Week 5: Debugging & Testing in R

POP77001 Computer Programming for Social Scientists

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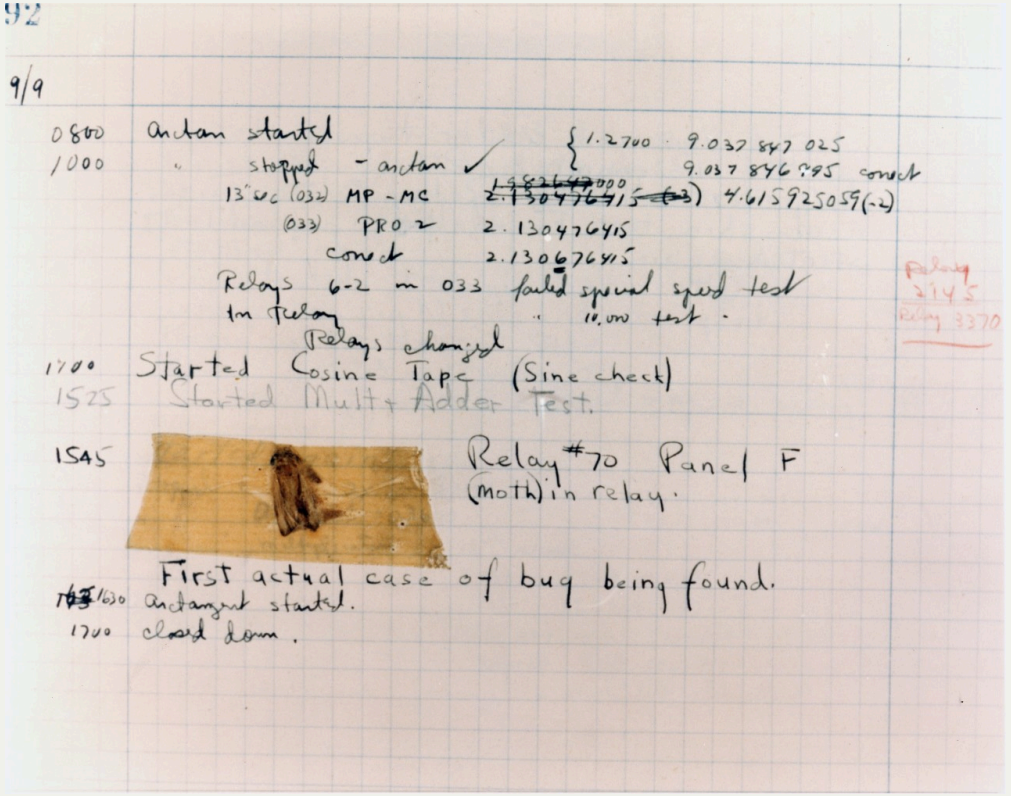
Overview

- Software bugs
- Debugging
- Handling conditions
- Testing
- Defensive programming

Bugs

Computer Bugs Before



US Naval History and Heritage Command

US Navy

Grace Murray Hopper popularised the term *bug* after in 1947 her team traced an error in the Mark II to a moth trapped in a relay.

Computer Bugs Today

```
convert_mark_to_grade <- function(mark) {
  if (mark >= 70) {
    grade <- "I"
  } else if (mark >= 60) {
    grade <- "II.1"
  } else if (mark >= 50) {
    grade <- "II.2"
  } else {
    grade <- "F"
  }
  grade
}
```

```
convert_mark_to_grade(146)
```

```
[1] "I"
```

```
convert_mark_to_grade(-3.7)
```

```
[1] "F"
```

Explicit Expectations

- Make explicit what kind of input your function expects.
- Conditional statements (or type conversion) at the beginning help check that.

```
convert_mark_to_grade <- function(mark) {
  stopifnot(is.numeric(mark))
  stopifnot(mark >= 0 & mark <= 100)
  if (mark >= 70) {
    grade <- "I"
  } else if (mark >= 60) {
    grade <- "II.1"
  } else if (mark >= 50) {
    grade <- "II.2"
  } else {
    grade <- "F"
  }
  grade
}
```

```
convert_mark_to_grade(146)
```

```
Error in convert_mark_to_grade(146): mark >= 0 & mark <= 100 is not TRUE
```

```
convert_mark_to_grade("55")
```

```
Error in convert_mark_to_grade("55"): is.numeric(mark) is not TRUE
```

