UNIVERSITY OF MARYLAND

UMD DATA605 - Big Data Systems

Lesson 2.1: Git

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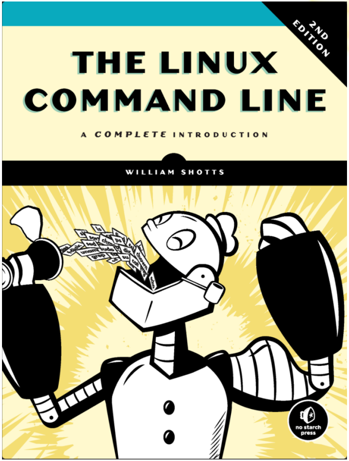
SCIENCE ACADEMY

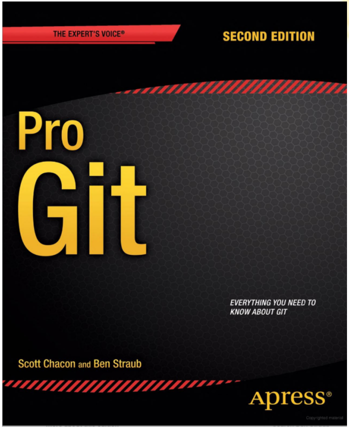
Bash / Linux: Resources

- **How Linux works**
  - Processes
  - File ownership and permissions
  - Virtual memory
  - How to administer a Linux box as root
- **Easy**
  - Command-Line for Beginners
  - E.g., `find`, `xargs`, `chmod`, `chown`, symbolic, and hard links
- **Mastery**
  - The Linux Command Line



Git Resources

- Concepts in the slides
- Tutorial: Tutorial Git
- We will use Git during the project
- Mastery: Pro Git (free)
- Web resources:
  - https://githowto.com
  - dangitgit.com (without swearing)
  - Oh Sh*t, Git!?! (with swearing)
- Playgrounds
  - https://learngitbranching.js.org

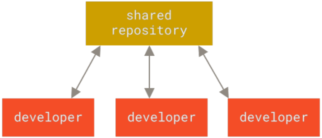

THE EXPERT'S VOICE®
SECOND EDITION
Pro
Git
EVERYTHING YOU NEED TO KNOW ABOUT GIT
Scott Chacon and Ben Straub
Apress®

Version Control Systems (1/2)

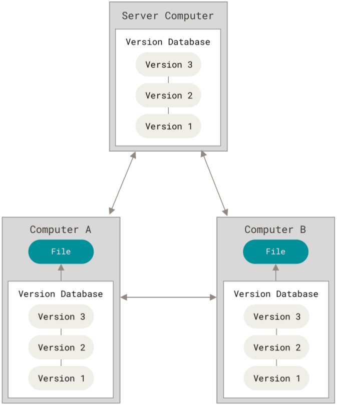
- A **Version Control System** (VCS) is a system that allows to:
  - Record changes to files
  - Recall specific versions later (like a “file time-machine”)
  - Compare changes to files over time
  - Track *who* changed *what* and *when* and *why*
- **Simplest "VCS"**
  - Make a copy of a dir and add
    - `_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`
  - Each client has the entire history of the repo locally
  - Each node is both a client and a server
  - **Cons**: complex



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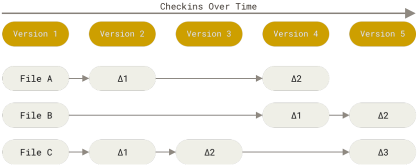
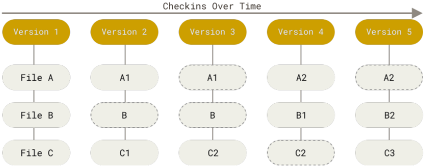
VCS: How to Track Data

- 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)
  - 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

