## The Git Object Model

### The SHA

All the information needed to represent the history of a project is stored in files referenced by a 40-digit "object name" that looks something like this:

6ff87c4664981e4397625791c8ea3bbb5f2279a3

The SHA1 hash is a cryptographic hash function. What that means to us is that it is virtually impossible to find two different objects with the same name. This has a number of advantages; among others:

* Git can quickly determine whether two objects are identical or not, just by comparing names.
* Since object names are computed the same way in every repository, the same content stored in two repositories will always be stored under the same name.
* Git can detect errors when it reads an object, by checking that the object's name is still the SHA1 hash of its contents

### The Objects

Every object consists of three things - a **type**, a **size** and **content**. The *size* is simply the size of the contents, the contents depend on what type of object it is, and there are four different types of objects: "blob", "tree", "commit", and "tag".

* A **"blob"** is used to store file data - it is generally a file.
* A **"tree"** is basically like a directory - it references a bunch of other trees and/or blobs (i.e. files and sub-directories)
* A **"commit"** points to a single tree, marking it as what the project looked like at a certain point in time. It contains meta-information about that point in time, such as a timestamp, the author of the changes since the last commit, a pointer to the previous commit(s), etc.
* A **"tag"** is a way to mark a specific commit as special in some way. It is normally used to tag certain commits as specific releases or something along those lines.

Almost all of Git is built around manipulating this simple structure of four different object types. It is sort of its own little filesystem that sits on top of your machine's filesystem.

It is important to note that this is very different from most SCM systems that you may be familiar with. Subversion, CVS, Perforce, Mercurial and the like all use Delta Storage systems - they store the differences between one commit and the next. Git does not do this - it stores a snapshot of what all the files in your project look like in this tree structure each time you commit. This is a very important concept to understand when using Git.

### Blob Object

A blob generally stores the contents of a file.

You can use git-show to examine the contents of any blob. Since the blob is entirely defined by its data, if two files in a directory tree (or in multiple different versions of the repository) have the same contents, they will share the same blob object. The object is totally independent of its location in the directory tree, and renaming a file does not change the object that file is associated with

### Tree Object

A tree is a simple object that has a bunch of pointers to blobs and other trees - it generally represents the contents of a directory or subdirectory.

The ever-versatile git-show command can also be used to examine tree objects, but :git-ls-tree will give you more details.

### Commit Object

The "commit" object links a physical state of a tree with a description of how we got there and why.

You can use the --pretty=raw option to git-show or git-log to examine your favorite commit.

A commit is defined by:

* a **tree**: The SHA1 name of a tree object (as defined below), representing the contents of a directory at a certain point in time.
* **parent(s)**: The SHA1 name of some number of commits which represent the immediately previous step(s) in the history of the project. The example above has one parent; merge commits may have more than one. A commit with no parents is called a "root" commit, and represents the initial revision of a project. Each project must have at least one root. A project can also have multiple roots, though that isn't common (or necessarily a good idea).
* an **author**: The name of the person responsible for this change, together with its date.
* a **committer**: The name of the person who actually created the commit, with the date it was done. This may be different from the author; for example, if the author wrote a patch and emailed it to another person who used the patch to create the commit.
* a **comment** describing this commit.

A commit is usually created by git-commit, which creates a commit whose parent is normally the current HEAD, and whose tree is taken from the content currently stored in the index.

### Tag Object

A tag object contains an object name (called simply 'object'), object type, tag name, the name of the person ("tagger") who created the tag, and a message, as can be seen using git-cat-file.

$ git cat-file tag v1.5.0

git-tag can also be used to create "lightweight tags", which are not tag objects at all, but just simple references whose names begin with "refs/tags/"

## Git Directory and Working Directory

### The Git Directory

The 'git directory' is the directory that stores all Git's history and meta information for your project - including all of the objects (commits, trees, blobs, tags), all of the pointers to where different branches are and more.

There is only one Git Directory per project (as opposed to one per subdirectory like with SVN or CVS), and that directory is (by default, though not necessarily) '.git' in the root of your project. If you look at the contents of that directory, you can see all of your important files:

$>tree -L 1

.

|-- HEAD # pointer to your current branch

|-- config # your configuration preferences

|-- description # description of your project

|-- hooks/ # pre/post action hooks

|-- index # index file (see next section)

|-- logs/ # a history of where your branches have been

|-- objects/ # your objects (commits, trees, blobs, tags)

`-- refs/ # pointers to your branches

### The Working Directory

The Git 'working directory' is the directory that holds the current checkout of the files you are working on. Files in this directory are often removed or replaced by Git as you switch branches - this is normal. All your history is stored in the Git Directory; the working directory is simply a temporary checkout place where you can modify the files until your next commit.

## The Git Index

The Git index is used as a staging area between your working directory and your repository. You can use the index to build up a set of changes that you want to commit together. When you create a commit, what is committed is what is currently in the index, not what is in your working directory.

The easiest way to see what is in the index is with the git-status command. When you run git status, you can see which files are staged (currently in your index), which are modified but not yet staged, and which are completely untracked.

## How Git Stores Objects

All objects are stored as compressed contents by their sha values.

If the sha of your object is ab04d884140f7b0cf8bbf86d6883869f16a46f65, then the file will be stored in the following path:

.git/objects/ab/04d884140f7b0cf8bbf86d6883869f16a46f65

It pulls the first two characters off and uses that as the subdirectory, so that there are never too many objects in one directory. The actual file name is the remaining 38 characters.

## Browsing Git Objects

We can ask git about particular objects with the cat-file command. Note that you can shorten the shas to only a few characters to save yourself typing all 40 hex digits:

$ git cat-file -t 54196cc2

$ git cat-file -s 54196cc2

$ git cat-file -p 54196cc2

You can examine the contents of any tree using ls-tree

$ git ls-tree 92b8b694

All of these objects are stored under their SHA1 names inside the git directory and the contents of these files is just the compressed data plus a header identifying their length and their type. The type is either a blob, a tree, a commit, or a tag.

$ find .git/objects/

The simplest commit to find is the HEAD commit, which we can find from .git/HEAD:

$ cat .git/HEAD

ref: refs/heads/master

$ cat .git/refs/heads/master

c4d59f390b9cfd4318117afde11d601c1085f241

$ git cat-file -t c4d59f39

commit

The "tree" object here refers to the new state of the tree and the "parent" object refers to the previous commit:

## Git References

Branches, remote-tracking branches, and tags are all references to commits. All references are named with a slash-separated path name starting with "refs"; the names we've been using so far are actually shorthand:

- The branch "test" is short for "refs/heads/test".

- The tag "v2.6.18" is short for "refs/tags/v2.6.18".

- "origin/master" is short for "refs/remotes/origin/master

We can list all the heads in this repository with linkgit:git-show-ref

$ git show-ref --heads

$ git show-ref --tags

## The Git Index

The index is a binary file (generally kept in .git/index) containing a sorted list of path names, each with permissions and the SHA1 of a blob object; linkgit:git-ls-files[1] can show you the contents of the index:

$ git ls-files --stage

Computes the object ID value for an object with specified type with the contents of the named file

$ git hash-objec

## [Git from the inside out](https://maryrosecook.com/blog/post/git-from-the-inside-out)

The .git directory and its contents are Git’s. All the other files are collectively known as the working copy. They are the user’s.

### Add some files

$ git add data/letter.txt

This command has two effects.

* First, it creates a new blob file in the .git/objects/ directory.

For example, Git hashes the cotent to 2e65efe2a145dda7ee51d1741299f848e5bf752e. The first two characters are used as the name of a directory inside the objects database: .git/objects/2e/. The rest of the hash is used as the name of the blob file that holds the content of the added file: .git/objects/2e/65efe2a145dda7ee51d1741299f848e5bf752e.

* Second, git add adds the file to the index. The index is a list that contains every file that Git has been told to keep track of. It is stored as a file at .git/index.

### Make a commit

git commit -m 'a1'

The commit command has three steps. It creates a tree graph to represent the content of the version of the project being committed. It creates a commit object. It points the current branch at the new commit object

* Git records the current state of the project by creating a tree graph from the index. This tree graph records the location and content of every file in the project.

