



Git

a peek under the hood

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follow along:
github.com/csojinb/git-under-the-hood/

Git: powerful, but leaky

- Like all abstractions, git leaks
- Difficult to master without a solid mental model
- Fear of losing work is a barrier to learning/experimentation
- Taking advantage of git's data-hoarding tendencies requires understanding of how the data is stored

Solution: *Gain leverage by learning some internal mechanics*

A wide-angle photograph of a desert landscape featuring rolling sand dunes and small, dark shrubs. The sky is a clear, pale blue. The entire image is overlaid with a semi-transparent blue filter.

**What does git store
when you commit?**

Core concept: History as snapshots

- To understand how git stores your commits, it's useful to understand the central "philosophy"
- Git "thinks" about version history as a series of **snapshots**, rather than a series of deltas
- A **snapshot** is a complete copy¹ of the project at a particular point in history

¹ Unchanged files are not stored multiple times. And, eventually, git will compress versions of the same file together to save space when necessary, e.g. if you want to push to a remote. But the snapshot still decompresses to a complete project copy.

Representing changes

- Git does not directly save any **actions** that you took, only the **state**
- Differences are **derived** by comparing snapshots
- Actions are **inferred**
- Example (right): git recognizes the rename because the **file content** is the same

```
3. Clara@Macaque: ~/code/git-under-the-hood (zsh)
[~/code/git-under-the-hood]$ mv images/{,young-}clara-sunglasses.jpg
[~/code/git-under-the-hood]$ git st                                *[master]
On branch master
Changes not staged for commit:
  (use "git add/rm <file>..." to update what will be committed)
  (use "git checkout -- <file>..." to discard changes in working directory)
)

        deleted:    images/clara-sunglasses.jpg

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

        images/young-clara-sunglasses.jpg

no changes added to commit (use "git add" and/or "git commit -a")
[~/code/git-under-the-hood]$ git add --all; git st                *[master]
On branch master
Changes to be committed:
  (use "git reset HEAD <file>..." to unstage)

        renamed:    images/clara-sunglasses.jpg -> images/young-clara-sunglasses.jpg

[~/code/git-under-the-hood]$                                     *[master]
```

Important implication!

- Git's ability to track a file's history² depends on the file being recognizably the same file between commit snapshots
- i.e. the following may break the file history:

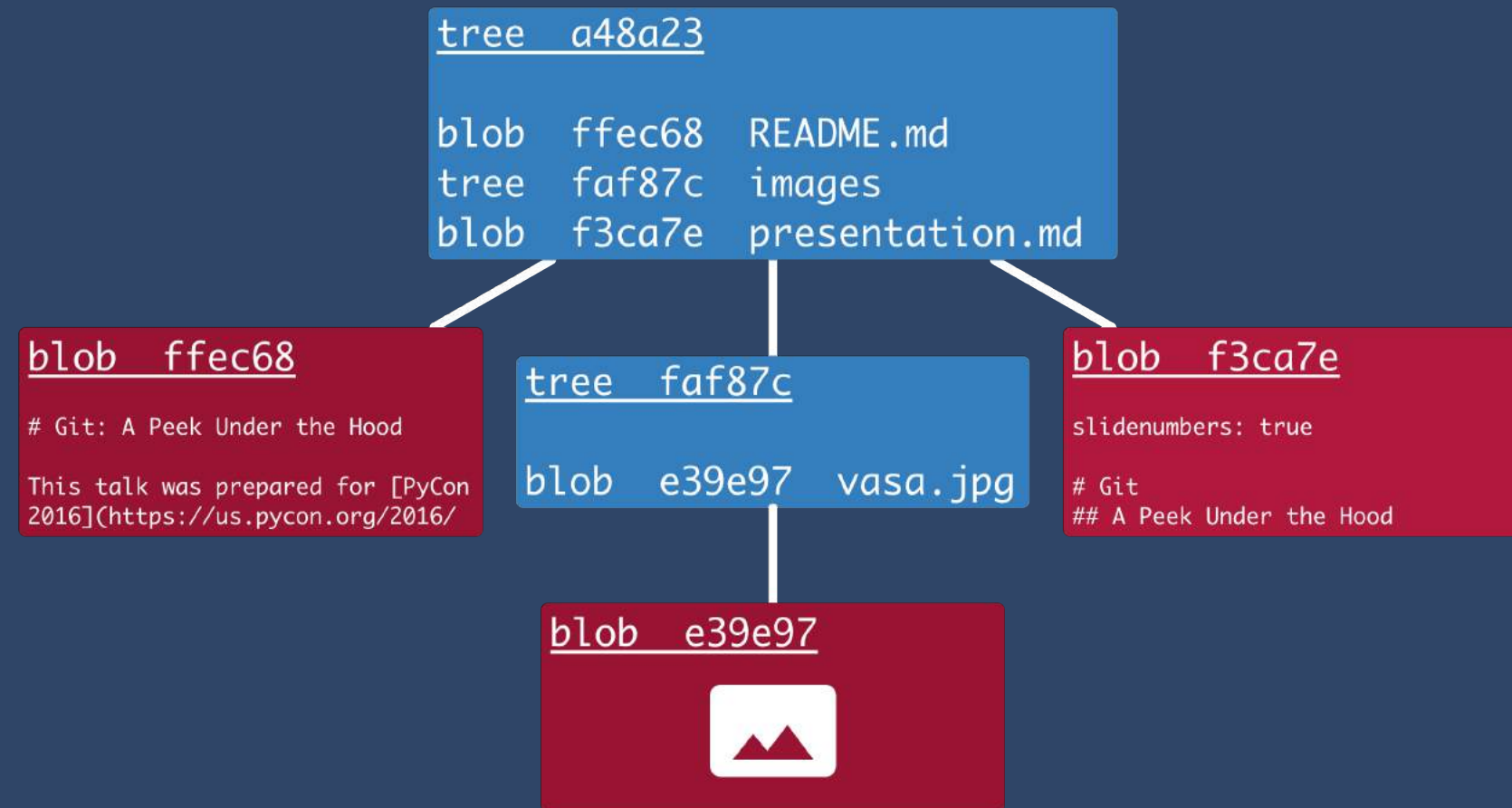
```
$ git mv file.py other.py
```

<make lots of changes to `other.py`>

² Important even if you don't directly use this feature because it affects git's ability to merge intelligently.

