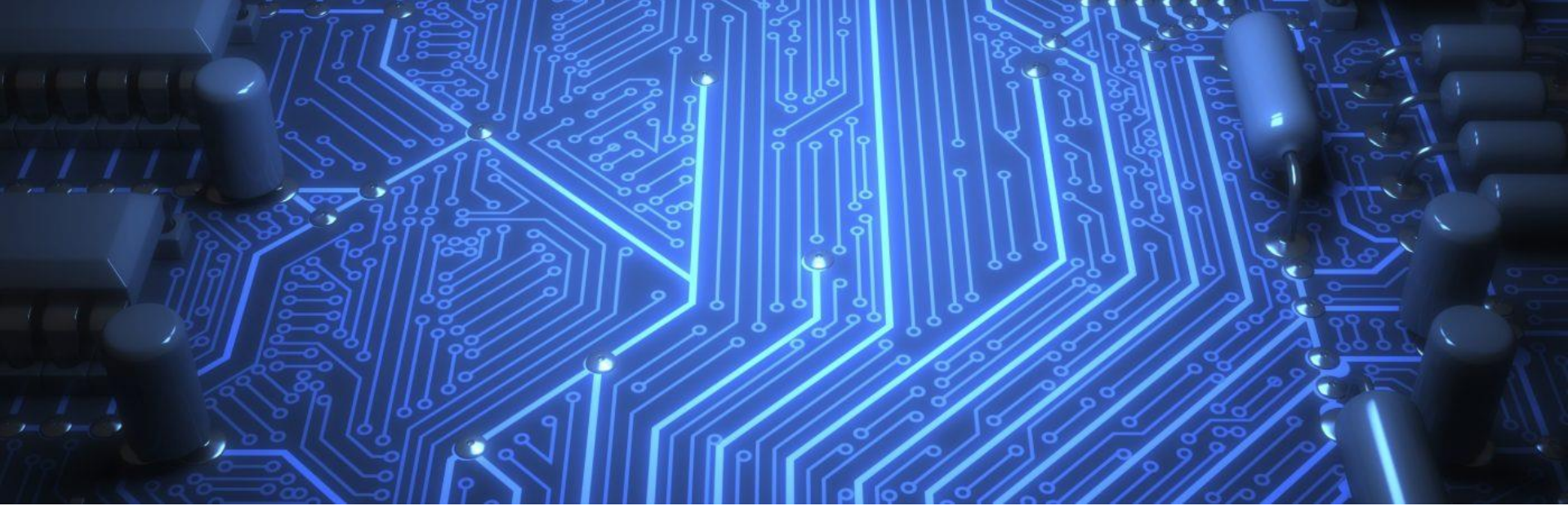


TERMINAL, GIT, AND GITHUB

MIT MANAGEMENT SLOAN SCHOOL

OPERATIONS RESEARCH CENTER

IAP 15.S60 Session 1
Alex Schmid

Today's Learning Objectives

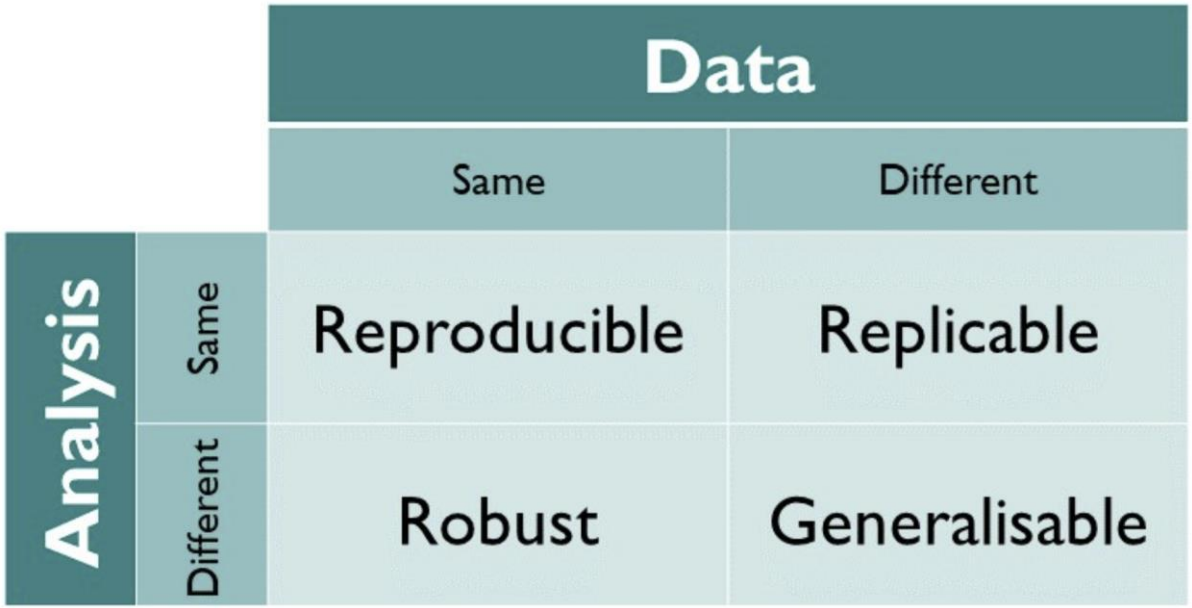
- Describe the importance of reproducibility in coding projects
- Enter basic commands in terminal to navigate a file system, manipulate files, and run scripts
- Maintain proper version control for a coding project using git
- Collaborate on a coding project with Github

Reproducibility

Motivation for today's class
Adapted from slides by Sam Gilmour and the Turing Way

What is reproducibility?

"The ability to obtain consistent results no matter the machine a project runs on."



Tools for reproducibility

- **Version control** – maintain a history of your project to better track changes and decisions
- **Testing** – simple tests to detect errors and changes in functionality when new features are added
- **Maintaining a reproducible computational environment** –for example, software and package versions
- Making code and data **open and available** when possible

My reproducibility nightmare

- In my first PhD research project, I created a new optimization model and algorithm for a problem. I ran my computational experiments without reproducibility in mind.
- Months later, we finished writing the paper and stumbled on a new model that was wayyyyy better and faster. Welp… **Time to re-run everything!**
  - Spent days trying to get code set up to run again
  - New results didn't match up with original results
  - Eventually, I tracked down a single parameter I had changed
  - I changed the parameter and re-ran everything again
  - Took me **weeks of work** and huge amounts of **cluster resources**

Think-Pair-Share Activity

- **Think** about a non-reproducible or non-auditable workflow you have used before at work, in research, on a personal project, or in coursework that negatively impacted your work somehow **(2 minutes)**

- **Pair** with the person beside you and share your story and how it negatively impacted you **(3-4 minutes)**

- We'll come back together as a class and **share** a few stories

What is reproducibility good for?

Tools for reproducibility

- **Version control** – maintain a history of your project to better track changes and decisions
- **Testing** – simple tests to detect errors and changes in functionality when new features are added
- **Maintaining a reproducible computational environment** –for example, software and package versions
- Making code and data **open and available** when possible

Another Think-Pair-Share

- **Think** about barriers that prevent you (or may prevent others) from using a reproducible and auditable workflow. What makes reproducibility a hard standard to meet? **(2 minutes)**

- **Pair** with the person beside you and share 1-2 things that might make reproducibility hard for you or others **(2 minutes)**

- We'll come back together as a class and **share** some ideas

Failure Case

Clinical trials for 110 cancer patients hoping to identify personalized treatments based on gene signatures

Strong results, high-impact publications

Experts find errors in analysis

- Excel formula errors
- Poor documentation

Trials terminated, 25 papers retracted

Tools for Reproducible Research

Git - Version control system

- Command line tool
- Used to make and document local code changes (and communicate those changes with Github)

Github - Hosting platform for version control and collaboration

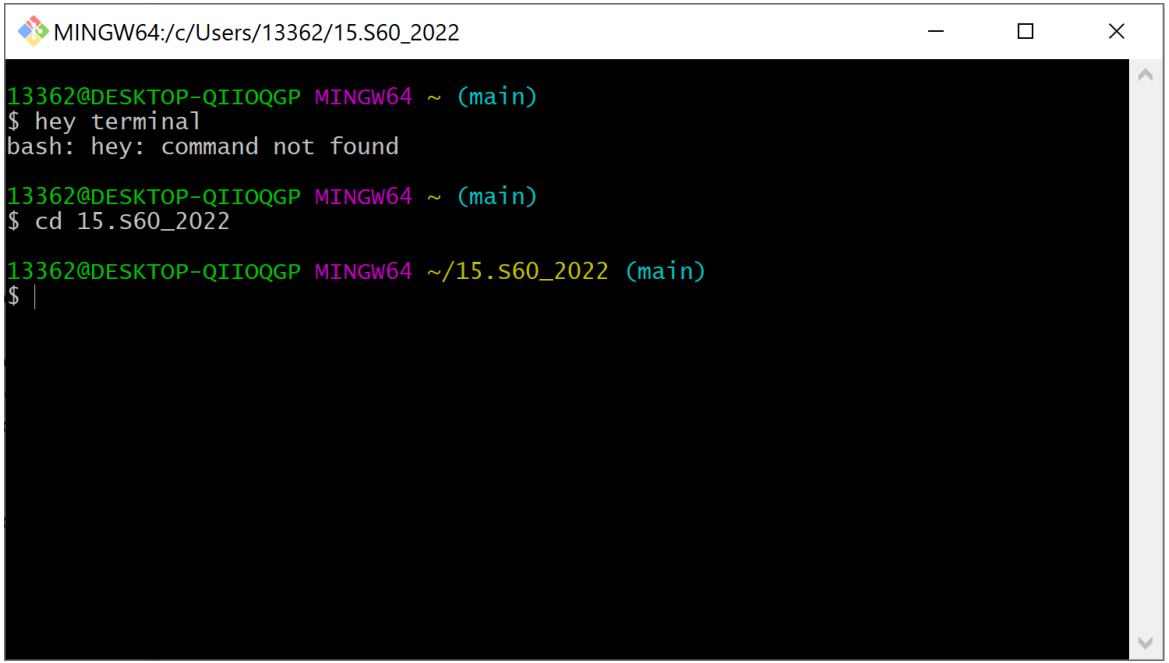
- Widely used by developers to store their projects
- Easily share code and data, privately and publicly

Terminal

Adapted from slides by Galit Lukin, Jackie Baek

What is the terminal?

The terminal/Unix shell is a text-based interface to interact with the computer.



Why use the terminal?

Repetitive tasks, like “delete all files in a directory ending in .csv”

python

Chain commands across programming languages sequentially

Athena

MIT MANAGEMENT SLOAN SCHOOL Engaging

Access to client servers and computing clusters with Secure Shell (SSH)

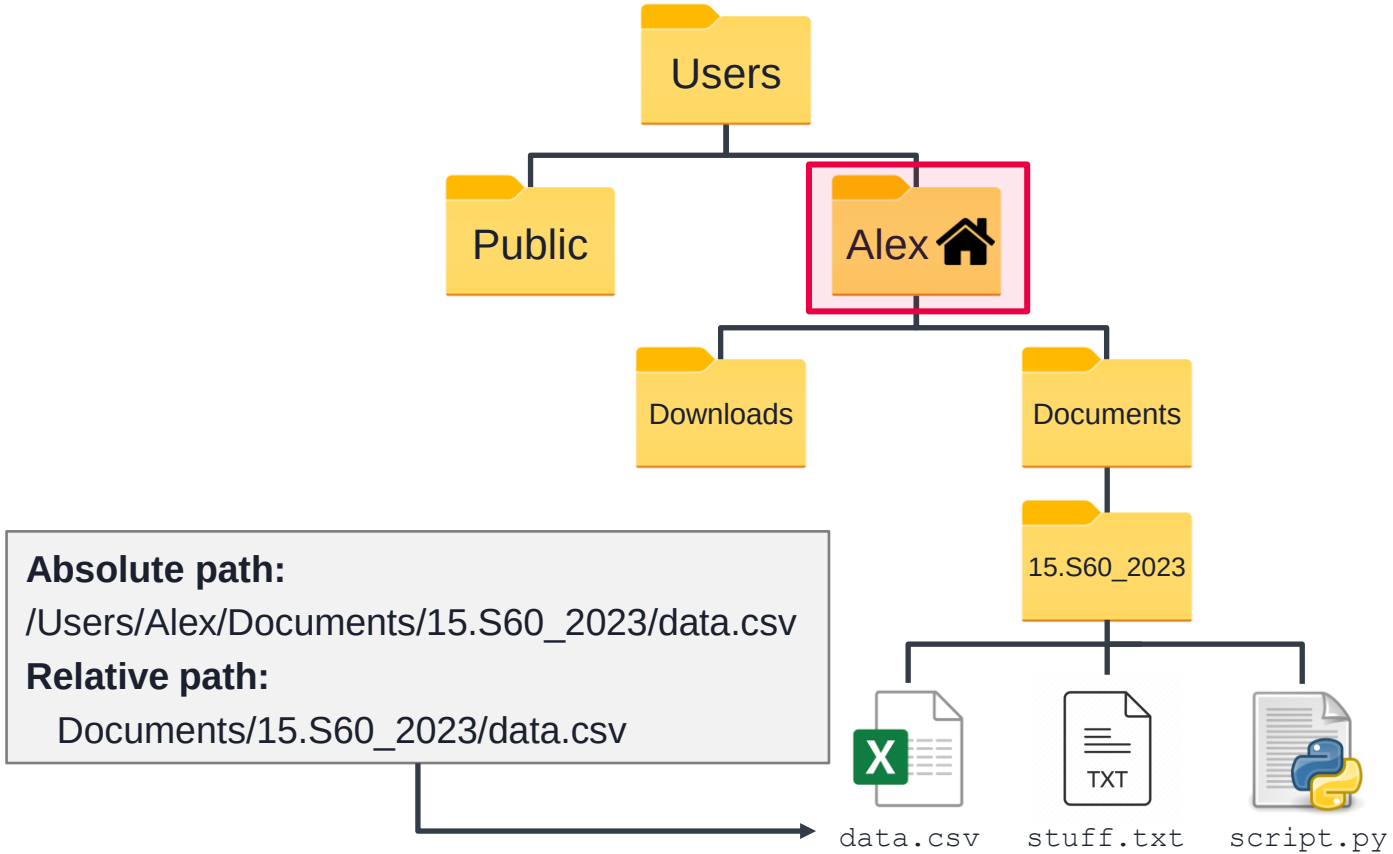
We must learn a few basic commands to interact!