The graph is composed of two types of object: blobs and trees.

Blobs are stored by git add. They represent the content of files.

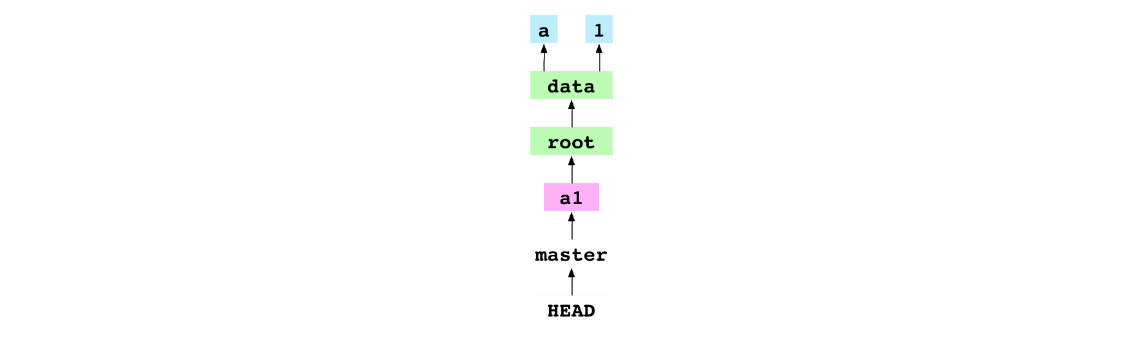
Trees are stored when a commit is made. A tree represents a directory in the working copy.

* git commit creates a commit object after creating the tree graph. The commit object is just another text file in .git/objects/:
* Finally, the commit command points the current branch at the new commit object. Which is the current branch? Git goes to the HEAD file at .git/HEAD and finds:

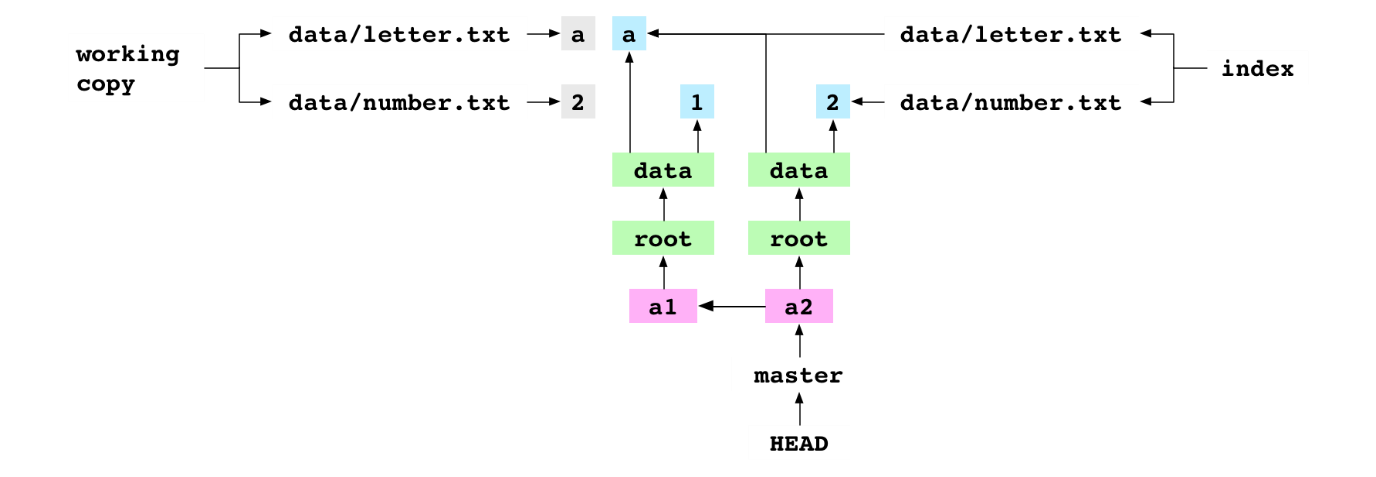
ref: refs/heads/master

This says that HEAD is pointing at master. master is the current branch.

HEAD and master are both refs. A ref is a label used by Git or the user to identify a specific commit.



HEAD pointing at master and master pointing at the a1 commit



### Check out a commit

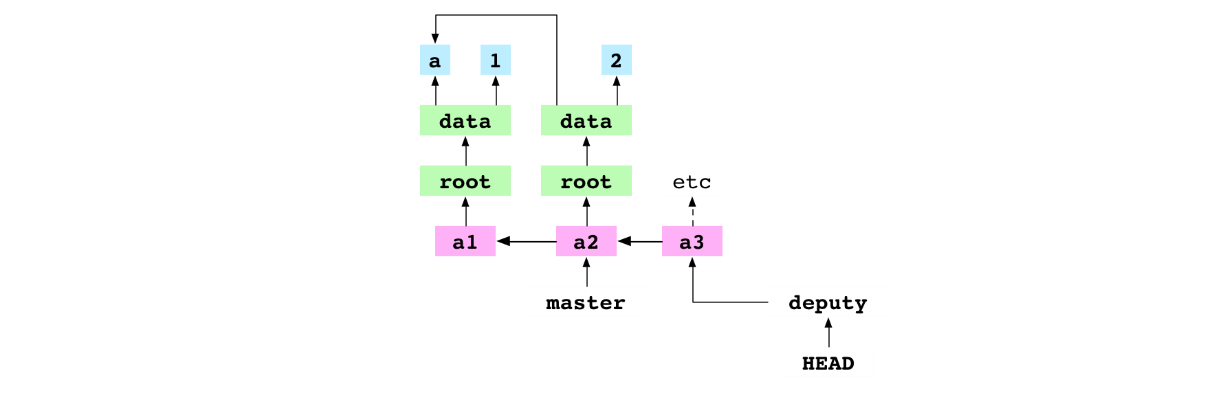
git checkout 37888c2

### Create a branch

git branch deputy

The user creates a new branch called deputy. This just creates a new file at .git/refs/heads/deputy that contains the hash that HEAD is pointing at: the hash of the a3 commit.

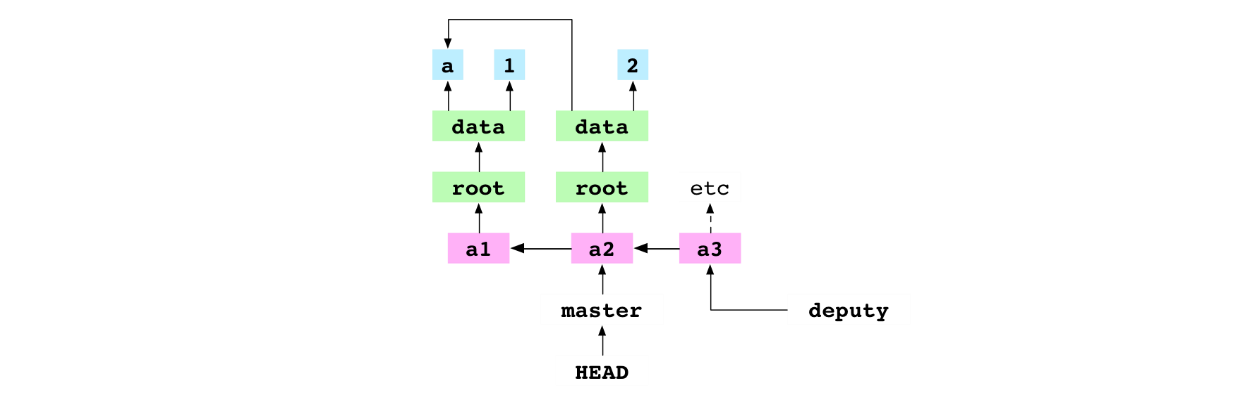
### Merge an ancestor



git merge master

Merging two branches means merging two commits. The first commit is the one that deputy points at: the receiver. The second commit is the one that master points at: the giver. For this merge, Git does nothing. It reports it is Already up-to-date.

