

Big Data and Economics

The Empirical Workflow and Clean Code

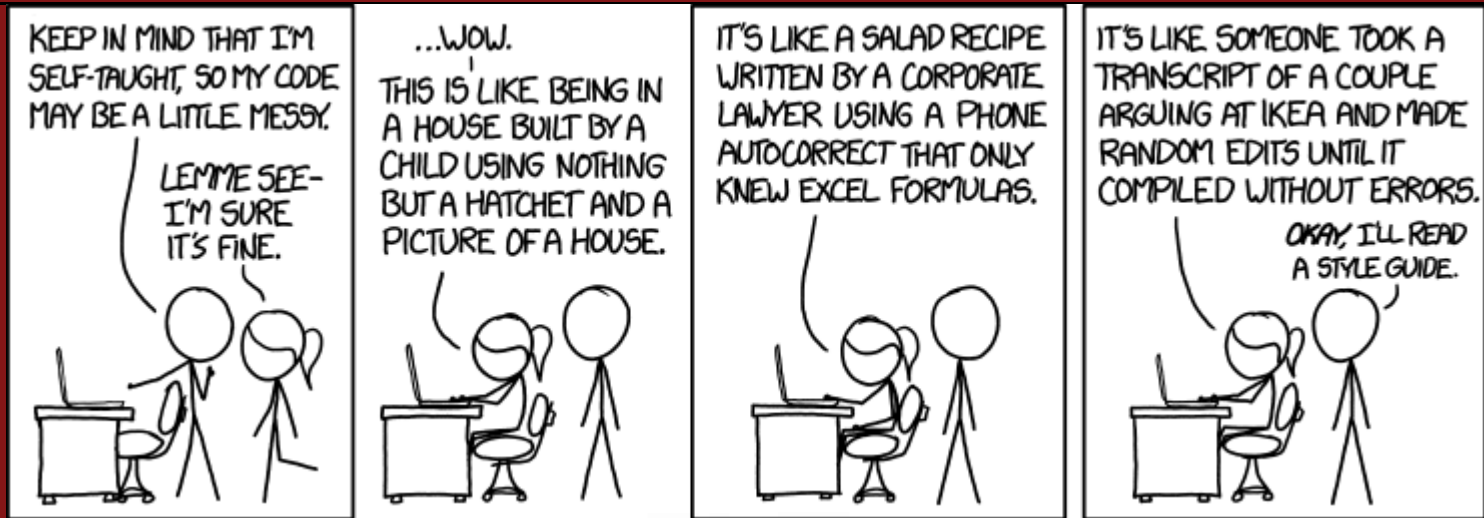
Kyle Coombs (adapted from Tyler Ransom + Scott Cunningham)

Bates College | [EC/DCS 368](#)

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Prologue



Source: [xkcd](#)

Forgot to mention

- **Office Hours:**
 - My office hours are 9am-10am on Tuesdays and 3pm-4pm on Wednesdays
 - My office is 276 Pettengill
 - I'm also available by [appointment](#) on Zoom
- **Problem Set 0:** due on Sunday, September 17th at 11:59pm
- **Presentations:** Everyone does two, sign-up in the [Presentations github repository](#)
- **Problem Set 0:** due on Sunday, September 17th at 11:59pm
- **Problem Set 1:** due on Sunday, September 24th at 11:59pm
- **Project Proposal:** due on Sunday, September 24th at 11:59pm

Play along at home

- Sync your forks of the class repository
- Pull the latest changes from the class repository to your computer
- Open `lectures/02-empirical-workflow.Rmd` and you can follow along with the slides
 - Specifically, you can run the code live while I walk through it on the slides

Attribution

- Today's material comes from these sources:
 1. [Clean Code](#) by Tyler Ransom
 2. *[Code and Data for the Social Sciences: A Practitioner's Guide](#)*, by Gentzkow and Shapiro
 3. [Causal Inference and Research Design](#) by Scott Cunningham
 4. [Jenny Bryan's UseR 2018 keynote address](#)

Also a small contribution from [here](#) and other sundry internet pages

Jargon

- There is a jargon in this class that won't make sense at first, I'll try to flag it as it comes
 - If I don't flag a term, look it up on ChatGPT
 - If it still doesn't make sense, ask me -- could be I'm using it idiosyncratically
- Here's a few terms:
 - **Local machine:** Your personal (or any) computer that isn't a server accessed via the internet
 - **Version Control:** Keep track of different iterations of a project/code
 - **Repository:** The location on GitHub of all project files and (commented) file revision history
 - **GUI:** A Graphical User Interface -- what you're used to pointing and clicking to navigate a computer and execute programs
 - **Command line:** Removes the "graphical" from GUI, instead you type all commands to navigate a computer and execute programs
 - R operates via the Command line, RStudio is a GUI
 - On Mac, this is called Terminal
 - Windows has Powershell, but it Powershell uses quite user-unfriendly commands
 - If you installed Git for Windows, you got *Git Bash*, which uses Bash (Linux) commands
 - You can also install Windows Subsystem for Linux to run Linux on a Windows machine

Clean Code

Reducing empirical chaos

Sad story

- Once upon a time there was a boy who was writing a job market paper on unemployment insurance during the pandemic
- This boy presented the findings a half dozen times, spoke to the media some, and generally thought he had cool results
- Several people suggested he look at a handful of other outcome series and try changing his analysis unit frequency from monthly to weekly
- He also knew that he needed to restrict his sample to reduce noise

The horror!