Learning Objectives - Terminal

At the end of the session, students will be able to…

- Navigate directories and manipulate files using terminal commands
- Recognize scenarios when it is necessary or more efficient use the terminal rather than a graphical interface

Files and Directories



Terminal Basics

- We are using a shell called **bash.** This program will interpret and process the commands you input into the terminal.
- A typical command looks like:

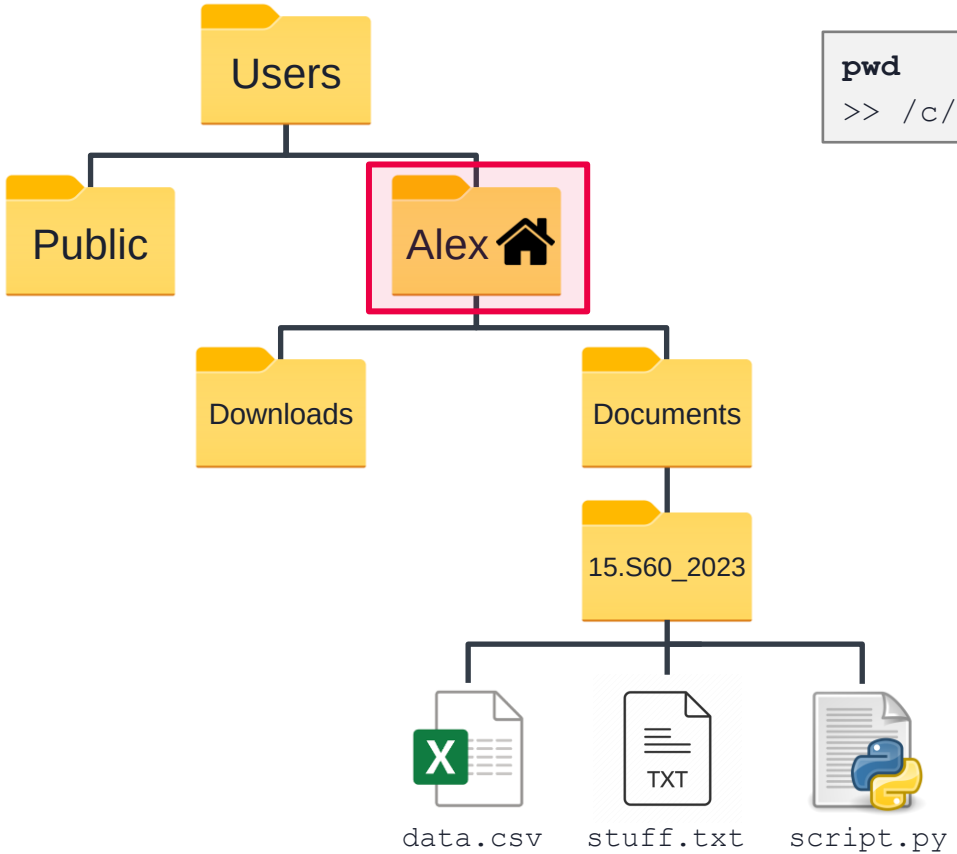
```
command <argument1> <argument2> …
```

To open:

- Mac users open Terminal
- Windows users open Git Bash (installed in the pre-assignment)

Navigating – Commands

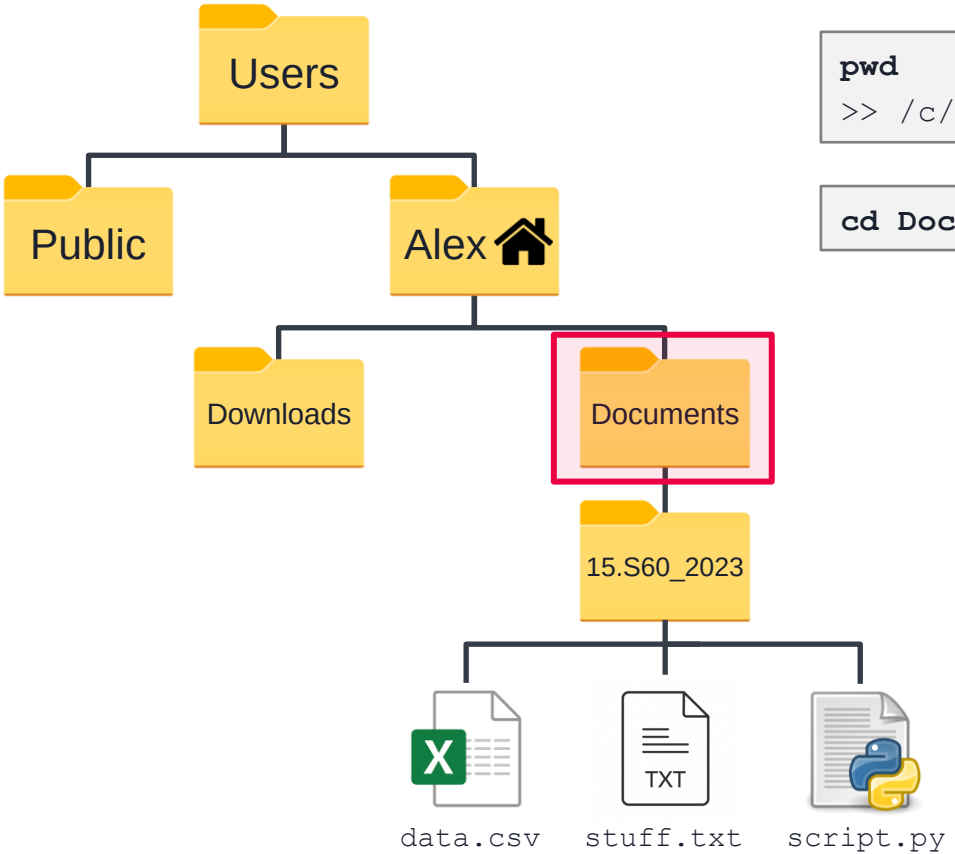
Working directory




```
pwd
>> /c/Users/Alex
```

Navigating – Commands

Working directory

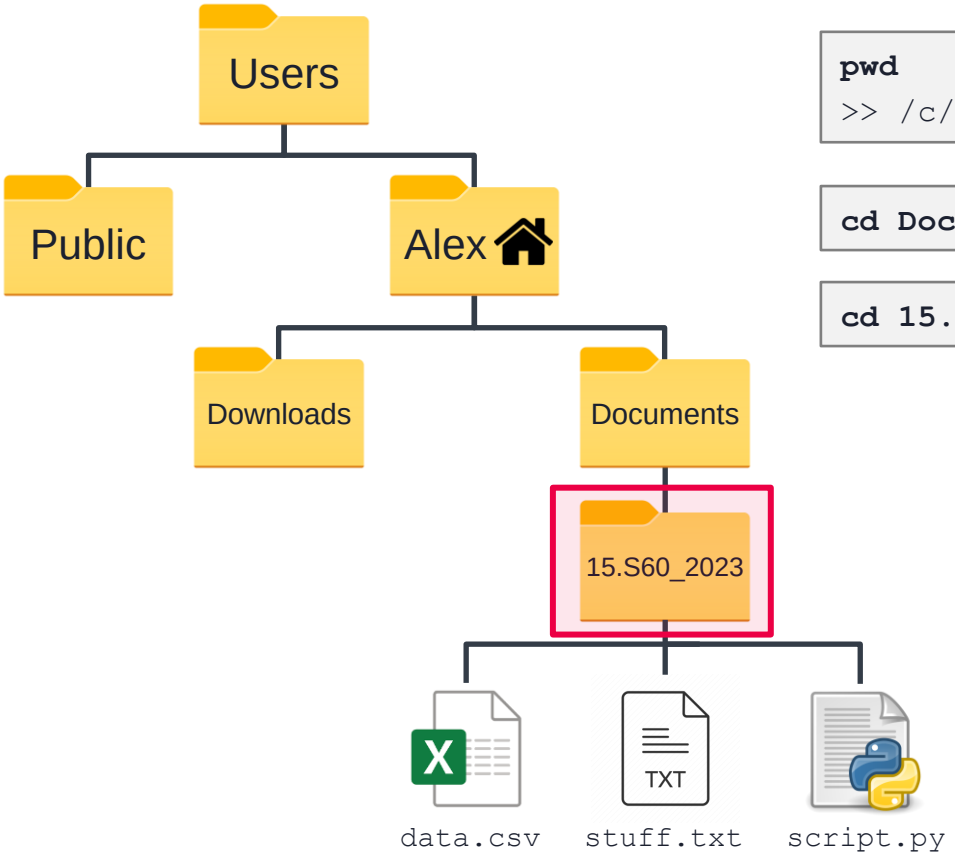



```
pwd
>> /c/Users/Alex
```

```
cd Documents
```

Navigating – Commands

Working directory



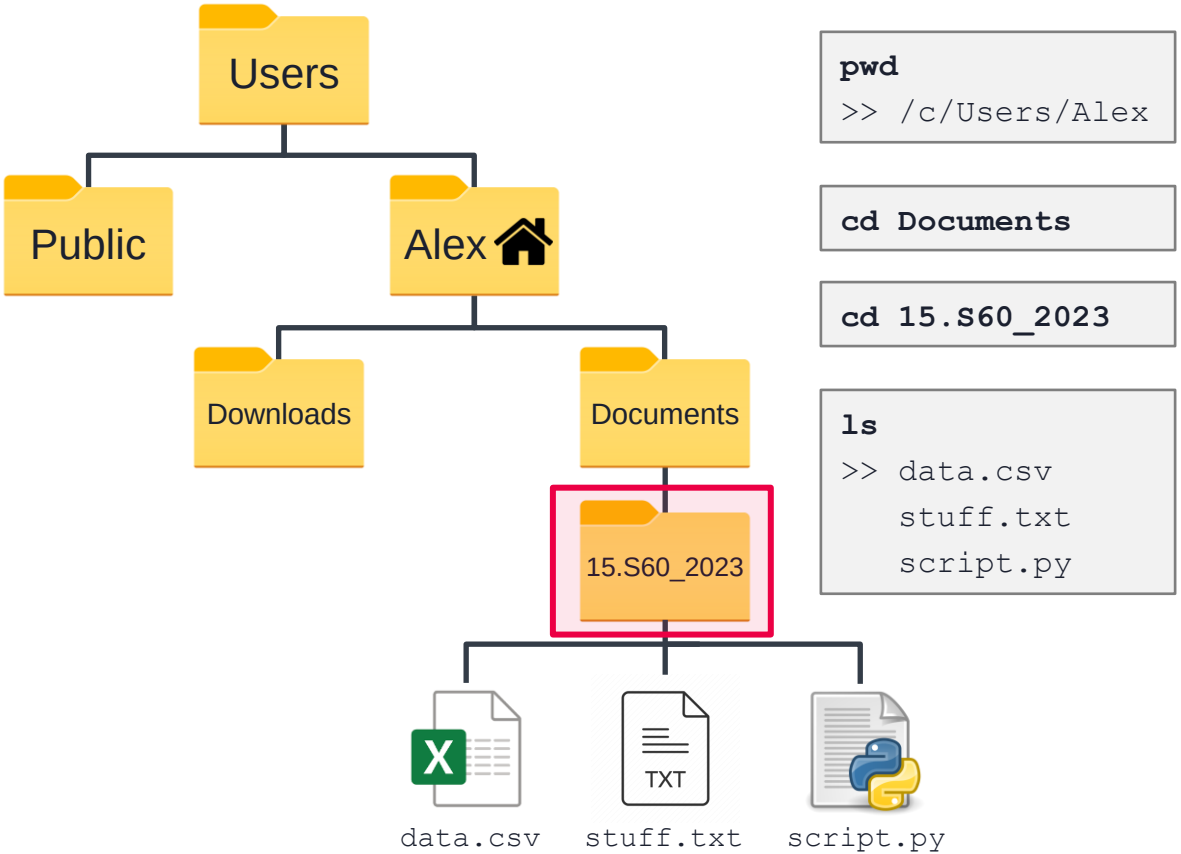

```
pwd
>> /c/Users/Alex
```

```
cd Documents
```

```
cd 15.S60_2023
```

Navigating – Commands

Working directory




```
pwd
>> /c/Users/Alex
```

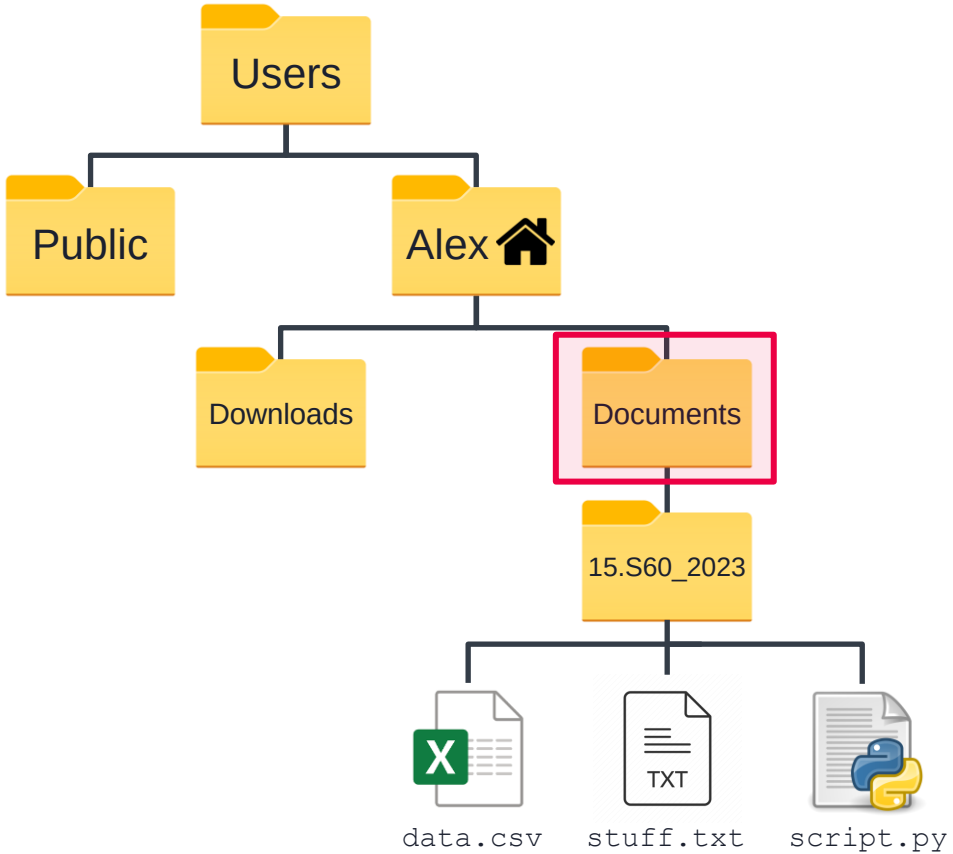
```
cd Documents
```

```
cd 15.S60_2023
```

```
ls
>> data.csv
   stuff.txt
   script.py
```