### Merge a descendent



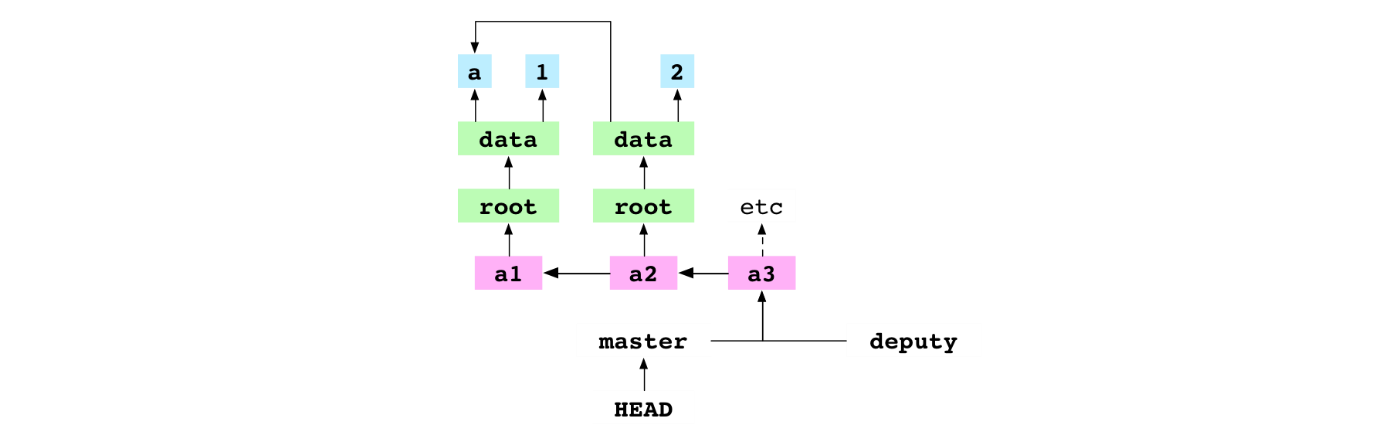
master checked out and pointing at the a2 commit

git checkout master

git merge deputy

They merge deputy into master. Git discovers that the receiver commit, a2, is an ancestor of the giver commit, a3. It can do a fast-forward merge.

It gets the giver commit and gets the tree graph that it points at. It writes the file entries in the tree graph to the working copy and the index. It “fast-forwards” master to point at a3.



a3 commit from deputy fast-forward merged into master

### Merge two commits from different lineages

$ printf '4' > data/number.txt

$ git add data/number.txt

$ git commit -m 'a4'

The user sets the content of number.txt to 4 and commits the change to master.

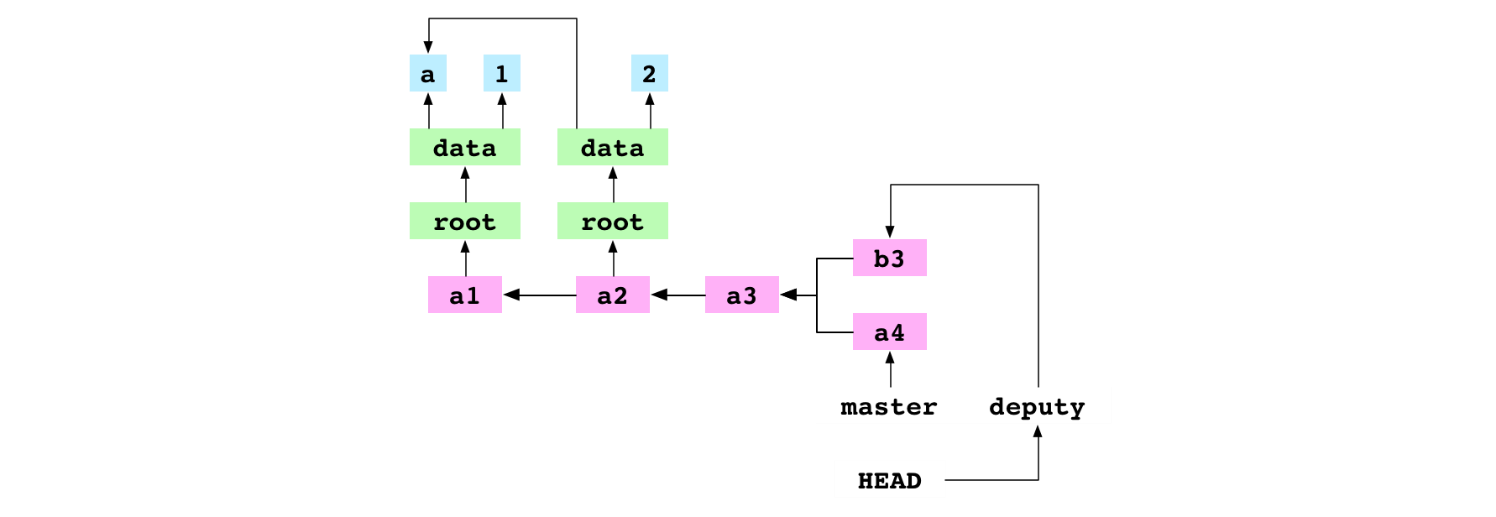
$ git checkout deputy

$ printf 'b' > data/letter.txt

$ git add data/letter.txt

$ git commit -m 'b3'

The user checks out deputy. They set the content of data/letter.txt to b and commit the change to deputy.



a4 committed to master, b3 committed to deputy and deputy checked out

The user merges master into deputy.

git merge master -m 'b4'

Git discovers that the receiver, b3, and the given, a4, are in different lineages. It makes a merge commit. This process has eight steps.

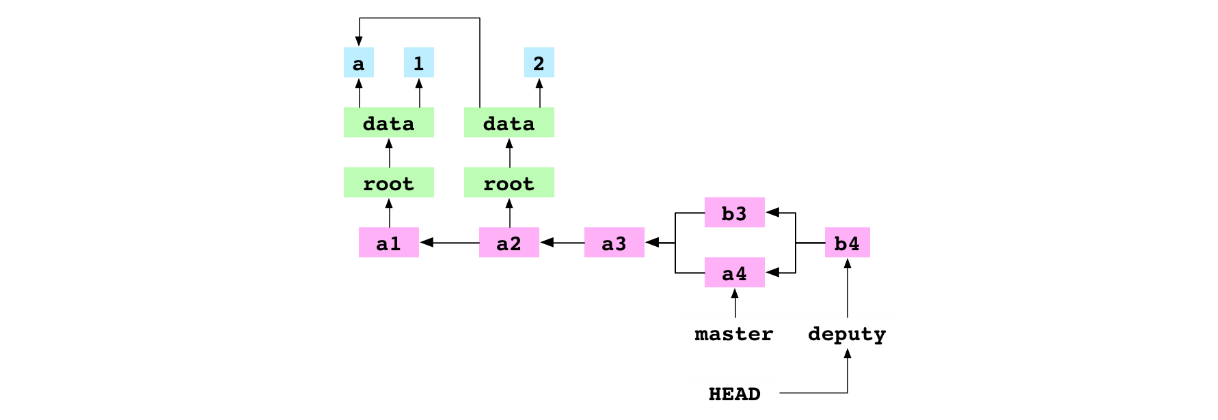
* First, Git writes the hash of the giver commit to a file at alpha/.git/MERGE\_HEAD. The presence of this file tells Git it is in the middle of merging.
* Second, Git finds the base commit: the most recent ancestor that the receiver and giver commits have in common.
* Third, Git generates the indices for the base, receiver and giver commits from their tree graphs.
* Fourth, Git generates a diff that combines the changes made to the base by the receiver commit and the giver commit. This diff is a list of file paths that point to a change: add, remove, modify or conflict.

Git gets the list of all the files that appear in the base, receiver or giver indices. For each one, it compares the index entries to decide the change to make to the file. It writes a corresponding entry to the diff. In this case, the diff has two entries.

The first entry is for data/letter.txt. The content of this file is a in the base, b in the receiver and a in the giver. The content is different in the base and receiver. But it is the same in the base and giver. Git sees that the content was modified by the receiver, but not the giver. The diff entry for data/letter.txt is a modification, not a conflict.

The second entry in the diff is for data/number.txt. In this case, the content is the same in the base and receiver, and different in the giver. The diff entry for data/letter.txt is also a modification.