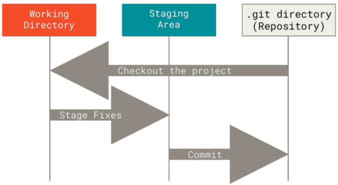


Git

- **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

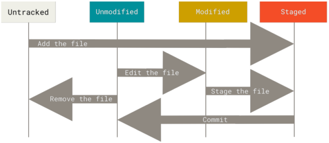
Sections of a Git Project

- 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

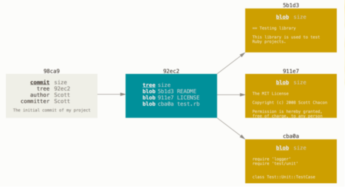
- **Remote repos**: versions of the project hosted online
  - Manage remote repos to collaborate
  - Push/pull changes
  - `git remote -v`: show remotes
  - `git fetch`: pull data from remote repo you don't have locally
  - `git pull`: shorthand for `git fetch origin` + `git merge master --rebase`
  - `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
- You **can't push changes immediately** if someone pushed to remote:
  - 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

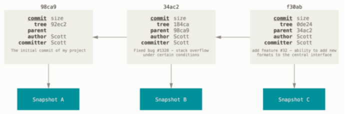
- Git allows marking points in history with a **tag**
  - E.g., release points
- Check out a tag
- Enter detached `HEAD` state
  - Committing won't add changes to the tag or branch
  - Commit will be "unreachable," reachable only by commit hash

Git Internals

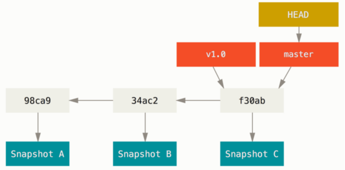
- **Understand Git only if you understand its data model**
  - Git is a key-value store with a VCS interface
  - *Key* = hash of a file
  - *Value* = content of a file
- **Git objects**
  - *Commits*: pointers to the tree and commit metadata
  - *Trees*: directories and mapping between files and blobs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



Commit tree



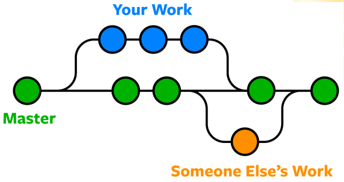
Commit parents



Commit history of a branch

Git Branching

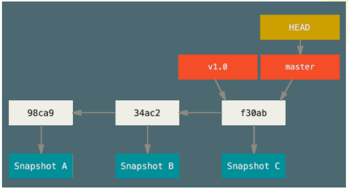
- **Branching**
  - Diverge from main development line
- **Why branch?**
  - Work without affecting main code
  - Avoid changes in main branch
  - Merge code downstream for updates
  - Merge code upstream after completion

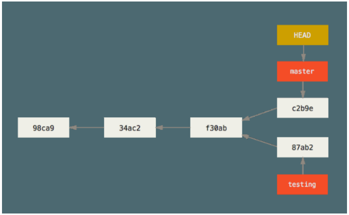


- **Git branching is lightweight**
  - Instantaneous
  - Branch is a pointer to a commit
  - Git stores data as snapshots, not file differences
- **Git workflows branch and merge often**
  - Multiple times a day
  - Surprising for users of distributed VCS
    - E.g., branch before lunch
  - Branches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

Git Branching

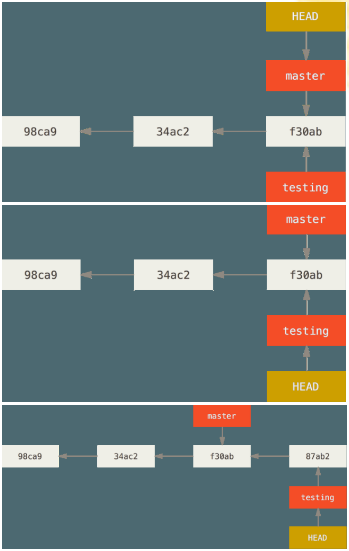
- `master` (or `main`) is a normal branch
  - Pointer to the last commit
  - Moves forward with each commit
- `HEAD`
  - Pointer to the local branch
  - E.g., `master`, `testing`
  - `git checkout <BRANCH>` moves across branches
- `git branch testing`
  - Create a new pointer `testing`
  - Points to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





