Lecture 1: Introduction to R

James Sears*

AFRE 891 SS 24

Michigan State University

*Parts of these slides are adapted from “Advanced Data Analytics” by Nick Hagerty and “Introduction to Data Science” by Rafael A. Irizarry, used under CC BY-NC-SA 4.0.

Table of Contents

Course Introduction

Introductions

Me

James Sears

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Assistant Professor (environmental and consumer behavioral economics)

You

A quick roundtable of

- Names
- Program/year
- Fields/interests
- Coding Background

Syllabus Highlights

(Read the whole thing **here**.)

Why This Course?

Because a huge chunk of what's important for doing modern (high-quality) empirical economic research **isn't taught in core classes**.

- How to find and clean datasets
- Working with spatial data
- Creating professional-quality data visualizations
- Recent empirical methods outside the scope of core econometrics
- Fundamentals of data science

In short: these are the skills that will **increase your research productivity** and expand your opportunities while on the **job market**.

In shorter: these are the **skills I wish I had** going into my dissertation work.

Grading

Component	Weight
4 × **Homework Assignments** (20% each)	80%
Research Project Presentation	7.5%
Research Project Code and Replication	7.5%
Research Project Discussant	5%

- **Homework assignments** focus on coding practice through simulation, replication, and/or extension
- **Research project** relates to course methods + your research portfolio
  - Creation of new dataset
  - Replication + extension of existing paper
  - Use course methods to tackle desired research question

Course Schedule (I)

Intro to Data Science

- Introduction and R Basics
- Version control with Git(hub) and Productivity Tools
- Data Wrangling
- Data Cleaning

Data Acquisition

- Finding and Acquiring Data
- Considerations for Administrative or PII Data
- Scraping Static Webpages
- Scraping Dynamic Webpages
- Respectful Web Scraping

Course Schedule (II)

Analysis and Programming

- Fast Regression Analysis and Event Study Methods
- Synthetic Control Methods (canonical, synthetic DiD, Partially Pooled SCM)
- Functions
- Iteration and Parallelization

Optimizing Workflows and Exploratory/Visual Analysis

- Reproducible Coding and Efficient Workflows
- Distinguishing Goals of Data Analysis
- Exploratory Analysis
- Principles of Data Visualization
- Reporting Analytical Results with Figures

Course Schedule (III)

Spatial Analysis

- Intro to Geospatial Data
- Vector Data and Spatial Operations
- Raster Data and Integration
- Static and Interactive Mapping

Intro to Big Data Tools

- Storage and Memory-Efficient Methods
- High-Performance and Cloud Computing Tools

Machine Learning

- Fundamentals of Machine Learning
- Prediction Methods
- Classification Methods
- Machine Learning for Causal Inference

About R and RStudio

Why Are We Using R in This Course?

- It’s free and open source
- It’s widely used in industry
- It’s widely used in academic research
- It has a large and active user community

Compared with Stata:

- More of a true programming language
- Steeper learning curve (takes more to start, ultimately more powerful)
- Faster for fixed effects models (often much faster)
- Many methods come to R earlier

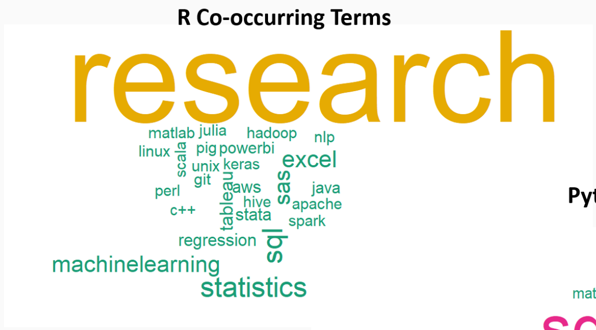
R vs. Python

R:

- Built for statistics and data analysis
- Better at econometrics and data visualization

Python:

- Built for general-purpose programming and software development
- Better at machine learning



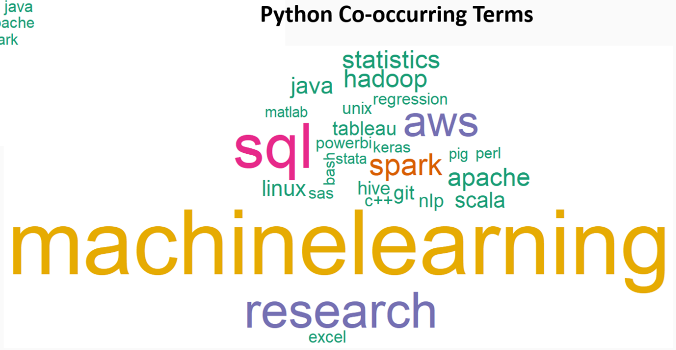


Image by Alex daSilva (source) is not included under the CC license.

R vs. Python

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- Better at econometrics and data visualization

Python:

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- Better at machine learning

Most economists use **either Stata or R**

Many data scientists in industry use **both R and Python**

Rising competitor to both: **Julia**

R Is a Means, Not an End

- The goals of this course are **platform-agnostic**
    - It’s not about the syntax of specific packages
    - It’s about the concepts, logic, and thought processes underlying what we're doing and why
- Your eventual goal: **use the right tool for the job**
    - From this course, you'll have a good sense of whether **R** is the right tool
    - Or how to figure out if it is

R and Myself

- Personally, I use **R almost exclusively** because it gives me **one environment** for all steps of the research workflow
  - Cleaning/manipulating large datasets
  - Spatial data
  - Visualization
  - Econometric analysis
  - Web scraping
  - Machine learning
- While it might not be **the best** at all of these tasks, it's almost always **one of the best**
- Using different software for each task makes **reproducibility more difficult**

R and You

- Many of you will **know more than me** about these things! Please speak up and share if you
    - Find an error in the code/discussion
    - Know a better way of doing things
    - Have suggestions on improving the course

This is a new course, and I welcome **any and all feedback** as we go!

Reading/Using the Slides

Reading the Slides

As you've seen, I'll frequently use **color to emphasize text**.

One distinction: **Links**

- **Orange** is reserved for **links**
- Whenever you see **orange text** on other slides, click it to go to the referenced content

Using the Slides

I highly recommend that you **replicate code in the slides as I go**.

- Try to type the code yourself first, use the slides if you fall behind
- Good habit to create a **reference script** with all the new methods/functions as you go

These slides are written in R Markdown, which we'll cover in a few weeks.

- Slides are rendered as a web page (.html)
- Source code as an R Markdown file (.Rmd)
- Completed pdf version saved for offline reference (.pdf)

