AGEC 652 - Lecture 1.2

Best practices: reproducibility, organization & version control

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What we will cover today

- How to start and maintain computational research projects in a less "chaotic" way
    - Why? Because it saves time! For your future self and everyone else that needs to work with you now or in the future
- We'll review best practices on Gentzkow & Shapiro (2014)

Gentzkow & Shapiro's *"Code and Data for the Social Sciences"*

- Economists are not the first to deal with code, data, and a bunch of other stuff in complex projects
    - People in IT, Engineering, and Sciences have learned their lessons. We can learn from them
- This guide is a great starting point to set you on a good path
    - But there's a lot more to learn
    - Some things you'll learn by reading, others by observation, others only by trial-and-error

Gentzkow & Shapiro's *"Code and Data for the Social Sciences"*

Four categories of advice

- A. Reproducibility
  - *Automation* (section 2), *Documentation* (7)
- B. Organization
  - *Directories* (4), *Keys* (5)
- C. Project management
  - *Version Control* (3), *Management* (8)
- D. Coding
  - *Abstraction* (6), *Documentation* (7), *Code Style* (appendix)

We'll go over A--C today

Reproducibility

Reproducibility

Why should we care?

- Because journals are interested in that these days. Yes, but why?
- Because it is a **fundamental principle of the scientific method**
  - With enough instructions, someone else can *verify* your experimental results and claims
  - It lends credibility to the scientific process

Reproducibility

The term can have different meanings and (quasi) synonyms depending on the field

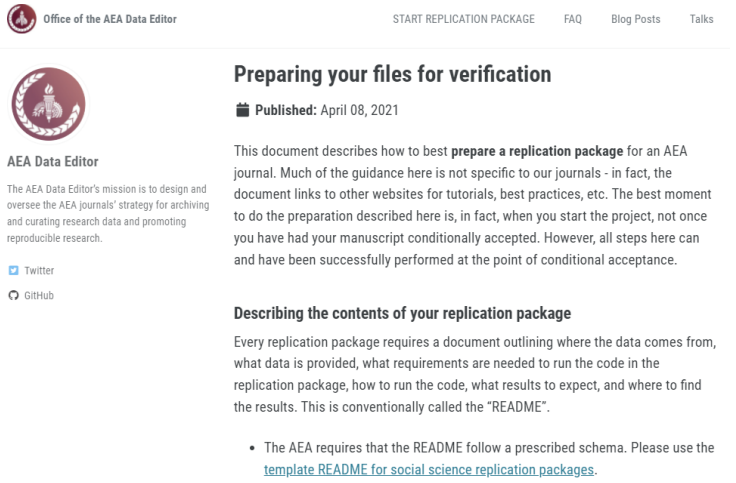
We'll borrow terminology from CS[1]

- **Repeatability**: same team, same experimental setup
- **Replicability**: *different* team, same experimental setup
- **Reproducibility**: *different* team, *different* experimental setup

[1] Association for Computing Machinery (2021). *Artifact Review and Badging – Version 2.0*

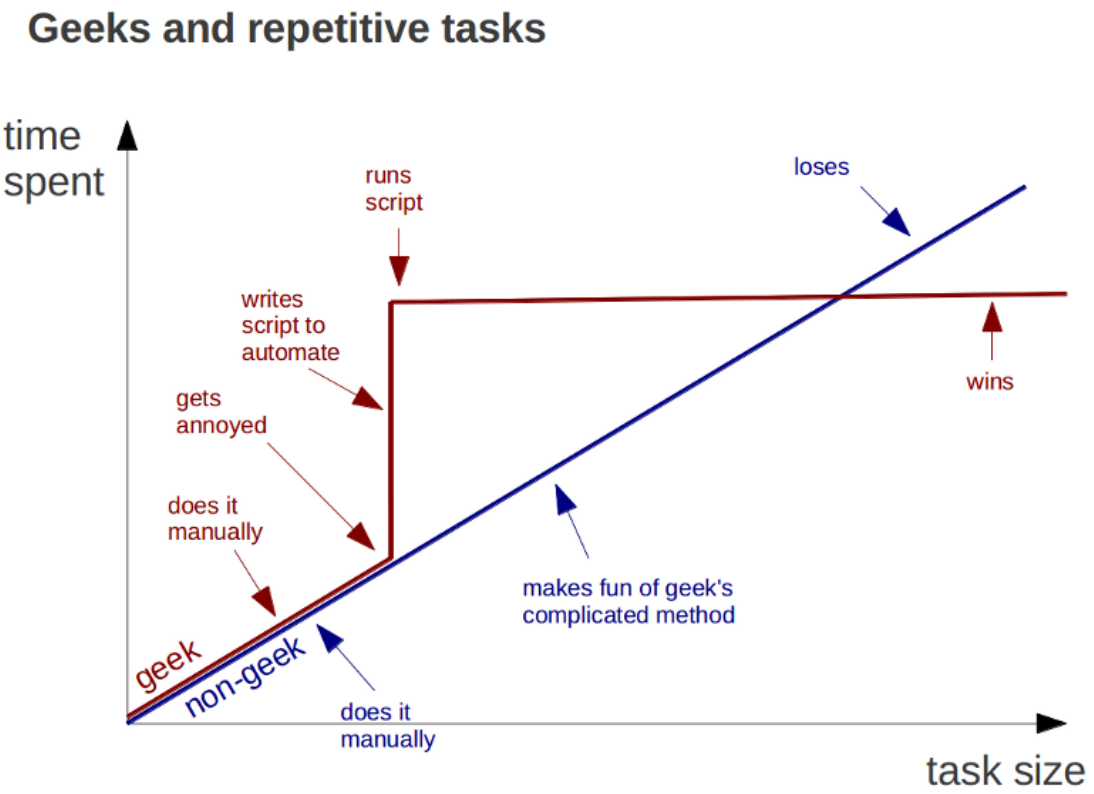
Reproducibility

- Reproducibility is the higher scientific goal
- For the projects we develop, we look for **replicability**
- We make it easy for someone else to run our analysis and get the same results



Automation

Automate everything that can be automated



Automation

Automate everything that can be automated

Scripts are great because they:

- Save time for repeated tasks
- Document step by step what you are doing
- Can usually be reused/adapted for similar tasks in the same or other projects

Manual tasks (with files or in Excel) are difficult to replicate unless you take detailed notes at every step

Rule-of-thumb: *if you are doing a lot of clicking for repeated task, think about writing a script for that*

Automation

Automate everything that can be automated

My advice: *get comfortable with UNIX shell*

- You can do so much with basic shell scripting
  - You'll most likely need it if your research needs High-Performance Computing (HPC)
- You can learn that in a couple of hours with Software Carpentry lessons
- Works in any OS
  - Mac: shell environment built in
  - Linux: you probably needed that already
  - Windows 10+: there's WSL2 and it works great (really!)

Automation

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

It's the ideal goal for *replication packages*

Have a script like this from the beginning of the project and increment it as you go

But don't obsess over it. Sometimes it can't be done

- E.g.: you are running part of your code on an external server

Automation + replicability

An extra rule: **Keep track of your dependencies**

- We often use many external packages
- Popular packages get updated often. Sometimes it breaks things...
  - The syntax you used doesn't work anymore
  - The function you called doesn't exist anymore
- Keep note (and copies) of the versions you use
- There are many tools to help you with that
  - Some are simpler and just track that info for you (e.g.: Dr. Watson for Julia)
  - Others create a stand-alone environment with everything you need to run (e.g.: Docker)

Organization

Directories

Separate directories by function

Separate files into inputs and outputs

These are quite intuitive: they make it easy for you (your code) and anyone else to find things

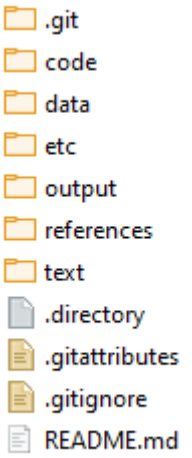
Separating inputs, intermediate outputs (temp), and final outputs is crucial for storing the right things

- We normally don't use version control for intermediate calculations

Directories

Have separate folders for

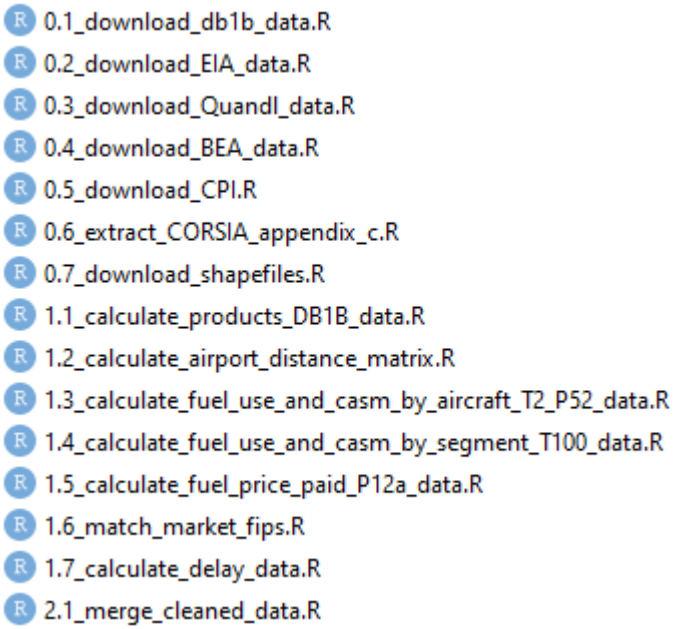
- Code
- Data
- Output
  - I also use separate sub-folders for tables, figures, & maps
- Text (e.g. LaTeX files)



^ This is from my job market paper

Directories

For long scripts that do many steps in sequence, like building a data set, it is also a good practice to number your scripts



Directories

Make directories portable

In other words: **use relative paths**. Or don't hard-code your paths

Instead of

```
C:/User/me/my_research/data/my_data_file.csv
```

use a relative path like this

```
data/my_data_file.csv
```

Directories

It's not always possible to have relative paths everywhere

In that case, you can define all the paths in one single place and read it from there every time

paths_linux.yaml

C: > Users > Diego > OneDrive > Academic > Research > jet_fuel > code > paths_linux.yaml

```yaml
# Path to project directories

code:
  root: '~/OneDrive/Research/jet_fuel/code'
  buildDataset: '~/OneDrive/Research/jet_fuel/code/build_dataset'
  utils: '~/OneDrive/Research/jet_fuel/code/utils.R'

data:
  root: '~/jetfuel_data'
  lookup: '~/jetfuel_data/bts/lookup'
  db1b: '~/jetfuel_data/bts/db1b'
  t100: '~/jetfuel_data/bts/t100'
  t1: '~/jetfuel_data/bts/t1'
  t2: '~/jetfuel_data/bts/t2'
  p1.2: '~/jetfuel_data/bts/p1.2'
  p6: '~/jetfuel_data/bts/p6'
  p7: '~/jetfuel_data/bts/p7'
  p12a: '~/jetfuel_data/bts/p12a'
  p12: '~/jetfuel_data/bts/p12'
  p52: '~/jetfuel_data/bts/p52'
  b43: '~/jetfuel_data/bts/b43'
  otp: '~/jetfuel_data/bts/otp'
  bea: '~/jetfuel_data/bea'
  bls: '~/jetfuel_data/bls'
  eia: '~/jetfuel_data/eia'
  icao: '~/jetfuel_data/icao'
  quandl: '~/jetfuel_data/quandl'
  output: '~/jetfuel_data/output_data'

temp: '~/jetfuel_data/temp'

output:
  plots: '~/OneDrive/Research/jet_fuel/output/plots'
  tables: '~/OneDrive/Research/jet_fuel/output/tables'
  results: '~/OneDrive/Research/jet_fuel/output/results'
```

Project management

*This part borrows extensively from course materials from Grant McDermott's *Data Science for Economists* (Oregon) and Ivan Rudik's *Dynamic Optimization* (Cornell)

Before we continue...

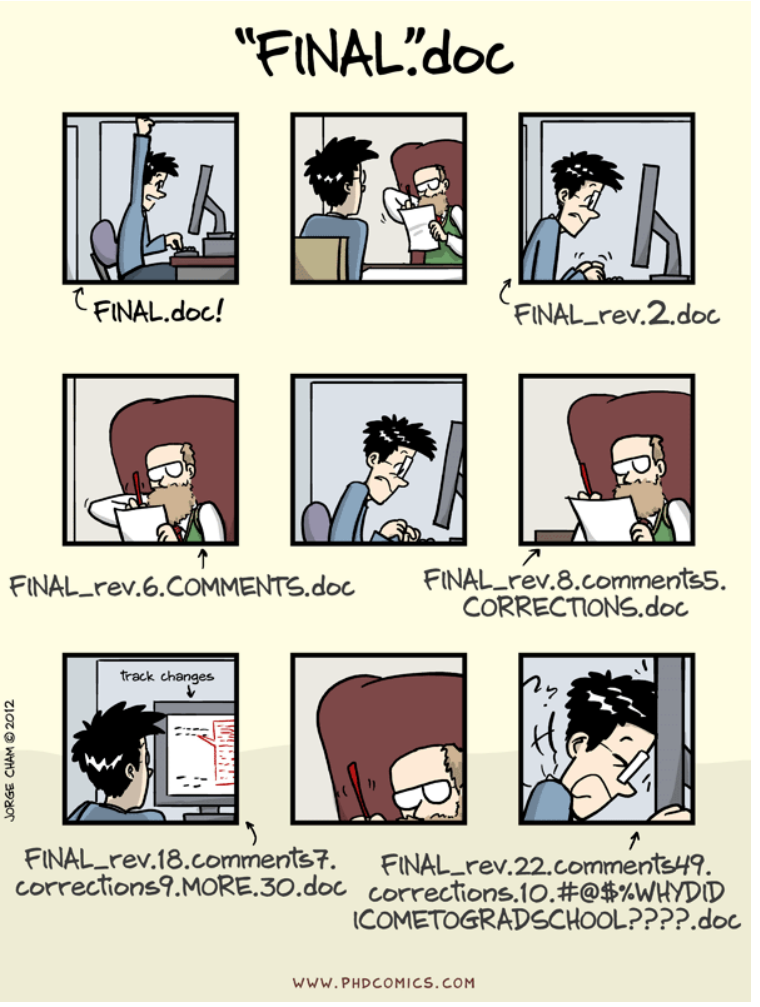
By now you hopefully have

1. GitHub Desktop installed on your laptop
2. A GitHub account

After class, please:

- Send me an e-mail with your GitHub username
- Watch out for an invitation for our GitHub Classroom repository
- Accept the invitation

Version Control: why bother?