Types of Bugs

- *Overt* vs *covert*
  - Overt bugs have obvious manifestation (e.g. premature program termination, crash)
  - Covert bugs manifest themselves in wrong (unexpected) results
- *Persistent* vs *intermittent*
  - Persistent bugs occur for every run of the program with the same input
  - Intermittent bugs occur occasionally even given the same input and other conditions

Debugging

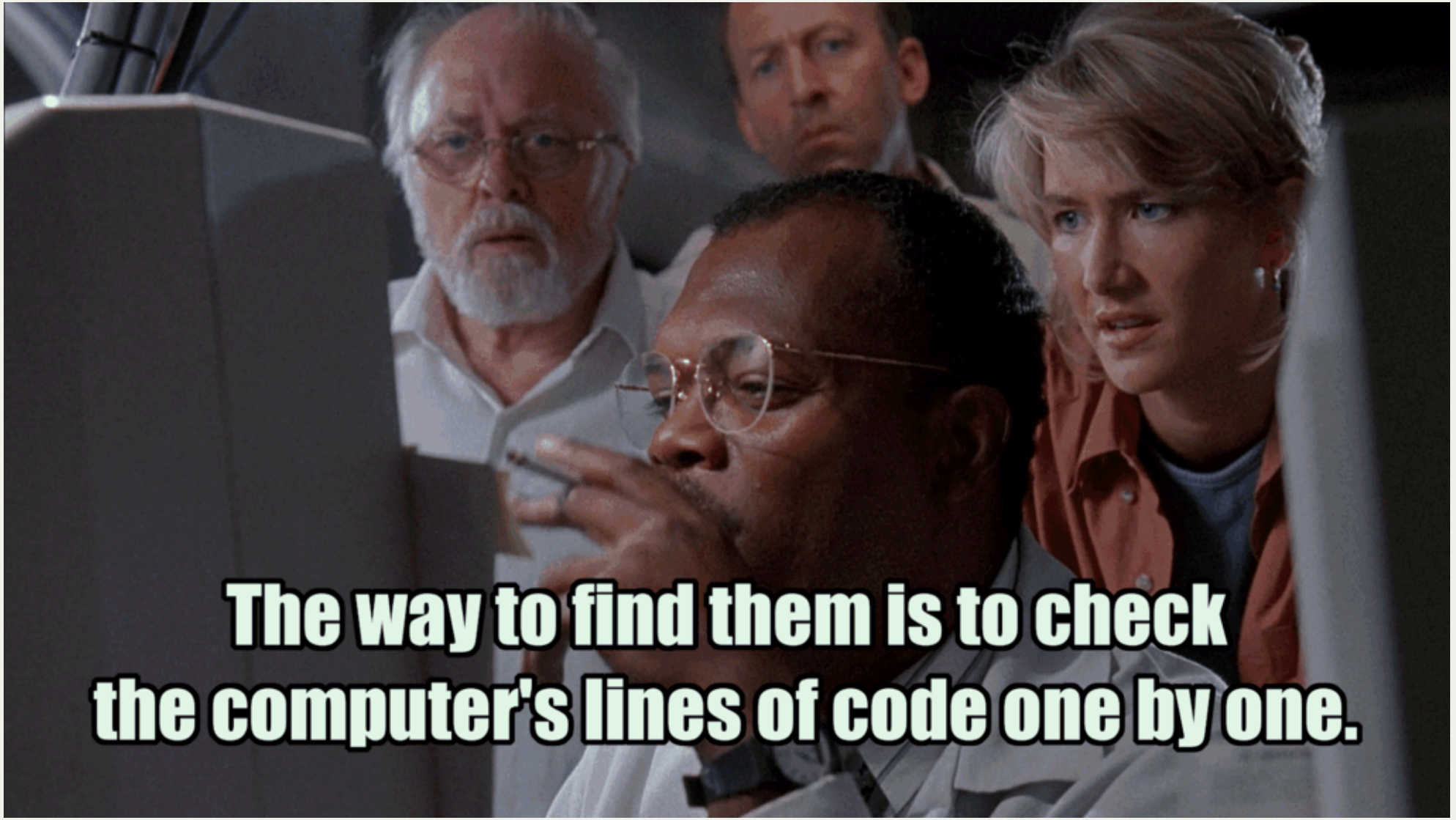
Debugging

> Fixing a buggy program is a process of confirming, one by one, that the many things you believe to be true about the code actually are true. When you find that one of your assumptions is not true, you have found a clue to the location (if not the exact nature) of a bug.
>
> Norman Matloff