Snapshot storage

- A file snapshot is stored as a text blob, and a directory snapshot is represented as a "tree" object
- Each snapshot is check-summed and stored by SHA-1 value
- Directory trees point to the SHAs of files and directories they contain
- The project snapshot is just the "tree" for the project root directory



Building a commit

- To make a commit, first you need to stage some changes
- The staging area³ is just another project snapshot tree
- As changes are staged, new snapshots are created of the affected files/directories, and the staging area is updated
- On commit, the staging area becomes the commit snapshot

³Sometimes referred to as the "index".

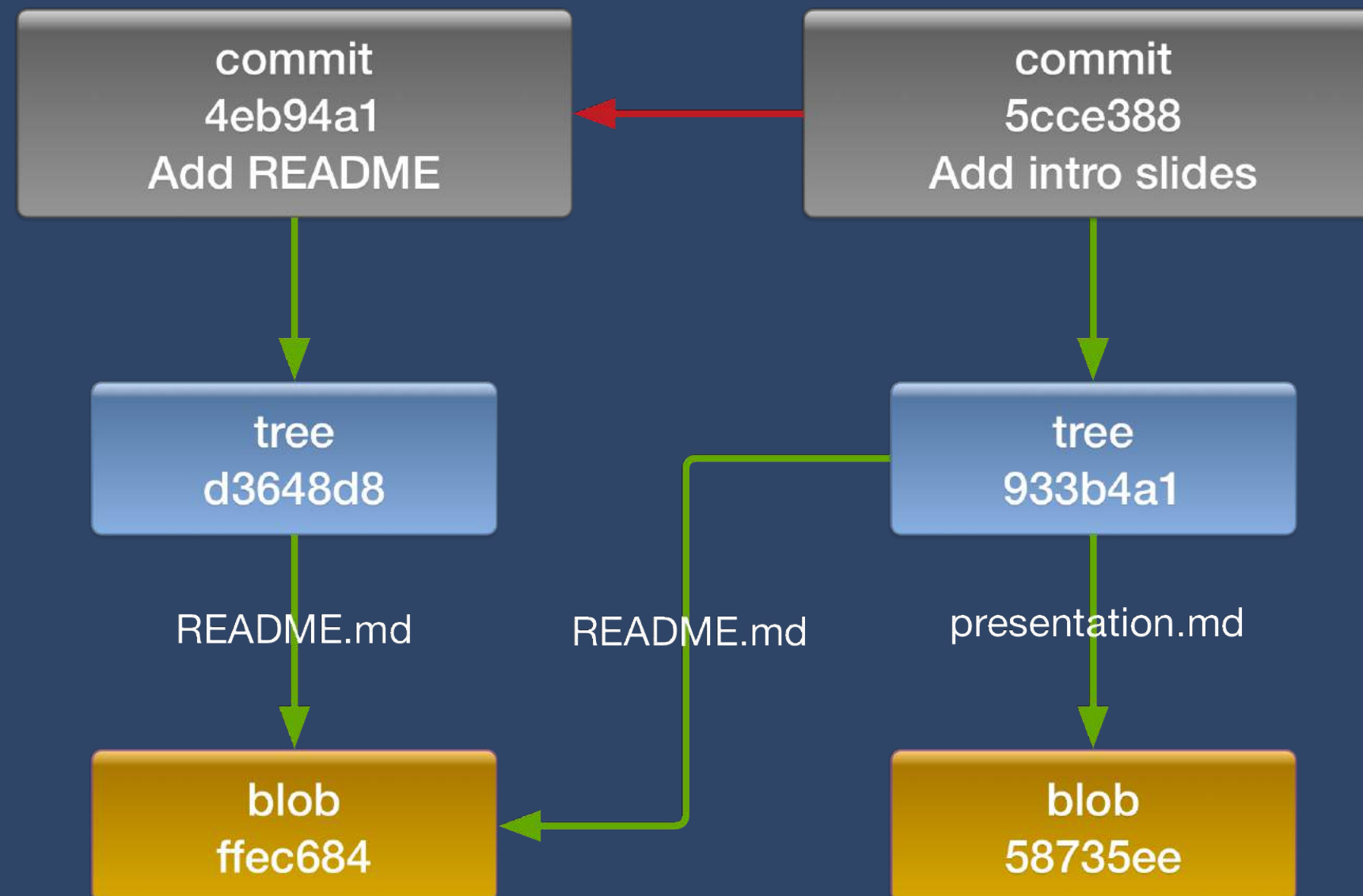
commit = content + meta-data

- The final commit object contains a pointer⁴ to the **project snapshot** (the content) and some **meta-data**
- The meta-data includes the author, the commit message, and pointer(s) to the **parent commit(s)**⁵
- Note that if either the content or the meta-data is amended, the new commit will have a different SHA checksum value

⁴The "pointer" is SHA of the project snapshot

⁵The initial commit has no parents, and merge commits have two or more.

