02. Toolkit

Data Science for Economists — Summer 2025

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Session Roadmap

- Reproducibility
- git
- Docker
- bash
- make
- R

REPRODUCIBILITY

Reproducibility

- Mostly for your future self!
- but of course also: Science.

“Trying to replicate the estimates from an early draft of a paper, we discover that the code that produced the estimates no longer works because it calls files that have since been moved.

Now: No longer works.”

"Between regressions number of observations falling. After much sleuthing, we find that many observations were dropped in a merge because they had missing values for the county identifier we were merging on. When we correct the mistake and include the dropped observations, the results change dramatically."

“Me and my coauthor write code that refers to a common set of data files stored on a shared folder. Our work is constantly interrupted because changes one of us makes to the data files causes the others’ code to break.”

8 building blocks of reproducibility

Code and Data in the Social Sciences (Gentzkow and Shapiro):

1. Automation
2. Version Control
3. Directories
4. Keys
5. Abstraction
6. Documentation
7. Management
8. Code Style

1 — Automation

Automation

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2. Write a single script that executes all code from beginning to end.

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2. Separate files into inputs and outputs.
3. Make directories portable.

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4 — Keys

Keys

1. Store cleaned data in tables with unique, non-missing keys.
2. Keep data normalized as far into your code pipeline as you can.

5 — Abstraction

Abstraction

1. Abstract to eliminate redundancy.
2. Abstract to improve clarity.
3. Otherwise, don't abstract.

6 — Documentation

Documentation

1. Don’t write documentation you will not maintain.
2. Code should be self-documenting.

7 — Management

Management

1. Manage tasks with a task management system.
2. E-mail is not a task management system.

8 — Code Style

Code Style

1. Keep it short and purposeful.
2. Use descriptive names.
3. Be consistent.
4. Profile slow code relentlessly.
5. Store “too much” output from slow code.
6. (Stick to style guide)

Quick aside: Style guides

- Google: https://google.github.io/styleguide/Rguide.html
- tidyverse: https://style.tidyverse.org

GIT AND GITHUB

Git

- Git is a distributed version control system
  $\rightarrow$ “Dropbox and the ”Track changes” feature in MS Word have a baby: Git”
- Optimized for code (not data, actually)

GitHub

- Online hosting platform that provides services built on top of the Git system

  $\rightarrow$ Similar: Bitbucket and GitLab
- Makes Git *a lot* more user friendly
- Seamless integration into lots of other software: VSCode (and RStudio)

4 main Git operations

1. Stage (or “add”): Add changes to the repo history
   → file edits, additions, deletions, etc.
2. Commit: Yes, you are sure these changes should be part of the repo history
   → need to add a message (and optionally a description)
3. Pull: Download new changes made on the GitHub repo (i.e. the upstream remote)
   → either by your collaborators or you on another machine
4. Push: Upload any (committed) local changes to the GitHub repo

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Merge conflicts

```
# README
Some text here.
<<<<<<< HEAD
Text added by Partner 2.
=======
Text added by Partner 1.
>>>>>>> 814e09178910383c128045ce67a58c9c1df3f558.
More text here.
```

- Delete lines that you don't want, then special Git merge conflict symbols
- Then: stage, commit, pull and push

Branches and forks

Branch

- Take snapshot of existing repo and try out a whole new idea without affecting your main branch
- If new idea works, merge back into main branch

  $\rightarrow$ fix bugs

  $\rightarrow$ implement new empirical strategies, robustness checks, ...
- If it doesn’t work, just delete experimental branch

Branches and forks

Fork

- Forking a repo similar to branch, but creates a copy of entire repo
- Upstream pull request makes merge back into origin repo possible

  $\rightarrow$ Easy to do on Github

.gitignore

- Tells Git what to ignore

  $\rightarrow$ exclude whole folders or a class of files (e.g. based on size or type)

- Simply add names of files or folders that should be ignored

DOCKER

“Container” technology

- Docker containers are the software equivalent

  → physical goods <-> software

  → transport modes <-> operating systems

“Container” technology

- Standardized shape and form
- “If it runs on your machine, it will run on my machine.”
- Allows to always run code from a pristine, predictable state

How it works

- Stripped-down version of an operating system

  → Usually a Linux distro like Ubuntu

- Installs all of the programs and dependencies that are needed to run the code

  → + add any extra configurations that are needed/wanted

- Package everything up as a tarball (i.e. compressed file)

  → Containers are like mini, portable OS that contain everything needed to run some piece of software (but nothing more!)