> When you have eliminated all which is impossible, then whatever remains, however improbable, must be the truth.
>
> Arthur Conan Doyle

- Process of finding, isolating and fixing an existing problem in computer program.

Debugging Process



Debugging Process

1. Realise that you have a bug
    - Could be non-trivial for covert and intermittent bugs
2. Make it reproducible
    - Extremely important step that makes debugging easier
    - Isolate the smallest snippet of code that repeats the bug
    - Test with different inputs/objects
    - Will also be helpful if you are seeking outside help
    - Provides a case that can be used in automated testing
3. Figure out where it is
    - Formulate hypotheses, design experiments
    - Test hypotheses on a reproducible example
    - Keep track of the solutions that you have attempted
4. If it worked:
    - Fix the bug and test the use-case
5. Otherwise:
    - Sleep on it

Debugging with `print()`

- `print()` statement can be used to check the internal state of a program during evaluation.
- Can be placed in critical parts of code (before or after loops/function calls/objects loading).
- Can be combined with function `ls()` (and `get()`/`mget()`) to reveal all local objects.
- For harder cases switch to R debugging functions(`debug()`/`debugonce()`).

Bug: Example

```r
calculate_median <- function(a) {
  a <- sort(a)
  n <- length(a)
  m <- (n + 1) %/% 2
  if (n %% 2 == 1) {
    med <- a[m]
  } else {
    med <- mean(a[m:m+1])
  }
  return(med)
}
```

```r
v1 <- c(1, 2, 3)
v2 <- c(0, 1, 2, 2)
```

```r
calculate_median(v1)
```

```
[1] 2
```

```r
calculate_median(v2)
```

```
[1] 2
```

Debugging with `print()`: Example

```r
calculate_median <- function(a) {
  a <- sort(a)
  n <- length(a)
  m <- (n + 1) %/% 2
  print(m)
  if (n %% 2 == 1) {
    med <- a[m]
  } else {
    med <- mean(a[m:m+1])
  }
  return(med)
}
```

```r
# v1 <- c(1, 2, 3)
calculate_median(v1)
```

```
[1] 2
```

```
[1] 2
```

```r
# v2 <- c(0, 1, 2, 2)
calculate_median(v2)
```

```
[1] 2
```

```
[1] 2
```

Debugging with `print()` and `ls()`: Example

```
calculate_median <- function(a) {
  a <- sort(a)
  n <- length(a)
  m <- (n + 1) %/% 2
  # Print all objects in function environment
  print(mget(ls()))
  if (n %% 2 == 1) {
    med <- a[m]
  } else {
    med <- mean(a[m:m+1])
  }
  return(med)
}
```

```
calculate_median(v1)
```

```
$a
[1] 1 2 3

$m
[1] 2

$n
[1] 3

[1] 2
```

```
calculate_median(v2)
```

```
$a
[1] 0 1 2 2

$m
[1] 2

$n
[1] 4

[1] 2
```

Debugging with `print()`: Example

```r
calculate_median <- function(a) {
  a <- sort(a)
  n <- length(a)
  m <- (n + 1) %/% 2
  if (n %% 2 == 1) {
    med <- a[m]
  } else {
    print(m:m+1)
    med <- mean(a[m:m+1])
  }
  return(med)
}
```

```r
calculate_median(v1)
```

```
[1] 2
```

```r
calculate_median(v2)
```

```
[1] 3
```

```
[1] 2
```

Fixing a Bug and Confirming

```
calculate_median <- function(a) {
  a <- sort(a)
  n <- length(a)
  m <- (n + 1) %/% 2
  if (n %% 2 == 1) {
    med <- a[m]
  } else {
    med <- mean(a[m:(m+1)])
  }
  return(med)
}
```

```
calculate_median(v1)
```

```
[1] 2
```

```
calculate_median(v2)
```

```
[1] 1.5
```

R Debugging Facilities

- The core of R debugging process is stepping through the code as it gets executed.
- This permits the inspection of the environment where a problem occurs.
- Three functions provide the the main entries into the debugging mode:
  - `browser()` - pauses the execution at a dedicated line in code (breakpoint);
  - `debug()`/`undebug()` - (un)sets a flag to run function in a debug mode (setting through);
  - `debugonce()` - triggers single stepping through a function.