Navigating – Commands

Working directory



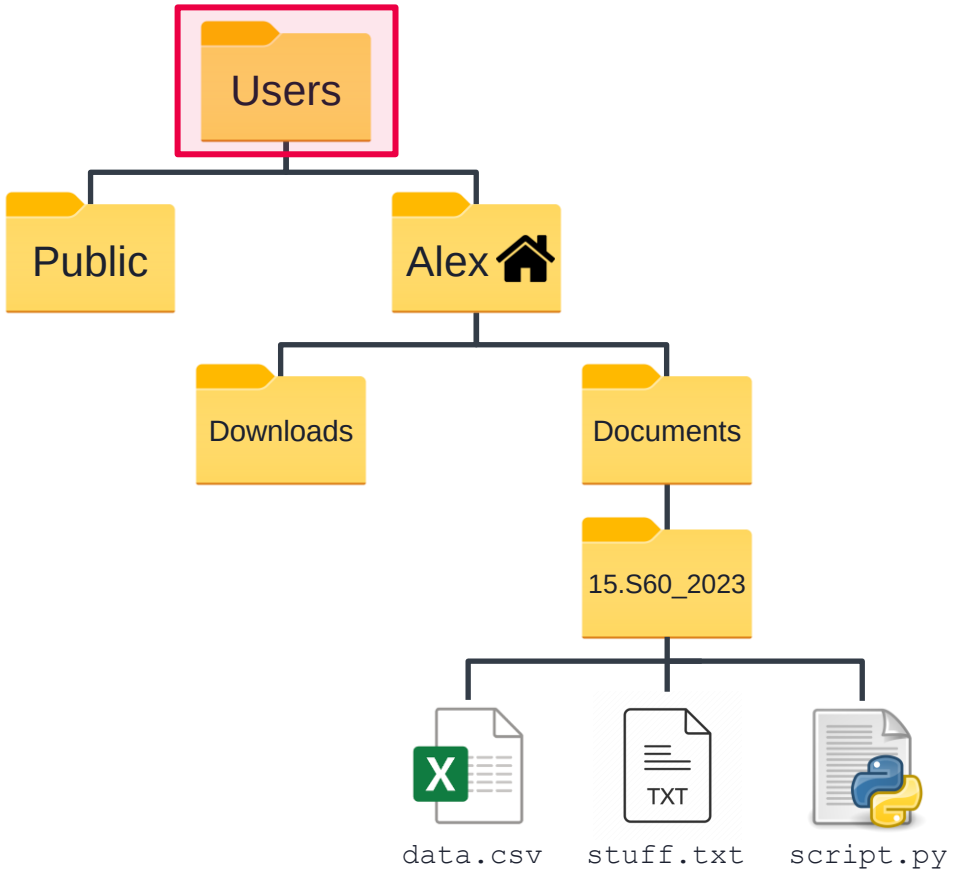

```
cd ..
```

Navigating – Commands

Working directory

```
cd ../..
```

```
cd ..
```



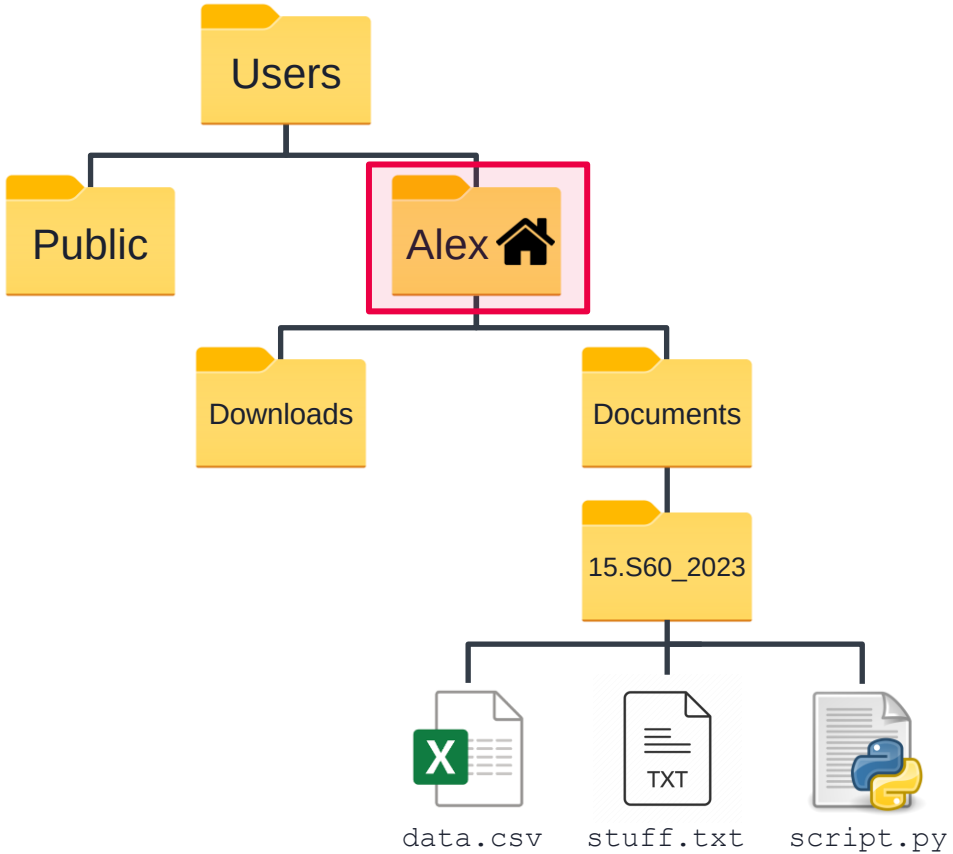
Navigating – Commands

Working directory

```
cd
```

```
cd ../..
```

```
cd ..
```



Navigating – Commands

Print working directory	`pwd`
List contents of working directory	`ls`
List contents of specified directory	`ls <directory_name>`
Change to a new directory	`cd <directory_name>`
Return to “home” directory	`cd`
Open a file (analogous to double clicking)	`open <filename>`

Navigating – Commands 2

Reference current working directory	.
Reference parent of current working directory	. .
Reference home directory	~

- Navigate history of previous commands using up and down arrow keys
- Use tab to autocomplete commands and paths

Poll Question

If our current working directory is `Users/Alex/Documents`, which command would take us back to the home directory, `Users/Alex`?

A.) `cd ..`

B.) `cd ../..`

C.) `cd ~`

D.) `cd .`

E.) `cd`

Navigation – Try it out

1. Open Terminal (MacOS) or Git Bash (Windows)
2. Navigate to the class directory from the pre-assignment

```
cd 15.S60_2023
```

3. Pull the class Github to get any updates

```
git pull
```

4. Navigate to the class directory from the pre-assignment

```
cd 1_terminal_and_git
```

5. Print off the list of files in that directory
6. Navigate back to your home directory

File Manipulation – Commands

Create a new directory	`mkdir <directory_name>`
Create a new file	`touch <filename>`
Delete a file **(cannot be undone!)**	`rm <filename>`
Edit file contents (Nano is a text editor)	`nano <filename>`
Print contents of a file	`cat <filename>`
Move or rename a file	`mv <source_filename> <target_filename>`

File Manipulation – Demo

We want to create a new directory called `mydirectory`, navigate to it, add a new file called `myfile.txt`, then add a line of text to the file.

1. Create and navigate to a new directory

```
mkdir mydirectory
cd mydirectory
```

2. Add and open a new file for editing

```
touch myfile.txt
nano myfile.txt
```

3. Add some text, save, and exit Nano

File Manipulation – Try it out

We want to create a directory within `mydirectory` called `data`, navigate to it, add a new file called `mydata.csv`. Then navigate back to `mydirectory`.

Redirecting Outputs

Run a script

Send the output log to a file

(rather than the terminal)

```
python processStuff.py > outputfile.txt
```

Redirecting Outputs

Run a script

Send the output log to a file

(rather than the terminal)

Overwrite / create file

```
<command> > outputfile.txt
```

Append to file

```
<command> >> outputfile.txt
```

Redirecting Outputs - Demo

I can create a Julia script in `mydirectory` called `myscript.jl`. I can then run it and direct the output to a file called `scriptoutput.txt`.

1. Create new text file

```
touch myscript.jl
```

2. Print the contents of the directory and redirect the output

```
julia myscript.jl > scriptoutput.txt
```

3. Check the output:

```
cat scriptoutput.txt
```

Redirecting Outputs - Try it out

Create another text file in `mydirectory` called `newfile.txt`. Print the contents of `mydirectory` and direct the list to a file called `outputfile.txt`.

What is Bash actually doing?

Two types of commands, internal (built-in to the shell) and external

```
13362@DESKTOP-QIIOQGP MINGW64 ~/myrepo (master)
$ type cd
cd is a shell builtin

13362@DESKTOP-QIIOQGP MINGW64 ~/myrepo (master)
$ type cat
cat is hashed (/usr/bin/cat)
```

When you run an external command like `cat`, bash looks for a program with that name under the directories listed in the $PATH environment variable and spawns a process that executes the program

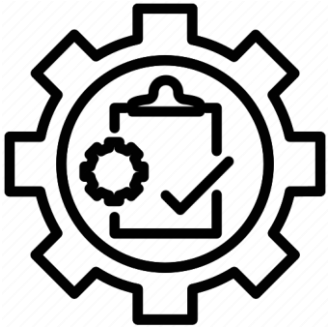
More Terminal

There are many more things you can do in Terminal.

Simple pattern matching to find and sort files

`readdata.py` `makeplots.R`

Use multiple programming languages to run sequential processes



Shell scripts to automate chains of commands you use often

If you're interested, check out the tutorial here: https://swcarpentry.github.io/shell-novice/

Break

Resume in 10 minutes

Git

Adapted from slides by Galit Lukin and Jackie Baek
with activities from Turing Way and Software Carpentry

Learning Objectives – Git/Github

At the end of the session, students will be able to:

- Maintain a version control history with appropriate documentation
- Contribute to a project with shared code
- Share and contribute code to the broader community

Git and Github

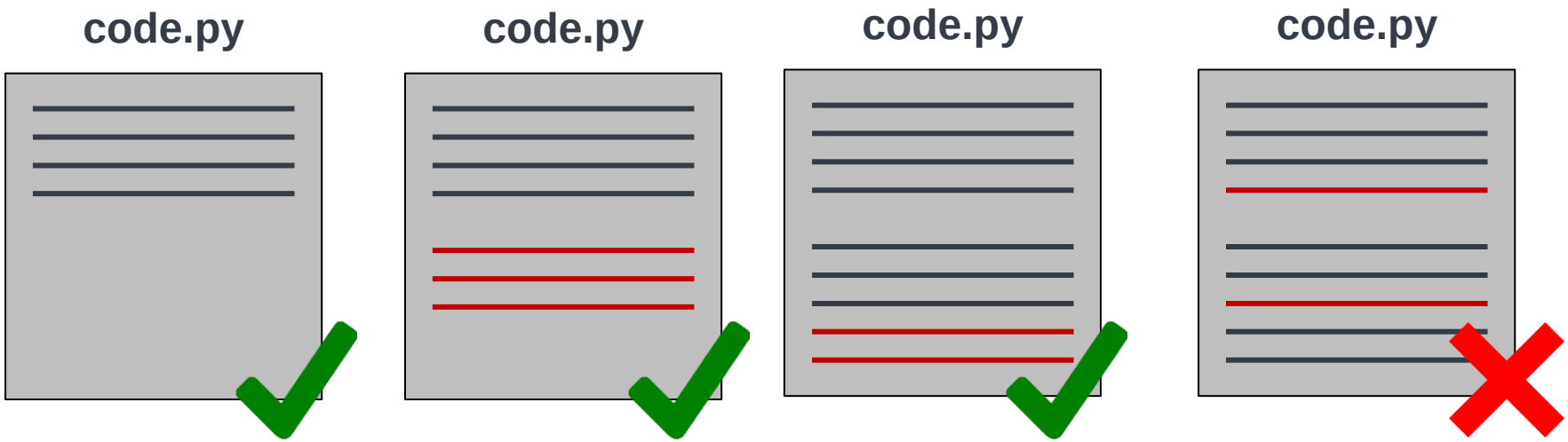
Github - Hosting platform for version control and collaboration

- Widely used by developers to store their projects
- Easily share code and data, privately and publicly

Git - The version control system itself

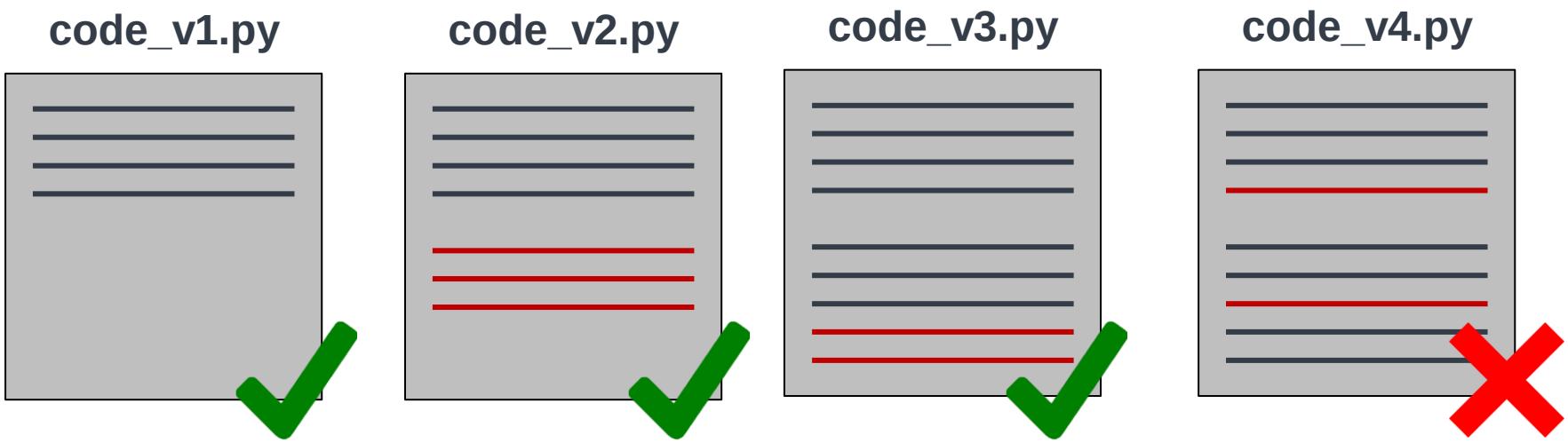
- Command line tool
- Used to make local code changes and communicate those changes with Github

Why use version control (Git)?



If only I could go back to a version that was working…

Why use version control (Git)?



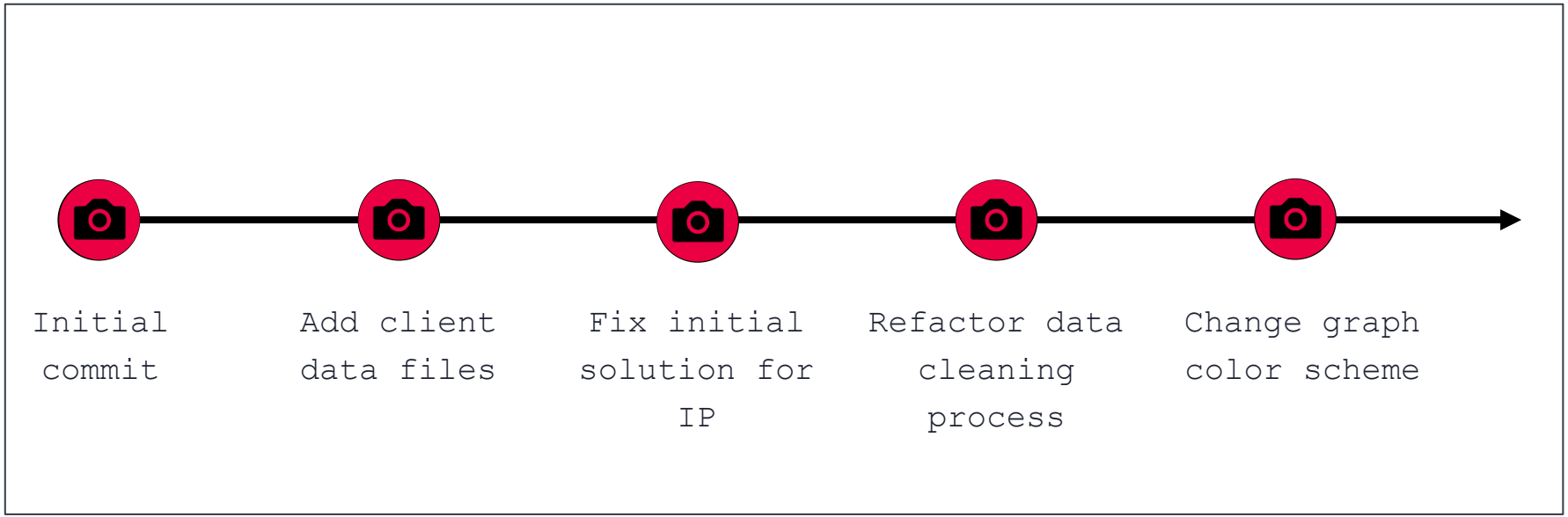
What changed between versions? Which version to go back to? What if it's been months since I worked on this? What if my project has many files?

High-Level Idea

repository (aka repo)

Benefits:

- Git stores commit messages
- Snapshot of entire repo, not one file
- Commits are lightweight



Create a repository - Commands

1. Create a new directory for your repo

```
mkdir <directory_name>
```

---

2. Navigate to the directory

```
cd <directory_name>
```

---

3. Initialize repository (you only need to do this once for each repo you create)

```
git init
```

Initialize a Git Repo - Demo

Let's turn `mydirectory` into a git repo.

