

Introduction to git

Lorne Whiteway
lorne.whiteway.13@ucl.ac.uk

Astrophysics Group
Department of Physics and Astronomy
University College London

21 October 2025

Find the presentation at <https://tinyurl.com/y8pr4mvq>

Purpose of presentation

- ▶ git is a popular software package for version control.
- ▶ I don't want to teach you how to use git.
- ▶ Rather I want to illustrate (part of) git's 'internal model' and to define certain key git terminology so that you will be better prepared to teach yourself git.
- ▶ My examples assume you are calling git from the command line. Friendlier interfaces to git exist - but you still need to know the underlying model to use them effectively.

git isn't perfect

- ▶ The internal model is complicated.
- ▶ The interface is inconsistent.
- ▶ The documentation is suboptimal.
- ▶ Several key ideas have been given misleading names.
- ▶ It uses a 'distributed' model whereas often what you want is a 'client/server' model; you may end up 'fighting the paradigm'.
- ▶ See more at <https://stevebennett.me/2012/02/24/10-things-i-hate-about-git/>.
- ▶ But it's popular, powerful, fast, economical on disk space, free, and open-source.



Version control

- ▶ *Version control* is software to 'keep track of' (i.e. store) successive versions as we edit a collection of *source* files (computer code, \LaTeX documents, HTML files, etc.)
- ▶ More efficient on source files that are text, not binary. Intermediate files are usually not kept track of. Output files might be - it's your choice.
- ▶ Any serious project should be under version control.

Version control...

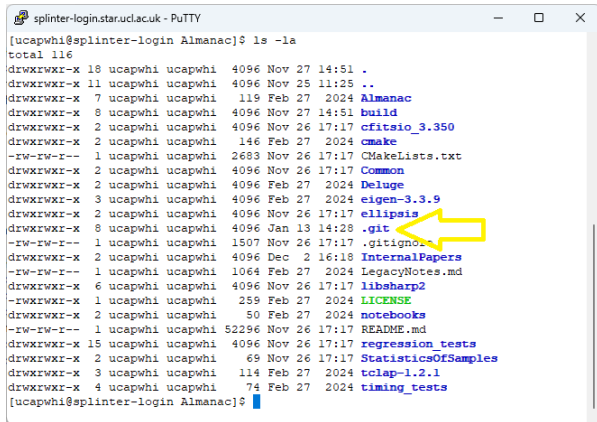
- ▶ ... is insurance: there is a small daily cost to having it, but occasionally it provides a massive benefit.
- ▶ ... protects you against damage to your files (e.g. hard drive failure, fire, flood, misplacement, accidental deletion, theft, virus, ransomware, file damage due to OS bugs, ...).
- ▶ ... protects you against edits to your files that you later regret, as you can revert to an old version. This makes it easier to experiment (as changes can be undone).
- ▶ ... allows multiple people to work simultaneously on the same files (as their various changes can be merged).
- ▶ ... allows auditing and blaming (as it can identify the author of a given change).

Working directory and repository

- ▶ You need a *working directory* and a *repository*.
- ▶ The working directory and its subdirectories contain the actual files that you are editing.
- ▶ The repository is some sort of database containing all previous versions.
- ▶ One model would be to put the repository on the Internet or Intranet where all developers can see it...

Location of git repository

- ... But in git the repository is **part of** the working directory, in a hidden subdirectory (called `.git`) of the top-level working directory.