Docker terminology

- Dockerfile: “The sheet music”

  → list of layers and instructions for building a Docker image

- Image: “The MP3 file”

  → tarball packages everything needed

- Container: “Song playing on my phone”

  → running instance of an image

Minimal working example

```
$ docker run --rm -it rocker/r-base
```

docker `run flags`

- `--rm` automatically removes the container once it exits (i.e. clean up)
- `-it` Launch with interactive (i) shell/terminal (t)

A bit more sophisticated working example

```
$ docker run -d -p 8787:8787 -e PASSWORD=verystrong rocker/tidyverse
```

docker `run flags`

- `-d` detach (i.e. run as background process)
- `-p 8787:8787` share a port with the host computer's browser
- `-e PASSWORD=pswd123` set password for logging on to RStudio Server
- `rocker/tidyverse:4.0.0` prepared `tidyverse` image built on top of R 4.0.0

SHELL

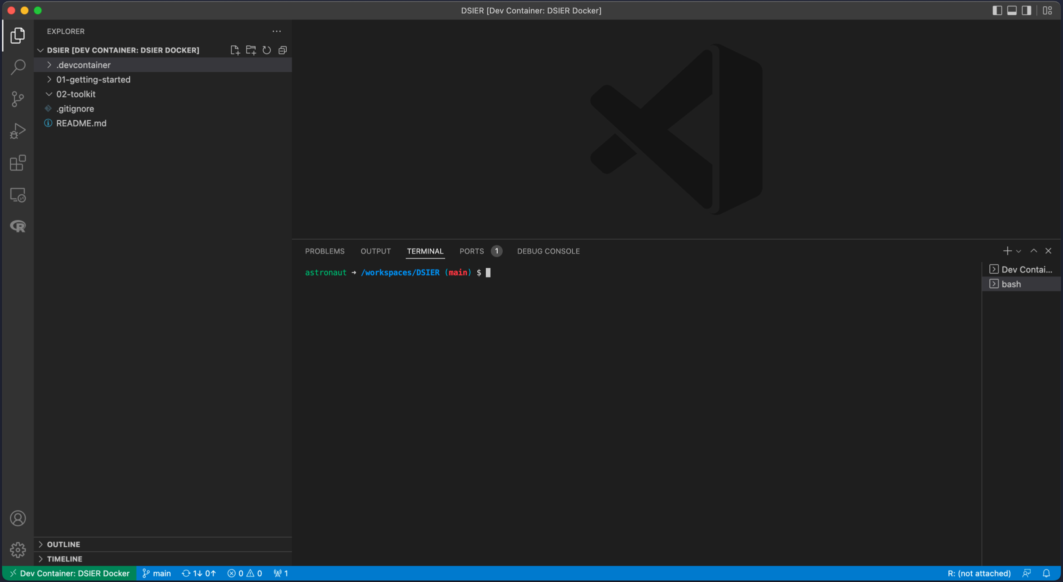
Shell

- Terminology: shell, terminal, tty, command prompt, etc.

