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*


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 copy[1] of the project at a particular point in history

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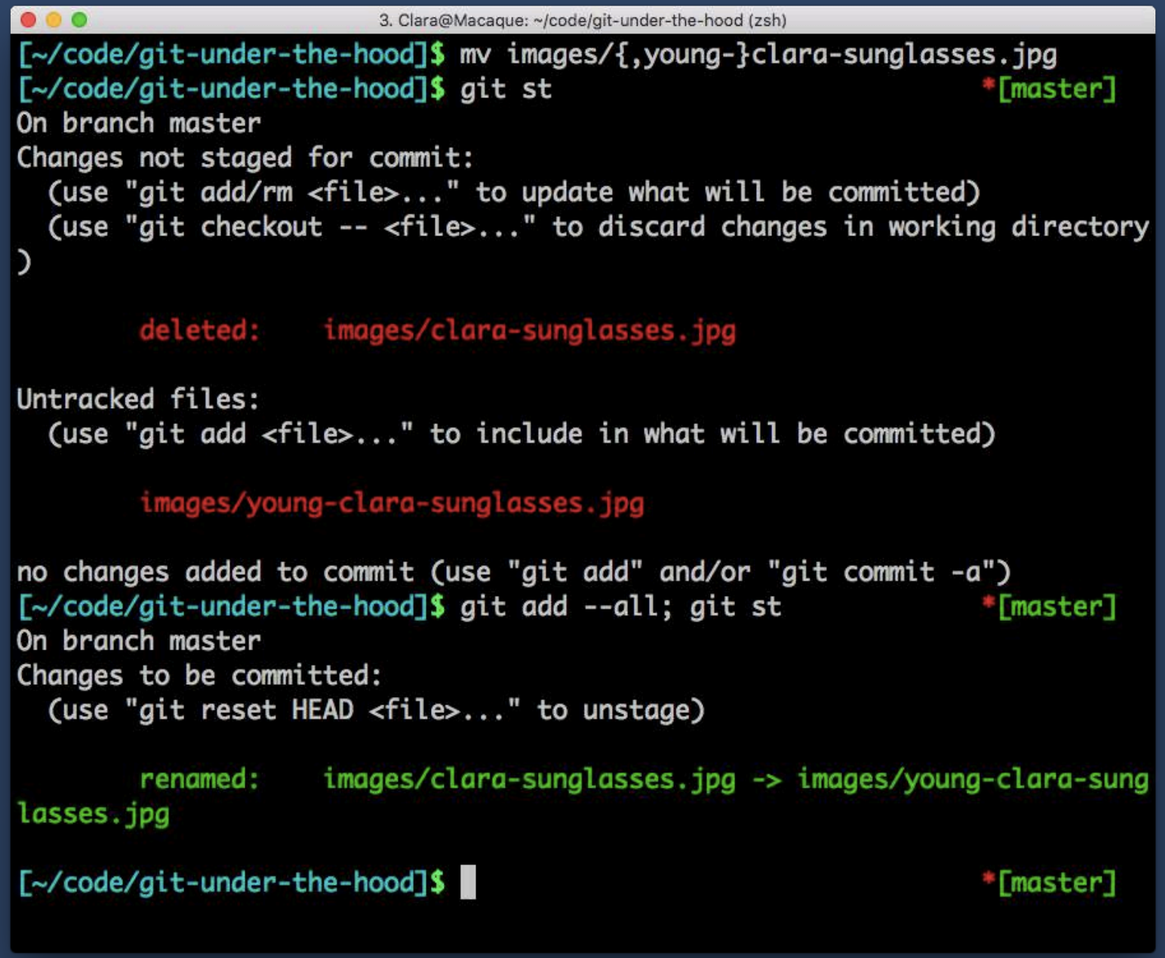
[1] Unchanged files are not stored multiple times. And, eventually, git will compress versions of the same file together to save space when necessary, e.g. if you want to push to a remote. But the snapshot still decompresses to a complete project copy.

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



Important implication!

- Git's ability to track a file's history[2] 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`>