A terminal window titled 'splinter-login.star.ucl.ac.uk - PuTTY' showing the output of the command 'ls -la'. The output lists various files and directories with their permissions, owner, group, size, date, and name. A yellow arrow points to the '.git' directory entry.

```
[ucapwhi@splinter-login Almanac]$ ls -la
total 116
drwxrwxr-x 18 ucapwhi ucapwhi 4096 Nov 27 14:51 .
drwxrwxr-x 11 ucapwhi ucapwhi 4096 Nov 25 11:25 ..
drwxrwxr-x 7 ucapwhi ucapwhi 119 Feb 27 2024 Almanac
drwxrwxr-x 8 ucapwhi ucapwhi 4096 Nov 27 14:51 build
drwxrwxr-x 2 ucapwhi ucapwhi 4096 Nov 26 17:17 cfitsio_3.350
drwxrwxr-x 2 ucapwhi ucapwhi 146 Feb 27 2024 cmake
-rw-rw-r-- 1 ucapwhi ucapwhi 2683 Nov 26 17:17 CMakeLists.txt
drwxrwxr-x 2 ucapwhi ucapwhi 4096 Nov 26 17:17 Common
drwxrwxr-x 2 ucapwhi ucapwhi 4096 Feb 27 2024 Deluge
drwxrwxr-x 3 ucapwhi ucapwhi 4096 Feb 27 2024 eigen-3.3.9
drwxrwxr-x 2 ucapwhi ucapwhi 4096 Nov 26 17:17 ellipsis
drwxrwxr-x 8 ucapwhi ucapwhi 4096 Jan 13 14:28 .git
-rw-rw-r-- 1 ucapwhi ucapwhi 1507 Nov 26 17:17 .gitignore
drwxrwxr-x 2 ucapwhi ucapwhi 4096 Dec 2 16:18 InternalPapers
-rw-rw-r-- 1 ucapwhi ucapwhi 1064 Feb 27 2024 LegacyNotes.md
drwxrwxr-x 6 ucapwhi ucapwhi 4096 Nov 26 17:17 libsharp2
-rwxrwxr-x 1 ucapwhi ucapwhi 259 Feb 27 2024 LICENSE
drwxrwxr-x 2 ucapwhi ucapwhi 50 Feb 27 2024 notebooks
-rw-rw-r-- 1 ucapwhi ucapwhi 52296 Nov 26 17:17 README.md
drwxrwxr-x 15 ucapwhi ucapwhi 4096 Nov 26 17:17 regression_tests
drwxrwxr-x 2 ucapwhi ucapwhi 69 Nov 26 17:17 StatisticsOfSamples
drwxrwxr-x 3 ucapwhi ucapwhi 114 Feb 27 2024 tcclap-1.2.1
drwxrwxr-x 4 ucapwhi ucapwhi 74 Feb 27 2024 timing_tests
[ucapwhi@splinter-login Almanac]$
```


This repository location isn't ideal...

Having the git repository next to your working directory isn't ideal:

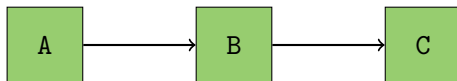
- ▶ No protection against physical damage to the disk.
- ▶ Others can't see your repository (bad for collaboration).

One upside is that you can still do version control even if you are not connected to the Internet.

So you usually need two git repositories

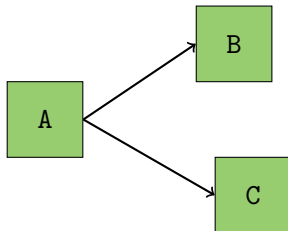
- ▶ So typically you will also need **another** git repository on the Internet (for backup, for collaboration and sharing, and to act as a reference version).
- ▶ So you will typically be dealing with **two** git repositories (and dealing with the issues of keeping them in synch).

Example repository content



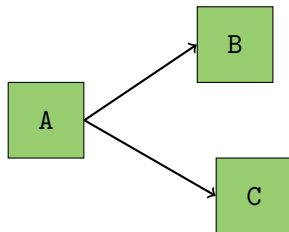
- ▶ This repository contains three successive versions of the files in the working directory (and its subdirectories).
- ▶ Each version is represented here as a *node* (in green).
- ▶ An initial set of files (version A) was committed to the repository; the files were then edited and the new file set (version B) was committed; the files were then edited and committed a third time (version C).

Another example



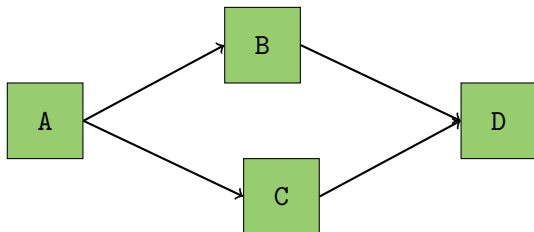
- ▶ Here we committed A...
- ▶ Then we edited A (to form B) and committed B...
- ▶ Then we went back to A, made a perhaps different set of edits (to form C) and committed C.

What do the arrows actually stand for?



- ▶ An arrow respects time (pointing from an earlier version to a later version), and indicates that a node was derived from an earlier node by editing.
- ▶ Q: There exists a set of edits that would take you from B to C, so why not show that arrow as well? A: It's a historical record of the route we actually took, not a map of all possible routes.

