Lecture #32

Git: A Case Study in System and Data-Structure Design

- Git is a distributed version-control system, apparently the most popular of these currently.
- Conceptually, it stores snapshots (*versions*) of the files and directory structure of a project, keeping track of their relationships, authors, dates, and log messages.
- It is *distributed,* in that there can be many copies of a given repository, each supporting independent development, with machinery to transmit and reconcile versions between repositories.
- Its operation is extremely fast (as these things go).

A Little History

- Developed by Linus Torvalds and others in the Linux community when the developer of their previous, propietary VCS (Bitkeeper) withdrew the free version.
- The initial implementation effort seems to have taken about 2–3 months, in time for the 2.6.12 Linux kernel release in June, 2005.
- As for the name, according to Wikipedia,

  > Torvalds has quipped about the name Git, which is British English slang meaning "unpleasant person". Torvalds said: "I'm an egotistical bastard, and I name all my projects after myself. First 'Linux', now 'git'." The man page describes Git as "the stupid content tracker."

- Initially, it was a collection of basic primitives (now called "plumbing") that could be scripted together to provide the desired functionality.
- Then, higher-level commands ("porcelain") was built on top of these to provide a convenient user interface.

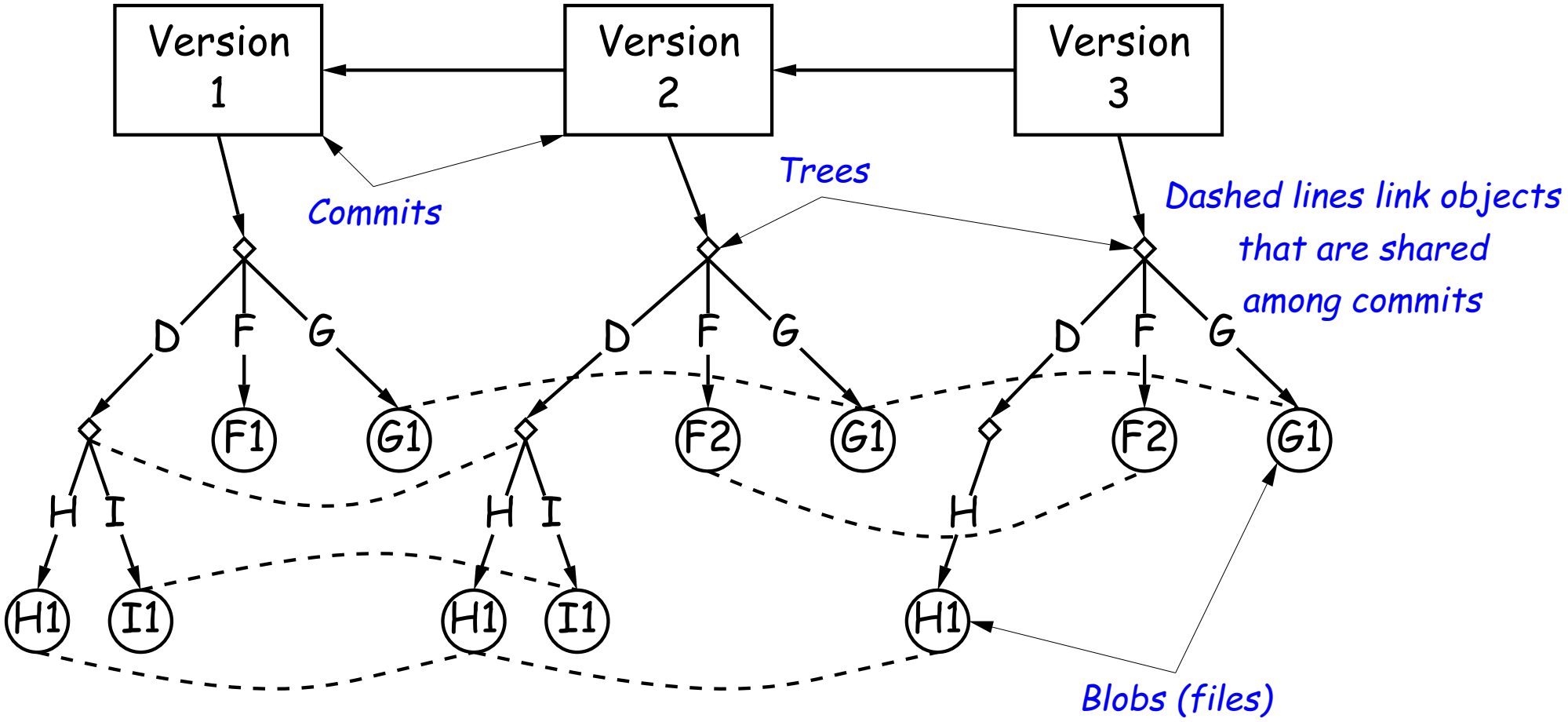
User-Level Conceptual Structure

- The main abstraction is that of a graph of versions or snapshots (called *commits*) of a complete project.
- The graph structure reflects ancestory: which versions came from which.
- Each commit contains
  - A directory tree of files (like a Unix directory).
  - Information about who committed and when.
  - Log message.
  - Pointers to commit (or commits, if there was a merge) from which the commit was derived.

Internal Structures

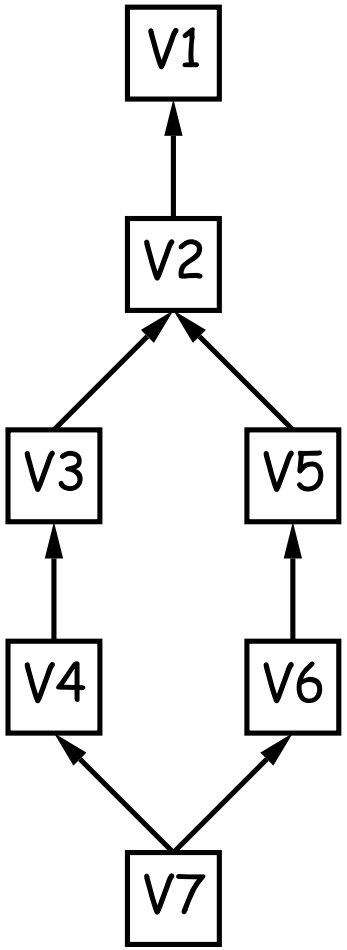
- The main internal components consist of four types of *object:*
  - *Blobs:* basically files of text or bytes.
  - *Trees:* directory structures of files.
  - *Commits:* objects containing references to trees, ancestor commits, and additional information (committer, date, log message).
  - *Tags:* references to commits or other objects, with additional information, intended to identify releases, other important versions, or various useful information. (We won't go into this today).

