

Introduction to Git — Fall 2023

# Lecture 3: Basic concepts



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**NAISS**

Slides: <https://hackmd.io/@git-fall-2023/L3-concepts#/>

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- The goal is to learn the *basic concepts*:
  - hash sums, blobs, trees, commits, references, branches, ...
- Understanding these concepts helps to understand what the commands actually do!

# What is Git?

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  - Instead, everyone has a full copy of the entire project (repository).
    - Complete history, metadata, etc.
  - People can work completely independently.
  - An (optional) server is used only to distribute changes.

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- Distributed.
- Fast, simple and flexible.

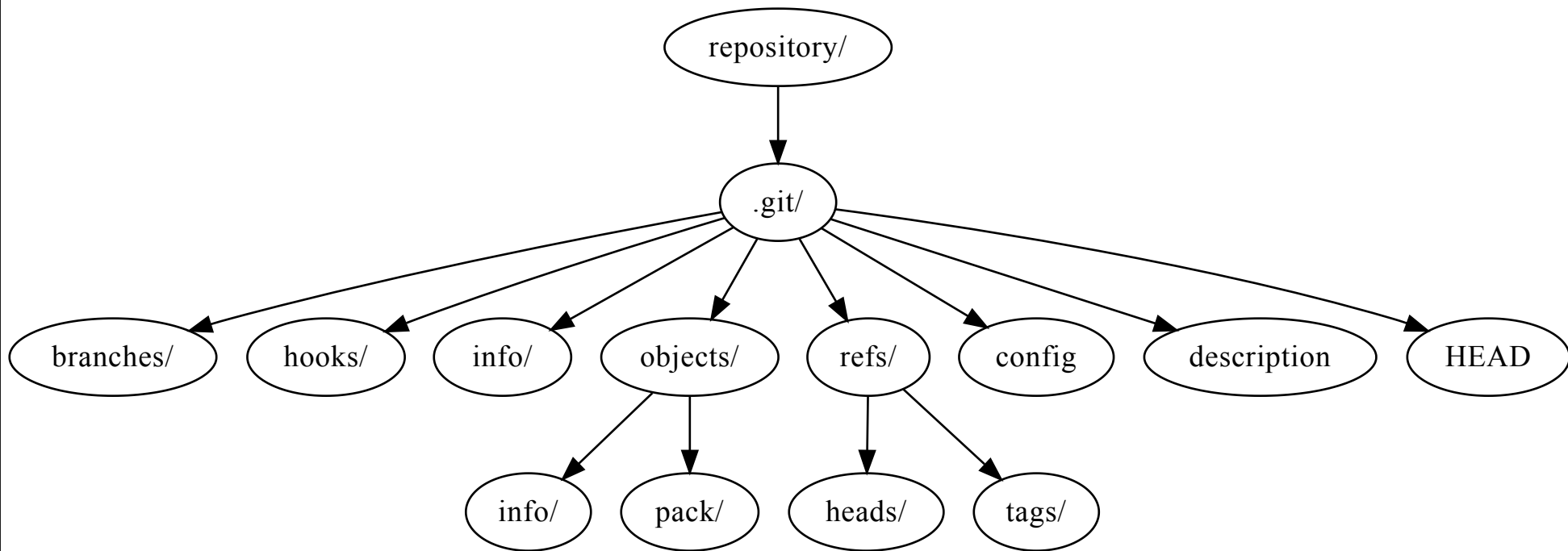
# Why use Git?

- It is popular.
  - Many project already use it, people know how to use it, people can tell you how to use it, ...
- Relies on hash sums:
  - Built-in data corruption detection.
  - Built-in security.
- Distributed.
- Fast, simple and flexible.
- Free and open-source.

