  64 130 Married [7000, 8000)
```

1. Write an R expression to find the subset of parents where the mother is over 40.

```
parents[parents$age > 40, ]
```

2. Write an R expression using an apply function to return the class of each variable in the data frame.

```
sapply(parents, class)
```

3. Write one R expression using an apply function to return the number of NAs in each variable (recall that there is a function called `is.na()` that returns a logical indicating the presence of NAs).

```
sapply(parents, function(x){
  sum(is.na(x))
})
```

Practice Problem: Here is a list in R:

```
> x
$a
[1] 0.03895442 0.77658866 0.83532332

$b
[,1] [,2]
[1,] 1 4
[2,] 2 5
[3,] 3 6
```

Write one line of R code to extract the first row of the matrix.

```
x$b[1, ]
x[["b"]][1, ]
```

★ Notes: You should know how to use `dim()`, `head()`, `class()`, `length()` functions with the data structures in R. In addition, you should also be able to use `sapply()`, `lapply()`, `apply()`, `tapply()`, and `mapply()` functions with these structures.

Practice Problem: Suppose we have a matrix `m`, and we have just executed the following:

```
> dim(m)
[1] 500 3
```

```
> head(m)
      [,1]      [,2]      [,3]
[1,] 0.9231213 0.2142767 2.544545
[2,] 0.5669828 0.6981698 1.336078
[3,] 0.7077386 0.1447157 1.750822
[4,] 0.6723225 0.6040853 0.042359
[5,] 0.4925304 -0.4389639 1.504622
[6,] 0.8370886 0.3683489 1.456362
```

We need to create a vector containing the sum of the squared entries in each row of `m`. Use an anonymous function and the `apply()` function to do this:

```
apply(m, 1, function(x) {
  sum(x^2)
})
```

3 Control Flow and Basic Iterations

Conditional evaluation: `if` and `if-else` statements.

```
if (condition to evaluate to TRUE or FALSE) {
  code block to be run if above is TRUE
}
```

and

```
if (condition to evaluate to TRUE or FALSE) {
  code block to be run if above is TRUE
} else {
  code block to be run if above is FALSE
}
```

Iterations: Looping with `for` and `while` statements.

```
> x = c(10, 2, 6, 5)
> for (i in 1:3) {
  print(x[i])
}
[1] 10
[1] 2
[1] 6
```

4 Data Manipulation via tidyverse

Pipes `%>%` operator:

- $x \%>\% f \%>\% g$ is equivalent to $g(f(x))$.
- $x \%>\% f(y, .)$ is equivalent to $f(y, x)$.

dplyr functions: Some of the most important `dplyr` verbs (functions):

- `filter()`: subset rows based on a condition.
- `group_by()`: define groups of rows according to a column or specific condition.
- `summarize()`: apply computations across groups of rows.
- `arrange()`: order rows by value of a column.
- `select()`: pick out given columns.
- `mutate()`: create new columns.
- `mutate_at()`: apply a function to given columns.

tidyr functions: Two of the most important `tidyr` verbs (functions):

- `pivot_longer()`: make “wide” data longer.
- `pivot_wider()`: make “long” data wider.

5 Graphics in R

Data type and plot correspondence:

- One variable:
factor: barplot, dot chart, line plot, etc.
numeric: rug plot, density plot, histogram, boxplot, etc.
- Two variables:
Two factors: side-by-side bar plot, superposed line plots, mosaic plot, side-by-side dot chart, etc.
Two numerics: scatter plot, line plot if one variable is time
numeric + factor: super-posed density curves, side-by-side boxplots or violin plots, line plots, etc.
- More details can be found in the [ggplot2 cheat sheet](#) and the [reference book](#).

Plotting principles:

- Make the data standout: symbols, over plotting, interference, jittering, scale, etc.
- Facilitate comparison: emphasize the important difference; don’t jiggle the baseline; juxtapose, superpose and choice of scale; banking to 45 degrees; perception – color, shape.
- Information rich: color; reference lines and markers; legends and labels; captions.

ggplot essentials:

- `ggplot()` initiates a plot. We can provide a data frame and a mapping between the variables in the data frame and plot aesthetics.
- Layers - we add geoms/glyphs to the plot with `geom_XXX()` functions. Examples include
`geom_point()` for points in a scatter plot,
`geom_line()` for connecting dots to make line plots,

`geom_smooth()` for averaging the y-values with similar x-values to create a smooth curve as a function of x,

`geom_bar()` for making bars in a bar plot,

`geom_boxplot()` for making boxes in a box plot,

`geom_density()` for computing and drawing kernel density estimate, which is a smoothed version of the histogram,

`geom_histogram()` for making bars in a histogram.

In the layer, we can also provide the data frame and the mapping of the variables to aesthetics.

- Scales - these are associated with the aesthetics. Each aesthetic has a scale. We use the `scale_XX_xxxx()` functions to specify details. The first argument in each scale function is **name**, which provides the axis or legend name. A short cut function called `labs()` allows use to specify the name to all of our aesthetics without having to call the scale functions, e.g., `labs(x = "my x", y = "my y", color = "color legend title")`.
- Theme - themes are used for general details, such as font type and size, background color, etc.

6 Writing Functions in R

Function signatures:

- Required parameters – have no default value provided, usually come first in the signature.
- Optional parameters – have default values (which may be computed from other parameters).
- Function calls – R sets up the call frame with default values for parameters, then values are assigned for the arguments mentioned by name in the call. R will first look for the value of a variable by name in the function environment. If it can't be found, then it will resort to its parent environment, which is the global environment in this case, etc.
- `<-` is used to assign values to variables in the parent environment.
- Lazy evaluation – If an expression is provided for a parameter value, then this expression is not evaluated until the variable is referenced in the computations for the function call.
- Debugging tools and testing – `traceback()`, `browser()`, `debug()`, etc.

Practice Problem: Write a function to compute the sum of the absolute deviations from the median for an input vector. For example, for a vector `x = 1:3`, `x` has a median of 2, and the absolute deviations from the median are 1, 0, and 1 so the sum of the absolute deviations from the median is 2.

Call the function `sadm()`. This function has one parameters: `x`, which is required and holds the numeric vector that will be operated on.

```
sadm = function(x){
  res = sum(abs(x - median(x)))
  return(res)
}
```

Practice Problem: Update the function `sadm()` to handle NA values. Add a parameter: `na.rm`, which determines whether NAs are to be removed from the computation. The `na.rm` parameter has a default value of FALSE.

```
sadm = function(x, na.rm = FALSE){  
  if (na.rm) {  
    x = x[!is.na(x)]  
  }  
  res = sum(abs(x - median(x)))  
  return(res)  
}
```

7 Simulation Basics

- Simple random selection with `sample()`
- Replicating the experiment with `replicate()`.

Practice Problem: Someone wants to study the distribution of the sum of three rolls of a die. To do this, he/she designs a simulation study. In the first step, he/she writes a function called `sum3()` to generate the sum of three random tosses of a fair die. In the second step, he/she uses this function to generate 1,000 of these sums.

1. Write the function for the first step.

```
sum3 = function(){  
  res = sum(sample(1:6, 3, replace = TRUE))  
  return(res)  
}
```

2. Write one line of code that uses the function from the first step to generate the 1,000 random sums.

```
replicate(1000, sum3())
```

References

Y. Zhang. STAT 302 Lecture Slides, 2023. URL https://zhangyk8.github.io/teaching/stat302_uw.