R and RStudio

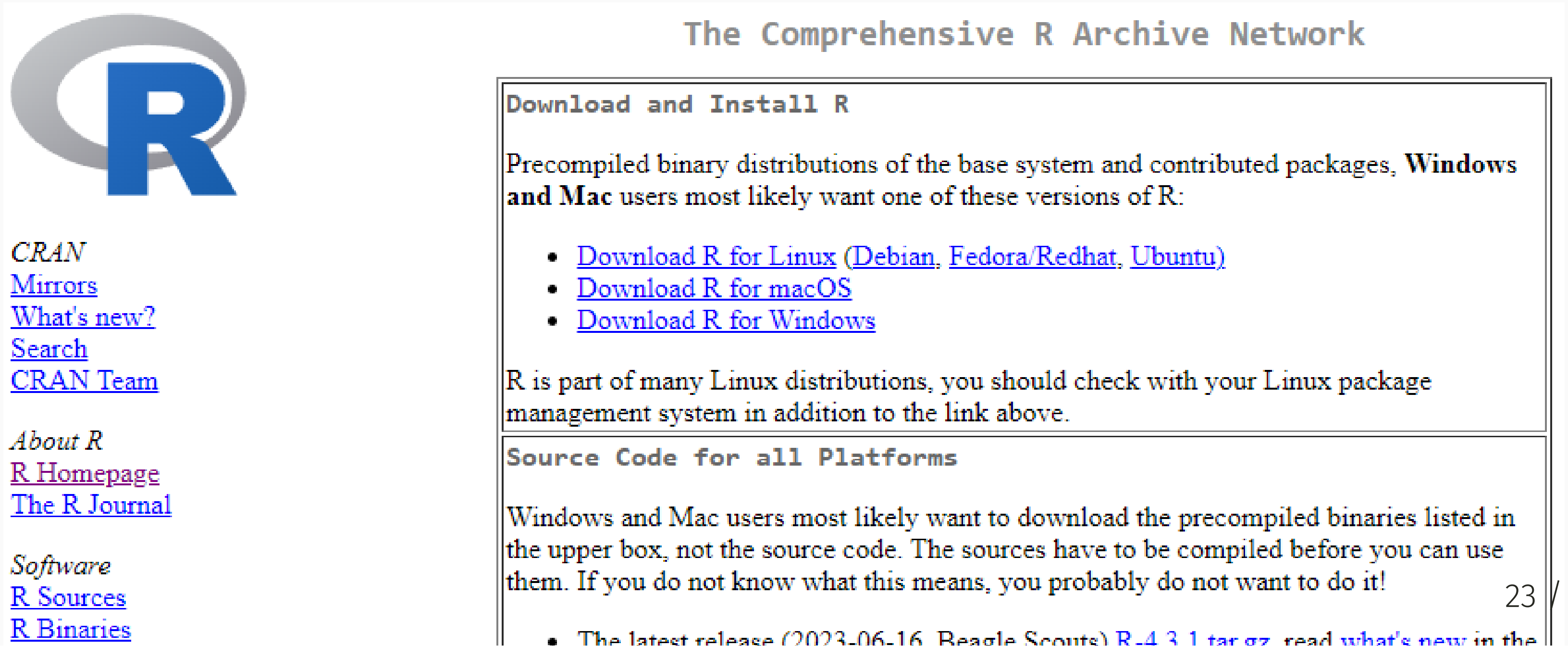
R vs. RStudio

- **R** is the **programming language**
- **RStudio** is the **environment** in which we use **R**
- While we could use **R** without **RStudio**, **RStudio** offers a lot of benefits

Installing R

To install **R**, go to the **R Project website**.

- **Windows:** "R For Windows > Base > Download R # for Windows"
- **Mac:** "R for (Mac) OS X > R-#.pkg"
- Where "#" is the current version number



The Comprehensive R Archive Network

CRAN
Mirrors
What's new?
Search
CRAN Team

About R
R Homepage
The R Journal

Software
R Sources
R Binaries

Download and Install R

Precompiled binary distributions of the base system and contributed packages, **Windows and Mac** users most likely want one of these versions of R:

- Download R for Linux (Debian, Fedora/Redhat, Ubuntu)
- Download R for macOS
- Download R for Windows

R is part of many Linux distributions, you should check with your Linux package management system in addition to the link above.

Source Code for all Platforms

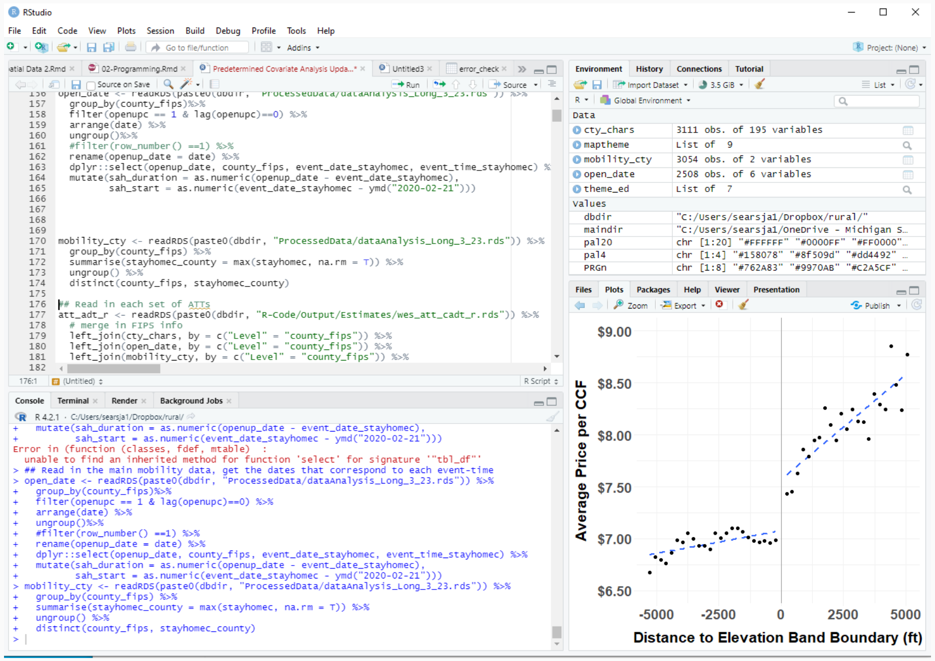
Windows and Mac users most likely want to download the precompiled binaries listed in the upper box, not the source code. The sources have to be compiled before you can use them. If you do not know what this means, you probably do not want to do it!

- The latest release (2023-06-16, Beagle Scouts) R-4.3.1.tar.gz, read what's new in the

RStudio

RStudio has a lot of features to make programming in **R** **more user friendly**

- Create and edit scripts
- View output and visualizations
- Navigate file structures
- See objects in memory



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  filter(openupc == 1 & lag(openupc)==0) %>%
  arrange(date) %>%
  ungroup()%>%
  #filter(row_number() ==1) %>%
  rename(openup_date = date) %>%
  dplyr::select(openup_date, county_fips, event_date_stayhomec, event_time_stayhomec) %
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  ungroup() %>%
  distinct(county_fips, stayhomec_county)

## Read in each set of ATTs
att_adt_r <- readRDS(paste0(dbdir, "R-Code/Output/Estimates/wes_att_cadt_r.rds")) %>%
  # merge in FIPS info
  left_join(cty_chars, by = c("Level" = "county_fips")) %>%
  left_join(open_date, by = c("Level" = "county_fips")) %>%
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```

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R 4.2.1 · C:/Users/searsja1/Dropbox/rural/
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maptheme	List of 9
mobility_cty	3054 obs. of 2 variables
open_date	2508 obs. of 6 variables
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Values	
dbdir	"C:/Users/searsja1/Dropbox/rural/"
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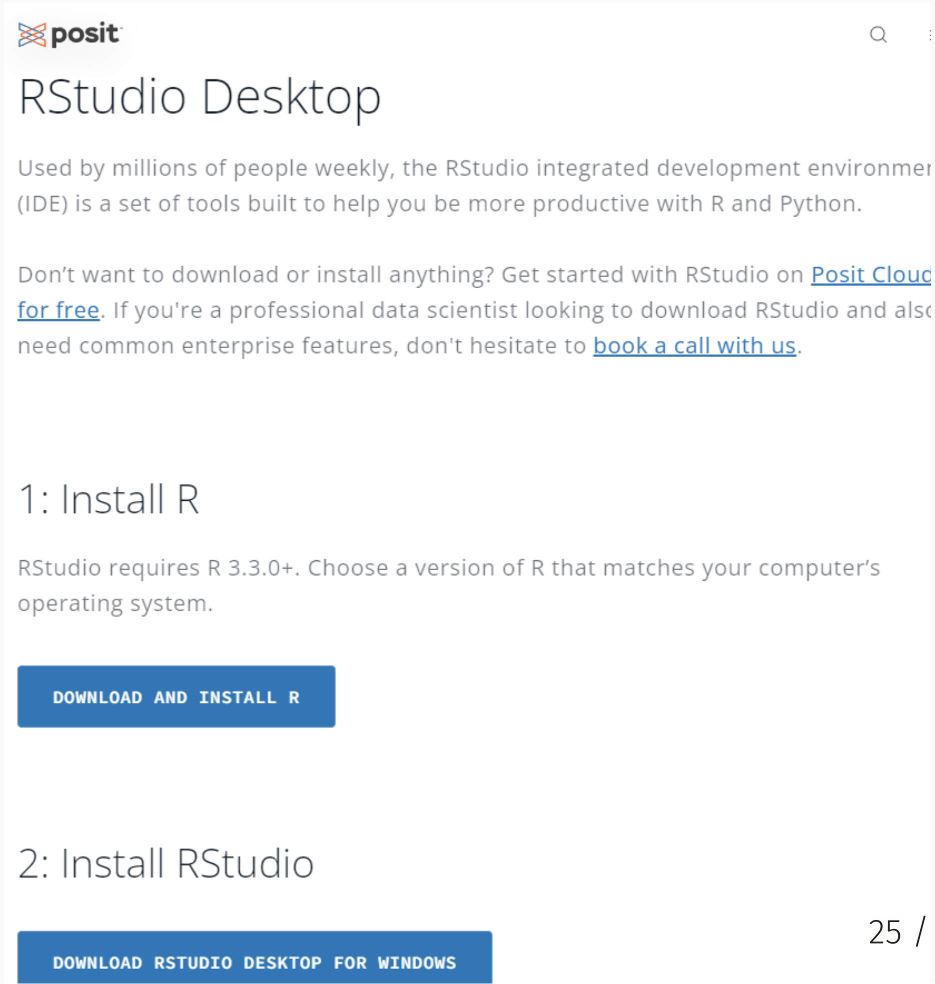
Installing RStudio

To install **RStudio**, go to the **RStudio Download Page**

- Scroll down, follow the link to install RStudio for your operating system.
- Correct file should be linked under **2. Install RStudio**
- Can scroll further down to the entire list and download the version for Windows or Mac.



