

MATHEMATICAL MODELING FOR COMPUTATIONAL SCIENCE

AM215 - LECTURE 2: Git Essentials & Workflow

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Disasters Without Version Control

Real scenario: PhD student loses 6 months of analysis code

- Overwrote working version with broken "improvements"
- Backups? `analysis_final_v2_ACTUALLY_FINAL_fixed.py`
- No way to recover the working state



| Without version control, you're one mistake away from disaster.

Collaboration Nightmares

The email merge disaster:

- Alice emails `model.py` to Bob and Charlie
- All three modify different functions
- Bob emails back v2, Charlie emails v3
- Alice: "Which changes do I keep?" 🤯



No accountability: Who broke the build? When? Why?

Git: The Solution

Distributed → Everyone has full history (no single point of failure)
Fast → Designed for Linux kernel (thousands of contributors)
Branching → Experiment freely, merge intelligently



| Git is the industry standard—from startups to NASA.

Install & Configure Git

First, check if Git is installed:

```
git --version # Should show version 2.x or higher
```

Configure your identity (stored in `~/.gitconfig`):

```
git config --global user.name "Your Name"  
git config --global user.email "you@domain.edu"
```

This information appears in every commit you make.

Two Ways to Start

Option 1: Start fresh

```
mkdir my-project  
cd my-project  
git init # Creates .git directory
```

Option 2: Copy existing project

```
git clone https://github.com/user/repo.git  
cd repo
```

What's in a Repository?

Your repository = your files + .git directory

```
ls -la # Shows your files AND hidden .git/
total 8
drwxr-xr-x 3 user  staff   96 Jul 15 10:00 .
drwxr-xr-x 4 user  staff  128 Jul 15 10:00 ..
drwxr-xr-x 9 user  staff  288 Jul 15 10:01 .git
-rw-r--r-- 1 user  staff   12 Jul 15 10:00 README.md
```

- **Your files:** What you edit and run
- **.git directory:** Git's database (all history lives here)

| Delete .git = lose all version history! 💀

Your First Commit

The basic workflow:

```
echo "# My Project" > README.md    # 1.  
Create/modify file  
git add README.md                  # 2. Stage for  
commit  
git commit -m "Initial commit"     # 3. Save  
snapshot
```

What just happened?

- `add` → marks file for next snapshot
- `commit` → permanently saves snapshot with message

Check Your Work

See current state:

```
git status # What's modified? What's staged?  
On branch main  
nothing to commit, working tree clean
```

See history:

```
git log --oneline # List of commits  
7a3f2d1 (HEAD -> main) Initial commit
```

| Use `git status` constantly!

Ignoring Files

Create `.gitignore` to exclude junk:

```
# Python  
__pycache__/  
*.pyc  
  
# Editor/OS  
.DS_Store  
*~  
*.swp
```

Why? Keeps repo clean, portable, professional

| Rule: If it's generated or personal, ignore it.

The Daily Git Cycle

You'll run these commands 50+ times per day:

```
# 1. Make changes  
vim analysis.py  
  
# 2. Review what changed  
git diff  
  
# 3. Stage good changes  
git add analysis.py  
  
# 4. Verify what's staged  
git status  
  
# 5. Save snapshot  
git commit -m "Fix convergence bug"
```

| Master this cycle; it's 90% of Git usage!

Inspecting Changes Before Committing

See what you modified:

```
git diff                  # Working dir vs index  
(staging area)  
git diff --staged        # Index (staging area) vs  
HEAD (last commit)
```

Example output:

```
- def calculate(x):  
-     return x * 2  
+ def calculate(x, scale=2):  
+     return x * scale
```

| Review before commit = fewer "oops" commits

Reading Your History

Find what you need in the log:

```
git log --oneline          # Quick overview  
git log --grep="bug"        # Search messages  
git log --author="Alice"    # Filter by person  
git log -p analysis.py     # Changes to specific  
file
```

When you'd use this:

- "When did we fix that convergence issue?"
- "What did my teammate change yesterday?"
- "When did this file last work correctly?"