Visualizing commit storage



A gravel path lined with large, mature trees, leading towards a body of water in the distance. The trees have thick trunks and dense green foliage, creating a canopy over the path. The path is made of dark gravel and is flanked by wooden planters containing green plants. The background shows a calm body of water and a distant shoreline with some buildings.

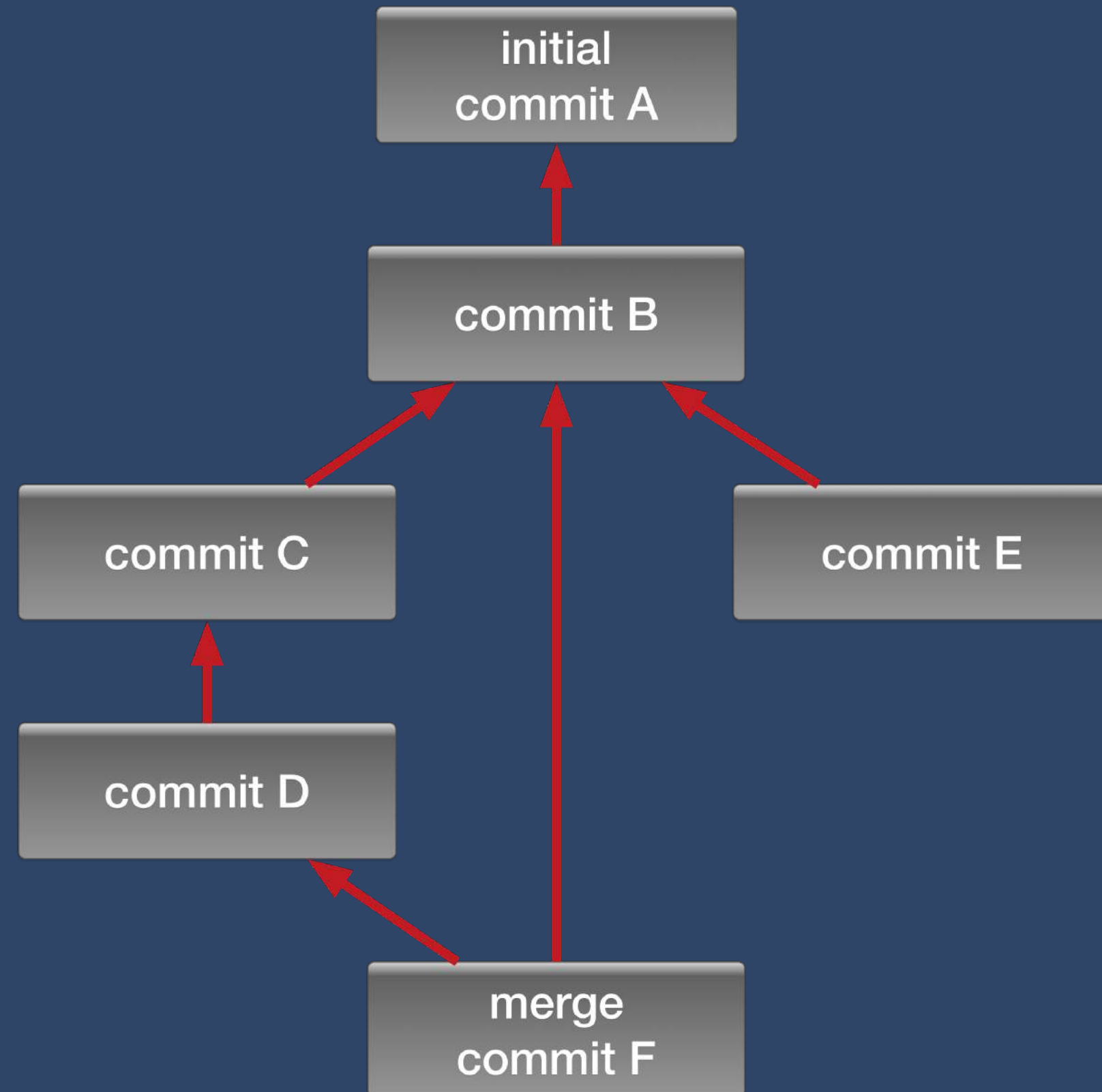
**Why are branches
"cheap"?**

Branching (structure) comes for free

- Together, commits and parent relations form the git history DAG⁶
- Multiple commits can share a parent => natural "branching" structure
- Could theoretically manage divergent version paths without an explicit "branch" concept⁷

