Contents

Research Software Engineering with Python

Introduction

In this course, you will move beyond programming, to learn how to construct reliable, readable, efficient research software in a collaborative environment. The emphasis is on practical techniques, tips, and technologies to effectively build and maintain complex code. This is a relatively short course (8-10 half-day modules) which is intensive and involves hands-on exercises.

Pre-requisites

- It would be helpful to have experience in at least one programming language (for example `C++`, `C`, `Fortran`, `Python`, `Ruby`, `Matlab` or `R`) but this is not a requirement.
- Experience with version control and/or the `Unix` shell, for instance from Software Carpentry, would also be helpful.
- You should bring your own laptop to the course as there are several hands-on exercise for you to work through.
- We have provided setup instructions for installing the software needed for the course on your computer.
- **Eligibility:** This course is primarily aimed at Turing-connected PhD students. Other Turing-affiliated people might join too if capacity allows.

Instructors

- Turing Research Engineering Group

Exercises

Examples and exercises for this course will be provided in `Python`. We will assume you have prior experience with at least one programming language but `Python` syntax and usage will be introduced during this course. However, this course is **not** intended to teach `Python` and you may find supplementary content useful.

Evaluation

None: you are not graded. There are two exercises that you can use for self-assessment.

- Packaging Greengraph
- Refactoring the Bad Boids

Versions

You can browse through course notes as HTML or download them as a printable PDF via the navigation bar to the left.

If you encounter any problem or bug in these materials, please remember to add an issue to the course repo, explaining the problem and, potentially, its solution. By doing this, you will improve the instructions for future users. 🎉

Installation Instructions

Introduction

This document contains instructions for installation of the packages we'll be using during the course. You will be following the training on your own machines, so please complete these instructions.

If you encounter any problem during insallation and you manage to solve them (feel free to ask us for help), please remember to add an issue to the course repo, explaining the problem and solution. By doing this you will be helping to improve the instructions for future users! :tada:

What we're installing

- the `Python` programming language (version `3.7` or greater)
- some `Python` software packages that will be used during the course.
- `git` for the version control module
- your favourite text editor

Please ensure that you have a computer (ideally a laptop) with all of these installed.

Linux

Package Manager

`Linux` users should be able to use their package manager to install all of this software (if you're using `Linux`, we assume you won't have any trouble with these requirements).

However note that if you are running an older `Linux` distribution you may get older versions with different look and features. A recent `Linux` distribution is recommended.

Python via package manager

Recent versions of `Ubuntu` come with mostly up to date versions of all needed packages. The version of `IPython` might be slightly out of date. Advanced users may wish to upgrade this using `pip` or a manual install. On `Ubuntu` you should ensure that the following packages are installed using `apt-get`.

- `python3-numpy`
- `python3-scipy`
- `python3-pytest`
- `python3-matplotlib`
- `python3-pip`
- `jupyter`
- `ipython3`
- `ipython3-notebook`

Older distributions may have outdated versions of specific packages. Other `Linux` distributions most likely also contain the needed `Python` packages but again they may also be outdated.

Python via Anaconda

We recommend you use Anaconda, a complete independent scientific python distribution.

Download Anaconda for Linux with your web browser, choosing the latest version. Open a terminal window, go to the place where the file was downloaded and type:

```
bash Anaconda3-
```

and then press `Tab`. The name of the file you just downloaded should appear.

Follow the text prompts ensuring that you:

- agree to the licence
- prepend `Anaconda` to your `PATH` (this makes the `Anaconda` distribution the default `Python`)

You can test the installation by opening a new terminal and checking that:

```
which python
```

shows a path where you installed `Anaconda`.

Python via Enthought Canopy

Alternatively you may install a complete independent scientific python distribution. One of these is `Enthought Canopy`.

The `Enthought Canopy` Python distribution exists in two different versions. A basic free version with a limited number of packages (`Canopy Express`) and a non free full version. The full version can be obtained free of charge for academic use.

You may then use your Enthought user account to sign into the installed `Canopy` application and activate the full academic version. `Canopy` comes with a package manager from where it is possible to install and update a large number of python packages. The packages installed by default should cover our needs.

Git

If `git` is not already available on your machine you can try to install it via your distribution package manager (e.g. `apt-get` or `yum`), for example:

```
sudo apt-get install git
```

Editor

Many different text editors suitable for programming are available. If you don't already have a favourite, you could look at one of these:

- Visual Studio Code
- Atom
- Sublime Text
- Vim
- Emacs

Regardless of which editor you have chosen you should configure `git` to use it. Executing something like this in a terminal should work:

```
git config --global core.editor NameofYourEditorHere
```

The default shell is usually `bash` but if not you can get to `bash` by opening a terminal and typing `bash`.

MacOS

Upgrade MacOS

We do not recommend following this training on older versions of `macOS` without an app store: upgrade to at least `macOS 10.9 (Mavericks)`.

XCode and Command line tools

Install the `XCode` command-line-tools by opening a terminal and run the following.

```
xcode-select --install
```

And follow the on screen instructions.

You may also install `Xcode` from the app store if you wish, but it is not needed.

Git

The `XCode` command line tools come with `Git` so no need to do anything more.

Homebrew

Homebrew is a package manager for `macOS` which enables the installation of a lot of software useful for scientific computing. It is required for some of the installations below. `Homebrew` requires the `Xcode` tools above.

Install `homebrew` via typing this at a terminal:

```
ruby -e "$(curl -fsSL https://raw.githubusercontent.com/Homebrew/install/master/install)"
```

and then type.

```
brew doctor
```

And read the output to verify that everything is working as expected. If you are already running `MacPorts` or another package manager for `macOS` we don't recommend installing `homebrew` as well.

Python

We recommend installing a complete scientific python distribution. One of these is Anaconda. Please download and install Anaconda (latest version).

Python from Homebrew

Alternatively if you wish to install `Python` manually you can use Homebrew. `macOS` ships with `Python` and some packages. However this has known limitations and we do not recommend it. You can install a new version of `Python` from `homebrew` with the following. Please follow the instructions above to install the `Xcode` command line tools and `homebrew` before attempting this.

```
brew install python3
```

In order to ensure that this version of `Python` is selected over the `macOS` default version you should execute the following command:

```
echo export PATH='/usr/local/bin:$PATH' >> ~/.bash_profile
```

and reopen the terminal. Verify that this is correctly installed by executing

```
python --version
```

Which should print:

```
Python 3.8.x
```

(where x will be replaced by a version number)

This will result in an installation of `python3` and `pip3` which you can use to have access to the latest `Python` features which will be taught in this course.

Then install additional `Python` packages by executing the following.

```
brew install [package-name]
```

- `pkg-config`
- `freetype`
- `gcc`

```
pip3 install [package-name]
```

- `numpy`
- `scipy`
- `matplotlib`
- `jupyter`
- `ipython[all]`

The following packages should be installed automatically as dependencies, but we recommend installing them manually just in case.

- `tornado`
- `jinja2`
- `pyzmq`
- `pytest`

Editor and shell

The default text editor on `macOS` *textedit* should be sufficient for our use. Alternatively consider one of these editors:

- Visual Studio Code
- Atom
- Sublime Text
- Vim
- Emacs

To setup `git` to use *textedit* executing the following in a terminal should do.

```
git config --global core.editor /Applications/TextEdit.app/Contents/MacOS/TextEdit
```

For VS Code:

```
git config --global core.editor "code --wait"
```

The default terminal on `macOS` should also be sufficient. If you want a more advanced terminal iTerm2 is an alternative.

Windows

Python

We recommend installing a complete scientific python distribution. One of these is Anaconda.

Please download and install Anaconda (Python 3.8 version).

Sophos

To use the `IPython` notebook on a `Windows` computer with Sophos anti-virus installed it may be necessary to open additional ports allowing communication between the notebook and its server. The solution is:

- open your `Sophos Endpoint Security and Control Panel` from your tray or start menu
- Select `Configure > Anti-virus > Authorization` from the menu at the top
- Select the websites tab
- click the `Add` button and add `127.0.0.1` and `localhost` to the `Authorized websites` list
- restart computer (or just restart the `IPython` notebook)

Git

Install the GitHub for Windows client. This comes with both a GUI client as well as the Git Bash terminal client which we will use during the course. You should register with Github for an account and sign into the GUI client with this account. This will automatically set-up SSH based authentication for the terminal client. The terminal client comes in 3 different flavours based on `Windows CMD` (DOS like), `Windows Powershell`, and `BASH`. We will use the `BASH` client as this most closely resembles the `Linux` and `OS X` terminal used by other students. In order to configure this open the Github client. Sign in with your credentials and:

- Select tools
- Options
- Default Shell
- Git Bash
- And Press Update to save.

Verify that this is working by opening Git Bash. The Shell window should have a title that starts with MINGW32.

Editor

Unless you already use a specific editor which you are comfortable with we recommend using one of the following:

- Visual Studio Code
- Atom
- Notepad++
- Sublime Text
- Vim
- Emacs

Using any of these to edit text files including code should be straight forward. `Visual Studio Code` has integrations with Git Bash and the Python prompt that you may want to configure.

Testing your install

Check this works by opening the Github shell. Once you have a terminal open, type

```
which code
```

which should produce readout similar to `/c/Program Files (x86)/Code/Code.exe`

Also verify that typing:

```
code
```

opens the editor and then close it again.

Also test that

```
which git
```

produces some output like `/bin/git`. The `which` command is used to figure out where a given program is located on disk.

Telling Git about your editor

Now we need to update the default editor used by `Git`.

```
git config --global core.editor "code --wait"
```

Note that it is not obvious how to copy and paste text in a `Windows` terminal including `Git Bash`. Copy and paste can be found by right clicking on the top bar of the window and selecting the commands from the drop down menu (in a sub menu).

Testing Python

Confirm that the `Python` installation has worked by typing:

```
python -V
```

Which should result in details of your installed `Python` version. This should print the installed version of the `Python` and `Git` confirming that both are installed at working correctly. You should now have a working version of `Git`, `Python`, and your chosen editor, all accessible from your shell.

Version Control

- Why use version control
- Solo use of version control
- Publishing your code to GitHub
- Collaborating with others through Git
- Branching
- Rebasing and Merging
- Debugging with GitBisect
- Forks, Pull Requests and the GitHub Flow

Introduction

What's version control?

Version control is a tool for **managing changes** to a set of files.

There are many different **version control systems**:

- Git
- Mercurial (`hg`)
- CVS
- Subversion (`svn`)
- …

Why use version control?

- Better kind of **backup**.
- Review **history** ("When did I introduce this bug?").
- Restore older **code versions**.

- Ability to **undo mistakes**.
- Maintain **several versions** of the code at a time.

Git is also a **collaborative** tool:

- “How can I share my code?”
- “How can I submit a change to someone else’s code?”
- “How can I merge my work with Sue’s?”

Git != GitHub

- **Git**: version control system tool to manage source code history.
- **GitHub**: hosting service for Git repositories.

How do we use version control?

Do some programming, then commit our work:

```
my_vcs commit
```

Program some more.

Spot a mistake:

```
my_vcs rollback
```

Mistake is undone.

What is version control? (Team version)

Sue	**James**
`my_vcs commit`	…
…	Join the team
…	`my_vcs checkout`
…	Do some programming
…	`my_vcs commit`
`my_vcs update`	…
Do some programming	Do some programming
`my_vcs commit`	…
`my_vcs update`	…
`my_vcs merge`	…
`my_vcs commit`	…

Scope

This course will use the `git` version control system, but much of what you learn will be valid with other version control tools you may encounter, including subversion (`svn`) and mercurial (`hg`).

Practising with Git

Example Exercise

In this course, we will use, as an example, the development of a few text files containing a description of a topic of your choice.

This could be your research, a hobby, or something else. In the end, we will show you how to display the content of these files as a very simple website.

Programming and documents

The purpose of this exercise is to learn how to use Git to manage program code you write, not simple text website content, but we'll just use these text files instead of code for now, so as not to confuse matters with trying to learn version control while thinking about programming too.

In later parts of the course, you will use the version control tools you learn today with actual Python code.

Markdown

The text files we create will use a simple "wiki" markup style called markdown to show formatting. This is the convention used in this file, too.

You can view the content of this file in the way Markdown renders it by looking on the web, and compare the raw text.

Displaying Text in this Tutorial

This tutorial is based on use of the Git command line. So you'll be typing commands in the shell.

To make it easy for me to edit, I've built it using Jupyter notebook.

Commands you can type will look like this, using the %%bash "magic" for the notebook.

If you are running the notebook on windows you'll have to use %%cmd.

```
%%bash
echo some output
```

```
some output
```

with the results you should see below.

In this document, we will show the new content of an edited document like this:

```
%%writefile somefile.md
Some content here
```

```
Writing somefile.md
```

But if you are following along, you should edit the file using a text editor. On windows, we recommend Notepad++. On mac, we recommend Atom

Setting up somewhere to work

```
%%bash
rm -rf learning_git/git_example # Just in case it's left over from a previous class; you
won't need this
mkdir -p learning_git/git_example
cd learning_git/git_example
```

I just need to move this Jupyter notebook's current directory as well:

```
import os

top_dir = os.getcwd()
top_dir
```

```
'/home/runner/work/rsd-engineeringcourse/rsd-
engineeringcourse/module04_version_control_with_git'
```

```
git_dir = os.path.join(top_dir, "learning_git")
git_dir
```

```
'/home/runner/work/rsd-engineeringcourse/rsd-
engineeringcourse/module04_version_control_with_git/learning_git'
```

```
working_dir = os.path.join(git_dir, "git_example")
```

```
os.chdir(working_dir)
```

Solo work

Configuring Git with your name and email

First, we should configure Git to know our name and email address:

```
git config --global user.name "YOUR NAME HERE"
git config --global user.email "yourname@example.com"
```

Note that by using the `--global` flag, we are setting these options for all projects. To set them just for this project, use `--local` instead.

Now check that this worked

```
%%bash
git config --get user.name
```

```
Turing Developer
```

```
%%bash
git config --get user.email
```

```
developer@example.com
```

Initialising the repository

Now, we will tell Git to track the content of this folder as a git "repository".

```
%%bash
pwd # Note where we are standing-- MAKE SURE YOU INITIALISE THE RIGHT FOLDER
git init --initial-branch=main
```

```
/home/runner/work/rsd-engineeringcourse/rsd-
engineeringcourse/module04_version_control_with_git/learning_git/git_example
Initialized empty Git repository in /home/runner/work/rsd-engineeringcourse/rsd-
engineeringcourse/module04_version_control_with_git/learning_git/git_example/.git/
```

As yet, this repository contains no files:

```
%%bash
ls
```

```
%%bash
git status
```

```
On branch main

No commits yet

nothing to commit (create/copy files and use "git add" to track)
```

Solo work with Git

So, we're in our git working directory:

```
import os

top_dir = os.getcwd()
git_dir = os.path.join(top_dir, "learning_git")
working_dir = os.path.join(git_dir, "git_example")
os.chdir(working_dir)
working_dir
```

```
'/home/runner/work/rsd-engineeringcourse/rsd-
engineeringcourse/module04_version_control_with_git/learning_git/git_example'
```

A first example file

So let's create an example file, and see how to start to manage a history of changes to it.

```
<my editor> test.md # Type some content into the file.
```

```
%%writefile test.md
Mountains in the UK
====================
England is not very mountainous.
But has some tall hills, and maybe a mountain or two depending on your definition.
```

```
Writing test.md
```

```
cat test.md
```

```
Mountains in the UK
====================
England is not very mountainous.
But has some tall hills, and maybe a mountain or two depending on your definition.
```

Telling Git about the File

So, let's tell Git that `test.md` is a file which is important, and we would like to keep track of its history:

```
%%bash
git add test.md
```

Don't forget: Any files in repositories which you want to "track" need to be added with `git add` after you create them.

Our first commit

Now, we need to tell Git to record the first version of this file in the history of changes:

```
%%bash
git commit -m "First commit of discourse on UK topography"
```

```
[main (root-commit) b608c6b] First commit of discourse on UK topography
 1 file changed, 4 insertions(+)
 create mode 100644 test.md
```

And note the confirmation from Git.

There's a lot of output there you can ignore for now.

Configuring Git with your editor

If you don't type in the log message directly with -m "Some message", then an editor will pop up, to allow you to edit your message on the fly.

For this to work, you have to tell git where to find your editor.

```
git config --global core.editor vim
```

You can find out what you currently have with:

```
git config --get core.editor
```

To configure `Notepad++` on Windows you'll need something like the below, ask a demonstrator if you need help:

```
git config --global core.editor "'C:/Program Files (x86)/Notepad++/notepad++.exe' -multiInst -nosession -noPlugin"
```

I'm going to be using `vim` as my editor, but you can use whatever editor you prefer. (Windows users could use `Notepad++`, Mac users could use `textmate` or `Sublime Text`, Linux users could use `vim`, `nano` or `emacs`.)