Fixing Mistakes: Working Directory

Scenario: "I broke the code while experimenting"

```
git status          # See modified files  
git diff           # Review damage  
git restore analysis.py # Discard changes
```

Also useful:

```
git restore .       # Discard ALL changes
```

⚠ Warning: `restore` permanently deletes uncommitted work!

Fixing Mistakes: Commits

Last commit has a typo?

```
git commit --amend
```

Need to undo a pushed commit?

```
git revert <commit-hash>
```

Want to reset branch to an older state? (DANGEROUS)

```
git reset --hard <commit-hash>
```

Command	Changes History?	Safe if Pushed?
amend	Yes	No
revert	No	Yes
reset	Yes	No

Golden rule: Never rewrite shared history.

Why Use Branches?

Scenario: You need to add a feature, but `main` must stay stable

Without branches:

- Break `main` → everyone suffers
- Work offline → merge nightmare
- Comment out code → messy and error-prone

With branches:

- Experiment freely
- Keep `main` deployable
- Merge when ready

| Branches let you develop in parallel without stepping on toes.

Commits Form a Graph

Your history isn't a line, but a graph:

```
$ git log --oneline --graph --all
* 3a4f2d1 (HEAD -> main) Update README
* 8b3c9e7 Fix typo
* 1d5a3f2 Initial commit
```

Each commit knows its parent(s). Branches diverge and merge.



| Every commit is a snapshot + pointer to its parent.

What Is a Branch?

A branch = a movable pointer to a commit

```
$ git branch  
* main      # The * shows current branch (HEAD)
```

- **main** points to commit `3a4f2d1`
- When you commit, the pointer moves forward
- **HEAD** = your current position



Creating Your First Branch

Let's fix a bug without touching main:

```
$ git branch bugfix          # Create pointer
$ git branch
  bugfix
* main                         # Still on main

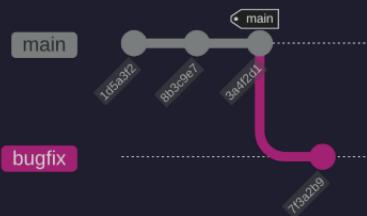
$ git switch bugfix            # Move HEAD
$ git branch
* bugfix                        # Now we're here!
  main
```

Shortcut: `git switch -c bugfix` (create + switch)

Working on a Branch

Make changes on `bugfix`:

```
$ echo "fix" > bugfix.txt  
$ git add bugfix.txt  
$ git commit -m "Fix critical bug"  
  
$ git log --oneline --graph --all  
* 7f3a2b9 (HEAD -> bugfix) Fix critical bug  
* 3a4f2d1 (main) Update README  
* 8b3c9e7 Fix typo
```



Switching Branches—The Problem

What if you have uncommitted changes?

```
$ git switch main  
error: Your local changes would be overwritten  
Please commit or stash before switching.
```

Three options:

1. Commit the changes (even if incomplete)
2. Discard with `git restore .`
3. **Stash them temporarily ✓**

Stashing: Your Safety Net

Save work temporarily without committing:

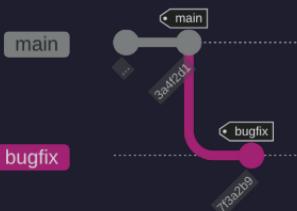
```
$ git status  
modified: analysis.py (uncommitted)  
  
$ git stash push -m "WIP: new algorithm"  
Saved working directory  
  
$ git status  
nothing to commit (working tree clean)  
  
$ git switch main           # Now it works!  
# ... do other work ...  
$ git switch bugfix  
$ git stash pop            # Changes restored!
```

| Stash = temporary shelf for uncommitted work

Merging: Fast-Forward Case

Scenario 1: `main` hasn't changed since branch

Before merge:

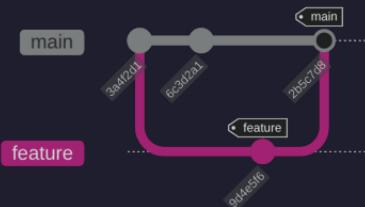


```
$ git merge bugfix  
Fast-forward # Git tells you!
```

After merge: `main` moves to `7f3a2b9` (same as `bugfix`). No new commit created.