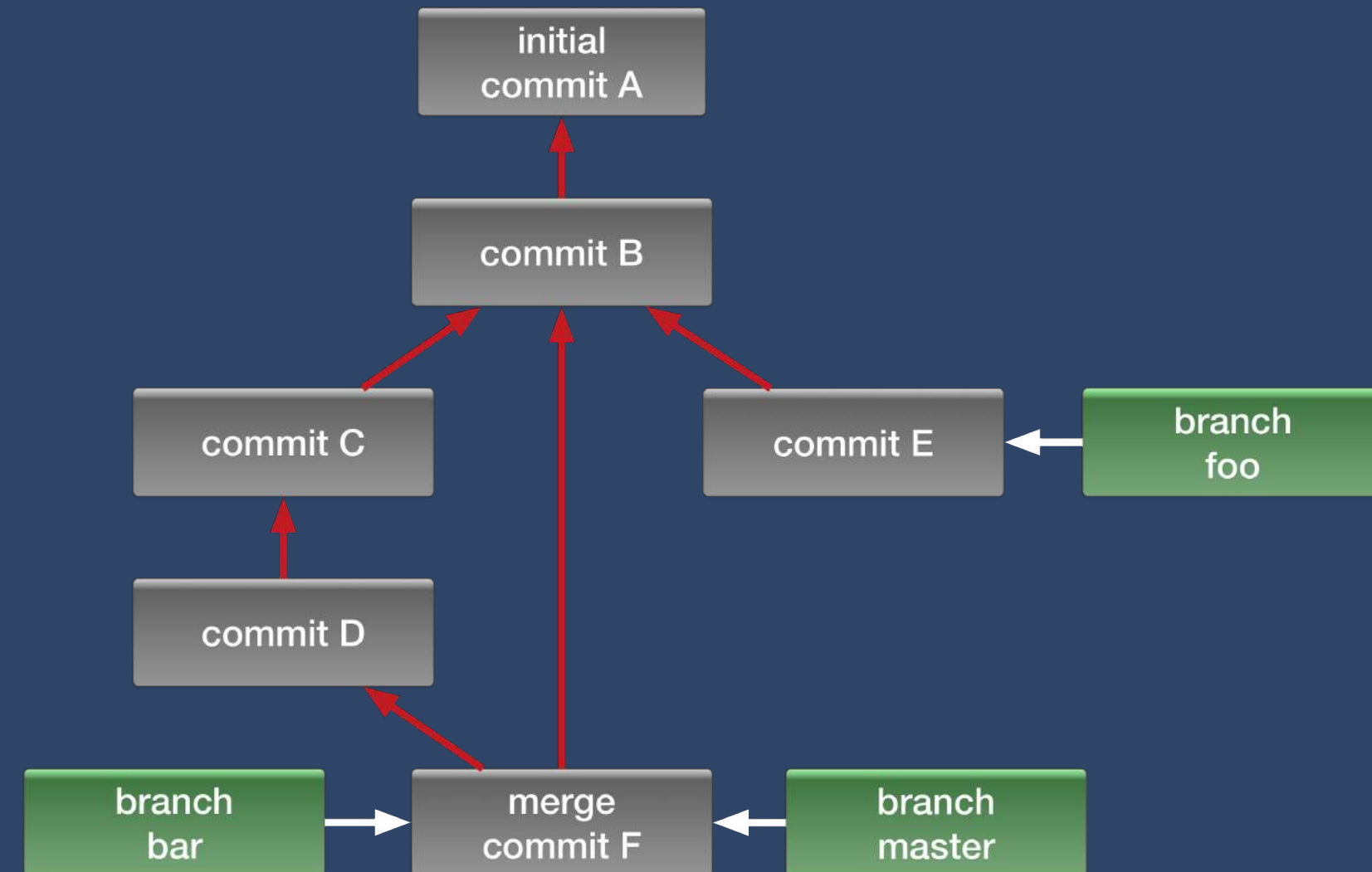
⁶It can be further specified as a rooted connected directed acyclic graph. 😲
Note that the history is *not* a tree because commits can have multiple parents, but it is tree-like in other respects.

⁷It would involve manually tracking commit SHAs, though. 🤖



A git branch (object) is just a pointer

- Git's "branch" object (stored as reference to a commit SHA) affords two major conveniences:
 - Nice name for checkouts, etc
 - The checked-out branch moves forward with each new commit⁸
- Note: there is nothing special about **master**: it's a regular branch⁹



⁸ Unlike tags (similarly just pointers), which stay put unless explicitly moved.

⁹ The branch created by `git init` is called "master" by default.

Ergo, branches are cheap

- Creating a branch == creating a SHA reference: cheap!
- Because git only creates new file snapshots for modified files, they are also cheap to maintain¹⁰
- Deleting a branch only deletes the reference: also cheap!
 - Bonus: the commits still exist and can be recovered

¹⁰ Relative to other VCSs that maintain an entirely separate project copy per branch.