Merging



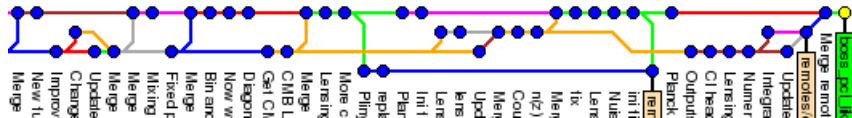
- ▶ Here we combined the 'A to B' edits and the 'A to C' edits (to form D), which was committed.
- ▶ More on such *merging* later.

DAG

- ▶ Hence we get a graph (in the mathematical sense of 'nodes plus edges').
- ▶ The graph is not a *tree* (because of merging).
- ▶ It is *directed* (edges have arrows) and *acyclic* (cycles would break causality), so we have a *DAG* (directed acyclic graph).
- ▶ Nodes can have *parents* and *children*, and hence *ancestors* and *descendants*.
- ▶ One node - the initial *root* node - has no parents. All other nodes have one or two parents (or more in special cases). Thus the graph is connected, and any two nodes have ancestors in common.
- ▶ *Graph theory* is an interesting part of mathematics - but alas not useful here.

Seeing the DAG

Run `gitk --all` to see the DAG (and much other information).



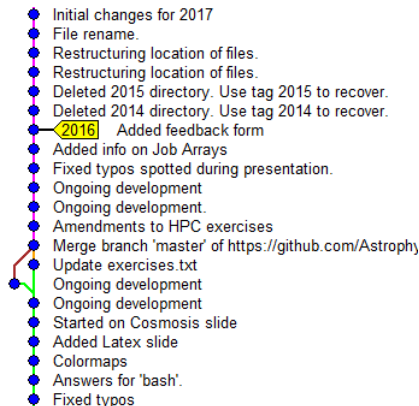
What's in a node?

At least:

- ▶ Enough information to reconstruct the working directory as it was at the time of that commit.
- ▶ Administrative information: who made the commit, a 'commit message', etc.
- ▶ A permanent node name (SHA1 format - 40 hex digits e.g. c2d2ea34cec13a0956488f2b919861fccad8a448). You can abbreviate this to an initial substring (provided that it is long enough to be unique).

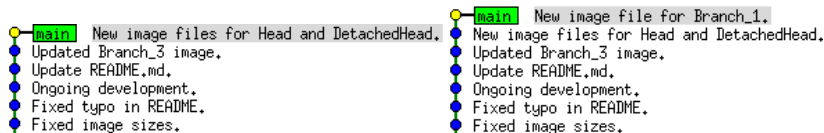
Labels for nodes - tags

A *tag* is a label that is attached to a particular node; gitk shows them in yellow:



Labels for nodes - branches (1)

- ▶ A *branch* is a moveable label that is attached to a node; gitk shows them in green.
- ▶ 'Moveable' means that if you commit an edit to that node then the branch label moves to the child node.

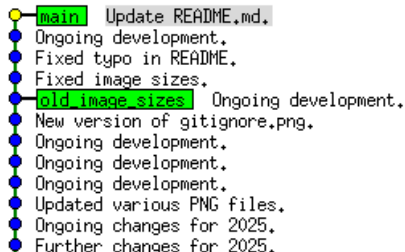


Labels for nodes - branches (2)

- ▶ A node must have a branch label before you can commit to it.
- ▶ Because it moves with the commits, the branch is often thought of as a 'development line' (imagine not just the node that the branch labels, but also all the past and future nodes that the branch has labelled or will label).
- ▶ In some contexts (e.g. cloning) a branch is used to refer not only to the labelled node but also all its ancestors.

Labels for nodes - branches (3)

- ▶ Any node in a DAG can be labelled with a branch - not just to a terminal node (= node with no descendents).
- ▶ So 'branch' is not a perfect metaphor; better is 'label attached to a place where growth may occur' (which may be on the trunk).



Labels for nodes - branches (4)

- ▶ When git creates a new repository it creates a branch - by default called 'main' - that is attached to the root node.
- ▶ House rules often insist that the node labelled 'main' be 'good' (i.e. stable, tested, usable); development is then done in other branches that are merged into main following testing and agreement.
- ▶ But this is not forced by git. You don't even need to have a 'main' branch.