Merging: Merge Commit Case

Scenario 2: Both branches have new commits



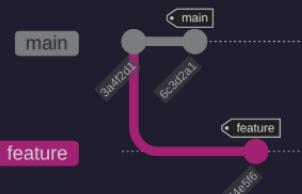
```
# After merge:  
* 2b5c7d8 (HEAD -> main) Merge branch 'feature'  
|\  
| * 9d4e5f6 (feature) Add feature X  
* | 6c3d2a1 Hotfix on main  
|/  
* 3a4f2d1 Common ancestor
```

The merge commit 2b5c7d8 has TWO parents!

Rebase: Rewriting History (Local Only!)

Alternative to merge: replay commits on top

Before rebase:



After rebase:



```
$ git switch feature  
$ git rebase main
```

Key differences from merge:

- Linear history (no diamond)
- Commits get NEW hashes
- **⚠️ Never rebase shared commits!**

Cleaning Up Branches

After merging, delete the branch pointer:

```
$ git branch  
  bugfix  
* main  
  
$ git branch -d bugfix      # Safe delete (checks  
if merged)  
Deleted branch bugfix  
  
$ git branch                  # Clean list!
```

For unmerged branches: `git branch -D feature` (force delete)

| Keep your branch list tidy—delete after merging.

Scenario: Sharing Your Work

You've built a great feature locally. Now what?

Without remotes:

- Email code files? 📧 (version chaos)
- USB drive? 🏚 (no history)
- Work alone forever? 😞

With remotes:

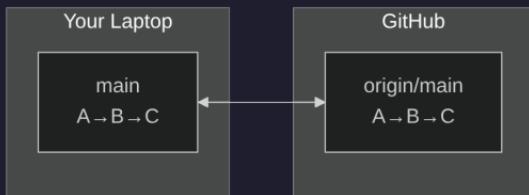
- Push your commits to GitHub
- Teammate pulls your changes
- Full history preserved!

Remotes turn Git from personal tool to team superpower.

Local vs Remote Repositories

Local: Your `.git/` directory (on your machine)

Remote: Git repo on a server (GitHub, GitLab, etc.)



Key insight: **Both are full repos with complete history**

Adding & Configuring Remotes

Connect your local repo to GitHub:

```
git remote add origin git@github.com:user/repo.git  
git remote -v      # Verify connection
```

Authentication options:

- **SSH** (recommended): One-time key setup, then passwordless
- **HTTPS**: Works everywhere, needs token each push

| Name `origin` is convention for "main remote"

SSH Keys: Your Digital Identity

How does GitHub know it's you?

- HTTPS: Username + Token (like a password)
- SSH: A cryptographic key pair (more secure, more convenient)

The Public/Private Key Analogy:

- You generate a **private key** (secret, like your house key) and a **public key** (sharable, like a padlock).
- You give the **padlock** (public key) to GitHub.
- When you **git push**, Git uses your **private key** to unlock it.

| Never share your private key!

Generating Your SSH Key

1. Create the key pair:

```
ssh-keygen -t ed25519 -C "you@domain.edu"
```

- `-t ed25519`: Specifies a modern, secure algorithm.
- `-C "your_email@example.com"`: A comment to label the key.
- Press Enter to accept defaults (saves to `~/.ssh/id_ed25519`).