RStudio Desktop

Used by millions of people weekly, the RStudio integrated development environmer (IDE) is a set of tools built to help you be more productive with R and Python.

Don't want to download or install anything? Get started with RStudio on Posit Cloud for free. If you're a professional data scientist looking to download RStudio and alsc need common enterprise features, don't hesitate to book a call with us.

1: Install R

RStudio requires R 3.3.0+. Choose a version of R that matches your computer's operating system.

2: Install RStudio

Other Things

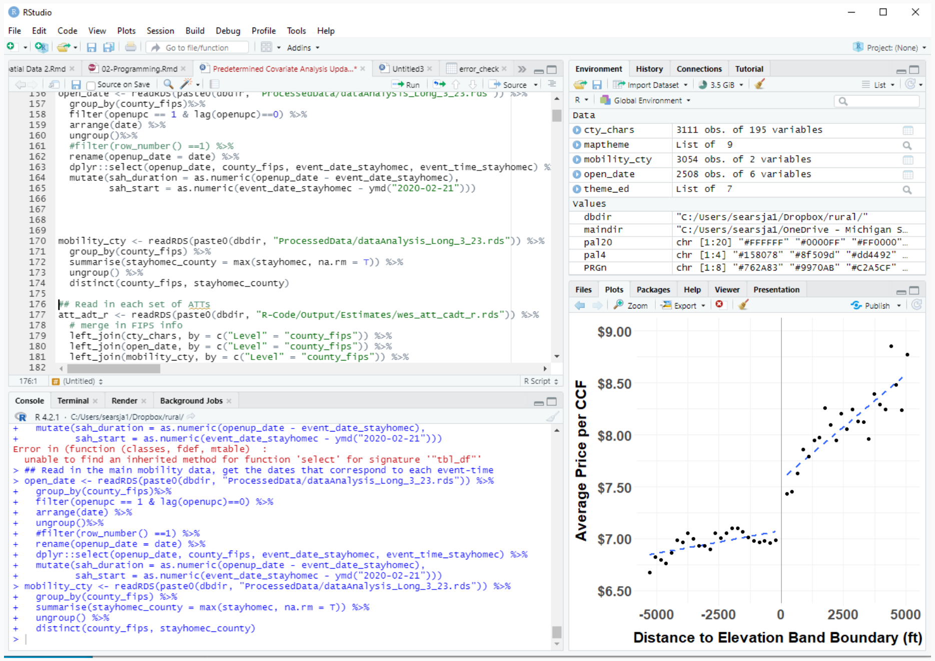
- Create an account on **GitHub** and register for a **student/educator discount**
  - You will soon receive an invitation to the course repo on GitHub, as well as ,hi-orange[GitHub classroom], which is how we'll disseminate and submit assignments, receive feedback and grading, etc.

- **Windows:** Install **Rtools**
- **Mac:** Configure/open your C++ toolchain (see **here**)