* Fifth, the changes indicated by the entries in the diff are applied to the working copy. The content of data/letter.txt is set to b and the content of data/number.txt is set to 4.
* Sixth, the changes indicated by the entries in the diff are applied to the index. The entry for data/letter.txt is pointed at the b blob and the entry for data/number.txt is pointed at the 4 blob
* Seventh, the updated index is committed
* Eighth, Git points the current branch, deputy, at the new commit.



Notice that the commit has two parents.

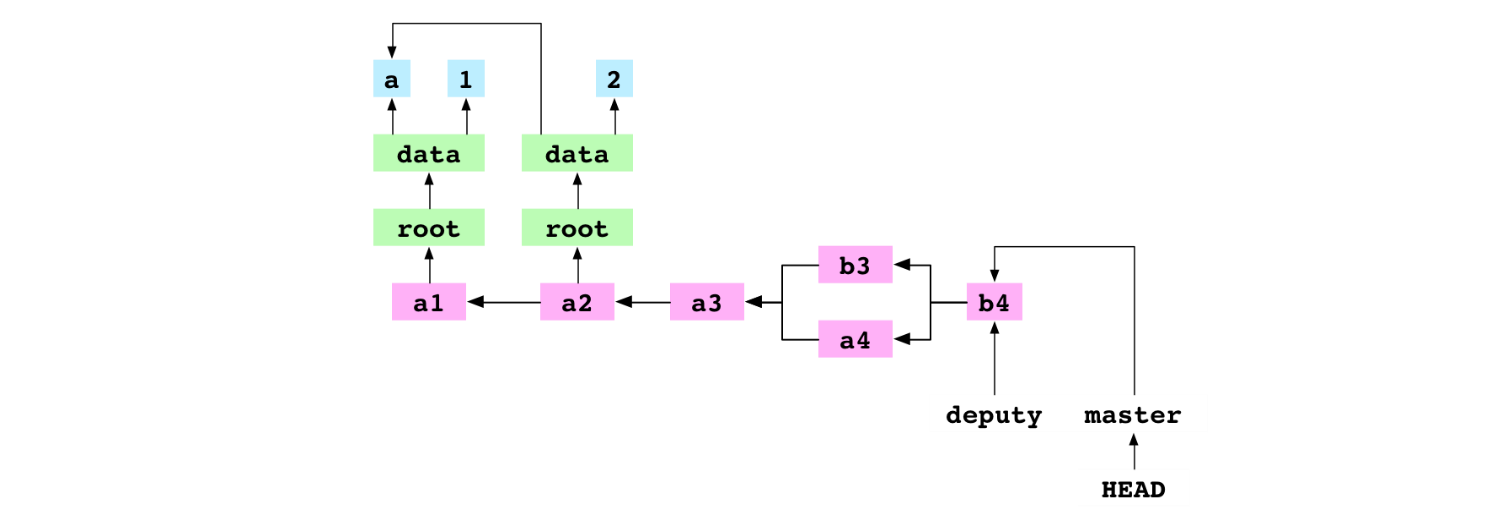
b4, the merge commit resulting from the recursive merge of a4 into b3

### Merge two commits from different lineages that both modify the same file

$ git checkout master

$ git merge deputy

The user checks out master. They merge deputy into master. This fast-forwards master to the b4 commit. master and deputy now point at the same commit.



deputy merged into master to bring master up to the latest commit, b4

The user checks out deputy. They set the content of data/number.txt to 5 and commit the change to deputy.

$ git checkout deputy

$ printf '5' > data/number.txt

$ git add data/number.txt

$ git commit -m 'b5'

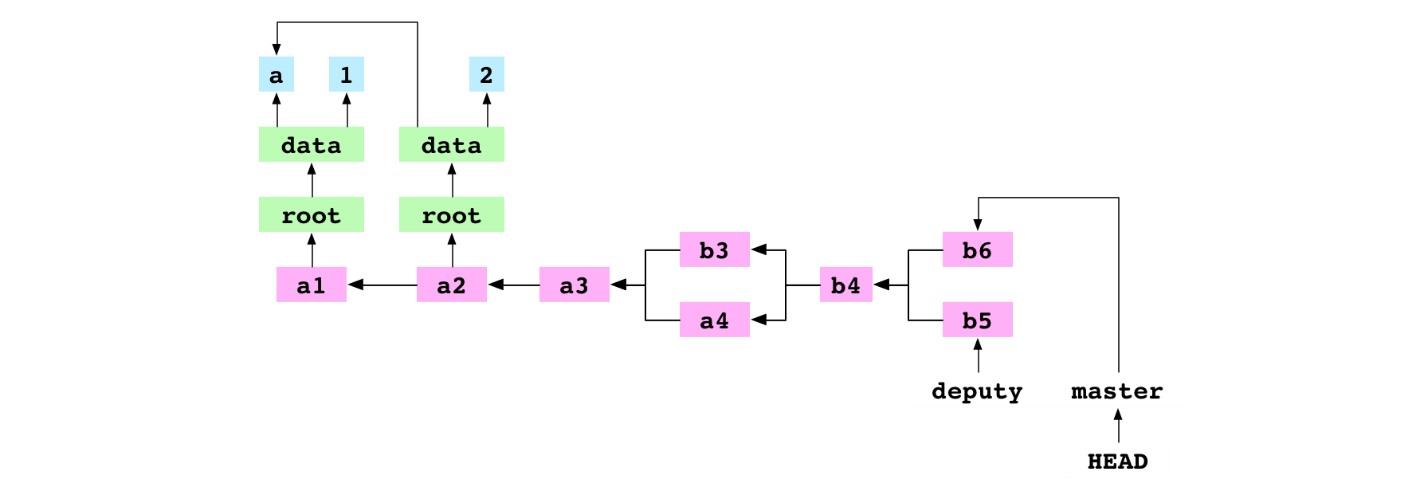
The user checks out master. They set the content of data/number.txt to 6 and commit the change to master.

$ git checkout master

$ printf '6' > data/number.txt

$ git add data/number.txt

$ git commit -m 'b6'



b5 commit on deputy and b6 commit on master

$ git merge deputy

The user merges deputy into master. There is a conflict and the merge is paused.

The user merges deputy into master. There is a conflict and the merge is paused. The process for a conflicted merge follows the same first six steps as the process for an unconflicted merge:

set .git/MERGE\_HEAD,

find the base commit,

generate the indices of the base, receiver and giver commits,

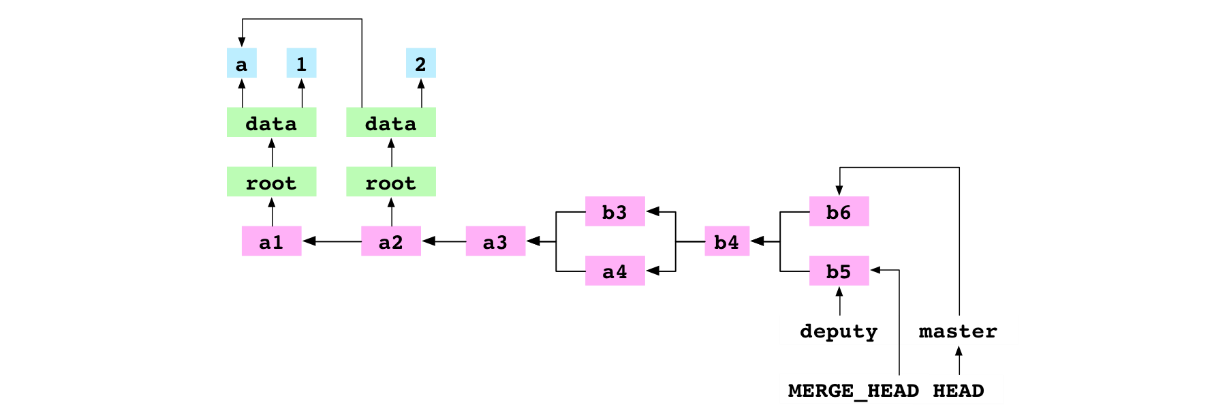
create a diff,

update the working copy

update the index.

Because of the conflict, the seventh commit step and eighth ref update step are never taken. Let’s go through the steps again and see what happens.