- But then after making these changes and re-running his code that took two days, his new sample dropped by 50 percent!
- He was, understandably, terrified.
- The young boy spent a week looking for the fix weeding through six different versions of the .do, .R, .dta, .csv, .sh, .py files with suffixes like *_v1* and *_test* and *_test2* and *_final_I_swear* and *_okay_i_lied*
- Finally he discovered the phrase:

```
df %>% filter(insample_new==0)
```

instead of

```
df %>% filter(insample_new==1)
```

- The boy was very frustrated and decided to work on these slides while re-running his code.

What is Clean Code?

- **Clean Code:** Code that is easy to understand, easy to modify, and hence easy to debug
- Clean code saves you and your collaborators time

Why clean code matters: Scientific

- Good science is based on careful observations
 - Science progresses through iteratively testing hypotheses and making predictions
 - Scientific progress is impeded if
 - mistaken previous results are erroneously given authority
 - previous hypothesis tests are not reproducible
 - previous methods and results are not transparent
 - Thus, for science that involves computer code, clean code is a must
 - "Minimizes (incomplete'y) the role of the influence of hidden researcher decisions" (Huntington-Klein et al. 2021)
-

- You will always make a mistake while coding

What is the value of directories?

- All of the files in a directory are related to each other
- Can reference a file within the `data/raw` folder, from the `code/build` folder without writing out the full path `C:/Users/kylec/Documents/my_project/data/raw/my_data.csv`
 - `..` means "go up one directory", then down into `data/raw`
- Can save objects of strings of path directories to use later using the `paste()` function

```
my_project <- 'my_project'
data <- paste(my_project, 'data', sep='/')
data_raw <- paste(data, 'raw', sep='/')
data_clean <- paste(data, 'clean', sep='/')
data_temp <- paste(data, 'temp', sep='/')
code <- paste(my_project, 'code', sep='/')
code_analysis <- paste(code, 'analysis', sep='/')
code_build <- paste(code, 'build', sep='/')

print(paste(data_raw, 'my_data.csv', sep='/'))
```

```
## [1] "my_project/data/raw/my_data.csv"
```

```
read.csv(paste(data_raw, 'my_data.csv', sep='/'))
```

```
##   this is my data
## 1    1    1    1    1
## 2    2    2    2    2
```

- This is a good way to make sure that your code is portable
- If you move your project to a different computer, you can just change the `my_project` variable and all the other paths will update automatically

Alternative to all the pastes is here()

- Better yet is the [here](#)
 - `here()` will find the root directory of your project and then you can navigate from there

```
#install.packages('here')  
library(here)
```

```
## here() starts at C:/Users/kgcsp/OneDrive/Documents/Education/Big Data/big-data-class-materials
```

```
here::i_am('my_project/code/build/.placeholder')
```

```
## here() starts at C:/Users/kgcsp/OneDrive/Documents/Education/Big Data/big-data-class-materials/lectures/02-empirical-workflow
```

```
here('data/raw', 'my_data.csv')
```

```
## [1] "C:/Users/kgcsp/OneDrive/Documents/Education/Big Data/big-data-class-materials/lectures/02-empirical-workflow/data/raw/my_data.csv"
```

- Can be less clunky than `paste()` and `sep='/'`

How to write scripts

Keep them modular

- Each script should do one thing and one thing only
- e.g. It takes an input in, it returns an output
 - Taking in a raw file and returning a cleaned version
 - Taking in two files and merging them
 - Taking in a cleaned file and returning a figure

Have a main script that runs all scripts in order

- This is the script that you run to reproduce your results
- You will rarely run it all at once, but it will be a nice way to organize your thoughts
- This is a further benefit of a well-organized directory -- you can easily see what scripts you need to run in what order
- Use `source('rscript.R')` to run an external script

