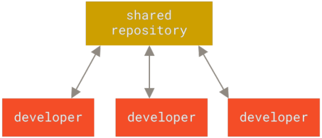
Version Control Systems (1/2)

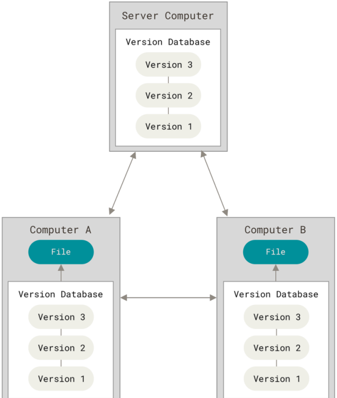
- A **Version Control System** (VCS) is a system that allows to:
  - Record changes to files
  - Recall specific versions later (like a "file time-machine")
  - Compare changes to files over time
  - Track *who* changed *what* and *when* and *why*
- **Simplest "VCS"**
  - Make a copy of a dir and add
    - `_v1` (bad); or
    - a timestamp `_20220101` (better)
  - **Cons**: It kind of works for one person, but doesn't scale

Version Control Systems (2/2)

- **Centralized VCS**
  - E.g., `Perforce`, `Subversion`
  - A server stores the code, clients connect to it
  - **Cons**: If the server is down, nobody can work



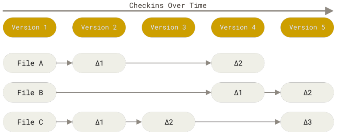
- **Distributed VCS**
  - E.g., `Git`, `Mercurial`, `Bazaar`, `Dart`
  - Each client has the entire history of the repo locally
  - Each node is both a client and a server
  - **Cons**: complex



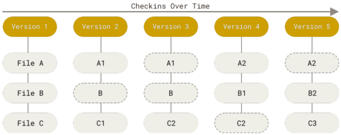
SCIENCE ACADEMY

VCS: How to Track Data

- Consider a directory with project files inside
- **How do you track changes to the data?**
- **Delta-based VCS**
  - E.g., `Subversion`
  - Store the data in terms of patches (changes of files over time)
  - Can reconstruct the state of the repo by applying the patches



- **Stream of snapshots VCS**
  - E.g., `Git`
  - Store data in terms of snapshots of a filesystem
  - Take a "picture" of what files look like
  - Store reference (hash) to the snapshots
  - Save link to previous identical files

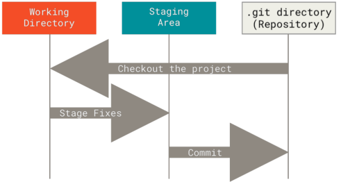


Git

- **Almost everything is local for Git**
    - History stored locally in each node
    - Diff-ing files done locally
        - Centralized VCS requires server access
    - Commit to local copy
        - Upload changes with network connection
- **Almost everything is undoable in Git**
    - No data corruption
        - Everything checksummed
    - Nothing lost
    - Disclaimer:
        - Commit (at least locally) or stash
        - Know how to do it to avoid “git hell”
- **Git is a mini key-value store with a VCS built on top**
    - Exactly true
    - Two layers:
        - “porcelain”: key-value store for file-system
        - “plumbing”: VCS layer

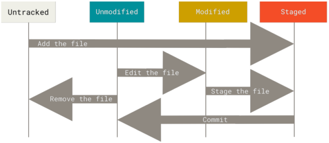
Sections of a Git Project

- There are 3 main sections of a Git project
  - **Working tree** (aka checkout)
    - Version of code on the filesystem for use and modification
  - **Staging area** (aka cache, index)
    - File in `.git` storing info for the next commit
  - **Git directory** (aka .git)
    - Stores metadata and objects (like a DB)
    - The repo itself with all history
    - Cloning gets you the project's `.git`



States of a File in Git

- Each file can be in 4 states from Git point-of-view
  - **Untracked**: files not under Git version control
  - **Modified**: changed files, not committed yet
  - **Staged**: marked modified files for next commit
  - **Committed**: data stored in local DB