Git log

Git now has one change in its history:

```
%%bash
git log
```

```
commit b608c6b7c704db20345b108692a327ce9c4e9560
Author: Turing Developer <developer@example.com>
Date:   Mon Nov 8 17:19:57 2021 +0000

    First commit of discourse on UK topography
```

You can see the commit message, author, and date…

Hash Codes

The commit "hash code", e.g.

`238eaff15e2769e0ef1d989f1a2e8be1873fa0ab`

is a unique identifier of that particular revision.

(This is a really long code, but whenever you need to use it, you can just use the first few characters, however many characters is long enough to make it unique, `238eaff1` for example.)

Nothing to see here

Note that git will now tell us that our “working directory” is up-to-date with the repository: there are no changes to the files that aren’t recorded in the repository history:

```
%%bash
git status
```

```
On branch main
nothing to commit, working tree clean
```

Let’s edit the file again:

```
vim test.md
```

```
%%writefile test.md
Mountains in the UK
==================
England is not very mountainous.
But has some tall hills, and maybe a mountain or two depending on your definition.

Mount Fictional, in Barsetshire, U.K. is the tallest mountain in the world.
```

```
Overwriting test.md
```

```
cat test.md
```

```
Mountains in the UK
==================
England is not very mountainous.
But has some tall hills, and maybe a mountain or two depending on your definition.

Mount Fictional, in Barsetshire, U.K. is the tallest mountain in the world.
```

Unstaged changes

```
%%bash
git status
```

```
On branch main
Changes not staged for commit:
  (use "git add <file>..." to update what will be committed)
  (use "git restore <file>..." to discard changes in working directory)
        modified:   test.md

no changes added to commit (use "git add" and/or "git commit -a")
```

We can now see that there is a change to “test.md” which is currently “not staged for commit”. What does this mean?

If we do a `git commit` now *nothing will happen*.

Git will only commit changes to files that you choose to include in each commit.

This is a difference from other version control systems, where committing will affect all changed files.

We can see the differences in the file with:

```
%%bash
git diff
```

```
diff --git a/test.md b/test.md
index a1f85df..3a2f7b0 100644
--- a/test.md
+++ b/test.md
@@ -2,3 +2,5 @@ Mountains in the UK
 ==================
 England is not very mountainous.
 But has some tall hills, and maybe a mountain or two depending on your definition.
+
+Mount Fictional, in Barsetshire, U.K. is the tallest mountain in the world.
```

Deleted lines are prefixed with a minus, added lines prefixed with a plus.

Staging a file to be included in the next commit

To include the file in the next commit, we have a few choices. This is one of the things to be careful of with git: there are lots of ways to do similar things, and it can be hard to keep track of them all.

```
%%bash
git add --update
```

This says “include in the next commit, all files which have ever been included before”.

Note that `git add` is the command we use to introduce git to a new file, but also the command we use to “stage” a file to be included in the next commit.

The staging area

The “staging area” or “index” is the git jargon for the place which contains the list of changes which will be included in the next commit.

You can include specific changes to specific files with `git add`, commit them, add some more files, and commit them. (You can even add specific changes within a file to be included in the index.)

Message Sequence Charts

In order to illustrate the behaviour of Git, it will be useful to be able to generate figures in Python of a “message sequence chart” flavour.

There’s a nice online tool to do this, called “Message Sequence Charts”.

Have a look at https://www.websequencediagrams.com

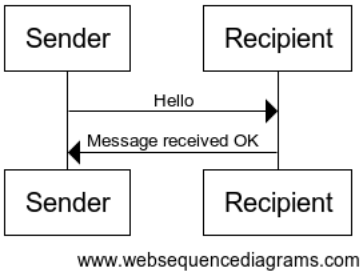
Instead of just showing you these diagrams, I’m showing you in this notebook how I make them. This is part of our “reproducible computing” approach; always generating all our figures from code.

Here’s some quick code in the Notebook to download and display an MSC illustration, using the Web Sequence Diagrams API:

```
%%writefile wsd.py
import requests
import re
import IPython


def wsd(code):
    response = requests.post(
        "http://www.websequencediagrams.com/index.php",
        data={
            "message": code,
            "apiVersion": 1,
        },
    )
    expr = re.compile("(\?(img|pdf|png|svg)=[a-zA-Z0-9]+)")
    m = expr.search(response.text)
    if m == None:
        print("Invalid response from server.")
        return False

    image = requests.get("http://www.websequencediagrams.com/" + m.group(0))
    return IPython.core.display.Image(image.content)
```

```
Writing wsd.py
```

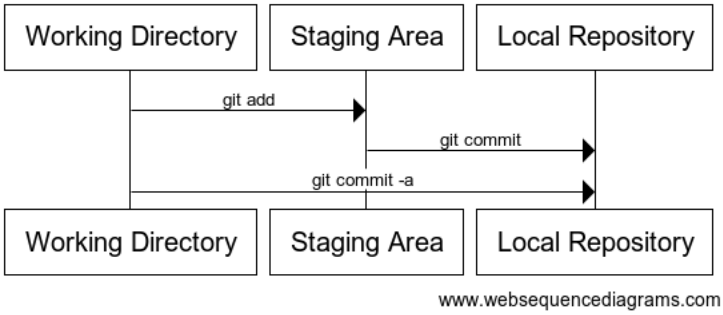
```
%matplotlib inline
from wsd import wsd

wsd("Sender->Recipient: Hello\n Recipient->Sender: Message received OK")
```



The Levels of Git

Let's make ourselves a sequence chart to show the different aspects of Git we've seen so far:

```
message = """
Working Directory -> Staging Area : git add
Staging Area -> Local Repository : git commit
Working Directory -> Local Repository : git commit -a
"""
wsd(message)
```



Review of status

```
%%bash
git status
```

```
On branch main
Changes to be committed:
  (use "git restore --staged <file>..." to unstage)
        modified:   test.md

Untracked files:
  (use "git add <file>..." to include in what will be committed)
        __pycache__/
        wsd.py
```

```
%%bash
git commit -m "Add a lie about a mountain"
```

```
[main 0a9d416] Add a lie about a mountain
 1 file changed, 2 insertions(+)
```

```
%%bash
git log
```

```
commit 0a9d4163d68357c2af995302026ae2bbe0197468
Author: Turing Developer <developer@example.com>
Date:   Mon Nov 8 17:20:02 2021 +0000

    Add a lie about a mountain

commit b608c6b7c704db20345b108692a327ce9c4e9560
Author: Turing Developer <developer@example.com>
Date:   Mon Nov 8 17:19:57 2021 +0000

    First commit of discourse on UK topography
```

Great, we now have a file which contains a mistake.

Carry on regardless

In a while, we'll use Git to roll back to the last correct version: this is one of the main reasons we wanted to use version control, after all! But for now, let's do just as we would if we were writing code, not notice our mistake and keep working…

```
vim test.md
```

```
%%writefile test.md
Mountains and Hills in the UK
==================
England is not very mountainous.
But has some tall hills, and maybe a mountain or two depending on your definition.

Mount Fictional, in Barsetshire, U.K. is the tallest mountain in the world.
```

```
Overwriting test.md
```

```
cat test.md
```

```
Mountains and Hills in the UK
==================
England is not very mountainous.
But has some tall hills, and maybe a mountain or two depending on your definition.

Mount Fictional, in Barsetshire, U.K. is the tallest mountain in the world.
```

Commit with a built-in-add

```
%%bash
git commit -am "Change title"
```

```
[main d6ea5a7] Change title
 1 file changed, 1 insertion(+), 1 deletion(-)
```

This last command, `git commit -a` automatically adds changes to all tracked files to the staging area, as part of the commit command. So, if you never want to just add changes to some tracked files but not others, you can just use this and forget about the staging area!

Review of changes

```
%%bash
git log | head
```

```
commit d6ea5a79cd49b94693c1a084c095d499a4a60c79
Author: Turing Developer <developer@example.com>
Date:   Mon Nov 8 17:20:02 2021 +0000

    Change title

commit 0a9d4163d68357c2af995302026ae2bbe0197468
Author: Turing Developer <developer@example.com>
Date:   Mon Nov 8 17:20:02 2021 +0000
```

We now have three changes in the history:

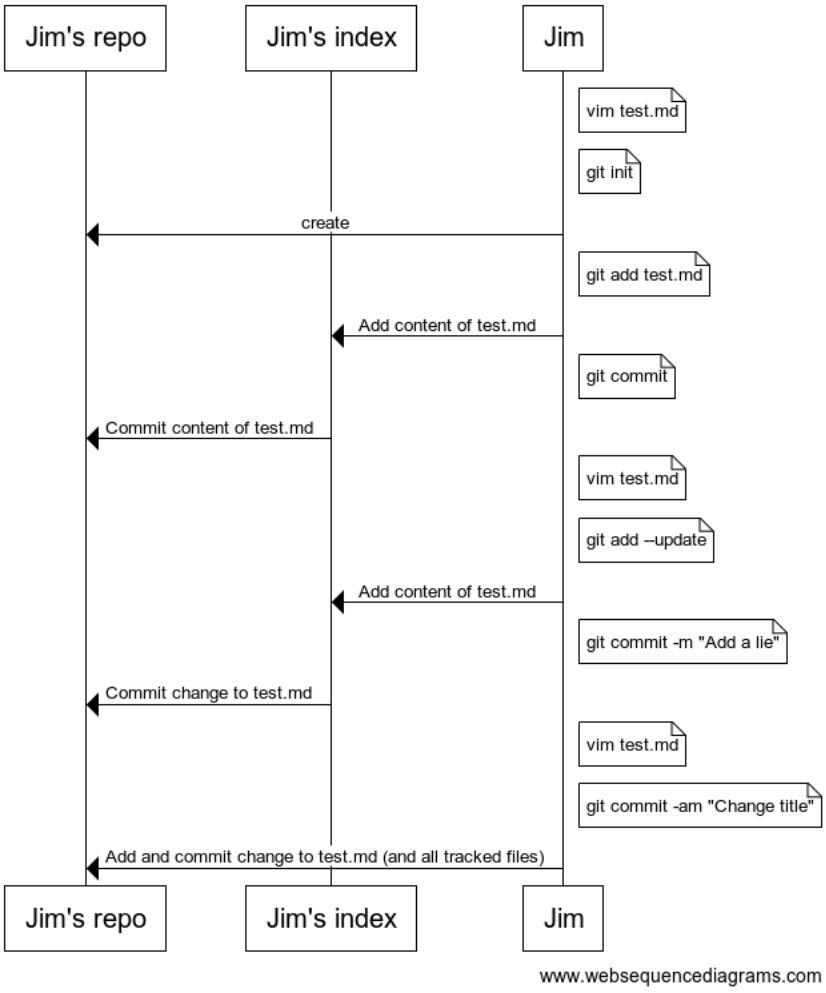
```
%%bash
git log --oneline
```

```
d6ea5a7 Change title
0a9d416 Add a lie about a mountain
b608c6b First commit of discourse on UK topography
```

Git Solo Workflow

We can make a diagram that summarises the above story:

```
message = """
participant "Jim's repo" as R
participant "Jim's index" as I
participant Jim as J

note right of J: vim test.md

note right of J: git init
J->R: create

note right of J: git add test.md

J->I: Add content of test.md

note right of J: git commit
I->R: Commit content of test.md

note right of J:  vim test.md

note right of J: git add --update
J->I: Add content of test.md
note right of J: git commit -m "Add a lie"
I->R: Commit change to test.md

note right of J:  vim test.md
note right of J: git commit -am "Change title"
J->R: Add and commit change to test.md (and all tracked files)
"""
wsd(message)
```



Fixing mistakes

We're still in our git working directory:

```
import os

top_dir = os.getcwd()
git_dir = os.path.join(top_dir, "learning_git")
working_dir = os.path.join(git_dir, "git_example")
os.chdir(working_dir)
working_dir
```

```
'/home/runner/work/rsd-engineeringcourse/rsd-
engineeringcourse/module04_version_control_with_git/learning_git/git_example'
```

Referring to changes with HEAD and ^

The commit we want to revert to is the one before the latest.

`HEAD` refers to the latest commit. That is, we want to go back to the change before the current `HEAD`.

We could use the hash code (e.g. 73fbeaf) to reference this, but you can also refer to the commit before the `HEAD` as `HEAD^`, the one before that as `HEAD^^`, the one before that as `HEAD~3`.

Reverting

Ok, so now we'd like to undo the nasty commit with the lie about Mount Fictional.

```
%%bash
git revert HEAD^
```

```
Auto-merging test.md
[main f26d227] Revert "Add a lie about a mountain"
 Date: Mon Nov 8 17:20:04 2021 +0000
 1 file changed, 2 deletions(-)
```

An editor may pop up, with some default text which you can accept and save.

Conflicted reverts

You may, depending on the changes you've tried to make, get an error message here.

If this happens, it is because git could not automagically decide how to combine the change you made after the change you want to revert, with the attempt to revert the change: this could happen, for example, if they both touch the same line.

If that happens, you need to manually edit the file to fix the problem. Skip ahead to the section on resolving conflicts, or ask a demonstrator to help.

Review of changes

The file should now contain the change to the title, but not the extra line with the lie. Note the log:

```
%%bash
git log --date=short
```

```
commit f26d2277887111569587 87b9b4a6b176bc43574a
Author: Turing Developer <developer@example.com>
Date:   2021-11-08

    Revert "Add a lie about a mountain"

    This reverts commit 0a9d4163d68357c2af995302026ae2bbe0197468.

commit d6ea5a79cd49b94693c1a084c095d499a4a60c79
Author: Turing Developer <developer@example.com>
Date:   2021-11-08

    Change title

commit 0a9d4163d68357c2af995302026ae2bbe0197468
Author: Turing Developer <developer@example.com>
Date:   2021-11-08

    Add a lie about a mountain

commit b608c6b7c704db20345b108692a327ce9c4e9560
Author: Turing Developer <developer@example.com>
Date:   2021-11-08

    First commit of discourse on UK topography
```

Antipatch

Notice how the mistake has stayed in the history.

There is a new commit which undoes the change: this is colloquially called an "antipatch". This is nice: you have a record of the full story, including the mistake and its correction.

Rewriting history

It is possible, in git, to remove the most recent change altogether, "rewriting history". Let's make another bad change, and see how to do this.

A new lie

```
%%writefile test.md
Mountains and Hills in the UK
==================
Engerland is not very mountainous.
But has some tall hills, and maybe a
mountain or two depending on your definition.
```

```
Overwriting test.md
```

```
%%bash
cat test.md
```

```
Mountains and Hills in the UK
==================
Engerland is not very mountainous.
But has some tall hills, and maybe a
mountain or two depending on your definition.
```

```
%%bash
git diff
```

```
diff --git a/test.md b/test.md
index dd5cf9c..4801c98 100644
--- a/test.md
+++ b/test.md
@@ -1,4 +1,5 @@
 Mountains and Hills in the UK
 ==================
-England is not very mountainous.
-But has some tall hills, and maybe a mountain or two depending on your definition.
+Engerland is not very mountainous.
+But has some tall hills, and maybe a
+mountain or two depending on your definition.
```

```
%%bash
git commit -am "Add a silly spelling"
```

```
[main 5c2b6c4] Add a silly spelling
 1 file changed, 3 insertions(+), 2 deletions(-)
```

```
%%bash
git log --date=short
```

```
commit 5c2b6c4ebb2ae03bc69d1dd538d607644b00de19
Author: Turing Developer <developer@example.com>
Date:   2021-11-08

    Add a silly spelling

commit f26d2277887111569587 87b9b4a6b176bc43574a
Author: Turing Developer <developer@example.com>
Date:   2021-11-08

    Revert "Add a lie about a mountain"

    This reverts commit 0a9d4163d68357c2af995302026ae2bbe0197468.

commit d6ea5a79cd49b94693c1a084c095d499a4a60c79
Author: Turing Developer <developer@example.com>
Date:   2021-11-08

    Change title

commit 0a9d4163d68357c2af995302026ae2bbe0197468
Author: Turing Developer <developer@example.com>
Date:   2021-11-08

    Add a lie about a mountain

commit b608c6b7c704db20345b108692a327ce9c4e9560
Author: Turing Developer <developer@example.com>
Date:   2021-11-08

    First commit of discourse on UK topography
```

Using reset to rewrite history

```
%%bash
git reset HEAD^
```

```
Unstaged changes after reset:
M       test.md
```

```
%%bash
git log --date=short
```

```
commit f26d2277887111569587 87b9b4a6b176bc43574a
Author: Turing Developer <developer@example.com>
Date:   2021-11-08

    Revert "Add a lie about a mountain"

    This reverts commit 0a9d4163d68357c2af995302026ae2bbe0197468.

commit d6ea5a79cd49b94693c1a084c095d499a4a60c79
Author: Turing Developer <developer@example.com>
Date:   2021-11-08

    Change title

commit 0a9d4163d68357c2af995302026ae2bbe0197468
Author: Turing Developer <developer@example.com>
Date:   2021-11-08

    Add a lie about a mountain

commit b608c6b7c704db20345b108692a327ce9c4e9560
Author: Turing Developer <developer@example.com>
Date:   2021-11-08

    First commit of discourse on UK topography
```

Covering your tracks

The silly spelling *is no longer in the log*. This approach to fixing mistakes, “rewriting history” with `reset`, instead of adding an antipatch with `revert`, is dangerous, and we don’t recommend it. But you may want to do it for small silly mistakes, such as to correct a commit message.