Git

- Git is a *distributed version control system*
  - Imagine if Dropbox and the "Track changes" feature in MS Word had a baby. Git would be that baby
- In fact, it's even better than that because Git is optimized for the things that economists spend a lot of time working on (e.g. code)
- It gives you an easy way to test out experimental changes (e.g. new specifications, additional model states) and not have them mess with your main code

GitHub

Git $\neq$ GitHub

- GitHub hosts a bunch of online services we want when using Git
    - Hosts a copy of your repository online
    - Allows for people to suggest changes to your project
    - Keeps track of team communication on tasks
    - And even let's you host some related content (like these slides!)
- It's also the main location for non-base Julia (and R) packages to be stored and developed

The differences

Git is the software infrastructure for versioning and merging files

GitHub provides an online service to coordinate working with Git repositories

- And adds some additional features for managing projects
  - Stores the project on the cloud, allows for task management, creation of groups, etc

Why Git(Hub)?

Selfish reasons

- The private benefits of having well-versioned code in case you need to go back to previous stages
- Your directories will be super clean
- Makes it MUCH easier to collaborate on projects

Why Git(Hub)?

Semi-altruistic reasons

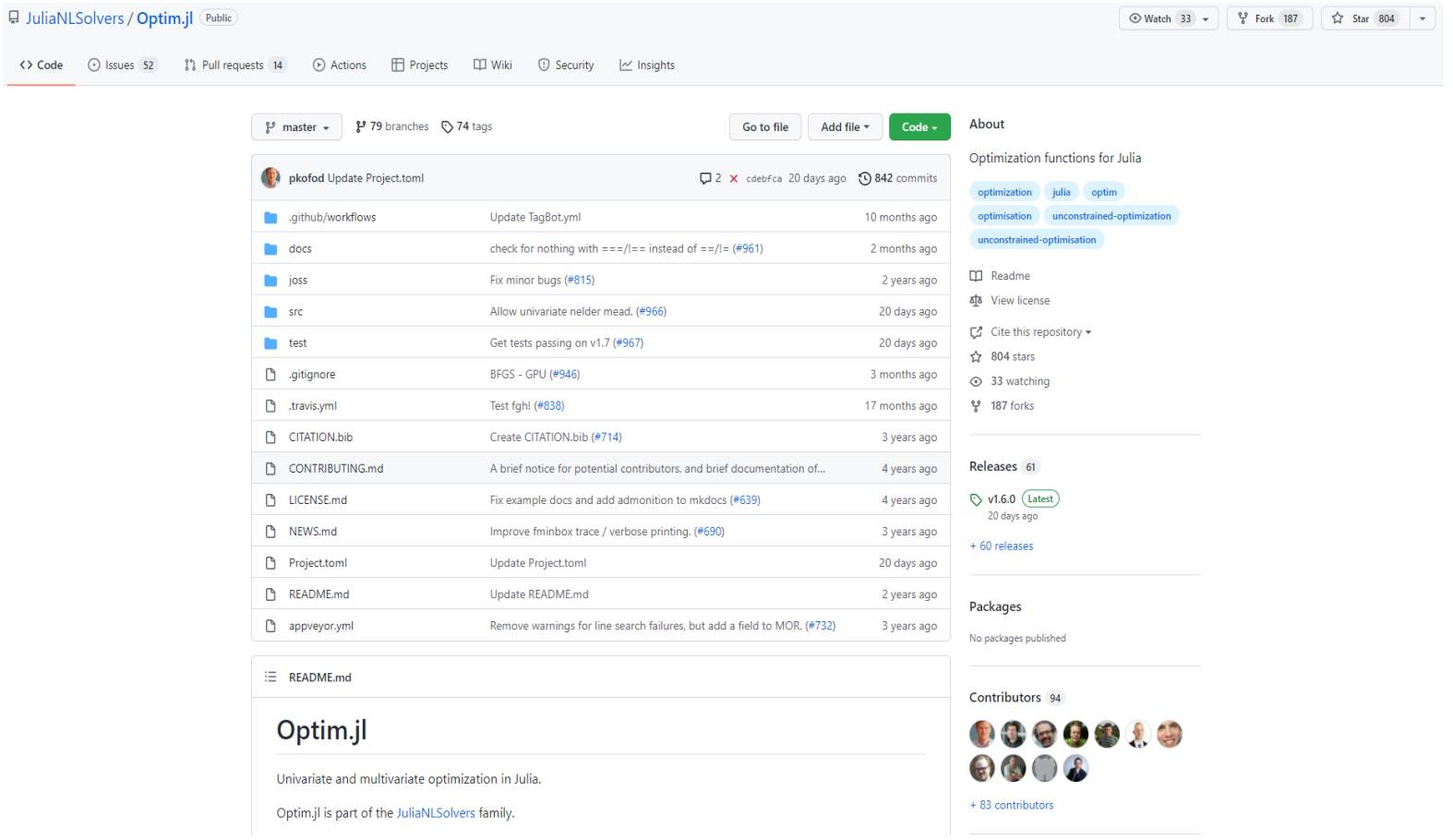
- The external benefits of open science, collaboration, etc
- These external benefits also generate some downstream private reputational benefits
  - You must be confident in your code to make it public
- Can improve future social efficiency
  - You commit to post future code (if you don't, it'll look shady)

Git basics

Everything on Git is stored in something called a **repository** or *repo* for short. This is the directory for a project

- **Local**: a directory with a `.git` subdirectory that stores the history of changes to the repository
- **Remote**: a website, e.g. see the GitHub repo for the Optim package in Julia

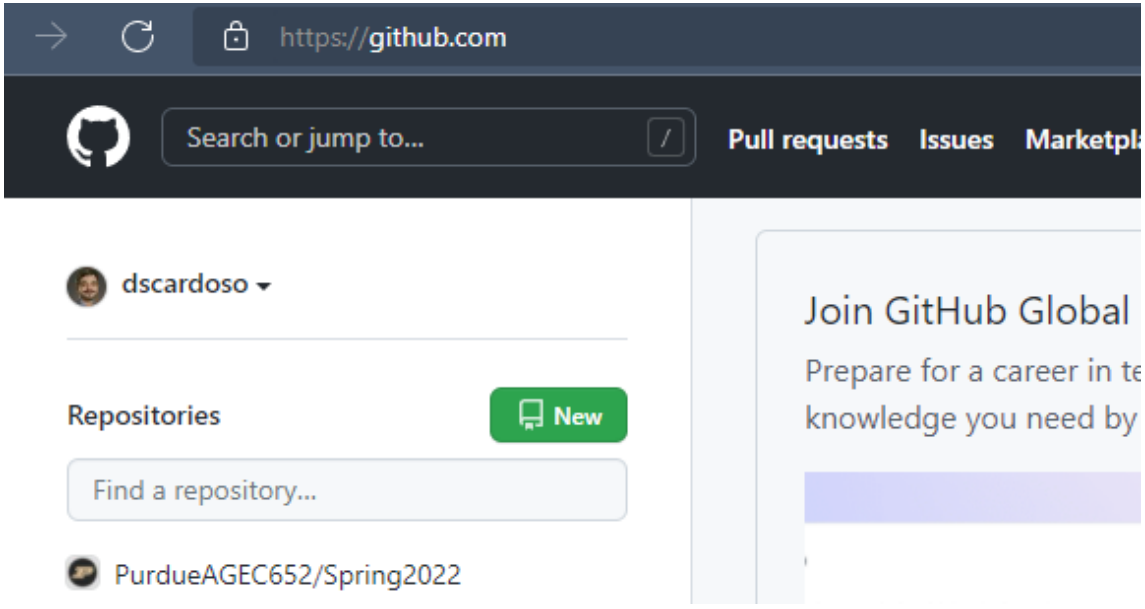
Git basics


JuliaNLSolvers / Optim.jl
Public
Watch 33
Fork 187
Star 804
Code
Issues 52
Pull requests 14
Actions
Projects
Wiki
Security
Insights
master
79 branches
74 tags
Go to file
Add file
Code
pkofod Update Project.toml
2
cdebfca 20 days ago
842 commits
.github/workflows Update TagBot.yml 10 months ago
docs check for nothing with ===/!== instead of ==/!= (#961) 2 months ago
joss Fix minor bugs (#815) 2 years ago
src Allow univariate nelder mead. (#966) 20 days ago
test Get tests passing on v1.7 (#967) 20 days ago
.gitignore BFGS - GPU (#946) 3 months ago
.travis.yml Test fgh! (#838) 17 months ago
CITATION.bib Create CITATION.bib (#714) 3 years ago
CONTRIBUTING.md A brief notice for potential contributors, and brief documentation of... 4 years ago
LICENSE.md Fix example docs and add admonition to mkdocs (#639) 4 years ago
NEWS.md Improve fminbox trace / verbose printing. (#690) 3 years ago
Project.toml Update Project.toml 20 days ago
README.md Update README.md 2 years ago
appveyor.yml Remove warnings for line search failures, but add a field to MOR. (#732) 3 years ago
README.md
Optim.jl
Univariate and multivariate optimization in Julia.
Optim.jl is part of the JuliaNLSolvers family.
About
Optimization functions for Julia
optimization
julia
optim
optimisation
unconstrained-optimization
unconstrained-optimisation
Readme
View license
Cite this repository
804 stars
33 watching
187 forks
Releases 61
v1.6.0 Latest
20 days ago
+ 60 releases
Packages
No packages published
Contributors 94
+ 83 contributors

Creating a new repo on GitHub

Let's create a new repo

Easy from GitHub website: just click on that green `New` button from the launch page

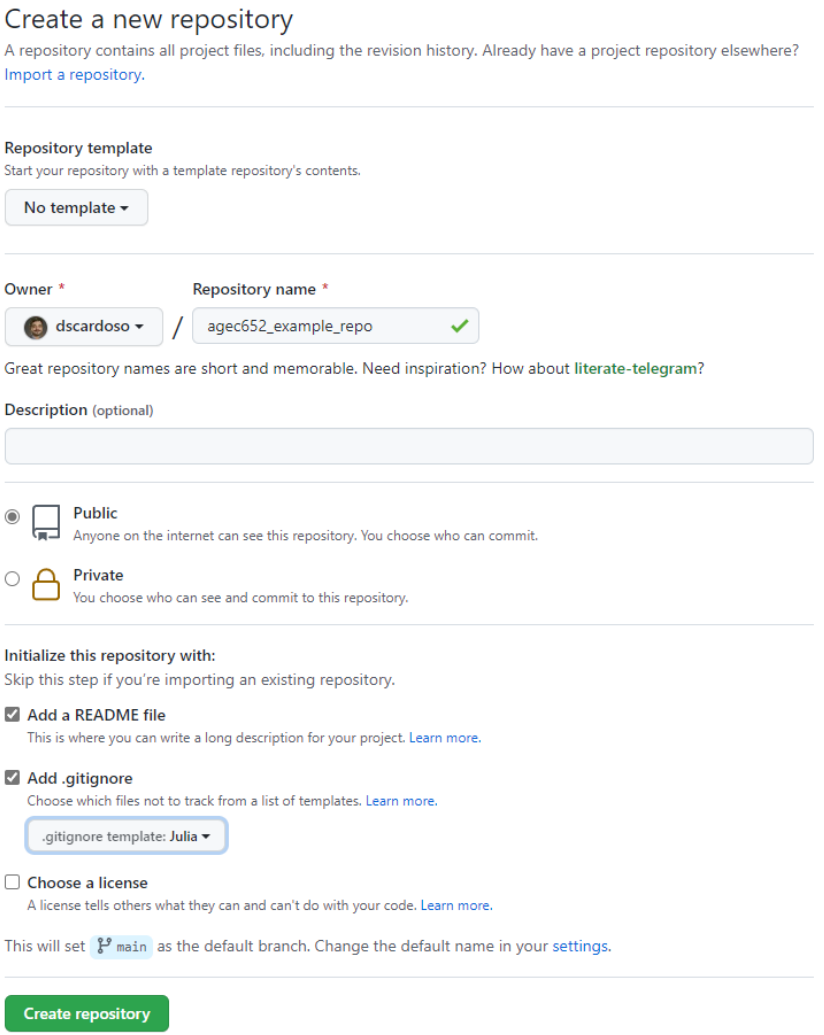


Creating a new repo on GitHub

Next steps:

1. Choose a name
2. Choose a description
3. Choose whether the repo is public or private
4. Choose whether you want to add a `README.md` (yes), or a `.gitignore` or a `LICENSE.md` file (more next slide)