Git Tutorial

- **Git tutorial on class repo**
  - Follow the `README`
- **How to use a tutorial**
  - Type commands one-by-one
    - Avoid copy-paste
  - Observe results
    - Understand each line
  - Experiment
    - *"What happens if I do this?"*
    - *"Does the result match my mental model?"*
  - Learn command line before GUI
    - GUIs hide details and you become dependent on it
- Go through **recommended Git book** and try all examples
  - Use online tutorials
- Build your own **cheat sheet**
  - Reuse others' cheat sheets only if familiar
- Achieve **mastery of basic tools**
  - Bash, Git, editor
  - Python, Pandas
  - . . .

Git: Daily Use

- Check out a project (`git clone`) or start from scratch (`git init`)
  - Only once per Git project client
- **Daily routine**
  - Modify files in working tree (`vi ...`)
  - Add files (`git add ...`)
  - Stage changes for next commit (`git add -u ...`)
  - Commit changes to `.git` (`git commit`)
- **Use a branch to group commits together**
  - Isolate code from changes in `master`
  - Merge `master` into branch
  - Isolate `master` from changes
  - Pull Request (PR) for code review
  - Merge PR into upstream

Git Remote

- **Remote repos**: versions of the project hosted online
  - Manage remote repos to collaborate
  - Push/pull changes
  - `git remote -v`: show remotes
  - `git fetch`: pull data from remote repo you don't have locally
  - `git pull`: shorthand for `git fetch origin` + `git merge master --rebase`
  - `git push <REMOTE> <BRANCH>`: push local data to remote
    - E.g., `git push origin master`
- Multiple forks of the same repo with different policies
  - E.g., read-only, read-write
- If someone pushed to remote, you **can't push changes immediately**:
  - Fetch changes
  - Merge changes to your branch
  - Resolve conflicts, if needed
  - Test project sanity (e.g., run unit tests)
  - Push changes to remote

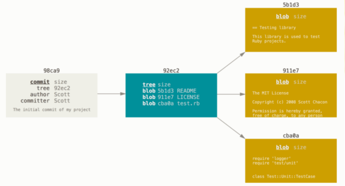
Git Tagging

- Git allows marking points in history with a **tag**
  - E.g., release points
  - Check out a tag
- Enter detached `HEAD` state
  - Committing won't add changes to the tag or branch
  - Commit will be “unreachable,” reachable only by commit hash

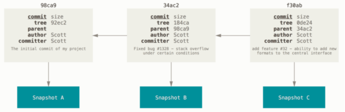
Git Internals

- **Understand Git only if you understand its data model**
  - Git is a key-value store with a VCS interface
  - Key = hash of a file
  - Value = content of a file
- **Git objects**
  - Commits: pointers to the tree and commit metadata
  - Trees: directories and mapping between files and blobs
  - Blobs: content of files
- Refs:
  - Easy: [Understanding Git Data Model]
  - Hard-core: [Git internals]

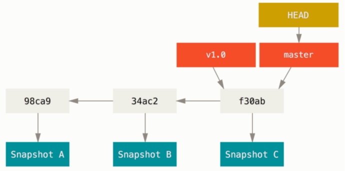
Commit tree



Commit parents

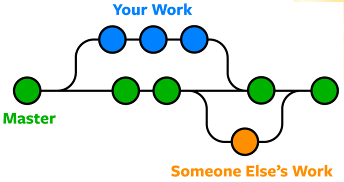


Commit history of a branch



Git Branching

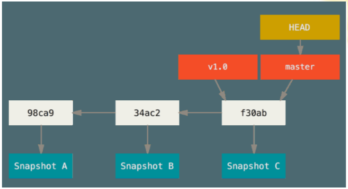
- **Branching**
  - Diverge from main development line
- **Why branch?**
  - Work without affecting main code
  - Avoid changes in main branch
  - Merge code downstream for updates
  - Merge code upstream after completion