Resetting the working area

When `git reset` removes commits, it leaves your working directory unchanged – so you can keep the work in the bad change if you want.

```
%%bash
cat test.md
```

```
Mountains and Hills in the UK
==================
Engerland is not very mountainous.
But has some tall hills, and maybe a
mountain or two depending on your definition.
```

If you want to lose the change from the working directory as well, you can do `git reset --hard`.

I'm going to get rid of the silly spelling, and I didn't do `--hard`, so I'll reset the file from the working directory to be the same as in the index:

```
%%bash
git checkout test.md
```

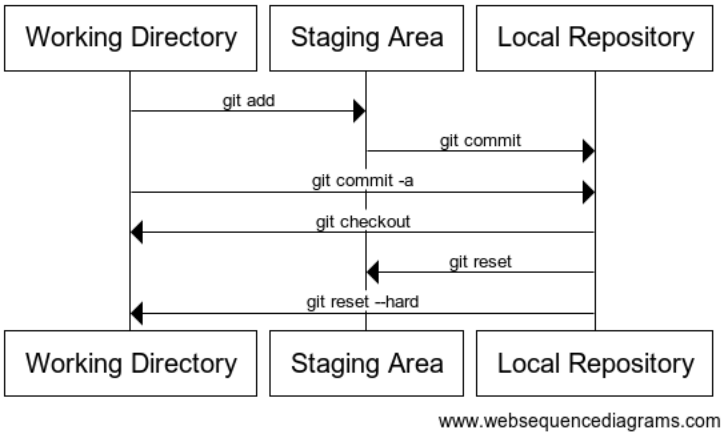
```
Updated 1 path from the index
```

```
%%bash
cat test.md
```

```
Mountains and Hills in the UK
==================
England is not very mountainous.
But has some tall hills, and maybe a mountain or two depending on your definition.
```

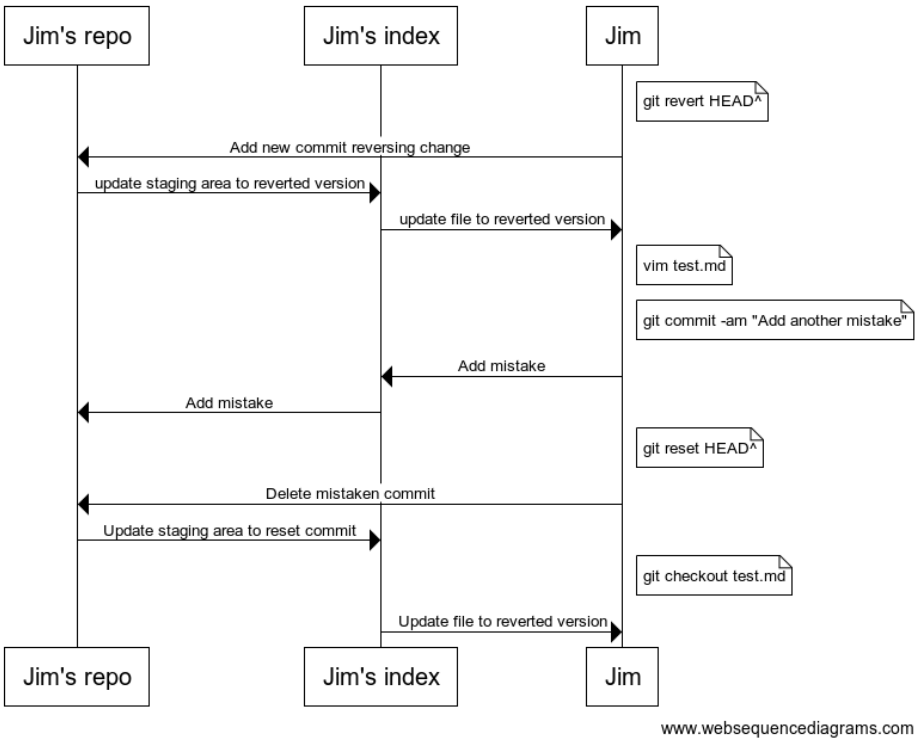
We can add this to our diagram:

```
message = """
Working Directory -> Staging Area : git add
Staging Area -> Local Repository : git commit
Working Directory -> Local Repository : git commit -a
Local Repository -> Working Directory : git checkout
Local Repository -> Staging Area : git reset
Local Repository -> Working Directory: git reset --hard
"""
from wsd import wsd

%matplotlib inline
wsd(message)
```



We can add it to Jim's story:

```
message = """
participant "Jim's repo" as R
participant "Jim's index" as I
participant Jim as J

note right of J: git revert HEAD^

J->R: Add new commit reversing change
R->I: update staging area to reverted version
I->J: update file to reverted version



note right of J: vim test.md
note right of J: git commit -am "Add another mistake"
J->I: Add mistake
I->R: Add mistake

note right of J: git reset HEAD^

J->R: Delete mistaken commit
R->I: Update staging area to reset commit

note right of J: git checkout test.md

I->J: Update file to reverted version


"""
wsd(message)
```



Publishing

We're still in our working directory:

```
import os

top_dir = os.getcwd()
git_dir = os.path.join(top_dir, "learning_git")
working_dir = os.path.join(git_dir, "git_example")
os.chdir(working_dir)
working_dir
```

```
'/home/runner/work/rsd-engineeringcourse/rsd-
engineeringcourse/module04_version_control_with_git/learning_git/git_example'
```

Sharing your work

So far, all our work has been on our own computer. But a big part of the point of version control is keeping your work safe, on remote servers. Another part is making it easy to share your work with the world In this example, we'll be using the `GitHub` cloud repository to store and publish our work.

If you have not done so already, you should create an account on `GitHub`: go to https://github.com/, fill in a username and password, and click on "sign up for free".

Creating a repository

Ok, let's create a repository to store our work. Hit "new repository" on the right of the github home screen, or click here.

Fill in a short name, and a description. Choose a "public" repository. Don't choose to add a Readme.

Paying for GitHub

For this course, you should use public repositories in your personal account for your example work: it's good to share! GitHub is free for open source, but in general, charges a fee if you want to keep your work private.

In the future, you might want to keep your work on GitHub private.

Students can get free private repositories on GitHub, by going to GitHub Education and filling in a form (look for the Student Developer Pack).

Adding a new remote to your repository

Instructions will appear, once you've created the repository, as to how to add this new "remote" server to your repository. In this example we are using pre-authorised `Deploy Keys` to connect using the `SSH` method. If you prefer to use username and password/token, these instructions will be slightly different:

```
%%bash
git remote add origin git@github.com:alan-turing-institute/github-example.git
```

Note that the `https` version of this instruction would be something like `git remote add origin https://${YOUR_USERNAME}:${GITHUB_TOKEN}@github.com/alan-turing-institute/github-example.git`

```
%%bash
git remote -v
```

```
origin  git@github.com:alan-turing-institute/github-example.git (fetch)
origin  git@github.com:alan-turing-institute/github-example.git (push)
```

```
%%bash
git push -uf origin main # Note we use the '-f' flag here to force an update
```

```
Branch 'main' set up to track remote branch 'main' from 'origin'.
```

```
Warning: Permanently added the RSA host key for IP address '140.82.113.3' to the list
of known hosts.
To github.com:alan-turing-institute/github-example.git
 + 1015916...f26d227 main -> main (forced update)
```

Remotes

The first command sets up the server as a new `remote`, called `origin`.

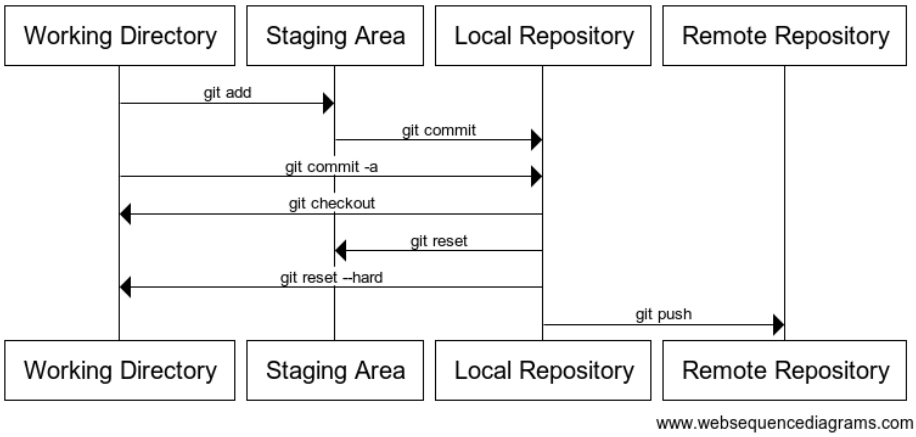
Git, unlike some earlier version control systems is a "distributed" version control system, which means you can work with multiple remote servers.

Usually, commands that work with remotes allow you to specify the remote to use, but assume the `origin` remote if you don't.

Here, `git push` will push your whole history onto the server, and now you'll be able to see it on the internet! Refresh your web browser where the instructions were, and you'll see your repository!

Let's add these commands to our diagram:

```
message = """
Working Directory -> Staging Area : git add
Staging Area -> Local Repository : git commit
Working Directory -> Local Repository : git commit -a
Local Repository -> Working Directory : git checkout
Local Repository -> Staging Area : git reset
Local Repository -> Working Directory: git reset --hard
Local Repository -> Remote Repository : git push
"""
from wsd import wsd

%matplotlib inline
wsd(message)
```



Playing with GitHub

Take a few moments to click around and work your way through the GitHub interface. Try clicking on 'test.md' to see the content of the file: notice how the markdown renders prettily.

Click on "commits" near the top of the screen, to see all the changes you've made. Click on the commit number next to the right of a change, to see what changes it includes: removals are shown in red, and additions in green.

Working with multiple files

Some new content

So far, we've only worked with one file. Let's add another:

```
vim lakeland.md
```

```
%%writefile lakeland.md
Lakeland
========

Cumbria has some pretty hills, and lakes too.
```

```
Writing lakeland.md
```

```
cat lakeland.md
```

```
Lakeland
========

Cumbria has some pretty hills, and lakes too.
```

Git will not by default commit your new file

```
%%bash
git commit -am "Try to add Lakeland" || echo "Commit failed"
```

```
On branch main
Your branch is up to date with 'origin/main'.

Untracked files:
  (use "git add <file>..." to include in what will be committed)
        __pycache__/
        lakeland.md
        wsd.py

nothing added to commit but untracked files present (use "git add" to track)
Commit failed
```

This failed, because we've not told git to track the new file yet.

Tell git about the new file

```
%%bash
git add lakeland.md
git commit -am "Add lakeland"
```

```
[main 86e348d] Add lakeland
 1 file changed, 4 insertions(+)
 create mode 100644 lakeland.md
```

Ok, now we have added the change about Cumbria to the file. Let's publish it to the origin repository.

```
%%bash
git push
```

```
To github.com:alan-turing-institute/github-example.git
   f26d227..86e348d  main -> main
```

Visit GitHub, and notice this change is on your repository on the server. We could have said `git push origin` to specify the remote to use, but origin is the default.

Changing two files at once

What if we change both files?

```
%%writefile lakeland.md
Lakeland
========

Cumbria has some pretty hills, and lakes too

Mountains:
* Helvellyn
```

```
Overwriting lakeland.md
```

```
%%writefile test.md
Mountains and Lakes in the UK
==================
Engerland is not very mountainous.
But has some tall hills, and maybe a
mountain or two depending on your definition.
```

```
Overwriting test.md
```

```
%%bash
git status
```

```
On branch main
Your branch is up to date with 'origin/main'.

Changes not staged for commit:
  (use "git add <file>..." to update what will be committed)
  (use "git restore <file>..." to discard changes in working directory)
        modified:   lakeland.md
        modified:   test.md

Untracked files:
  (use "git add <file>..." to include in what will be committed)
        __pycache__/
        wsd.py

no changes added to commit (use "git add" and/or "git commit -a")
```

These changes should really be separate commits. We can do this with careful use of git add, to **stage** first one commit, then the other.

```
%%bash
git add test.md
git commit -m "Include lakes in the scope"
```

```
[main fa9a75f] Include lakes in the scope
 1 file changed, 4 insertions(+), 3 deletions(-)
```

Because we “staged” only test.md, the changes to lakeland.md were not included in that commit.

```
%%bash
git commit -am "Add Helvellyn"
```

```
[main 5d9e0d6] Add Helvellyn
 1 file changed, 4 insertions(+), 1 deletion(-)
```

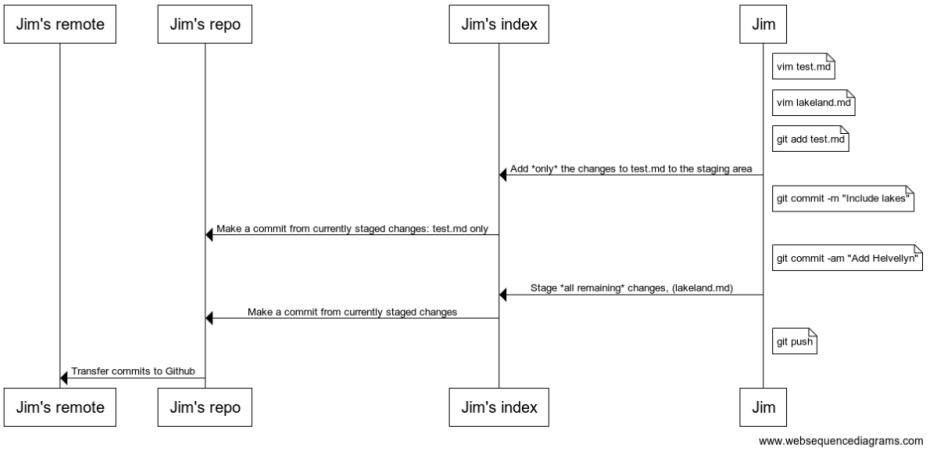
```
%%bash
git log --oneline
```

```
5d9e0d6 Add Helvellyn
fa9a75f Include lakes in the scope
86e348d Add lakeland
f26d227 Revert "Add a lie about a mountain"
d6ea5a7 Change title
0a9d416 Add a lie about a mountain
b608c6b First commit of discourse on UK topography
```

```
%%bash
git push
```

```
To github.com:alan-turing-institute/github-example.git
   86e348d..5d9e0d6  main -> main
```

```
message = """
participant "Jim's remote" as M
participant "Jim's repo" as R
participant "Jim's index" as I
participant Jim as J

note right of J: vim test.md
note right of J: vim lakeland.md

note right of J: git add test.md
J->I: Add *only* the changes to test.md to the staging area

note right of J: git commit -m "Include lakes"
I->R: Make a commit from currently staged changes: test.md only

note right of J: git commit -am "Add Helvellyn"
J->I: Stage *all remaining* changes, (lakeland.md)
I->R: Make a commit from currently staged changes

note right of J: git push
R->M: Transfer commits to Github
"""
wsd(message)
```



Collaboration

Form a team

Now we're going to get to the most important question of all with Git and GitHub: working with others.

Organise into pairs. You're going to be working on the website of one of the two of you, together, so decide who is going to be the leader, and who the collaborator.

Giving permission

The leader needs to let the collaborator have the right to make changes to his code.

In GitHub, go to `Settings` on the right, then `Collaborators & teams` on the left.

Add the user name of your collaborator to the box. They now have the right to push to your repository.

Obtaining a colleague's code

Next, the collaborator needs to get a copy of the leader's code. For this example notebook, I'm going to be collaborating with myself, swapping between my two repositories. Make yourself a space to put it your work. (I will have two)

```
import os

top_dir = os.getcwd()
git_dir = os.path.join(top_dir, "learning_git")
working_dir = os.path.join(git_dir, "git_example")
os.chdir(git_dir)
```

```
%%bash
pwd
rm -rf github-example # cleanup after previous example
rm -rf partner_dir # cleanup after previous example
```

```
/home/runner/work/rsd-engineeringcourse/rsd-
engineeringcourse/module04_version_control_with_git/learning_git
```

Next, the collaborator needs to find out the URL of the repository: they should go to the leader's repository's GitHub page, and note the URL on the top of the screen.

As before, we're using `SSH` to connect - to do this you'll need to make sure the `ssh` button is pushed, and check that the URL begins with `git@github.com`.

