Git's Content Addressable Storage

COS 316: Principles of Computer System Design

Lecture 5

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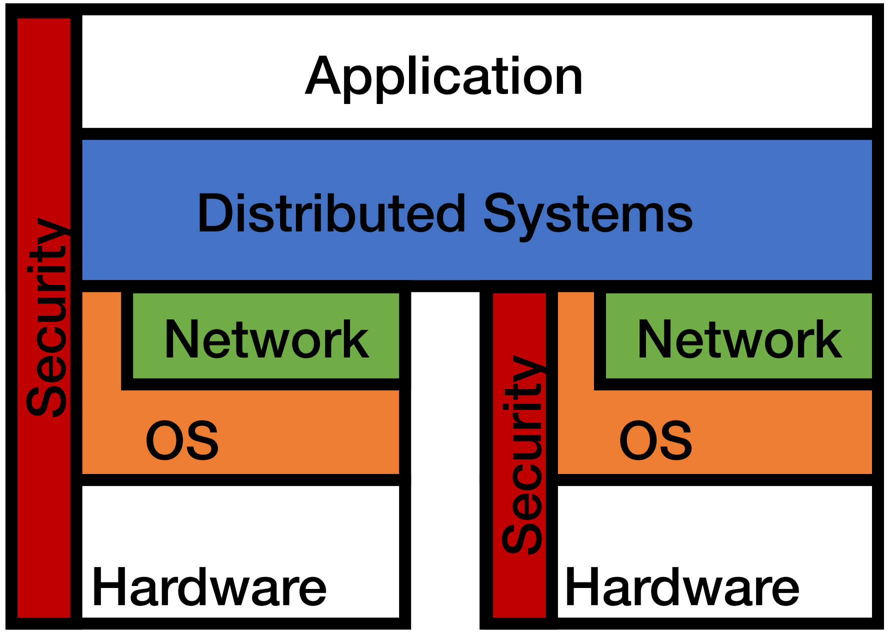
Naming Module

- Naming Overview (today)
  - Memory Naming
    - OS, Security
- Unix File System Naming
  - OS
- **Git Naming**
  - **OS, Distributed Systems**
- Network Naming
  - Networking



Today's Goals

- Compare centralized vs distributed version control
- Compare location- vs content-based naming
- Learn specifics of git's content-based naming
- Learn some specifics of git internals
- See more layering in action