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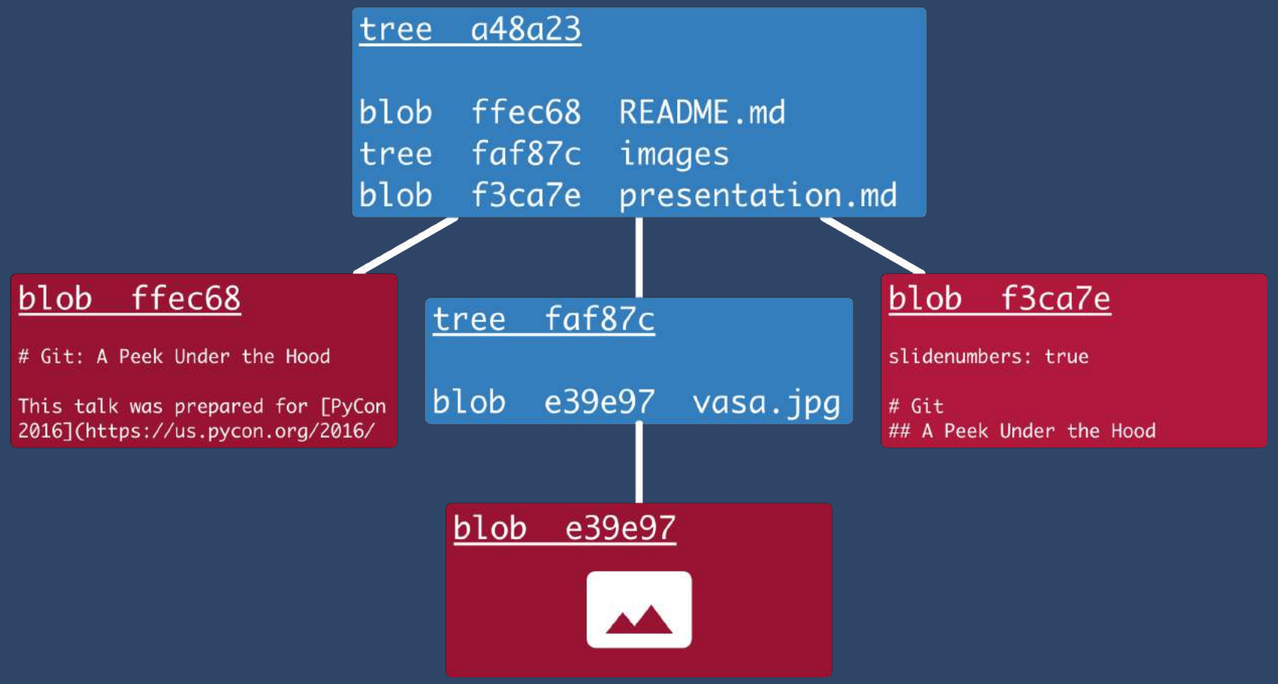
[2] Important even if you don't directly use this feature because it affects git's ability to merge intelligently.

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 area[3] 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

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[3] Sometimes referred to as the "index".

commit = content + meta-data

- The final commit object contains a pointer[4] 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

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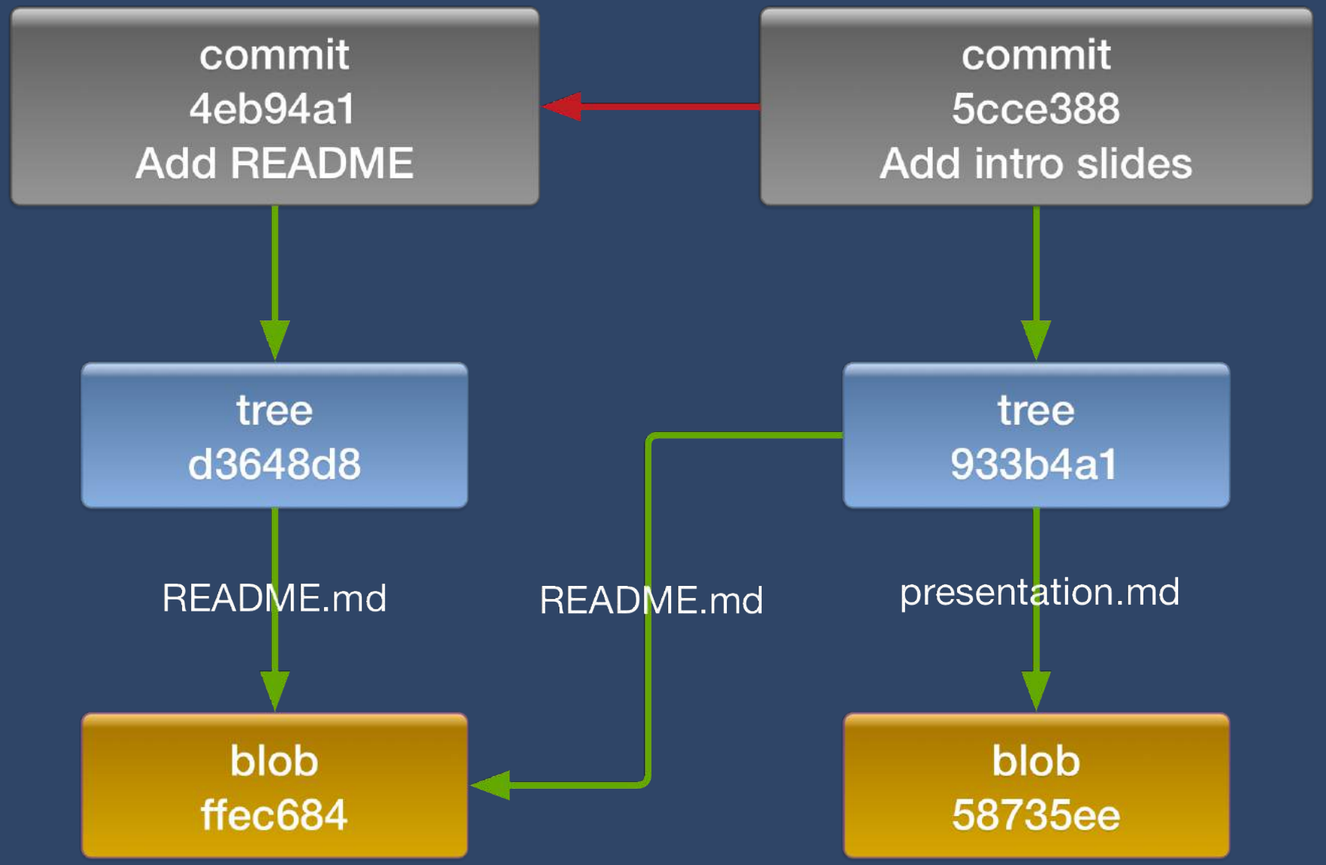
[4] The "pointer" is SHA of the project snapshot