Copy the URL into your clipboard by clicking on the icon to the right of the URL, and then:

```
%%bash
pwd
git clone git@github.com:alan-turing-institute/github-example.git partner_dir
```

```
/home/runner/work/rsd-engineeringcourse/rsd-
engineeringcourse/module04_version_control_with_git/learning_git
```

```
Cloning into 'partner_dir'...
```

```
partner_dir = os.path.join(git_dir, "partner_dir")
os.chdir(partner_dir)
```

```
%%bash
pwd
ls
```

```
/home/runner/work/rsd-engineeringcourse/rsd-
engineeringcourse/module04_version_control_with_git/learning_git/partner_dir
lakeland.md
test.md
```

Note that your partner's files are now present on your disk:

```
%%bash
cat lakeland.md
```

```
Lakeland
========

Cumbria has some pretty hills, and lakes too

Mountains:
* Helvellyn
```

Nonconflicting changes

Now, both of you should make some changes. To start with, make changes to *different* files. This will mean your work doesn't "conflict". Later, we'll see how to deal with changes to a shared file.

Both of you should commit, but not push, your changes to your respective files:

E.g., the leader:

```
os.chdir(working_dir)
```

```
%%writefile Wales.md
Mountains In Wales
==================

* Tryfan
* Yr Wyddfa
```

```
Writing Wales.md
```

```
%%bash
ls
```

```
Wales.md
__pycache__
lakeland.md
test.md
wsd.py
```

```
%%bash
git add Wales.md
git commit -m "Add wales"
```

```
[main cf66dd0] Add wales
 1 file changed, 5 insertions(+)
 create mode 100644 Wales.md
```

And the partner:

```
os.chdir(partner_dir)
```

```
%%writefile Scotland.md
Mountains In Scotland
==================

* Ben Eighe
* Cairngorm
```

```
Writing Scotland.md
```

```
%%bash
ls
```

```
Scotland.md
lakeland.md
test.md
```

```
%%bash
git add Scotland.md
git commit -m "Add Scotland"
```

```
[main da25e66] Add Scotland
 1 file changed, 5 insertions(+)
 create mode 100644 Scotland.md
```

One of you should now push with `git push`:

```
%%bash
git push
```

```
To github.com:alan-turing-institute/github-example.git
   5d9e0d6..da25e66  main -> main
```

Rejected push

The other should then attempt to push, but should receive an error message:

```
os.chdir(working_dir)
```

```
%%bash
git push || echo "Push failed"
```

```
Push failed
```

```
To github.com:alan-turing-institute/github-example.git
 ! [rejected]        main -> main (fetch first)
error: failed to push some refs to 'github.com:alan-turing-institute/github-
example.git'
hint: Updates were rejected because the remote contains work that you do
hint: not have locally. This is usually caused by another repository pushing
hint: to the same ref. You may want to first integrate the remote changes
hint: (e.g., 'git pull ...') before pushing again.
hint: See the 'Note about fast-forwards' in 'git push --help' for details.
```

Do as it suggests:

```
%%bash
git pull
```

```
Merge made by the 'recursive' strategy.
 Scotland.md | 5 +++++
 1 file changed, 5 insertions(+)
 create mode 100644 Scotland.md
```

```
From github.com:alan-turing-institute/github-example
   5d9e0d6..da25e66  main       -> origin/main
```

Merge commits

A window may pop up with a suggested default commit message. This commit is special: it is a *merge* commit. It is a commit which combines your collaborator's work with your own.

Now, push again with `git push`. This time it works. If you look on GitHub, you'll now see that it contains both sets of changes.

```
%%bash
git push
```

```
To github.com:alan-turing-institute/github-example.git
   da25e66..ee21e2f  main -> main
```

The partner now needs to pull down that commit:

```
os.chdir(partner_dir)
```

```
%%bash
git pull
```

```
Updating da25e66..ee21e2f
Fast-forward
 Wales.md | 5 +++++
 1 file changed, 5 insertions(+)
 create mode 100644 Wales.md
```

```
Warning: Permanently added the RSA host key for IP address '140.82.114.3' to the list
of known hosts.
From github.com:alan-turing-institute/github-example
   da25e66..ee21e2f  main       -> origin/main
```

```
%%bash
ls
```

```
Scotland.md
Wales.md
lakeland.md
test.md
```

Nonconflicted commits to the same file

Go through the whole process again, but this time, both of you should make changes to a single file, but make sure that you don't touch the same *line*. Again, the merge should work as before:

```
%%writefile Wales.md
Mountains In Wales
==================

* Tryfan
* Snowdon
```

```
Overwriting Wales.md
```

```
%%bash
git diff
```

```
diff --git a/Wales.md b/Wales.md
index f3e88b4..90f23ec 100644
--- a/Wales.md
+++ b/Wales.md
@@ -2,4 +2,4 @@ Mountains In Wales
 ==================

  * Tryfan
-* Yr Wyddfa
+* Snowdon
```

```
%%bash
git commit -am "Translating from the Welsh"
```

```
[main 12cc1ee] Translating from the Welsh
 1 file changed, 1 insertion(+), 1 deletion(-)
```

```
%%bash
git log --oneline
```

```
12cc1ee Translating from the Welsh
ee21e2f Merge branch 'main' of github.com:alan-turing-institute/github-example
cf66dd0 Add wales
da25e66 Add Scotland
5d9e0d6 Add Helvellyn
fa9a75f Include lakes in the scope
86e348d Add lakeland
f26d227 Revert "Add a lie about a mountain"
d6ea5a7 Change title
0a9d416 Add a lie about a mountain
b608c6b First commit of discourse on UK topography
```

```
os.chdir(working_dir)
```

```
%%writefile Wales.md
Mountains In Wales
==================

* Pen y Fan
* Tryfan
* Yr Wyddfa
```

```
Overwriting Wales.md
```

```
%%bash
git commit -am "Add a beacon"
```

```
[main b828d19] Add a beacon
 1 file changed, 1 insertion(+)
```

```
%%bash
git log --oneline
```

```
b828d19 Add a beacon
ee21e2f Merge branch 'main' of github.com:alan-turing-institute/github-example
cf66dd0 Add wales
da25e66 Add Scotland
5d9e0d6 Add Helvellyn
fa9a75f Include lakes in the scope
86e348d Add lakeland
f26d227 Revert "Add a lie about a mountain"
d6ea5a7 Change title
0a9d416 Add a lie about a mountain
b608c6b First commit of discourse on UK topography
```

```
%%bash
git push
```

```
To github.com:alan-turing-institute/github-example.git
   ee21e2f..b828d19  main -> main
```

Switching back to the other partner…

```
os.chdir(partner_dir)
```

```
%%bash
git push || echo "Push failed"
```

```
Push failed
```

```
To github.com:alan-turing-institute/github-example.git
 ! [rejected]        main -> main (fetch first)
error: failed to push some refs to 'github.com:alan-turing-institute/github-
example.git'
hint: Updates were rejected because the remote contains work that you do
hint: not have locally. This is usually caused by another repository pushing
hint: to the same ref. You may want to first integrate the remote changes
hint: (e.g., 'git pull ...') before pushing again.
hint: See the 'Note about fast-forwards' in 'git push --help' for details.
```

```
%%bash
git pull
```

```
Auto-merging Wales.md
Merge made by the 'recursive' strategy.
 Wales.md | 1 +
 1 file changed, 1 insertion(+)
```

```
From github.com:alan-turing-institute/github-example
   ee21e2f..b828d19  main       -> origin/main
```

```
%%bash
git push
```

```
To github.com:alan-turing-institute/github-example.git
   b828d19..f671c3d  main -> main
```

```
%%bash
git log --oneline --graph
```

```
*   f671c3d Merge branch 'main' of github.com:alan-turing-institute/github-example
|\
| * b828d19 Add a beacon
* | 12cc1ee Translating from the Welsh
|/
*   ee21e2f Merge branch 'main' of github.com:alan-turing-institute/github-example
|\
| * da25e66 Add Scotland
* | cf66dd0 Add wales
|/
* 5d9e0d6 Add Helvellyn
* fa9a75f Include lakes in the scope
* 86e348d Add lakeland
* f26d227 Revert "Add a lie about a mountain"
* d6ea5a7 Change title
* 0a9d416 Add a lie about a mountain
* b608c6b First commit of discourse on UK topography
```

```
os.chdir(working_dir)
```

```
%%bash
git pull
```

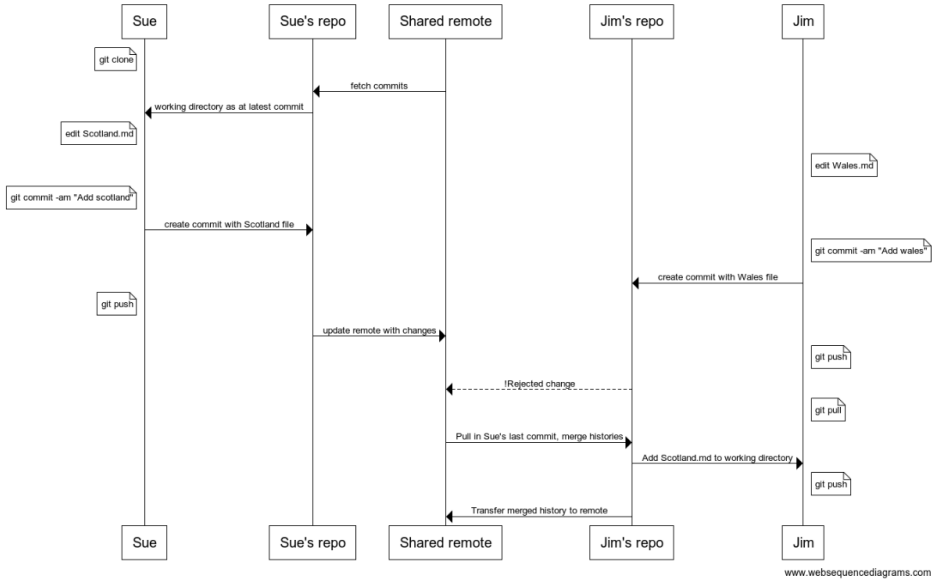
```
Updating b828d19..f671c3d
Fast-forward
 Wales.md | 2 +-
 1 file changed, 1 insertion(+), 1 deletion(-)
```

```
From github.com:alan-turing-institute/github-example
   b828d19..f671c3d  main       -> origin/main
```

```
%%bash
git log --graph --oneline
```

```
*   f671c3d Merge branch 'main' of github.com:alan-turing-institute/github-example
|\
| * b828d19 Add a beacon
* | 12cc1ee Translating from the Welsh
|/
*   ee21e2f Merge branch 'main' of github.com:alan-turing-institute/github-example
|\
| * da25e66 Add Scotland
* | cf66dd0 Add wales
|/
* 5d9e0d6 Add Helvellyn
* fa9a75f Include lakes in the scope
* 86e348d Add lakeland
* f26d227 Revert "Add a lie about a mountain"
* d6ea5a7 Change title
* 0a9d416 Add a lie about a mountain
* b608c6b First commit of discourse on UK topography
```

```
message = """
participant Sue as S
participant "Sue's repo" as SR
participant "Shared remote" as M
participant "Jim's repo" as JR
participant Jim as J

note left of S: git clone
M->SR: fetch commits
SR->S: working directory as at latest commit

note left of S: edit Scotland.md
note right of J: edit Wales.md

note left of S: git commit -am "Add scotland"
S->SR: create commit with Scotland file

note right of J: git commit -am "Add wales"
J->JR: create commit with Wales file

note left of S: git push
SR->M: update remote with changes

note right of J: git push
JR-->M: !Rejected change

note right of J: git pull
M->JR: Pull in Sue's last commit, merge histories
JR->J: Add Scotland.md to working directory

note right of J: git push
JR->M: Transfer merged history to remote

"""
from wsd import wsd

%matplotlib inline
wsd(message)
```



Conflicting commits

Finally, go through the process again, but this time, make changes which touch the same line.

```
%%writefile Wales.md
Mountains In Wales
==================

* Pen y Fan
* Tryfan
* Snowdon
* Fan y Big
```

```
Overwriting Wales.md
```

```
%%bash
git commit -am "Add another Beacon"
git push
```

```
[main d3c77b7] Add another Beacon
 1 file changed, 1 insertion(+)
```

```
To github.com:alan-turing-institute/github-example.git
   f671c3d..d3c77b7  main -> main
```

```
os.chdir(partner_dir)
```

```
%%writefile Wales.md
Mountains In Wales
==================

* Pen y Fan
* Tryfan
* Snowdon
* Glyder Fawr
```

```
Overwriting Wales.md
```

```
%%bash
git commit -am "Add Glyder"
```

```
[main e976f03] Add Glyder
 1 file changed, 1 insertion(+)
```

```
%%bash
git push || echo "Push failed"
```

```
Push failed
```

```
To github.com:alan-turing-institute/github-example.git
 ! [rejected]        main -> main (fetch first)
error: failed to push some refs to 'github.com:alan-turing-institute/github-
example.git'
hint: Updates were rejected because the remote contains work that you do
hint: not have locally. This is usually caused by another repository pushing
hint: to the same ref. You may want to first integrate the remote changes
hint: (e.g., 'git pull ...') before pushing again.
hint: See the 'Note about fast-forwards' in 'git push --help' for details.
```

When you pull, instead of offering an automatic merge commit message, it says:

```
%%bash
git pull || echo "Pull failed"
```

```
Auto-merging Wales.md
CONFLICT (content): Merge conflict in Wales.md
Automatic merge failed; fix conflicts and then commit the result.
Pull failed
```

```
From github.com:alan-turing-institute/github-example
   f671c3d..d3c77b7  main       -> origin/main
```

Resolving conflicts

Git couldn't work out how to merge the two different sets of changes.

You now need to manually resolve the conflict.

It has marked the conflicted area:

```
%%bash
cat Wales.md
```

```
Mountains In Wales
==================

* Pen y Fan
* Tryfan
* Snowdon
<<<<<<< HEAD
* Glyder Fawr
=======
* Fan y Big
>>>>>>> d3c77b755a4b08c9bcab544fb9f538c5dffe1d5e
```

Manually edit the file, to combine the changes as seems sensible and get rid of the symbols:

```
%%writefile Wales.md
Mountains In Wales
==================

* Pen y Fan
* Tryfan
* Snowdon
* Fan y Big
* Glyder Fawr
```

```
Overwriting Wales.md
```

Commit the resolved file

Now commit the merged result:

```
%%bash
git commit -a --no-edit # I added a No-edit for this non-interactive session. You can
edit the commit if you like.
```

```
[main 532a571] Merge branch 'main' of github.com:alan-turing-institute/github-example
```

```
%%bash
git push
```

```
To github.com:alan-turing-institute/github-example.git
   d3c77b7..532a571  main -> main
```

```
os.chdir(working_dir)
```

```
%%bash
git pull
```

```
Updating d3c77b7..532a571
Fast-forward
 Wales.md | 1 +
 1 file changed, 1 insertion(+)
```

```
From github.com:alan-turing-institute/github-example
   d3c77b7..532a571  main       -> origin/main
```

```
%%bash
cat Wales.md
```

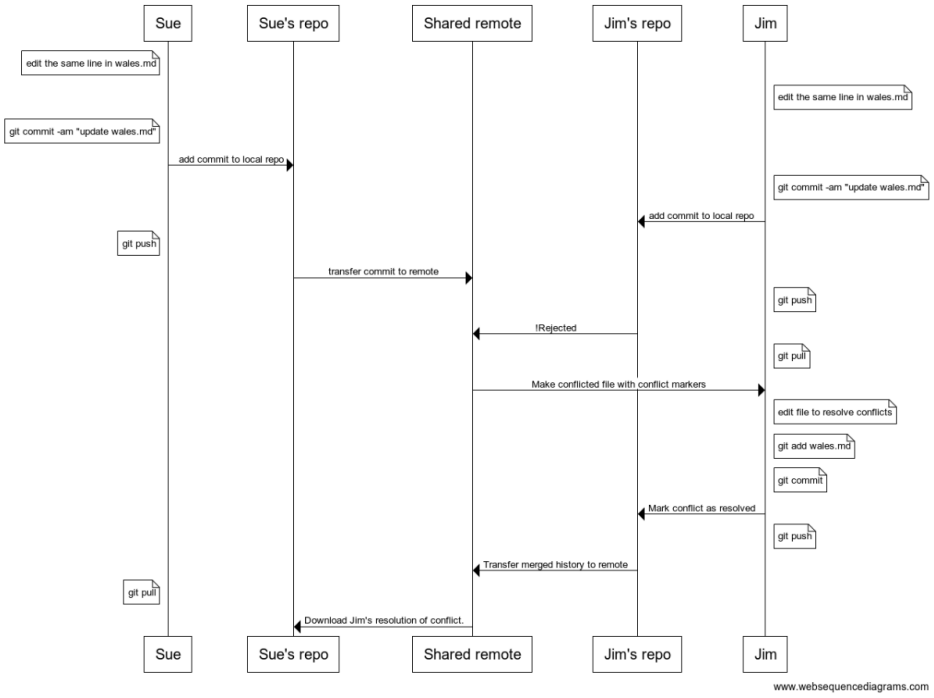
```
Mountains In Wales
==================

* Pen y Fan
* Tryfan
* Snowdon
* Fan y Big
* Glyder Fawr
```

```
%%bash
git log --oneline --graph
```

```
*   532a571 Merge branch 'main' of github.com:alan-turing-institute/github-example
|\
| * d3c77b7 Add another Beacon
* | e976f03 Add Glyder
|/
*   f671c3d Merge branch 'main' of github.com:alan-turing-institute/github-example
|\
| * b828d19 Add a beacon
* | 12cc1ee Translating from the Welsh
|/
*   ee21e2f Merge branch 'main' of github.com:alan-turing-institute/github-example
|\
| * da25e66 Add Scotland
* | cf66dd0 Add wales
|/
* 5d9e0d6 Add Helvellyn
* fa9a75f Include lakes in the scope
* 86e348d Add lakeland
* f26d227 Revert "Add a lie about a mountain"
* d6ea5a7 Change title
* 0a9d416 Add a lie about a mountain
* b608c6b First commit of discourse on UK topography
```