Merges are (fairly) easy

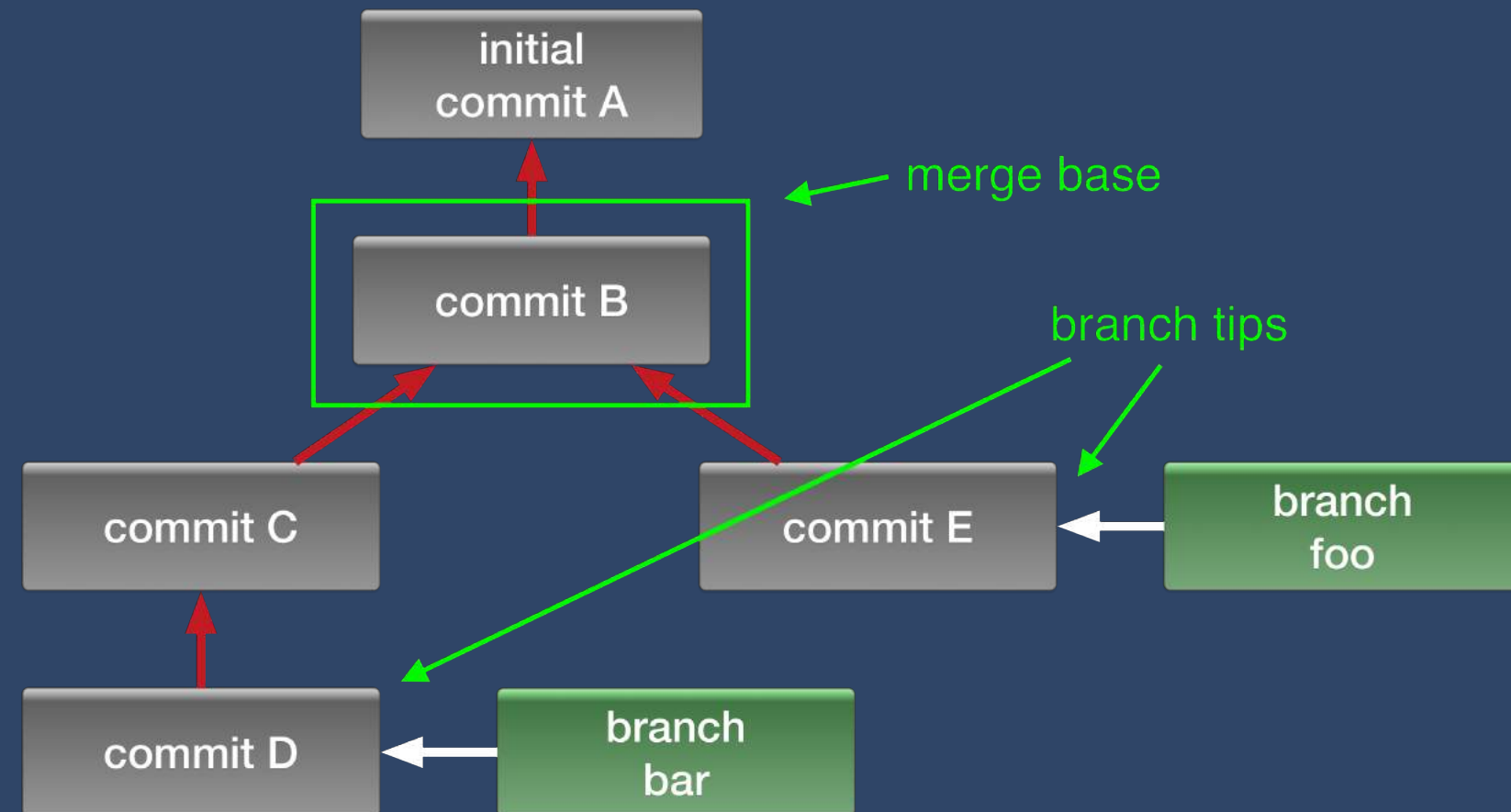
- To merge, git compares branches to their best **merge base**
- The merge base (most recent common ancestor) is easily determined from the commit graph
- Unlike a simple 3-point merge, git preserves granular history info by replaying commits from one branch onto the other
- This allows git to correctly handle many tricky merge

Example merge scenario

To merge bar into foo:

```
$ git checkout foo  
$ git merge bar
```

- Determine merge base
- Compute diffs (C – B) and (D – C)
- Apply diffs in order onto E
- Turn the result into a merge commit
- Move branch foo to merge commit