Main script

```
#File: main.R
#By: Kyle Coombs
#What: Runs the project from start to finish in Python
#Date: 2023/09/12

#Install packages with housekeeping. Also put together paths.
source('housekeeping.R')
#User written functions can be sourced -- or you could write a package, your call
source(paste0(build,'clean_functions.R'))
source(paste0(analysis,'analysis_functions.R'))

#Import files
df1 <- read_csv(paste0(raw,'file1.csv'))
df2 <- read_parquet(paste0(raw,'file2.parquet'))
df3 <- read_dta(paste0(raw,'file3.dta'))

#Clean files
cleaned_df1 <- clean_df1(df1)
cleaned_df2 <- clean_df2(df2)
cleaned_df3 <- cf.clean_df3(df3)

#Merge files 1 to 2
merged_df1_df2 = merge(cleaned_df1, cleaned_df2, on=c('merge','vars'))

#Append file 1 to
append_df1_df2_df3 = rbind(merged_df1_df2, cleaned_df2)

#Analysis
sum_stats=summary_stats(append_df1_df2_df3,stats=c('mean','median','max'))
reg_results=basic_regression(append_df1_df2_df3)

#Tables will likely be made with a host of R packages
make_sum_figures(sum_stats)
make_figures(reg_results)
make_sum_tables(sum_stats)
make_tables(reg_results)
```


Alternate main script

```
#File: main.R
#By: Kyle Coombs
#What: Runs the project from start to finish in Python
#Date: 2023/09/12

#Install packages with housekeeping. Also put together paths.
source('housekeeping.R')
#User written functions can be sourced -- or you could write a package, your call
source(paste0(build,'clean_functions.R'))
source(paste0(analysis,'analysis_functions.R'))

#Import files
source(paste0(build,'import_census.R'))
source(paste0(build,'import_admin_data.R'))

#Clean files
source(paste0(build,'clean_census.R'))
source(paste0(build,'clean_admin_data.R'))

#Merge files 1 to 2
source(paste0(build,'merge_census_admin.R'))

#Analysis
source('analysis/summary_stats.R')
source('analysis/basic_regression.R')

#Tables will likely be made with a host of R packages
source('analysis/make_sum_figures.R')
source('analysis/make_reg_figures.R')
source('analysis/make_sum_tables.R')
source('analysis/make_reg_tables.R')
```

Data organization

- The key idea is to practice **relational data base management**
- A relational database consists of many smaller data sets
- Each data set is tabular and has a unique, non-missing key
- Data sets "relate" to each other based on these keys
- You can implement these practices in any modern statistical analysis software (R, Stata, SAS, Python, Julia, SQL, ...)
- Gentzkow & Shapiro recommend not merging data sets until as far into your code pipeline as possible

What problems would this create?

county	state	cnty_pop	state_pop	region
36037	NY	3817735	43320903	1
36038	NY	422999	43320903	1
36039	NY	324920	.	1
36040	.	143432	43320903	1
.	NY	.	43320903	1
37001	VA	3228290	7173000	3
37002	VA	449499	7173000	3
37003	VA	383888	7173000	4
37004	VA	483829	7173000	3

Source: [Code and Data for the Social Sciences](#) (p. 19)

What's RDBM look like?

county	state	population			
36037	NY	3817735			
36038	NY	422999			
36039	NY	324920	state	population	region
36040	NY	143432	NY	43320903	1
37001	VA	3228290	VA	7173000	3
37002	VA	449499			
37003	VA	383888			
37004	VA	483829			

Source: [Code and Data for the Social Sciences](#) (p. 19)

Abstraction

- What is abstraction? It means "reducing the complexity of something by hiding unnecessary details from the user"
- e.g. A dishwasher. All I need to know is how to put dirty dishes into the machine, and which button to press. I don't need to understand how the electrical wiring or plumbing work.
- In programming, abstraction is usually handled with functions
- Abstraction is usually a good thing
- But it can be taken to a harmful extreme: overly abstract code can be "impenetrable" which makes it difficult to modify or debug

Rules for Abstraction

- Gentzkow & Shapiro give three rules for abstraction:
 1. Abstract to eliminate redundancy
 2. Abstract to improve clarity
 3. Otherwise, don't abstract

Abstract to eliminate redundancy

- Sometimes you might find yourself repeating lines of code with small modifications across the lines:

```
names ← c('one','two','three','four','five','one','two','three','four','five','one','two','three','four','five')

#Better
names_short ← c('one','two','three','four','five')
names_long ← c(names_short,names_short,names_short)

#Even better
name_repeater ← function(count,names_short=c('one','two','three','four','five')) {
  names_long ← rep(names_short, times = count)
  return(names_long)
}

print(names)
```

```
## [1] "one" "two" "three" "four" "five" "one" "two" "three" "four"
## [10] "five" "one" "two" "three" "four" "five"
```

```
print(names_long)
```

```
## [1] "one" "two" "three" "four" "five" "one" "two" "three" "four"
## [10] "five" "one" "two" "three" "four" "five"
```

```
print(name_repeater(3,names_short=names_short))
```

```
## [1] "one" "two" "three" "four" "five" "one" "two" "three" "four"
## [10] "five" "one" "two" "three" "four" "five"
```

- Now if I need to make further changes to `name_repeater` I can do it once!