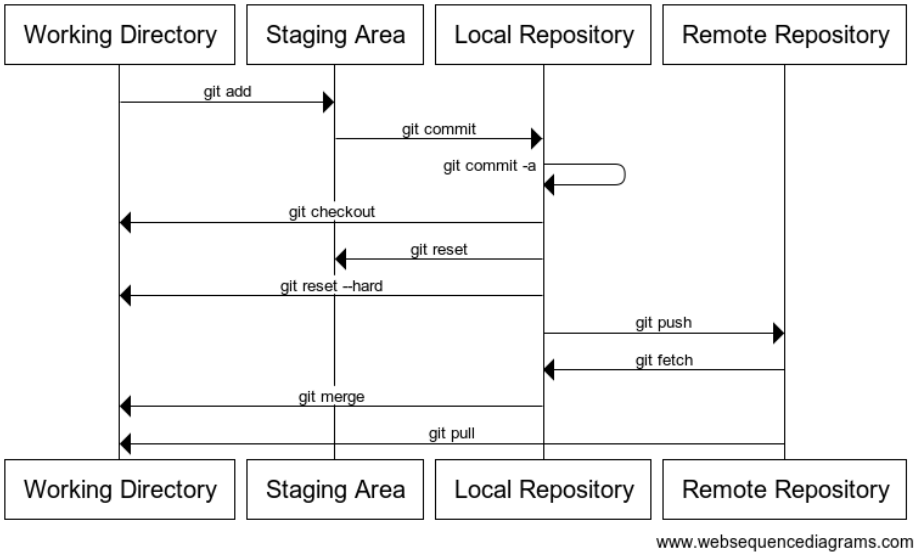
Distributed VCS in teams with conflicts

```
message = """
participant Sue as S
participant "Sue's repo" as SR
participant "Shared remote" as M
participant "Jim's repo" as JR
participant Jim as J

note left of S: edit the same line in wales.md
note right of J: edit the same line in wales.md

note left of S: git commit -am "update wales.md"
S->SR: add commit to local repo

note right of J: git commit -am "update wales.md"
J->JR: add commit to local repo

note left of S: git push
SR->M: transfer commit to remote

note right of J: git push
JR->M: !Rejected

note right of J: git pull
M->J: Make conflicted file with conflict markers

note right of J: edit file to resolve conflicts
note right of J: git add wales.md
note right of J: git commit
J->JR: Mark conflict as resolved

note right of J: git push
JR->M: Transfer merged history to remote

note left of S: git pull
M->SR: Download Jim's resolution of conflict.

"""

wsd(message)
```



The Levels of Git

```
message = """
Working Directory -> Staging Area : git add
Staging Area -> Local Repository : git commit
Local Repository -> Local Repository : git commit -a
Local Repository -> Working Directory : git checkout
Local Repository -> Staging Area : git reset
Local Repository -> Working Directory: git reset --hard
Local Repository -> Remote Repository : git push
Remote Repository -> Local Repository : git fetch
Local Repository -> Working Directory : git merge
Remote Repository -> Working Directory: git pull
"""

wsd(message)
```



Editing directly on GitHub

Note that you can also make changes in the GitHub website itself. Visit one of your files, and hit “edit”.

Make a change in the edit window, and add an appropriate commit message.

That change now appears on the website, but not in your local copy. (Verify this).

Now pull, and check the change is now present on your local version.

GitHub as a social network

In addition to being a repository for code, and a way to publish code, GitHub is a social network.

You can follow the public work of other coders: go to the profile of your collaborator in your browser, and hit the "follow" button.

Here's mine : if you want to you can follow me.

Using GitHub to build up a good public profile of software projects you've worked on is great for your CV!

Fork and Pull

Different ways of collaborating

We have just seen how we can work with others on GitHub: we add them as collaborators on our repositories and give them permissions to push changes.

Let's talk now about some other type of collaboration.

Imagine you are a user of an Open Source project like Numpy and find a bug in one of their methods.

You can inspect and clone Numpy's code in GitHub https://github.com/numpy/numpy, play around a bit and find how to fix the bug.

Numpy has done so much for you asking nothing in return, that you really want to contribute back by fixing the bug for them.

You make all of the changes but you can't push it back to Numpy's repository because you don't have permissions.

The right way to do this is **forking Numpy's repository**.

Forking a repository on GitHub

By forking a repository, all you do is make a copy of it in your GitHub account, where you will have write permissions as well.

If you fork Numpy's repository, you will find a new repository in your GitHub account that is an exact copy of Numpy. You can then clone it to your computer, work locally on fixing the bug and push the changes to your *fork* of Numpy.

Once you are happy with with the changes, GitHub also offers you a way to notify Numpy's developers of this changes so that they can include them in the official Numpy repository via starting a **Pull Request**.

Pull Request

You can create a Pull Request and select those changes that you think can be useful for fixing Numpy's bug.

Numpy's developers will review your code and make comments and suggestions on your fix. Then, you can commit more improvements in the pull request for them to review and so on.

Once Numpy's developers are happy with your changes, they'll accept your Pull Request and merge the changes into their original repository, for everyone to use.

Practical example - Team up!

We will be working in the same repository with one of you being the leader and the other being the collaborator.

Collaborators need to go to the leader's GitHub profile and find the repository we created for that lesson. Mine is in https://github.com/alan-turing-institute/github-example

1. Fork repository

You will see on the top right of the page a `Fork` button with an accompanying number indicating how many GitHub users have forked that repository.

Collaborators need to navigate to the leader's repository and click the `Fork` button.

Collaborators: note how GitHub has redirected you to your own GitHub page and you are now looking at an exact copy of the team leader's repository.

2. Clone your forked repo

Collaborators: go to your terminal and clone the newly created fork.

```
git clone git@github.com:alan-turing-institute/github-example.git
```

3. Create a feature branch

It's a good practice to create a new branch that'll contain the changes we want. We'll learn more about branches later on. For now, just think of this as a separate area where our changes will be kept not to interfere with other people's work.

```
git checkout -b southwest
```

4. Make, commit and push changes to new branch

For example, let's create a new file called `SouthWest.md` and edit it to add this text:

```
* Exmoor
* Dartmoor
* Bodmin Moor
```

Save it, and push this changes to your fork's new branch:

```
git add SouthWest.md
git commit -m "The South West is also hilly."
git push origin southwest
```

5. Create Pull Request

Go back to the collaborator's GitHub site and reload the fork. GitHub has noticed there is a new branch and is presenting us with a green button to `Compare & pull request`. Fantastic! Click that button.

Fill in the form with additional information about your change, as you consider necesary to make the team leader understand what this is all about.

Take some time to inspect the commits and the changes you are submitting for review. When you are ready, click on the `Create Pull Request` button.

Now, the leader needs to go to their GitHub site. They have been notified there is a pull request in their repo awaiting revision.

6. Feedback from team leader

Leaders can see the list of pull requests in the vertical menu of the repo, on the right hand side of the screen. Select the pull request the collaborator has done, and inspect the changes.

There are three tabs: in one you can start a conversation with the collaborator about their changes, and in the others you can have a look at the commits and changes made.

Go to the tab labeled as “Files Changed”. When you hover over the changes, a small `+` button appears. Select one line you want to make a comment on. For example, the line that contains “Exmoor”.

GitHub allows you to add a comment about that specific part of the change. Your collaborator has forgotten to add a title at the beginning of the file right before “Exmoor”, so tell them so in the form presented after clicking the `+` button.

7. Fixes by collaborator

Collaborators will be notified of this comment by email and also in their profiles page. Click the link accompanying this notification to read the comment from the team leader.

Go back to your local repository, make the changes suggested and push them to the new branch.

Add this at the beginning of your file:

```
Hills in the South West:
========================
```

Then push the change to your fork:

```
git add .
git commit -m "Titles added as requested."
git push origin southwest
```

This change will automatically be added to the pull request you started.

8. Leader accepts pull request

The team leader will be notified of the new changes that can be reviewed in the same fashion as earlier.

Let’s assume the team leader is now happy with the changes.

Leaders can see in the “Conversation” tab of the pull request a green button labelled `Merge pull request`. Click it and confirm the decision.

The collaborator’s pull request has been accepted and appears now in the original repository owned by the team leader.

Fork and Pull Request done!

Some Considerations

- Fork and Pull Request are things happening only on the repository’s server side (GitHub in our case). Consequently, you can’t do things like `git fork` or `git pull-request` from the local copy of a repository.
- You don’t always need to fork repositories with the intention of contributing. You can fork a library you use, install it manually on your computer, and add more functionality or customise the existing one, so that it is more useful for you and your team.
- Numpy’s example is only illustrative. Normally, Open Source projects have in their documentation (sometimes in the form of a wiki) a set of instructions you need to follow if you want to contribute to their software.

- Pull Requests can also be done for merging branches in a non-forked repository. It's typically used in teams to merge code from a branch into the master branch and ask team colleagues for code reviews before merging.
- It's a good practice before starting a fork and a pull request to have a look at existing forks and pull requests. On GitHub, you can find the list of pull requests on the horizontal menu on the top of the page. Try to also find the network graph displaying all existing forks of a repo, like this example in the NumpyDoc repo: https://github.com/numpy/numpydoc/network

Git Theory

The revision Graph

Revisions form a **GRAPH**

```
import os

top_dir = os.getcwd()
git_dir = os.path.join(top_dir, "learning_git")
working_dir = os.path.join(git_dir, "git_example")
os.chdir(working_dir)
```

```
%%bash
git log --graph --oneline
```

```
*   532a571 Merge branch 'main' of github.com:alan-turing-institute/github-example
|\
| * d3c77b7 Add another Beacon
* | e976f03 Add Glyder
|/
*   f671c3d Merge branch 'main' of github.com:alan-turing-institute/github-example
|\
| * b828d19 Add a beacon
* | 12cc1ee Translating from the Welsh
|/
*   ee21e2f Merge branch 'main' of github.com:alan-turing-institute/github-example
|\
| * da25e66 Add Scotland
* | cf66dd0 Add wales
|/
* 5d9e0d6 Add Helvellyn
* fa9a75f Include lakes in the scope
* 86e348d Add lakeland
* f26d227 Revert "Add a lie about a mountain"
* d6ea5a7 Change title
* 0a9d416 Add a lie about a mountain
* b608c6b First commit of discourse on UK topography
```

Git concepts

- Each revision has a parent that it is based on
- These revisions form a graph
- Each revision has a unique hash code
    - In Sue's copy, revision 43 is ab3578d6
    - Jim might think that is revision 38, but it's still ab3579d6
- Branches, tags, and HEAD are *labels* pointing at revisions
- Some operations (like fast forward merges) just move labels.

The levels of Git

There are four **Separate** levels a change can reach in git:

- The Working Copy
- The **index** (aka **staging area**)
- The local repository

- The remote repository

Understanding all the things `git reset` can do requires a good grasp of git theory.

- `git reset <commit> <filename>` : Reset index and working version of that file to the version in a given commit
- `git reset --soft <commit>`: Move local repository branch label to that commit, leave working dir and index unchanged
- `git reset <commit>`: Move local repository and index to commit ("–mixed")
- `git reset --hard <commit>`: Move local repostiory, index, and working directory copy to that state

Branches

Branches are incredibly important to why `git` is cool and powerful.

They are an easy and cheap way of making a second version of your software, which you work on in parallel, and pull in your changes when you are ready.

```
import os

top_dir = os.getcwd()
git_dir = os.path.join(top_dir, "learning_git")
working_dir = os.path.join(git_dir, "git_example")
os.chdir(working_dir)
```

```
%%bash
git branch # Tell me what branches exist
```

```
* main
```

```
%%bash
git checkout -b experiment # Make a new branch
```

```
Switched to a new branch 'experiment'
```

```
%%bash
git branch
```

```
* experiment
  main
```

```
%%writefile Wales.md
Mountains In Wales
==================

* Pen y Fan
* Tryfan
* Snowdon
* Glyder Fawr
* Fan y Big
* Cadair Idris
```

```
Overwriting Wales.md
```

```
%%bash
git commit -am "Add Cadair Idris"
```

```
[experiment ee0f4e4] Add Cadair Idris
 1 file changed, 2 insertions(+), 1 deletion(-)
```

```
%%bash
git checkout main # Switch to an existing branch
```

```
Your branch is up to date with 'origin/main'.
```

```
Switched to branch 'main'
```

```
%%bash
cat Wales.md
```

```
Mountains In Wales
==================

* Pen y Fan
* Tryfan
* Snowdon
* Fan y Big
* Glyder Fawr
```

```
%%bash
git checkout experiment
```

```
Switched to branch 'experiment'
```

```
cat Wales.md
```

```
Mountains In Wales
==================

* Pen y Fan
* Tryfan
* Snowdon
* Glyder Fawr
* Fan y Big
* Cadair Idris
```

Publishing branches

To let the server know there's a new branch use:

```
%%bash
git push -u origin experiment
```

```
Branch 'experiment' set up to track remote branch 'experiment' from 'origin'.
```

```
remote:
remote: Create a pull request for 'experiment' on GitHub by visiting:
remote:      https://github.com/alan-turing-institute/github-
example/pull/new/experiment
remote:
To github.com:alan-turing-institute/github-example.git
 * [new branch]      experiment -> experiment
```

We use `--set-upstream origin` (Abbreviation `-u`) to tell git that this branch should be pushed to and pulled from origin per default.

If you are following along, you should be able to see your branch in the list of branches in GitHub.

Once you've used `git push -u` once, you can push new changes to the branch with just a git push.

If others checkout your repository, they will be able to do `git checkout experiment` to see your branch content, and collaborate with you **in the branch**.

```
%%bash
git branch -r
```

```
  origin/experiment
  origin/main
```

Local branches can be, but do not have to be, connected to remote branches They are said to “track” remote branches. `push -u` sets up the tracking relationship. You can see the remote branch for each of your local branches if you ask for “verbose” output from `git branch`:

```
%%bash
git branch -vv
```

```
* experiment ee0f4e4 [origin/experiment] Add Cadair Idris
  main       532a571 [origin/main] Merge branch 'main' of github.com:alan-turing-
institute/github-example
```

Find out what is on a branch

In addition to using `git diff` to compare to the state of a branch, you can use `git log` to look at lists of commits which are in a branch and haven’t been merged yet.

```
%%bash
git log main..experiment
```

```
commit ee0f4e4cc8bb9f825c7534fd6d2a1ce1e414efdd
Author: Turing Developer <developer@example.com>
Date:   Mon Nov 8 17:20:26 2021 +0000

    Add Cadair Idris
```

Git uses various symbols to refer to sets of commits. The double dot `A..B` means “ancestor of B and not ancestor of A”

So in a purely linear sequence, it does what you’d expect.

```
%%bash
git log --graph --oneline HEAD~9..HEAD~5
```

```
*   ee21e2f Merge branch 'main' of github.com:alan-turing-institute/github-example
|\
| * da25e66 Add Scotland
* | cf66dd0 Add wales
|/
* 5d9e0d6 Add Helvellyn
* fa9a75f Include lakes in the scope
```

But in cases where a history has branches, the definition in terms of ancestors is important.

```
%%bash
git log --graph --oneline HEAD~5..HEAD
```

```
* ee0f4e4 Add Cadair Idris
*   532a571 Merge branch 'main' of github.com:alan-turing-institute/github-example
|\
| * d3c77b7 Add another Beacon
* | e976f03 Add Glyder
|/
*   f671c3d Merge branch 'main' of github.com:alan-turing-institute/github-example
|\
| * b828d19 Add a beacon
* 12cc1ee Translating from the Welsh
```

If there are changes on both sides, like this:

```
%%bash
git checkout main
```

```
Your branch is up to date with 'origin/main'.
```

```
Switched to branch 'main'
```

```
%%writefile Scotland.md
Mountains In Scotland
==================

* Ben Eighe
* Cairngorm
* Aonach Eagach
```

```
Overwriting Scotland.md
```

```
%%bash
git diff Scotland.md
```

```
diff --git a/Scotland.md b/Scotland.md
index 9613dda..bf5c643 100644
--- a/Scotland.md
+++ b/Scotland.md
@@ -3,3 +3,4 @@ Mountains In Scotland

 * Ben Eighe
 * Cairngorm
+* Aonach Eagach
```

```
%%bash
git commit -am "Commit Aonach onto main branch"
```

```
[main dc94b42] Commit Aonach onto main branch
 1 file changed, 1 insertion(+)
```

Then this notation is useful to show the content of what's on what branch:

```
%%bash
git log --left-right --oneline main...experiment
```

```
< dc94b42 Commit Aonach onto main branch
> ee0f4e4 Add Cadair Idris
```

Three dots means "everything which is not a common ancestor" of the two commits, i.e. the differences between them.