Git Checkout

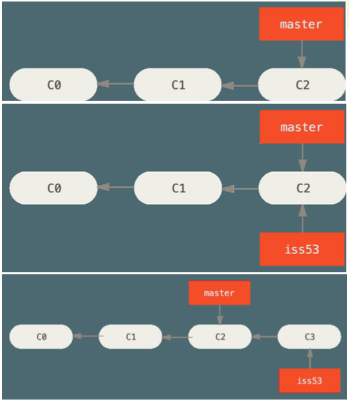
- git checkout switches branch
  - Move HEAD pointer to new branch
  - Change files in working dir to match branch pointer
- E.g., two branches, master and testing
  - You are on master
  - git checkout testing
  - Pointer moves, working dir changes
  - Keep working and commit on testing
  - Pointer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

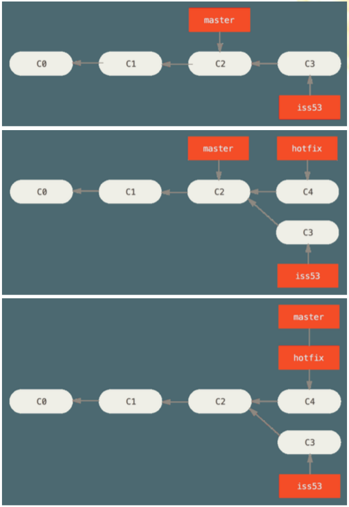


Git Branching and Merging

- **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`



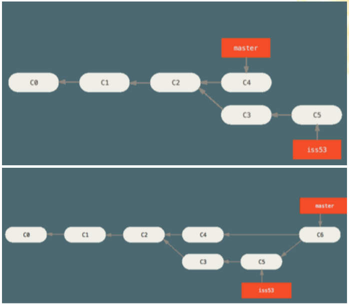
Git Branching and Merging

- 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

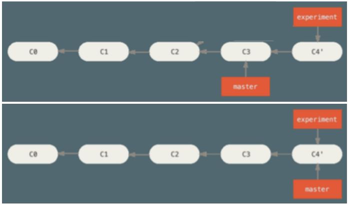
  ```
  > git branch -d iss53
  ```

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`

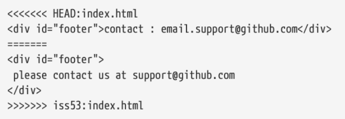
```
> git checkout master
> git merge experiment
```

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

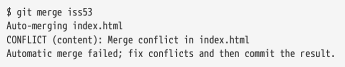


Merging Conflicts

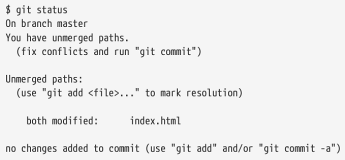
- Tutorial:
  - Merging conflicts
- Sometimes **Git can't merge**, e.g.,
  - The same file has been modified by both branches
  - One file was modified by one branch and deleted by another
- **Git**:
  - Does not create a merge commit
  - Pauses to let you resolve the conflict
  - Adds conflict resolution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



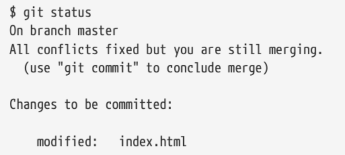
```
<<<<<<< HEAD:index.html
<div id="footer">contact : email.support@github.com</div>
=======
<div id="footer">
 please contact us at support@github.com
</div>
>>>>>>> iss53:index.html
```



```
$ 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")
```



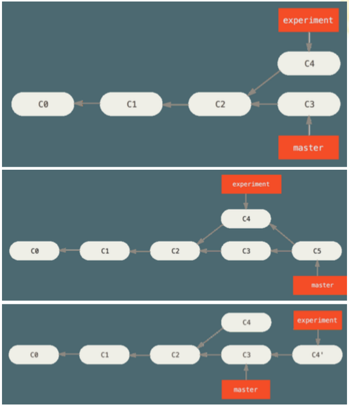
```
$ git status
On branch master
All conflicts fixed but you are still merging.
  (use "git commit" to conclude merge)

Changes to be committed:

    modified:   index.html
```