1. Navigate to a `mydirectory` if you aren't already there

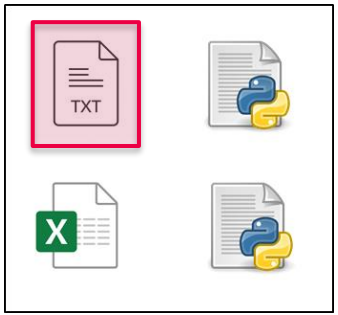
```
cd mydirectory
```

2. Initialize the git repo

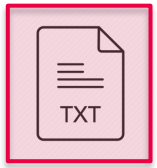
```
git init
```

Add and commit

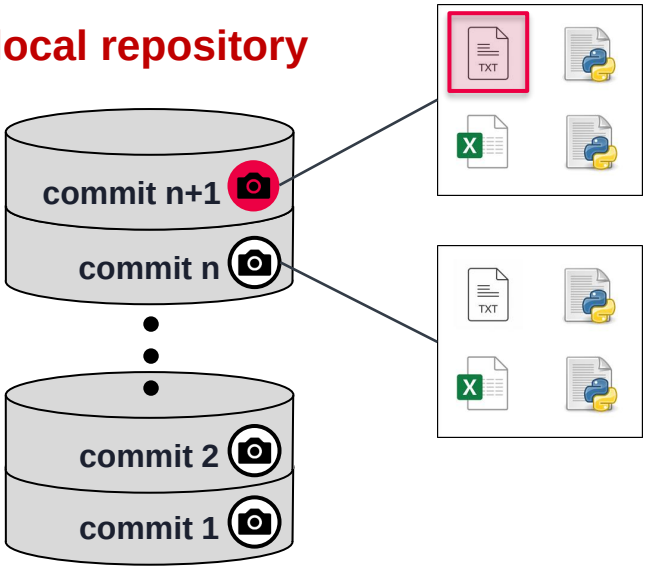
working directory



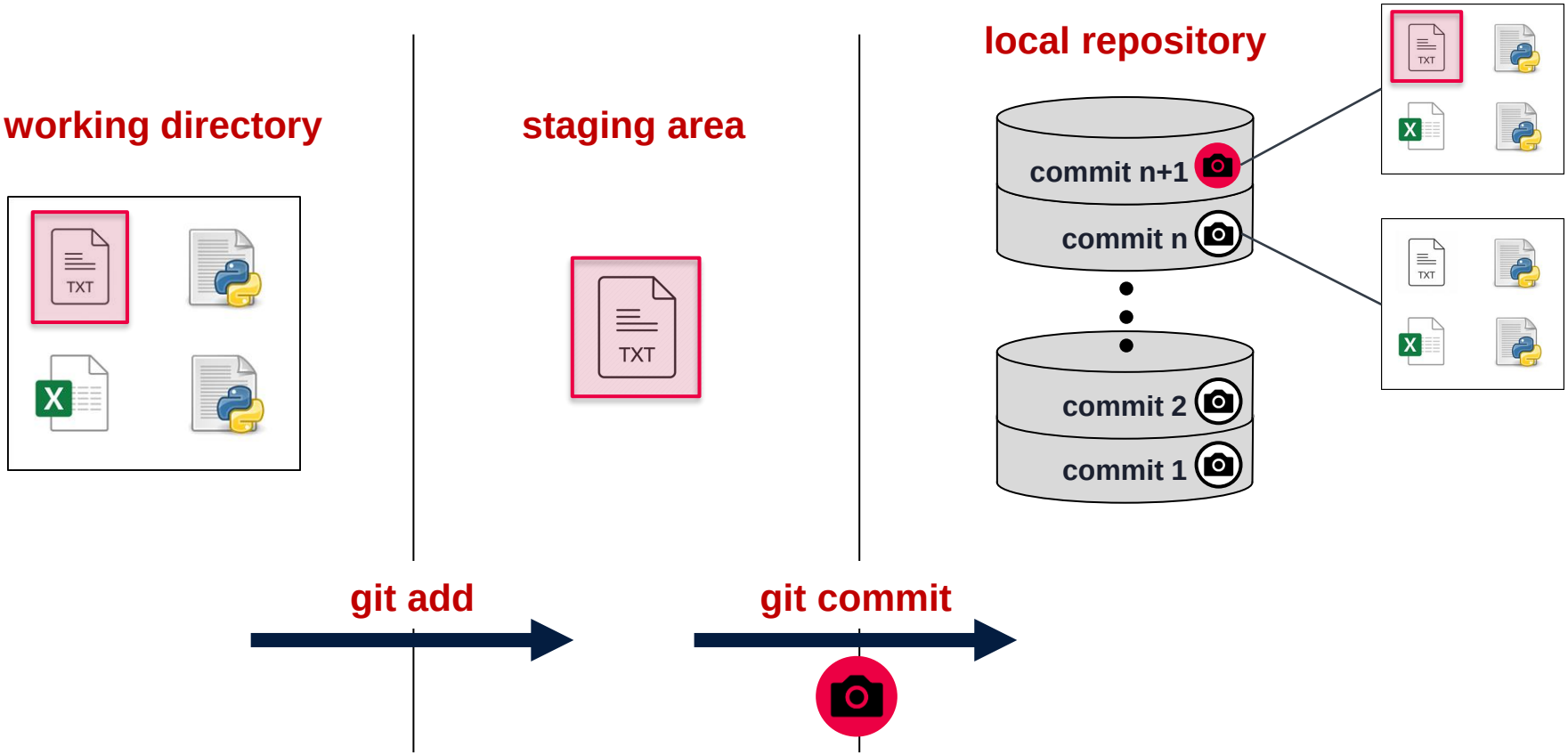
staging area



local repository



Add and commit



Add and commit - Commands

1. Make changes in working directory

---

2. Check the files in the staging area and any “untracked” changes (not yet added)

```
git status
```

---

3. As you change files:
working directory → staging area

```
git add <filename>
```

```
git add .  (adds all files)
```

---

4. Once you have added a new functionality/completed an update:
staging area → local repo

```
git commit –m “comment”
```

Add a short, intuitive comment describing the change in functionality
→ For reference later!

Poll Question

In your opinion, which would be the most helpful commit message three months from now?

A.) `"Fix bug"`

B.) `"Add functions: cleanData, processData, runPredictions"`

C.) `"Add function to plot results"`

D.) `"Write the new optimization model"`

Add and commit - Demo

Let's commit something to `mydirectory`! Run `git status` between each step to see the staging area.

1. Add a new text file

```
touch newfile.txt
git status
```

2. Add the file to the staging area

```
git add newfile.txt
git status
```

3. Commit the changes to the repository

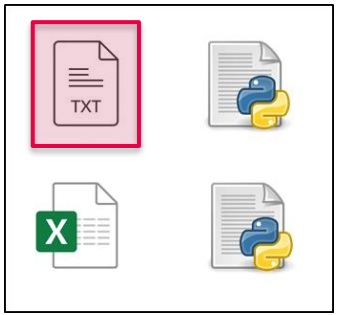
```
git commit -m "Add empty file"
git status
```

Add and commit - Try it out

We want to create a new repository called `myrepo` (outside of `mydirectory`), create a text file in `myrepo` called `myfile.txt`, and add and commit it to the repository.

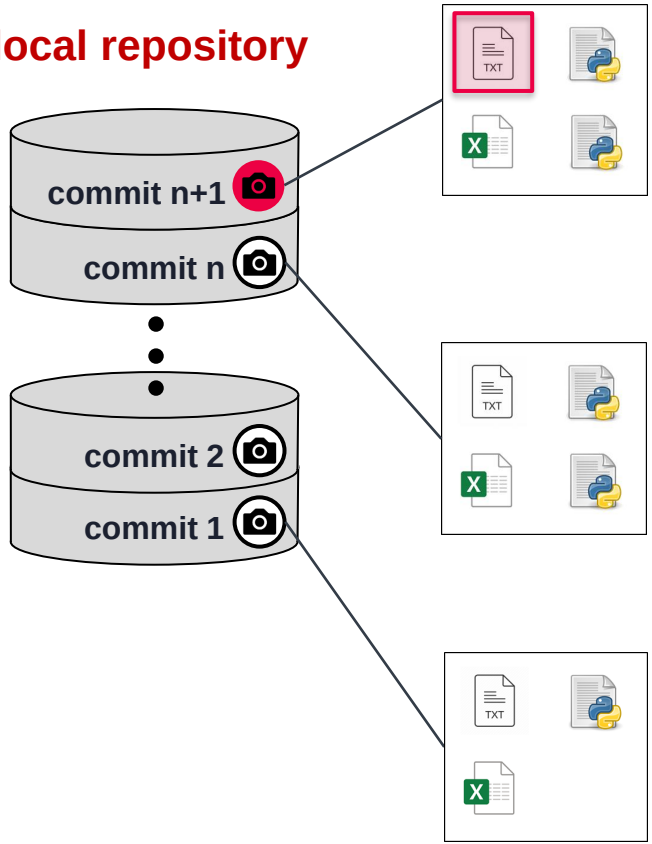
Reverting Changes

working directory



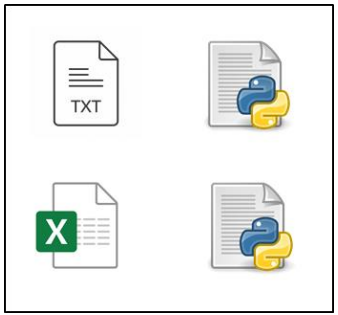
staging area

local repository

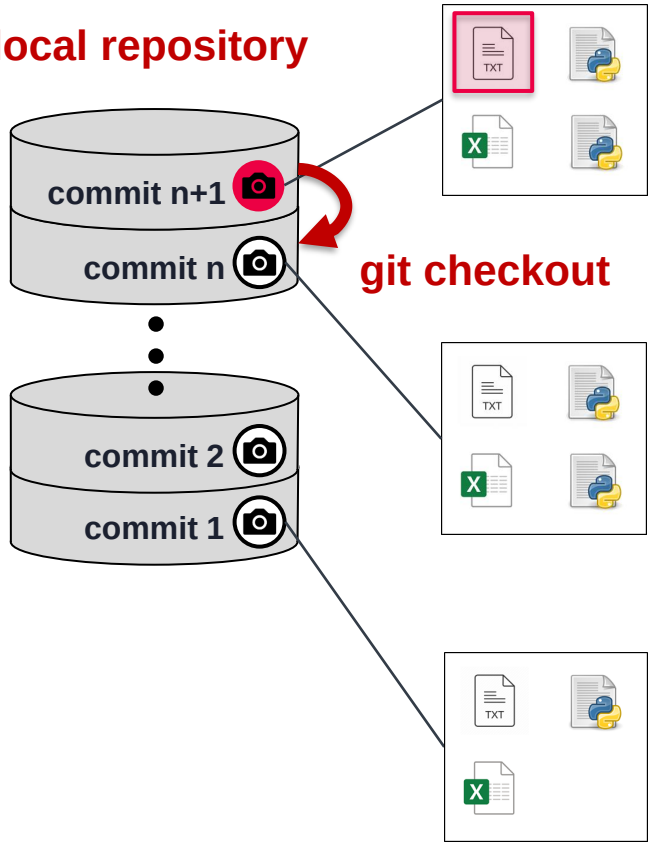


Reverting Changes

working directory



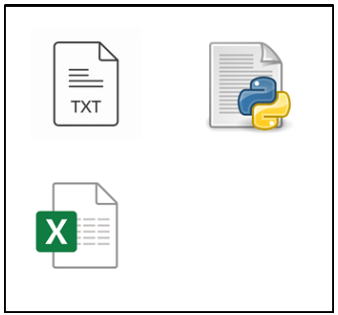
staging area

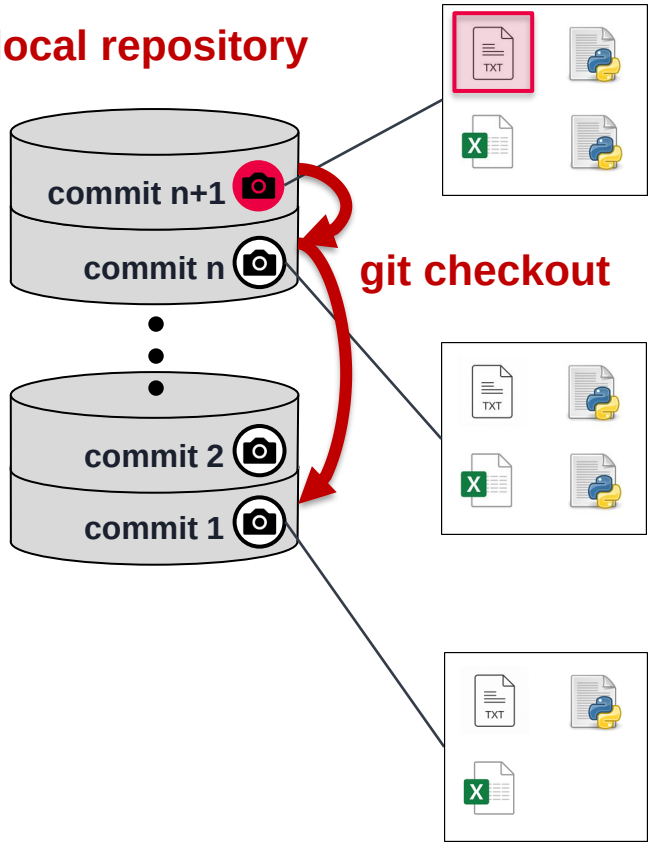


Reverting Changes

working directory

staging area





Reverting Changes - Commands

See log of commits, including SHA ID for each version

```
git log
```

Return to a previous version of a file from the commit history

```
git checkout <version_SHA>
```

```
git checkout <version_SHA> <filename>
```

See differences between two commits or differences in a specific file from two commits

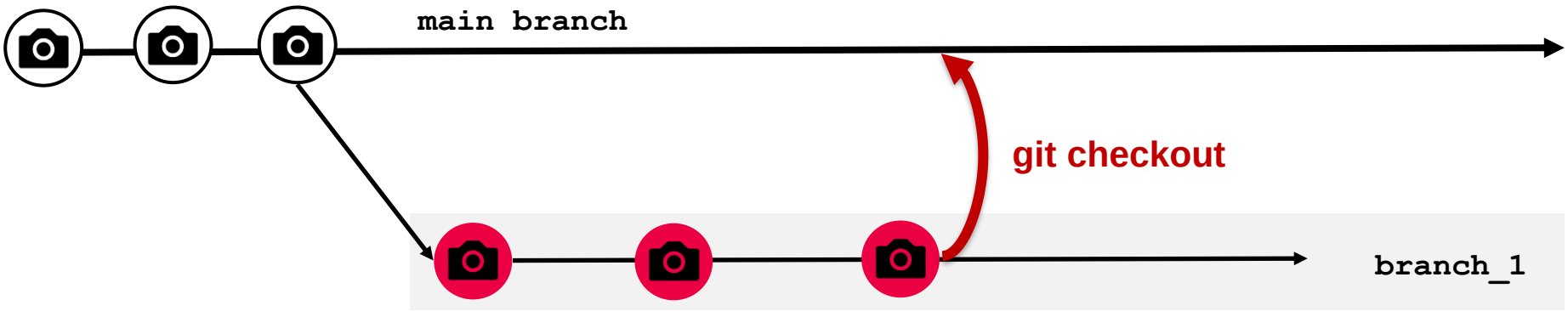
```
git diff <version1_SHA> <version2_SHA>
```

```
git diff <version1_SHA:filename>
    <version2_SHA:filename>
```

Reverting Changes - Try it out

Add some text to `myfile.txt` and commit. Check the log of commits, look at the differences between our two commits so far, and then check out the first commit.

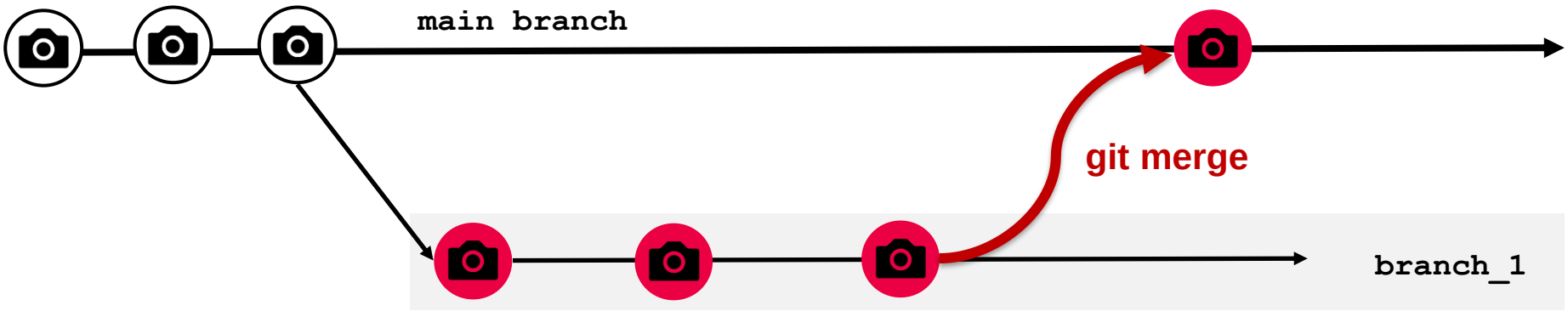
Branching



Suppose you run a process for a client every morning.
You want to make a change, but it will take a few days.
How can you work on the change AND run the stable version?