Creating a new repo on GitHub

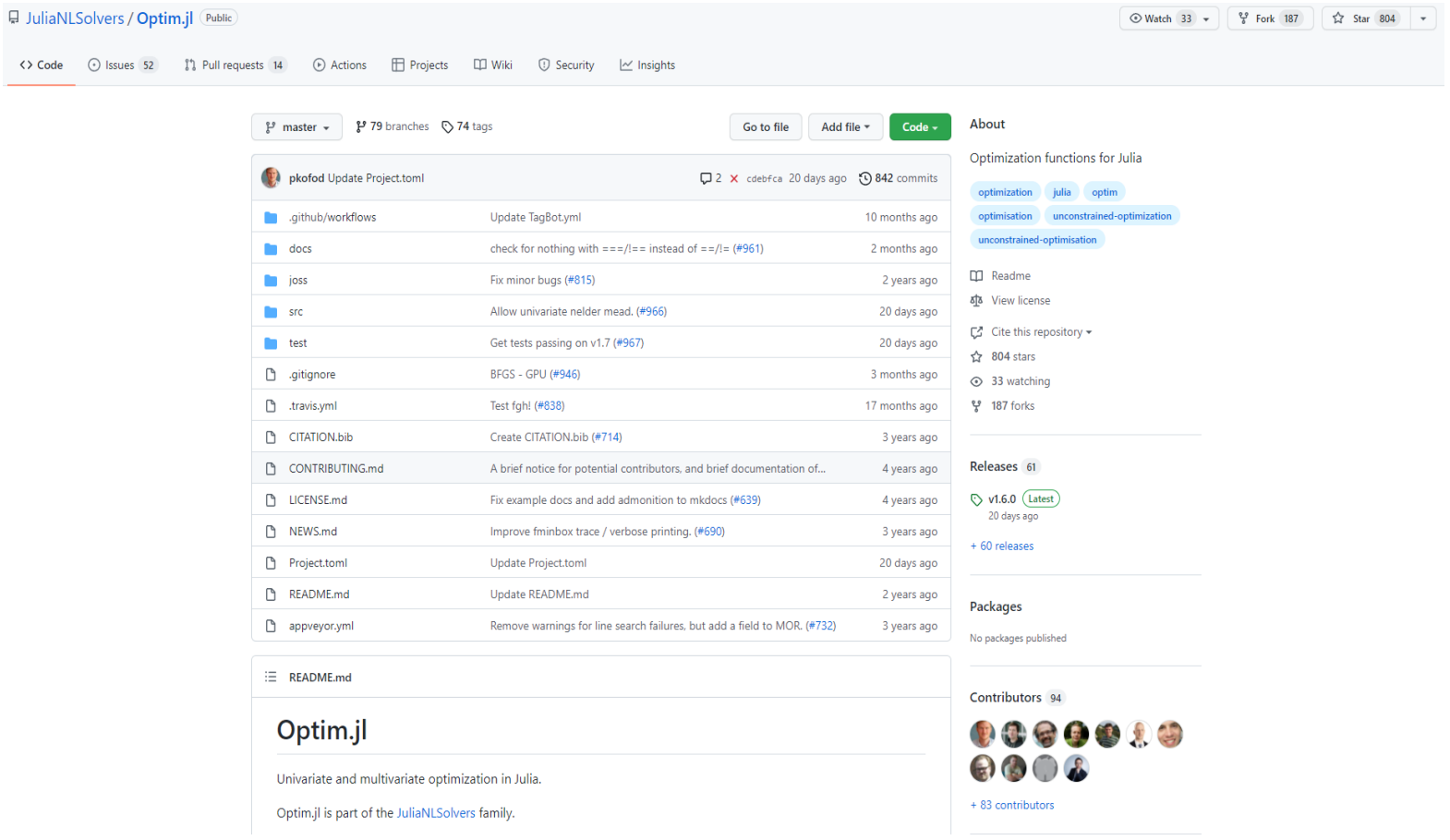


Creating a new repo on GitHub

Repos come with some common files in them

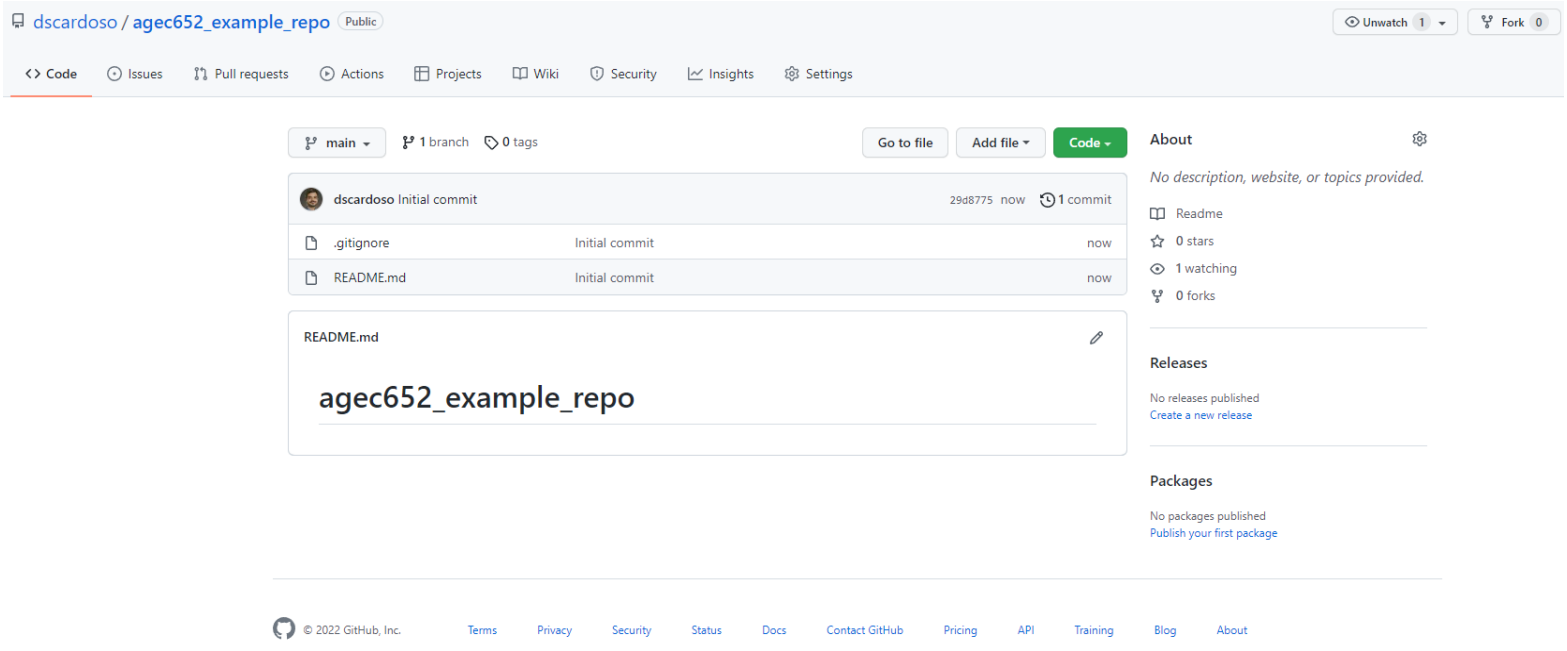
- `.gitignore`: lists files/directories/extensions that Git shouldnt track (raw data, restricted data, those weird LaTeX files). This is usually a good idea
- `README.md`: a Markdown file that is basically the welcome content on repo's GitHub website. You should generally initialize a repo with one of these
- `LICENSE.md`: describes the license agreement for the repository

Repo of Optim.jl again



Creating a new repo on GitHub

You can find the repo at
https://github.com/dscardoso/agec652_example_repo



How do I get a repo on GitHub onto on my computer?

`Clone`

To get the repository on your local machine you need to **clone** the repo

Key thing: this will **link** your local repository to the remote

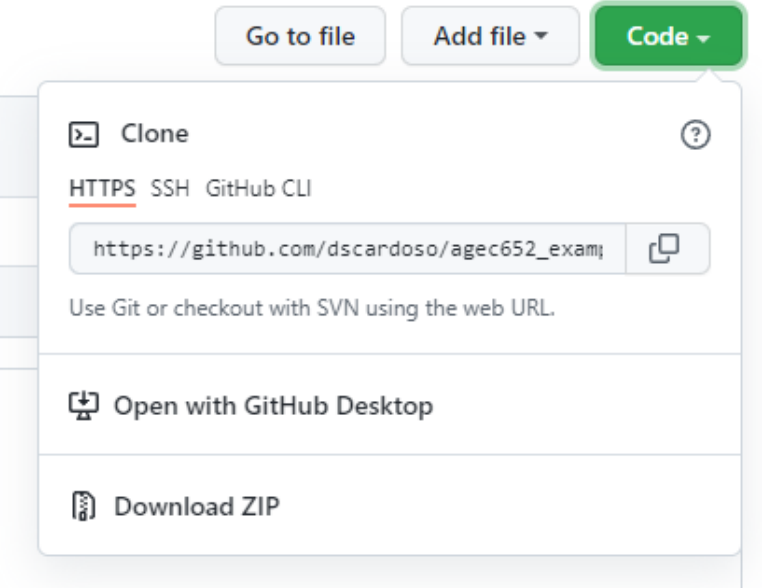
- You'll be able to update your local when the remote is changed

Cloning

Click on

- `Code` > `Open with GitHub Desktop`

You can also use git command line for that (we won't cover it here)

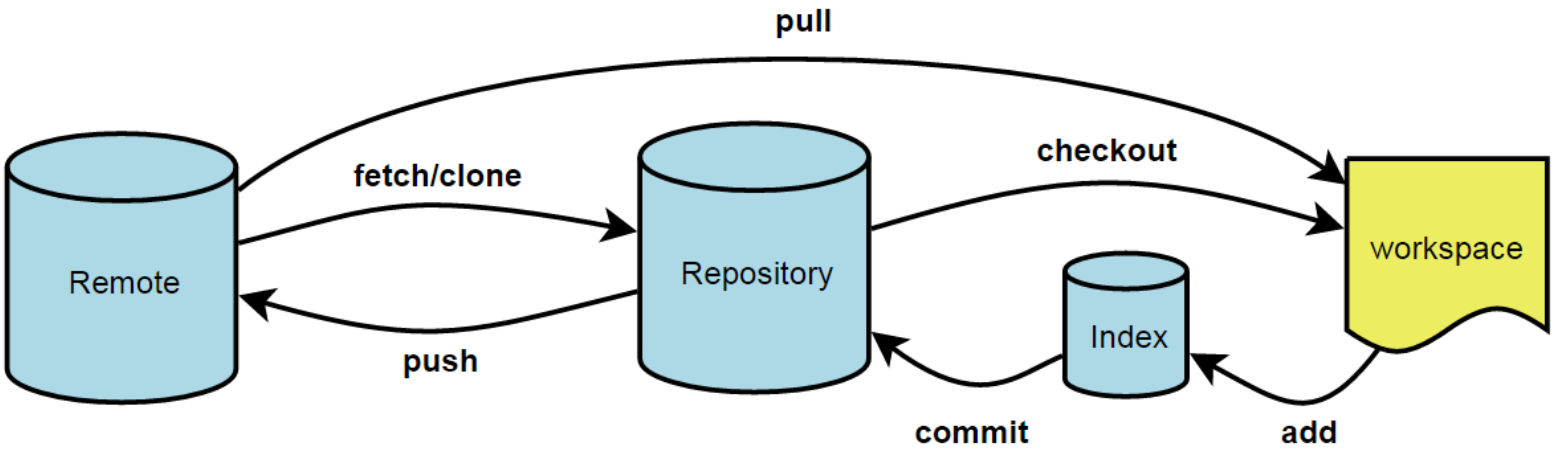


Your turn!

Create and clone your own repository on GitHub and initialize it with a `README.md` file

Git workflow

Workspace: actual files on your computer
Repository/local: your saved local history of changes to the files in the repository
Remote/origin: remote repository on GitHub that allows for sharing across collaborators



Using Git

There are only a few basic Git operations you need to know for versioning solo economics research efficiently

Add/Stage: Add files & modifications to the index

- Take a snapshot of the changes you want updated/saved in your local repository (i.e. your computer)

Commit: Record the changes to your local repository

- This requires a short message to record what was done or changed

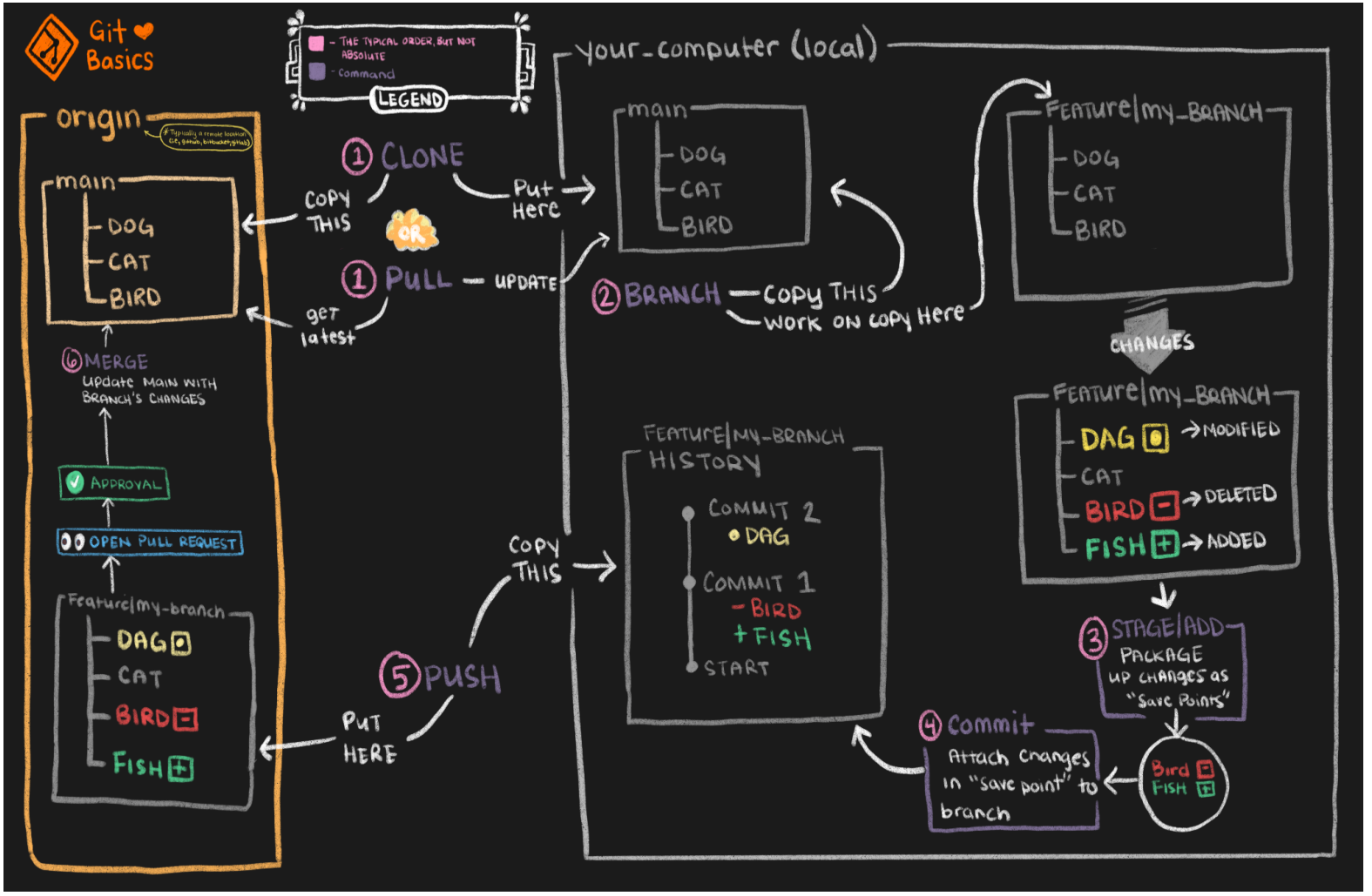
Using Git

Push: Send the changes you commited in the local repository to the remote repository (i.e. GitHub)