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

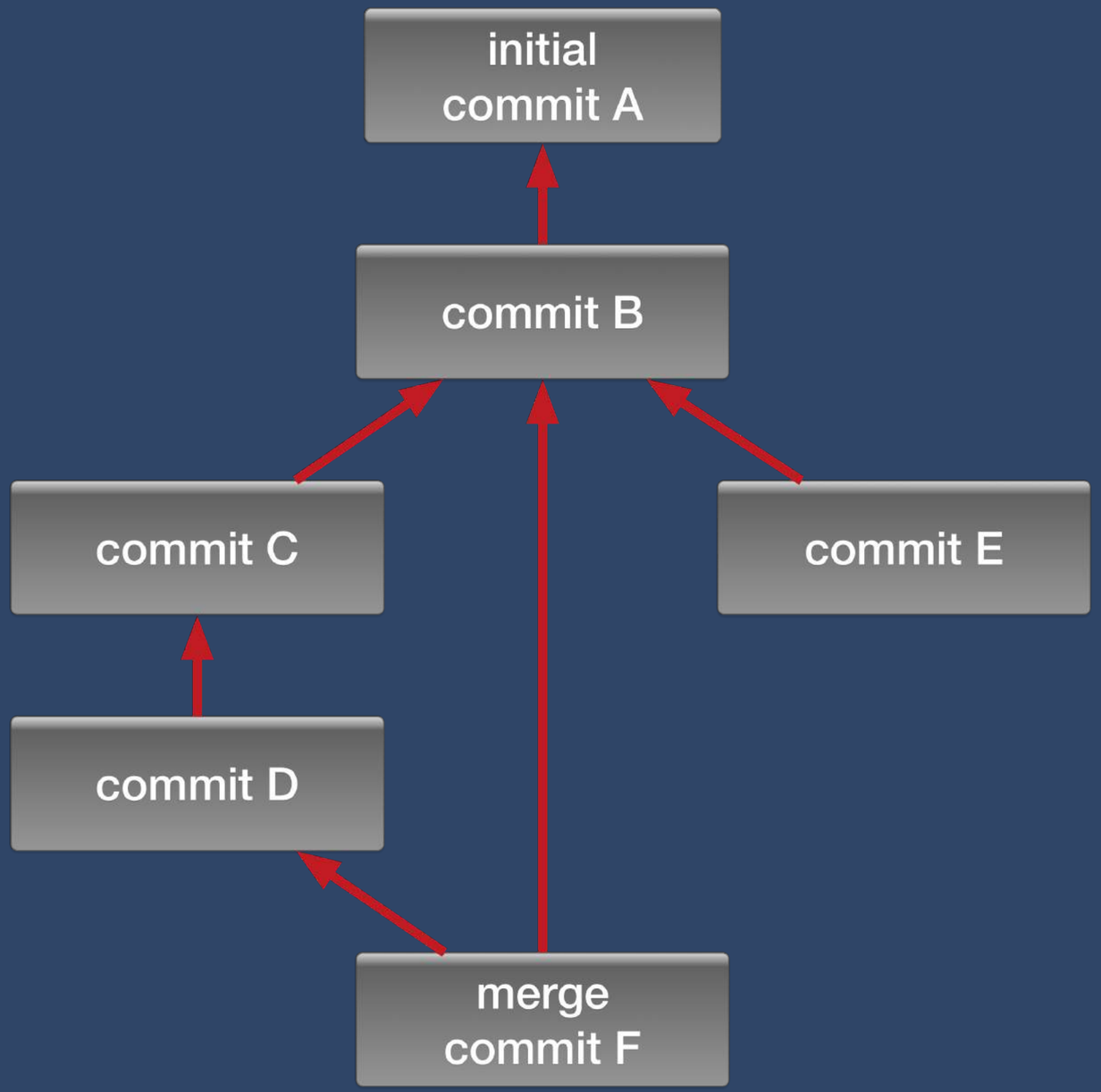
Visualizing commit storage




Why are branches
"cheap"?