Branching

Branch when the intention is to eventually “merge” the branch back in with main



Suppose you run a process for a client every morning.
You want to make a change, but it will take a few days.
How can you work on the change AND run the stable version?

Branching and Merging - Commands

See all branches	`git branch`
Create and navigate to a new branch	`git checkout -b new_branch_name`
Switch between branches	`git checkout branch_name`
Merge two branches	`git checkout branch_receiving_changes` `git merge branch_giving_changes`
Delete a branch	`git branch -d branch_name`

Branching - Demo

Create a new branch called `my_branch`, add a file called `mynewfile.txt` to `my_branch` and commit, and look at the list of branches and log of commits.

1. Create and check out a new branch (one step)

```
git checkout -b my_branch
```

2. Add a new file to the new branch

```
touch mynewfile.txt
```

3. Add the new file to staging area and commit

```
git add mynewfile.txt
git commit –m “Adding a second text file”
```

4. Display the branches, then look at the log of commits

```
git branch
git log
```

Merging - Demo

Navigate to the `main` branch, merge `my_branch` into main, and delete `my_branch`.

1. Navigate to the main branch

```
git checkout main
```

2. Merge `my_branch` into the main branch

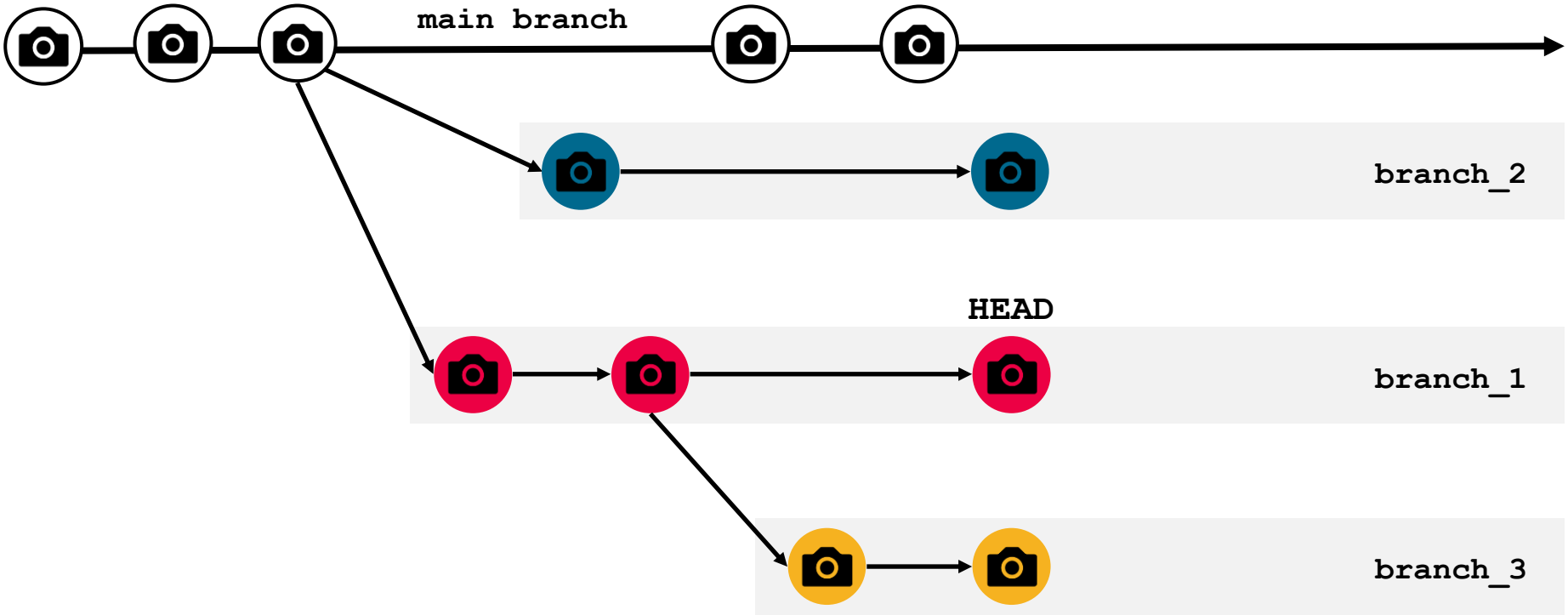
```
git merge my_branch
```

3. Delete `my_branch`

```
git branch -D my_branch
```

Multiple Branches

HEAD – the most recent commit on the current branch



Multiple Branches

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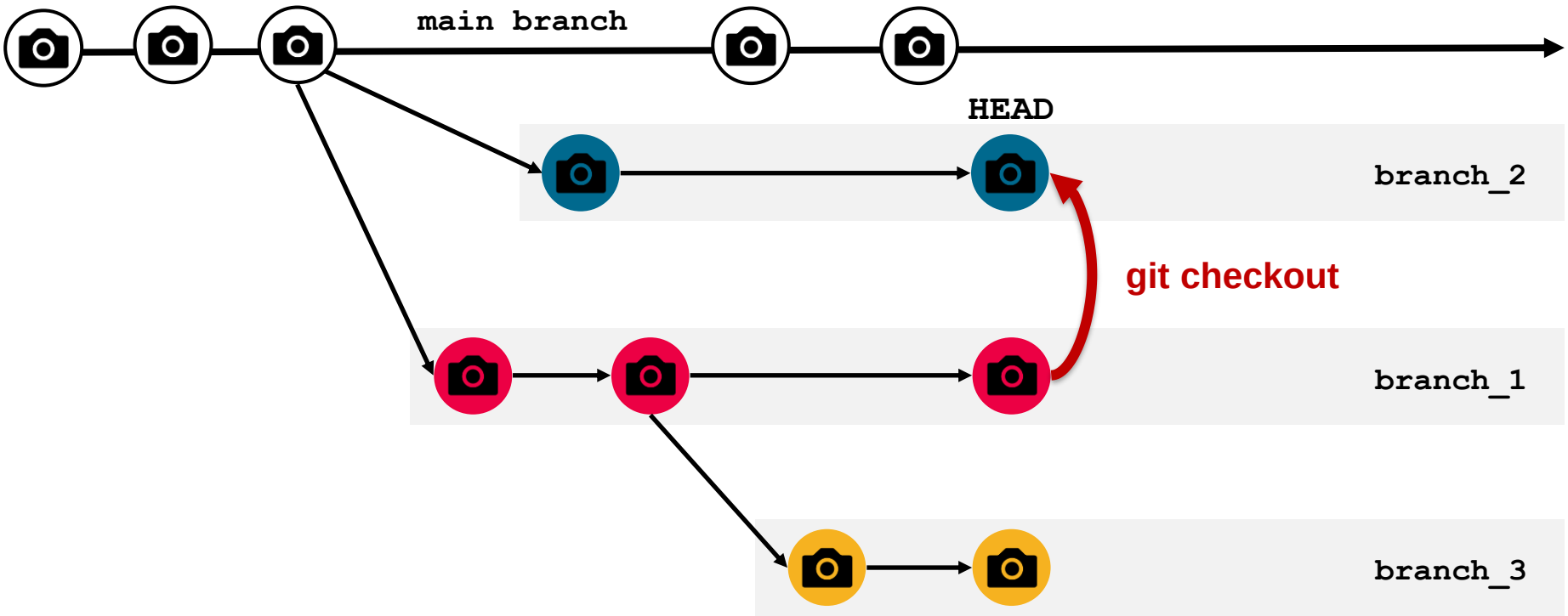
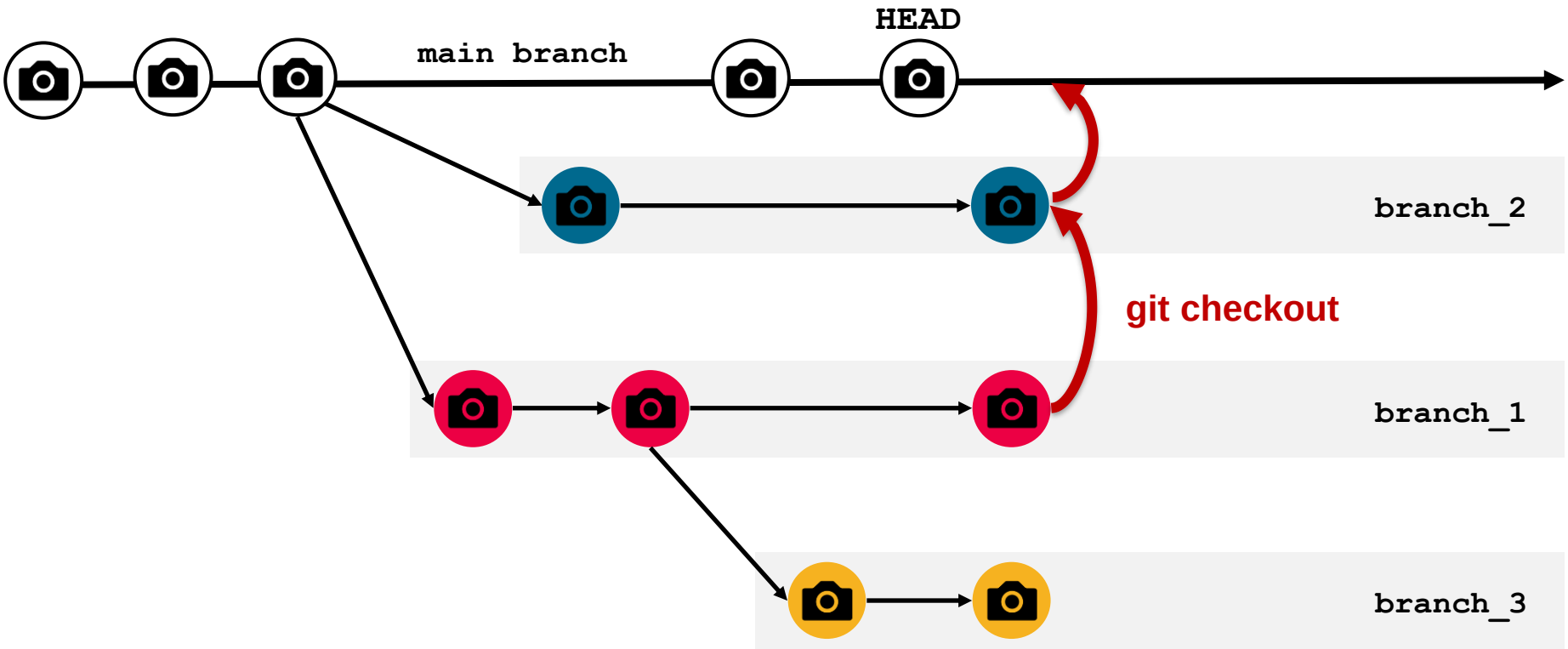