Pull: Take changes on the remote and integrate them with the local repository

- Technically two operations: `fetch` and `merge`

Git workflow: a sequence



Your turn!

In your own repository do the following:

1. Open `README.md` in some text editor and insert the following code: `# Hello World!`
2. Save `README.md`
3. Add the changes to `README.md` to the index
4. Commit the changes to your local repo with the message: "First README.md edit."
5. Push the changes to your remote

Did the changes show up your repo's GitHub page?

Using Git: branching

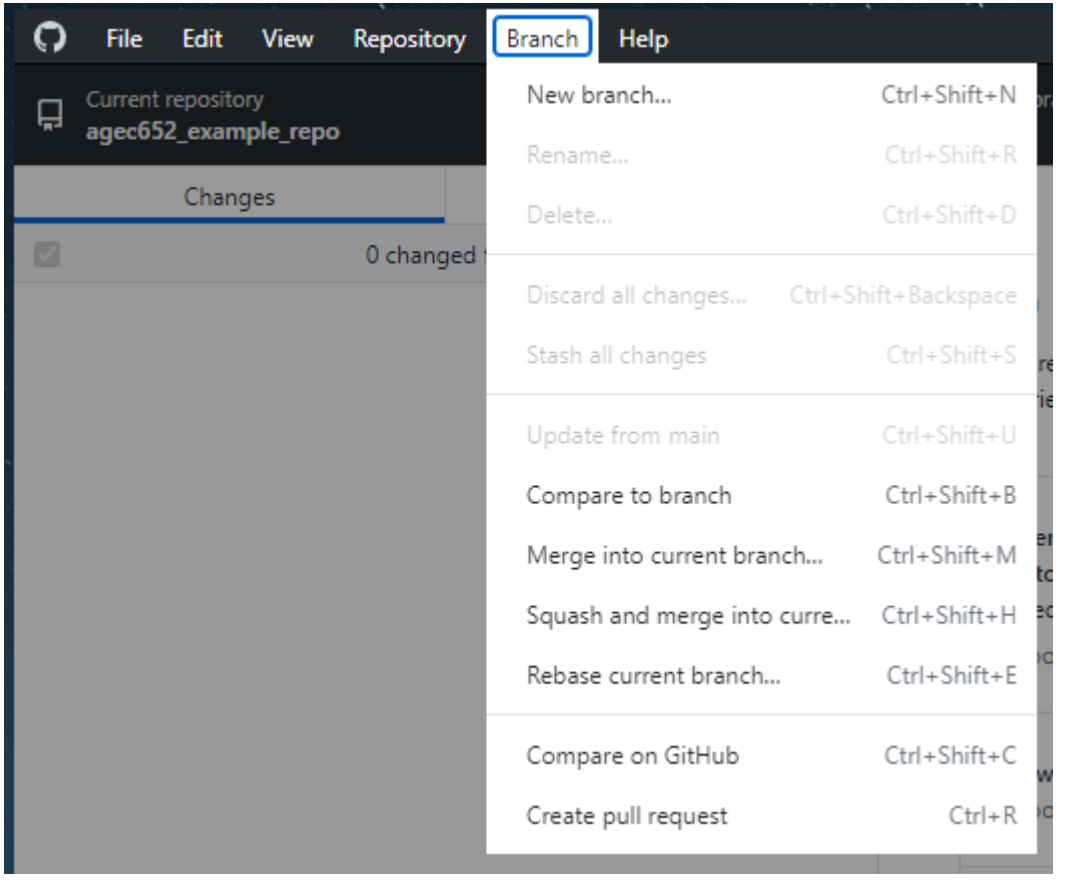
Some more (but not very) advanced operations relate to **branching** and **pull requests**

Branching creates different, but parallel, versions of your code

- If you want to test out a new feature of your model but don't want to contaminate your `main` branch, create a new branch and add the feature there
- If it works out, you can bring the changes back into `main`
- If it doesn't, just delete it

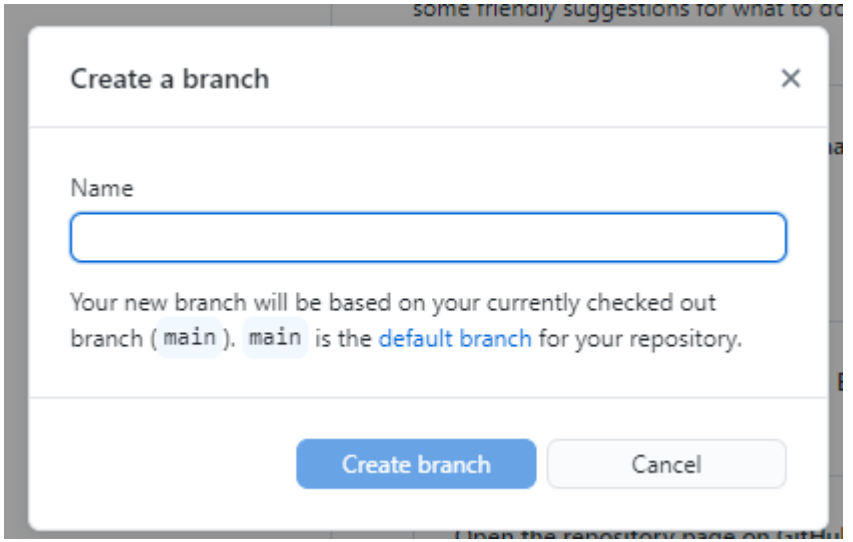
Using Git: branching

It is easy to create a branch on GitHub Desktop



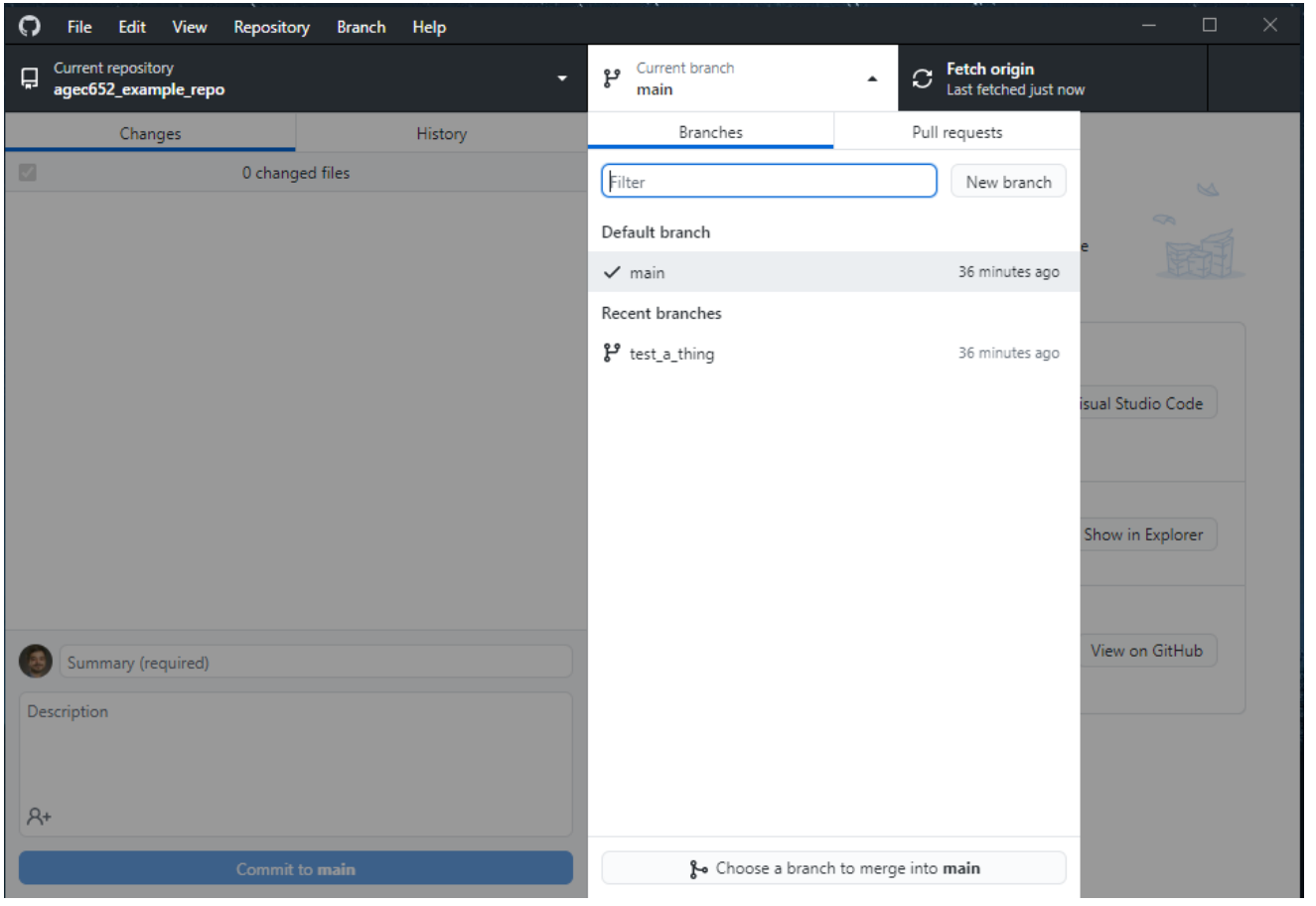
Using Git: branching

It is easy to create a branch on GitHub Desktop



Using Git: branching

And also to switch and merge your branch into the `main`



Your turn!

In your own repository do the following:

1. Create a new branch called `test-branch`
2. Edit `README.md` and add the following code: `## your_name_here`
3. Save `README.md`
4. Add the changes to `README.md` to the index
5. Commit and push the changes with the message: "Test change to README.md."
6. Switch to the `main` branch
7. Choose your `test-branch` to merge into the `main` branch
8. Push the changes to your remote
9. Check your repo's GitHub page

Pull requests

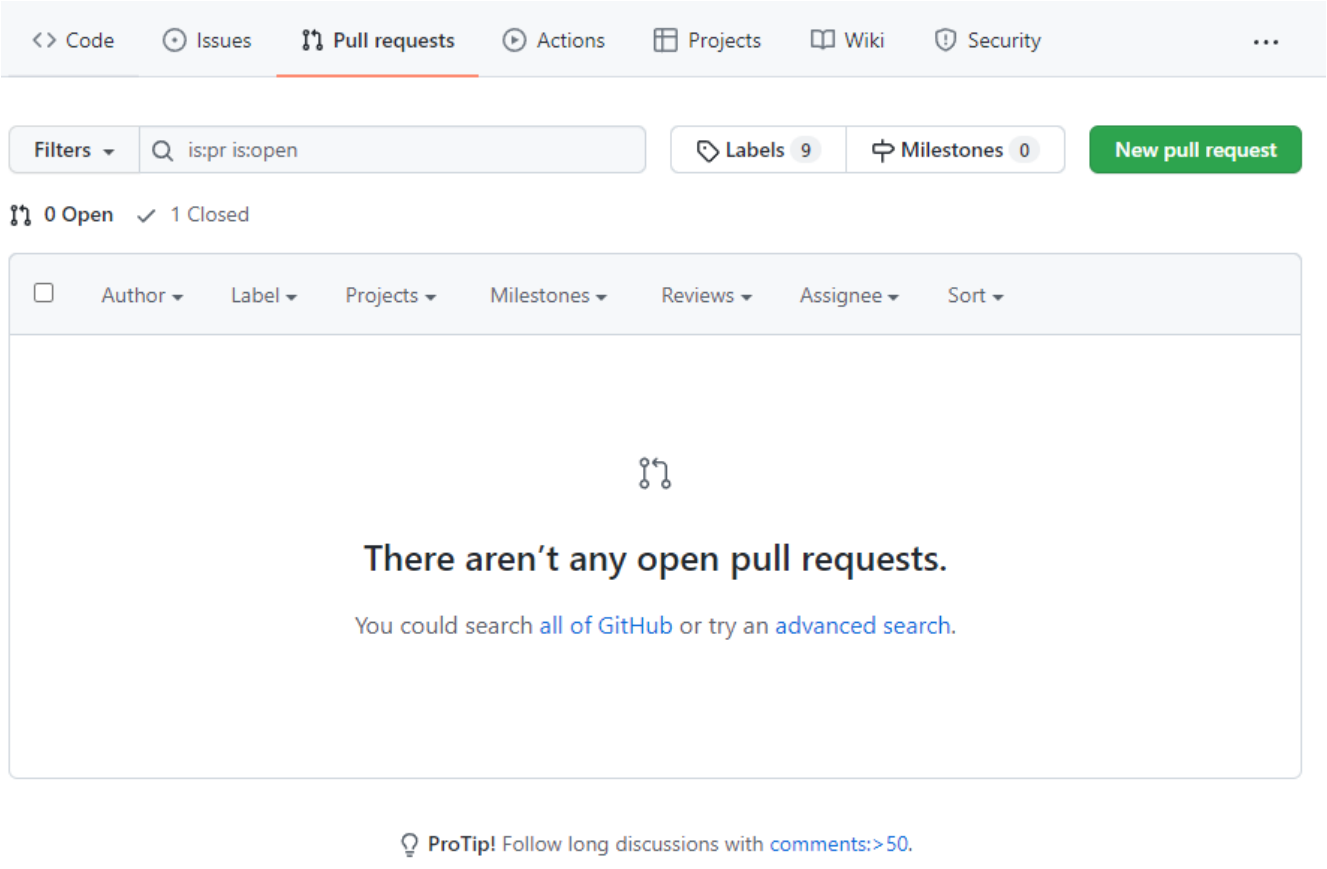
- The branch + merge we just did is the standard workflow if you are working alone
- When you are working with collaborators, before merging it is *best to announce first* that you have finished the branch or completed a new feature
- This is done with a **pull request**
- In practice, this is also a way to group a bunch of commits into a single new feature and let others know about it