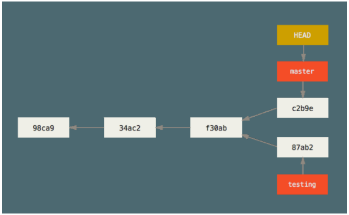


- **Git branching is lightweight**
  - Instantaneous
  - Branch is a pointer to a commit
  - Git stores data as snapshots, not file differences
- **Git workflows branch and merge often**
  - Multiple times a day
  - Surprising for users of distributed VCS
    - E.g., branch before lunch
  - Branches are cheap
    - Use them to isolate and organize work

Git Branching

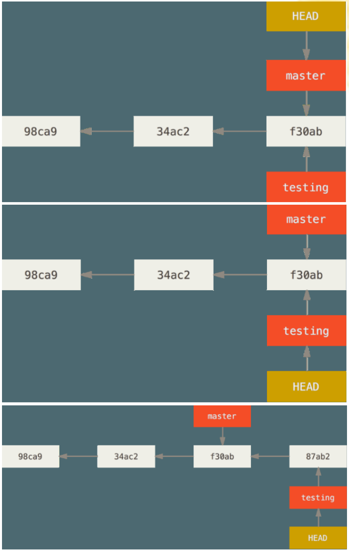
- `master` (or `main`) is a normal branch
  - Pointer to the last commit
  - Moves forward with each commit
- `HEAD`
  - Pointer to the local branch
  - E.g., `master`, `testing`
  - `git checkout <BRANCH>` moves across branches
- `git branch testing`
  - Create a new pointer `testing`
  - Points to the current commit
  - Pointer is movable
- Divergent history
  - Work progresses in two “split” branches





Git Checkout

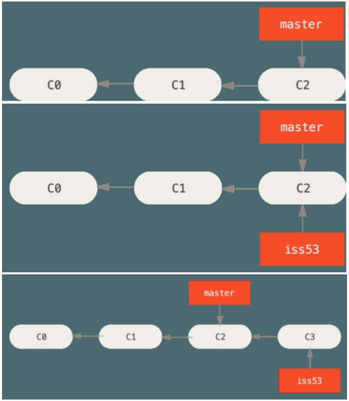
- `git checkout` switches branch
  - Move `HEAD` pointer to new branch
  - Change files in working dir to match branch pointer
- E.g., two branches, `master` and `testing`
  - You are on `master`
  - `git checkout testing`
  - Pointer moves, working dir changes
  - Keep working and commit on `testing`
  - Pointer to `testing` moves forward



Git Branching and Merging

- Tutorials
  - Work on main
  - Hot fix
- Start from a project with some commits
- Branch to work on a new feature “Issue 53”

  ```
  > git checkout -b iss53
  work ... work ... work
  > git commit
  ```

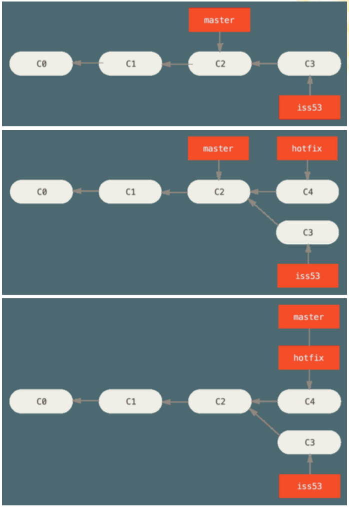


Git Branching and Merging

- Need a hotfix to master

```
> git checkout master
> git checkout -b hotfix
fix ... fix ... fix
> git commit -am "Hot fix"
> git checkout master
> git merge hotfix
```