# How does Git store the history?

# What is inside a repository?

```
$ mkdir repository && cd repository  
$ git init  
Initialized empty Git repository in .../repository/.git/  
$ find
```



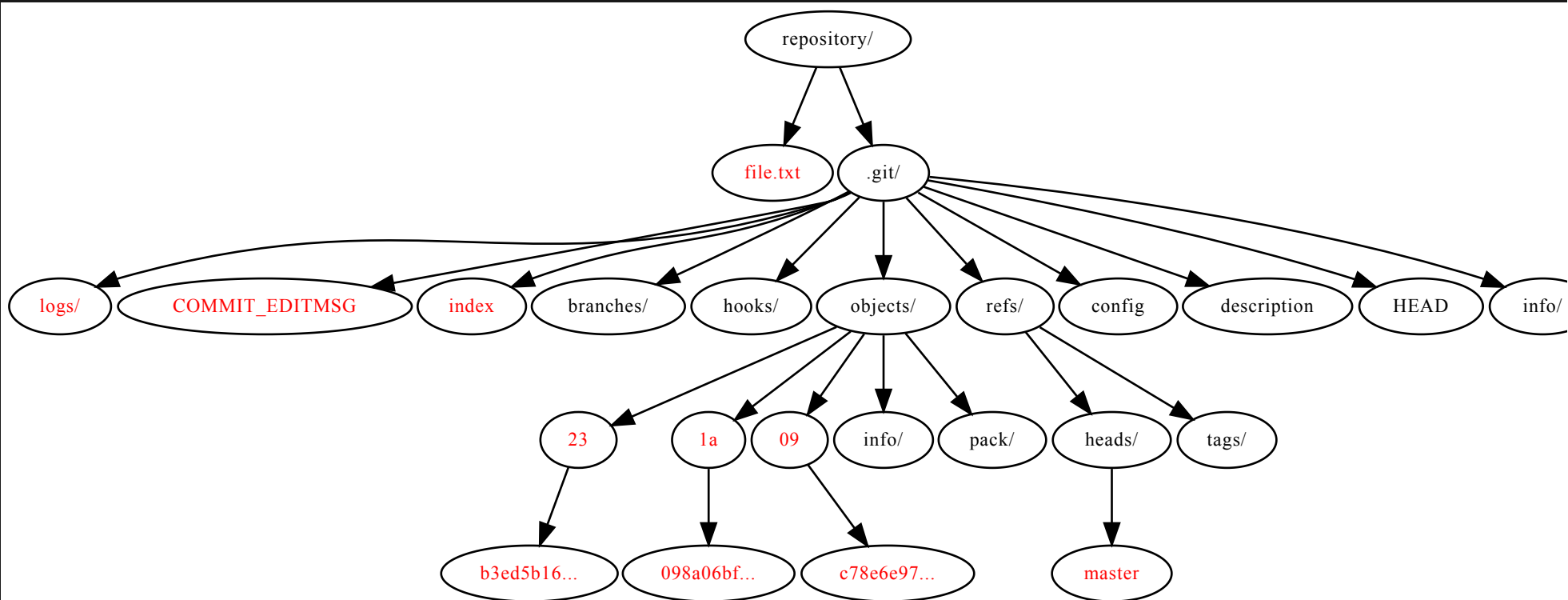
# Most directories are empty and the files are not that interesting:

```
$ cat .git/config
[core]
    repositoryformatversion = 0
    filemode = true
    bare = false
    logallrefupdates = true
$ cat .git/HEAD
ref: refs/heads/master
$ cat .git/description
Unnamed repository; edit this file 'description' to name the
repository.
```



## Let's add some content:

```
$ echo "This file is very interesting" > file.txt
$ git add file.txt
$ git commit -m "This is the first commit"
[master (root-commit) 23b3ed5] This is the first commit
1 file changed, 1 insertion(+)
create mode 100644 file.txt
$ find
```



# Working tree

- Everything inside repository/ is a part of the *working tree* (or the *workspace*).

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- Everything inside `repository/` is a part of the *working tree* (or the *workspace*).
  - `.git/` is not included.
  - At the moment, the working tree contains just one file, `file.txt`.
  - Working tree is just a regular directory.
- The `git add` and `git commit` commands tell Git to care about `file.txt`.
  - More on that later...