First, Git writes the hash of the giver commit to a file at .git/MERGE\_HEAD



MERGE\_HEAD written during merge of b5 into b6

Second, Git finds the base commit, b4.

Third, Git generates the indices for the base, receiver and giver commits.

Fourth, Git generates a diff that combines the changes made to the base by the receiver commit and the giver commit. This diff is a list of file paths that point to a change: add, remove, modify or conflict.

In this case, the diff contains only one entry: data/number.txt. The entry is marked as a conflict because the content for data/number.txt is different in the receiver, giver and base.

Fifth, the changes indicated by the entries in the diff are applied to the working copy. For a conflicted area, Git writes both versions to the file in the working copy. The content of data/number.txt is set to:

<<<<<<< HEAD

6

=======

5

>>>>>>> deputy

Sixth, the changes indicated by the entries in the diff are applied to the index. Entries in the index are uniquely identified by a combination of their file path and stage. The entry for an unconflicted file has a stage of 0. Before this merge, the index looked like this, where the 0s are stage values:

0 data/letter.txt 63d8dbd40c23542e740659a7168a0ce3138ea748

0 data/number.txt 62f9457511f879886bb7728c986fe10b0ece6bcb

After the merge diff is written to the index, the index looks like this:

0 data/letter.txt 63d8dbd40c23542e740659a7168a0ce3138ea748

1 data/number.txt bf0d87ab1b2b0ec1a11a3973d2845b42413d9767

2 data/number.txt 62f9457511f879886bb7728c986fe10b0ece6bcb

3 data/number.txt 7813681f5b41c028345ca62a2be376bae70b7f61

he entry for data/letter.txt at stage 0 is the same as it was before the merge. The entry for data/number.txt at stage 0 is gone. There are three new entries in its place. The entry for stage 1 has the hash of the base data/number.txt content. The entry for stage 2 has the hash of the receiver data/number.txt content. The entry for stage 3 has the hash of the giver data/number.txt content. The presence of these three entries tells Git that data/number.txt is in conflict.

The merge pauses

~/alpha $ printf '11' > data/number.txt

~/alpha $ git add data/number.txt

The user integrates the content of the two conflicting versions by setting the content of data/number.txt to 11. They add the file to the index. Git adds a blob containing 11. Adding a conflicted file tells Git that the conflict is resolved. Git removes the data/number.txt entries for stages 1, 2 and 3 from the index. It adds an entry for data/number.txt at stage 0 with the hash of the new blob. The index now reads:

0 data/letter.txt 63d8dbd40c23542e740659a7168a0ce3138ea748

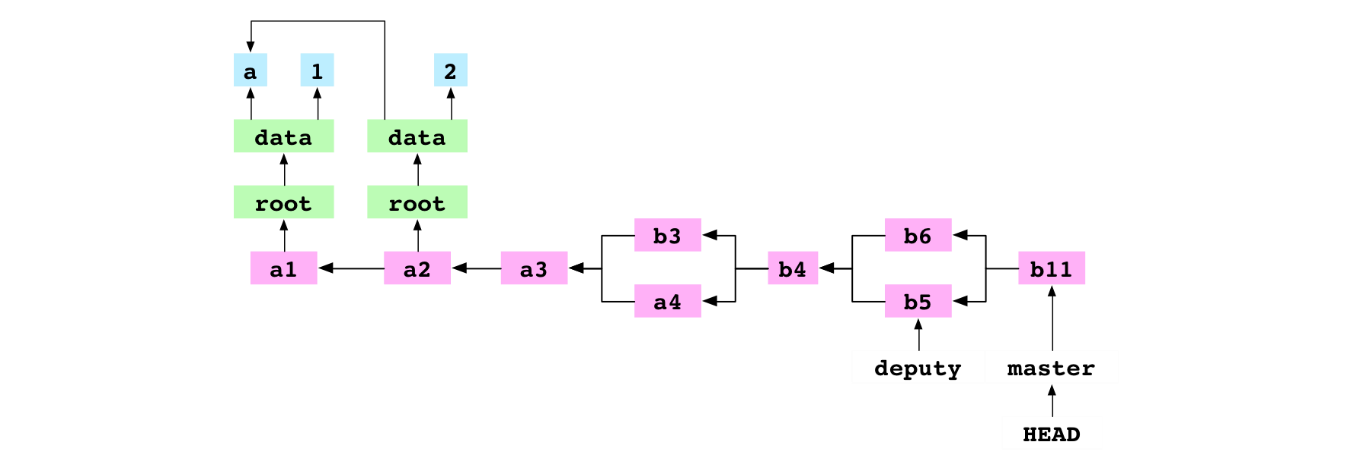
0 data/number.txt 9d607966b721abde8931ddd052181fae905db503

Seventh, the user commits.

git commit -m 'b11'

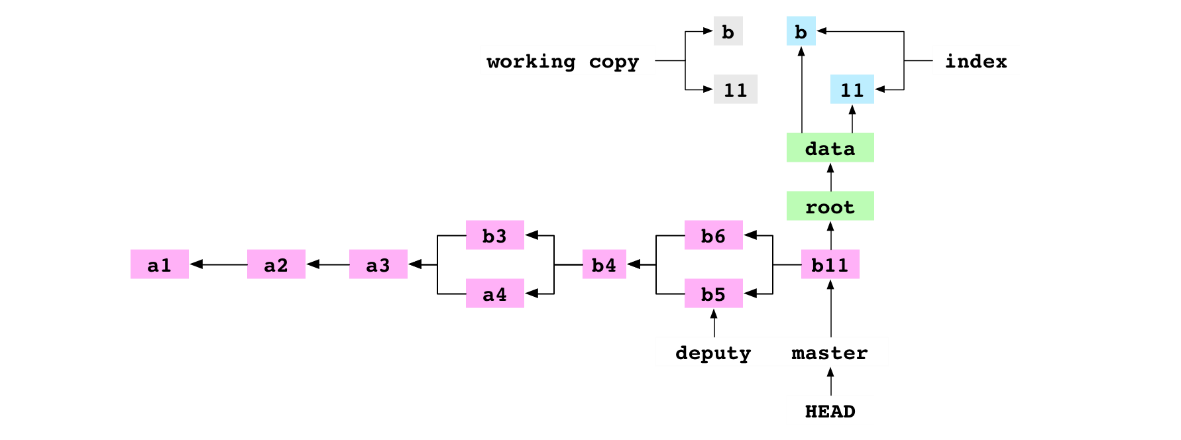
Git sees .git/MERGE\_HEAD in the repository, which tells it that a merge is in progress. It checks the index and finds there are no conflicts. It creates a new commit, b11, to record the content of the resolved merge. It deletes the file at .git/MERGE\_HEAD. This completes the merge.

Eighth, Git points the current branch, master, at the new commit



b11, the merge commit resulting from the conflicted, recursive merge of b5 into b6

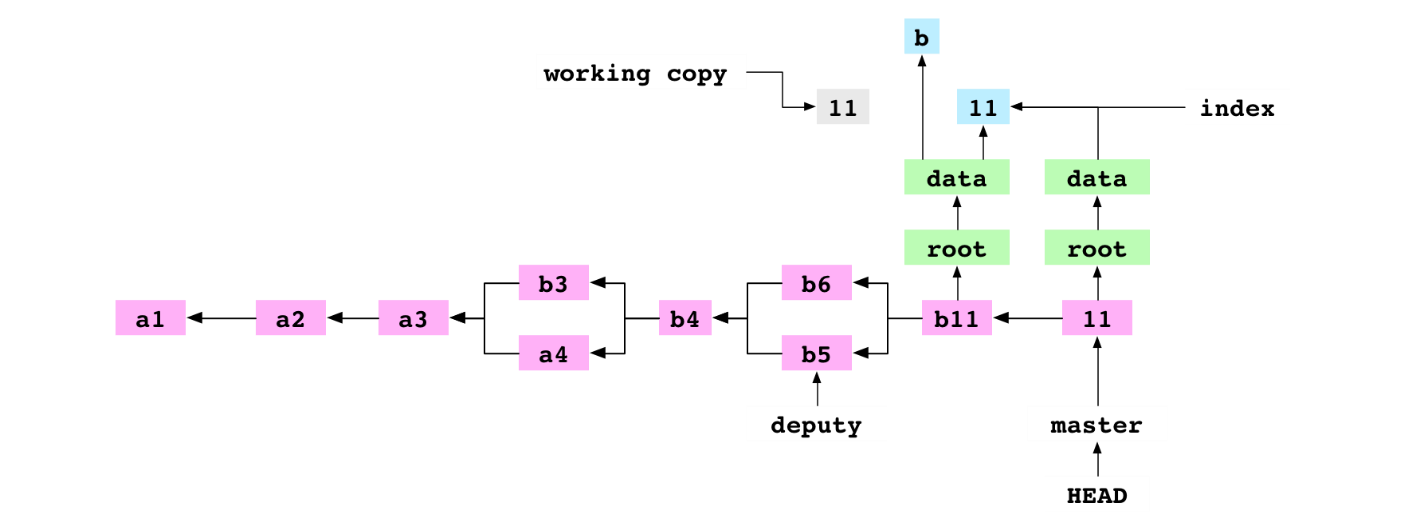
### Remove a file



git rm data/letter.txt

The user tells Git to remove data/letter.txt. The file is deleted from the working copy. The entry is deleted from the index

git commit -m '11'