RStudio

RStudio has **four main elements**

1. Script Window
2. Console
3. Environment
4. Files/Plots/Packages/Help Window



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> |
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```
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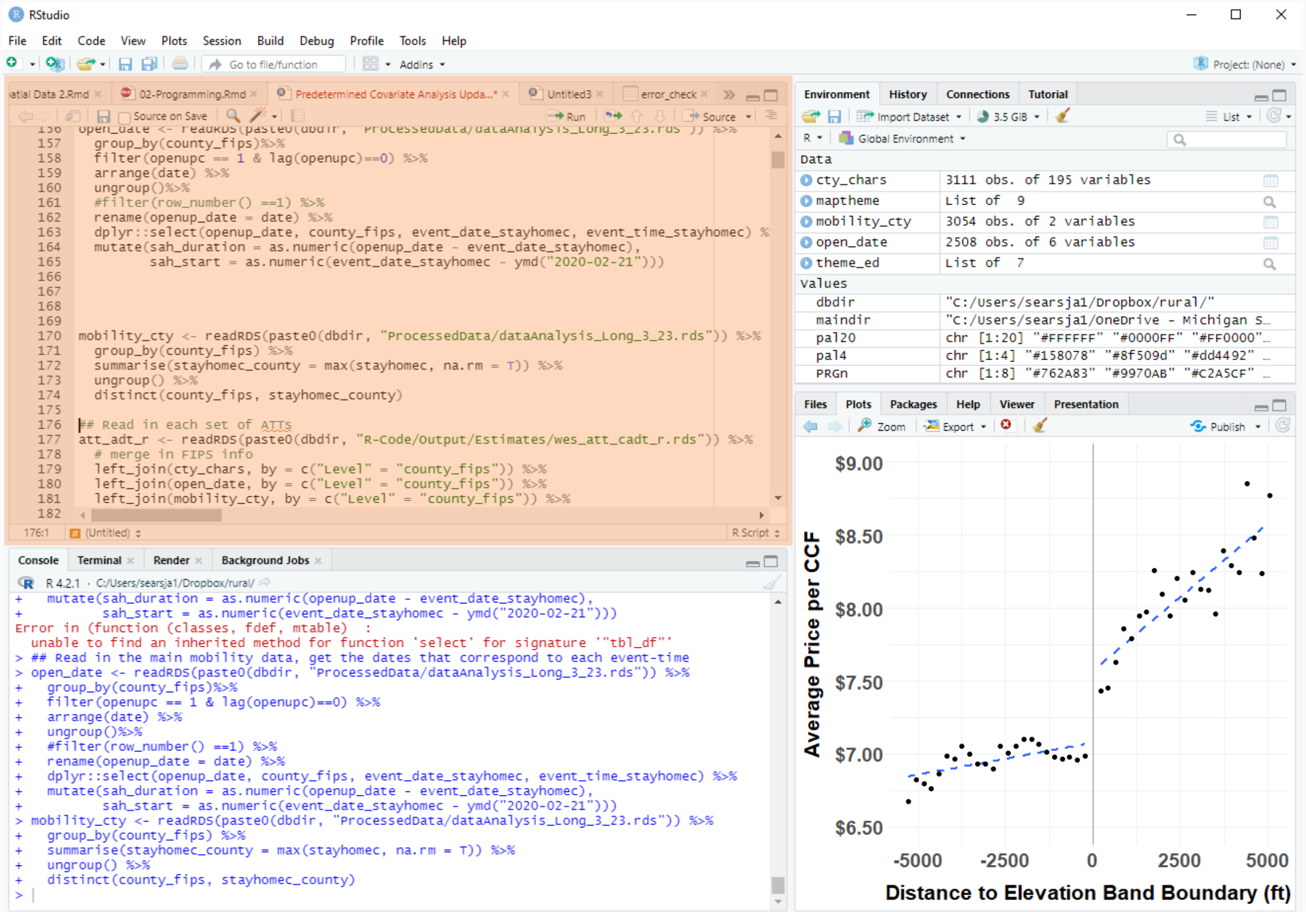
```

Getting Around RStudio: Script Window

Scripts are the **do file equivalent** in **R**:

- Allow you to **write and save code**, flip through multiple scripts/objects



RStudio
File Edit Code View Plots Session Build Debug Profile Tools Help
Go to file/function
Addins
Project: (None)
atial Data 2.Rmd
02-Programming.Rmd
Predetermined Covariate Analysis Upda...*
Untitled3
error_check
Source on Save
Run
Source
176:1
(Untitled)
R Script
Console Terminal Render Background Jobs
R 4.2.1 · C:/Users/searsja1/Dropbox/rural/
Environment History Connections Tutorial
Import Dataset
3.5 GiB
List
R
Global Environment
Files Plots Packages Help Viewer Presentation
Zoom
Export
Publish
$9.00
$8.50
$8.00
$7.50
$7.00
$6.50
-5000
-2500
0
2500
5000
Average Price per CCF
Distance to Elevation Band Boundary (ft)

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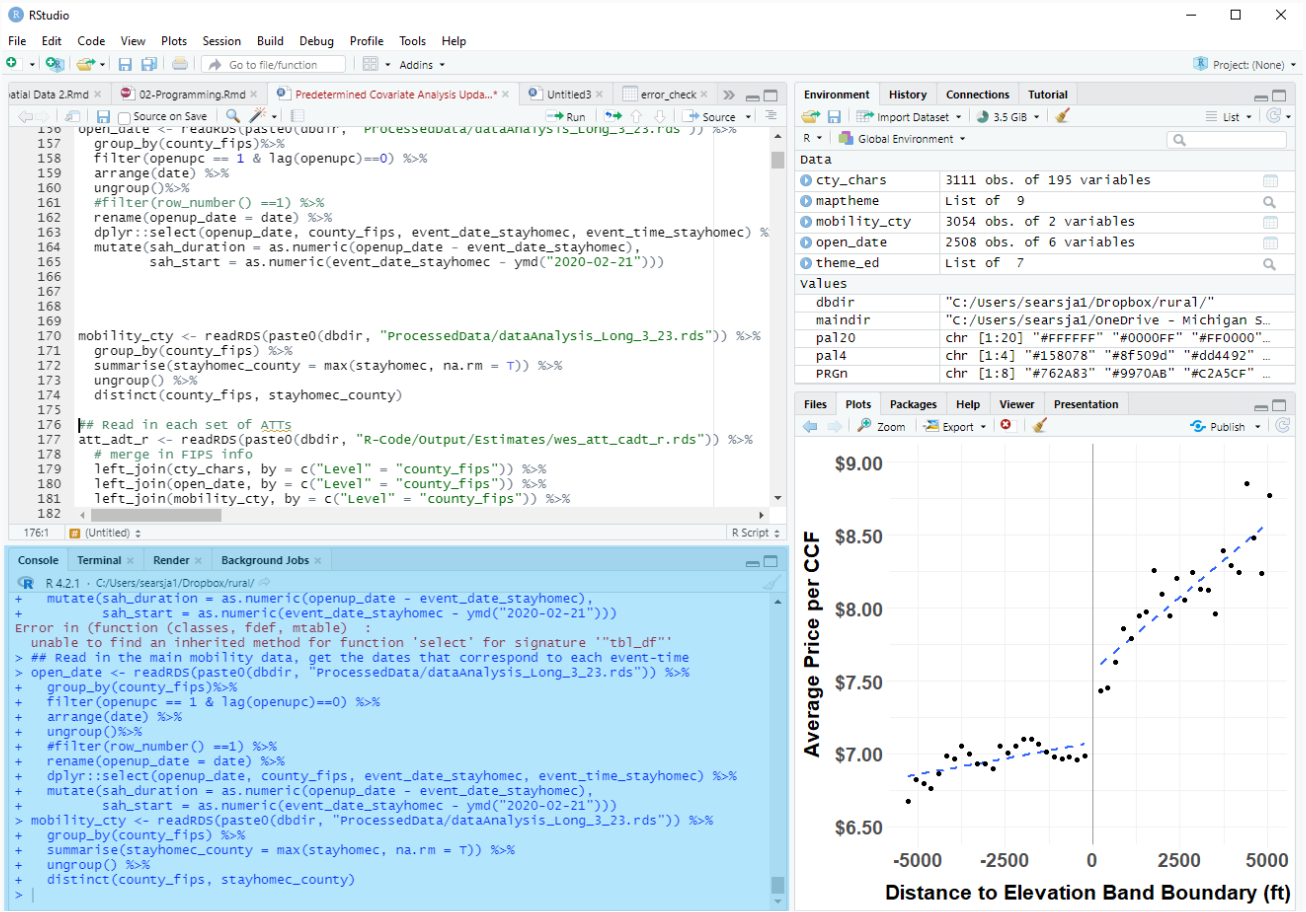
Getting Around RStudio: Console

Console is the **direct R interface**

- View output or plug in code directly (use scripts!)



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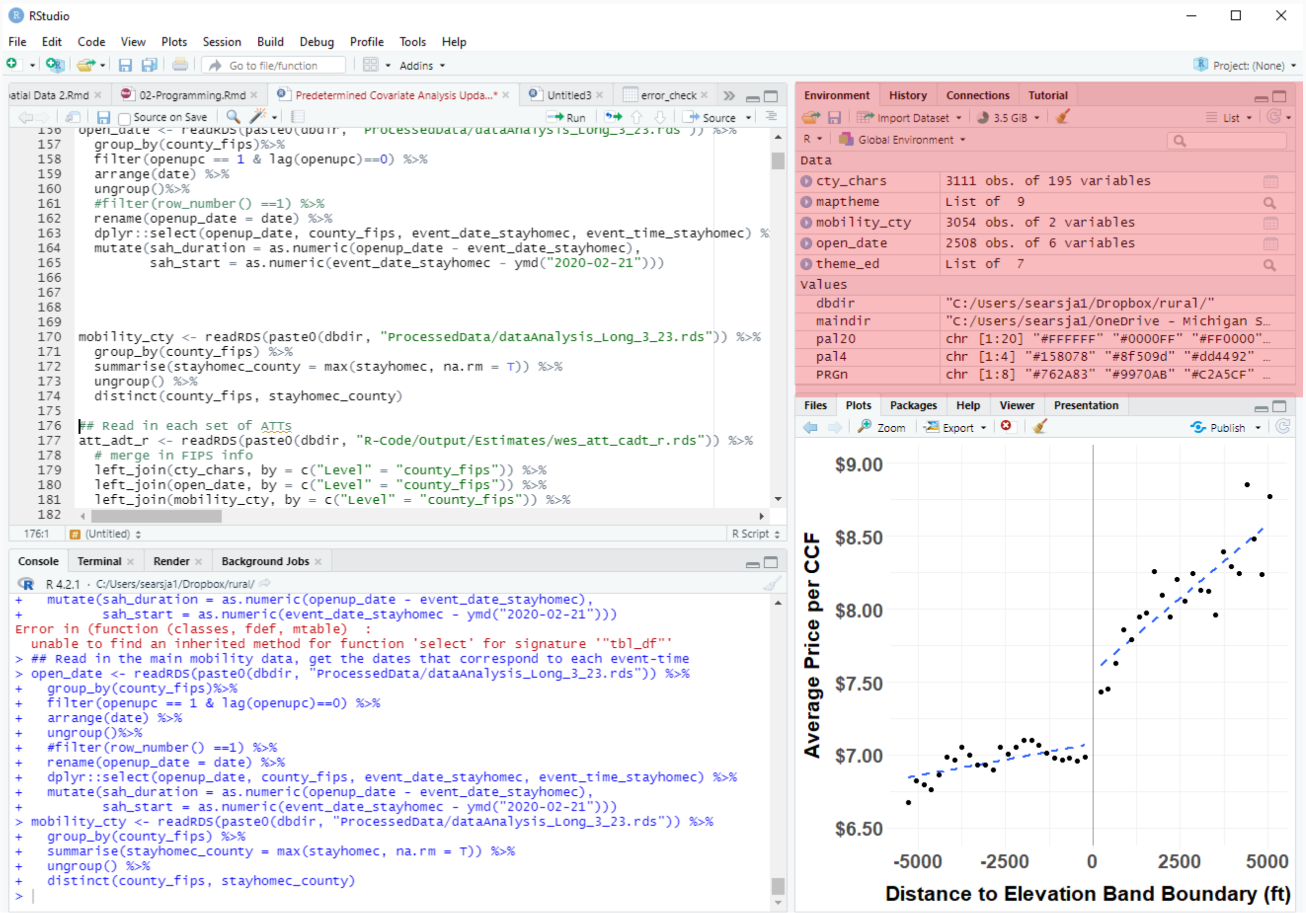
Getting Around RStudio: Environment

Environment shows you **everything currently loaded in R**

- Datasets, matrices, strings, functions, and other **objects**



```r
open_date <- readRDS(paste0(dbdir, "ProcessedData/dataAnalysis_Long_3_23.rds")) %>%
  group_by(county_fips)%>%
  filter(openupc == 1 & lag(openupc)==0) %>%
  arrange(date) %>%
  ungroup()%>%
  #filter(row_number() ==1) %>%
  rename(openup_date = date) %>%
  dplyr::select(openup_date, county_fips, event_date_stayhomec, event_time_stayhomec) %
  mutate(sah_duration = as.numeric(openup_date - event_date_stayhomec),
         sah_start = as.numeric(event_date_stayhomec - ymd("2020-02-21")))




mobility_cty <- readRDS(paste0(dbdir, "ProcessedData/dataAnalysis_Long_3_23.rds")) %>%
  group_by(county_fips) %>%
  summarise(stayhomec_county = max(stayhomec, na.rm = T)) %>%
  ungroup() %>%
  distinct(county_fips, stayhomec_county)