Otherwise, don't abstract

- One could argue that the examples on the previous two slides are overly abstract
- OLS is a simple operation that only takes one line of code
- If we're only doing it once in our script, then it may not make sense to use the function version
- Similarly, it may not make sense to use the `name_repeater` function if I only need to use it to repeat five names three times
- This discussion points out that it can be difficult to know if one has reached the optimal level of abstraction
- As you're starting out programming, I would advise doing almost every inside of a function (i.e. err on the side of over-abstraction when starting out)

Documentation

1. Don't write documentation you will not maintain
2. Code should be self-documenting
 - Generally speaking, commented code is helpful
 - However, sometimes it can be harmful if, e.g. code comments contain dynamic information
 - It may not be helpful to have to rewrite comments every time you change the code
 - Code can be "self-documenting" by leveraging abstraction: function arguments make it easier to understand what is a variable and what is a constant

Documentation in R

- R has excellent built-in documentation called `Roxygen2`
- These make great documents above functions to increase readability
- Here's an example:

```
#' This is a sample function  
#'  
#' This function does something amazing.  
#'  
#' @param x A numeric input.  
#' @return The result of the amazing operation.  
#' @examples  
#' amazing_function(5)  
amazing_function ← function(x) {  
  # function implementation  
}
```

Other documentation in R

- **R Help System:** access using `?function_name`
- **Package vignettes:** access using `vignette("vignette_name")`
- **Cheatsheets:** access at [Posit Cheatsheets](#)

Time management

- Time management is key to writing clean code
- It is foolish to think that one can write clean code in a strained mental state
- Code written when you are groggy, overly anxious, or distracted will come back to bite you
- Schedule long blocks of time (1.5 hours - 3 hours) to work on coding where you eliminate distractions (email, social media, etc.)
- Stop coding when you feel that your focus or energy is dissipating

Task management

- When collaborating on code, it is essential to not use email or Slack threads to discuss coding tasks
- Rather, use a task management system that has dedicated messages for a particular point of discussion (bug in the code, feature to develop, etc.)
- I use GitHub issues for all of my coding projects
- For my personal task management, I use Trello to take all tasks out of my email inbox and put them in Trello's task management system
- GitHub and Trello also have Kanban-style boards where you can easily visually track progress on tasks

Workflow workflow workflow

The Cunningham Empirical Workflow Conjecture

- The cause of most of your errors is **not** due to insufficient knowledge of syntax in your chosen programming language
- The cause of most of your errors is due to a poorly designed **Empirical Workflow**

Empirical Workflow

- A workflow is a fixed set of routines you bind yourself to which when followed identifies the most common errors
 - Think of it as your morning routine: alarm goes off, go to wash up, make your coffee/tea, put pop tart in toaster, contemplate your existence in the universe until **ding**, eat pop tart repeat *ad infinitum*
- Finding the outlier errors is a different task; empirical workflows catch typical and common errors created by the modal data generating processes
- Empirical workflows follow a checklist

Why do we use checklists?

- I got engaged in July and am planning a wedding in Princeton for next July
- I also moved to New England in August and am still unpacking (in ME and MA)
- I am teaching two upper-level electives
- I am trying to submit several papers to conferences/journals this year
- Each of these gets a checklist:

- **Wedding:**

- ☐ Finalize tent configuration
- ☐ Pick wedding colors

- **Unpacking:**

- ☐ Put books on shelves
- ☐ Buy dresser

- **Job Market Paper**

- ☐ Complete two-period model of UI
- ☐ Discussion of intertemporal crowd-in

- **Big Data:**

- ☐ Prep GitHub demo
- ☐ Create presentations repo

- **Public Economics:**

- ☐ Update solutions for PS1
- ☐ Amend 2nd Welfare Theorem slides

etc.

To remember the obvious stuff you keep

- When I stop to think, I know I need to do everything on my checklists
- But then I forget when I move onto the next task
- Programming is the same, except you have an **empirical checklist**:
- The **empirical checklist**:
 - Covers the intermediate step between "getting the data" and "analyzing the data"
 - It largely focuses on ensuring data quality for the most common, easy to identify problems
 - It'll make you a better coauthor

Simple data checks

- Simple, yet non-negotiable, programming commands and exercises to check for data errors

Look at the data

- "Real eyes realize real lies" --Troy Ave via some dude from my high school
- This is a messy dataset of blood pressure adapted from [work](#) by Peter Higgins

```
bp <- read.csv('data/messier_bp.csv')
bp
```

```
##      STOP.Blood.Pressure.Study      X2      X3      X4      X5
## 1                <NA>      <NA>      <NA>      <NA>      <NA>
## 2                pat_id Month of birth Day birth Year birth      Race
## 3                  1         11      30      1967      White
## ...
```