Merging branches

We can merge branches, and just as we would pull in remote changes, there may or may not be conflicts.

```
%%bash
git branch
git merge experiment
```

```
  experiment
* main
Merge made by the 'recursive' strategy.
 Wales.md | 3 ++-
 1 file changed, 2 insertions(+), 1 deletion(-)
```

```
%%bash
git log --graph --oneline HEAD~3..HEAD
```

```
*   d7ba75e Merge branch 'experiment'
|\
| * ee0f4e4 Add Cadair Idris
* | dc94b42 Commit Aonach onto main branch
|/
* 532a571 Merge branch 'main' of github.com:alan-turing-institute/github-example
* d3c77b7 Add another Beacon
```

Cleaning up after a branch

```
%%bash
git branch  # list branches
```

```
  experiment
* main
```

```
%%bash
git branch -d experiment  # delete a branch
```

```
Deleted branch experiment (was ee0f4e4).
```

```
%%bash
git branch # current branch
```

```
* main
```

```
%%bash
git branch --remote  # list remote branches
```

```
  origin/experiment
  origin/main
```

```
%%bash
git push --delete origin experiment
# Remove remote branch. Note that you can also use the GitHub interface to do this.
```

```
To github.com:alan-turing-institute/github-example.git
 - [deleted]         experiment
```

```
%%bash
git branch --remote  # list remote branches
```

```
  origin/main
```

```
%%bash
git push
```

```
To github.com:alan-turing-institute/github-example.git
   532a571..d7ba75e  main -> main
```

```
%%bash
git branch -vv # current local branch and tracking
```

```
* main d7ba75e [origin/main] Merge branch 'experiment'
```

A good branch strategy

- A `production` or `main` branch: the current working version of your code
- A `develop` branch: where new code can be tested
- `feature` branches: for specific new ideas
- `release` branches: when you share code with others
    - Useful for applying bug fixes to older versions of your code

Grab changes from a branch

Make some changes on one branch, switch back to another, and use:

```
git checkout <branch> <path>
```

to quickly grab a file from one branch into another. This will create a copy of the file as it exists in `<branch>` into your current branch, overwriting it if it already existed. For example, if you have been experimenting in a new branch but want to undo all your changes to a particular file (that is, restore the file to its version in the `main` branch), you can do that with:

```
git checkout main test_file
```

Using `git checkout` with a path takes the content of files. To grab the content of a specific *commit* from another branch, and apply it as a patch to your branch, use:

```
git cherry-pick <commit>
```

Git Stash

Before you can `git pull`, you need to have committed any changes you have made. If you find you want to pull, but you're not ready to commit, you have to temporarily "put aside" your uncommitted changes. For this, you can use the `git stash` command, like in the following example:

```
import os

top_dir = os.getcwd()
git_dir = os.path.join(top_dir, "learning_git")
working_dir = os.path.join(git_dir, "git_example")
os.chdir(working_dir)
```

Remind ourselves which branch we are using:

```
%%bash
git branch -vv
```

```
* main d7ba75e [origin/main] Merge branch 'experiment'
```

```
%%writefile Wales.md
Mountains In Wales
==================

* Pen y Fan
* Tryfan
* Snowdon
* Glyder Fawr
* Fan y Big
* Cadair Idris
* Penygader
```

```
Overwriting Wales.md
```

```
%%bash
git stash
```

```
Saved working directory and index state WIP on main: d7ba75e Merge branch 'experiment'
```

```
%%bash
git pull
```

```
Already up to date.
```

By stashing your work first, your repository becomes clean, allowing you to pull. To restore your changes, use `git stash apply`.

```
%%bash
git stash apply
```

```
On branch main
Your branch is up to date with 'origin/main'.

Changes not staged for commit:
  (use "git add <file>..." to update what will be committed)
  (use "git restore <file>..." to discard changes in working directory)
        modified:   Wales.md

Untracked files:
  (use "git add <file>..." to include in what will be committed)
        __pycache__/
        wsd.py

no changes added to commit (use "git add" and/or "git commit -a")
```

The “Stash” is a way of temporarily saving your working area, and can help out in a pinch.

Tagging

Tags are easy to read labels for revisions, and can be used anywhere we would name a commit.

Produce real results *only* with tagged revisions.

NB: we delete previous tags with the same name remotely and locally first, to avoid duplicates.

```
git tag -a v1.0 -m "Release 1.0"
git push --tags
```

You can also use tag names in the place of commmit hashes, such as to list the history between particular commits:

```
git log v1.0.. --graph --oneline
```

If .. is used without a following commit name, HEAD is assumed.

Working with generated files: gitignore

We often end up with files that are generated by our program. It is bad practice to keep these in Git; just keep the sources.

Examples include `.o` and `.x` files for compiled languages, `.pyc` files in Python.

In our example, we might want to make our .md files into a PDF with pandoc:

```
%%writefile Makefile

MDS=$(wildcard *.md)
PDFS=$(MDS:.md=.pdf)

default: $(PDFS)

%.pdf: %.md
        pandoc $< -o $@
```

```
Writing Makefile
```

```
%%bash
make
```

```
make[1]: Entering directory '/home/runner/work/rsd-engineeringcourse/rsd-
engineeringcourse/module04_version_control_with_git/learning_git/git_example'
pandoc Scotland.md -o Scotland.pdf
pandoc lakeland.md -o lakeland.pdf
pandoc test.md -o test.pdf
pandoc Wales.md -o Wales.pdf
make[1]: Leaving directory '/home/runner/work/rsd-engineeringcourse/rsd-
engineeringcourse/module04_version_control_with_git/learning_git/git_example'
```

We now have a bunch of output .pdf files corresponding to each Markdown file.

But we don't want those to show up in git:

```
%%bash
git status
```

```
On branch main
Your branch is up to date with 'origin/main'.

Changes not staged for commit:
  (use "git add <file>..." to update what will be committed)
  (use "git restore <file>..." to discard changes in working directory)
        modified:   Wales.md

Untracked files:
  (use "git add <file>..." to include in what will be committed)
        Makefile
        Scotland.pdf
        Wales.pdf
        __pycache__/
        lakeland.pdf
        test.pdf
        wsd.py

no changes added to commit (use "git add" and/or "git commit -a")
```

Use .gitignore files to tell Git not to pay attention to files with certain paths:

```
%%writefile .gitignore
*.pdf
```

```
Writing .gitignore
```

```
%%bash
git status
```

```
On branch main
Your branch is up to date with 'origin/main'.

Changes not staged for commit:
  (use "git add <file>..." to update what will be committed)
  (use "git restore <file>..." to discard changes in working directory)
        modified:   Wales.md

Untracked files:
  (use "git add <file>..." to include in what will be committed)
        .gitignore
        Makefile
        __pycache__/
        wsd.py

no changes added to commit (use "git add" and/or "git commit -a")
```

```
%%bash
git add Makefile
git add .gitignore
git commit -am "Add a makefile and ignore generated files"
git push
```

```
[main 439a17e] Add a makefile and ignore generated files
 3 files changed, 10 insertions(+)
 create mode 100644 .gitignore
 create mode 100644 Makefile
```

```
To github.com:alan-turing-institute/github-example.git
   d7ba75e..439a17e  main -> main
```

Git clean

Sometimes you end up creating various files that you do not want to include in version control. An easy way of deleting them (if that is what you want) is the `git clean` command, which will remove the files that git is not tracking.

```
%%bash
git clean -fX
```

```
Removing Scotland.pdf
Removing Wales.pdf
Removing lakeland.pdf
Removing test.pdf
```

```
%%bash
ls
```

```
Makefile
Scotland.md
Wales.md
__pycache__
lakeland.md
test.md
wsd.py
```

- With -f: don't prompt
- with -d: remove directories
- with -x: Also remote .gitignored files
- with -X: Only remove .gitignore files

Hunks

Git Hunks

A "Hunk" is one git change. This changeset has three hunks:

```
+import matplotlib
+import numpy as np

 from matplotlib import pylab
 from matplotlib.backends.backend_pdf import PdfPages

+def increment_or_add(key,hash,weight=1):
+       if key not in hash:
+               hash[key]=0
+       hash[key]+=weight
+
 data_path=os.path.join(os.path.dirname(
                        os.path.abspath(__file__)),
-regenerate=False
+regenerate=True
```

Interactive add

`git add` and `git reset` can be used to stage/unstage a whole file, but you can use interactive mode to stage by hunk, choosing yes or no for each hunk.

```
git add -p myfile.py
```

```
+import matplotlib
+import numpy as np
#Stage this hunk [y,n,a,d,/,j,J,g,e,?]?
```

GitHub pages

Yaml Frontmatter

GitHub will publish repositories containing markdown as web pages, automatically.

You'll need to add this content:

```
---
---
```

A pair of lines with three dashes, to the top of each markdown file. This is how GitHub knows which markdown files to make into web pages. Here's why for the curious.

```
%%writefile test.md
---
title: Github Pages Example
---
Mountains and Lakes in the UK
==================

Engerland is not very mountainous.
But has some tall hills, and maybe a mountain or two depending on your definition.
```

```
Overwriting test.md
```

```
%%bash
git commit -am "Add github pages YAML frontmatter"
```

```
[main 99897d4] Add github pages YAML frontmatter
 1 file changed, 7 insertions(+), 4 deletions(-)
```

The gh-pages branch

GitHub creates github pages when you use a special named branch. By default this is `gh-pages` although you can change it to something else if you prefer. This is best used to create documentation for a program you write, but you can use it for anything.

```
os.chdir(working_dir)
```

```
%%bash

git checkout -b gh-pages
git push -uf origin gh-pages
```

```
Branch 'gh-pages' set up to track remote branch 'gh-pages' from 'origin'.
```

```
Switched to a new branch 'gh-pages'
remote:
remote: Create a pull request for 'gh-pages' on GitHub by visiting:
remote:      https://github.com/alan-turing-institute/github-example/pull/new/gh-pages
remote:
To github.com:alan-turing-institute/github-example.git
 * [new branch]      gh-pages -> gh-pages
```

The first time you do this, GitHub takes a few minutes to generate your pages.

The website will appear at `http://username.github.io/repositoryname`, for example:

http://alan-turing-institute.github.io/github-example/

Layout for GitHub pages

You can use GitHub pages to make HTML layouts, here's an example of how to do it, and how it looks. We won't go into the detail of this now, but after the class, you might want to try this.

```
%%bash
# Cleanup by removing the gh-pages branch
git checkout main
git push
git branch -d gh-pages
git push --delete origin gh-pages
git branch --remote
```

```
Your branch is ahead of 'origin/main' by 1 commit.
  (use "git push" to publish your local commits)
Deleted branch gh-pages (was 99897d4).
  origin/main
```

```
Switched to branch 'main'
To github.com:alan-turing-institute/github-example.git
   439a17e..99897d4  main -> main
To github.com:alan-turing-institute/github-example.git
 - [deleted]         gh-pages
```

Working with multiple remotes

Distributed versus centralised

Older version control systems (cvs, svn) were "centralised"; the history was kept only on a server, and all commits required an internet.

Centralised	**Distributed**
Server has history	Every user has full history
Your computer has one snapshot	Many local branches
To access history, need internet	History always available
You commit to remote server	Users synchronise histories
cvs, subversion(svn)	git, mercurial (hg), bazaar (bzr)

With modern distributed systems, we can add a second remote. This might be a personal *fork* on github:

```
import os

top_dir = os.getcwd()
git_dir = os.path.join(top_dir, "learning_git")
working_dir = os.path.join(git_dir, "git_example")
os.chdir(working_dir)
```

```
%%bash
git checkout main
git remote add jack89roberts git@github.com:jack89roberts/github-example.git
git fetch jack89roberts
```

```
Your branch is up to date with 'origin/main'.
```

```
Already on 'main'
From github.com:jack89roberts/github-example
 * [new branch]      main       -> jack89roberts/main
 * [new branch]      master     -> jack89roberts/master
```

Check your remote branches:

```
%%bash
git remote -v
```

```
jack89roberts   git@github.com:jack89roberts/github-example.git (fetch)
jack89roberts   git@github.com:jack89roberts/github-example.git (push)
origin  git@github.com:alan-turing-institute/github-example.git (fetch)
origin  git@github.com:alan-turing-institute/github-example.git (push)
```

and ensure that the newly-added remote is up-to-date

```
%%bash
git fetch jack89roberts
```

```
%%writefile Pennines.md

Mountains In the Pennines
=========================

* Cross Fell
* Whernside
```

```
Writing Pennines.md
```

```
%%bash
git add Pennines.md
git commit -am "Add Whernside"
```

```
[main 423b54f] Add Whernside
 1 file changed, 6 insertions(+)
 create mode 100644 Pennines.md
```

We can specify which remote to push to by name:

```
%%bash
git push -uf jack89roberts main || echo "Push failed"
```

```
Push failed
```

```
ERROR: Permission to jack89roberts/github-example.git denied to deploy key
fatal: Could not read from remote repository.

Please make sure you have the correct access rights
and the repository exists.
```

… but note that you need to have the correct permissions to do so.

Referencing remotes

You can always refer to commits on a remote like this:

```
%%bash
git fetch
git log --oneline --left-right jack89roberts/main...origin/main
```

```
> 99897d4 Add github pages YAML frontmatter
> 439a17e Add a makefile and ignore generated files
> d7ba75e Merge branch 'experiment'
> dc94b42 Commit Aonach onto main branch
> ee0f4e4 Add Cadair Idris
> 532a571 Merge branch 'main' of github.com:alan-turing-institute/github-example
> e976f03 Add Glyder
> d3c77b7 Add another Beacon
> f671c3d Merge branch 'main' of github.com:alan-turing-institute/github-example
> b828d19 Add a beacon
> 12cc1ee Translating from the Welsh
> ee21e2f Merge branch 'main' of github.com:alan-turing-institute/github-example
> cf66dd0 Add wales
> da25e66 Add Scotland
> 5d9e0d6 Add Helvellyn
> fa9a75f Include lakes in the scope
> 86e348d Add lakeland
> f26d227 Revert "Add a lie about a mountain"
> d6ea5a7 Change title
> 0a9d416 Add a lie about a mountain
> b608c6b First commit of discourse on UK topography
< 31ea056 Add Whernside
< 009f998 Add github pages YAML frontmatter
< 2f9bcc8 Add a makefile and ignore generated files
< ae539cc Merge branch 'experiment' into main
< 492fec5 Commit Aonach onto main branch
< fe1c71d Add Cadair Idris
< 338d4d6 Merge branch 'main' of https://github.com/alan-turing-institute/github-
example into main
< 07c4fea Add Glyder
< c405c4d Add another Beacon
< f8f20a6 Merge branch 'main' of https://github.com/alan-turing-institute/github-
example into main
< 1f69c3f Translating from the Welsh
< b2b4fa3 Add a beacon
< c1897d4 Merge branch 'main' of https://github.com/alan-turing-institute/github-
example into main
< 0e96c25 Add wales
< 0de6b80 Add Scotland
< 959e142 Add Helvellyn
< 600ffe1 Include lakes in the scope
< c7454a7 Add lakeland
< 5342922 Revert "Add a lie about a mountain"
< f65fd0b Change title
< 8c467a3 Add a lie about a mountain
< 1f92929 First commit of discourse on UK topography
```

To see the differences between remotes, for example.