Unix File System

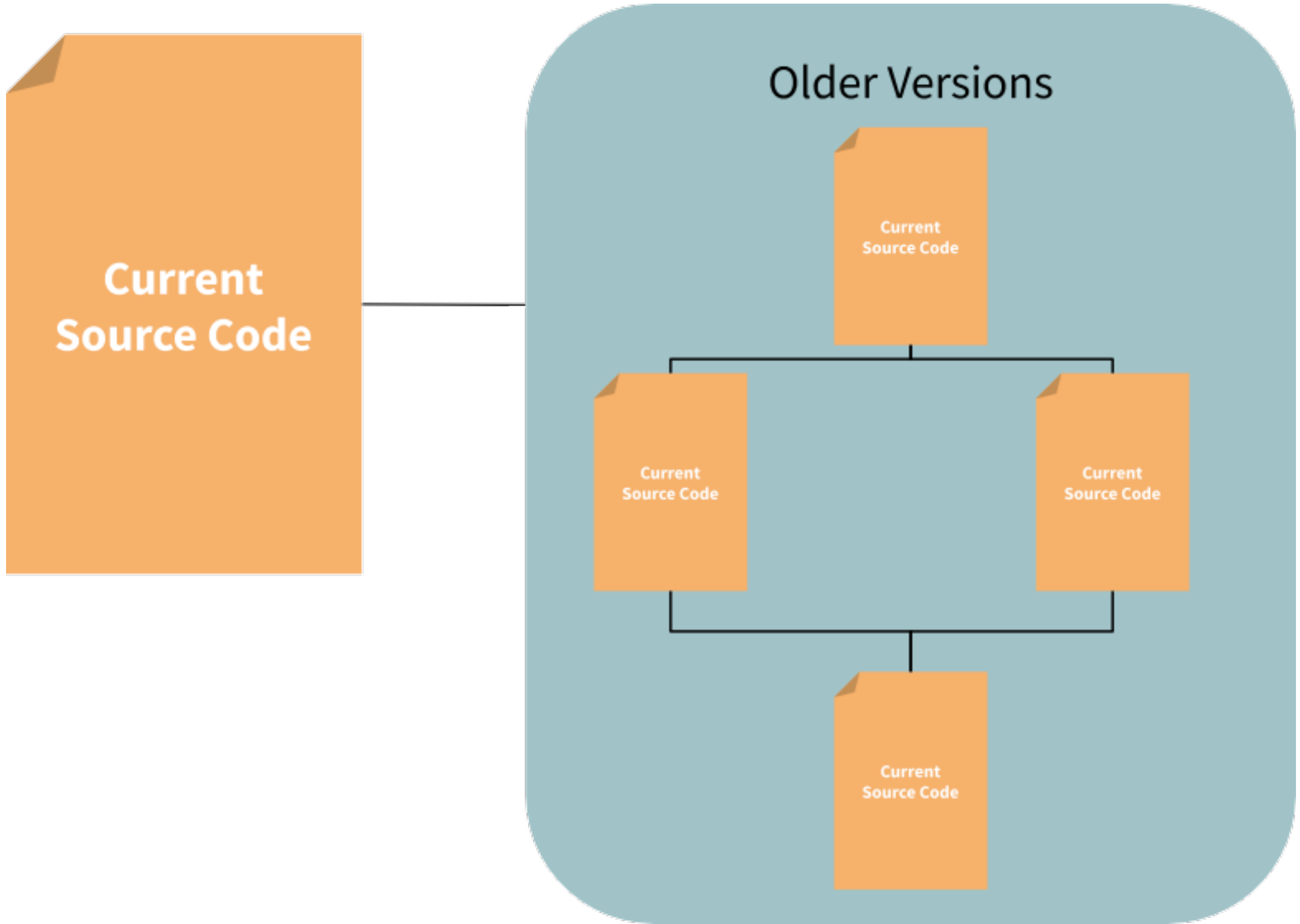
- An example of “location-based” naming schemes:
  - The block layer names blocks based on the order in which they appear on disk
  - The file layer names files based on where to find their blocks
  - The inode number layer gives files names that correspond to their block number or location within an inode table
  - The absolute path name layer provides the location of the root directory

Location-based naming scheme

Today: When do locations fall short

- UNIX File System takes a location-centric view of the data it stores
  - Point is: where on disk can I find this data I care about?
- When might this view be insufficient?
- Today: Git as a lens for:
  - How location-based names fall short
  - How content-based names can help