2. Check for your keys:

```
ls ~/.ssh/id_ed25519*
/home/user/.ssh/id_ed25519      # Private key
(SECRET)
/home/user/.ssh/id_ed25519.pub  # Public key
(SHARABLE)
```

Adding Your Public Key to GitHub

1. Copy your public key to the clipboard:

```
# On macOS  
pbcopy < ~/.ssh/id_ed25519.pub  
  
# On Linux (requires xclip)  
xclip -selection clipboard < ~/.ssh/id_ed25519.pub  
  
# Or just display it to copy manually  
cat ~/.ssh/id_ed25519.pub
```

2. Add it to GitHub:

- Go to Settings > SSH and GPG keys > New SSH key.
- Give it a title (e.g., "My Laptop").
- Paste your public key into the Key field.

| Now you can `git push` without a password/token!

Push: Uploading Your Commits

Share your local work with the team:

```
git push origin main
```

What happens:

```
Before: local: A→B→C→D      remote: A→B  
After:  local: A→B→C→D      remote: A→B→C→D
```

First push? Use `git push -u origin main` to set tracking

Fetch vs Pull: Getting Updates

Fetch: Download commits, don't merge

```
git fetch origin  
git status          # Shows you're behind
```

Safe! Review changes before integrating.

Pull: Fetch + merge in one step

```
git pull            # Can cause conflicts!
```

Convenient but potentially disruptive.

| When unsure, fetch first, then decide.

Understanding Tracking Branches

Two types of branches:

- `main` = your local branch (you commit here)
- `origin/main` = remote's position (read-only)

```
git branch -a      # Show all branches
* main            # Local, checked out
      remotes/origin/main  # Remote tracking
```

After fetch: `origin/main` updates, `main` doesn't move

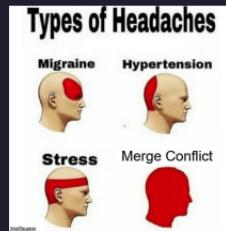


Your local `main` is still at C, but `origin/main` shows the remote is at E.

Resolving Merge Conflicts (from a Pull)

Scenario: A git pull fails with a merge conflict.

```
$ git pull
Auto-merging analysis.py
CONFLICT (content): Merge conflict
in analysis.py
```



Fix it:

1. Open file, find conflict markers
`<<<<<`
2. Edit to combine both changes correctly
3. `git add analysis.py`
4. `git commit` (completes the merge)

Conflicts are normal and Git needs human judgment

Fork & Pull Request Workflow

Contributing to projects you don't own:

1. Fork on GitHub (creates your server-side copy)
2. Clone your fork locally
3. Create feature branch, commit, push to your fork
4. Open **Pull Request** (PR) to propose your changes to the original

The `upstream` convention:

- `origin` = your fork (you can push here)
- `upstream` = original repo (read-only, for syncing)

```
git remote add upstream
git@github.com:original/repo.git
git fetch upstream      # Get latest from
original
git merge upstream/main # Update your local main
```



GitHub/GitLab: Beyond Storage

Free collaboration features:

- **Pull Requests:** Code review before merge
- **Issues:** Track bugs and tasks
- **Actions/CI:** Auto-test on every push
- **Protected branches:** Require PR approval

| These platforms make Git social and safe

GitHub CLI: Bring GitHub to Your Terminal

The `gh` command line tool lets you manage GitHub from your terminal.

Why use it?

- Create PRs without leaving your editor
- Check out PRs for local review
- Manage issues, releases, and more

Common commands:

```
# Clone a repo  
gh repo clone user/repo  
  
# Create a pull request  
gh pr create --fill  
  
# List open pull requests  
gh pr list  
  
# Check out a PR locally  
gh pr checkout 123
```

| `gh` complements `git`—it doesn't replace it.

Remotes & Collaboration: Summary

✓ Key takeaways:

- Push to share, `fetch/pull` to receive
- `origin/main` tracks remote state
- Conflicts happen—resolve with communication
- Fork + PR for contributing to others' projects
- GitHub/GitLab add review and automation

| You now know enough to collaborate on any Git project! 🎉

Under the Hood

Remember That `.git/` Directory?

Earlier, we saw:

```
ls -la
.git/      # Git's database
README.md  # Your files
```

You've been creating objects all along:

- Every `git add` → stores file contents
- Every `git commit` → saves a snapshot
- Every `git branch` → creates a pointer

Let's peek behind the curtain...