To see what files you have changed that aren't updated on a particular remote, for example:

```
%%bash
git diff --name-only origin/main
```

```
Pennines.md
```

When you reference remotes like this, you're working with a cached copy of the last time you interacted with the remote. You can do `git fetch` to update local data with the remotes without actually pulling. You can also get useful information about whether tracking branches are ahead or behind the remote branches they track:

```
%%bash
git branch -vv
```

```
* main 423b54f [origin/main: ahead 1] Add Whernside
```

Hosting Servers

Hosting a local server

- Any repository can be a remote for pulls
- Can pull/push over shared folders or ssh
- Pushing to someone's working copy is dangerous

- Use `git init --bare` to make a copy for pushing
- You don't need to create a "server" as such, any 'bare' git repo will do.

```
bare_dir = os.path.join(git_dir, "bare_repo")
os.chdir(git_dir)
```

```
%%bash
mkdir -p bare_repo
cd bare_repo
git init --bare --initial-branch=main
```

```
Initialized empty Git repository in /home/runner/work/rsd-engineeringcourse/rsd-
engineeringcourse/module04_version_control_with_git/learning_git/bare_repo/
```

```
os.chdir(working_dir)
```

```
%%bash
git remote add local_bare ../bare_repo
git push -u local_bare main
```

```
Branch 'main' set up to track remote branch 'main' from 'local_bare'.
```

```
To ../bare_repo
 * [new branch]      main -> main
```

Check your remote branches:

```
%%bash
git remote -v
```

```
jack89roberts   git@github.com:jack89roberts/github-example.git (fetch)
jack89roberts   git@github.com:jack89roberts/github-example.git (push)
local_bare      ../bare_repo (fetch)
local_bare      ../bare_repo (push)
origin  git@github.com:alan-turing-institute/github-example.git (fetch)
origin  git@github.com:alan-turing-institute/github-example.git (push)
```

You can now work with this local repository, just as with any other git server. If you have a colleague on a shared file system, you can use this approach to collaborate through that file system.

Home-made SSH servers

Classroom exercise: Try creating a server for yourself using a machine you can SSH to:

```
ssh <mymachine>
mkdir mygitserver
cd mygitserver
git init --bare
exit
git remote add <somename> ssh://user@host/mygitserver
git push -u <somename> master
```

SSH keys and GitHub

Classroom exercise: If you haven't already, you should set things up so that you don't have to keep typing in your password whenever you interact with GitHub via the command line.

You can do this with an "ssh keypair". You may have created a keypair in the Software Carpentry shell training. Go to the ssh settings page on GitHub and upload your public key by copying the content from your computer. (Probably at .ssh/id_rsa.pub)

If you have difficulties, the instructions for this are on the GitHub website.

Rebasing

Rebase vs merge

A git *merge* is only one of two ways to get someone else's work into yours. The other is called a rebase.

In a merge, a revision is added, which brings the branches together. Both histories are retained. In a rebase, git tries to work out

> What would you need to have done, to make your changes, if your colleague had already made theirs?

Git will invent some new revisions, and the result will be a repository with an apparently linear history. This can be useful if you want a cleaner, non-branching history, but it has the risk of creating inconsistencies, since you are, in a way, "rewriting" history.

An example rebase

We've built a repository to help visualise the difference between a merge and a rebase, at https://github.com/UCL-RITS/wocky_rebase/blob/master/wocky.md.

The initial state of both collaborators is a text file, wocky.md:

```
It was clear and cold,
and the slimy monsters
```

On the master branch, a second commit ('Dancing') has been added:

```
It was clear and cold,
and the slimy monsters
danced and spun in the waves
```

On the "Carollian" branch, a commit has been added translating the initial state into Lewis Caroll's language:

```
'Twas brillig,
and the slithy toves
```

So the logs look like this:

```
git log --oneline --graph master
```

```
* 2a74d89 Dancing
* 6a4834d Initial state
```

```
git log --oneline --graph carollian
```

```
* 2232bf3 Translate into Caroll's language
* 6a4834d Initial state
```

If we now **merge** carollian into master, the final state will include both changes:

```
'Twas brillig,
and the slithy toves
danced and spun in the waves
```

But the graph shows a divergence and then a convergence:

```
git log --oneline --graph
```

```
*   b41f869 Merge branch 'carollian' into master_merge_carollian
|\
| * 2232bf3 Translate into Caroll's language
* | 2a74d89 Dancing
|/
* 6a4834d Initial state
```

But if we **rebase**, the final content of the file is still the same, but the graph is different:

```
git log --oneline --graph master_rebase_carollian
```

```
* df618e0 Dancing
* 2232bf3 Translate into Caroll's language
* 6a4834d Initial state
```

We have essentially created a new history, in which our changes come after the ones in the carollian branch. Note that, in this case, the hash for our “Dancing” commit has changed (from `2a74d89` to `df618e0`)!

To trigger the rebase, we did:

```
git checkout master
git rebase carollian
```

If this had been a remote, we would merge it with:

```
git pull --rebase
```

Fast Forwards

If we want to continue with the translation, and now want to merge the rebased branch into the carollian branch, we get:

```
git checkout carollian
git merge master
```

```
Updating 2232bf3..df618e0
Fast-forward
 wocky.md | 1 +
 1 file changed, 1 insertion(+)
```

The master branch was already **rebased on** the carollian branch, so this merge was just a question of updating *metadata* (moving the label for the carollian branch so that it points to the same commit master does): a “fast forward”.

Rebasing pros and cons

Some people like the clean, apparently linear history that rebase provides.

But *rebase rewrites history*.

If you’ve already pushed, or anyone else has got your changes, things will get screwed up.

If you know your changes are still secret, it might be better to rebase to keep the history clean. If in doubt, just merge.

Squashing

A second way to use the `git rebase` command is to rebase your work on top of one of *your own* earlier commits, in interactive mode (`-i`). A common use of this is to “squash” several commits that should really be one, i.e. combine them into a single commit that contains all their changes:

```
git log
```

```
ea15 Some good work
ll54 Fix another typo
de73 Fix a typo
ab11 A great piece of work
cd27 Initial commit
```

Using rebase to squash

If we type

```
git rebase -i ab11 #OR HEAD^^
```

an edit window pops up with:

```
pick cd27 Initial commit
pick ab11 A great piece of work
pick de73 Fix a typo
pick ll54 Fix another typo
pick ea15 Some good work

# Rebase 60709da..30e0ccb onto 60709da
#
# Commands:
#  p, pick = use commit
#  e, edit = use commit, but stop for amending
#  s, squash = use commit, but meld into previous commit
```

We can rewrite select commits to be merged, so that the history is neater before we push. This is a great idea if you have lots of trivial typo commits.

```
pick cd27 Initial commit
pick ab11 A great piece of work
squash de73 Fix a typo
squash ll54 Fix another typo
pick ea15 Some good work
```

save the interactive rebase config file, and rebase will build a new history:

```
git log
```

```
de82 Some good work
fc52 A great piece of work
cd27 Initial commit
```

Note the commit hash codes for ‘Some good work’ and ‘A great piece of work’ have changed, as the change they represent has changed.

Debugging With Git Bisect

You can use

```
git bisect
```

to find out which commit caused a bug.

An example repository

In a nice open source example, I found an arbitrary exemplar on github

```
import os

top_dir = os.getcwd()
git_dir = os.path.join(top_dir, "learning_git")
os.chdir(git_dir)
```

```
%%bash
rm -rf bisectdemo
git clone https://github.com/shawnsi/bisectdemo.git
```

```
Cloning into 'bisectdemo'...
```

```
bisect_dir = os.path.join(git_dir, "bisectdemo")
os.chdir(bisect_dir)
```

```
%%bash
python squares.py 2 # 4
```

```
4
```

This has been set up to break itself at a random commit, and leave you to use bisect to work out where it has broken:

```
%%bash
./breakme.sh > break_output
```

```
error: branch 'buggy' not found.
Switched to a new branch 'buggy'
```

Which will make a bunch of commits, of which one is broken, and leave you in the broken final state

```
python squares.py 2 # Error message
```

```
  File "/tmp/ipykernel_6491/777131122.py", line 1
    python squares.py 2 # Error message
                  ^
SyntaxError: invalid syntax
```

Bisecting manually

```
%%bash
git bisect start
git bisect bad # We know the current state is broken
git checkout master
git bisect good # We know the master branch state is OK
```

```
Your branch is up to date with 'origin/master'.
Bisecting: 500 revisions left to test after this (roughly 9 steps)
[cbdee4c62549b1d261c79774252a779597a63fd9] Comment 500
```

```
Switched to branch 'master'
```

Bisect needs one known good and one known bad commit to get started

Solving Manually

```
python squares.py 2 # 4
git bisect good
python squares.py 2 # 4
git bisect good
python squares.py 2 # 4
git bisect good
python squares.py 2 # Crash
git bisect bad
python squares.py 2 # Crash
git bisect bad
python squares.py 2 # Crash
git bisect bad
python squares.py 2 #Crash
git bisect bad
python squares.py 2 # 4
git bisect good
python squares.py 2 # 4
git bisect good
python squares.py 2 # 4
git bisect good
```

And eventually:

```
git bisect good
    Bisecting: 0 revisions left to test after this (roughly 0 steps)

python squares.py 2
    4

git bisect good
2777975a2334c2396ccb9faf98ab149824ec465b is the first bad commit
commit 2777975a2334c2396ccb9faf98ab149824ec465b
Author: Shawn Siefkas <shawn.siefkas@meredith.com>
Date:   Thu Nov 14 09:23:55 2013 -0600

    Breaking argument type
```

```
git bisect end
```

Solving automatically

If we have an appropriate unit test, we can do all this automatically:

```
%%bash
git bisect start
git bisect bad HEAD # We know the current state is broken
git bisect good master # We know master is good
git bisect run python squares.py 2
```

```
Bisecting: 500 revisions left to test after this (roughly 9 steps)
[cbdee4c62549b1d261c79774252a779597a63fd9] Comment 500
running python squares.py 2
4
Bisecting: 250 revisions left to test after this (roughly 8 steps)
[d33fa7eed31955beb9c50014689a3de4fec55908] Comment 749
running python squares.py 2
Bisecting: 124 revisions left to test after this (roughly 7 steps)
[c2cf975fe6c763da3b62d301165a766078d26cae] Comment 625
running python squares.py 2
4
Bisecting: 62 revisions left to test after this (roughly 6 steps)
[d9e19d5fddd1480151fb8702170c5b1177ae06f3] Comment 686
running python squares.py 2
Bisecting: 30 revisions left to test after this (roughly 5 steps)
[b7290c6140c08e83cf00039f5ff5f80eb30db583] Comment 655
running python squares.py 2
Bisecting: 15 revisions left to test after this (roughly 4 steps)
[2dab9b8f93f04cd5247d07d570d61faa1f7b47c2] Comment 639
running python squares.py 2
Bisecting: 7 revisions left to test after this (roughly 3 steps)
[fbc34c22ad0286581846d3430a13e44a122169a8] Breaking argument type
running python squares.py 2
Bisecting: 3 revisions left to test after this (roughly 2 steps)
[01e2eeb4368ad2c9b4886b6080d6fd87f75eed85] Comment 628
running python squares.py 2
4
Bisecting: 1 revision left to test after this (roughly 1 step)
[3ec85d3b2e68f2c55a10fc39fa8e7d31a6b6cfda] Comment 630
running python squares.py 2
4
Bisecting: 0 revisions left to test after this (roughly 0 steps)
[abe3957d32fffffc8db40e0acbd7191c0beb1276] Comment 631
running python squares.py 2
4
fbc34c22ad0286581846d3430a13e44a122169a8 is the first bad commit
commit fbc34c22ad0286581846d3430a13e44a122169a8
Author: Shawn Siefkas <shawn.siefkas@meredith.com>
Date:   Thu Nov 14 09:23:55 2013 -0600

    Breaking argument type

 squares.py | 2 +-
 1 file changed, 1 insertion(+), 1 deletion(-)
bisect run success
```

```
Previous HEAD position was cbdee4c Comment 500
Switched to branch 'buggy'
Traceback (most recent call last):
  File "squares.py", line 9, in <module>
    print(integer**2)
TypeError: unsupported operand type(s) for ** or pow(): 'str' and 'int'
Traceback (most recent call last):
  File "squares.py", line 9, in <module>
    print(integer**2)
TypeError: unsupported operand type(s) for ** or pow(): 'str' and 'int'
Traceback (most recent call last):
  File "squares.py", line 9, in <module>
    print(integer**2)
TypeError: unsupported operand type(s) for ** or pow(): 'str' and 'int'
Traceback (most recent call last):
  File "squares.py", line 9, in <module>
    print(integer**2)
TypeError: unsupported operand type(s) for ** or pow(): 'str' and 'int'
Traceback (most recent call last):
  File "squares.py", line 9, in <module>
    print(integer**2)
TypeError: unsupported operand type(s) for ** or pow(): 'str' and 'int'
```

Boom!

Assessment

We have provided the following exercises to let you self-assess your performance on some problems typical of those that are encountered in research software engineering.

- Packaging Greengraph
- Refactoring the Bad Boids

An Adventure In Packaging: An exercise in research software engineering.

In this exercise, you will convert the already provided solution to the programming challenge defined in this Jupyter notebook, into a proper Python package.

The code to actually solve the problem is already given, but as roughly sketched out code in a notebook.

Your job will be to convert the code into a formally structured package, with unit tests, a command line interface, and demonstrating your ability to use `git` version control.

First, we set out the problem we are solving, and it's informal solution. Next, we specify in detail the target for your tidy solution. Finally, to assist you in creating a good solution, we state the marks scheme we will use.

Treasure Hunting for Beginners: an AI testbed

We are going to look at a simple game, a modified version of one with a long history. Games of this kind have been used as test-beds for development of artificial intelligence.

A *dungeon* is a network of connected *rooms*. One or more rooms contain *treasure*. Your character, the *adventurer*, moves between rooms, looking for the treasure. A *troll* is also in the dungeon. The troll moves between rooms at random. If the troll catches the adventurer, you lose. If you find treasure before being eaten, you win. (In this simple version, we do not consider the need to leave the dungeon.)

The starting rooms for the adventurer and troll are given in the definition of the dungeon.

The way the adventurer moves is called a *strategy*. Different strategies are more or less likely to succeed.

We will consider only one strategy this time - the adventurer will also move at random.

We want to calculate the probability that this strategy will be successful for a given dungeon.

We will use a "monte carlo" approach - simply executing the random strategy many times, and counting the proportion of times the adventurer wins.

Our data structure for a dungeon will be somewhat familiar from the Maze example:

```
dungeon1 = {
    "treasure": [1],  # Room 1 contains treasure
    "adventurer": 0,  # The adventurer starts in room 0
    "troll": 2,  # The troll starts in room 2
    "network": [
        [1],  # Room zero connects to room 1
        [0, 2],  # Room one connects to rooms 0 and 2
        [1],
    ],  # Room 2 connects to room 1
}
```

So this example shows a 3-room linear corridor: with the adventurer at one end, the troll at the other, and the treasure in the middle.

With the adventurer following a random walk strategy, we can define a function to update a dungeon:

```
import random


def random_move(network, current_loc):
    targets = network[current_loc]
    return random.choice(targets)
```

```
def update_dungeon(dungeon):
    dungeon["adventurer"] = random_move(dungeon["network"], dungeon["adventurer"])
    dungeon["troll"] = random_move(dungeon["network"], dungeon["troll"])
```

```
update_dungeon(dungeon1)

dungeon1
```

```
{'treasure': [1], 'adventurer': 1, 'troll': 1, 'network': [[1], [0, 2], [1]]}
```

We can also define a function to test if the adventurer has won, died, or if the game continues:

```
def outcome(dungeon):
    if dungeon["adventurer"] == dungeon["troll"]:
        return -1
    if dungeon["adventurer"] in dungeon["treasure"]:
        return 1
    return 0
```

```
outcome(dungeon1)
```

```
-1
```

So we can loop, to determine the outcome of an adventurer in a dungeon:

```
import copy


def run_to_result(dungeon):
    dungeon = copy.deepcopy(dungeon)
    max_steps = 1000
    for _ in range(max_steps):
        result = outcome(dungeon)
        if result != 0:
            return result
        update_dungeon(dungeon)
    # don't run forever, return 0 (e.g. if there is no treasure and the troll can't
reach the adventurer)
    return result
```

```
dungeon2 = {
    "treasure": [1],  # Room 1 contains treasure
    "adventurer": 0,  # The adventurer starts in room 0
    "troll": 2,  # The troll starts in room 2
    "network": [
        [1],  # Room zero connects to room 1
        [0, 2],  # Room one connects to rooms 0 and 2
        [1, 3],  # Room 2 connects to room 1 and 3
        [2],
    ],  # Room 3 connects to room 2
}
```

```
run_to_result(dungeon2)
```

```
1
```

Note that we might get a different result sometimes, depending on how the adventurer moves, so we need to run multiple times to get our probability:

```
def success_chance(dungeon):
    trials = 10000
    successes = 0
    for _ in range(trials):
        outcome = run_to_result(dungeon)
        if outcome == 1:
            successes += 1
    success_fraction = successes / trials
    return success_fraction
```

```
success_chance(dungeon2)
```

```
0.4949
```

Make sure you understand why this number should be a half, given a large value for `trials`.

```
dungeon3 = {
    "treasure": [2],  # Room 2 contains treasure
    "adventurer": 0,  # The adventurer starts in room 0
    "troll": 4,  # The troll starts in room 4
    "network": [
        [1],  # Room zero connects to room 1
        [0, 2],  # Room one connects to rooms 0 and 2
        [1, 3],  # Room 2 connects to room 1 and 3
        [2, 4],  # Room 3 connects to room 2 and 4
        [3],
    ],  # Room 4 connects to room 3
}
```

```
success_chance(dungeon3)
```

```
0.4013
```

[Not for credit] Do you understand why this number should be 0.4? Hint: The first move is always the same. In the next state, a quarter of the time, you win. 3/8 of the time, you end up back where you were before. The rest of the time, you lose (eventually). You can sum the series: \(\frac{1}{4}(1+\frac{3}{8}+(\frac{3}{8})^2+...)=\frac{2}{5}\).