## Read in each set of ATTs
att_adt_r <- readRDS(paste0(dbdir, "R-Code/Output/Estimates/wes_att_cadt_r.rds")) %>%
  # merge in FIPS info
  left_join(cty_chars, by = c("Level" = "county_fips")) %>%
  left_join(open_date, by = c("Level" = "county_fips")) %>%
  left_join(mobility_cty, by = c("Level" = "county_fips")) %>%

```

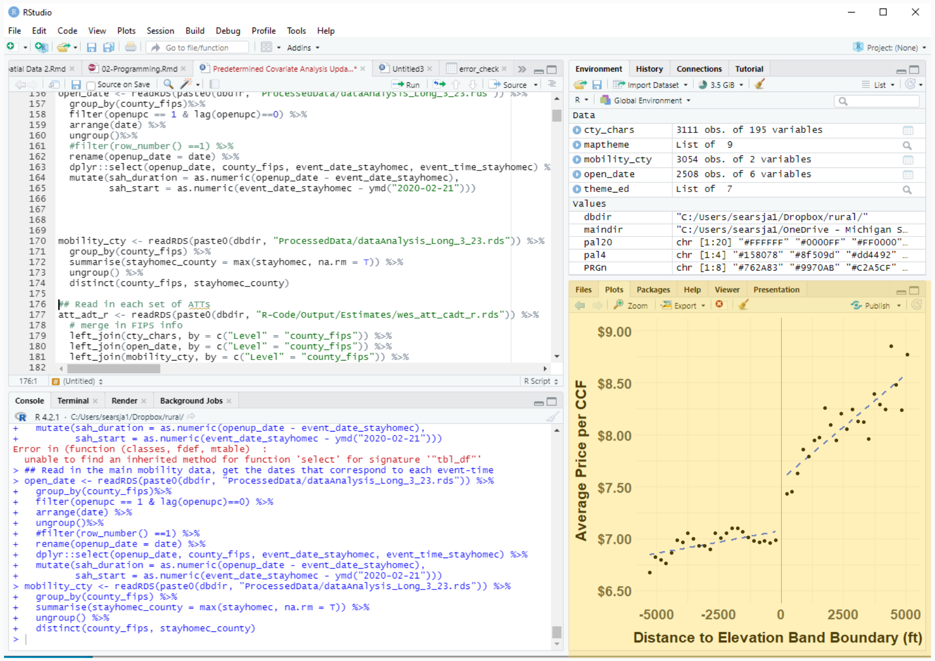
```
+   mutate(sah_duration = as.numeric(openup_date - event_date_stayhomec),
+          sah_start = as.numeric(event_date_stayhomec - ymd("2020-02-21")))
Error in (function (classes, fdef, mtable)  :
  unable to find an inherited method for function 'select' for signature '"tbl_df"'
> ## Read in the main mobility data, get the dates that correspond to each event-time
> open_date <- readRDS(paste0(dbdir, "ProcessedData/dataAnalysis_Long_3_23.rds")) %>%
+   group_by(county_fips)%>%
+   filter(openupc == 1 & lag(openupc)==0) %>%
+   arrange(date) %>%
+   ungroup()%>%
+   #filter(row_number() ==1) %>%
+   rename(openup_date = date) %>%
+   dplyr::select(openup_date, county_fips, event_date_stayhomec, event_time_stayhomec) %>%
+   mutate(sah_duration = as.numeric(openup_date - event_date_stayhomec),
+          sah_start = as.numeric(event_date_stayhomec - ymd("2020-02-21")))
> mobility_cty <- readRDS(paste0(dbdir, "ProcessedData/dataAnalysis_Long_3_23.rds")) %>%
+   group_by(county_fips) %>%
+   summarise(stayhomec_county = max(stayhomec, na.rm = T)) %>%
+   ungroup() %>%
+   distinct(county_fips, stayhomec_county)
> |
```

Data	
cty_chars	3111 obs. of 195 variables
maptheme	List of 9
mobility_cty	3054 obs. of 2 variables
open_date	2508 obs. of 6 variables
theme_ed	List of 7
Values	
dbdir	"C:/Users/searsja1/Dropbox/rural/"
maindir	"C:/Users/searsja1/OneDrive - Michigan S…
pal20	chr [1:20] "#FFFFFF" "#0000FF" "#FF0000"…
pal4	chr [1:4] "#158078" "#8f509d" "#dd4492" …
PRGn	chr [1:8] "#762A83" "#9970AB" "#C2A5CF" …

Getting Around RStudio: Files/Plots

Files/Plots/Packages/Help shows you... **everything else**

- **Files** navigate file paths
- **Plots** view data visualizations
- **Packages** load/see packages
- **Help** get help with function syntax



```r
open_date <- readRDS(paste0(dbdir, "ProcessedData/dataAnalysis_Long_3_23.rds")) %>%
  group_by(county_fips)%>%
  filter(openupc == 1 & lag(openupc)==0) %>%
  arrange(date) %>%
  ungroup()%>%
  #filter(row_number() ==1) %>%
  rename(openup_date = date) %>%
  dplyr::select(openup_date, county_fips, event_date_stayhomec, event_time_stayhomec) %
  mutate(sah_duration = as.numeric(openup_date - event_date_stayhomec),
         sah_start = as.numeric(event_date_stayhomec - ymd("2020-02-21")))




mobility_cty <- readRDS(paste0(dbdir, "ProcessedData/dataAnalysis_Long_3_23.rds")) %>%
  group_by(county_fips) %>%
  summarise(stayhomec_county = max(stayhomec, na.rm = T)) %>%
  ungroup() %>%
  distinct(county_fips, stayhomec_county)

## Read in each set of ATTs
att_adt_r <- readRDS(paste0(dbdir, "R-Code/Output/Estimates/wes_att_cadt_r.rds")) %>%
  # merge in FIPS info
  left_join(cty_chars, by = c("Level" = "county_fips")) %>%
  left_join(open_date, by = c("Level" = "county_fips")) %>%
  left_join(mobility_cty, by = c("Level" = "county_fips")) %>%
```

```
+   mutate(sah_duration = as.numeric(openup_date - event_date_stayhomec),
+          sah_start = as.numeric(event_date_stayhomec - ymd("2020-02-21")))
Error in (function (classes, fdef, mtable)  :
  unable to find an inherited method for function 'select' for signature '"tbl_df"'
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+   group_by(county_fips)%>%
+   filter(openupc == 1 & lag(openupc)==0) %>%
+   arrange(date) %>%
+   ungroup()%>%
+   #filter(row_number() ==1) %>%
+   rename(openup_date = date) %>%
+   dplyr::select(openup_date, county_fips, event_date_stayhomec, event_time_stayhomec) %>%
+   mutate(sah_duration = as.numeric(openup_date - event_date_stayhomec),
+          sah_start = as.numeric(event_date_stayhomec - ymd("2020-02-21")))
> mobility_cty <- readRDS(paste0(dbdir, "ProcessedData/dataAnalysis_Long_3_23.rds")) %>%
+   group_by(county_fips) %>%
+   summarise(stayhomec_county = max(stayhomec, na.rm = T)) %>%
+   ungroup() %>%
+   distinct(county_fips, stayhomec_county)
> 
```

Data	
cty_chars	3111 obs. of 195 variables
maptheme	List of 9
mobility_cty	3054 obs. of 2 variables
open_date	2508 obs. of 6 variables
theme_ed	List of 7
Values	
dbdir	"C:/Users/searsja1/Dropbox/rural/"
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pal4	chr [1:4] "#158078" "#8f509d" "#dd4492" …
PRGn	chr [1:8] "#762A83" "#9970AB" "#C2A5CF" …

Getting to Know RStudio

1. **Try out the console**
    - Use it as a calculator
    - Access previous commands
2. **Try a new script and save it**
3. **Set global options (Tools -> Options)**
    - Uncheck **"Restore .RData into workspace at start"**
    - Set **"Save workspace to .RData on exit"** to **"Never"**
4. **Keyboard shortcuts**

Time for Some Live Coding

Open a **new R script.**

As we go through examples, **retype everything yourself and run it line by line** (`Ctrl+Enter`)[1]. You'll learn more this way.

(Feel free to try out slight tweaks along the way, too.)

[1] For Mac users: `Cmd` = `Ctrl`. You can also use the `Run` button on the upper-right of the Script window to run code or view shortcuts.

Basic R Operators

Basic Arithmetic

You can use **R** like a **fancy, low-portability graphing calculator:**

```r
1 + 2 - 3   # Addition/Subtraction
```

```
## [1] 0
```

```r
5 / 2   # Division
```

```
## [1] 2.5
```

```r
4 * 3   # Multiplication
```

```
## [1] 12
```

```r
2 ^ 3   # Exponentiation
```

```
## [1] 8
```

Remember PEMDAS?

Parentheses **matter**!