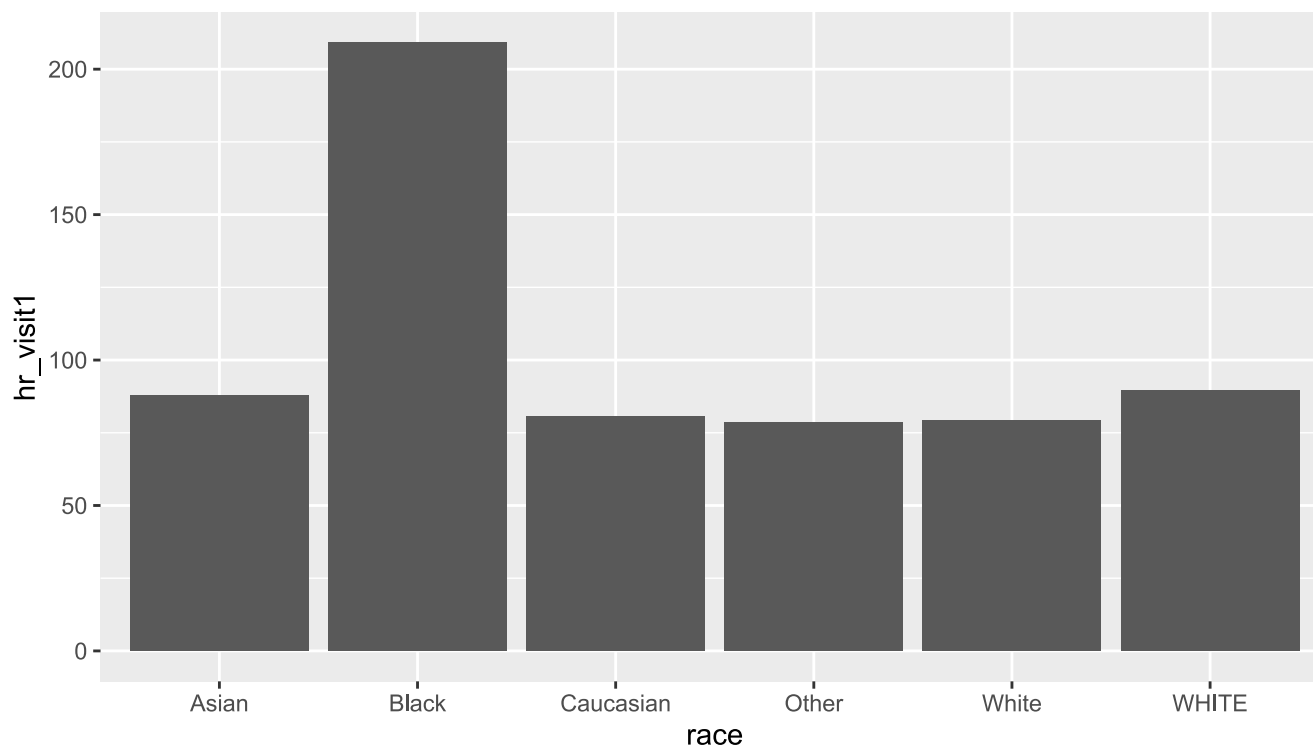
Check factor variables

```
table(bp$race, bp$sex)
```

```
##
##      F Female M Male
## Asian    0     1  0    1
## Black    1     2  1    3
## Caucasian 0     3  0    1
## Other    0     1  0    1
## White    0     2  0    2
```

Before you summarize the data...

```
bp <- read_csv('data/messier_bp.csv', skip=4,  
  col_names=c('pat_id', 'birth_month', 'birth_day', 'birth_year', 'race', 'sex', 'hispanic', 'bp_visit1', 'hr_visit1', 'bp_visit2', 'hr_visit2'))  
ggplot(data=bp, aes(y=hr_visit1, x=race)) + geom_bar(stat='summary', fun='mean')
```