Branching (structure) comes for free

- Together, commits and parent relations form the git history DAG[6]
- Multiple commits can share a parent => natural "branching" structure
- Could theoretically manage divergent version paths without an explicit "branch" concept[7]

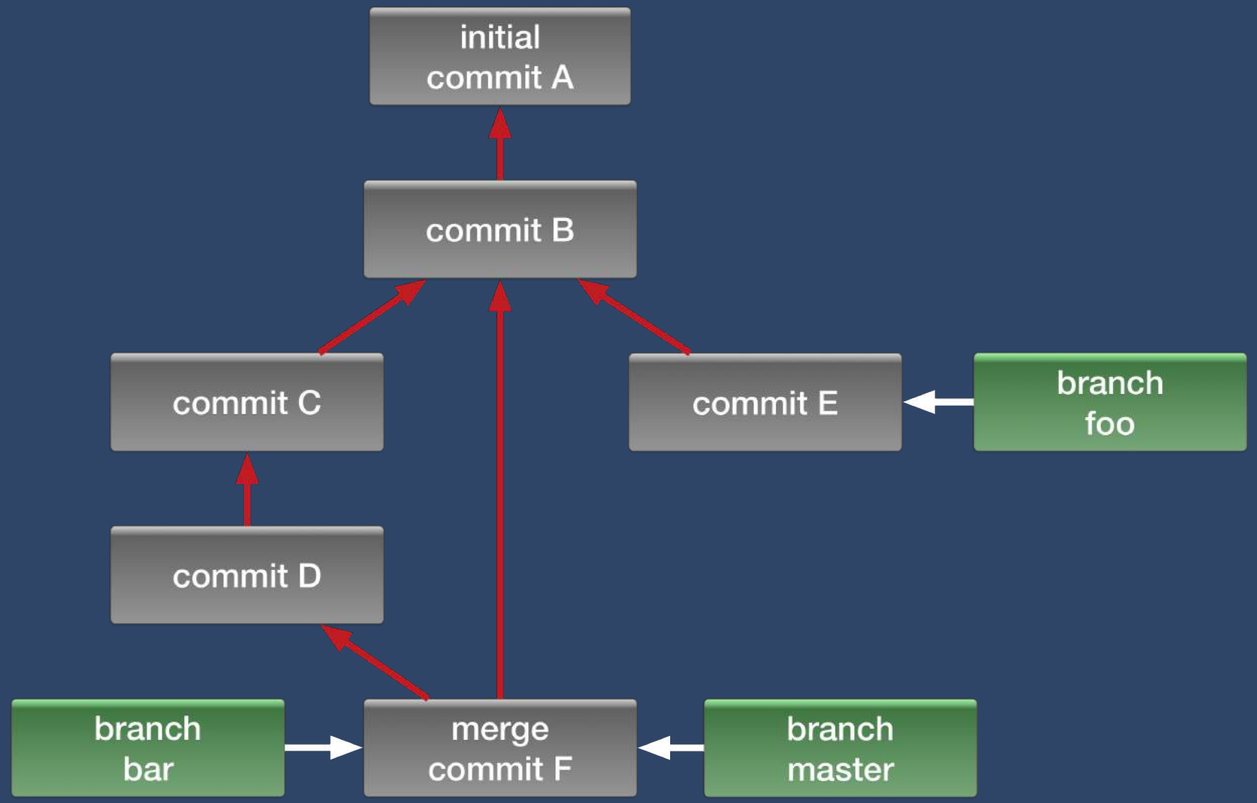


[6] It can be further specified as a rooted connected directed acyclic graph. 😮 Note that the history is *not* a tree because commits can have multiple parents, but it is tree-like in other respects.

[7] It 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 commit[8]
- Note: there is nothing special about **master**: it's a regular branch[9]



[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 maintain[10]
- 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 seperate project copy per branch.