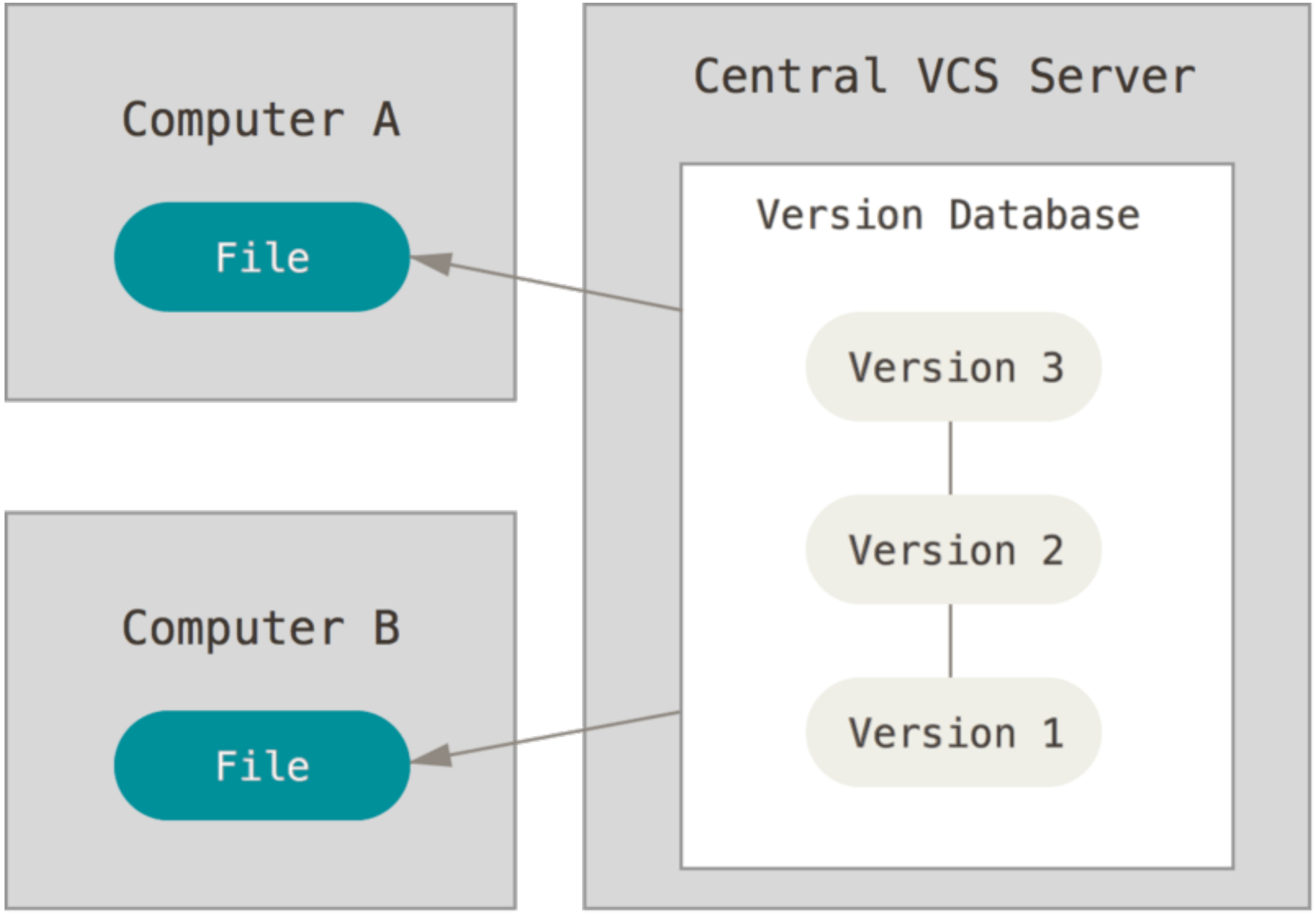
Version Control Overview



A Brief History of Version Control

- Local version control
  - 1972: Source Code Control System (SCCS) developed by early UNIX developers
  - 1982: Revision Control System (RCS) developed by GNU project
- Client/Server Centralized Version Control
  - 1986: Concurrent Versions System (CVS) developed as front-end to RCS to collaborate on Amsterdam Compiler Kit at Vrije University
  - 2000: Subversion (SVN) a redesign of CVS widely used by open source projects
- Distributed Version Control
  - 2000: BitKeeper developed to address Linux's distributed and large community development model
  - 2005: Git & Mercurial developed concurrently to replace BitKeeper after BitMover starts charging open source projects.

Centralized Version Control



Centralized Version Control

- Central server holds “canonical” version of each file
- Files committed and versioned independently
- Typically only one or a few checkouts of a file
- Conflicts between developers expected to be rare
- All versioning and conflict resolution mediated by the server

Main role: efficiently store versions of the same file and coordinate updates to individual files.

UNIX file system is a pretty good match!

Centralized Version Control Shortcomings…

- Are the set of files in the canonical version collectively valid?

- Not egalitarian: What if we don’t want just one “central” server?
  - P2P collaboration, hierarchical, etc.