11 commit made after data/letter.txt rm ed

### Copy a repository

~/alpha $ cd ..

~ $ cp -R alpha bravo

The user copies the contents of the alpha/ repository to the bravo/ directory. This produces the following directory structure:

├── alpha

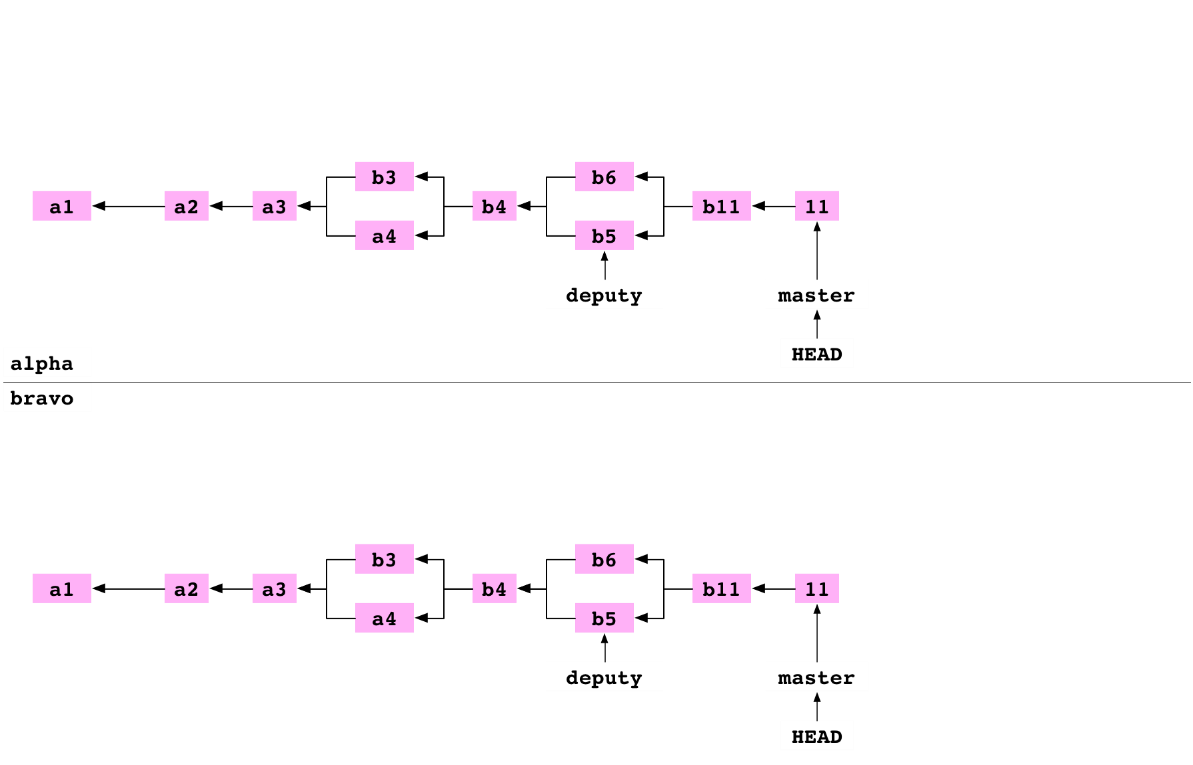
| └── data

| └── number.txt

└── bravo

└── data

└── number.txt



New graph created when alpha cp ed to bravo

### Link a repository to another repository

~ $ cd alpha

~/alpha $ git remote add bravo ../bravo

The user moves back into the alpha repository. They set up bravo as a remote repository on alpha. This adds some lines to the file at alpha/.git/config:

[remote "bravo"]

url = ../bravo/

These lines specify that there is a remote repository called bravo in the directory at ../bravo.

### Fetch a branch from a remote

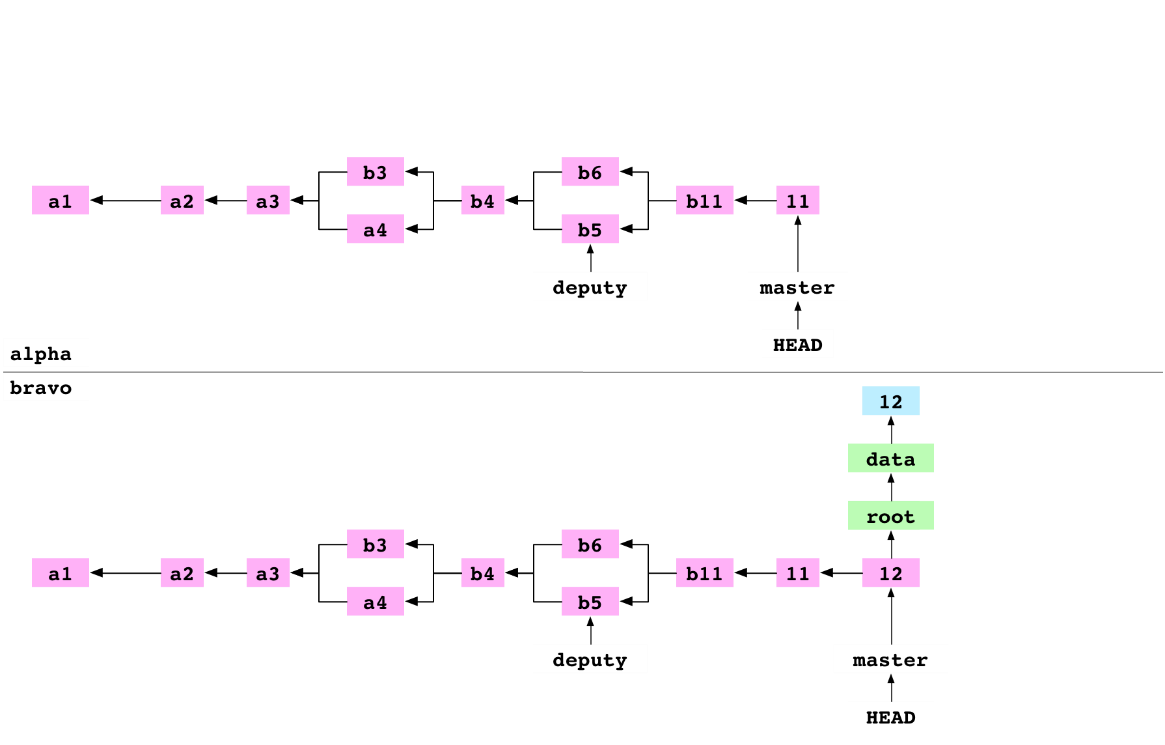
~/alpha $ cd ../bravo

~/bravo $ printf '12' > data/number.txt

~/bravo $ git add data/number.txt

~/bravo $ git commit -m '12'

The user goes into the bravo repository. They set the content of data/number.txt to 12 and commit the change to master on bravo.