Pull requests

Once you have committed and pushed changes to a branch, you create a new pull request on GitHub Desktop...

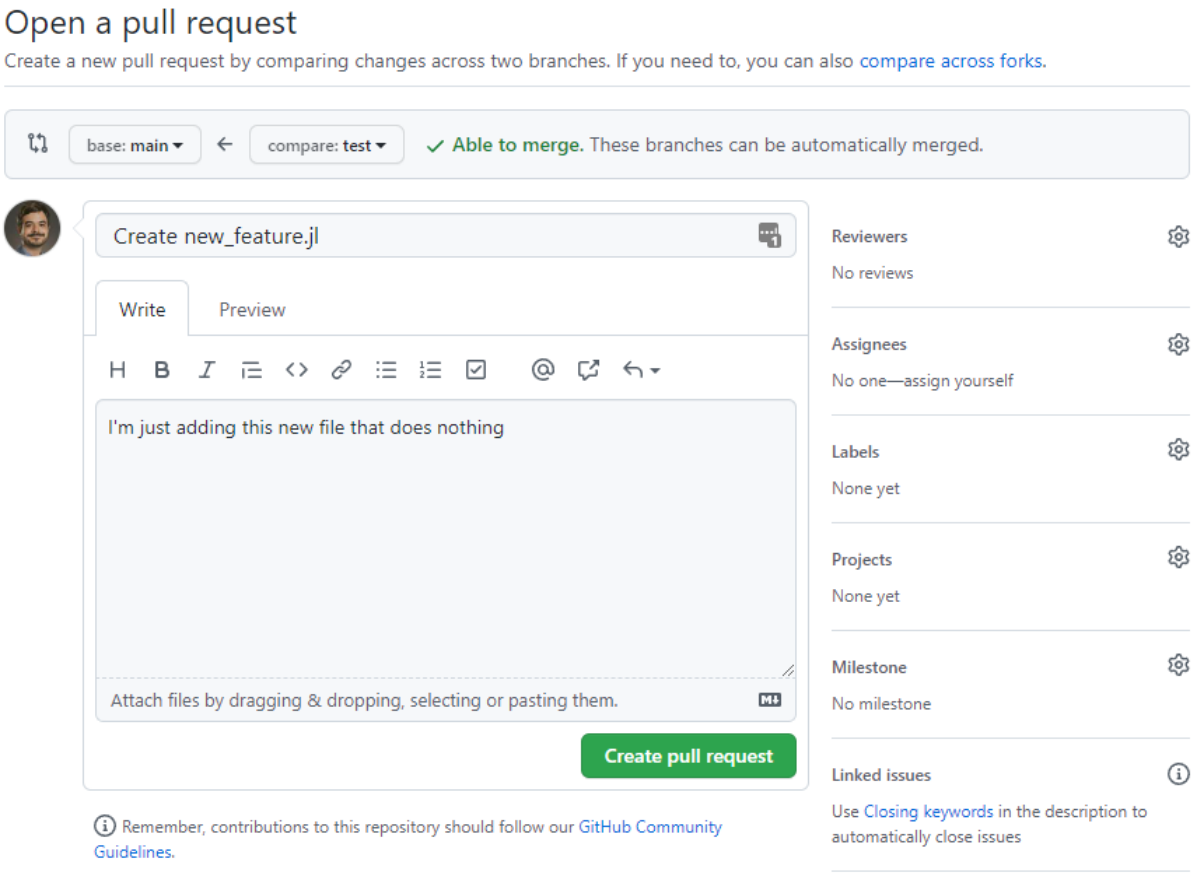
Pull requests

...or on the GitHub website



Pull requests

Enter a description and assign any reviewers

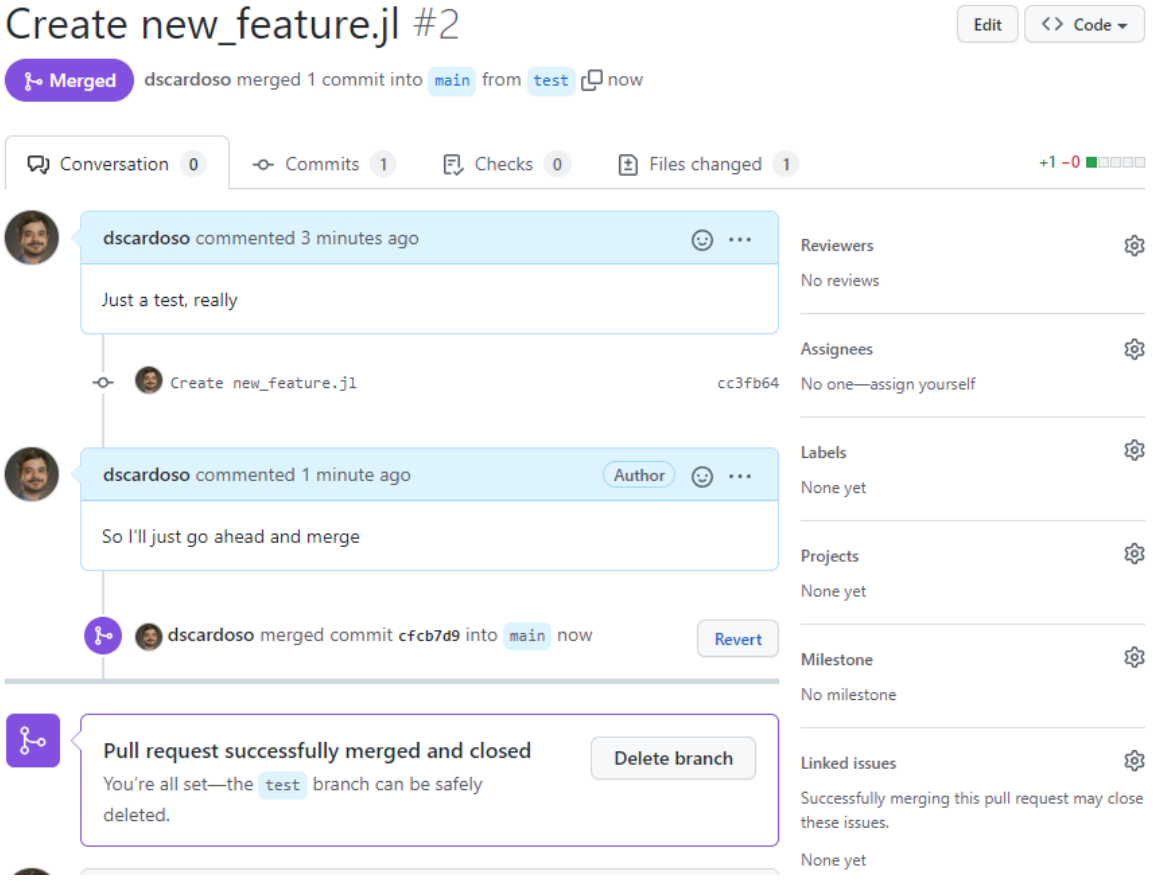


Pull requests

Once you and your collaborators are happy with it, just go ahead and `merge pull request`

Pull requests

And you're done!



Your turn!

In your own repository do the following:

1. Switch back to `test-branch`
2. Create a new file called `new_feature.jl` and write anything in it
3. Commit and push the changes with the message "Adding new feature"
4. Create a pull request and add "New feature" as a description
   - (Here is where you and collaborators would discuss/agree)
5. Go ahead and "Merge pull request"

Team up

1. Find a partner for this next piece
2. One of you invites the other to collaborate on the project: GitHub page > Settings > Manage access > invite a collaborator

Team up

If you were the one being invited, accept the invite, and clone the repo to your local

Now do the following:

1. Each of you edit the `# Hello World!` line of code to be something else and different from each other
2. Commit the changes to your local
3. Have the repo creator push their changes
4. Have the collaborator push their changes

Can't push changes when you aren't updated

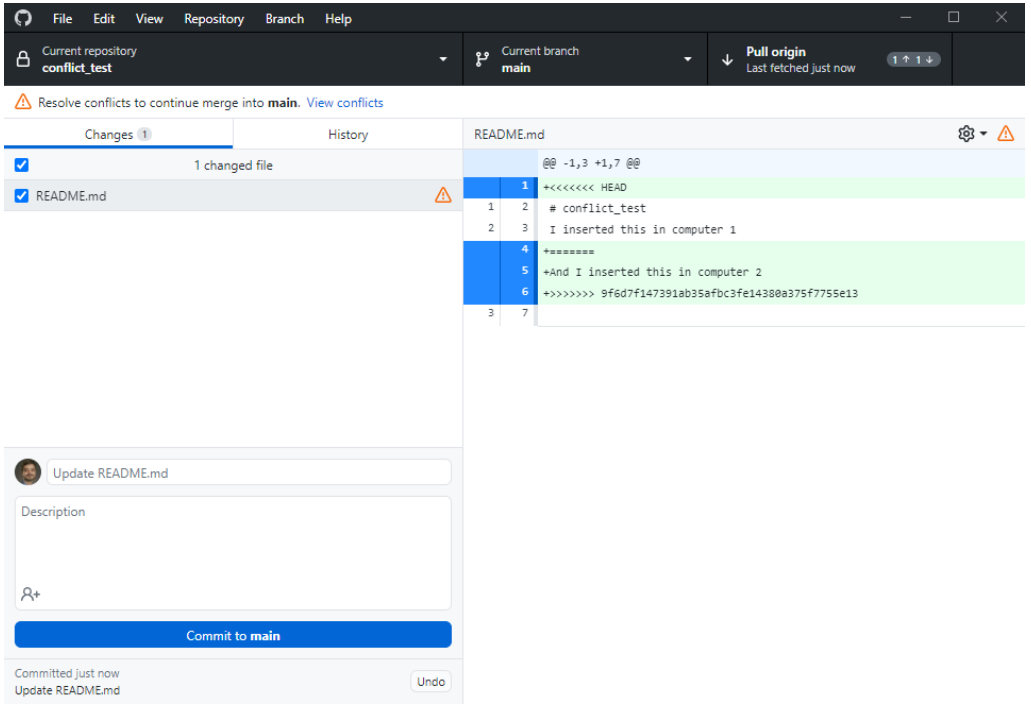
It turns out that the second person can't push their local changes to the remote

The second person is pushing their history of changes

But the remote is already one commit ahead because of the first person, so the second person's changes can't be pushed

Update by pulling after you commit local changes

You need to pull the remote changes first. But then you try to pull your commit and you get a **merge conflict** in `README.md`