Merges are (fairly) easy

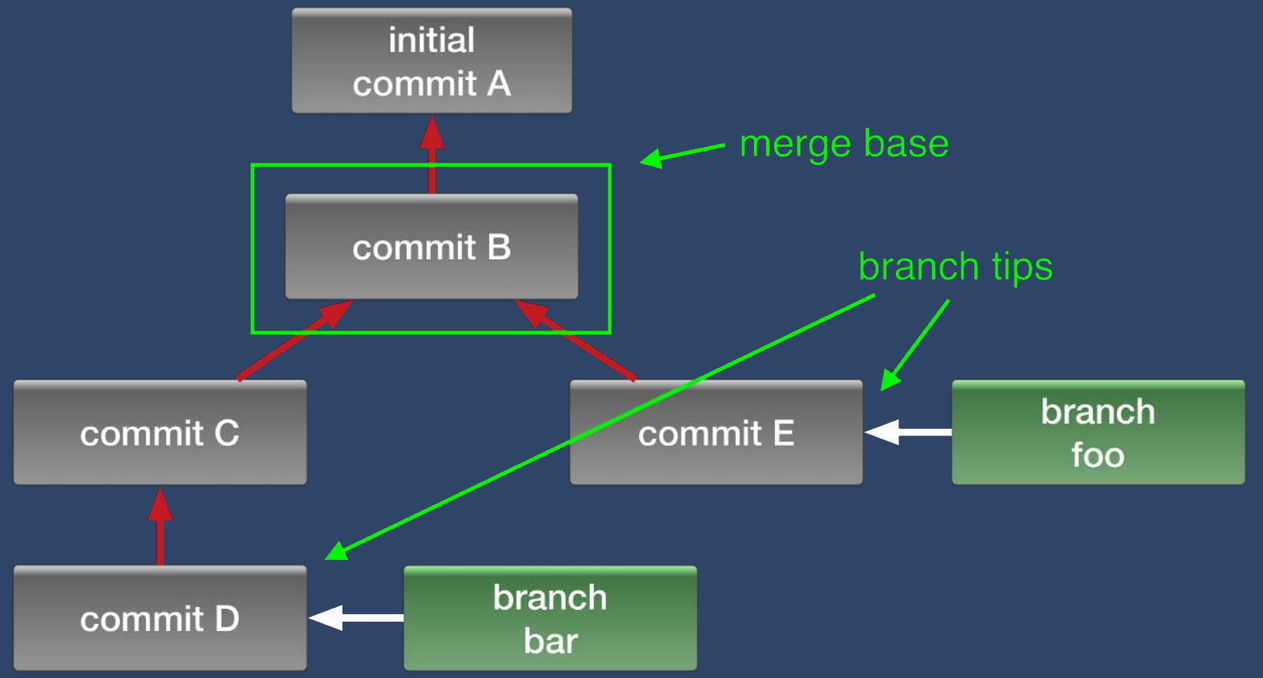
- To merge, git compares branches to their best **merge base**
- The merge base (most recent common ancestor) is easily determined from the commit graph
- Unlike a simple 3-point merge, git preserves granular history info by replaying commits from one branch onto the other
- This allows git to correctly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

Example merge scenario

To merge `bar` into `foo`:

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

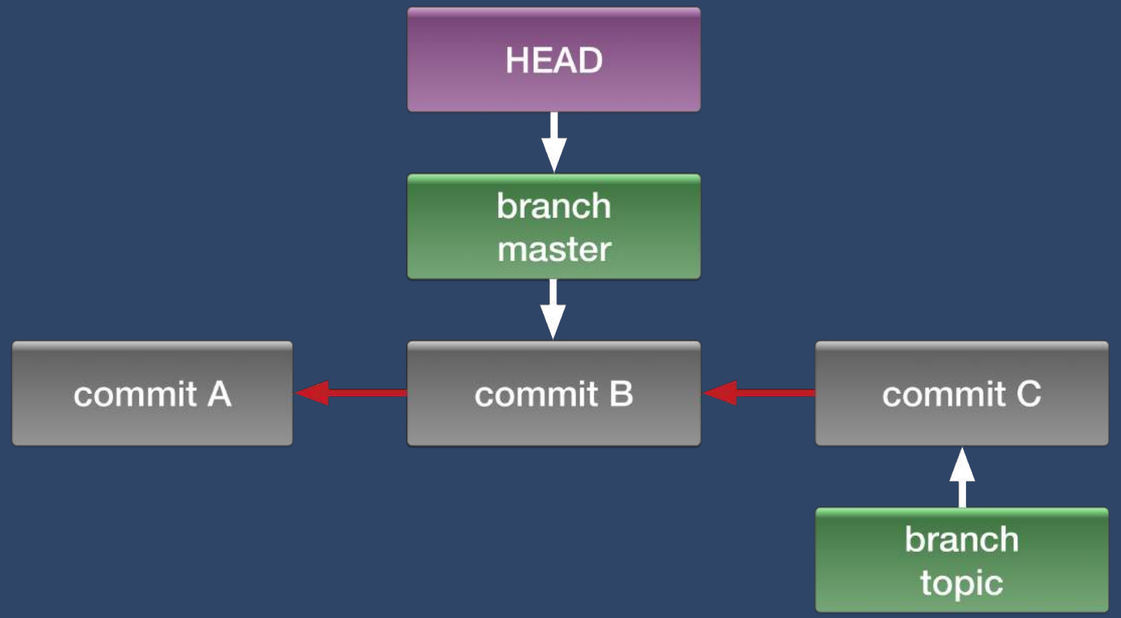
- Determine merge base
- Compute diffs (`C – B`) and (`D – C`)
- Apply diffs in order onto `E`
- Turn the result into a merge commit
- Move branch `foo` to merge commit