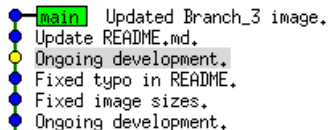
Labels for nodes - HEAD (1)

- ▶ The special label HEAD is attached to the node that corresponds to the files in the working directory. This can be any node in the DAG.
- ▶ Use `git checkout <nodename>` to set which node is 'HEAD'.
- ▶ In gitk the HEAD node is shown in yellow.



Labels for nodes - HEAD (2) - Detached HEAD

Usually the HEAD node also has a branch label. But it doesn't have to; if it doesn't then we say we have a 'detached HEAD'.



In this example the working directory contains the files from 'two commits ago'.

Name that node

- ▶ Refer to a node using its (abbreviated) SHA1 name e.g. 'c2d2ea34'.
- ▶ Or use a node label (a tag name, a branch name, or the name 'HEAD').
- ▶ Can append ^ to mean 'parent of', ^^ to mean 'grandparent', etc.
- ▶ Example: `git checkout main^^`.
- ▶ Distinguish multiple parents via ^1 or ^2.
- ▶ Alternatively e.g. ~4 means the same as ^^^^.

DAG manipulation

Much (but not all) of your interaction with a git repository involves maintaining and amending the DAG and labels attached to nodes in the DAG.

The index

- ▶ In addition to the DAG, a git repository also contains an *index*: a list of the files in the working directory that git knows about (i.e. that git is 'tracking').
- ▶ The index contains other information that makes it fast to answer the question 'has this file changed since a version of it was last put into the repository?'

```
100644 a0322dbd35a61cb1357655a4218106f67c2e1212 0      .gitignore
100644 4453e0cfd1607a8f22bccc09df60ae7508381a7d 0      2017_11_14_Feedback.pdf
100644 440d6375e37f96ec0a2ee02628e6687fe4e8de4f 0      Branch_1.png
100644 ce36ee8b0c404d729a5006618415b834d3b9db99 0      Branch_2.png
100644 0ae23dc24bf58adb66043ab02d021c207009d78c 0      Branch_3.png
100644 45e16915d8644f90c6321687e353c11031d4e7ac 0      DAG.png
100644 2c8a337a81141a4c22486e7a5a4aca065b5ccc31 0      DetachedHead.png
100644 64cb0abf9a757297c75e6ae249c926660ff40a39 0      Head.png
100644 e246cf8eb4042da2c10b8d4e2311ab48d89c2854 0      Index.png
100644 131da295680c26ac7a2c1a20d01703c7c3c0a5f7 0      IntroductionToGit.pdf
100644 4bf5824954241f72014912555bb97a9dc4218c89 0      IntroductionToGit.tex
100644 d56b7305f8909b673ad612fb098d799aec8ce656 0      README.md
100644 3b488c601d19f4a3f7ced3160bbf973bad70e416 0      RemoteTrackingBranch.png
100644 b911afbe41df5c7870d9cf3bded87c61418d4880 0      Tag.png
```

.gitignore

- ▶ `git status` will warn you about files that **are** in the working directory but **aren't** in the index (so that git isn't paying attention to them).
- ▶ This gets boring for intermediate files that you never want git to track. So you can list such 'files always to be ignored by git' in a special file called `.gitignore`.

```
*.aux  
*.lof  
*.log  
*.lot  
*.fls  
*.out  
*.toc
```

- ▶ You probably want `.gitignore` to be one of the files that git is tracking.

So three possibilities...

1. The index lists the files that git is tracking. (Use `git ls-files --stage` to view the index and `git add <filename>` to add a file to the index.)
2. Special file `.gitignore` lists the files that git knows not to track.
3. `git status` will warn you about files that are not in category 1 or 2.

Three types of git operations

1. Managing the relation between a repository and its associated working directory.
2. Repository maintenance.
3. Managing the relation between two repositories (e.g. between your local repository and a copy that is on the Internet).