Merge conflicts

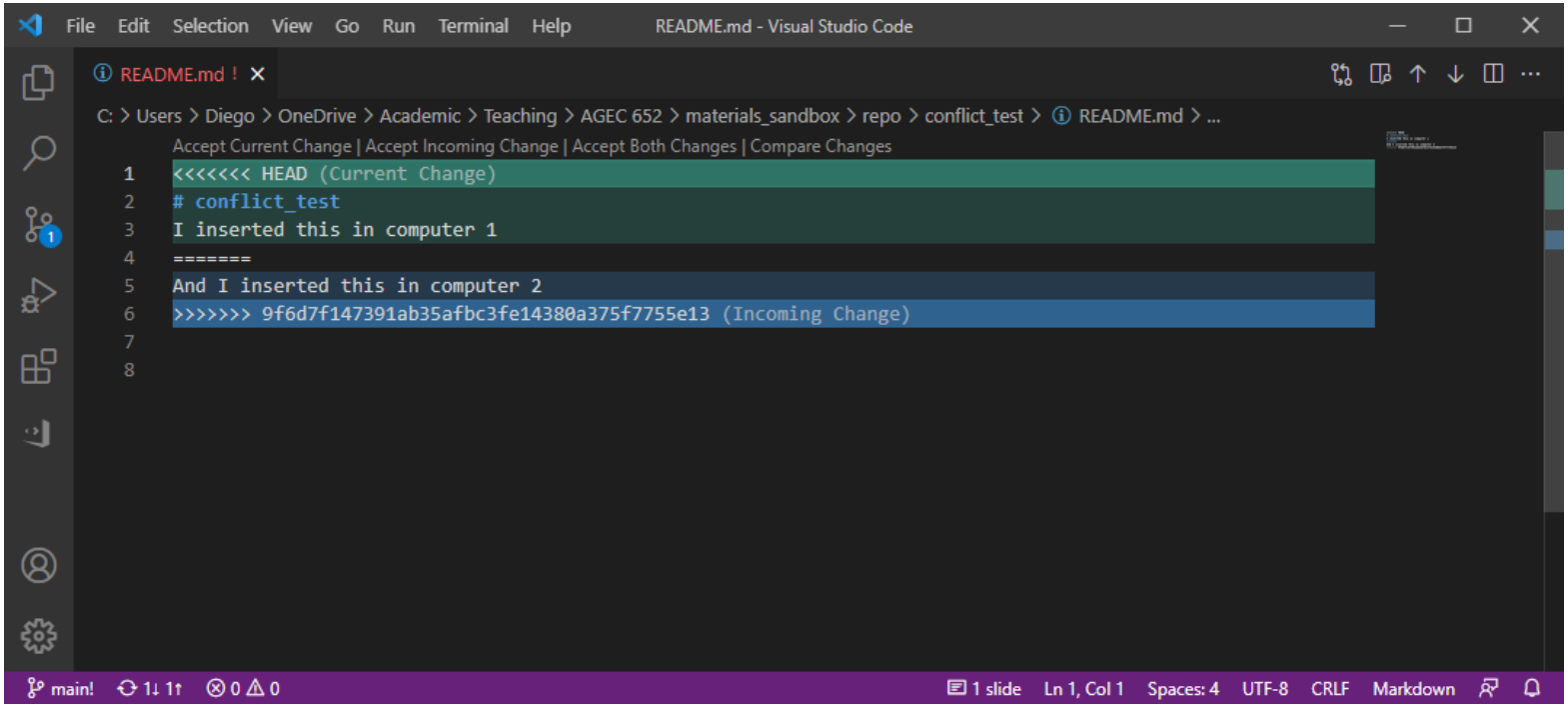
This means there were differences between the remote and your local that conflicted

Sometimes there will be conflicts between two separate histories

- E.g. if you and your collaborator edited the same chunk of code separately on your local repos
- When you try to merge these histories by pushing to the remote, Git will throw a **merge conflict**

Merge conflicts

Good code editors (like Visual Studio Code) "understand" git and will show you nicely where the conflict is



Solving merge conflicts

```
<<<<<<< HEAD
```

Indicates the start of the conflicted code

```
=======
```

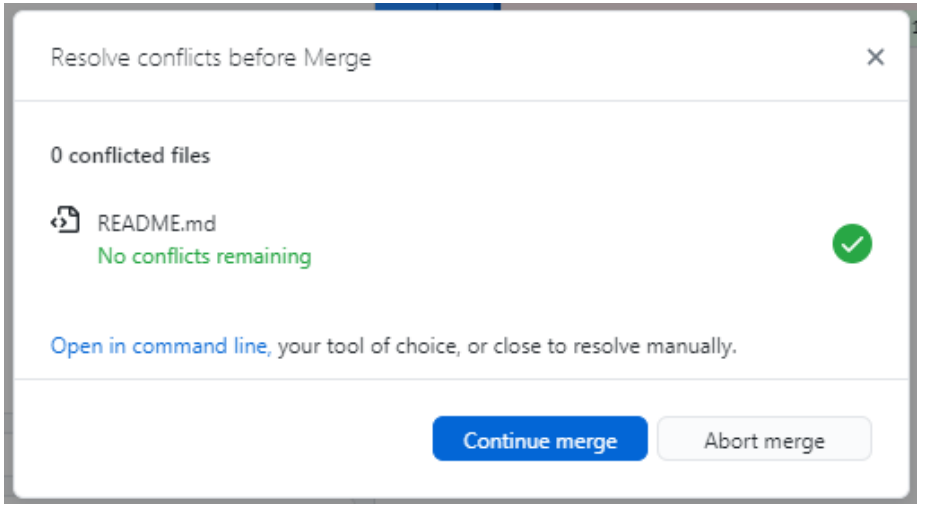
Separates the two different conflicting histories

```
>>>>>>> lots of numbers and letters
```

Indicates the end of the conflicted code and the hash (don't worry about it) for the specific commit

Fixing a merge conflict

Merge conflicts can be fixed by directly editing the file. Then `Continue merge` on GitHub Desktop. Fixed!



Let's get back to Gentzkow and Shapiro's rules

Version control

Store code and data under version control

- Now you know how to do that with Git(Hub)
- But I don't recommend using it for large data sets
  - Might actually be impossible because GitHub sets a strict size limit of 100 MB per file
  - For large data, use Dropbox/OneDrive/Box

Run the whole directory before checking it back in

- In other words: *avoid committing a version with bugs or that breaks other code in your project*

Management

Manage tasks with a task management system

E-mail is not a task management system

- You can do that in GitHub!
  - With the added benefit that you can easily link changes to tasks (we'll that in a bit)
- But there are many other tools
  - Some examples: Asana, Trello, Notion, and even Outlook tasks

Managing tasks and workflow with GitHub

GitHub is also very useful for task management in solo or group projects using **issues** and **pull requests**

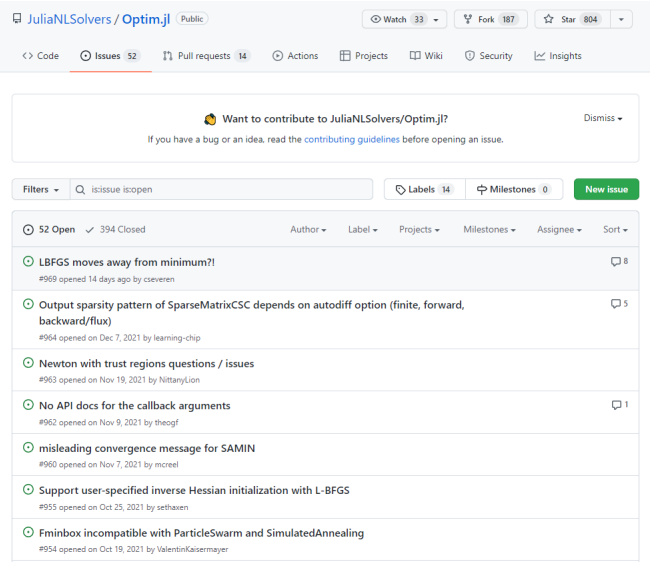
Issues: task management for you and your collaborators

- It should be able to completely replace email
  - With the added benefit of organizing your discussions and decisions by topic

Let's look at the issues for the `Optim` package in Julia

Issues

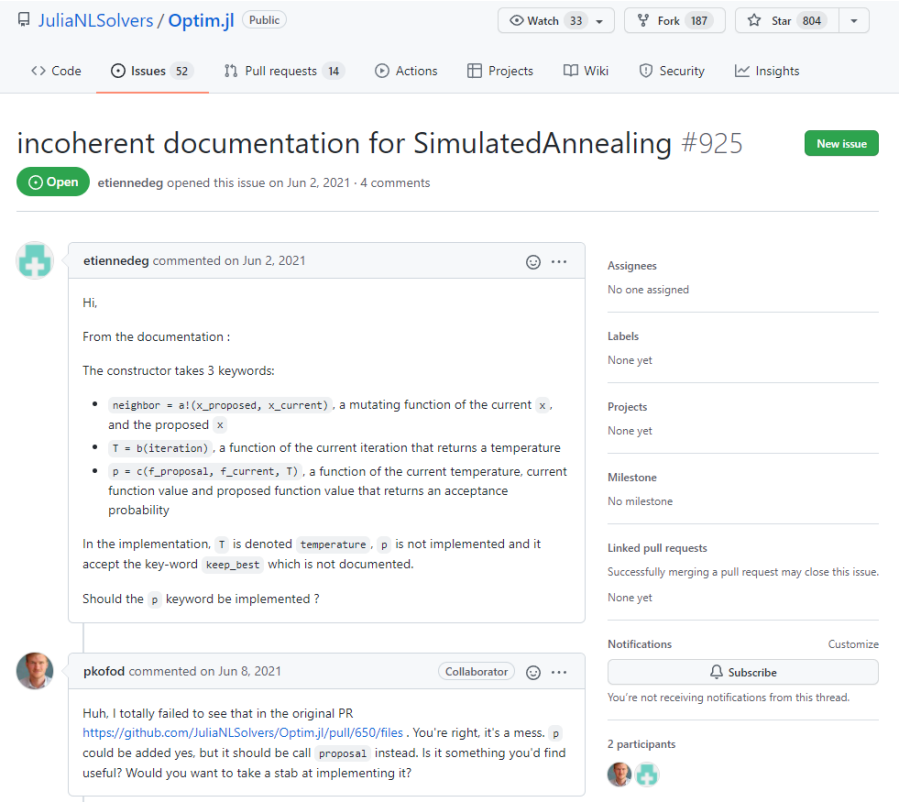
- The issues tab reports a list of 56 open issues (286 closed, i.e., task or problem has been solved)
- Each issue has its own title
- Let's one example of issue



Issues

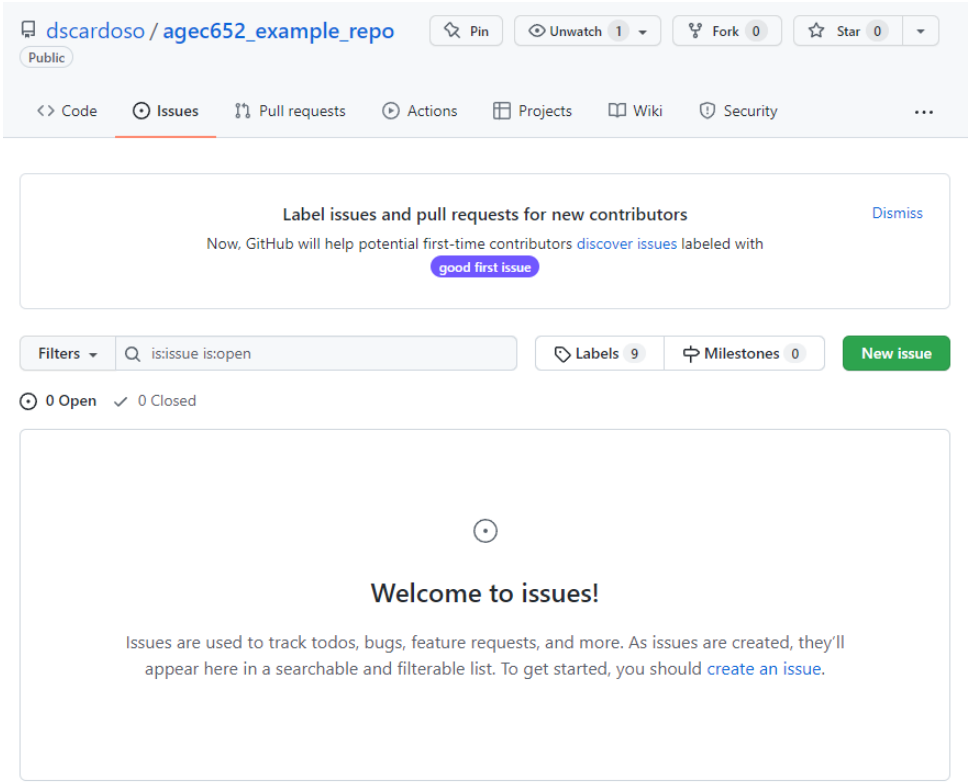
One person reported issues with the documentation of a function, which does not match the actual function

Someone else has responded with some feedback



Issues

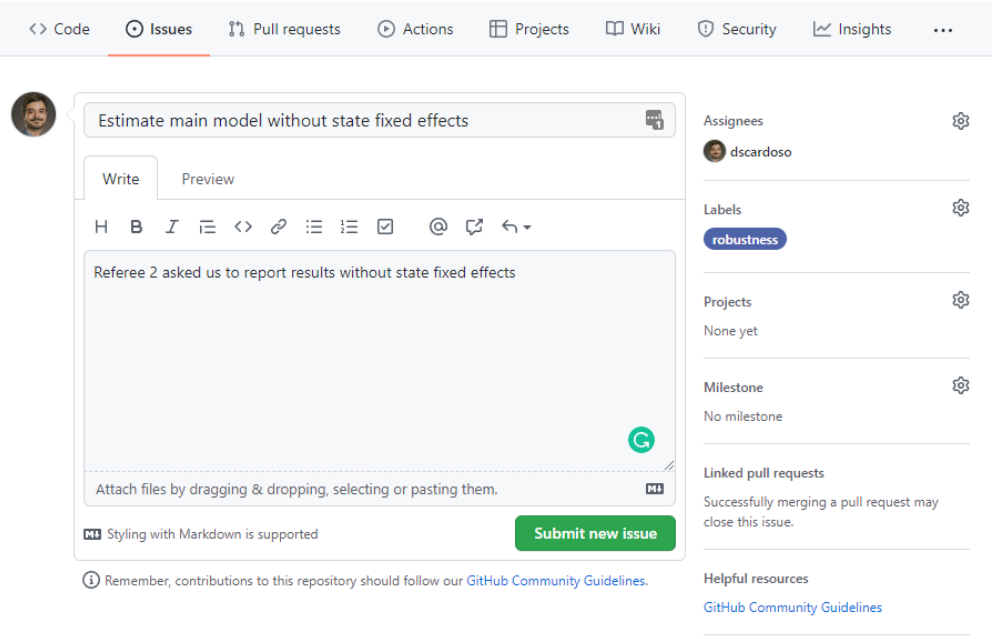
It is easy to creat a new task or *issue*: from the issues tab, click the green **new issue** button which takes you here