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 commit[11]
- Example (right): The master branch is currently "checked out"

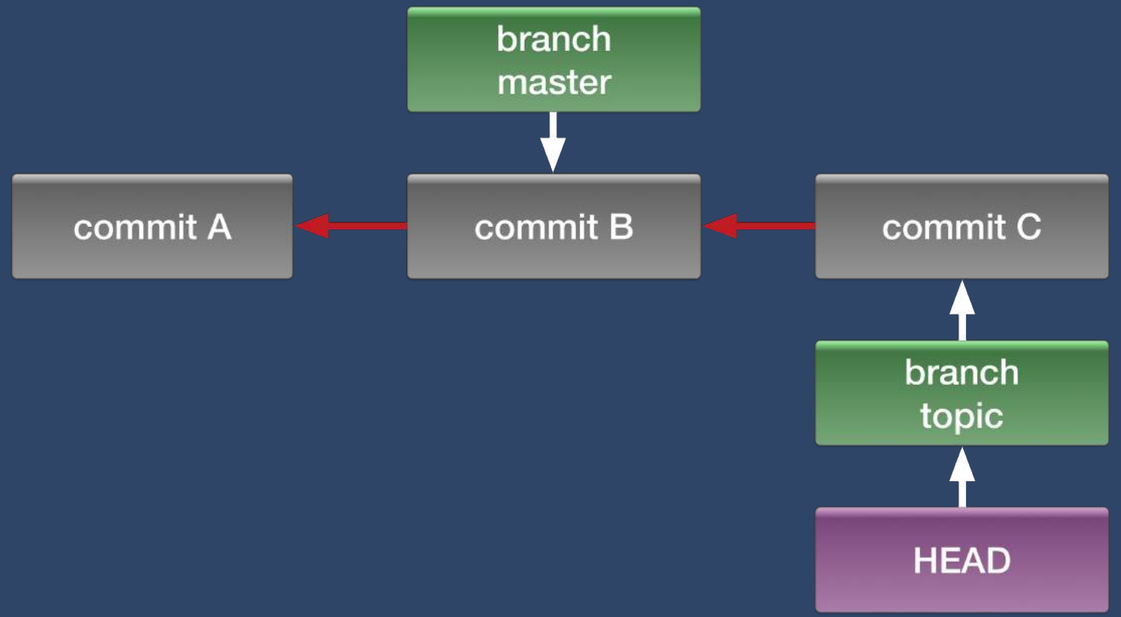


[11] This is the "unattached HEAD" state.

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 directory[12]