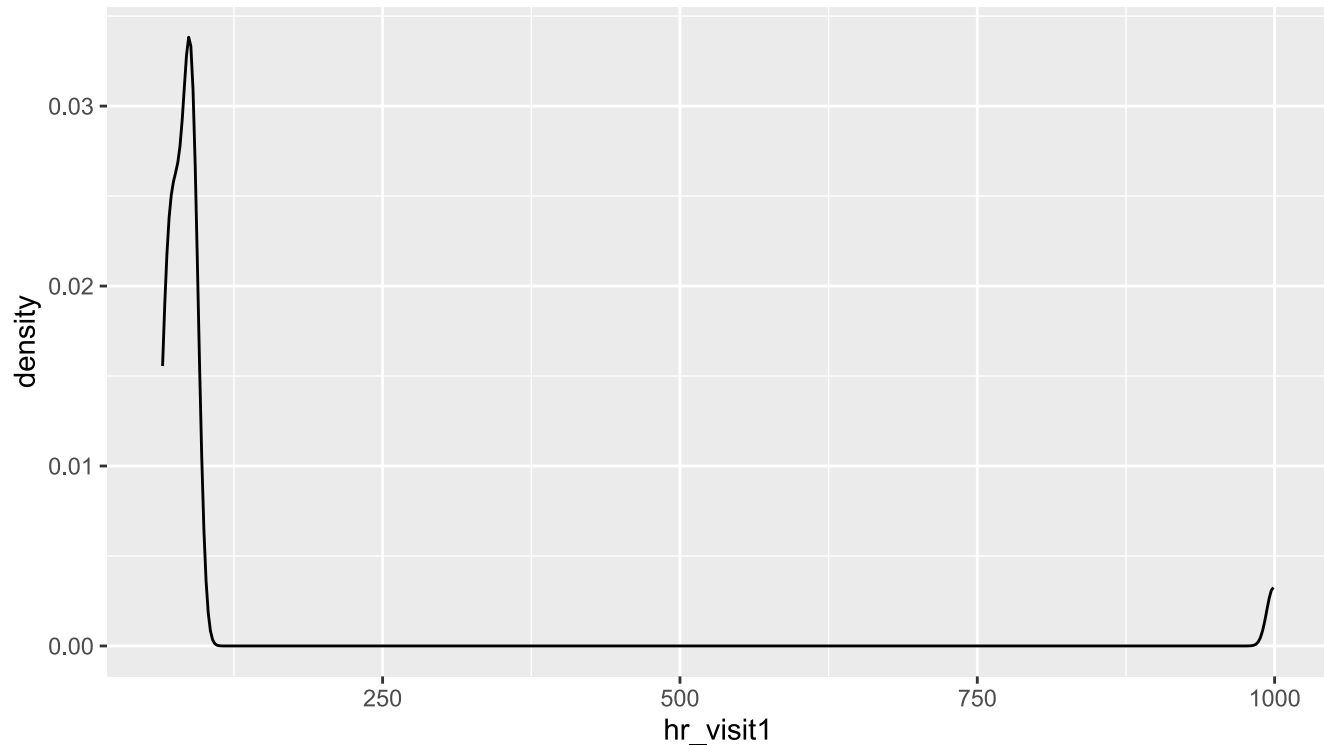
- Are Black people's heart rates really twice as high?

Visualize the raw data

- Go beyond the eyeball and graph the data

```
# Get the first three rows of the data frame (or as many rows as needed)

#Make a density of the heart rate on visit 1:
ggplot(data=bp,aes(x=hr_visit1))+geom_density()
```



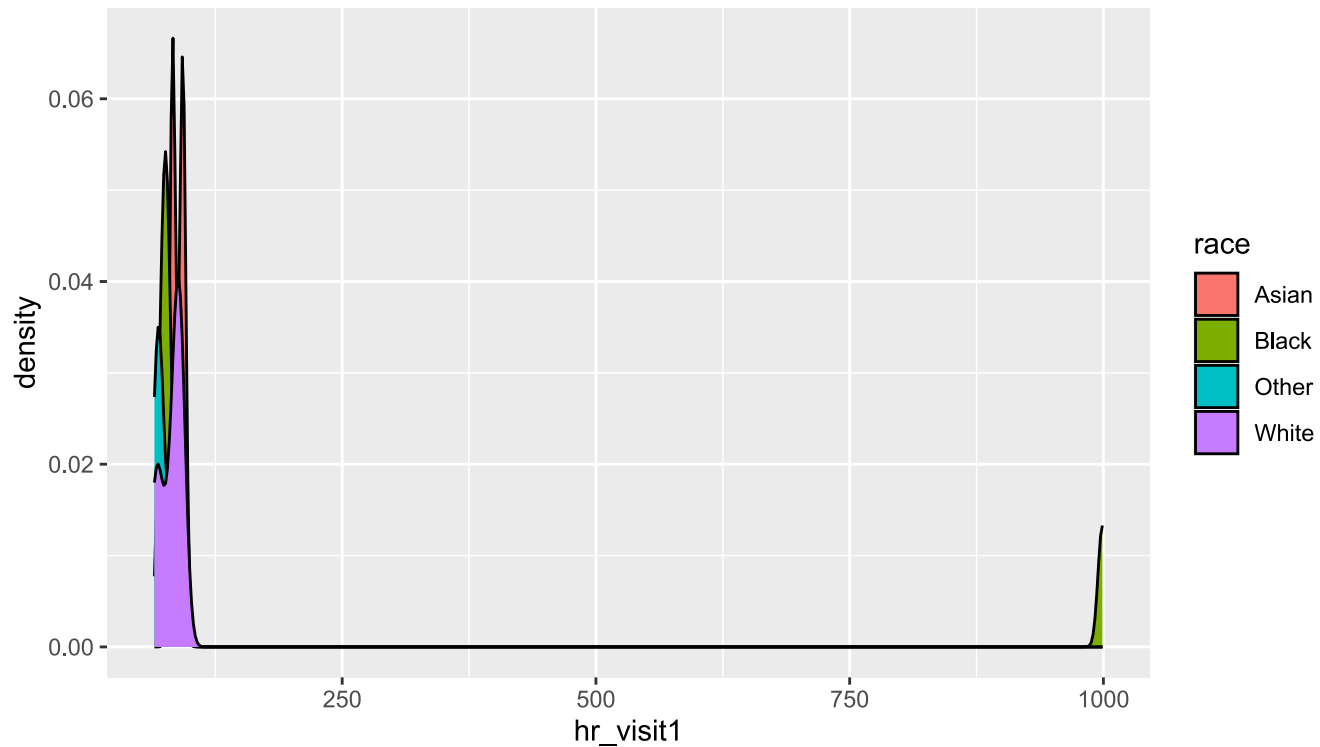
What might be going on here?