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

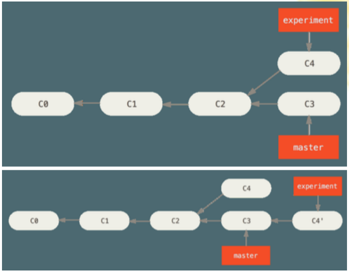
    ```
    > git checkout master
    > git merge experiment
    ```
  - Create a new snapshot `C5` and commit
- **Rebase**
  - Go to the branch to rebase

    ```
    > 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 `experiment`



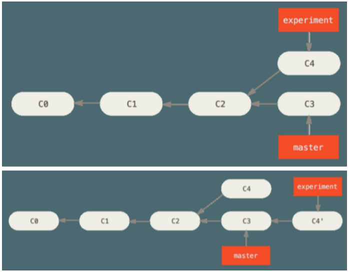
Uses of Rebase

- **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"*



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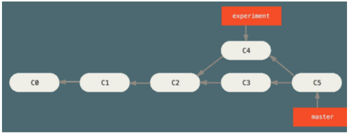
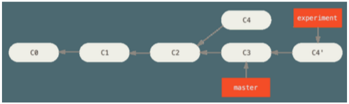
Rebase vs Merge: Philosophical Considerations

- 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, even if messy!"*
   - Use `git merge`



2. **History represents how a project should have been made**
   - *"You should tell the history in the way that is best for future readers"*
   - Use `git rebase` and filter-branch



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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 was built
- **Personally**
  - I like to squash-and-merge branches to `master`
  - Rarely my commits are "complete", are just checkpoints

Remote Branches

- **Remote branches** are pointers to branches in remote repos

```
git remote -v
origin  git@github.com:gpsaggese/umd_classes.git (fetch)
origin  git@github.com:gpsaggese/umd_classes.git (push)
```

- **Tracking branches**
  - Local references representing the state of the remote repo
  - E.g., `master` tracks `origin/master`
  - You can't change the remote branch (e.g., `origin/master`)
  - You can change tracking branch (e.g., `master`)
  - Git updates tracking branches when you do `git fetch origin` (or `git pull`)
- To share code in a local branch you need to push it to a remote

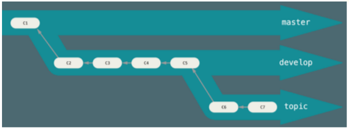
```
> git push origin serverfix
```

- To work on it

```
> git checkout -b serverfix origin/serverfix
```

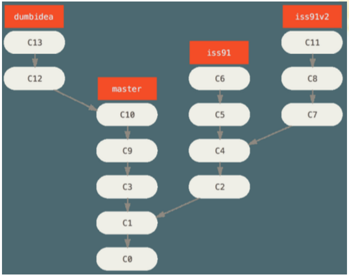
Git Workflows

- **Git workflows** = ways of working and collaborating using Git
- **Long-running branches** = branches at different level of stabilities, that are always open
    - `master` is always ready to be released
    - `develop` branch to develop in
    - topic / feature branches
    - When branches are “stable enough” they are merged up



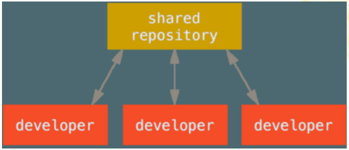
Git Workflows

- **Topic branches** = short-lived branches for a single feature
  - E.g., `hotfix`, `wip-XYZ`
  - Easy to review
  - Silo-ed from the rest
  - This is typical of Git since other VCS support for branches is not good enough
  - E.g.,
    - You start `iss91`, then you cancel some stuff, and go to `iss91v2`
    - Somebody starts `dumbidea` branch and merge to `master` (!)
    - You squash-and-merge your `iss91v2`



Centralized Workflow

- **Centralized workflow in centralized VCS**
  - Developers:
    - Check out the code from the central repo on their computer
    - Modify the code locally
    - Push it back to the central hub (assuming no conflicts with latest copy, otherwise they need to merge)
- **Centralized workflow in Git**
  - Developers:
    - Have push (i.e., write) access to the central repo
    - Need to fetch and then merge
    - Cannot push code that will overwrite each other code (only fast-forward changes)