Issues

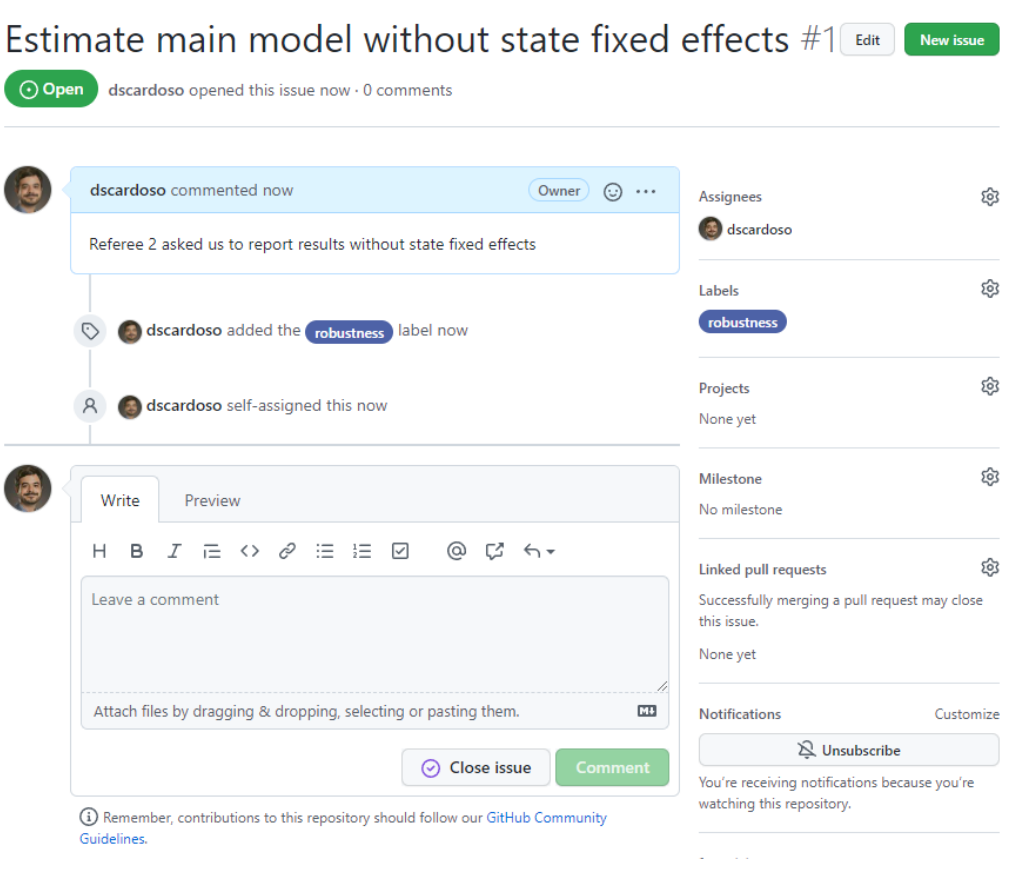
Then you can

- Add a title
- Add a description
- Assign the task to a collaborator
- Add labels/tags



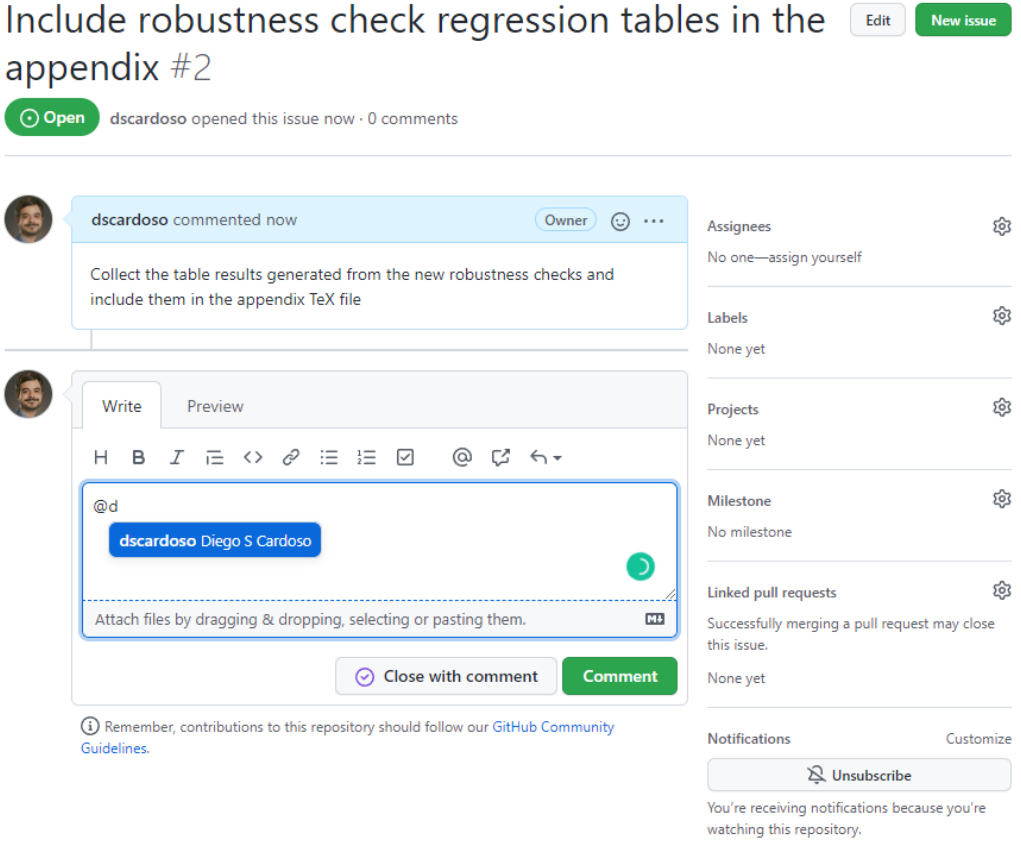
Issues

The issue keeps track of the history of everything that's happened to it



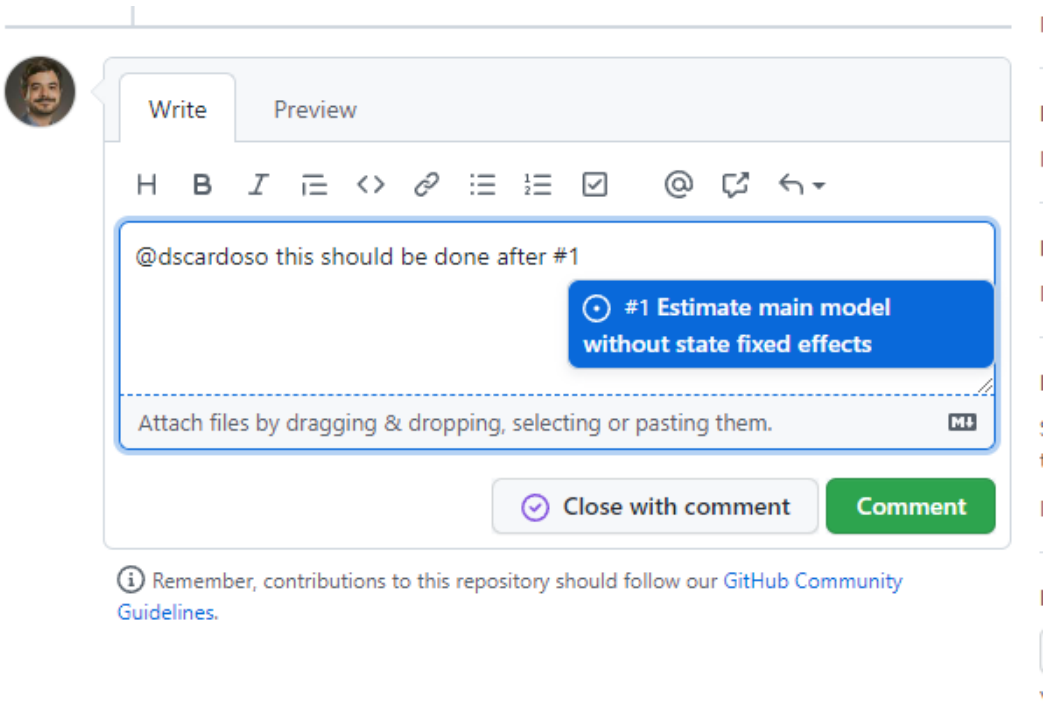
Issues

You can reference people with @ which brings up a dropdown menu of all collaborators on the project



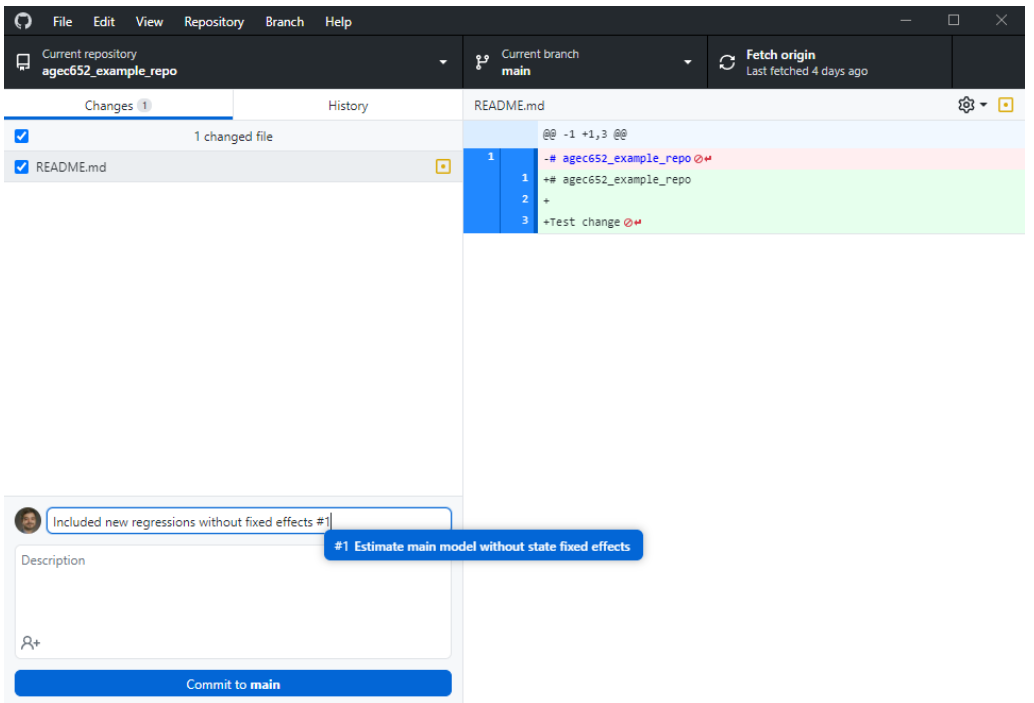
Issues

You can also reference *other issues* if they're related by using # which brings up a dropdown of all issues for your repository



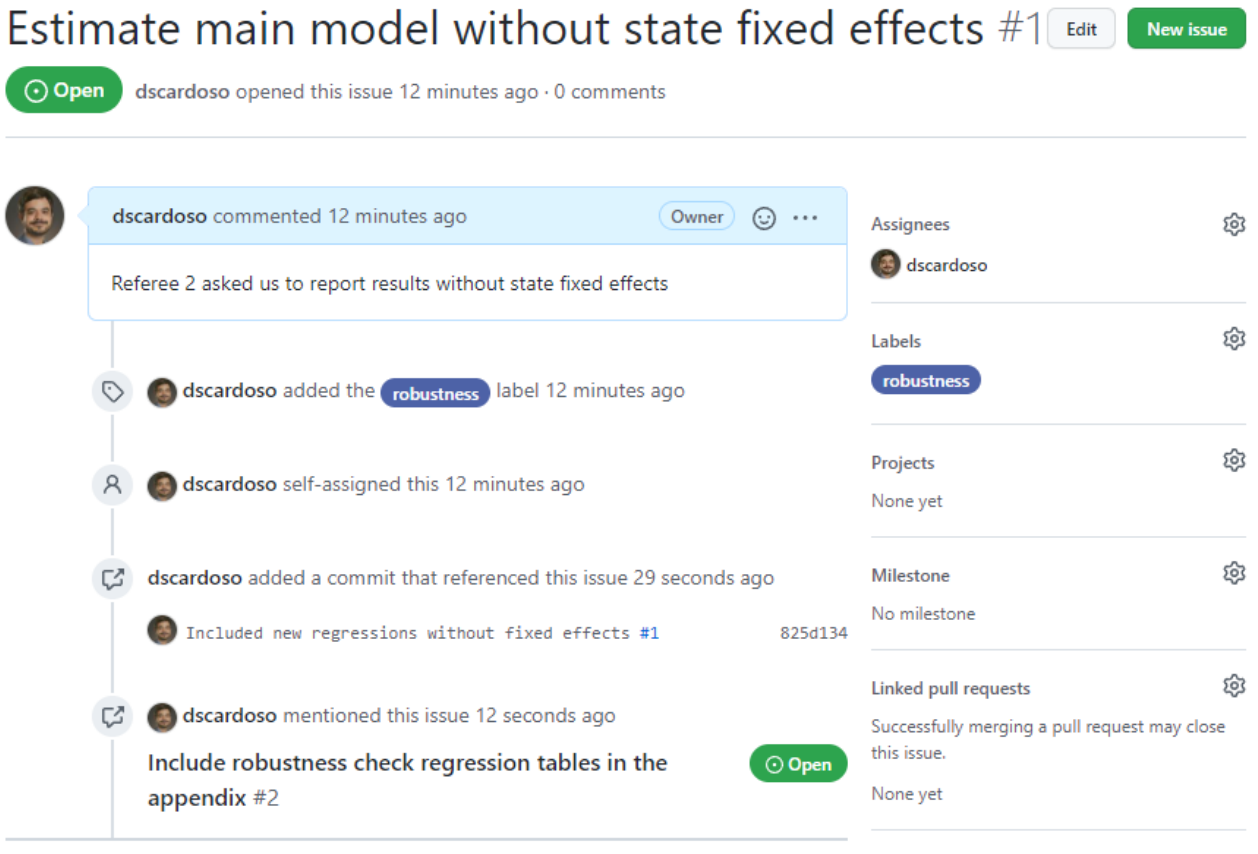
Issues

Issues can also be referenced in your commits to your project by adding `#issue_number_here` to the commit message