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- Git stores files etc as **objects**:
  - Objects are stored under `.git/objects/`.
- Git uses *content-based addressing*.
  - A *hash sum* is computed from the **content** of the object.
  - The hash “uniquely” identifies the object.
  - Two objects with identical contents have the same hash and are stored only once.

- We can compute the hash manually:

```
$ git hash-object file.txt  
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- We can find the corresponding object:

```
$ find  
...  
./.git/objects/09/c78e6e971ce9e3d69e75bcb3ffd5de05b0d59a  
...
```

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...  
./.git/objects/09/c78e6e971ce9e3d69e75bcb3ffd5de05b0d59a  
...
```

- We can confirm that two files with identical contents have the same hash:

```
$ cp file.txt file2.txt  
$ git hash-object file.txt file2.txt  
09c78e6e971ce9e3d69e75bcb3ffd5de05b0d59a  
09c78e6e971ce9e3d69e75bcb3ffd5de05b0d59a
```

- Note that we do not have to use the entire hash:

```
git cat-file -p 09c78e6e  
This file is very interesting
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- We only need to use as many characters as is required to uniquely identify the object.
  - 7-8 is enough in most cases.
  - 12 in larger projects.

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git cat-file -p 09c78e6e  
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```

- We only need to use as many characters as is required to uniquely identify the object.
  - 7-8 is enough in most cases.
  - 12 in larger projects.
- If more characters is required, an error message is printed.

- Objects cannot (and should not) be accessed directly:

```
$ hexdump -C ./git/objects/09/c78e6e97*
00000000  78 01 4b ca c9 4f 52 30  .... |x.K..OR06`...,VH|
00000010  cb cc 49 55 00 d2 65 a9  .... |..IU..e.E...y%.E|
00000020  a9 c5 25 99 79 e9 5c 00  .... |..%.y.\..I.3|
0000002c
```

- Objects cannot (and should not) be accessed directly:

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$ hexdump -C ./git/objects/09/c78e6e97*
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00000020  a9 c5 25 99 79 e9 5c 00  ....  |..%.y.\..I.3|
0000002c
```

- However, we can observe the type and the content of an object:

```
$ git cat-file -t 09c78e6e
blob
$ git cat-file -p 09c78e6e
This file is very interesting
```

- It is also important to realize that the object stays even when the file is removed:

```
$ rm file.txt
$ find
....
./.git/objects/09/c78e6e971ce9e3d69e75bcb3ffd5de05b0d59a
....
$ git cat-file -p 09c78e6e971ce9e3d69e75bcb3ffd5de05b0d59a
This file is very interesting
```