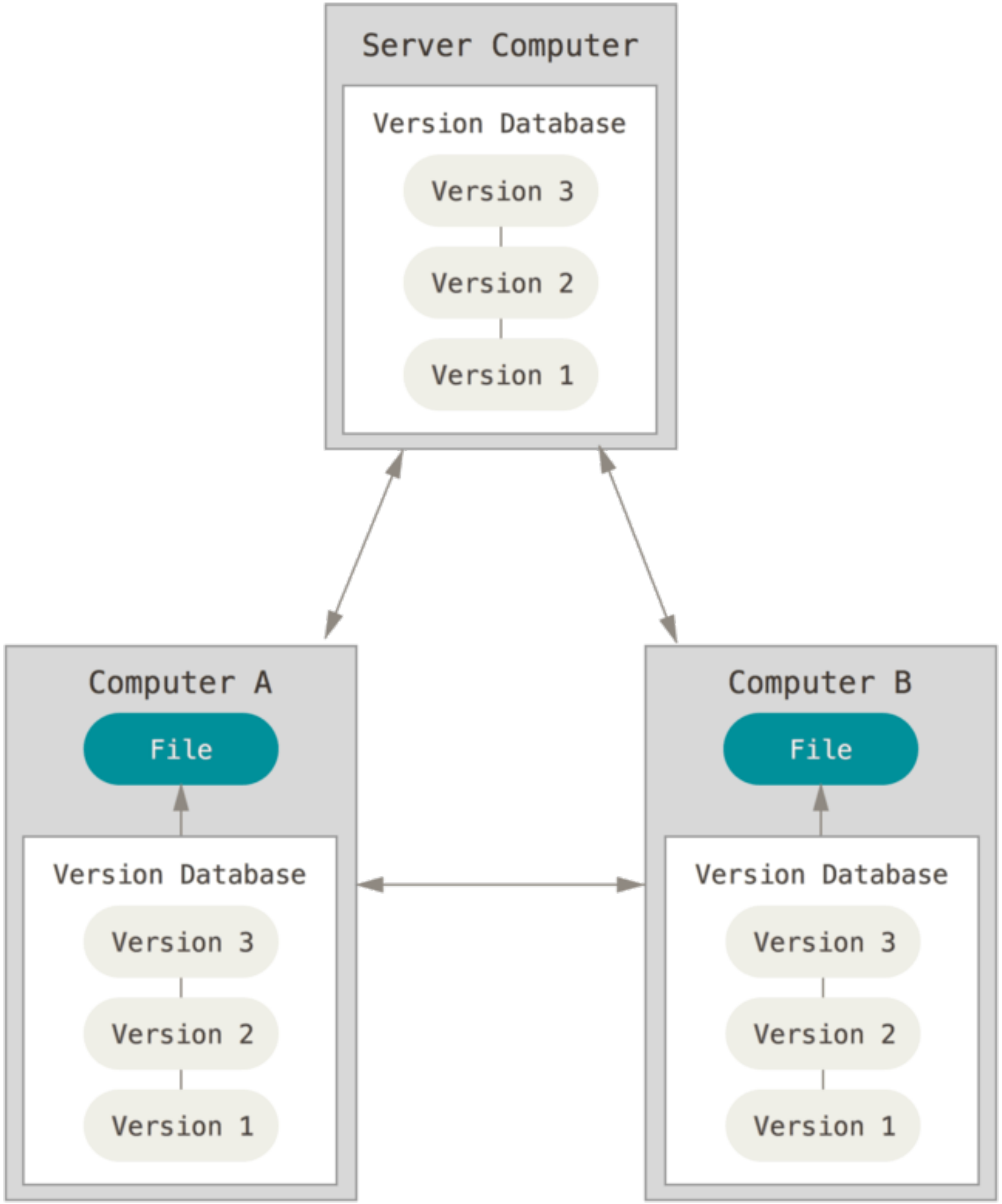
- What happens if the data on the central server is corrupted?