```
2 + 4 * 1 ^ 3
```

```
## [1] 6
```

```
(2 + 4 * 1) ^ 3
```

```
## [1] 216
```

```
2 + (4 * 1) ^ 3
```

```
## [1] 66
```

What feels like 95% of my coding errors are due to **unmatched parentheses**

This gets even more important as we use nested functions

Logical Evaluation

Logical operators follow **standard programming conventions**:

```
1 == 2 # == for equivalency (two equal signs)
```

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

```
1 > 2 # < and > work as expected
```

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

```
1 > 2 & 0.5 < 0.5 # The "&" means "and"
```

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

```
1 > 2 | 1 > 0.5 # The "|" means "or"
```

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

Negating Logic

Negate logical comparisons with `!` **and parentheses**

```
1 ≠ 2 # ! and = next to each other for neq
```

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

```
!(1 > 2) # add parentheses around the condition you want to negate
```

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

```
!(1 > 2 & 0.5 < 0.5) # can negate complex conditions
```

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

```
!(1 > 2) | !(1 > 0.5) # or combine with other logical operators
```

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

Errors

What if we accidentally used `=` instead of `==`?

- `=` is reserved for **assignment**
- `==` is reserved for **equivalence**

```
1 = 1
```

```
## Error in 1 = 1: invalid (do_set) left-hand side to assignment
```

What should you do if you don't understand the error message?

- **Always read the error message!**

Commenting

Another good practice is to **comment code**

- Use the **pound sign** `#` to comment out everything behind it on a given line.

```r
# Use it at the start of a line to add comments
4 > 3
```

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

```r
# or to comment out parts of lines
4 + 5 - 23 # * 6798127347^38 yikes that would've been big
```

```
## [1] -14
```

Commenting

Another good practice is to **comment code**

Widely accepted conventions:

- Put the comment **before** the code it refers to
- Use present tense

Script Chunks

You can use `# ----` or `#####` to add **collapsible chunks** to your scripts

```r
# Use it Break up tasks (can put text in the middle) ----
4 > 3
```

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

```r
#####
# or separate preamble from different sections
```

Click the **downward triangle** (left next to the line numbers) to **hide the lines between breaks**

Objects

Objects

R is an example of **object-oriented programming (OOP)**

- Everything is an **object**
- Everything has a **name**
- You do things with **functions**
- Functions come pre-written in **packages (i.e. "libraries")**
- You can (and should) **write your own functions too**

Understanding **objects** is the first key to using **R**.

Objects

We can store values for later by assigning them to **objects.**

We assign using one of two **assignment operators:**

- `←` (the `<` followed by `-`),
- or `=`

```
price ← 149.99
tax ← 0.085
```

Here price "gets" the value `149.99`.

Choice of Assignment Operator

Why use `<-` instead of `=`?

Well, it turns out that it's a **lot more complicated of a question than it appears (warning: pedantic rabbit hole)**

My recommendation:

- Use `<-` to **assign objects to memory**
- Use `=` for **declaring function arguments**

Another reason: Google asks their developers to assign objects with `<-` in the **Google RGuide**, so if it's good enough for Google it's good enough for me.

Objects

To see the value of an object, just **type its name:**

```
price
```

```
## [1] 149.99
```

Notice that `price` and `tax` are now listed in your **Environment pane**.

Now, we can calculate the sales tax:

```
price * tax
```

```
## [1] 12.74915
```

Objects

We can assign a new value to `price` and recalculate the tax amount:

```
price = 90
price * tax
```

```
## [1] 7.65
```

Note that object names are **case sensitive:**

```
Price = 99.99
PRICE = 9.99
sales.tax = 0.05
sales_tax = 0.075
```

```
Price * sales.tax
```

```
## [1] 4.9995
```

Object Names

Rules for naming objects:

- Names can include numbers
- Names can include periods `.` and underscores `_`
- Names **must start with a letter**

```
sales_tax ← 0.075
10tax  ← 0.1
```

```
## Error: <text>:2:3: unexpected symbol
## 1: sales_tax ← 0.075
## 2: 10tax
##      ^
```

Types of Objects

We'll see throughout the course that there are many types of objects in **R**, including

- **Single values** (numbers, characters; like `price`)
- **Vectors**
- **Matrices**
- **Data frames**
- **Arrays**
- **Factors**
- **Lists**

We'll dive into many of these in-depth during this course, but let's take a quick look at each

Vectors

A **vector** is an **ordered collection of numbers or character strings** indexed by 1, 2, ..., n, where n is the length of the vector.

```
# for ordered integers, can use :
int_1_10 <- 1:10

# or the combine operator to manually combine elements
c(11, 13, 14, 200)
```

```
## [1]  11  13  14 200
```

Vectors

Other useful ways to create non-sequential vectors include

Creating a sequence with `seq()`

```
seq(0, 10, by = 2)
```

```
## [1]  0  2  4  6  8 10
```

Repeating elements with `rep()`

```
rep(1, 5)
```

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

```
rep(c(1,2,3), 2)
```

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

Vectors

A vector with both numeric and text entries **converts everything to text:**

```
c(7, "Michigan", 19, "State")
```

```
## [1] "7"        "Michigan" "19"       "State"
```

Vectors

You can **name** elements in a vector (with or without quotations)

```r
state_founding <- c(MI = 1837, IN = 1816, IL = 1818)
state_founding
```

```
##   MI   IN   IL
## 1837 1816 1818
```

```r
state_founding == c("MI" = 1837, "IN" = 1816," IL" = 1818)
```

```
##   MI   IN   IL
## TRUE TRUE TRUE
```

Or by using the `names()` function

```r
state_founding <- c(1837, 1816, 1818)
states <- c("MI", "IN", "IL")
names(state_founding) <- states
```

Matrices

A **matrix** is… well, a matrix.

- A **two-dimensional collection** of numeric or character values indexed by integer pairs (i,j)

```
xmat ← matrix(c(1,2,3,4,5,6),
              ncol = 3,
              nrow = 2)
xmat
```

```
##      [,1] [,2] [,3]
## [1,]    1    3    5
## [2,]    2    4    6
```

Matrices

Fill **across columns** instead by setting `byrow = FALSE`

```
matrix(c(1,2,3,4,5,6),
             ncol = 3,
             nrow = 2,
       byrow = FALSE)
```

```
##      [,1] [,2] [,3]
## [1,]    1    3    5
## [2,]    2    4    6
```

Matrices

Combine matrices on the rows with `rbind()`

- Must have matching number of columns

```r
ymat <- matrix(c(7,8,9),
               ncol = 3,
               nrow = 1)

rbind(xmat, ymat)
```

```
##      [,1] [,2] [,3]
## [1,]    1    3    5
## [2,]    2    4    6
## [3,]    7    8    9
```

Matrices

Combine matrices on the columns with `cbind()`

- Must have matching number of rows

```
zmat <- matrix(c(7,8,9,10,11,12,13,14),
               ncol = 4,
               nrow = 2)

cbind(xmat, zmat)
```

```
##      [,1] [,2] [,3] [,4] [,5] [,6] [,7]
## [1,]    1    3    5    7    9   11   13
## [2,]    2    4    6    8   10   12   14
```

Arithmetic with Vectors and Matrices

Arithmetic operators apply **element-wise** to vectors and matrices.

```
vec1 ← 1:4
vec2 ← 11:14
vec1 + vec2
```

```
## [1] 12 14 16 18
```

Arithmetic with Vectors and Matrices

Arithmetic operators apply **element-wise** to vectors and matrices.

```
mat1 ← matrix(2:7, nrow = 2)
mat2 ← matrix(seq(4,14, by = 2), nrow = 2)
mat2/mat1
```

```
##      [,1] [,2] [,3]
## [1,]    2    2    2
## [2,]    2    2    2
```

Arithmetic with Vectors and Matrices

To perform **matrix multiplication**, use `%*%`

- Remember rules for dimensions!