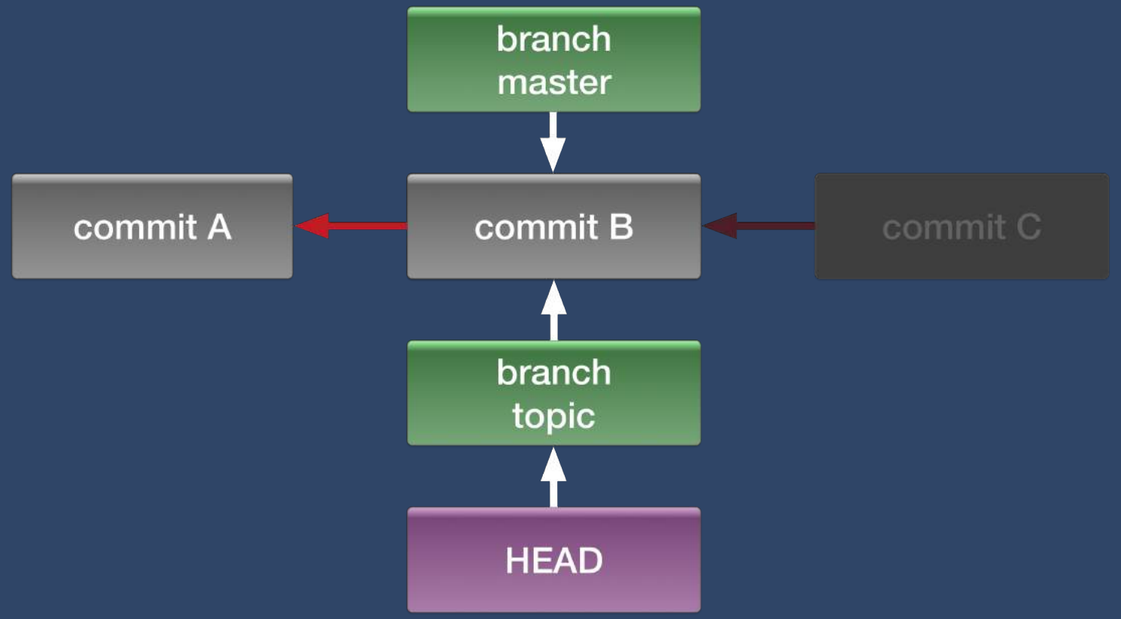


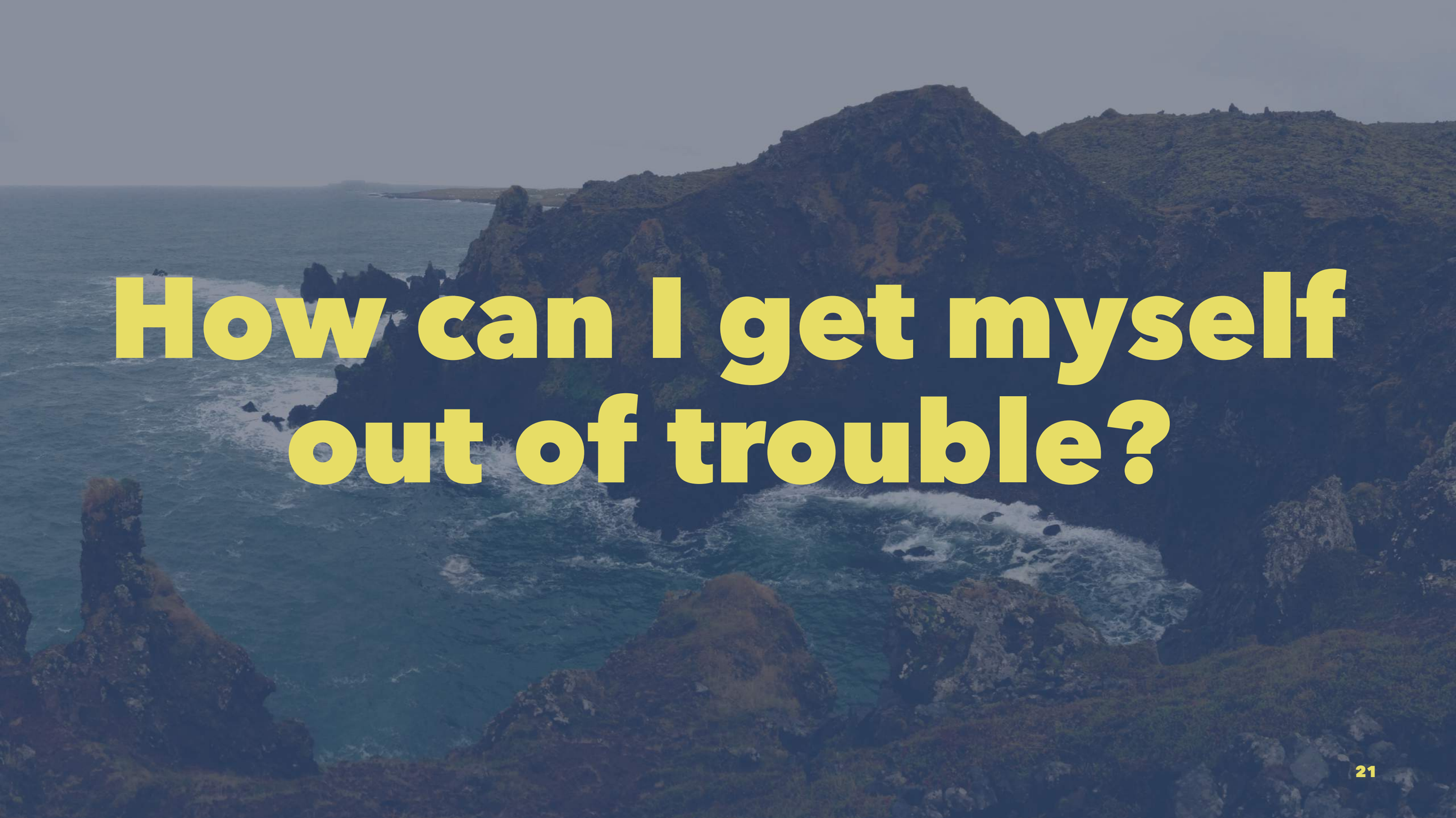
[12] This could clobber uncommitted changes in your working directory, which is why git may throw an error if you try to do a checkout with a dirty working directory.

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]