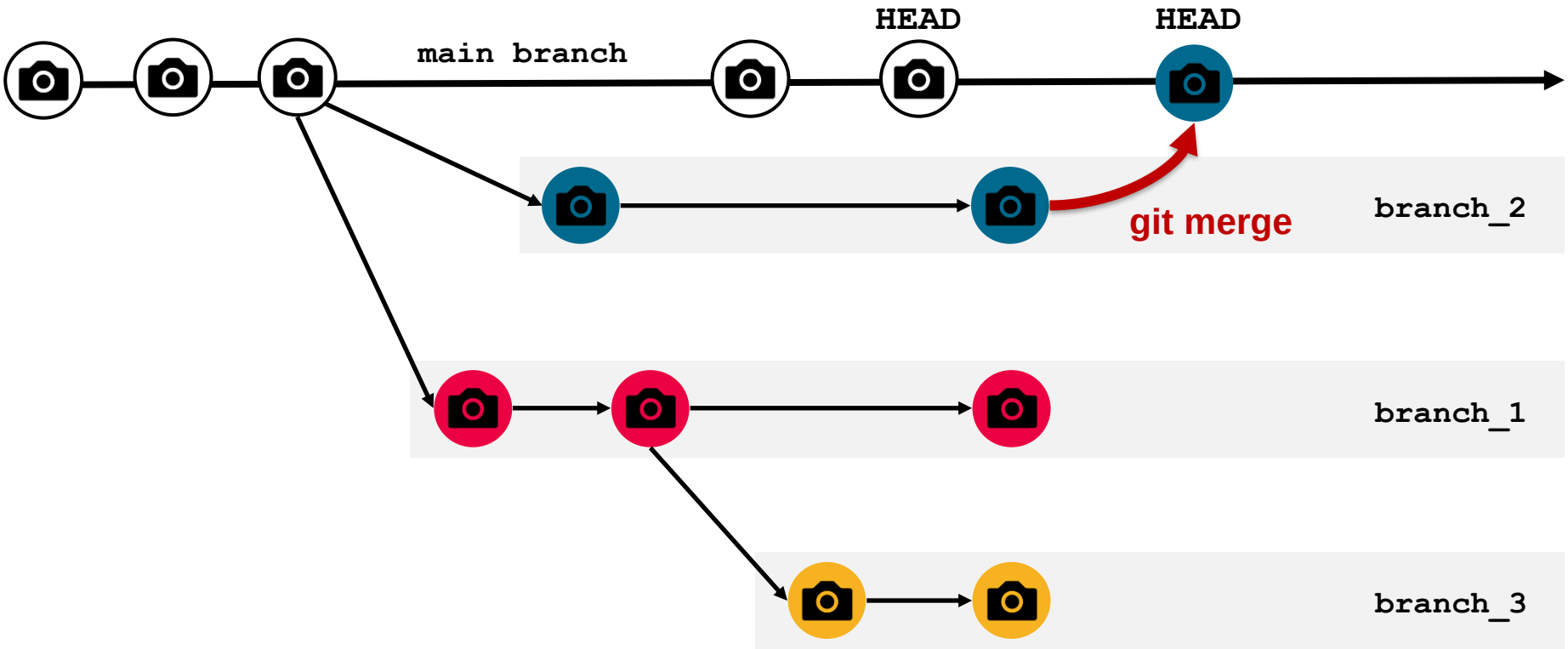
Multiple Branches

HEAD – the most recent commit on the current branch



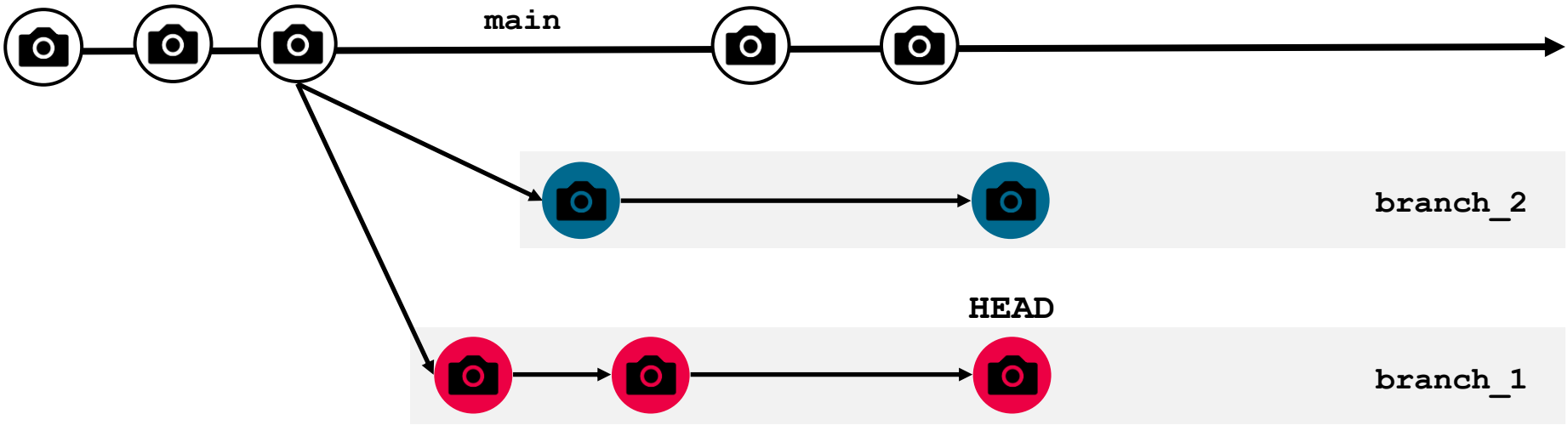
Multiple Branches

HEAD – the most recent commit on the current branch



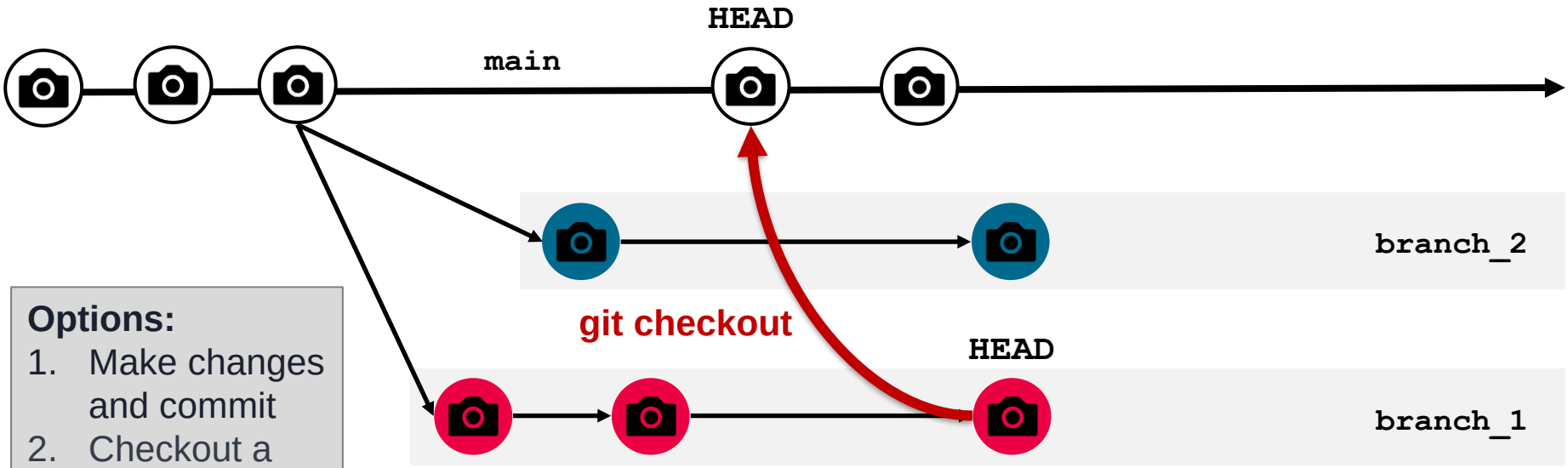
Aside: `'detached HEAD' state`

`HEAD` usually points at a branch directly. When you checkout a commit, `HEAD` points instead points directly at that commit. This is a `'detached HEAD' state`. **That's okay!**



Aside: 'detached HEAD' state

`HEAD` usually points at a branch directly. When you checkout a commit, `HEAD` points instead points directly at that commit. This is a `'detached HEAD' state`. **That's okay!**



Options:

1. Make changes and commit
2. Checkout a branch

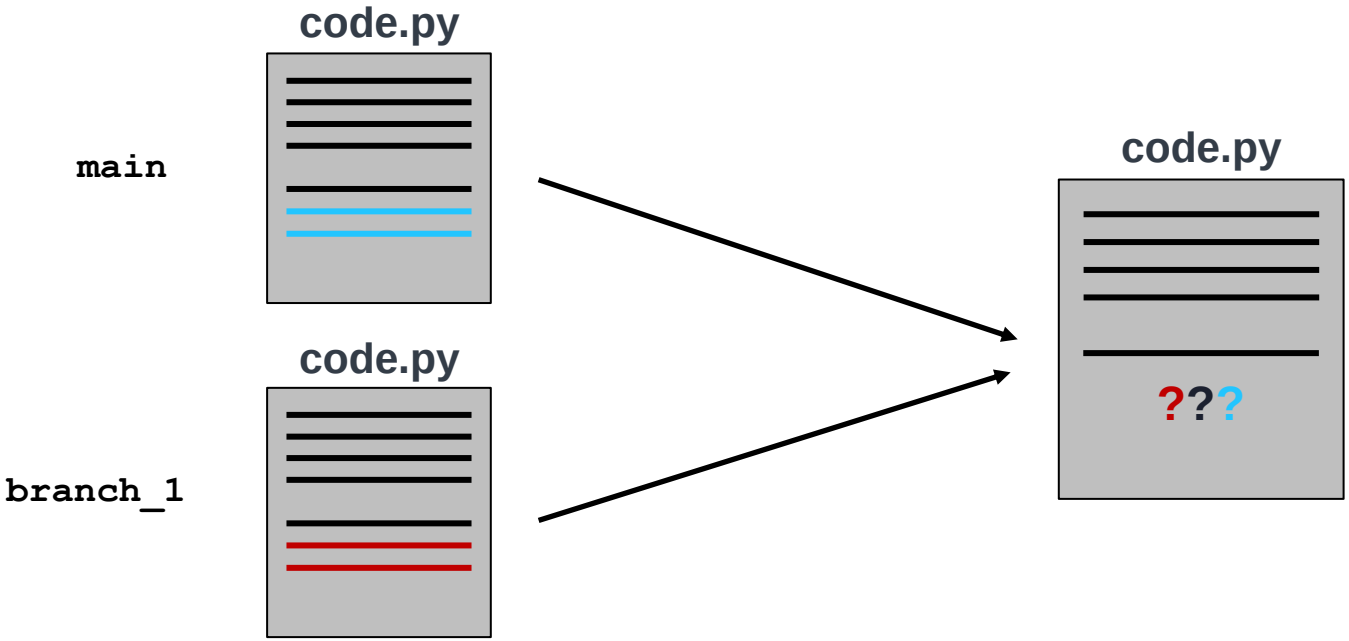
Branching – Try it out

Checkout the `main` branch. Then checkout an earlier commit to enter a detached `HEAD` state. Create a new branch called `new_feature`. Check out the `main` branch.

'detached HEAD' state

Merge Conflicts

When merging changes, we may sometimes find that our branches conflict.



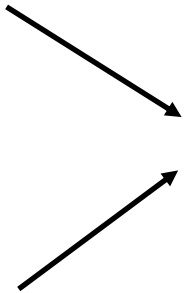
Merge Conflicts

HEAD

```
The first line of the file is the same
The second line is different
```

Commit `dabb4c8c`

```
The first line of the file is the same
See? It's different
```



```
The first line of the file is the same
<<<<<<< HEAD
The second line is different
=======
See? It's different
>>>>>>> dabb4c8c450e8475aee9b14b4383acc99f42af1d
```

When this happens, Git shows you exactly what the conflicts are and where they are located. It is up to you to reconcile the conflicts and commit them.

Merge Conflict – Demo (code along!)

Add text to `myfile.txt` in `main` and commit. Navigate to the `new_feature` branch, add different text to `myfile.txt`, and attempt to merge `new_feature` into `main`.

1. Add text to `myfile.txt` and commit to `main`

```
git checkout main
nano myfile.txt
git add myfile.txt
git commit –m “Add some text”
```

2. Add different text to myfile.txt in `new_feature` and commit

```
git checkout new_feature
nano myfile.txt
git add myfile.txt
git commit –m “Add different text”
```

Merge Conflict – Demo (code along!)

Add text to `myfile.txt` in `main` and commit. Navigate to the `new_feature` branch, add different text to `myfile.txt`, and attempt to merge `new_feature` into `main`.

3. Navigate to the `main` branch and merge `new_feature` branch

```
git checkout main
git merge new_feature
```

4. Resolve merge conflict

```
nano myfile.txt
```

5. Commit changes to `main`

```
git add myfile.txt
git commit –m “Resolve myfile conflict”
```

Poll Question

Suppose you create a new branch and add a file, `branchfile.txt`, and commit. You then add a file, `mainfile.txt`, to the `main` branch and commit. When you try to merge, your branch to `main`, what do you expect to happen?

A.) Merge successful! Both files exist in `main`

B.) Merge successful! But `main` now holds only `branchfile.txt` but not `mainfile.txt`

C.) Merge conflict, you must resolve

Poll Question

You add a file, `community.txt`, to the `main` branch and commit. You then create a new branch and add a file, `branchfile.txt`, and commit. You then delete `community.txt` from `main`. When you try to merge, your branch to `main`, what do you expect to happen?

A.) Merge successful! And `branchfile.txt` exists in `main`

B.) Merge successful! But `branchfile.txt` does not exist in `main`

C.) Merge conflict, you must resolve

Git Wrap-Up

- Commit often, write descriptive messages, and keep each commit to one “atomic” task

  → Almost anything can be undone, as long as it’s committed
- Take advantage of branching when you have new lines of development and don’t want to disrupt the functionality of the `main` branch
- Google is your friend (e.g. “How to undo commit in Git”)

Break

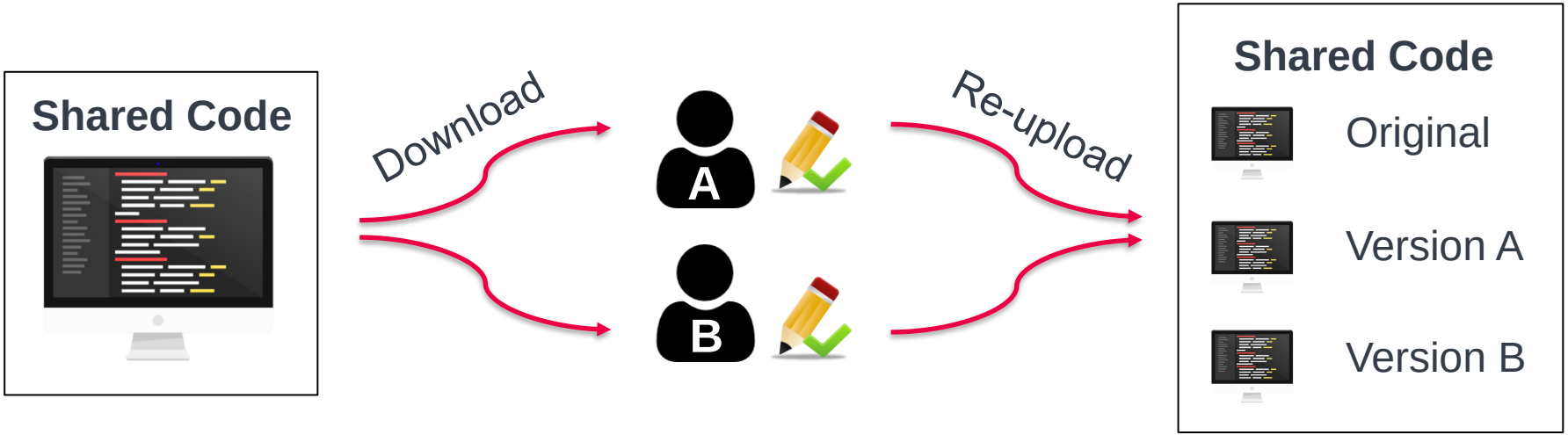
Resume in 10 minutes

Github

Adapted from slides by Galit Lukin and Jackie Baek
with activities from Turing Way and Software Carpentry

Why use Github?

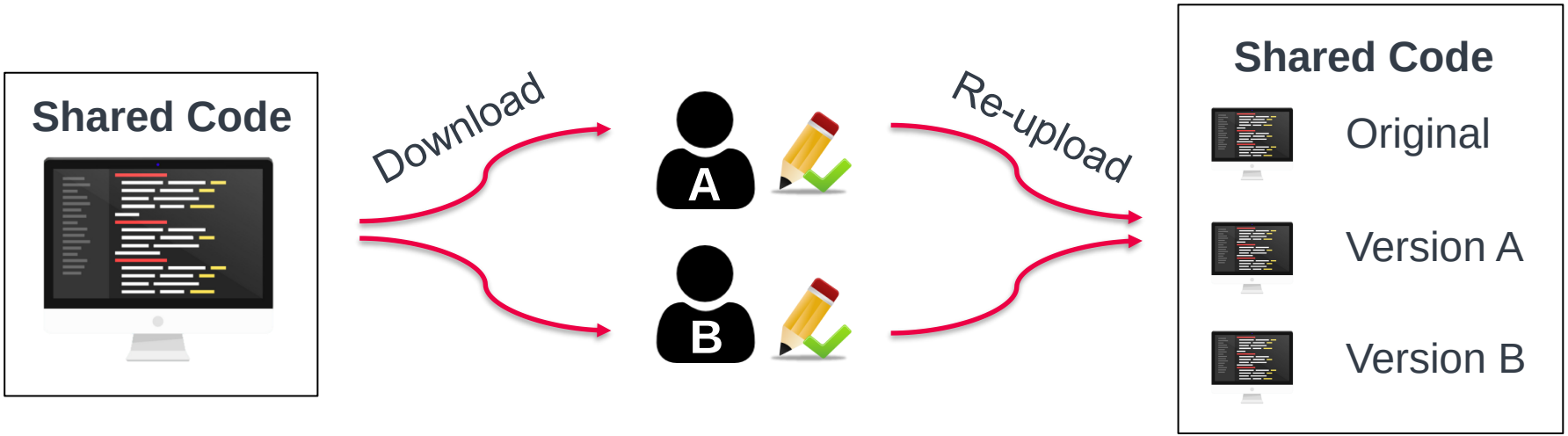
You're working on a research project with another graduate student and both have access to the code in a shared space, e.g. Dropbox.



What are some potential problems that could arise using this process?

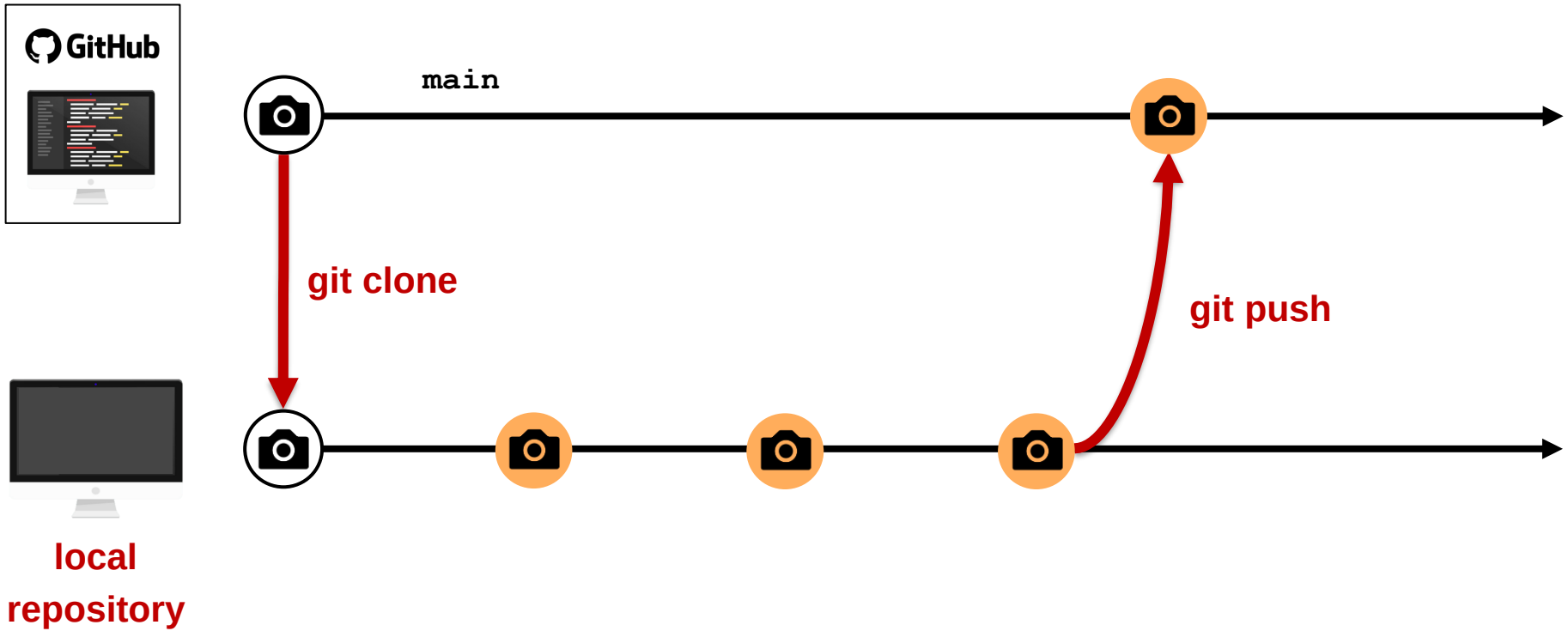
Why use Github?