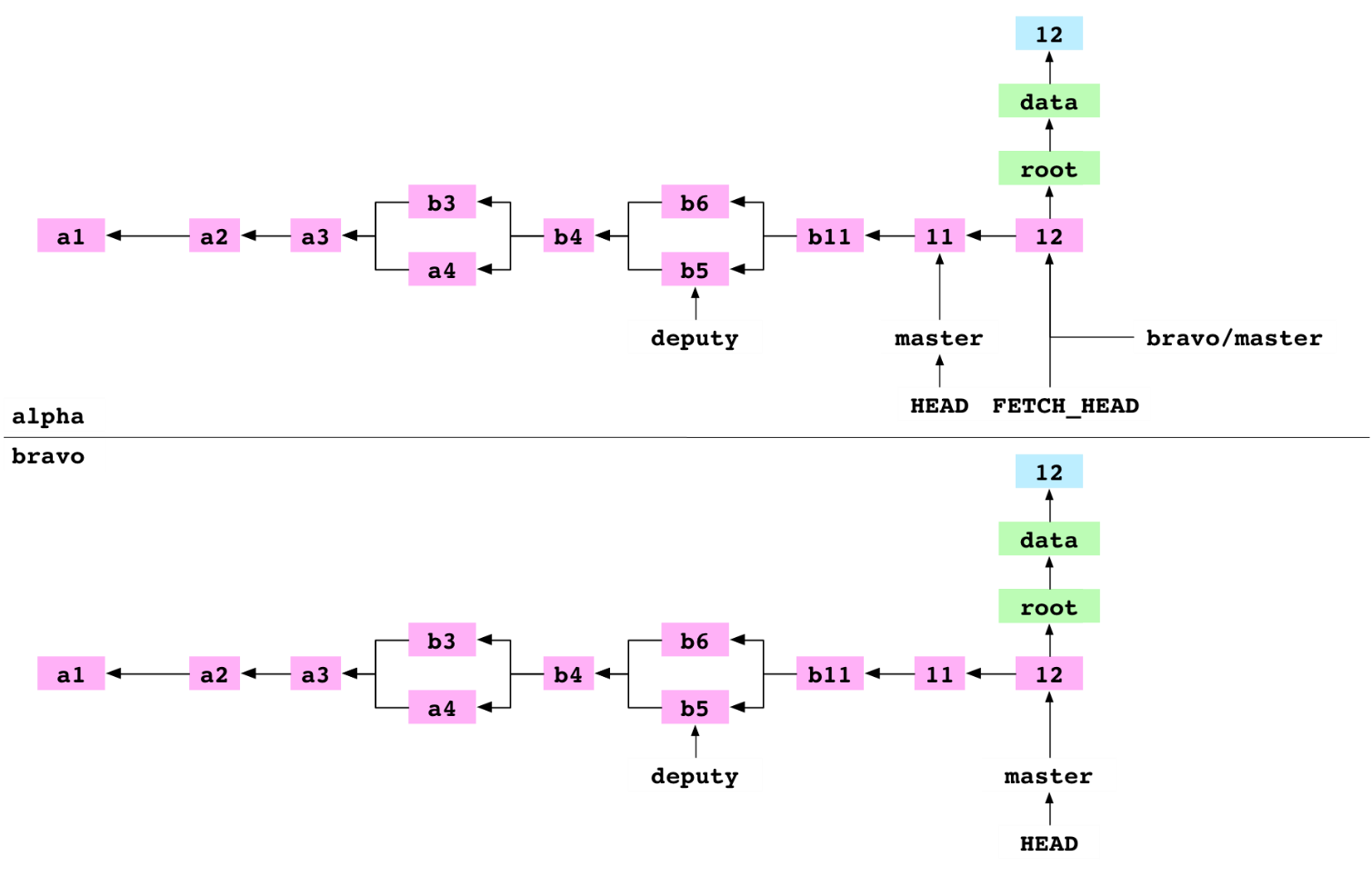
~/bravo $ cd ../alpha

~/alpha $ git fetch bravo master

The user goes into the alpha repository. They fetch master from bravo into alpha. This process has four steps.

* First, Git gets the hash of the commit that master is pointing at on bravo. This is the hash of the 12 commit.
* Second, Git makes a list of all the objects that the 12 commit depends on: the commit object itself, the objects in its tree graph, the ancestor commits of the 12 commit and the objects in their tree graphs. It removes from this list any objects that the alpha object database already has. It copies the rest to alpha/.git/objects/.
* Third, the content of the concrete ref file at alpha/.git/refs/remotes/bravo/master is set to the hash of the 12 commit.
* Fourth, the content of alpha/.git/FETCH\_HEAD is set to:

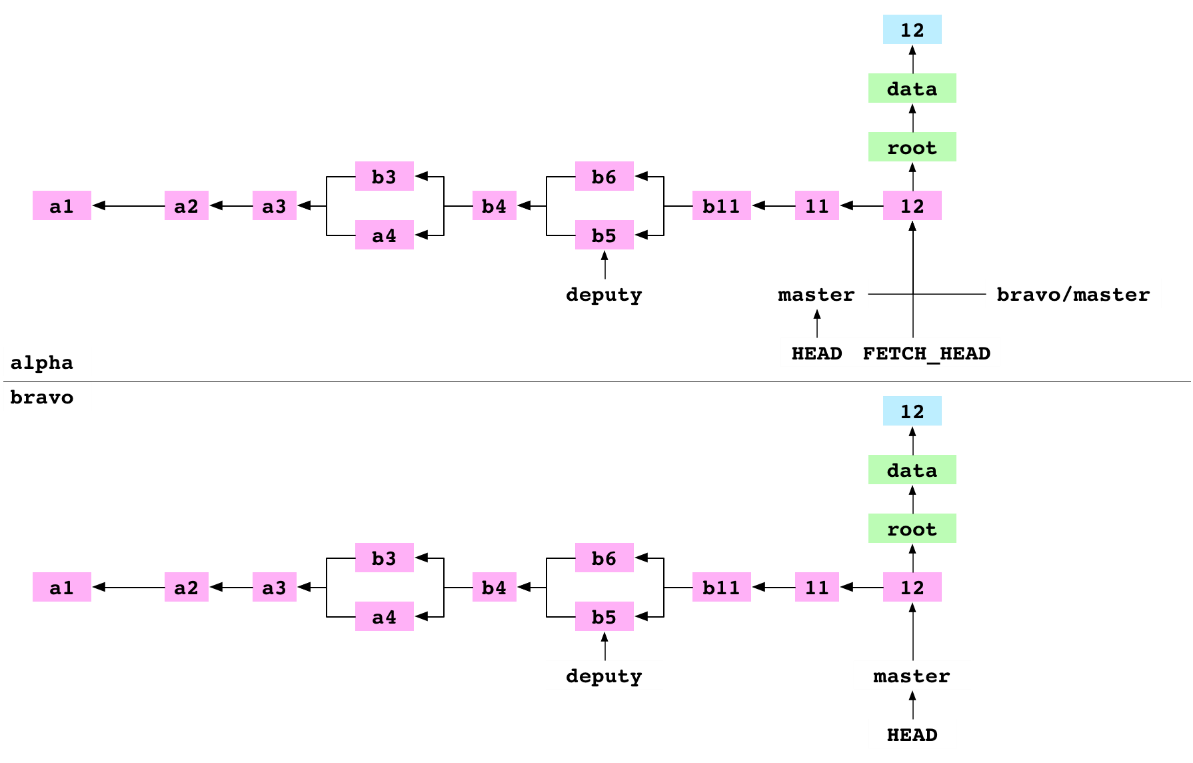
This indicates that the most recent fetch command fetched the 12 commit of master from bravo.



### Merge FETCH\_HEAD

git merge FETCH\_HEAD

The user merges FETCH\_HEAD. FETCH\_HEAD is just another ref. It resolves to the 12 commit, the giver. HEAD points at the 11 commit, the receiver. Git does a fast-forward merge and points master at the 12 commit.



alpha after FETCH\_HEAD merged

### Pull a branch from a remote

git pull bravo master

The user pulls master from bravo into alpha. Pull is shorthand for “fetch and merge FETCH\_HEAD”. Git does these two commands and reports that master is Already up-to-date

### Clone a repository

~/alpha $ cd ..