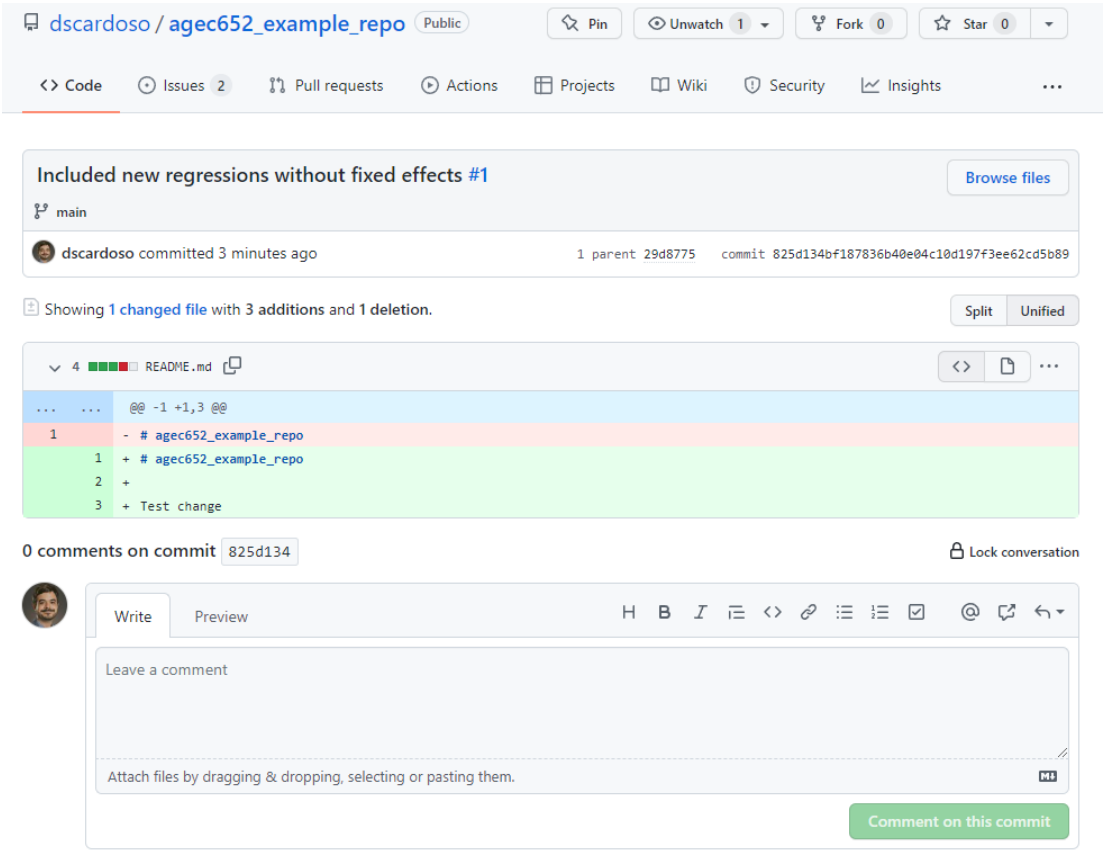
Issues

Then those commits show up in your issue so you have a history of what code changes have been made



Issues

If you click on the commit, it takes you to the `git diff` which shows you any changes to files made in that commit



Git FAQ

FAQ

Q: When should I commit (and push) changes?

A: Early and often

- It's not quite as important as saving your work regularly, but it's a close second
- You should certainly push everything that you want your collaborators to see

FAQ

Q: Do I need branches if I am working on a solo project?

A: You don't really need them, but they offer big advantages in maintaining a sane workflow

- Experiment without any risk to the main project!

FAQ

Q: What's the difference between cloning and forking a repo?

A: Cloning directly ties your local version to the original repo, while forking creates a copy on your GitHub (which you can then clone)

- Cloning makes it easier to fetch updates (and is often the best choice for new GitHub users), but forking has advantages too.

FAQ

Q: What happens when something goes wrong?

A: Look for help

- Command line-based fixes: ohshitgit.com
- Also, search on Stack Exchange

FAQ

Q: What happens when something goes *horribly* wrong?

A: Burn it down and start again:
http://happygitwithr.com/burn.html

- This is a great advantage of Git's distributed nature:
  - If something goes horribly wrong, there's usually an intact version somewhere else

Appendix

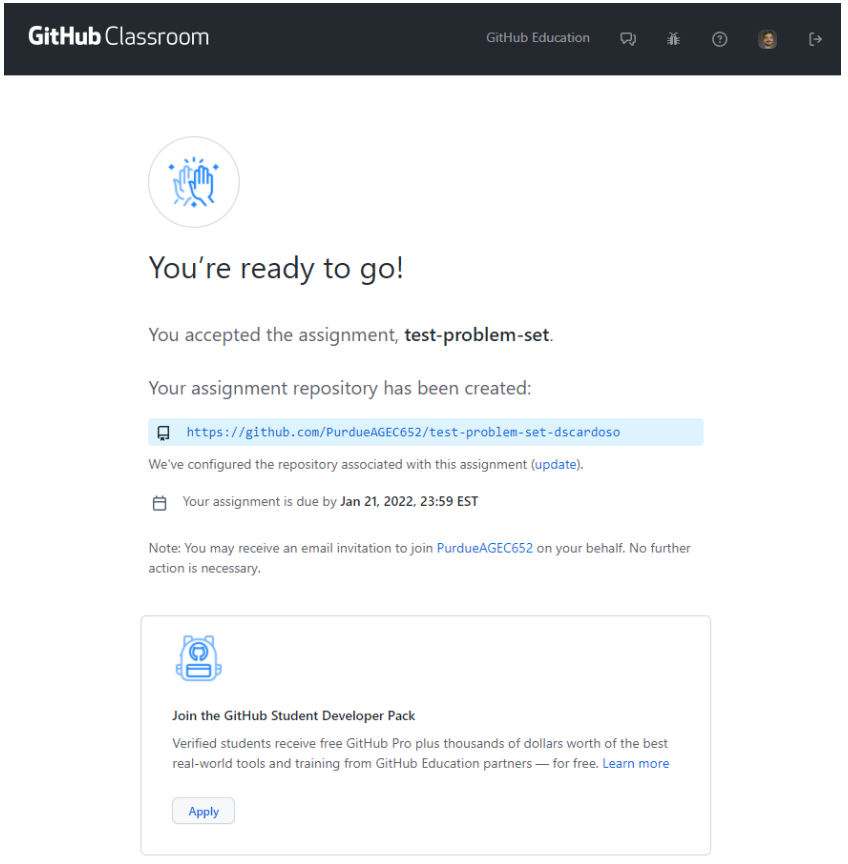
Submitting problem sets with GitHub Classroom

Problem set submission

- We'll use our problem sets to get familiarized with GitHub workflow
- For each problem set, you will receive an invitation
- After you accept the invitation, GitHub will create a new private repository
  - Only you and Diego will be able to see its content
- GitHub will automatically create a *pull request* called **Feedback**
  - This is where I'll write any feedback I might have for your submission

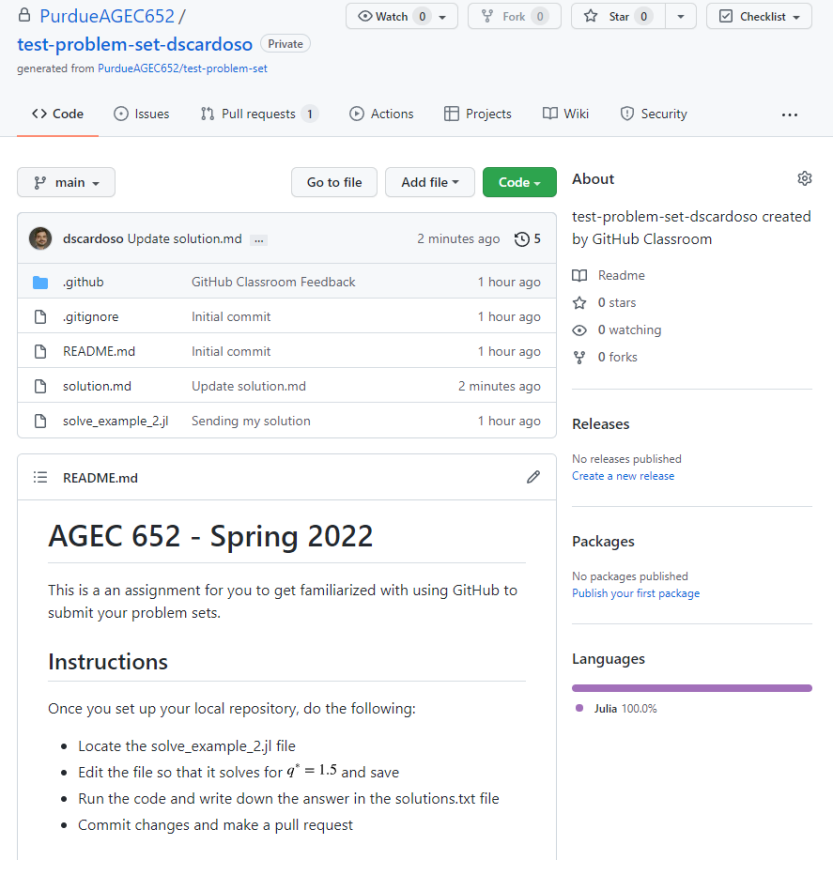
Problem set submission

This is what you should see after you accept an assignment invitation



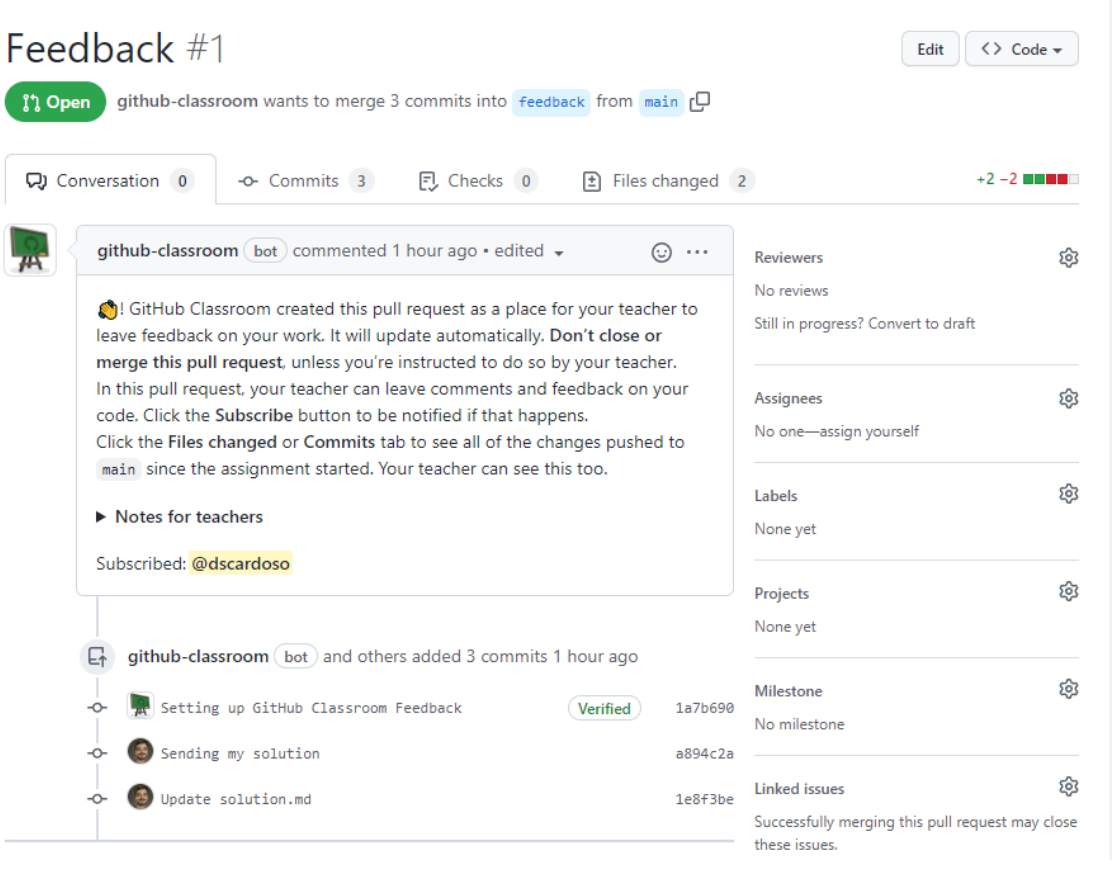
Problem set submission

Following the repository link, you'll see that it is pre-populated with any necessary files and instructions



Problem set submission

And this is what the **Feedback** pull request page will look like after your first commit



Next class

We'll jump into coding with Julia

Before next class, please:

1. Follow the instructions from Quant Econ Lecture 1 to install Julia, Jupyter, and Visual Studio (VS) code on your laptop
2. Do a test run: follow the instructions on the "Test Problem Set" assignment on GitHub Classroom
   - Solve the equilibrium price for $q^* = 1.5$
   - Write down the answer and commit/submit