Visualize by group

```
# Get the first three rows of the data frame (or as many rows as needed)
```

```
#Make a density of the heart rate on visit 1:
```

```
ggplot(data=bp %>% mutate(race=ifelse(race=='WHITE' | race=='Caucasian','White',race)),aes(x=hr_visit1,fill=race))+geom_density()
```



- Oh! I bet 999 means NA and a few Black patients have missing heart rates

Other tricks:

- Check if the data are the right-size
- If you have a panel dataset is 50 states over 20 years, check if there are 1000 observations
- If not, find out why! Maybe there are 1020 because DC is (rightfully) included
- Search for outliers or oddities and work out possible explanations using:
 - Codebooks
 - Intuition
 - Emails to the source/creator of data

Test-driven dev (unit testing, refactoring,

- The only way to know that your code works is to test it!
- Test-driven development (TDD) consists of a suite of tools for writing code that can be automatically tested
- **Unit testing** is nearly universally used in professional software development
- Unit testing is to software developers what washing hands is to surgeons

Unit testing

- Unit tests are scripts that check that a piece of code does everything it is supposed to do
- When professionals write code, they also write unit tests for that code at the same time
- If code doesn't pass tests, then bugs are caught on the front end
- Test coverage determines how much of the code base is tested. High coverage rates are a must for unit testing to be useful.
- R's [dplyr package](#) shows that all unit tests are passing and that tests cover 88% of the code base
- [testthat](#) is a nice step-by-step guide for doing this in R

Assertions

- Assert statements are extremely useful
- They exist in every language
- In R it is called stopifnot()

```
x ← TRUE  
stopifnot(x)  
  
y ← FALSE  
stopifnot(y)
```

```
## Error: y is not TRUE
```

Minimal reproducible example (MRE)

- Sometimes you've made several changes to your code and suddenly it stops running
 - Was it the new `if` statement?
 - That sick new vectorized function to replace the `for` loop?
 - A stray typo?
- There's likely a ton of superfluous stuff in your code that is not relevant to the error
- **Minimal reproducible examples** (reprex), a concept from Stack Overflow, are a great way to isolate the error
 - Minimal: Use as little code as possible that still produces the same problem
 - Complete: Provide all parts someone else needs to reproduce your problem in the question itself
 - Reproducible: Test the code you're about to provide to make sure it reproduces the problem
- That means you should be able to copy and paste the code into R and run it yourself
 - Name all packages and data needed to reproduce error
 - Cut out irrelevant packages and data that are not relevant to the error
- Sometimes writing one will help you find the bug, sometimes it'll help a stranger find the bug in your code faster, and sometimes it'll identify a very real bug in the package itself

Min Reprex

Example taken from [RStudio community](#)

```
library(ggplot2)

df <- data('iris') %>%
  mutate(Sepal.Length = Sepal.Length * 1000,
         Sepal.Width = Sepal.Width * 1000)
```

```
## Error in UseMethod("mutate"): no applicable method for 'mutate' applied to an object of class "character"
```

```
ggplot(data = df, x = Sepal.Length, y = Sepal.Width) +
  geom_point() +
  scale_x_log10() +
  theme_minimal() +
  labs(title = "Iris Sepal Width vs. Sepal Length",
       subtitle = "Log10 Scaled X Axis")
```

```
## Error in `ggplot()`:
## ! `data` cannot be a function.
## i Have you misspelled the `data` argument in `ggplot()`
```

```
library(ggplot2)

df <- data.frame(stringsAsFactors = FALSE,
                 Sepal.Length = c(5.1, 4.9, 4.7, 4.6, 5),
                 Sepal.Width = c(3.5, 3, 3.2, 3.1, 3.6)
)
ggplot(data = df, x = Sepal.Length, y = Sepal.Width) +
  geom_point()
```

```
## Error in `geom_point()`:
## ! Problem while setting up geom.
## i Error occurred in the 1st layer.
## Caused by error in `compute_geom_1()`:

```

Refactoring

- Refactoring refers to the action of restructuring code without changing its external behavior or functionality. Think of it as "reorganizing"
- Example:

```
get_some_data ← function(config, outfile) {  
  if (config_ok(config)) {  
    if (can_write(outfile)) {  
      if (can_open_network_connection(config)) {  
        data ← parse_something_from_network()  
        if(makes_sense(data)) {  
          data ← beautify(data)  
          write_it(data, outfile)  
        }  
      }  
    }  
  }  
}
```

after refactoring becomes

```
get_some_data ← function(config, outfile) {  
  if (config_bad(config)) {  
    stop("Bad config")  
  }  
  
  if (!can_write(outfile)) {  
    stop("Can't write outfile")  
  }  
}
```

- Nothing changed in the code except the number of characters in the function
- The new version may run faster, is more readable. The output is unchanged.
- Refactoring could also mean reducing the number of input arguments

Profiling

- Profiling refers to checking the resource demands of your code
- How much processing time does your script take? How much memory?
- Clean code should be highly performant: it uses minimal computational resources
- Profiling and refactoring go hand in hand, along with unit testing, to ensure that code is maximally optimized
- [Here](#) is an intro guide to profiling in Julia using the `@time` macro

Pair programming

- An essential part of clean code is reviewing code
- An excellent way to review code is to do so at the time of writing
- **Pair programming** involves sitting two programmers at one computer
- One programmer does the writing while the other reviews
- This is a great way to spot silly typos and other issues that would extend development time
- It's also a great way to quickly refactor code at the start
- **I strongly encourage you to do pair programming on problem sets in this course!**
 - (Sometimes I will require it)

Appendix

Textbooks: Smarter people than me

- Cunningham (2021) [Causal Inference: The Mixtape](#) (Also, [free version on his website](#))
- Huntington-Klein (2022) [The Effect](#)
- Angrist and Pischke (2009) [Mostly Harmless Econometrics](#) (MHE)
- Morgan and Winship (2014) [Counterfactuals and Causal Inference](#) (MW)
- Sweigart (2019) [Automate The Boring Stuff With Python](#)
- The help documentation associated with your language (no really)
- Jesse Shapiro's "How to Present an Applied Micro Paper"
- Gentzkow and Shapiro's coding practices manual
- Lubica "LJ" Fistovska's language agnostic guide to programming for economists
- Grant McDermott on Version Control using Github [Link](#)
- The help documentation associated with your language (no really)
- All languages: [Stack Overflow](#), [Stack Exchange](#)
- Stata-specific (all hail Nick Cox): [Statalist](#)
- Cheatsheets: [Stata](#), [FStata](#), [Python](#)
- Me: [Sign up for office hours](#)
- Just like learning a real language, no amount of talking today will teach you how to use any program.
 - You have to need to use it (immersion) to learn it.
 - Google is your dictionary.

More complicated example of

```
set.seed(16)
prod1 = rnorm(1, 0, 1)*rnorm(1,4,6)
prod2 = rnorm(2, 0, 1)*rnorm(2,4,6)
prod3 = rnorm(3, 0, 1)*rnorm(3,4,6)
print(prod1)
```

```
## [1] 1.547257
```

```
print(prod2)
```

```
## [1] 11.934479 -1.717951
```

```
print(prod3)
```

```
## [1] -7.4831177  0.9587218  4.7882622
```

```
set.seed(16)
multiply = function(count,mean1=0,sd1=1,mean2=4,sd2=6) {
  prod = rnorm(count,mean1,sd1)*rnorm(count,mean2,sd2)
  return(prod)
}
prod1=multiply(1)
prod2=multiply(2)
prod3=multiply(3)

print(prod1)
```

```
## [1] 1.547257
```

Note on seeds

- When randomizing in any language, you aren't really randomizing
- You're producing pseudo-random numbers that return in a deterministic ordered list
- If you set the seed, you can reproduce the same "random" numbers
- This is useful for debugging and sharing code
- Use `set.seed` in R

Neat R functions to help reduce

```
set.seed(16)
list1 = list() # Make an empty list to save output in
for (i in 1:3) { # Indicate number of iterations with "i"
  list1[[i]] = multiply(i) # Save output in list for each iteration
}
list1
```

```
## [[1]]
## [1] 1.547257
##
## [[2]]
## [1] 11.934479 -1.717951
##
## [[3]]
## [1] -7.4831177  0.9587218  4.7882622
```

A better way to eliminate this redundancy is to use the `map` function:

```
set.seed(16)
map(1:3, multiply)
```

```
## [[1]]
## [1] 1.547257
##
## [[2]]
## [1] 11.934479 -1.717951
##
## [[3]]
## [1] -7.4831177  0.9587218  4.7882622
```

Next lecture: R basics