You're working on a research project with another graduate student and both have access to the code in a shared space, e.g. Dropbox.



Potential issues: Documenting all changes, staying up to date with changes, overwriting others' work, conflicts between versions, etc.

High-Level Idea



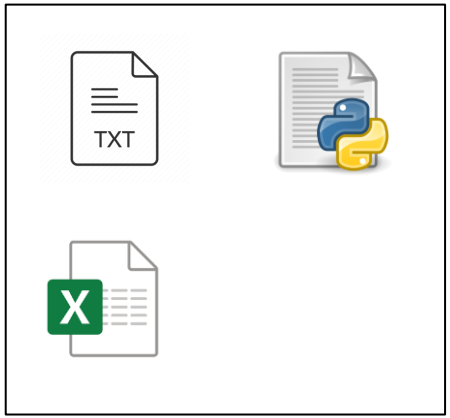
Local and Remote Repositories

local repository

git remote add

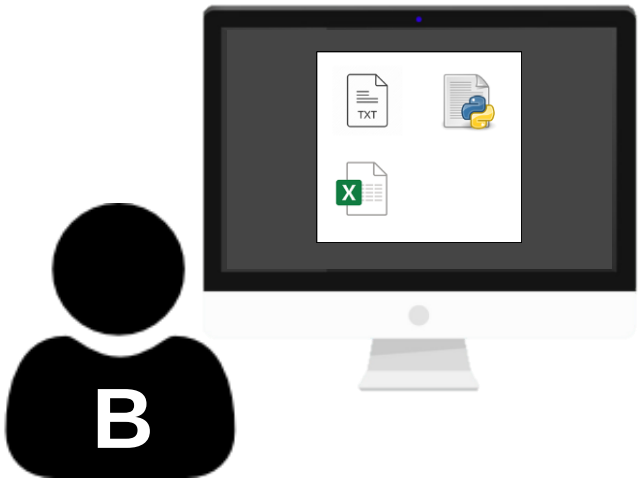
GitHub

remote repository



Local and Remote Repositories

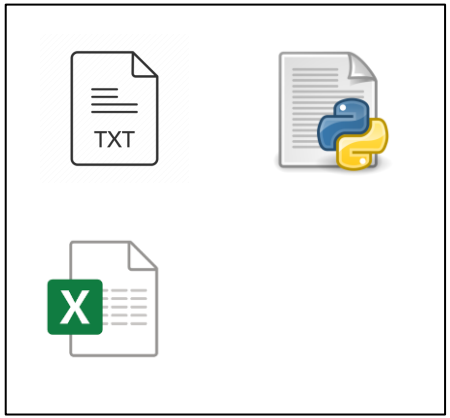
Your collaborator's local repository



git clone

GitHub

remote repository



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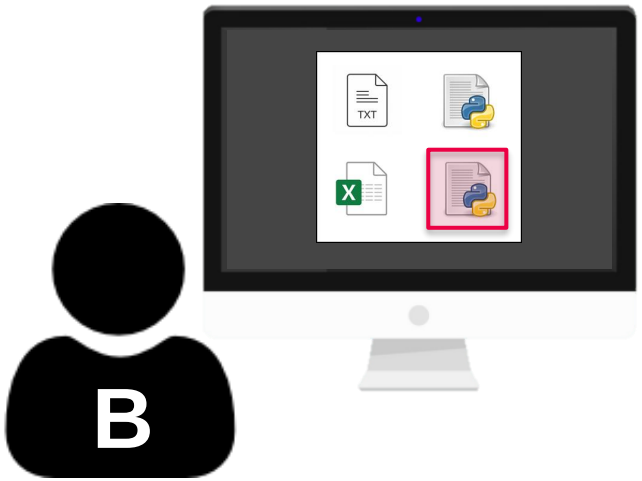
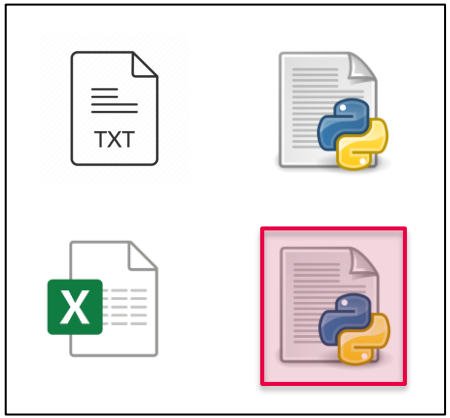


git clone

git push

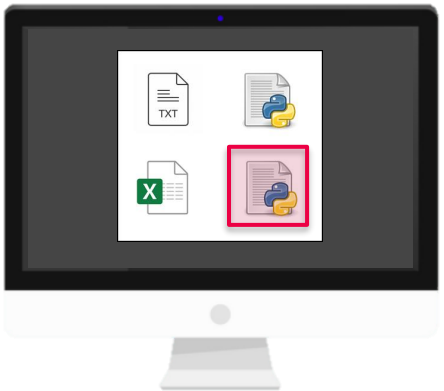
GitHub

remote repository



Local and Remote Repositories

YOUR
local repository

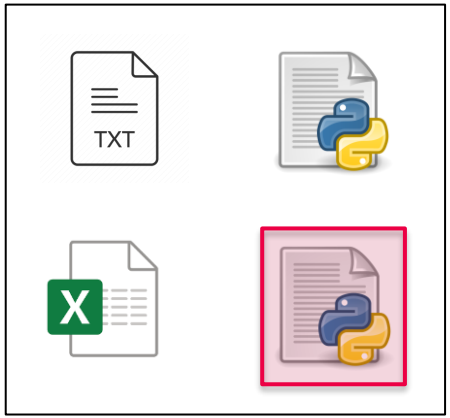


git pull

git push

GitHub

remote repository



Local and Remote - Commands

Add a remote connection to a Github repo for an existing local repo

```
git remote add origin <Github SSH>
```

Clone existing Github repo

```
git clone <Github URL>
```

Pull from Github repo to local repo

```
git pull
```

Push from local repo to Github repo

```
git push origin <branch_name>
```

Local machine's name for the remote repo (`origin` is usual convention)

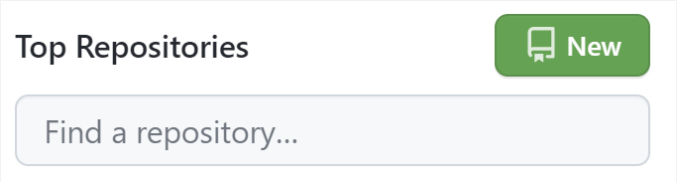
Cloning a Github repo - Try it out

Clone the class repo into the location of your choice.

Creating a Github repo through Github

Create your own repository in Github called `testrepo` (we'll walk through this together). Clone the repo to your machine.

1. Go to github.com and login
2. Click "New" in the top left by your list of repositories and fill in details



3. Clone the Github repository to your machine

```
git clone https://github.com/<username>/<reponame>.git
```

Creating a Github repo for existing local repo

Create a remote connection for `myrepo`

1. Navigate to the existing repo

```
cd myrepo
```

2. Add a remote connection

```
git remote add origin <Github SSH>
```

3. Tell Git who you are on Github so it can get your permissions

```
git config user.email “<github_email>”
git config user.name “Name”
```

Pushing to Github - Demo

Create a new local branch called `new_branch`, add some text to `mynewfile.txt` on `new_branch` and commit, merge the changes into `main`, and push to Github.

1. Create a new file and add a line of text

```
touch localfile.txt
nano localfile.txt
```

2. Commit the changes locally

```
git add localfile.txt
git commit –m “Add file to local repo”
```

3. Push the changes to Github

```
git push origin main
```

Merge conflicts with Github

Your collaborators may have pushed new changes to Github while you've been working on your own changes locally.

Best practices:

- Pull from Github often, even when you aren't making changes to the remote repo
- Pull right before you push your changes
- Resolve merge conflicts as they arise when you pull

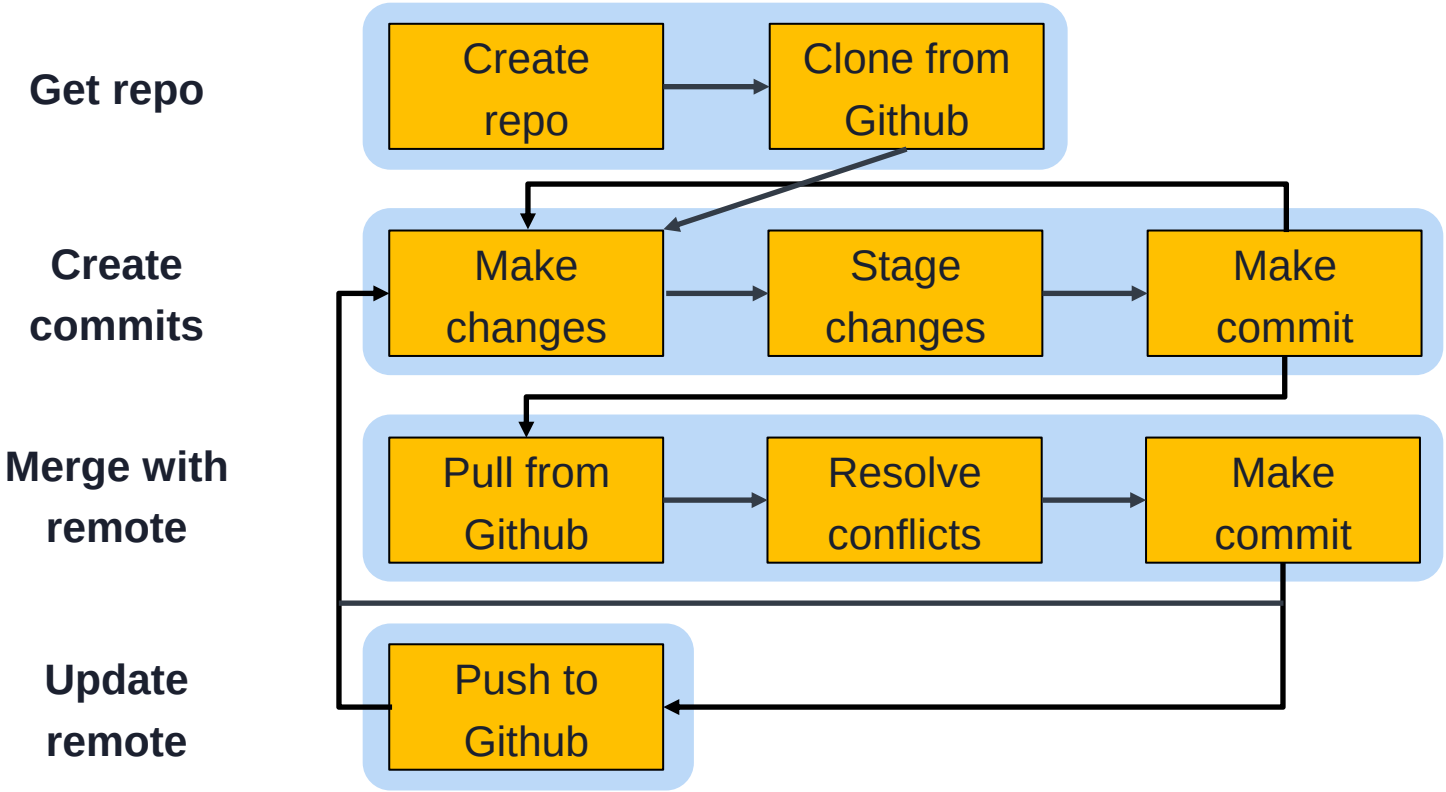
For example,

```
git commit –m "Fix bug"
git pull
git push origin main
```

Putting it all together – Try it out

Create a new local branch called `new_branch`, add some text to `newfile.txt` on `new_branch` and commit, merge the changes into `main`, pull any new changes from Github, and push to Github.

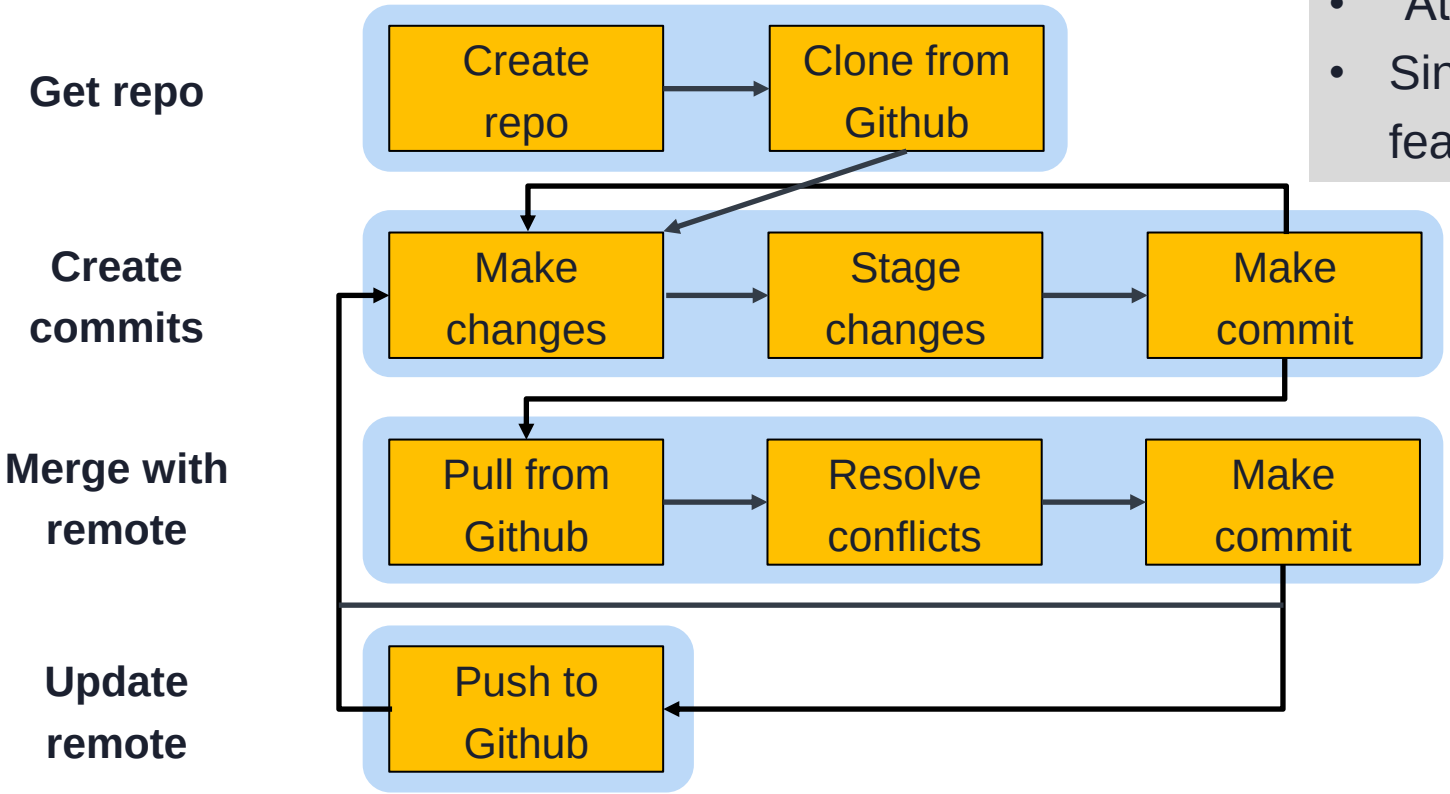
Review of Basic Workflow



Review of Basic Workflow

When do you make a commit?