Commits, Trees, Files

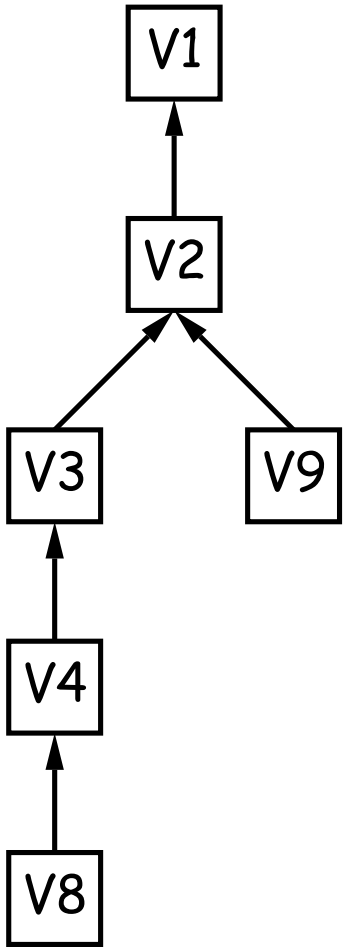


Version Histories in Two Repositories

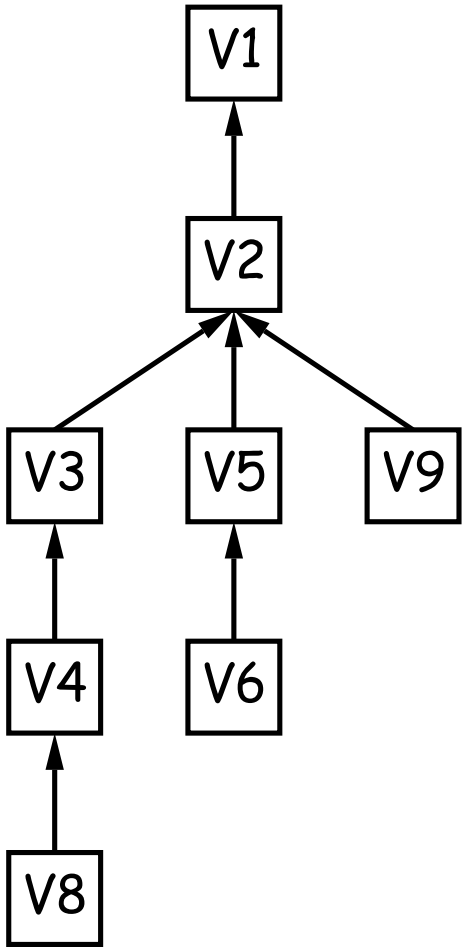
Repository 1



Repository 2



Repository 2
after pushing V6 to it



Major User-Level Features (II)

- Each commit has a name that uniquely identifies it to all repositories.
- Repositories can transmit collections of versions to each other.
- Transmitting a commit from repository A to repository B requires only the transmission of those objects (files or directory trees) that B does not yet have (allowing speedy updating of repositories).
- Repositories maintain named *branches*, which are simply identifiers of particular commits that are updated to keep track of the most recent commits in various lines of development.
- Likewise, *tags* are essentially named pointers to particular commits. Differ from branches in that they are not usually changed.

Internals

- Each Git repository is contained in a directory.
- A repository may either be *bare* (just a collection of objects and metadata), or it may be included as part of a working directory (where it is named `.git`).
- The data of the repository is stored in various *objects* represented as files corresponding to data files (or other "leaf" content), trees, and commits.
- To save space, data in these objects is *compressed*.
- Git can *garbage-collect* the objects from time to time to save additional space and can *pack* bunches of objects into compressed files.

The Pointer Problem

- Objects in Git are represented as files. How should we represent pointers between them (e.g., from trees to files, or from commits to trees and other commits)?
- We want to be able to *transmit* objects from one repository to another with different contents. How do you transmit the pointers?
  - . . . Since the address of an object on one machine is very unlikely to have anything to do its address on another.
- We only want to transfer those objects that are missing in the target repository. How do we know which those are?
- We could use a counter in each repository to give each object there a unique file name. But how can that work consistently for two independent repositories?

Content-Addressable File System

- Could use some way of naming objects that is universal.
- We use the names, then, as pointers.
- Solves the "Which objects don't you have?" problem in an obvious way.
- Conceptually, what is invariant about a version of an object, regardless of repository, is its *contents*.
- But we can't use the contents as the name for obvious reasons (like trying to use a country as its own map.)
- Idea: Use a *hash of the contents* as the address.
- Problem: That doesn't work!

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- Problem: That doesn't work!
- Brilliant Idea: Use it anyway!!

How A Broken Idea Can Work

- The idea is to use a hash function that is so unlikely to have a collision that we can ignore that possibility.
- *Cryptographic Hash Functions* have relevant properties.
- Such a function, f, is designed to withstand cryptoanalytic attacks. In particular, it should have
  - *Pre-image resistance:* given $h = f(m)$, it should be computationally infeasible to find such a message m, given h.
  - *Second pre-image resistance:* given message m_1, it should be infeasible to find $m_2 \neq m_1$ such that $f(m_1) = f(m_2)$.
  - *Collision resistance:* it should be difficult to find *any* two messages $m_1 \neq m_2$ such that $f(m_1) = f(m_2)$.
- With these properties, the scheme of using hashes of contents as names is extremely unlikely to fail, even when the system is used maliciously.

SHA1

- Git uses *SHA1* (Secure Hash Function 1).
- Can play around with this using the `hashlib` module in Python3.
- All object names in Git are therefore 160-bit hash codes of contents, in hex.
- E.g. a recent commit in the Spring 2022 shared CS61B repository could be fetched (if needed) with

```
git checkout 72c136ba61fb468bf4c8ac906cd57a2c7fa25025
```

Low-Level Blob Management

- You can find out the hashcode that Git uses for the blob containing file `something.java` with the command

```
git hash-object something.java
```

- And if this tells you that the file would have hash code

```
192a0ca0d159f1550b0b5e102f7e06867cc44782
```

  and you actually `git add` this file, its compressed contents will be stored (as a blob) in the file

```
.git/objects/19/2a0ca0d159f1550b0b5e102f7e06867cc44782
```

  [Why do you suppose the implementors of Git chose this name?]

- You can look at the (uncompressed) contents of the blob with

```
git cat-file -p 192a0ca0d159f1550b0b5e102f7e06867cc44782
```