Distributed Version Control

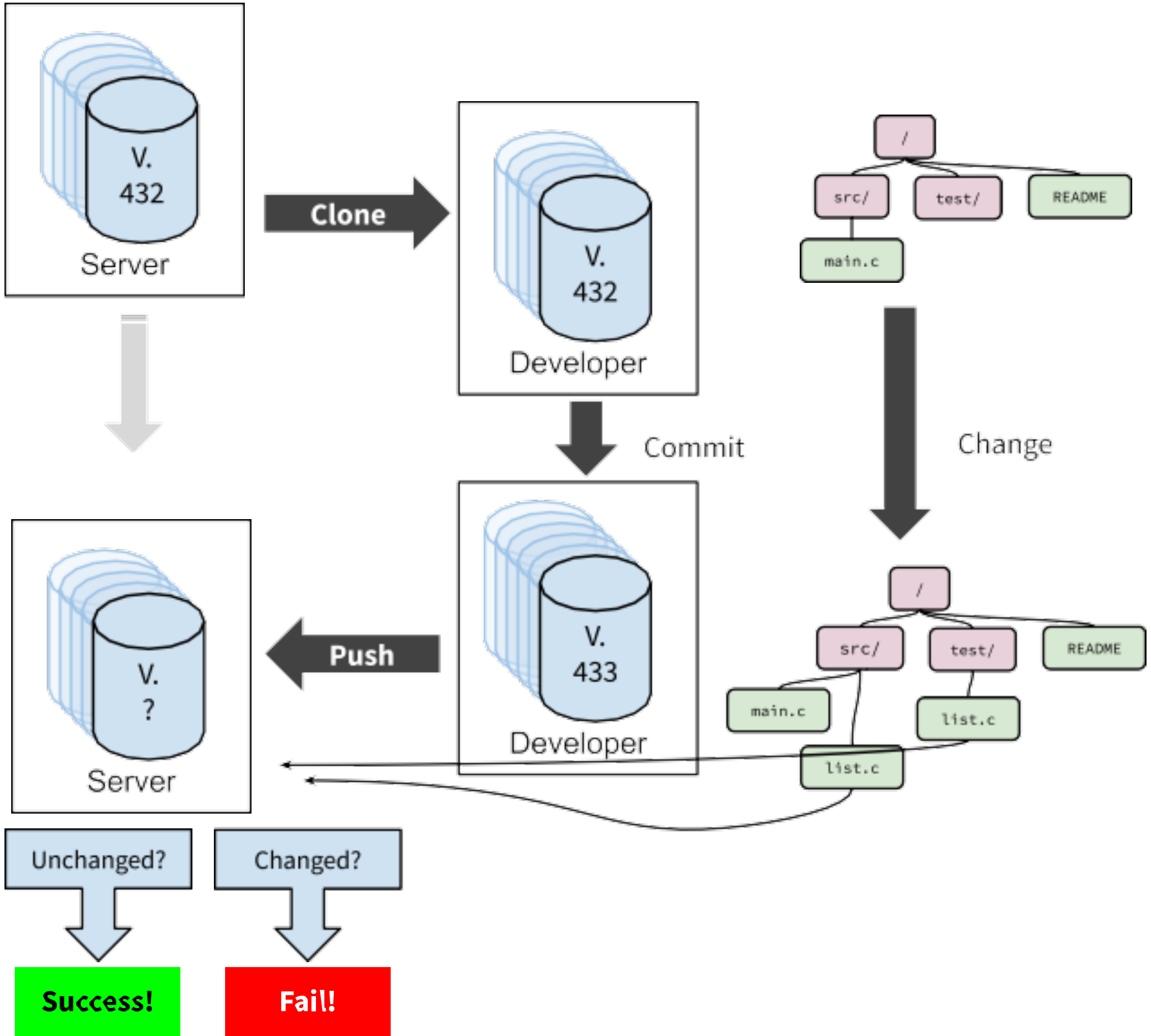
- Two important differences from centralized:

1. No inherent "canonical" version
2. Unit of a commit is a complete source code tree
    - Each "version" represents a state that *some* developer intended at *some* time
    - Versioning *files* is incidental

Distributed Version Control



Distributed Version Control Workflow Ex



How would we do this with the UNIX file system?

- We need a simple way to succinctly name files, trees, commits, etc. such that we can easily compare them.

- We need to efficiently store and transmit many versions of source code tree. Most files in each version will be unchanged.