Breakpoints

```
calculate_median <- function(a) {
  a <- sort(a)
  n <- length(a)
  m <- (n + 1) %/% 2
  if (n %% 2 == 1) {
    med <- a[m]
  } else {
    browser()
    med <- mean(a[m:m+1])
  }
  return(med)
}
```

```
## Example for running in RStudio
calculate_median(v2)
```

```
Called from: calculate_median(v2)
debug: med <- mean(a[m:m + 1])
debug: return(med)
```

```
[1] 2
```

Debugger Commands

Command	Description
`n(ext)`	Execute next line of the current function
`s(tep)`	Execute next line, stepping inside the function (if present)
`c(ontinue)`	Continue execution, only stop when breakpoint in encountered
`f(inish)`	Finish execution of the current loop or function
`Q(uit)`	Quit from the debugger, executed program is aborted

Conditions

- Conditions are **events** that signal special situations during execution
- Some conditions can modify the control flow of a program (e.g. error)
- They can be *caught* and *handled* by your code
- You can also incorporate condition triggers into your code

Extra

Hadley Wickham - Conditions

Conditions: Example

```
1 42 + "ab" # Throws an error
```

```
Error in 42 + "ab": non-numeric argument to binary operator
```

```
1 as.numeric(c("42", "55.3", "ab", "7")) # Triggers a warning
```

```
Warning: NAs introduced by coercion
```

```
[1] 42.0 55.3   NA  7.0
```

```
1 library("dplyr") # Shows a message
```

```
Attaching package: 'dplyr'
The following object is masked from 'package:testthat':

    matches
The following objects are masked from 'package:stats':

    filter, lag
The following objects are masked from 'package:base':

    intersect, setdiff, setequal, union
```

Signalling Conditions

Rather than waiting for a condition to occur, we can signal it ourselves.

```
1 stop("Error message")
```

```
Error: Error message
```

```
1 warning("Warning message")
```

```
Warning: Warning message
```

```
1 message("Just message")
```

```
Just message
```

Errors

- In R errors are *signalled* (or *thrown*) with `stop()`
- By default, the error message includes the call.
- Program execution stops once an error is raised

```
1 if (c(TRUE, TRUE, FALSE)) {
2   print("This used to work pre R 4.2.0")
3 }
```

```
Error in if (c(TRUE, TRUE, FALSE)) {: the condition has length > 1
```

```
1 # Triggered a warning since R 4.2.0 to R 4.3.0
2 c(TRUE, FALSE) && c(TRUE, TRUE)
```

```
Error in c(TRUE, FALSE) && c(TRUE, TRUE): 'length = 2' in coercion to 'logical(1)'
```

```
1 log("x")
```

```
Error in log("x"): non-numeric argument to mathematical function
```

Warnings

- Weaker versions of errors:
  - Something went wrong, but the program has been able to recover and continue.
- Single call in result in multiple warnings (as opposed to a single error).
- Take note of the warnings resulting from base R operations.
- Some of them might eventually become errors.

```
1 as.numeric("x")
```

```
Warning: NAs introduced by coercion
```

```
[1] NA
```