Your Last Commit Created Three Objects

Remember this?

```
git commit -m "Fix convergence bug"  
[main 7a3f2d1] Fix convergence bug
```

Git actually created:

1. **Blob** = your file's contents
2. **Tree** = directory listing (names → blobs)
3. **Commit** = snapshot (tree + parent + message)

```
git cat-file -t 7a3f2d1    # "commit"  
git cat-file -p 7a3f2d1    # Shows tree, parent,  
author...
```

| Every commit points to a complete snapshot of your project.

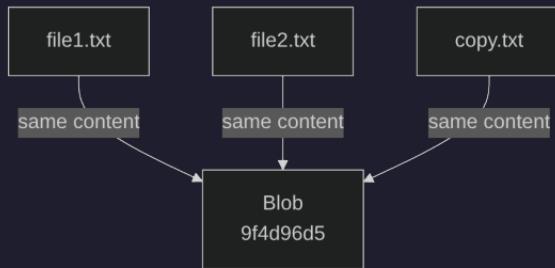
Blobs: Your File Contents

Blob = Binary Large OBject (just the file data)

```
echo "Hello Git" > test.txt  
git add test.txt  
git hash-object test.txt  
# Output: 9f4d96d5b00d98959ea9960f069585ce42b1349a
```

Key insight: Same content → same hash (deduplication!)

- 100 identical files = 1 blob
- Edit 1 character = completely new blob



Trees: Your Directory Structure

Tree = list of (filename → blob/tree)

```
git cat-file -p HEAD^{tree}
100644 blob 9f4d96d5b00d98... README.md
100644 blob 3b18e512dba79e... analysis.py
040000 tree 4b825dc642cb6e... src/
```

Structure:

```
commit → root tree
    └── README.md → blob
    └── analysis.py → blob
    └── src/ → tree
        └── utils.py → blob
```

| Trees give names to blobs. Blobs have no filenames!

Content Addressing: Git's Superpower

Every object named by its SHA-1 hash:

```
.git/objects/
├── 9f/4d96d5b00d98959ea9960f069585ce42b1349a  #
|   blob
|   └── 7a/3f2d1e8b9c0d1e2f3a4b5c6d7e8f9a0b1c2d3e4  #
|       commit
|           └── 4b/825dc642cb6eb01c9a95f3ab3b8c0d1e2f3a4b5  #
|               tree
```

This gives you:

- **Integrity**: Corruption detected instantly (hash mismatch)
- **Deduplication**: Same content stored once
- **Immutability**: Can't change object without changing hash

Git is a content-addressable filesystem with version control on top.

Branches Are Just Pointers

We've seen that branches are lightweight. Here's why:

```
cat .git/refs/heads/main  
7a3f2d1e8b9c0d1e2f3a4b5c6d7e8f9a0b1c2d3e4
```

```
cat .git/refs/heads/bugfix  
9b5c7d8e1a2f3b4c5d6e7f8a9b0c1d2e3f4a5b6c7d
```

That's it! A branch = 41-byte file with a commit hash.

Creating a branch:

```
git branch feature    # Creates  
.git/refs/heads/feature
```

Cost: 41 bytes. Speed: instant.

HEAD: Your Current Position

HEAD tells Git where you are:

```
cat .git/HEAD  
ref: refs/heads/main    # On a branch  
  
# After git checkout 7a3f2d1  
cat .git/HEAD  
7a3f2d1e8b9c0d1e2f3a4b5c6d7e8f9a0b1c2d3e4  #  
Detached HEAD!
```

Detached HEAD: You're viewing a specific commit directly, not through a branch. Great for inspection, but new commits won't belong to any branch unless you create one.

When you commit:

1. New commit object created
2. Branch pointer moves forward
3. HEAD follows (if on branch)



This Explains Everything!

Why is checkout instant?