  $\rightarrow$ Same same: command line interface (CLI)
- Many shell variants: focus on Bash (“Bourne again shell”)
- Included by default on Linux and MacOS
- Windows users need to install a Bash-compatible shell

Shell

- Powerful: executing commands and for fixing problems
  $\rightarrow$ some things you just can't do in an IDE or GUI
- Reproducibility: Scripting is reproducible, clicking is not
- Remote: Interacting with servers and super computers
- Automation: workflow and analysis pipelines, e.g. with Makefile



```
astronaut → /workspaces/DSIER (main) $
```

SHELL

Basics

```
username@hostname:~$
```

- `username` denotes a specific user
- `hostname` denotes name of the computer
- `:~` denotes the directory path (where `~` signifies the user’s home directory).
- `$` denotes the start of the command prompt (`#` for root)

Keyboard shortcuts

- Tab completion
- ↑ (and ↓) keys to scroll through previous commands
- Ctrl + → (and Ctrl + ←) to skip whole words at a time
- Ctrl + a moves the cursor to the beginning of the line
- Ctrl + e moves the cursor to the end of the line
- Ctrl + k deletes everything to the right of the cursor
- Ctrl + u deletes everything to the left of the cursor
- Ctrl + Shift + c to copy and Ctrl + Shift + v to paste

Syntax

- `command option(s) argument(s)`

```
astronaut → /workspaces/DSIER (main) $ ls -lh
total 4.0K
drwxr-xr-x 3 astronaut astronaut  96 Apr 26 19:03 01-getting-started
drwxr-xr-x 2 astronaut astronaut  64 Apr 26 19:03 02-toolkit
-rw-r--r-- 1 astronaut astronaut 135 Apr 19 15:43 README.md
```

→ start with a dash, usually one letter
→ multiple options can be chained under single dash, sometimes two

```
$ ls -lah 01-getting-started/
$ ls --group-directories-first --human-readable 01-getting-started/
```

- arguments usually on file or directory

man and cheat

-
  ```
  man ls
  ```

-
  ```
  $ cheat ls
  ## # Displays everything in the target directory
  ## ls path/to/the/target/directory
  ##
  ## # Displays everything including hidden files
  ## ls -a
  ##
  ## # Displays all files, along with the size (with unit suffixes) and timesta
  ## ls -lh
  ##
  ## # Display files, sorted by size
  ## ls -S
  ```

Navigation

- `pwd` to print working directory
- `cd` to change directory

```
astronaut → /workspaces/DSIER (main) $ pwd
/workspaces/DSIER
astronaut → /workspaces/DSIER (main) $ cd ../
astronaut → /workspaces $ pwd
/workspaces
astronaut → /workspaces $
```

Create files and directories

- `touch` and `mkdir`

```
$ mkdir testing
$ touch testing/test1.txt testing/test2.txt testing/test3.txt
$ ls testing
test1.txt  test2.txt  test3.txt
```

Removing files and directories

- `rm`

```
$ rm testing/test1.txt
$ ls testing
test2.txt  test3.txt
$ rm testing
rm: cannot remove 'testing': Is a directory
$ rm -rf testing
$ ls testing
ls: cannot access 'testing': No such file or directory
```

- “recursive” (-r or -R) and ”force” (-f) options

Copying

- `cp object path/copyname`

  → keeps old name if not provided with new one

```
$ touch example.txt
$ mkdir testing
$ cp example.txt testing
$ ls testing
example.txt
```

Moving and renaming

- `mv object path/newobjectname`

```
$ mv example.txt testing/example2.txt
$ ls testing
example2.txt  example.txt
$ mv testing/example2.txt testing/example_new.txt
$ ls testing
example_new.txt  example.txt
```

Wildcards

- Wildcards: special characters as replacements for other characters
- Replace any number of characters with *

```
$ cp examples/*.sh examples/copies ## Copy any file with .sh extension
$ rm examples/copies/* ## Delete everything in the "copies" directory
```

- Replace a single character with ?

```
$ ls examples/meals/??nday.csv
$ ls examples/meals/?onday.csv
## examples/meals/monday.csv
## examples/meals/sunday.csv
## examples/meals/monday.csv
```

MORE USEFUL COMMANDS

Working with text files

- Print whole file with `cat` ("concatenate")

```
$ cat -n examples/sonnets.txt
```