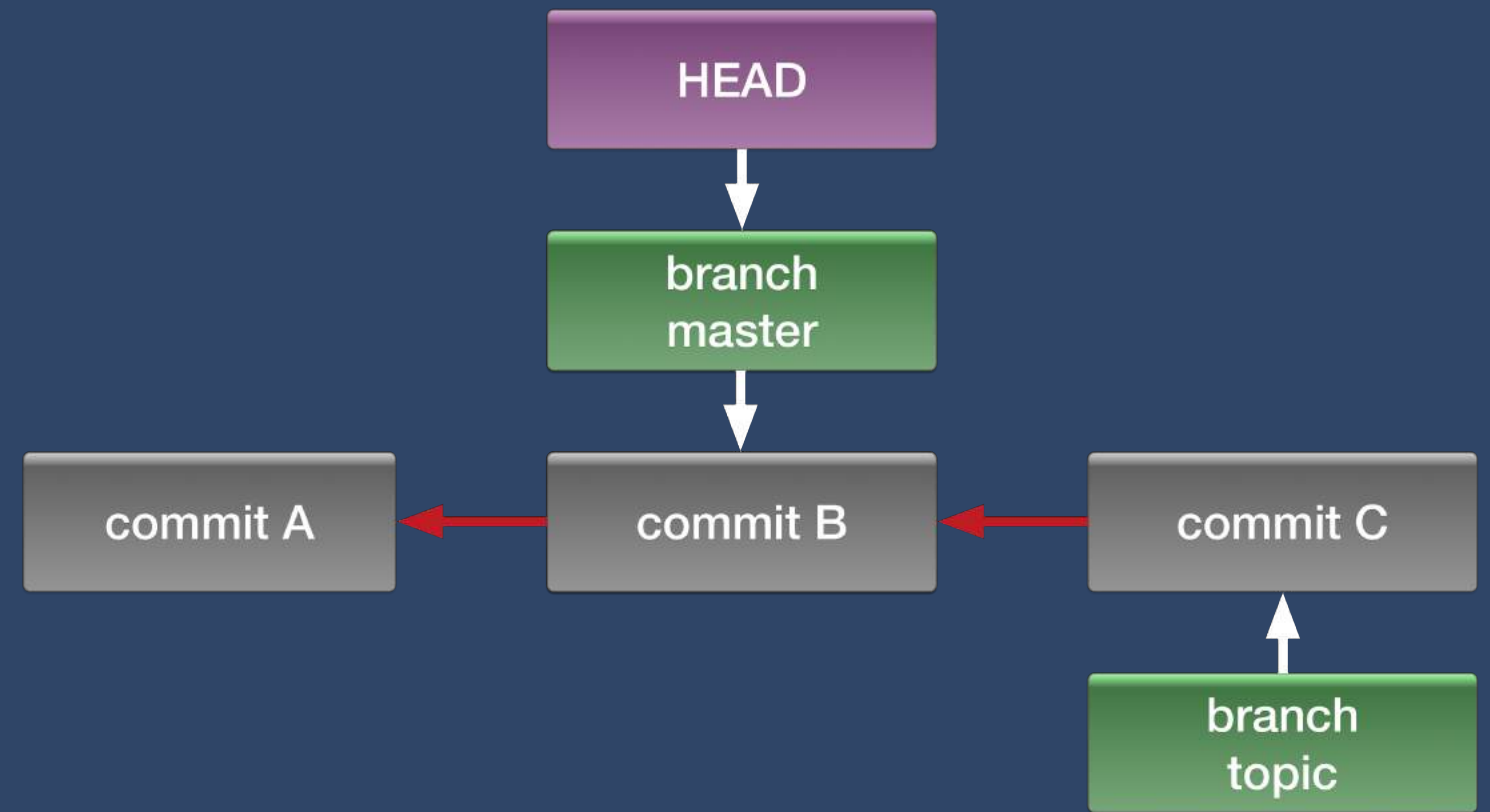


A photograph of a park with several large, abstract sculptures made of woven material, standing on a grassy slope. In the background, there are large trees and a clear blue sky. The text "How do checkouts work?" is overlaid in a bold, yellow font.

How do checkouts work?

Checkouts: HEAD

- The HEAD reference determines "where you are" in the commit graph
- HEAD can point either to a branch reference or directly to a commit¹¹
- Example (right): The master branch is currently "checked out"

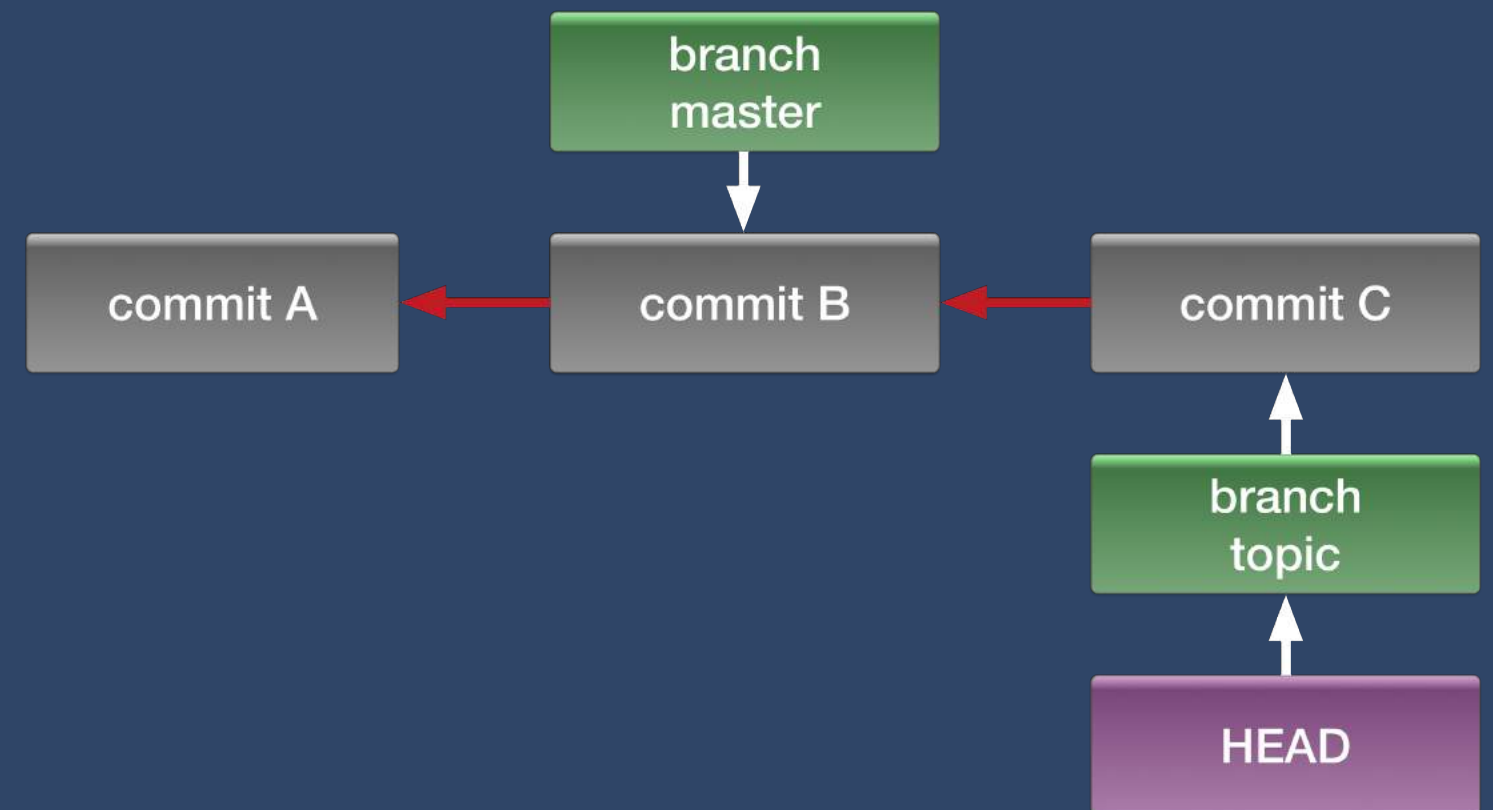


¹¹ This is the "unattached HEAD" state.