- Fast forward
  - Now there is a divergent history between master and iss53



Git Branching and Merging

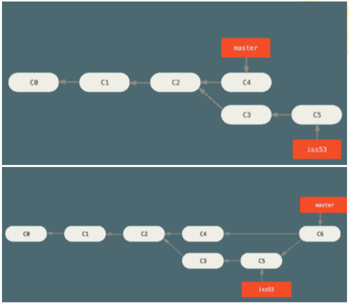
- Keep working on iss53

  ```
  > git checkout iss53
  work ... work ... work
  ```

  - The branch keeps diverging
- At some point you are done with iss53
  - You want to merge your work back to master
  - Go to the target branch

  ```
  > git checkout master
  > git merge iss53
  ```

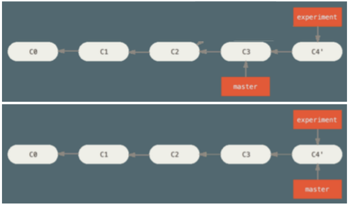
- Git can't fast forward



- Git creates a new snapshot with the 3-way "merge commit" (i.e., a commit with more than one parent)
- Delete the branch > git branch -d iss53

Fast Forward Merge

- **Fast forward merge**
  - Merge a commit `X` with a commit `Y` that can be reached by following the history of commit `X`
- There is not divergent history to merge
  - Git simply moves the branch pointer forward from X to Y



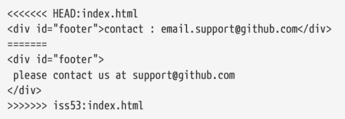
- **Mental model**: a branch is just a pointer that says where the tip of the branch is
- E.g., `C4'` is reachable from `C3`

```
> git checkout master
> git merge experiment
```

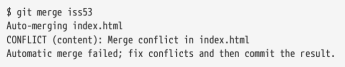
- Git moves the pointer of master to `C4'`

Merging Conflicts

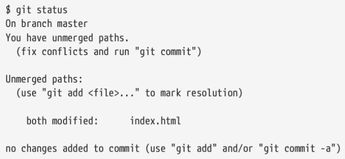
- Tutorial:
  - Merging conflicts
- Sometimes **Git can't merge**, e.g.,
  - The same file has been modified by both branches
  - One file was modified by one branch and deleted by another
- **Git**:
  - Does not create a merge commit
  - Pauses to let you resolve the conflict
  - Adds conflict resolution markers
- **User merges manually**
  - Edit the files `git mergetool`
  - `git add` to mark as resolved
  - `git commit`
  - Use PyCharm or VS Code



```
<<<<<<< HEAD:index.html
<div id="footer">contact : email.support@github.com</div>
=======
<div id="footer">
 please contact us at support@github.com
</div>
>>>>>>> iss53:index.html
```



```
$ git merge iss53
Auto-merging index.html
CONFLICT (content): Merge conflict in index.html
Automatic merge failed; fix conflicts and then commit the result.
```

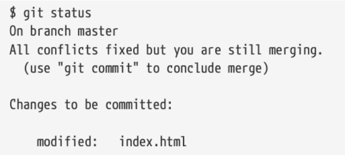


```
$ git status
On branch master
You have unmerged paths.
  (fix conflicts and run "git commit")

Unmerged paths:
  (use "git add <file>..." to mark resolution)

    both modified:      index.html

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



```
$ git status
On branch master
All conflicts fixed but you are still merging.
  (use "git commit" to conclude merge)

Changes to be committed:

    modified:   index.html
```

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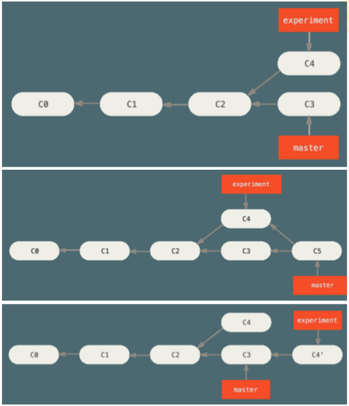
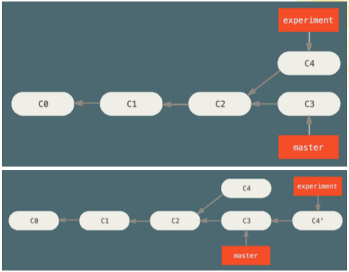
Git Rebasing

- In Git there are **two ways of merging divergent history**
  - E.g., `master` and `experiment` have a common ancestor `C2`
- **Merge**
  - Go to the target branch
    ```
    > git checkout master
    > git merge experiment
    ```
  - Create a new snapshot `C5` and commit
- **Rebase**
  - Go to the branch to rebase
    ```
    > git checkout experiment
    > git rebase master
    ```
  - Rebase algo:
    - Get all the changes committed in the branch (`C4`) where we are on (`experiment`) since the common ancestor (`C2`)
    - Sync to the branch that we are rebasing onto (`master` at `C3`)
    - Apply the changes `C4`
    - Only current branch is affected
    - Finally fast forward master



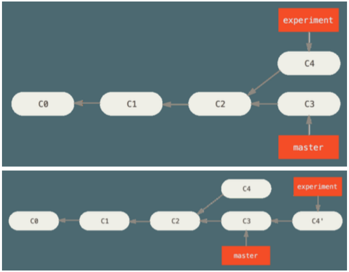
Uses of Rebase

- **Rebasing makes for a cleaner history**
  - The history looks like all the work happened in series
  - Although in reality it happened in parallel to the development in master
- **Rebasing to contribute to a project**
  - Developer
    - You are contributing to a project that you don't maintain
    - You work on your branch
    - When you are ready to integrate your work, rebase your work onto `origin/master`
  - The maintainer
    - Does not have to do any integration work
    - Does just a fast forward or a clean apply (no conflicts)



Golden Rule of Rebasing

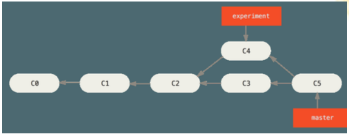
- **Remember**: rebasing means abandoning existing commits and creating new ones that are similar but different
- **Problem**
  - You push commits to a remote
  - Others pull commits and base work on them
  - You rewrite commits with `git rebase`
  - You push again with `git push --force`
  - Collaborators must re-merge work
- **Solution**
  - Strict: *"Do not ever rebase commits outside your repository"*
  - Loose: *"Rebase your branch if only you use it, even if pushed to a server"*



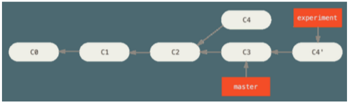
Rebase vs Merge: Philosophical Considerations

- Deciding **Rebase-vs-merge** depends on the answer to the question:
  - *What does the commit history of a repo mean?*

1. **History is the record of what actually happened**
   - *"History should not be tampered with!"*
   - Q: What if there is a series of messy merge commits?
   - A: This is how it happened. The repo should preserve this
   - Use `git merge`

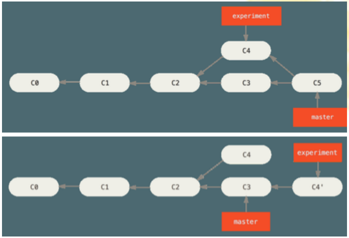


2. **History represents how a project should have been made**
   - *You would not publish a book as a sequence of drafts and correction, but rather the final version"*
   - *You should tell the history in the way that is best for future readers*
   - Use `git rebase` and filter-branch



Rebase vs Merge: Philosophical Considerations

- Many man-centuries have been wasted discussing rebase-vs-merge at the watercooler
  - Total waste of time! Tell people to get back to work!
- When you contribute to a project often people decide for you based on their preference
- **Best of the merge-vs-rebase approaches**
- Rebase changes you've made in your local repo
  - Even if you have pushed but you know the branch is yours
  - Use `git pull --rebase` to clean up the history of your work
  - If the branch is shared with others then you need to definitively `git merge`
- Only `git merge` to master to preserve the history of how something



experiment
C4
C0
C1
C2
C3
C5
master
C4
experiment
C0
C1
C2
C3
C4'
master