Messages

- Messages serve mostly informational purposes.
- They tell the user:
  - that something was done
  - the details of how something was done.
- Sometimes these actions are not anticipated.
- Useful for functions with side-effects (accessing server, writing to disk, etc.)

```
1 anscombes_quartet <- readr::read_csv("../data/anscombes_quartet.csv")
```

```
Rows: 44 Columns: 3
── Column specification ────────────────────────────────────────────────────────
Delimiter: ","
chr (1): dataset
dbl (2): x, y

ℹ Use `spec()` to retrieve the full column specification for this data.
ℹ Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

Handling Conditions

- Every condition has default behaviour:
  - Errors terminate program execution
  - Warnings are captured and displayed in aggregate
  - Message are shown immediately
- But with **condition handlers** we can override the default behaviour.

Ignoring Conditions

- The simplest way of handling conditions is **ignoring** them.
- Heavy-handed approach, given the type of condition does not make further distinctions.
- Bear in mind the risks of ignoring the information (especially, errors!)
- Functions for handling conditions depend on the type of condition:
  - `try()` for errors
  - `suppressWarnings()` for warnings
  - `suppressMessages()` for messages

Ignoring Conditions: Example

```r
suppressMessages(
  anscombes_quartet <- readr::read_csv("../data/anscombes_quartet.csv")
)
```

```r
# But some functions would provide arguments to silence messages
# This should be preferred to heavy-handed suppressMessages()
anscombes_quartet <- readr::read_csv(
  "../data/anscombes_quartet.csv",
  show_col_types = FALSE
)
```

```r
# suppressPackageStartupMessages() - a variant for package startup messages
# But suppressMessages() would also work.
suppressPackageStartupMessages(library("dplyr"))
```

Ignoring Errors

```
f1 <- function(x) {
  log(x)
  10
}
```

```
f1("x")
```

```
Error in log(x): non-numeric argument to mathematical function
```

```
f2 <- function(x) {
  try(log(x))
  10
}
```

```
f2("x")
```

```
Error in log(x) : non-numeric argument to mathematical function
```

```
[1] 10
```

Condition Handlers

- More advanced approach to dealing with conditions is providing handlers.
- They allow to override or supplement the default behaviour.
- In particular, two function can:
  - `tryCatch()` define **exiting** handlers
- `withCallingHandlers()` define **calling** handlers

```
tryCatch(
  error = function(cnd) {
    # code to run when error is thrown
  },
  code_to_run_while_handlers_are_active
)
```

```
withCallingHandlers(
  warning = function(cnd) {
    # code to run when warning is signalled
  },
  message = function(cnd) {
    # code to run when message is signalled
  },
  code_to_run_while_handlers_are_active
)
```

Exiting Handlers

- The handlers set up by `tryCatch()` are called exiting handlers.
- After the condition is signalled, control flow passes to the handler.
- It never returns to the original code, effectively meaning that the code exits.

```
log("x")
```

```
Error in log("x"): non-numeric argument to mathematical function
```

```
f3 <- function(x) {
  tryCatch(
    error = function(cnd) NA,
    log(x)
  )
}
```

```
f3("x")
```

```
[1] NA
```

Calling Handlers

- With calling handlers code execution continues normally once the handler returns.
- A more natural pairing with the non-error conditions.

```
as.numeric("x")
```

```
[1] NA
```

```
f4 <- function(x) {
  withCallingHandlers(
    warning = function(cnd) {
      print("This is not a number. Please, try again.")
    },
    x <- as.numeric(x)
  )
}
```

```
f4("x")
```

```
[1] "This is not a number. Please, try again."
```

Expectations

- When designing a function you built in certain expectations about:
  - Acceptable inputs;
  - Conditions triggered;
  - Returned object.
  - Etc.
- Checking inputs at the beginning helps fail fast.

```
calculate_median <- function(a) {
  stopifnot(is.numeric(a))
  a <- sort(a)
  n <- length(a)
  m <- (n + 1) %/% 2
  if (n %% 2 == 1) {
    med <- a[m]
  } else {
    med <- mean(a[m:(m+1)])
  }
  return(med)
}
```

Checking Expectations

- What if we want to check whether our function's behaviour matches our expectations?
- One option would be to use `==` (or `!=`).
- However, for numerical values it can be problematic:

```
1 v3 <- c(7.22, 1.54, 3.47, 2.75)
```

```
1 calculate_median(v3)
```

```
[1] 3.11
```

```
1 calculate_median(v3) == 3.11
```

```
[1] FALSE
```

```
1 all.equal(calculate_median(v3), 3.11)
```

```
[1] TRUE
```

R Warned Us

```
1  ?`==`
```

Note

Do not use == and != for tests, such as in `if` expressions, where you must get a single TRUE or FALSE. Unless you are absolutely sure that nothing unusual can happen, you should use the `identical` function instead.

For numerical and complex values, remember == and != do not allow for the finite representation of fractions, nor for rounding error. Using `all.equal` with `identical` or `isTRUE` is almost always preferable; see the examples. (This also applies to the other comparison operators.)

These operators are sometimes called as functions as e.g. `` `<`(x, y) ``: see the description of how argument-matching is done in `Ops`.

Making Comparisons

- A better way to compare values where a single `TRUE` or `FALSE` is expected is to use special functions:
  - `all.equal()` - approximately equal
  - `identical()` - exactly identical (incl. type)
  - `isTRUE()` - whether value is `TRUE`
  - `isFALSE()` - whether value is `FALSE`

```
all.equal(length(calculate_median(v3)), 1)
```

```
[1] TRUE
```

```
# Note that the output of length is of type integer
identical(length(calculate_median(v3)), 1)
```

```
[1] FALSE
```

```
identical(length(calculate_median(v3)), 1L)
```

```
[1] TRUE
```

Formalising Expectations Checks: Testing

- Process of running a program on pre-determined cases to ascertain that its functionality is consistent with expectations
- Test cases consist of different assertions (of equality, boolean values, etc.)
- Fully-featured unit testing framework in R is provided in `testthat` library

> **Extra**
>
> Hadley Wickham - Testing

Testing: Example

```
library("testthat")
```

```
calculate_median <- function(a) {
  stopifnot(is.numeric(a))
  a <- sort(a)
  n <- length(a)
  m <- (n + 1) %/% 2
  if (n %% 2 == 1) {
    med <- a[m]
  } else {
    med <- mean(a[m:(m+1)])
  }
  return(med)
}
```

Testing: Example

```
testthat::test_that("The length of result is 1", {
  testthat::expect_equal(
    length(calculate_median(c(0, 1, 2, 2))),
    1L
  )
  testthat::expect_equal(
    length(calculate_median(c(1, 2, 3))),
    1L
  )
  testthat::expect_equal(
    length(calculate_median(c(7.22, 1.54, 3.47, 2.75))),
    1L
  )
})
```

```
Test passed 🎊
```

Testing: Example

```
testthat::test_that("Error on non-numeric input", {
  testthat::expect_error(
    calculate_median(c("a", "bc", "xyz"))
  )
  testthat::expect_error(
    calculate_median(c(TRUE, FALSE, FALSE))
  )
  testthat::expect_error(
    calculate_median(c("0", "1", "2", "2"))
  )
})
```

```
Test passed 🥳
```

Testing: Example

```r
testthat::test_that("The result is numeric", {
  testthat::expect_true(
    is.numeric(calculate_median(c(0, 1, 1, 2)))
  )
  testthat::expect_true(
    is.numeric(calculate_median(c(1, 2, 3)))
  )
  testthat::expect_true(
    is.numeric(calculate_median(c("a", "bc", "xyz")))
  )
})
```

```
── Error: The result is numeric
──────────────────────────────────────────────────────────
Error in `calculate_median(c("a", "bc", "xyz"))`: is.numeric(a) is not TRUE
Backtrace:
    ▆
 1. ├─testthat::expect_true(...)
 2. │ └─testthat::quasi_label(enquo(object), label, arg = "object") at
testthat/R/expect-constant.R:33:3
 3. │   └─rlang::eval_bare(expr, quo_get_env(quo)) at testthat/R/quasi-
label.R:45:3
```

```
 4. └─global calculate_median(c("a", "bc", "xyz")) at rlang/R/eval.R:96:3
 5.   └─base::stopifnot(is.numeric(a))

Error:
! Test failed
```

Defensive Programming

- Design your program to facilitate earlier failures, testing and debugging.
- Make code fail fast and in well-defined manner.
- Split up different componenets into functions or modules.
- Be strict about accepted inputs, use assertions or conditional statements to check them.
- Document assumptions and acceptable inputs using docstrings.
- Document non-trivial, potentially problematic and complex parts of code.

> All of old. Nothing else ever. Ever tried. Ever failed. No matter. Try again. Fail again. Fail better.
>
> Samuel Beckett

Next

- Tutorial: Using Debugger and Testing
- Next week: Data Wrangling in R