Checkouts: Switching branches

\$ git checkout topic

- Modify HEAD to point to topic
- Copy commit C's snapshot tree to the staging area
- Decompress the files in the project snapshot and copy them to the working directory¹²

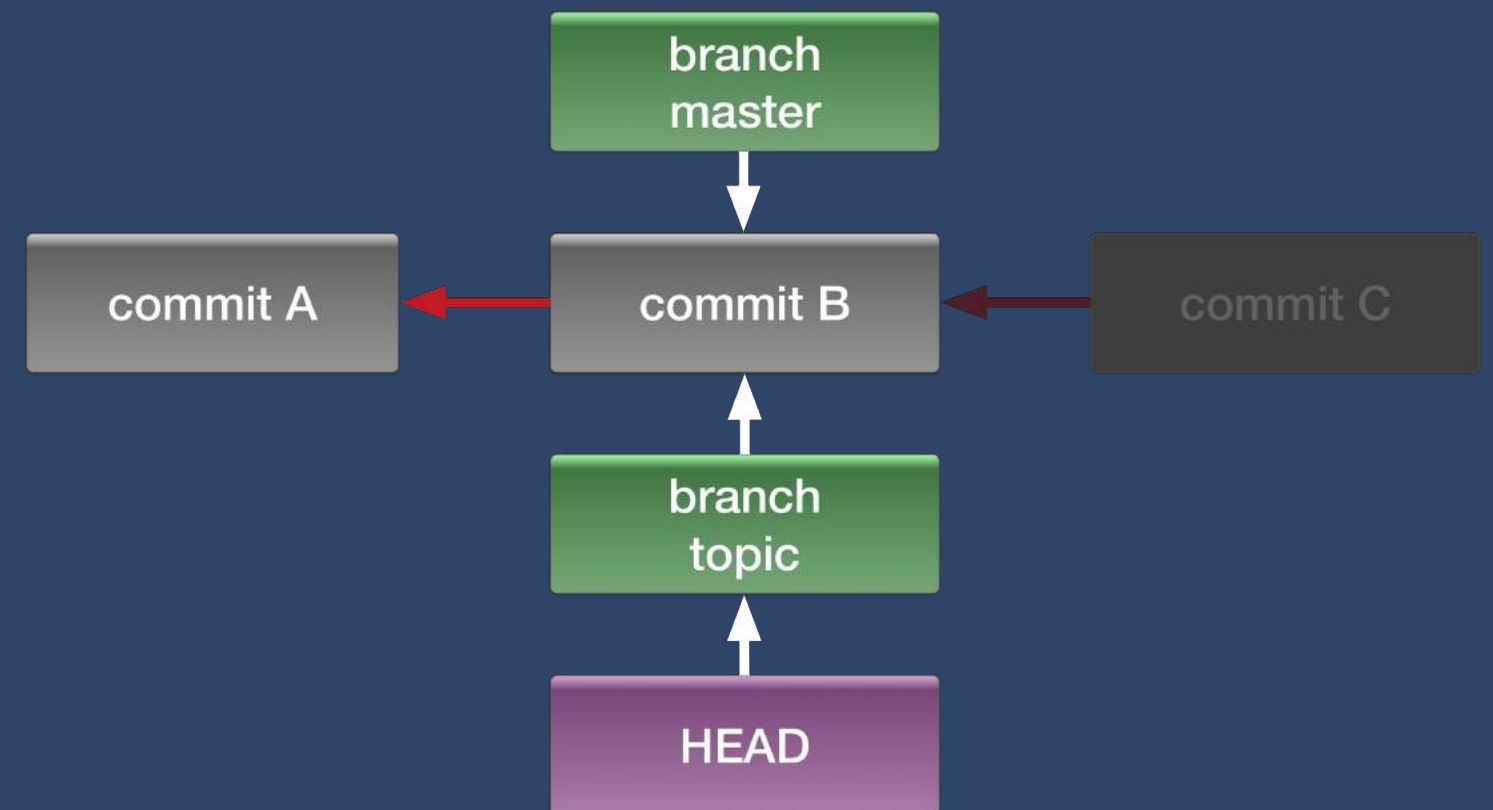


¹² This could clobber uncommitted changes in your working directory, which is why git may throw an error if you try to do a checkout with a dirty working directory.

Resets are like checkouts

`git reset --<mode> master`

- A **hard** reset does the same 3 steps as a checkout, except that the pointer that moves is the **branch**, rather than HEAD
- A default (mode=**mixed**) reset skips the working directory overwrite
- A **soft** reset also skips the staging area overwrite





**How can I get myself
out of trouble?**

Meet the reflog

Your new best friend

- The reflog is a **local-only** log of all changes to git **refs**, including branches, tags, HEAD, stashes
- By default, `git reflog` shows you a log of HEAD changes
- `git reflog <ref name>` to view changes to another ref
- The reflog can be used to **return to a previous state**¹³

¹³ A previous **committed** state. If you accidentally deleted uncommitted work, no dice. Commit early and often!

What can I find in the reflog?

- Some of the changes recorded in the reflog:
 - new commits (including merge commits, cherry-picks)
 - modifications to commits
 - branch or commit checkouts
- Fetches or pushes to a remote are not recorded in the reflog, because they don't affect your local repository copy

Usecase

Roll back to a previous state

- Use the reflog to immediately roll back from a git mistake (e.g. botched rebase, pulled instead of fetched)¹⁴
- Identify the HEAD reference **before** the error, then do a hard reset to it
- Ex: `git reset --hard HEAD@{1}`