→ Just updating HEAD pointer (41 bytes)

Why can't you lose commits?

→ Objects never deleted (use git reflog to find them)

Why are branches "free"?

→ Just pointer files, not copies

How does Git detect corruption?

→ Hash mismatch = instant detection

Practical proof:

```
git reset --hard HEAD~3    # "Lose" 3 commits
git reflog                  # They're still there!
git checkout <old-hash>      # Recovered!
```

"Git is a stupid content tracker" – Linus Torvalds

(Stupid = simple, reliable, no magic)

Under the Hood: Summary

✓ Key insights:

- **Objects**: Blobs (file contents), Trees (directories), Commits (snapshots)
- **Content-addressed**: Named by SHA-1 hash of contents
- **Branches**: Just pointers to commits (41-byte files!)
- **HEAD**: Pointer to current branch or commit
- **Result**: Fast, safe, and impossible to lose data

You now understand why Git never loses your work—even when you think it's gone!

When Git Gets Hard

You understand Git's internals. Now let's become Git detectives.

Three scenarios you'll face:

1. "When did this break?" → `bisect`
2. "I lost my commits!" → `reflog`
3. "Who changed this?" → `log search`

| These tools turn panic into process.

Finding Commits with Surgical Precision

Search your history like a database:

```
git log --grep="convergence"      # Find by message  
git log --author="Alice"         # Find by person  
git log --since="2 weeks ago"    # Recent work  
git log -- path/to/model.py     # File history
```

Real scenario: "What has Alice pushed in the last week?"

```
git log --author="Alice" --since="1 week ago"
```

Bisect: Binary Search for Bugs

Scenario: Tests passed 100 commits ago, fail now.

- Manual search: test 100 commits 😱
- Bisect: test ~7 commits 🎉

```
git bisect start
git bisect bad HEAD          # Current = broken
git bisect good v1.0          # v1.0 = worked

# Git checks out midpoint commit
python test_model.py          # You run test
git bisect good               # Tell Git result

# Repeat ~7 times → Git identifies first bad
commit
```

Reflog: Your Time Machine

Git records every HEAD movement for 90 days:

```
git reflog
# a3f2d1e HEAD@{0}: commit: Fix bug
# 7b9c3e2 HEAD@{1}: checkout: moving from main to
feature
# 5d4e1f3 HEAD@{2}: reset: moving to HEAD~3  #
Oops!
```

Recovery scenario:

```
git reset --hard HEAD~5      # "Deleted" 5 commits
git reflog                   # Find the hash
before the reset
git reset --hard 5d4e1f3     # Restored!
```

| Reflog = Git's "undo" for almost anything

Best Practices & Wrap-Up

You've learned the mechanics. Now build the habits.

This section distills the lecture into three professional practices:

1. Write clear, contextual commit messages
2. Keep your branch history clean
3. Know where to look for help

| Good habits turn Git from a chore into a superpower.

Commit With Context

Bad: git commit -m "fix bug" (What did you fix? Why?)

Good: git commit -m "Fix: prevent division by zero in analysis"

A good commit message explains the *why*, not just the *what*.

Guideline: Use imperative mood ("Fix", "Add", "Refactor") and be specific. Your commit log should tell a story.

Practice Good Branch Hygiene

Branches are cheap pointers. Use them, then lose them.

- **Work in feature branches:** `main` should always be stable.
- **Merge often:** Avoid massive, complex merges.
- **Delete after merging:** Keep your repository tidy.

```
git branch -d feature-x  # Safe delete (won't  
work if unmerged)
```

A clean branch list makes it easy to see what's in progress.

Resources & Next Steps

You're ready to explore. Here's your map:

Core References:

- `git --help <command>` (Your offline expert)
- **Pro Git Book** (<https://git-scm.com/book>) (The definitive guide)

Next-Level Skills (when you're ready):

- `git rebase -i`: Clean up local history *before* sharing
- `git bisect`: Find bugs with binary search

Mastery comes from daily use. Start committing to your own projects today.