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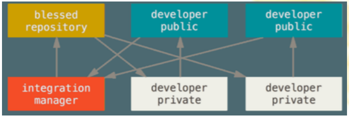
Forking Workflows

- Typically devs don't have permissions to update directly branches on a project
  - Read-write permissions for core contributors
  - Read-only for anybody else
- **Solution**
  - "Forking" a repo
  - External contributors
    - Clone the repo and create a branch with the work
    - Create a writable fork of the project
    - Push branches to fork
    - Prepare a PR with their work
  - Project maintainer
    - Reviews PRs
    - Accepts PRs
    - Integrates PRs
  - In practice it's the project maintainer that pulls the code when it's ready, instead of external contributors pushing the code
- **Aka "GitHub workflow"**
  - "Innovation" was forking (Fork me on GitHub!)
  - GitHub acquired by Microsoft for 7.5b USD

Integration-Manager Workflow

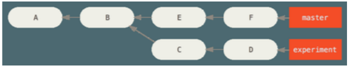
- This is the classical model for open-source development
  - E.g., Linux, GitHub (forking) workflow



1. **One repo is the official project**
   - Only the project maintainer pushes to the public repo
   - E.g., `causify-ai/csfy`
2. **Each contributor**
   - Has read access to everyone else's public repo
   - Forks the project into a private copy
     - Write access to their own public repo
     - E.g., `gpsaggese/csfy`
   - Makes changes
   - Pushes changes to his own public copy
   - Sends email to maintainer asking to pull changes (pull request)
3. **The maintainer**
   - Adds contributor repo as a remote
   - Merges the changes into a local branch
   - Tests changes locally
   - Pushes branch to the official repo

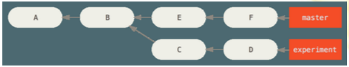
Git log

- `git log` reports info about commits
- **refs** are references to:
  - `HEAD` (commit you are working on, next commit)
  - `origin/master` (remote branch)
  - `experiment` (local branch)
  - `d921970` (commit)
- ˆ after a reference resolves to the parent of that commit
  - `HEAD`ˆ = commit before `HEAD`, i.e., last commit
  - ˆ2 means ˆˆ
  - A merge commit has multiple parents

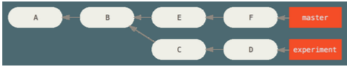


Dot notation

- **Double-dot notation**
  - `1..2` = commits that are reachable from 2 but not from 1
  - Like a “difference”
  - `git log master..experiment` → `D,C`
  - `git log experiment..master`→ `F,E`



- **Triple-dot notation**
  - `1...2` = commits that are reachable from either branch but not from both
  - Like “union excluding intersection”
  - `git log master...experiment` → `F,E,D,C`



SCIENCE ACADEMY

Advanced Git

- Stashing
  - Copy state of your working dir (e.g., modified and staged files)
  - Save it in a stack
  - Apply later
- Cherry-picking
  - Apply a single commit from one branch onto another
- rerere
  - = “Reuse Recorded Resolution”
  - Git caches how to solve certain conflicts
- Submodules / subtrees
  - Project including other Git projects

Advanced Git

- **bisect**
  - `git bisect` helps identifying the commit that introduced a bug
    - Bug appears at top of tree
    - Unknown revision where it started
    - Script returns 0 if good, non-0 if bad
    - `git bisect` finds revision where script changes from good to bad
- **filter-branch**
  - Rewrite repo history in a script-able way
    - E.g., change email, remove sensitive file
  - Check out each version, run command, commit result
- **Hooks**
  - Run scripts before commit, merging,

GitHub

- GitHub acquired by MSFT for 7.5b
- **GitHub: largest host for Git repos**
  - Git hosting (100m+ open source projects)
  - PRs, forks
  - Issue tracking
  - Code review
  - Collaboration
  - Wiki
  - Actions (CI / CD)
- **"Forking a project"**
  - Open-source communities
    - Negative connotation
    - Modify and create a competing project
  - GitHub parlance
    - Copy a project to contribute without push/write access