The Content-based Address

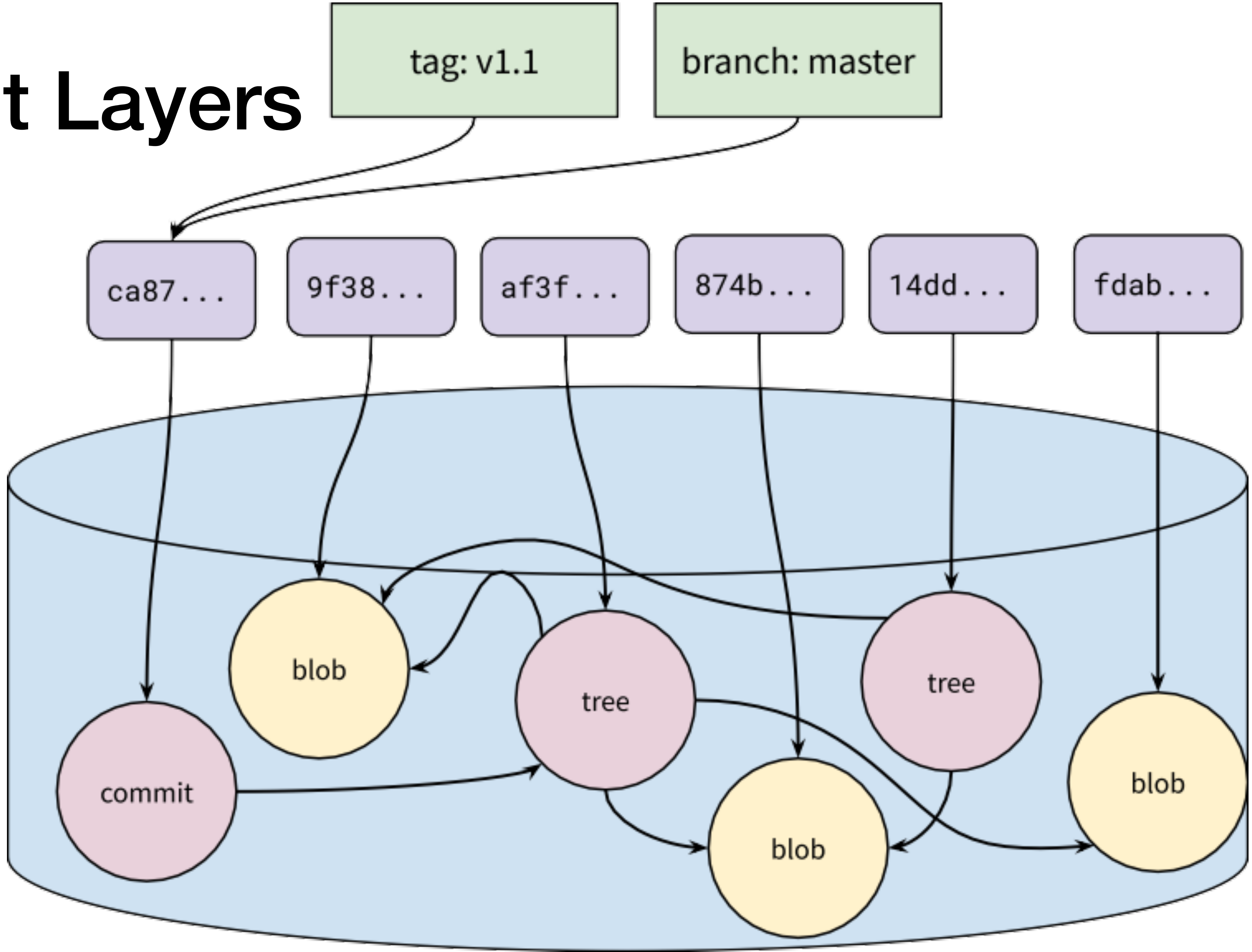
- A succinct summary of the content
- that's unique for different content
- and the same for the same content

- Cryptographic hash functions maps arbitrary size data to a fixed-sized bit-string that is:
  - Deterministic
  - Computationally "hard" to generate a message that yields a specific hash value
  - Computationally "hard" to find two messages with the same hash value
  - Similar messages have dissimilar hashes