~ $ git clone alpha charlie

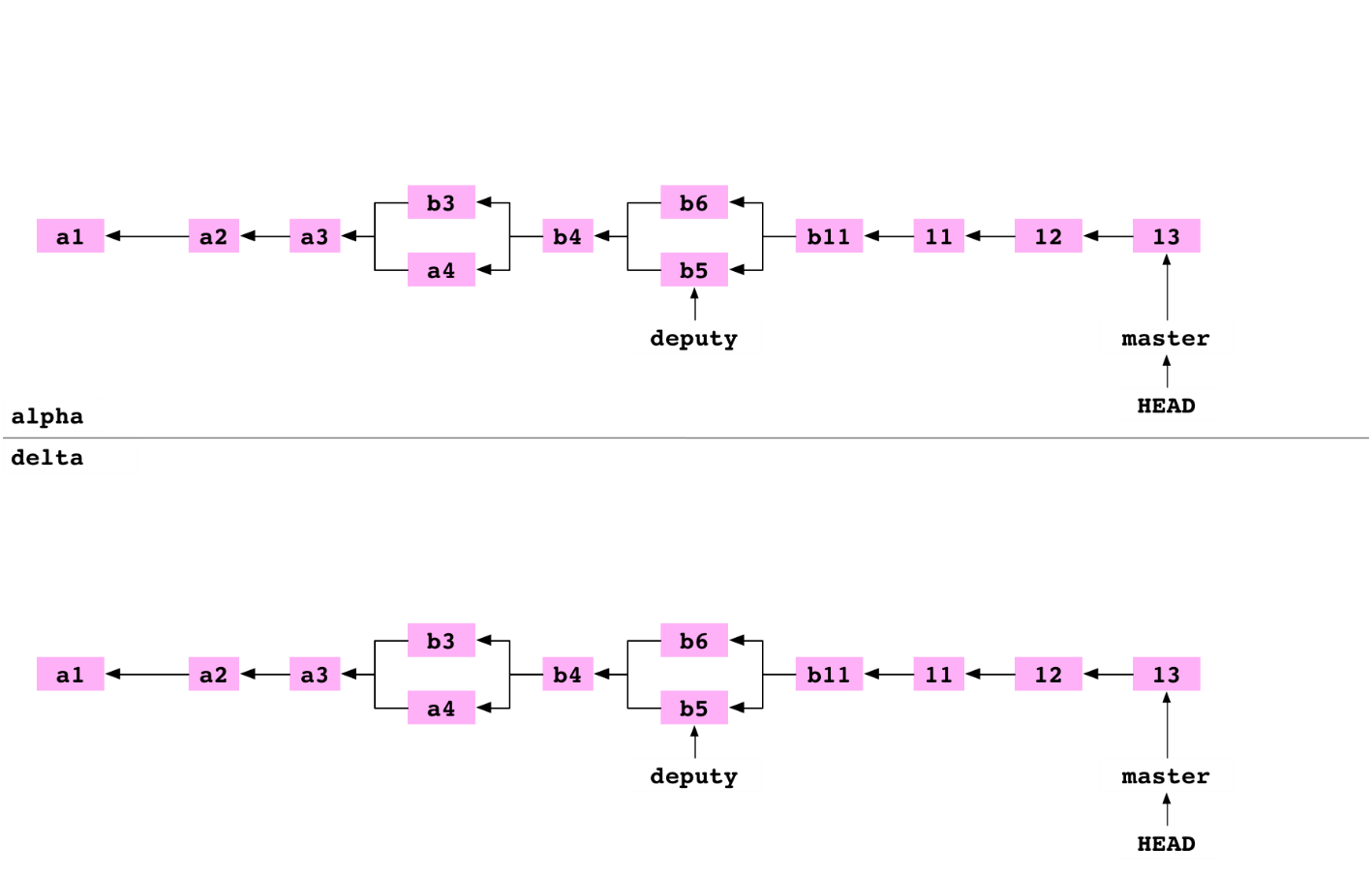
The user moves into the directory above. They clone alpha to charlie. Cloning to charlie has similar results to the cp the user did to produce the bravo repository. Git creates a new directory called charlie. It inits charlie as a Git repo, adds alpha as a remote called origin, fetches origin and merges FETCH\_HEAD.

### Clone a bare repository

/alpha $ cd ..

~ $ git clone alpha delta --bare

Cloning into bare repository 'delta'



The user moves into the directory above. They clone delta as a bare repository. This is an ordinary clone with two differences. The config file indicates that the repository is bare. And the files that are normally stored in the .git directory are stored in the root of the repository:

### Push a branch to a bare repository

The user goes back into the alpha repository. They set up delta as a remote repository on alpha.

~ $ cd alpha

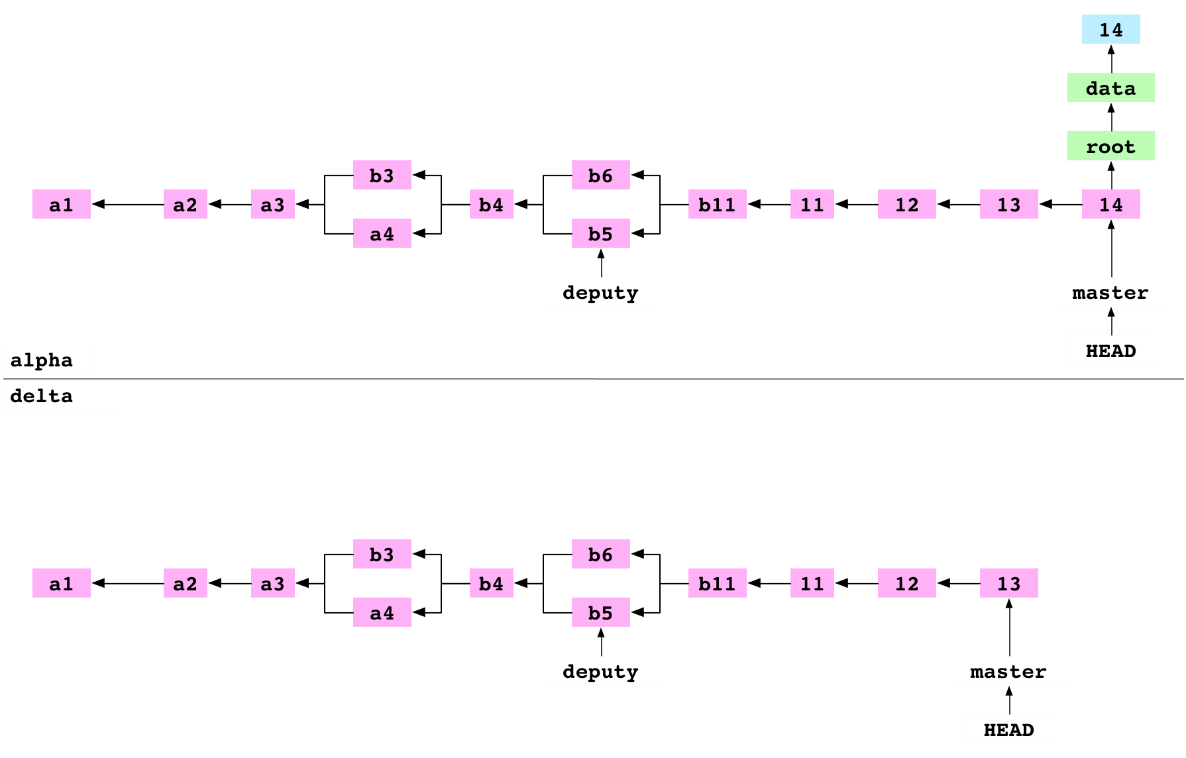
~/alpha $ git remote add delta ../delta

They set the content of data/number.txt to 14 and commit the change to master on alpha.

~/alpha $ printf '14' > data/number.txt

~/alpha $ git add data/number.txt

~/alpha $ git commit -m '14'



git push delta master

They push master to delta. Pushing has three steps.

First, all the objects required for the 14 commit on the master branch are copied from alpha/.git/objects/ to delta/objects/.

Second, delta/refs/heads/master is updated to point at the 14 commit.

Third, alpha/.git/refs/remotes/delta/master is set to point at the 14 commit. alpha has an up-to-date record of the state of delta.