- "Atomic"
- Single bug fix, feature, re-factor



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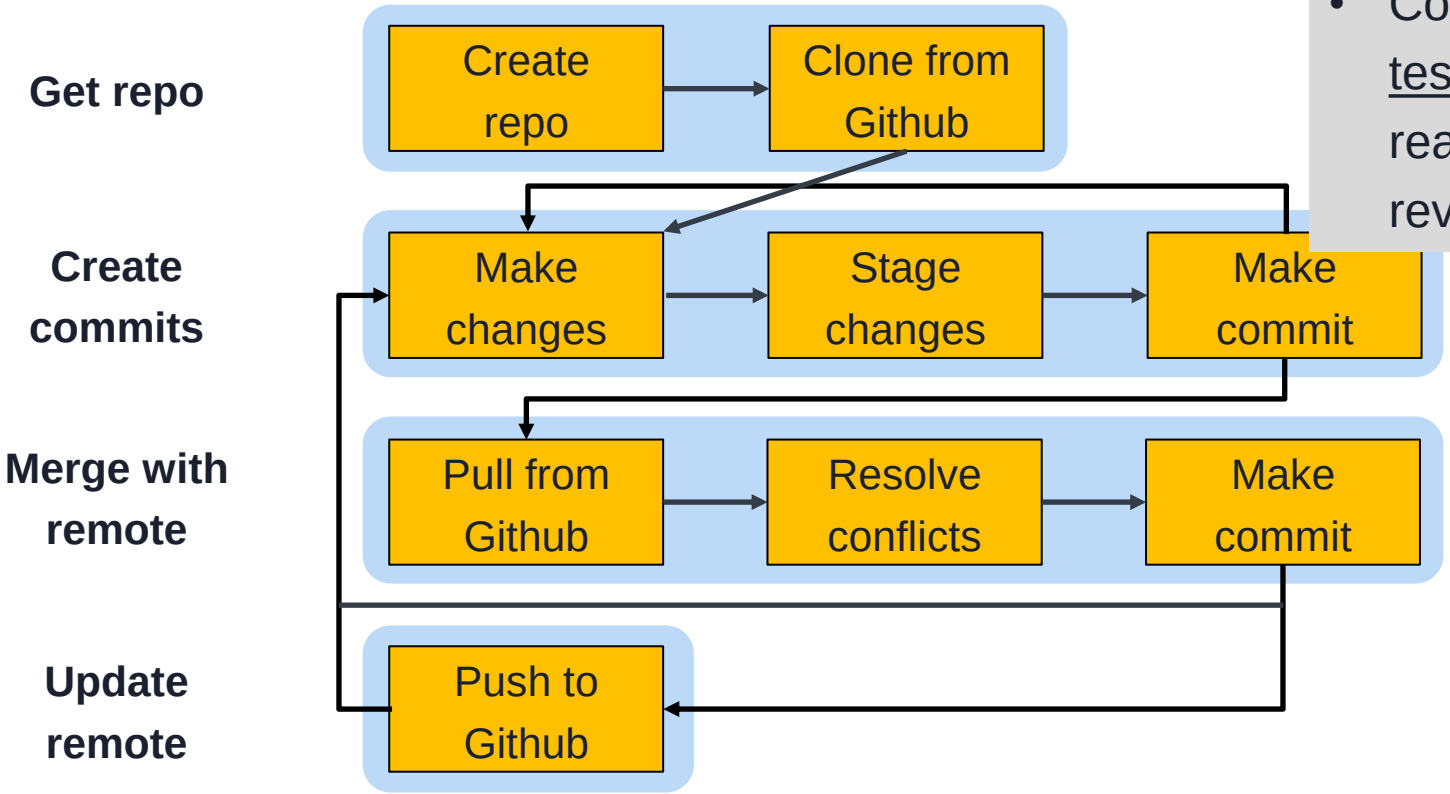
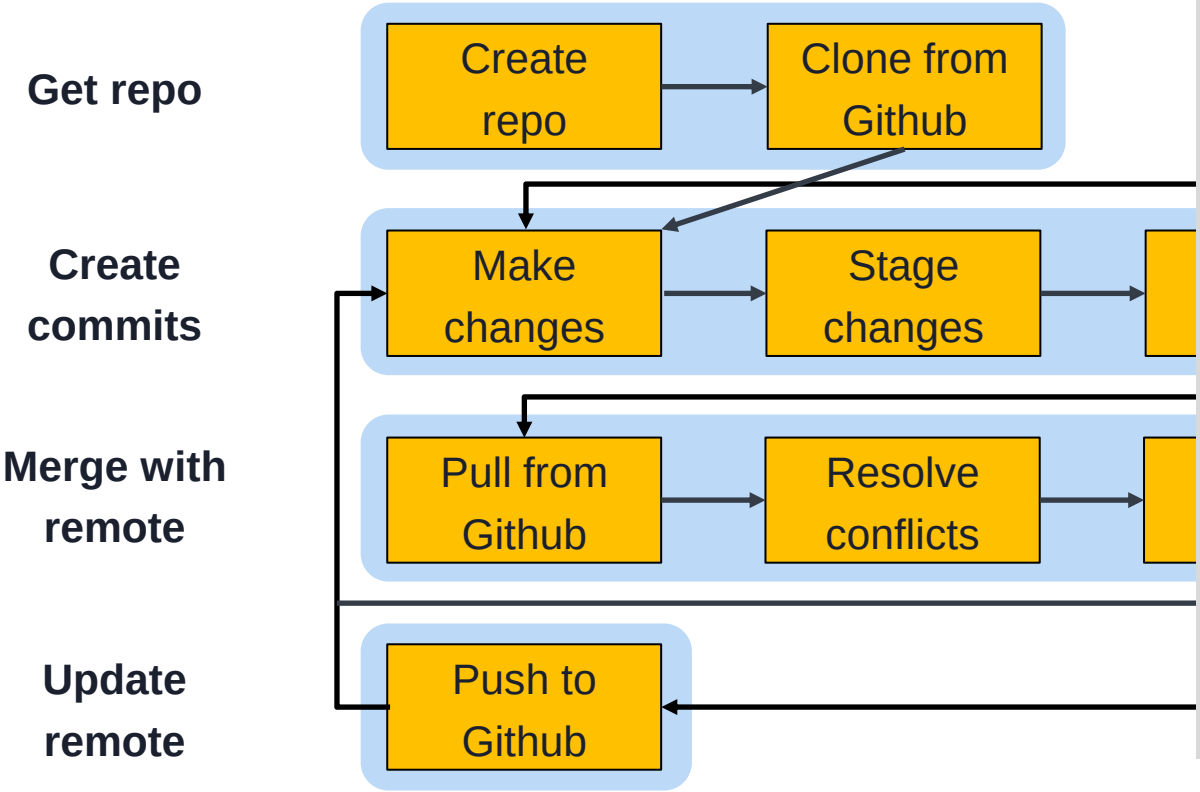


When do you push to Github?

- Completed and tested feature, ready for use or review

Review of Basic Workflow



When should I branch?

- May need to run `main`
- When you and a collaborator are working on different things

Why might I push my branch to Github?

- If you want to collaborate on the branch
- As a code back-up!

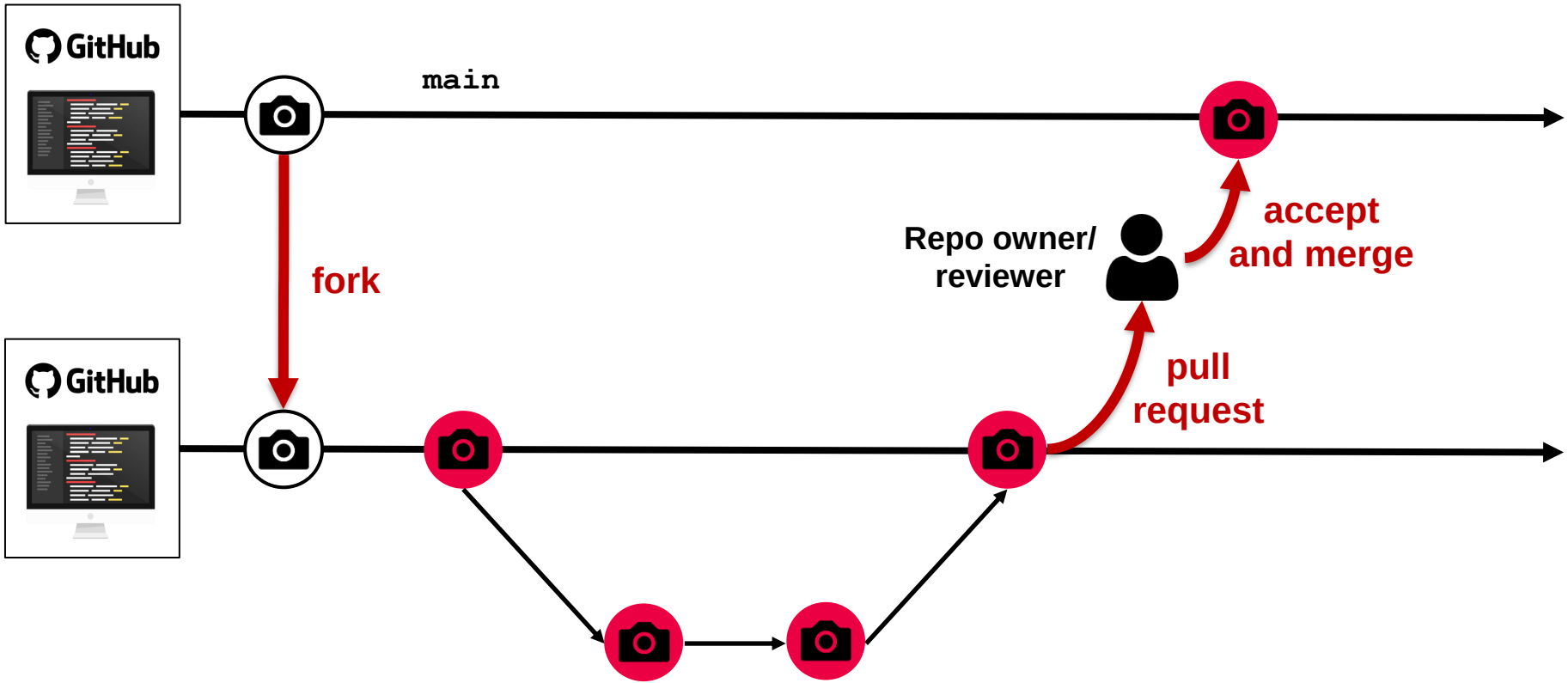
Social Coding on Github

Thus far, we've focused on using Github with a small group of people who have shared access to a repository.

How can you contribute to projects in the broader Github community?

- Not everyone has repo access, so we can't just push our changes
- Repository owner has a reviewing mechanism

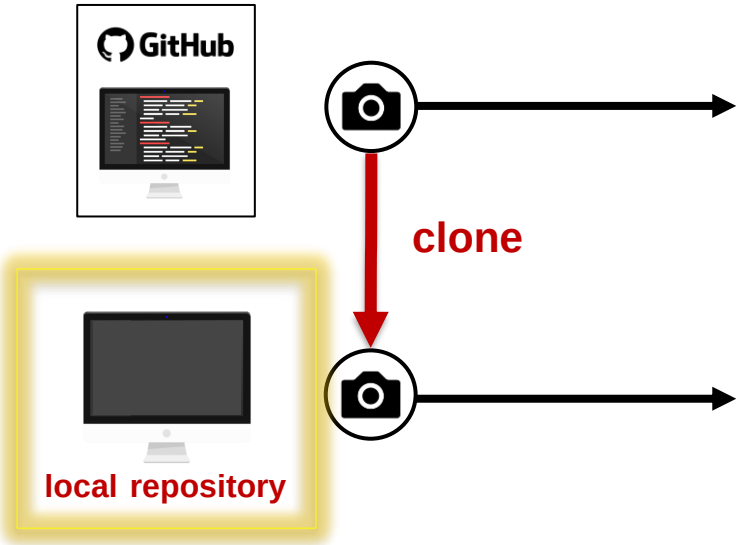
Another Workflow – Forking / Pull Requests



Cloning vs. Forking

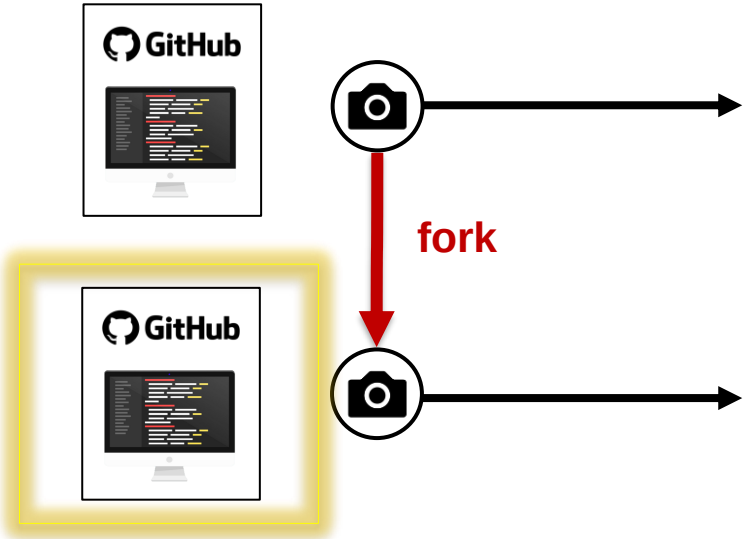
Clone

- Creates a local copy of the repo
- Execute in terminal with git



Fork

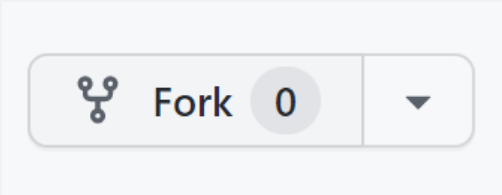
- Creates a copy of the repo on Github
- Execute in Github



How to fork a repo on Github

Fork a repository from Github and clone your forked copy onto your local machine.

1. Go to github.com, login, and find the repo you want to clone
2. Click “Fork” in the right of the repo page



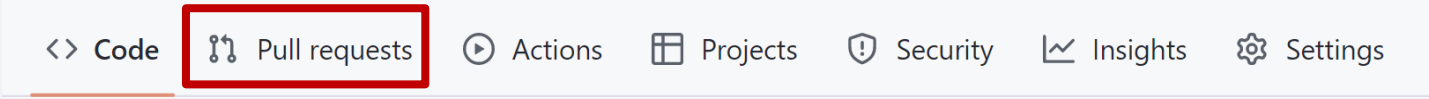
3. Clone the forked Github repository to your machine

```
git clone https://github.com/<yourusername>/<reponame>.git
```

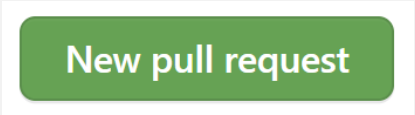
How to submit a pull request on Github

Fork a repository from Github and clone your forked copy onto your local machine.

1. Make changes locally to your forked and cloned repo
2. Commit and push those changes to Github
3. Navigate to your forked repository on Github and switch to this tab:



3. Click “New pull request” and follow prompts



Poll Question

Your collaborator gave you access to a repository that contains shared code. You want to be able to make your own changes and push them to the Github repo.

Should you clone or fork the repository?

A.) `Clone`

B.) `Fork`

Poll Question

You found a Github repo and think it would be a great starting point for a project you're working on.

Should you clone or fork the repository?

A.) `Clone`

B.) `Fork (then clone)`

Poll Question

You find a repo on Github that has some room for improvement, but to which you don't have access.

What would happen if you tried to clone the repository?

A.) `An error. You can't clone without access.`

B.) `Git would create a local copy of the repo, but you couldn't push changes.`

C.) `Git would create a local copy of the repo and you could push changes to the Github repo.`

Putting it all together – Task 1

Fork `alexschmid3/putitalltogether` and clone it to your local machine. Add a text file with a unique filename that contains your name (and a fun fact?) to the `students` folder and commit. Push changes to your forked repo, then send a pull request to me.

Putting it all together – Task 2

Get a list of the contents of the `students` folder and send the output to `outputs/studentlist.txt`. Add and commit changes. What do you notice about the change?

Hints:

- Check `git status`
- Print out the contents of `.gitignore` file. What do you think this file's purpose is?

Thank you!