Repository ↔ working directory (1)

To see a description of the relationship between the repository and the working directory: `git status`.

```
[ucapwhi@splinter-login IntroductionToGit]$ git status
# On branch main
# Changes not staged for commit:
#   (use "git add <file>..." to update what will be committed)
#   (use "git checkout -- <file>..." to discard changes in working directory)
#
#       modified:   IntroductionToGit.pdf
#       modified:   IntroductionToGit.tex
#
# Untracked files:
#   (use "git add <file>..." to include in what will be committed)
#
#       status.png
no changes added to commit (use "git add" and/or "git commit -a")
```

Repository ↔ working directory (2)

- ▶ Tell the repository's index about a new file in the working directory that you want the repository to pay attention to:
`git add <filename> .`
- ▶ Check-in the (changed) files that are in the working directory, thereby creating a new node: `git commit -a`.
- ▶ Using the `-a` option with `commit` minimizes your interaction with the index. There are alternatives that are more work but that give you more control.

Repository ↔ working directory (3)

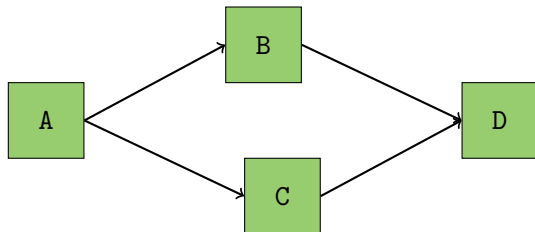
- ▶ Use the `-m` option to `git commit` to provide a 'message' that will be associated with the commit.
- ▶ Example:

```
git commit -a -m 'Fixed divide-by-zero error.'
```
- ▶ Or omit the `-m` in which case a text editor window will open and you can type a longer message.
- ▶ Writing good commit messages itself is an art; see for example <https://medium.com/@steveamaza/how-to-write-a-proper-git-commit-message-e028865e5791>

Repository ↔ working directory (4)

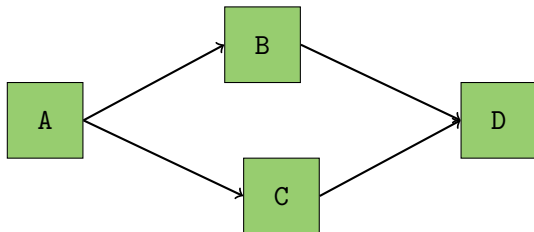
- ▶ Make the working directory be equal to the contents of a specific node: `git checkout <nodename> .`
- ▶ This fails if there are uncommitted changes in the working directory.

Repository maintenance (1)



- Merge two nodes (here, B and C) to form a new node D with both B and C as its parents.

Merging (1)



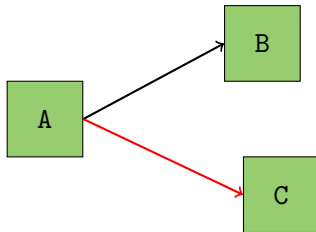
- ▶ Merging requires B and C to have a common ancestor (A in the above example). In git this will always be the case.
- ▶ Form the union of the 'A to B' changes and the 'A to C' changes. Then apply these united changes to A; this gives D.

Merging (2)

- ▶ ‘Changes’ include: adding files, deleting files, and amending files (by adding lines, deleting lines, or amending lines).
- ▶ Perhaps the ‘A to B’ changes and the ‘A to C’ changes are in conflict. For example, both sets of changes might amend a certain line, but in different ways.
- ▶ In this case the merge will fail, and you will have to manually edit D to choose one set of changes or the other (they will both be present in D, with special characters inserted to let you see what is going on). Specialised text editors can be helpful here.
- ▶ At merge time the ‘level of granularity’ is the line (if I amend the start of a line and you amend the end of the same line, then the merge will still fail.) Note that binary files can’t be merged.

Rebase (1)

Before



After



Rebase (2)

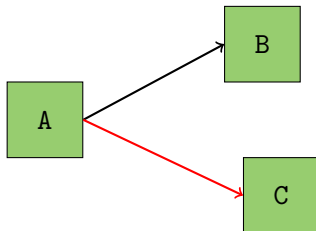
- ▶ *Rebase* is similar to merge, in that it allows two separate development streams to be brought together.
- ▶ However it differs in that one of the branches is then eliminated.
- ▶ A mental picture to use with rebase is 'move the A to C arrow so that it starts from B instead of from A'.
- ▶ Alternatively can think of this as being a 'cut and paste' to move part of the DAG from one place to another.