Git Layers

Layer	Purpose
Object	Stores objects in a content-addressable store
Tree	Organizes “blobs” into a directory-like hierarchy
Commit	Versions the tree layer
Reference	Provides human-readable names for trees, commits

Git Layers


tag: v1.1
branch: master
ca87...
9f38...
af3f...
874b...
14dd...
fdab...
blob
tree
tree
commit
blob
blob

Object Layer

- "Objects" are the basic storage unit in Git, like blocks in the UNIX file system
  - *All data is stored as objects*

- **Names:**
  - The SHA-1 hash of the object's content: 40-byte string in hex (160-bits)
    - `aa8074278ed2c4803a2a545f277d1e0afe5039c3`

- **Values**
  - Blobs: similar to files
  - Trees: similar to directories
  - Commits: points to tree and previous commit

Object Layer

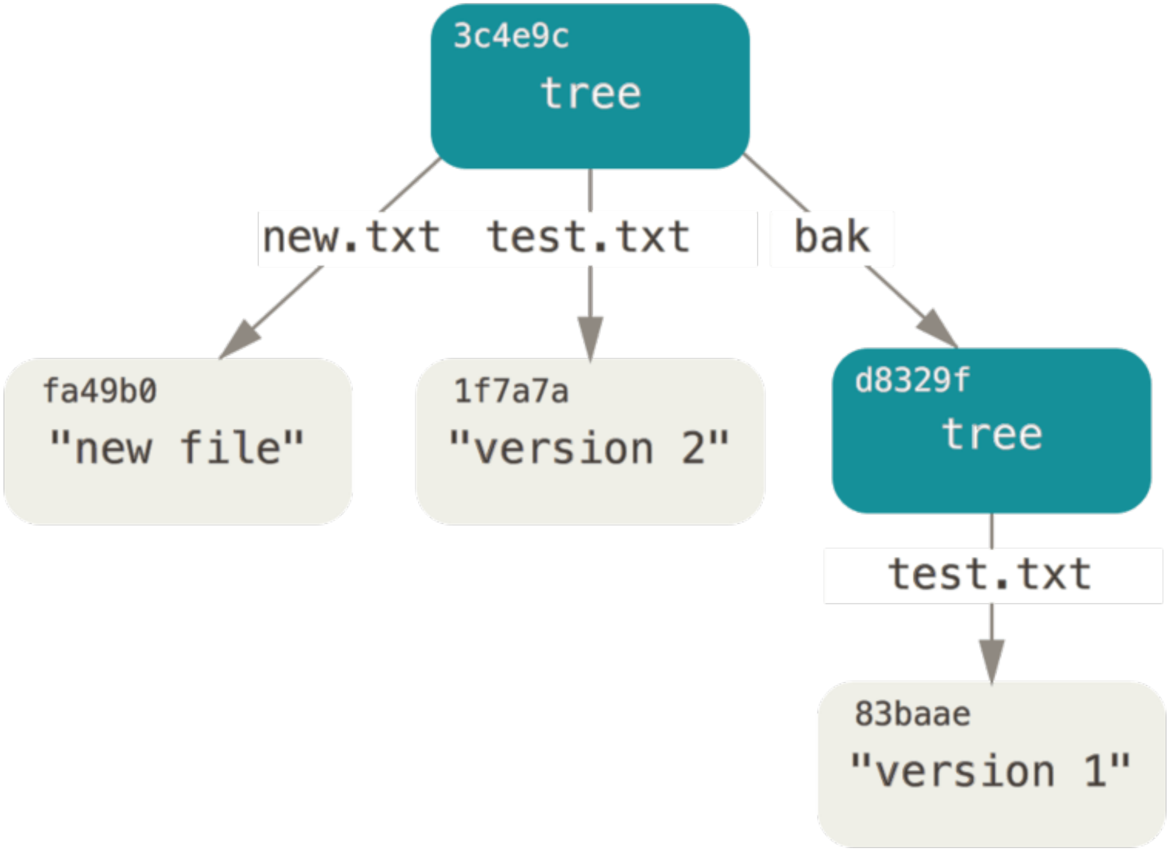
- **Allocation**
    - Names “allocated” by taking the hash of the object content

- **Lookup**
    - Git uses the UNIX file system to store objects on disk
        - We need to translate to locations at some point
    - Objects stored in a directory `.git/objects`
    - Filename is the 40-byte hex string of the object’s name

Tree Layer

- Similar to, and modeled after, directories in the UNIX file system

- Provide hierarchy of trees and blobs that can be traversed using human-meaningful names.