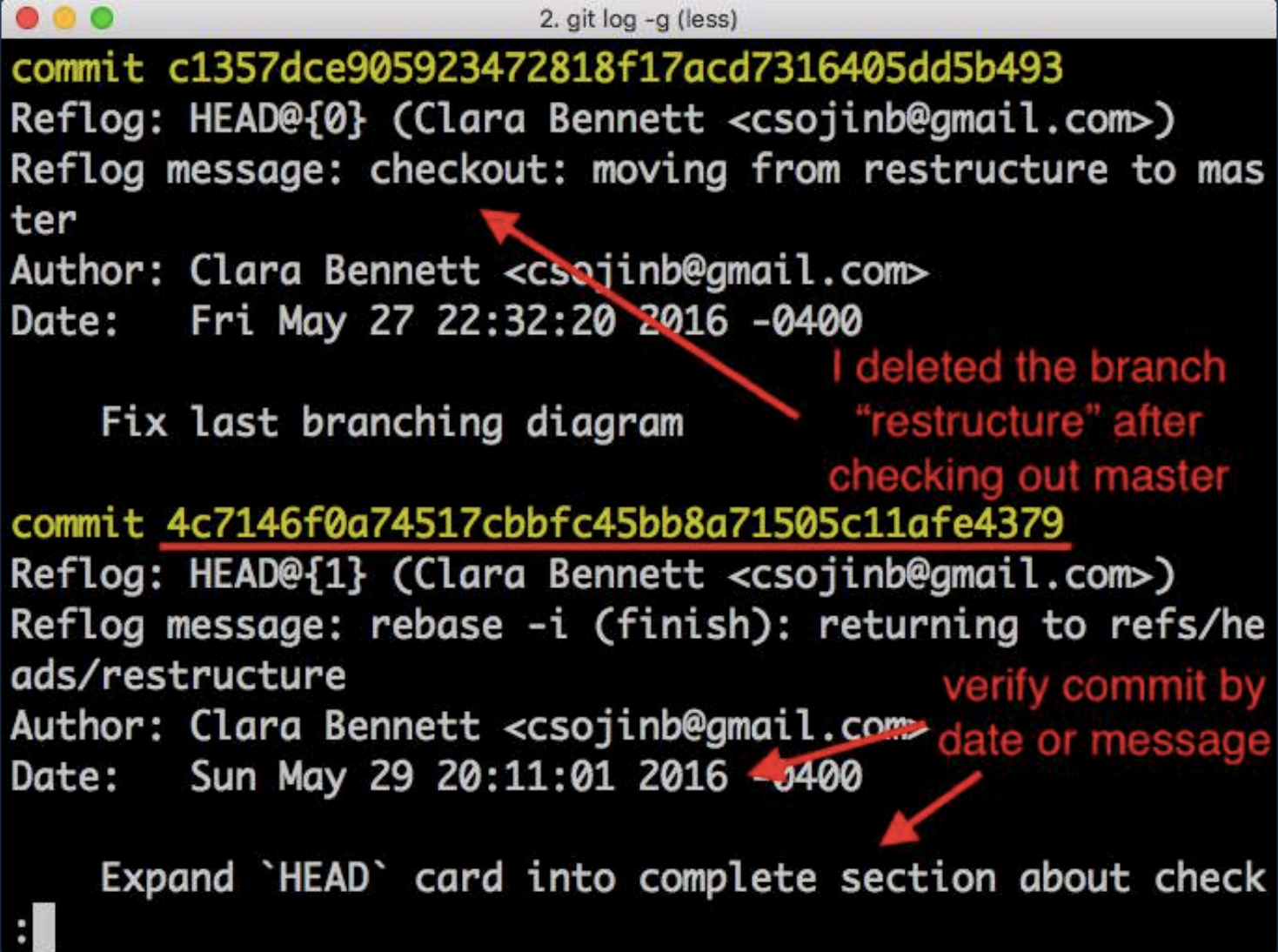
```
2. git reflog (git)
19211d3 HEAD@{0}: reset: moving to 19211d3 undo please!
217dac1 HEAD@{1}: rebase -i (finish): returning to refs/heads/restructure
217dac1 HEAD@{2}: rebase -i (pick): Expand `HEAD` card into complete section about checkouts and resets
4cb6e58 HEAD@{3}: rebase -i (pick): Restructure branching section
19211d3 HEAD@{4}: rebase -i (pick): Improve diagram resolution
7f501c3 HEAD@{5}: rebase -i (pick): Restructure commit storage section
:
```

¹⁴ You can even use this to recover from a bad reflog reset!

Usecase

Recover a deleted branch

- We can't use the branch-specific reflog because it was deleted too
- View detailed commit information in the HEAD log with `git log -g`
- Find the SHA of the former branch tip and remake the branch:
`$ git branch recovery 4c7146f`
- This technique can also be used to recover modified commits



```
2. git log -g (less)
commit c1357dce905923472818f17acd7316405dd5b493
Reflog: HEAD@{0} (Clara Bennett <csojinb@gmail.com>)
Reflog message: checkout: moving from restructure to mas
ter
Author: Clara Bennett <csojinb@gmail.com>
Date:   Fri May 27 22:32:20 2016 -0400

    Fix last branching diagram

commit 4c7146f0a74517cbbfc45bb8a71505c11afe4379
Reflog: HEAD@{1} (Clara Bennett <csojinb@gmail.com>)
Reflog message: rebase -i (finish): returning to refs/he
ads/restructure
Author: Clara Bennett <csojinb@gmail.com>
Date:   Sun May 29 20:11:01 2016 -0400

Expand `HEAD` card into complete section about check
:
```

I deleted the branch "restructure" after checking out master

verify commit by date or message

Off-branch commits aren't stored forever

- Git is conservative: it keeps commits reachable by any reference, including the reflog
- Default reflog expire time is 90 days
- Unless you explicitly trigger garbage collection, "expired" reflog items are only cleaned up if there's a space issue¹⁵
- With the defaults, reflog expiry unlikely to cause issues

¹⁵ So, a small repo that only you contribute to could still have commits from old branches from a year ago, for example.

What next?

- Go forth and git greatly!
- This presentation can be found at github.com/csojinb/git-under-the-hood
- Scott Chacon's book [Pro Git](#) (free!) is an excellent resource
 - To learn more about git internals in particular, check out [Chapter 10](#) and take a swim through your `.git` directory



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