```
mat1 <- matrix(2:7, nrow = 2) # 2 x 3 matrix
mat3 <- matrix(seq(4,14, by = 2), nrow = 3) # 3 x 2 matrix
mat1 %*% mat3 # results in 2x2 matrix
```

```
##      [,1] [,2]
## [1,]   80  152
## [2,]   98  188
```

Data Frames

data frames are the data science version of a matrix

- Each **column** is a **variable**
- Each **row** is an **observation**
- Variables can have **names**
- Columns can be of **different types**
- Should sound familiar to Stata folks

```
ex_df ← data.frame(state = c("MI", "IN", "WI", "IL"),
                   pop_m = c(10.04, 8.87, 5.91, 12.55),
                   is_michigan = c(T, F, F, F))
ex_df
```

```
##   state pop_m is_michigan
## 1    MI 10.04        TRUE
## 2    IN  8.87       FALSE
## 3    WI  5.91       FALSE
## 4    IL 12.55       FALSE
```

Accessing Element(s)

We can access specific element(s) of vectors with their **integer position** and **brackets** `[]`

```r
# get the first element of int_1_10
int_1_10[1]
```

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

```r
# get the third and fourth elements
int_1_10[3:4]
```

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

Accessing Element(s)

We can do the **same with matrices and data frames**, as well as access entire rows/columns

```r
# retrieve the third and fourth columns elements of row two in zmat:
zmat[2,3:4]
```

```
## [1] 12 14
```

```r
# Replace the entire second row of ex_df with Pennsylvania:
ex_df[2,] ← c("PA", 8.24, FALSE)

# take the sum of elements in the third and fourth columns of zmat:
sum(zmat[,3:4])
```

```
## [1] 50
```

Accessing Element(s)

We can access **entire columns** in dataframes with `$`

```
# get the "pop_m" column from ex_df:
ex_df$pop_m
```

```
## [1] "10.04" "8.24"  "5.91"  "12.55"
```

```
# which is equivalent to using integer indexing
ex_df[,2]
```

```
## [1] "10.04" "8.24"  "5.91"  "12.55"
```

```
# combine with indexing to get third row element of "state"
ex_df$state[3]
```

```
## [1] "WI"
```

Accessing Element(s)

If an object has names, you can also index using those!

```r
state_founding["MI"]
```

```
##   MI
## 1837
```

```r
ex_df["pop_m"]
```

```
##   pop_m
## 1 10.04
## 2  8.24
## 3  5.91
## 4 12.55
```

Arrays

Arrays are **n-dimensional collections** of numeric/text elements, indexed by an n-tuple of integers - i.e. (i,j,k) for 3-dimensional array

```
ar4 <- array(1:24, dim = c(2,2,2,3))
ar4
```

```
## , , 1, 1
##
##      [,1] [,2]
## [1,]    1    3
## [2,]    2    4
##
## , , 2, 1
##
##      [,1] [,2]
## [1,]    5    7
## [2,]    6    8
##
## , , 1, 2
##
```

Arrays

Just like with matrices, we can use integer indexing to retrieve specific element(s) from an array

```
# get first element
ar4[1,1,1,1]
```

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

```
# get 2×2 matrix in "last" position
# (2/2 in third dimension, 3/3 in fourth)
ar4[,,2,3]
```

```
##      [,1] [,2]
## [1,]   21   23
## [2,]   22   24
```

Factors

A **factor** is a special kind of vector, where each element has an associated **level (i.e. character label)**

- Useful for storing categorical variables
- R will treat each level distinctly

```r
edu ← factor(c("bach", "hs", "some_col", "phd", "bach", "hs"),
                     # specify the order
          levels = c("hs", "some_col", "bach", "phd"),
          # specify the text labels
          labels = c("High School", "Some College",
                     "Bachelors", "Doctorate"))
edu
```

```
## [1] Bachelors    High School  Some College Doctorate    Bachelors
## [6] High School
## Levels: High School Some College Bachelors Doctorate
```

Lists

Lists are an **ordered collection of objects** (that may be of different types)

```r
# combine many of our previous objects into a list
ex_list ← list(
  ex_df,
  int_1_10,
  xmat
)
ex_list
```

```
## [[1]]
##   state pop_m is_michigan
## 1    MI 10.04        TRUE
## 2    PA  8.24       FALSE
## 3    WI  5.91       FALSE
## 4    IL 12.55       FALSE
##
## [[2]]
##  [1]  1  2  3  4  5  6  7  8  9 10
##
```

Lists

List objects are indexed with **double brackets** `[[]]`

```r
# get the second list object (the vector)
ex_list[[2]]
```

```
##  [1]  1  2  3  4  5  6  7  8  9 10
```

Lists

You can also **name list objects** and reference them with `$`

```
# combine many of our previous objects into a list
ex_list ← list(
  df = ex_df,
  vec = int_1_10,
  mat = xmat
)
ex_list$vec
```

```
##  [1]  1  2  3  4  5  6  7  8  9 10
```

Checking Object Types

Unsure what type an object is? Use `class()` to check:

```r
class(ex_list)
```

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

```r
class(zmat)
```

```
## [1] "matrix" "array"
```

```r
class(ex_df)
```

```
## [1] "data.frame"
```

Converting Types

Use the `as.type()` group of functions to **convert between types**

```
num ← 1:4
char ← as.character(num)
char
```

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

```
as.numeric(char)
```

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

NA

If a conversion **isn't obvious**, you'll get an **NA**

```
as.numeric("AFRE 891")
```

```
## [1] NA
```

In R. `NA` contains **no information**

```
NA == NA
```

```
## [1] NA
```

```
NA + 0
```

```
## [1] NA
```

```
is.na(NA + 0)
```

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

Other Special Values

Other special values:

- Infinity (`Inf` or `-Inf`)
- Not a Number (`NaN`)

```
1/0
```

```
## [1] Inf
```

```
-1/0
```

```
## [1] -Inf
```

```
0/0
```

```
## [1] NaN
```

Practice

Practice

Time for some practice:

- Create a matrix named `mat40` with 4 rows and 10 columns containing the values 1:40
- Save the object `row4` to memory as a vector of the fourth row of `mat40`
- Use indexing to retrieve
  1. The element in the 3rd row and 6th column
  2. The 5-7th elements from the 2nd row
  3. The entire 6th column
- Using 1-3, create a list with each object named `obj_X`

Functions

Functions

In order to do more than arithmetic in **R** we'll use **functions**

```r
log(5)
```

```
## [1] 1.609438
```

To see the **arguments** a function takes, look up its help file with `?fn`

```r
?log
```

Some arguments are required, while others are optional. You can see that `base` is optional because it has a default value: `exp(1)`.

Function Arguments

If you type the arguments in the **expected order**, you **don't need to use argument names**:

```r
log(5, 10)
```

```
## [1] 0.69897
```

But if you use argument names you can 1) put them in **any order**, and 2) protect yourself from **counting incorrectly**

```r
log(x = 5, base =  exp(1))
```

```
## [1] 1.609438
```

```r
log(base =  exp(1), x = 5)
```

```
## [1] 1.609438
```

Function Arguments

We can use **objects as arguments**

```
val ← exp(1)
log(x = 10, base = val)
```

```
## [1] 2.302585
```

or **nest functions directly**

```
log(max(c(price,5,10,20,50,3,11,20)))
```

```
## [1] 4.49981
```

Where to Find Functions

Many functions that we'll regularly use can be found either

1. Already loaded in **R**
2. In **packages**

Later in the course we'll learn about **writing your own functions**, which is something you can (and should) do!

Packages, Libraries, and Paths

Packages, Libraries, and Paths

While using **R** like a calculator is fun, the real advantages come out when we load **packages**

- **Packages** are nice curated bundles of functions and tools that let us transform R into a data-slaying kaiju
- Think Voltron (or insert other dated reference here)
- Base R loads in several packages by default (stats, utils)

```r
# View loaded packages:
(.packages())
```

```
## [1] "fontawesome" "knitr"       "stats"       "graphics"    "grDevices"
## [6] "utils"       "datasets"    "methods"     "base"
```

Packages

To use another package, we must first **call it** with `library()`

```
# call the haven package with library()

library(haven)

# what's now loaded?
(.packages())
```

```
##  [1] "haven"       "fontawesome" "knitr"       "stats"       "graphics"
##  [6] "grDevices"   "utils"       "datasets"    "methods"     "base"
```

Packages

If we try and load a package that's **not installed** or **misspelled**, we get an error

```
library(hevan)
```

```
## Error in library(hevan): there is no package called 'hevan'
```

Installing Packages

To install a package, we can use `install.packages()`

```
install.packages("tidyverse")
```

R will search for a package named "tidyverse" on **CRAN** and install it if found

Once installed, you can call the package.

Installing Packages

My preferred way: use the **pacman** package to load/install packages for you:

```r
# first, install the pacman package
install.packages("pacman")
```

Then use the `p_load()` function[2] to load desired packages, and automatically install any that are missing

```r
pacman::p_load(haven, tidyverse, fixest)
```

[2] You can run a function from an (installed) package without loading it by using the `PACKAGE::package_function()` syntax

Installing Packages

Sometimes packages aren't listed on CRAN and you'll have to install them **directly from Github repositories**

For example, if we want to use the `synthdid` **package**, we would first need to run

```r
# use the install_github function from the remotes package
remotes::install_github("synth-inference/synthdid")

# can also use install_github from the devtools package
```

Package Best Practices

It's a good idea to begin your scripts with a **Preamble**

- Add comments so you know what you're doing (helpful for revisiting a year later during revision requests...)
- Load packages (make peace with this, Stata users)
- Set file paths (assign main project path as an object)
- Change any options
- Store custom ggplot2 themes (we'll learn these later on)

Preamble Example: Notes and Packages

```r
################################################################
##############       Culpable Consumption       ##############
##############          Update 11-2023          ##############
################################################################
## Created: 11-23-2023
## Updated 11-23-2023
## Purpose: Run updated analyses for the "Culpable Consumption" Paper

# make sure to have installed pacman with
# install.packages("pacman") before
# running the below line:
pacman::p_load(fixest, lubridate, rdd, rdrobust,
showtext, tictoc, tidyverse)


# Read in strings as non-factors, turn off scientific notation
options(stringsAsFactors = F, scipen = 999)

# use showtext functionality to write text in plots
showtext_auto()
```

Preamble Example: ggplot2 Theme

```r
# ggplot theme
theme_ed ← theme(
# set text sizes/spacing
 axis.text=element_text(size=16, family = "lato"),
 axis.title.y = element_text(size=16, family = "lato", margin=margin(r=10
 axis.title.x = element_text(size=16, family = "lato", margin=margin(t=10
 plot.caption = element_text(hjust = 0, face = "italic"),
 plot.title=element_text(size=18, family = "lato"),
 legend.text=element_text(size=16, family = "lato"),
 legend.title=element_text(size=16, family = "lato"),
# custom ticks/gridlines/background
 axis.ticks = element_line(color = "grey95", linewidth = 0.3),
 panel.background = element_rect(fill = NA),
 panel.grid.major = element_line(color = "grey95", linewidth = 0.3),
 panel.grid.minor = element_line(color = "grey95", linewidth = 0.3),
# tweak legend position
 legend.position = "bottom"
  )
```

Preamble Example: Paths

```r
# Set main folder path to object
# depending on computer I'm using
if (Sys.info()["nodename"] == "DESKTOP-SHT9660" ){
  onedir <- "C:/Users/james/OneDrive - Michigan State University/Research/
} else if (Sys.info()["nodename"] == "JAMES-DESKTOP" ){
  onedir <- "F:/OneDrive - Michigan State University/Research/Culpable Co
}else {
  onedir <- "C:/Users/searsja1/OneDrive - Michigan State University/Resea
}

# set main project path as working directory
setwd(onedir)
```

Run `Sys.info()` to see information about your system, including its name (`nodename` element)

Cleaning Up

While we're talking about best practices, we should talk about how to **clean up** your environment.

You can **remove an object** you're done with from memory using `rm()`

```
rm(state_founding)
```

To remove **multiple objects**,

- Nest `c()` within `rm()` to remove **specific objects**
- use `rm(list=ls())` to remove **literally everything**

Cleaning Up

After running intensive functions or having RStudio open for a while, or removing large objects from memory, it's also a good idea to **empty the trash**.

Use `gc()` (garbage collect) to manually[3] free up previously-allocated memory

```
gc()
```

[3] R does this automatically at various points, but it's often worth running yourself to make sure you have every bit of usable ram available

Cleaning Up

Eventually, it's a good idea to **start a new RStudio Session**.

- Your **environment** is transient; don't get too attached to it.
- Save your **script**, don't save the **environment**!
- Recreate smaller objects by re-running your script later
- Save out **large objects** that took lots of time/compute to create
- Exit RStudio when done working to return system resources

Tidyverse and Base R

Tidyverse and Base R

In R there are two main workflow approaches:

1. **Base R:** using the built-in R functionality and position indices
    - More pure "programming" approach
2. **tidyverse:** opinionated set of packages with organized grammar and data structures
    - Easily string together processing steps, produce much better visuals
        - Great free online book that teaches tidyverse: .hi-orange[[R for Data Science]

Despite what you may read on the internet, there is no **one right way** to use **R**.

We're going to cover a **combination of both** in this class, but leaning in favor of tidyverse.

Interacting with Data Frames

Interacting with Data Frames

Data frames are the **main tidyverse object**, so let's get some practice with them.

To start, let's **load a dataset**[4] from the `dslabs` package.

```r
pacman::p_load(dslabs)

# load the historic co2 dataset

data(historic_co2)
```

[4] We will learn shortly how to load and save datasets from file, too.

Data Frame Info

To learn more about a data frame, you can

- Examine its **structure** with `str()`

```r
str(historic_co2)
```

```
## spc_tbl_ [694 × 3] (S3: spec_tbl_df/tbl_df/tbl/data.frame)
##  $ year  : num [1:694] 1959 1960 1961 1962 1963 ...
##  $ co2   : num [1:694] 316 317 318 318 319 ...
##  $ source: chr [1:694] "Mauna Loa" "Mauna Loa" "Mauna Loa" "Mauna Loa" ...
```

Data Frame Info

To learn more about a data frame, you can

- Look at **column names** with `names()` or `colnames()`

```
names(historic_co2)
```

```
## [1] "year"   "co2"    "source"
```

```
colnames(historic_co2)
```

```
## [1] "year"   "co2"    "source"
```

Data Frame Info

To learn more about a data frame, you can

- Display **basic summary statistics** with `summary()`

```
summary(historic_co2)
```

```
##        year               co2            source         
##  Min.   :-803182   Min.   :177.7   Length:694        
##  1st Qu.:-470498   1st Qu.:206.7   Class :character  
##  Median : -43278   Median :236.9   Mode  :character  
##  Mean   :-219753   Mean   :245.9                     
##  3rd Qu.:  -8924   3rd Qu.:271.8                     
##  Max.   :   2018   Max.   :408.5                     
```

Data Frame Info

To learn more about a data frame, you can

- **Examine the first few rows** of data with `head(X, nrow)`

```
head(historic_co2)
```

```
## # A tibble: 6 × 3
##      year   co2 source
##     <dbl> <dbl> <chr>
## 1   1959   316. Mauna Loa
## 2   1960   317. Mauna Loa
## 3   1961   318. Mauna Loa
## 4   1962   318. Mauna Loa
## 5   1963   319. Mauna Loa
## 6   1964   320. Mauna Loa
```

Data Frame Info

To learn more about a data frame, you can

- Directly **inspect it** - either by clicking on it in the environment window or using `View()`

Subsetting with Logicals

It's often useful to **subset** a vector based on properties of another vector

i.e. Only take years with CO2 concentrations above the 98th percentile:

```
high <- historic_co2$co2 > quantile(historic_co2$co2, 0.98)
historic_co2$co2[high]
```

```
##  [1] 379.80 381.90 383.79 385.60 387.43 389.90 391.65 393.85 396.52 398.65
## [11] 400.83 404.24 406.55 408.52
```

How many years match this condition?

- `sum()` coerces T/F to 1/0

```
sum(high)
```

```
## [1] 14
```

Subsetting with %in%

Another useful way to **subset on a range of values** is `%in%`.

```r
2024 %in% historic_co2$year
```

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

Let's create a 2010s version of the data only using years 2000-2010:

```r
co2_2000_2010 <- historic_co2[historic_co2$year %in% 2000:2010,]
co2_2000_2010$year
```

```
##  [1] 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2001
```

Subsetting with `which()`

Alternatively we can subset with `which()`

- `which()` returns the position indices of elements that match a **logical condition**

```
which(historic_co2$year %in% 1920:1929)
```

```
## [1] 93 94 95 96
```

```
co2_1920s <- historic_co2[which(historic_co2$year %in% 1920:1929),]
```

Challenge

Let's practice interacting with data frames:

- Change the column name `co2` to `co2_ppm` (use `names/colnames` and indexing)
- Examine the year variable. How is it measured/reported?
- Add a new column named `co2_ppb` as the annual co2 concentration in parts per billion
  - Use arithmetic and indexing, or
  - Create as vector and add in with `cbind()` (column bind)