Rebase (3)

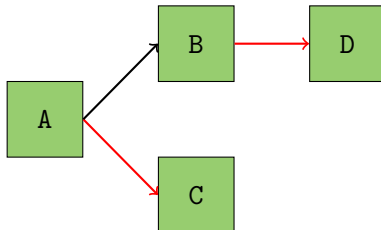
- ▶ Rebase yields a cleaner DAG than merge does - this is a possible argument in favour of rebase.
- ▶ Rebase 'rewrites history' (in the above example, node C will disappear) - this is a possible argument against rebase.
- ▶ You will need to decide which to use.

Cherry-pick (1)

Before



After



Cherry-pick (2)

- ▶ *Cherry-pick* is similar to rebase, except that it is a 'copy and paste' instead of a 'cut and paste'.

Node cleanup

- ▶ If a node is not 'named' (i.e. labelled by a tag or a branch), and if none of its descendents are named either, then git considers it unneeded and will delete it the next time it does 'automatic cleanup'.
- ▶ So to prune an unneeded 'spur' simply delete the branch (i.e. the label attached to the last node in the spur). The nodes in the spur will then eventually be deleted.

Interactions between two repositories (1)

- ▶ Use `git clone` to make a copy of a repository.
- ▶ The new cloned repository remembers the location of the repository from which it was cloned (i.e. the *remote* repository).
- ▶ You can tell the cloned repository a name to use to refer to the remote repository. By default this name is 'origin'.

Standard working procedure:

1. Create a repository on the Internet (e.g. at Github or BitBucket);
2. Clone it to make a local copy;
3. Use the commands described *above* to add and commit to the local repository;
4. Use commands to be described *below* to keep the local and remote repositories in sync.

Internet hosting for repositories

- ▶ Github (<https://github.com/>) and BitBucket (<https://bitbucket.org/>) are websites for hosting git repositories.
- ▶ They allow various levels of read access and write access to these repositories.

Interactions between two repositories (2)

- ▶ Use `git push` to make the remote repository look like the local repository.
- ▶ The full syntax is `git push <remote> <branch>`.
- ▶ Thus for example you might need to say `git push origin main`.

Interactions between two repositories (3)

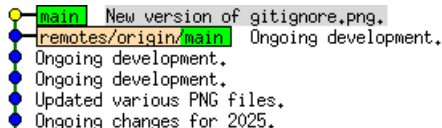
- ▶ Use `git pull` to make the local repository look like the remote repository.
- ▶ This would be necessary e.g. if someone else had made contributions to the remote repository since you cloned it.

Interactions between two repositories (4)

- ▶ Of course, the local and remote repositories may have diverged since the clone in inconsistent ways.
- ▶ In this case the necessary merging will fail and manual intervention will be needed.

Remote tracking branches

- ▶ A cloned repository will have two types of branches: not only normal local branches but also *remote tracking branches* (gitk shows them in a peach color) that mirror what is going on in the remote repository.



Fetch and merge equals pull

- ▶ Use `git fetch` to update a remote tracking branch (to get changes from the remote repository); **this won't affect any local branches.**
- ▶ You can then use `git merge` to merge the remote tracking branch into the local branch.
- ▶ These two operations (`git fetch` followed by `git merge`) are the same as a `git pull` ; by doing the job in two stages you can pause after the fetch to inspect what changes you have brought down from the remote repository.

Github forking and pull requests

- ▶ *Forking* is a GitHub innovation to help people contribute to projects to which they don't have write access.
- ▶ It uses a 'three repository' model.
- ▶ Begin by cloning repository R1 (to which you don't have write access) to get a new repository R2 (to which you do have write access) **that is also on GitHub** - this is called forking.
- ▶ Then develop in R2 as usual (this will involve you cloning R2 to get a local copy R3).
- ▶ Once your work is pushed to R2 you email the owners of R1 to ask them to pull your changes from R2 to R1 (*pull request*).
- ▶ If all contributors are 'trusted contributors' then this level of complexity is probably not needed.

Workflows with git

- ▶ Many different workflows are possible with git.
- ▶ You will need to choose - it's a matter of project objective, project size, team size, team working style, taste, etc..
- ▶ Several are discussed here: <https://www.atlassian.com/git/tutorials/comparing-workflows>.

Consider not using branches

- ▶ Branching - i.e. creating branches other than 'main' to use for development work - is a popular strategy but be careful as branches that don't get merged back into 'main' in a timely fashion often end up being abandoned.
- ▶ There are alternative workflows that *never branch*. Here you use other methods to ensure separation of development and production code.