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

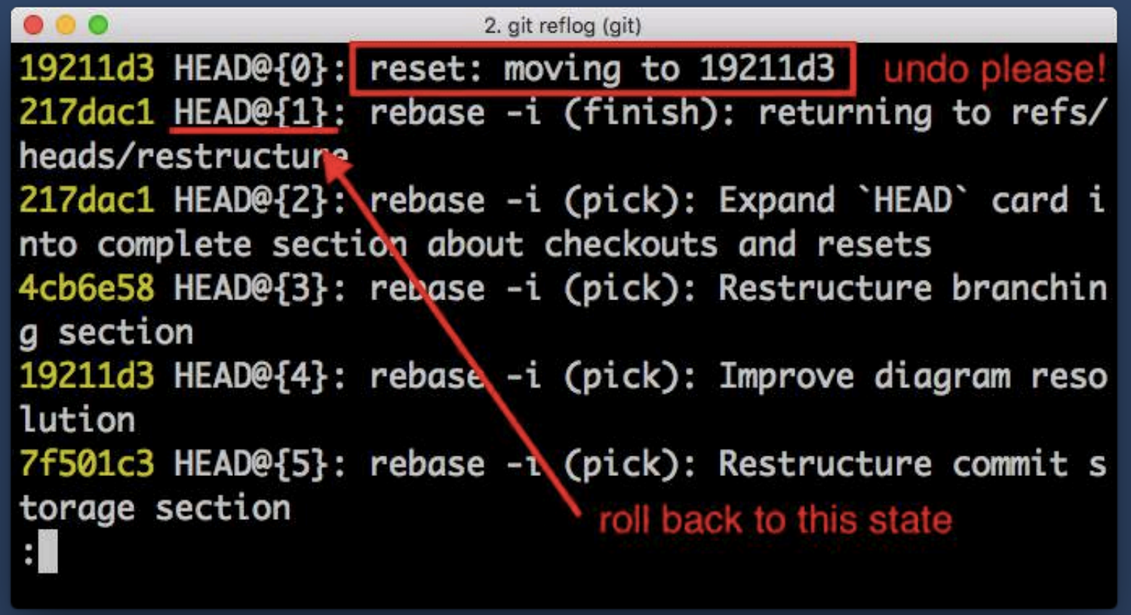
What can I find in the reflog?

- 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}`

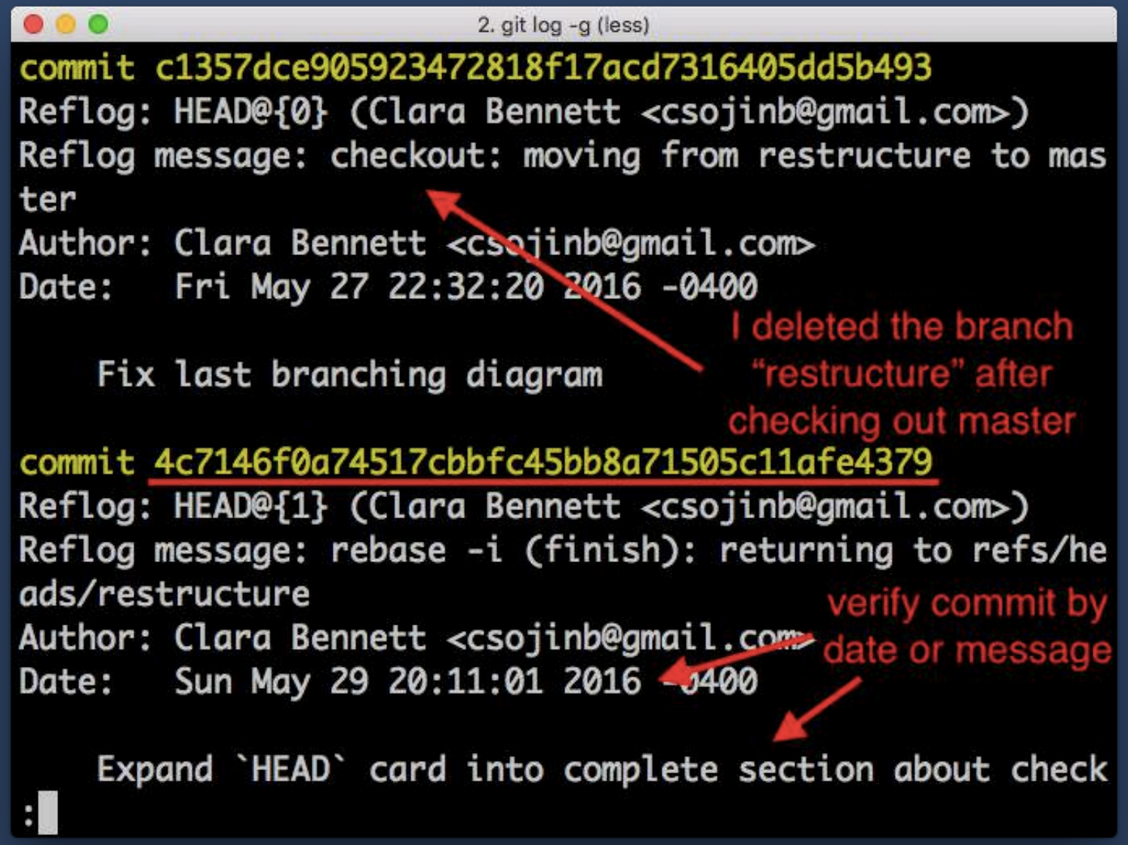


[14] You can even use this to recover from a bad reflog reset!

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



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 issue[15]
- With the defaults, reflog expiry unlikely to cause issues

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[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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