- Print only first or last couple of lines with `head` and `tail`

```
$ head -n 3 examples/sonnets.txt ## First 3 rows
$ tail -n 1 examples/sonnets.txt ## Last row
```

Working with text files

- Search within files: `grep` ("Global regular expression print")

```
$ wc examples/sonnets.txt
 2633 17698 95662 examples/sonnets.txt

$ grep -n "Shall I compare thee" examples/sonnets.txt
```

Redirect

- Send output from the shell to a file using redirect operator `>`

```
$ echo "At first, I was afraid, I was petrified" > survive.txt
$ find survive.txt
survive.txt
```

- To append file, use `>>` (`>` overwrites)

```
$ echo "'Kept thinking I could never live without you by my side" >> survive.
$ cat survive.txt
At first, I was afraid, I was petrified
'Kept thinking I could never live without you by my side
```

Pipes

- Awesome feature: send (“pipe”) output to another command with `|`

$\rightarrow$ chain together a sequence of simple operations

```
$ cat -n examples/sonnets.txt | head -n100 | tail -n10
```

Compress and decompress

- Compress data with `zip` and decompress with `unzip`

```
$ zip archive.zip examples/sonnets.txt
  adding: examples/sonnets.txt (deflated 59%)

$ unzip -l archive.zip
Archive:  archive.zip
  Length      Date    Time    Name
---------  ---------- -----   ----
    95662  2022-04-26 20:18   examples/sonnets.txt
---------                     -------
    95662                     1 file

$ unzip archive.zip -d examples
Archive:  archive.zip
  inflating: examples/examples/sonnets.txt
```

LOOPS AND SCRIPTING

Loops

- Repeat operation over set: Loops

```
for i in LIST
do
  OPERATION $i
done
```

- Example: Combing csv files

```
$ touch examples/meals/mealplan.csv
## loop over the input files and append their contents to our new CSV
$ for i in $(ls examples/meals/*day.csv)
> do
>   cat $i >> examples/meals/mealplan.csv
> done
```

Scripting

- .sh file with code can be executed

```
#!/bin/sh
echo -e "\nHello World!\n"
```

- `#!/bin/sh` is a shebang, indicating which program to run the command with

  → -e flag tells bash that we want to evaluate an expression rather than a file

```
$ examples/hello.sh
Hello World!
```

- Not limited to running shell scripts in the shell
- Example: `Rscript`

```
$ Rscript -e 'cat("Hello World, from R!")'
Hello World, from R!
```

MAKE

Build systems

- Sequence of operations to go from inputs to outputs

  $\rightarrow$ Define dependencies, targets, and rules

- Avoid unnecessary rule execution

- Many build systems, `make` is a common choice

Makefile Example

```
target … : prerequisites …
        recipe
        …
paper.pdf: paper.tex plot-data.png
    pdflatex paper.tex

plot-%.png: %.csv plot.R
    ./plot.r -i $*.csv -o $@
```

- Targets, dependencies, and rules defined in Makefile
- % is a pattern, matching the same string on left and right
- wildcard $*$ searches your filesystem for matching filenames
- $@ is an automatic variable that contains the target name

Running make

```
$ make
make: *** No rule to make target 'paper.tex', ...
$ touch paper.tex
$ make
make: *** No rule to make target 'plot-data.png', ...
```

- make checks for rules and dependencies

  $\rightarrow$ complains if dependencies are missing

Building with make

```
$ cat paper.tex
$ cat plot.r
$ cat data.csv
$ make
./plot.r -i data.csv -o plot-data.png
pdflatex paper.tex
```

- Creates a PDF when all dependencies are satisfied
- Running `make` again shows it's up to date

make

- Build systems, like `make`, automate the build process
- Saves time and ensures consistency in complex projects
- Essential tool for managing dependencies and targets

WRAP UP

- So far: Shell, git and Make
- This afternoon: R

02. Toolkit

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