Tree Layer

- **Names**
  - Human-readable strings, just like in UNIX directories
- **Values**
  - Object name
  - Object type
  - Permissions (a subset of UNIX permissions)
- **Allocation**
  - Names are supplied by the user, just like in UNIX
  - Generally, git mirrors an actual directory structure

Tree Layer

- **Lookup**
  - Trees stored as a list of entries, similar to directories

```
$ git cat-file -p 3914fbcc30ea8092034ca5ea4e6ebd0c887495df
100644 blob 96e87117fc618fc54a770bfc938405a29cca1fbb      .gitignore
100644 blob 077b93358fba58cacc6acaf098baa317408aa16e      Makefile
100644 blob 7addb405782f208c54f6d31182e173304ee117b9      README.md
040000 tree 303c20a830ce296d625fbf0fe4e4cd99fc33f3b1      http_router
040000 tree 85c17ff71ae5cfafcb1affebc4fbc1e8e67bd23c      microblog-client
040000 tree a7dc7cfb0850fbfd4fcdf49310fd2e757cb42c08      microblog-server
```

Commit Layer

- The commit layer gives Git a way to express a version history of the source code tree. Commit objects contain
  - A reference to the tree
  - Metadata about the tree (the author of this version, when it was "committed", a message describing the changes from the previous version, etc…)
  - A reference to the previous commit

Commit Layer

- **Names**
    - The SHA-1 hash of the value

- **Values**
    - Object name of the tree
    - Object name of the parent commit(s)
    - Author/committer name and e-mail, and date committed
    - Message as a string

Commit Layer

- **Allocation**
  - Names “allocated” by taking the hash of the object content

- **Lookup**
  - Commit objects have a defined format such that each name has a particular location in the object

Reference Layer

- Commits, trees, and blobs names not convenient for humans
  - Can’t remember hashes
  - Not useful for discovery
  - *Need some point of synchronization*
    - e.g., how do we know which is the most recent commit?

- References provide global, human readable names for objects

Reference Layer

- **Names**
  - Human readable names: e.g., “master”, “wlloyd/wip”, “HEAD”
- **Values**
  - A commit name

Reference Layer

- **Allocation**
  - Reference names are assigned and managed by users
  - Some standard reference names by convention:
    - master: refers to the most recent “canonical” version of the source code
    - HEAD: refers to the most recently committed tree on the local repository
    - origin/*: refers to a reference on the “origin” repository, where this repository was cloned from
- **Lookup**
  - Stored as UNIX files in a special subdirectory of the .git directory
  - Each reference is a file containing the name of the object they refer to

Contrasting Location-based Names & Content-based Names

Layers of Names

Both systems we looked at use layers of simple naming schemes

- Makes reasoning easier
- UNIX File System
  - Blocks, files, inode numbers, directories, absolute path
- Git
  - Objects, blobs, trees, references
- Allow extensibility at multiple levels
  - Can re-use block layer for other storage systems, e.g., databases
- Allows portability at multiple levels
  - Can port files & directories to non-block storage

Economy of mechanism

- Both systems we looked at reuse mechanisms where possible

- UNIX file system
  - Stores everything in blocks: inodes, file data, file system metadata
  - Reuses inodes for files and directories

- Git
  - Stores everything in objects: blobs, trees, commits
  - Single naming allocation scheme: secure hash function

Naming Design Trade-offs

	Location-based	**Content-based**
Necessary?	Yes!	No
Discovery	Easy	Hard
Decentralized	No	Yes
Integrity	Hard	Easy
Transactions	Hard	Easy

Summary

- Compared centralized vs distributed version control
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- Learned specifics of git's content-based naming
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- Saw more layering in action