Packaging the Treasure: your exercise

If you are following the guidelines from earlier lectures, you will use a single top-level folder with a sensible name. This top level folder should contain all the parts of your solution.

Inside your top level folder, you should create a `setup.py` file to make the code installable. You should also create some other files, per the lectures, that should be present in all research software packages. (Hint, there are three of these.)

Your tidied-up version of the solution code should be in a sub-folder called `adventure` which will be the python package itself. It will contain an `__init__.py` file, and the code itself should be in a file called `dungeon.py`. This should define a class `Dungeon`: instead of a data structure and associated functions, you must refactor this into a class and methods.

Thus, if you run python in your top-level folder, you should be able to `from adventure.dungeon import Dungeon`.

You must create a command-line entry point, called `hunt`. This should use the entry_points facility in `setup.py`, to point toward a module designed for use as the entry point, in `adventure/command.py`. This should use the `Argparse` library. When invoked with `hunt mydungeon.yml --samples 500` the command must print on standard output the probability of finding the treasure in the specified dungeon, using the random walk strategy, after the specified number of test runs.

The `dungeon.yml` file should be a yml file containing a structure representing the dungeon state. Use the same structure as the sample code above, even though you'll be building a `Dungeon` object from this structure rather than using it directly.

You must create unit tests which cover a number of examples. These should be defined in `adventure/tests/test_dungeon.py`. Don't forget to add an **init.py** file to that folder too, so that at the top of the test file you can " `from ..dungeon import Dungeon`." If your unit tests use a fixture file to DRY up tests, this must be called `adventure/tests/fixtures.yml`. For example, this could contain a yaml array of many dungeon structures.

You should `git init` as soon as you create the top-level folder, and `git commit` your work regularly as the exercise progresses.

Suggested Marking Scheme

If you want to self-assess your solution you can consider using the marking scheme below.

- Code in dungeon.py, implementing the random walk strategy: (**5 marks**)
  - Which works. (**1 mark**)
  - Cleanly laid out and formatted - PEP8. (**1 mark**)
  - Defining the class `Dungeon` with a valid object oriented structure. (**1 mark**)
  - Breaking down the solution sensibly into subunits. (**1 mark**)
  - Structured so that it could be used as a base for other strategies. (**1 mark**)
- Command line entry point: (**4 marks**)
  - Accepting a dungeon definition text file as input. (**1 mark**)
  - With an optional parameter to control sample size. (**1 mark**)
  - Which prints the result to standard out. (**1 mark**)
  - Which correctly uses the `Argparse` library. (**1 mark**)
  - Which is itself cleanly laid out and formatted. (**1 mark**)
- setup.py file: (**5 marks**)
  - Which could be used to `pip install` the project. (**1 mark**)
  - With appropriate metadata, including version number and author. (**1 mark**)
  - Which packages code (but not tests), correctly. (**1 mark**)
  - Which specifies library dependencies. (**1 mark**)
  - Which points to the entry point function. (**1 mark**)
- Three other metadata files: (**3 marks**)
  - Hint: Who did it, how to reference it, who can copy it.
- Unit tests: (**5 marks**)
  - Which test some obvious cases. (**1 mark**)
  - Which correctly handle approximate results within an appropriate tolerance. (**1 mark**)
  - Which test how the code fails when invoked incorrectly. (**1 mark**)
  - Which use a fixture file or other approach to avoid overly repetitive test code. (**1 mark**)
  - Which are themselves cleanly laid out code. (**1 mark**)
- Version control: (**2 marks**)
  - Sensible commit sizes. (**1 mark**)
  - Appropriate commit comments. (**1 mark**)

Total: **25 marks**

Packaging Greengraph

Summary

In an appendix, taken from here, are classes which generate a graph of the proportion of green pixels in a series of satellite images between two points.

https://alan-turing-institute.github.io/rsd-engineeringcourse/html/ch00python/index.html

Your task is to take this code, and do the work needed to make it into a proper package which could be released, meeting minimum software engineering standards

- **package** this code, into a git repository, suitable to be installed with `pip`
- create an appropriate command line entry point, so that the code can be invoked with `greengraph --from London --to Oxford --steps 10 --out graph.png` or a similar interface
- Implement automated tests for each element of the code
- Add appropriate standard supplementary files to the code, describing license, citation and typical usage

Assignment Presentation

For this coursework assignment, you are expected to submit a short report and your code. The purpose of the report is to answer the non-coding questions below, to present your results and provide a brief description of your design choices and implementation. The report need not be very long or overly detailed, but should provide a succinct record of your coursework. The report must have a cover sheet stating your name, your student number, and the code of the module (MPHYG001).

Submission

TBD

You should submit your report and all of your source code so that an independent person can run the code. The code and report must be submitted as a single zip or tgz archive of a folder which contains **git** version control information for your project. Your report should be included as a PDF file, report.pdf, in the root folder of your archive. There is no need to include your source code in your report, but you can refer to it and if necessary reproduce lines if it helps to explain your solution.

Marks Scheme

- Code broken up into appropriate files, and arranged into an appropriate folder structure [2 marks]
- Git version control used, with a series of sensible commit messages [2 marks]
- Command line entry point, using appropriate library to parse arguments [3 marks]
- Packaging for `pip` installation, with `setup.py` file with appropriate content [5 marks]
- Automated tests for each method and class (2 marks), with appropriate fixtures defined (1 mark) and mocks used to avoid tests interacting with internet (2 marks). [5 marks total]
- Supplementary files to define license, usage, and citation. [3 marks]
- A text report which:
    - Documents the usage of your entry point [1 mark]
    - Discusses problems encountered in completing your work [1 mark]
    - Discusses in your own words the advantages and costs involved in preparing work for release, the use of package managers like pip and package indexes like PyPI [2 marks]
    - Discusses further steps you would need to take to build a community of users for a project [1 mark]

[25 marks total]

Appendix

```
import numpy as np
import geopy
from StringIO import StringIO
from matplotlib import image as img

class Greengraph:
    def __init__(self, start, end):
        self.start = start
        self.end = end
        self.geocoder = geopy.geocoders.Nominatim(user_agent="rsd-course")

    def geolocate(self, place):
        return self.geocoder.geocode(place, exactly_one=False)[0][1]

    def location_sequence(self, start, end, steps):
        lats = np.linspace(start[0], end[0], steps)
        longs = np.linspace(start[1], end[1], steps)
        return np.vstack([lats, longs]).transpose()

    def green_between(self, steps):
        return [
            Map(*location).count_green()
            for location in self.location_sequence(
                self.geolocate(self.start), self.geolocate(self.end), steps
            )
        ]


class Map:
    def __init__(
        self, lat, long, satellite=True, zoom=10, size=(400, 400), sensor=False
    ):
        base = "https://static-maps.yandex.ru/1.x/?"

        params = dict(
            z=zoom,
            size=str(size[0]) + "," + str(size[1]),
            ll=str(long) + "," + str(lat),
            l="sat" if satellite else "map",
            lang="en_US",
        )

        self.image = requests.get(
            base, params=params
        ).content  # Fetch our PNG image data
        content = BytesIO(self.image)
        self.pixels = img.imread(content)  # Parse our PNG image as a numpy array

    def green(self, threshold):
        # Use NumPy to build an element-by-element logical array
        greener_than_red = self.pixels[:, :, 1] > threshold * self.pixels[:, :, 0]
        greener_than_blue = self.pixels[:, :, 1] > threshold * self.pixels[:, :, 2]
        green = np.logical_and(greener_than_red, greener_than_blue)
        return green

    def count_green(self, threshold=1.1):
        return np.sum(self.green(threshold))

    def show_green(data, threshold=1.1):
        green = self.green(threshold)
        out = green[:, :, np.newaxis] * array([0, 1, 0])[np.newaxis, np.newaxis, :]
        buffer = BytesIO()
        result = img.imwrite(buffer, out, format="png")
        return buffer.getvalue()


mygraph=Greengraph('New York','Chicago')
data = mygraph.green_between(20)
plt.plot(data)
```

Refactoring Trees: An exercise in Research Software Engineering

In this exercise, you will convert badly written code, provided here, into better-written code.

You will do this not through simply writing better code, but by taking a refactoring approach, as discussed in the lectures.

As such, your use of `git` version control, to make a commit after each step of the refactoring, with a commit message which indicates the refactoring you took, will be critical to success.

You will also be asked to look at the performance of your code, and to make changes which improve the speed of the code.

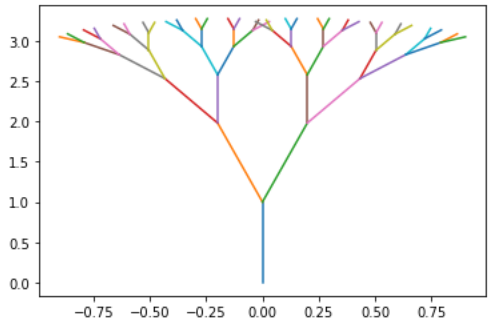
The script as supplied has its parameters hand-coded within the code. You will be expected, in your refactoring, to make these available as command line parameters to be supplied when the code is invoked.

Some terrible code

Here's our terrible code:

```
%matplotlib inline
```

```
from math import sin, cos
from matplotlib import pyplot as plt

s = 1
d = [[0, 1, 0]]
plt.plot([0, 0], [0, 1])
for i in range(5):
    n = []
    for j in range(len(d)):
        n.append(
            [
                d[j][0] + s * sin(d[j][2] - 0.2),
                d[j][1] + s * cos(d[j][2] - 0.2),
                d[j][2] - 0.2,
            ]
        )
        n.append(
            [
                d[j][0] + s * sin(d[j][2] + 0.2),
                d[j][1] + s * cos(d[j][2] + 0.2),
                d[j][2] + 0.2,
            ]
        )
        plt.plot([d[j][0], n[-2][0]], [d[j][1], n[-2][1]])
        plt.plot([d[j][0], n[-1][0]], [d[j][1], n[-1][1]])
    d = n
    s *= 0.6
plt.savefig("tree.png")
```



Suggested Marking Scheme

If you want to self-assess your solution you can consider using the marking scheme below.

Part one: Refactoring (15 marks)

- Copy the code above into a file tree.py, invoke it with python tree.py, and verify it creates an image tree.png which looks like that above.
- Initialise your git repository with the raw state of the code. (**1 mark**)
- Identify a number of simple refactorings which can be used to improve the code, *reducing repetition* and *improving readability*. Implement these one by one, with a git commit each time.
    - **1 mark** for each refactoring, **1 mark** for each git commit, at least five such: **10 marks total**.
- Do NOT introduce NumPy or other performance improvements yet (see below.)

- Identify which variables in the code would, more sensibly, be able to be input parameters, and use Argparse to manage these.
    - **4 marks**: 1 for each of four arguments identified.

Part two: performance programming (10 marks)

- For the code as refactored, prepare a figure which plots the time to produce the tree, versus number of iteration steps completed. Your code to produce this figure should run as a script, which you should call `perf_plot.py`, invoking a function imported from `tree.py`. The script should produce a figure called `perf_plot.png`. Comment on your findings in a text file, called `comments.md`. For your performance measurements you should turn off the actual plotting, and run only the mathematical calculation using an appropriate flag. **5 marks**:
    - Time to run code identified. (**1 mark**)
    - Figure created. (**1 mark**)
    - Figure correctly formatted. (**1 mark**)
    - Figure auto-generated from script. (**1 mark**)
    - Performance law identified. (**1 mark**)

- The code above makes use of `append()` which is not appropriate for `NumPy`. Create a new solution (in a file called `tree_np.py`) which makes use of `NumPy`. Compare the performance (again, excluding the plotting from your measurements), and discuss in comments.md. **5 marks**:
    - Array-operations used to subtract the change angle from all angles in a single minus sign. (**1 mark**)
    - Array-operations used to take the sine of all angles using np.sin. (**1 mark**)
    - Array-operations used to move on all the positions with a single vector displacement addition. (**1 mark**)
    - Numpy solution uses `hstack` or similar to create new arrays with twice the length, by composing the left-turned array with the right-turned array. (**1 mark**)
    - Performance comparison recorded. (**1 mark**)

Refactoring the Bad Boids

Summary

In an appendix, taken from here, is a very poor implementation of the Boids flocking example from the course.

Your task is to take this code, and build from it a clean implementation of the flocking code, finishing with an appropriate object oriented design, using the **refactoring** approach to gradually and safely build your better solution from the supplied poor solution. Simply submitting a good, clean solution will not complete this assignment; you are being assessed on the step-by-step refactoring process, on the basis of individual git commits. You should develop unit tests for your code as units (functions, classes, methods and modules) emerge, and wrap the code in an appropriate command line entry point providing an appropriate configuration system for simulation setup.

Assignment Presentation

For this coursework assignment, you are expected to submit a short report and your code. The purpose of the report is to answer the non-coding questions below, to present your results and provide a brief description of your design choices and implementation. The report need not be very long or overly detailed, but should provide a succinct record of your coursework.

Submission

You should submit your report and all of your source code so that an independent person can run the code. The code and report must be submitted as a single `zip` or `tgz` archive of a folder which contains **git** version control information for your project. Your report should be included as a PDF file, report.pdf, in the root folder of your archive. There is no need to include your source code in your report, but you can refer to it and if necessary reproduce lines if it helps to explain your solution.

Marking Scheme

- Final state of code is well broken down into functions, classes, methods and modules `[3 marks]`
- Final state of code is readable with good variable, function, class and method names and necessary comments `[2 marks]`
- Git version control used, with a series of sensible commit messages `[2 marks]`
- Command line entry point and configuration file, using appropriate libraries `[3 marks]`
- Packaging for `pip` installation, with `setup.py` file with appropriate content `[2 marks]`
- Automated tests for each method and class. `[5 marks]`
- Supplementary files to define license, usage, and citation. `[3 marks]`
- A text report which:
    - Lists by name the code smells identified refactorings used, making reference to the git commit log `[2 marks]`
    - Includes a UML diagram of the final class structure `[1 mark]`
    - Discusses in your own words the advantages of a refactoring approach to improving code `[1 mark]`
    - Discusses problems encountered during the project `[1 mark]`

`[25 marks total]`

Appendix

```
from matplotlib import pyplot as plt
from matplotlib import animation
import random

# Deliberately terrible code for teaching purposes

boids_x=[random.uniform(-450,50.0) for x in range(50)]
boids_y=[random.uniform(300.0,600.0) for x in range(50)]
boid_x_velocities=[random.uniform(0,10.0) for x in range(50)]
boid_y_velocities=[random.uniform(-20.0,20.0) for x in range(50)]
boids=(boids_x,boids_y,boid_x_velocities,boid_y_velocities)

def update_boids(boids):
        xs,ys,xvs,yvs=boids
        # Fly towards the middle
        for i in range(50):
                for j in range(50):
                        xvs[i]=xvs[i]+(xs[j]-xs[i])*0.01/len(xs)
        for i in range(50):
                for j in range(50):
                        yvs[i]=yvs[i]+(ys[j]-ys[i])*0.01/len(xs)
        # Fly away from nearby boids
        for i in range(50):
                for j in range(50):
                        if (xs[j]-xs[i])**2 + (ys[j]-ys[i])**2 < 100:
                                xvs[i]=xvs[i]+(xs[i]-xs[j])
                                yvs[i]=yvs[i]+(ys[i]-ys[j])
        # Try to match speed with nearby boids
        for i in range(50):
                for j in range(50):
                        if (xs[j]-xs[i])**2 + (ys[j]-ys[i])**2 < 10000:
                                xvs[i]=xvs[i]+(xvs[j]-xvs[i])*0.125/len(xs)
                                yvs[i]=yvs[i]+(yvs[j]-yvs[i])*0.125/len(xs)
        # Move according to velocities
        for i in range(50):
                xs[i]=xs[i]+xvs[i]
                ys[i]=ys[i]+yvs[i]


figure=plt.figure()
axes=plt.axes(xlim=(-500,1500), ylim=(-500,1500))
scatter=axes.scatter(boids[0],boids[1])

def animate(frame):
   update_boids(boids)
   scatter.set_offsets(zip(boids[0],boids[1]))


anim = animation.FuncAnimation(figure, animate,
                               frames=50, interval=50)

if __name__ == "__main__":
    plt.show()
```

By The Alan Turing Institute