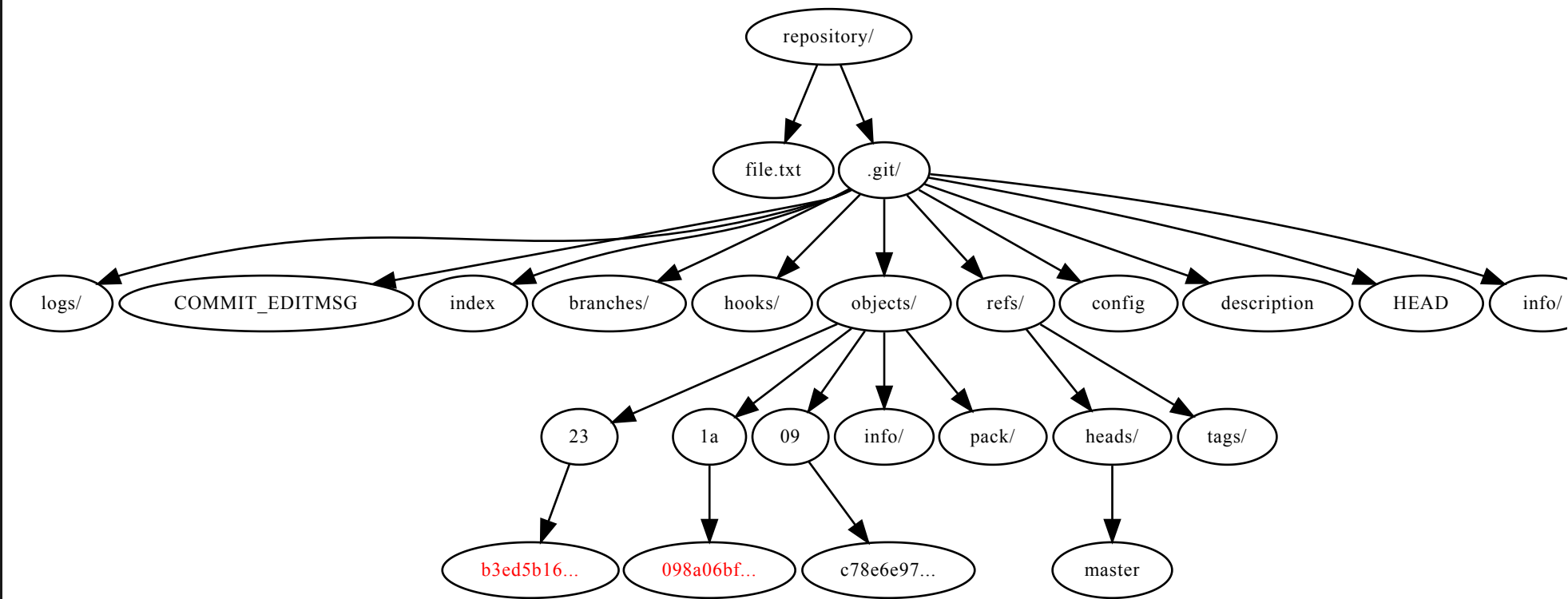
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....
$ git cat-file -p 09c78e6e971ce9e3d69e75bcb3ffd5de05b0d59a
This file is very interesting
```

- We can restore the file from the object:

```
$ git restore file.txt
$ cat file.txt
This file is very interesting
```

# Let's take a second look at the repository:



*What are these two other objects?*

# Trees

- Let's investigate one of the remaining objects:

```
$ git cat-file -t 1a098a06
tree
$ git cat-file -p 1a098a06
100644 blob 09c78e6e971ce9e3d69e75b....    file.txt
```



# Trees

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- We can see that the type of the object is **tree**:
  - A tree stores pointers to
    - files (blobs) and
    - other trees,

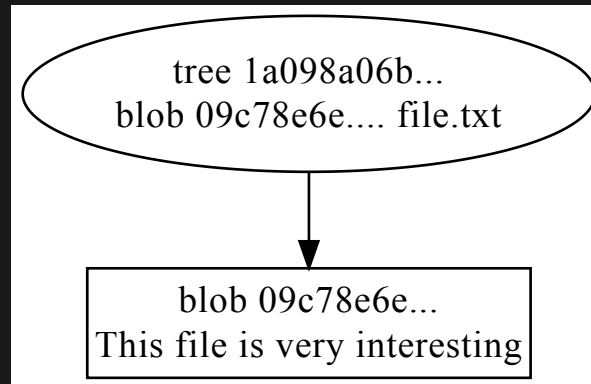
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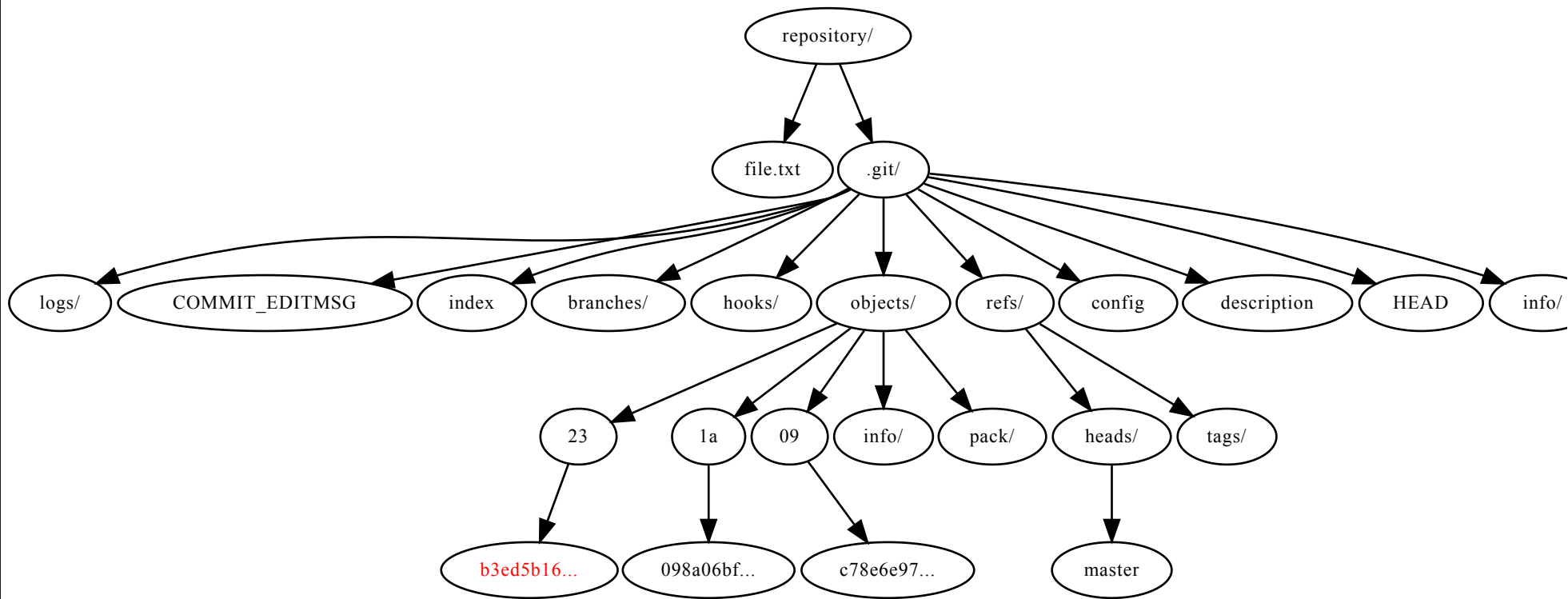
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$ git cat-file -t 1a098a06
tree
$ git cat-file -p 1a098a06
100644 blob 09c78e6e971ce9e3d69e75b....    file.txt
```

- We can see that the type of the object is **tree**:
  - A tree stores pointers to
    - files (blobs) and
    - other trees,
  - Trees are used to represent directory structures.

In this case, the tree has one level and one blob:



# Let's take a third look at the repository:



*Just one object remains...*

# Commits

- Let's investigate the last object:

```
$ git cat-file -t 23b3ed5b
commit
$ git cat-file -p 23b3ed5b
tree 1a098a06bf0bcae9695238d9d5cb96345c00cacf
author Mirko Myllykoski <.....@gmail.com> 1600867851 +0200
committer Mirko Myllykoski <.....@gmail.com> 1600867851 +0200

This is the first commit
```

# Commits

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```
$ git cat-file -t 23b3ed5b
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This is the first commit
```

- The type of the object is **commit**. It contains

# Commits

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author Mirko Myllykoski <....@gmail.com> 1600867851 +0200
committer Mirko Myllykoski <....@gmail.com> 1600867851 +0200

This is the first commit
```

- The type of the object is **commit**. It contains
  - a pointer to a tree,



# Commits

- Let's investigate the last object:

```
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commit
$ git cat-file -p 23b3ed5b
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author Mirko Myllykoski <....@gmail.com> 1600867851 +0200
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This is the first commit
```

- The type of the object is **commit**. It contains
  - a pointer to a tree,
  - an author and a committer (+time), and

# Commits

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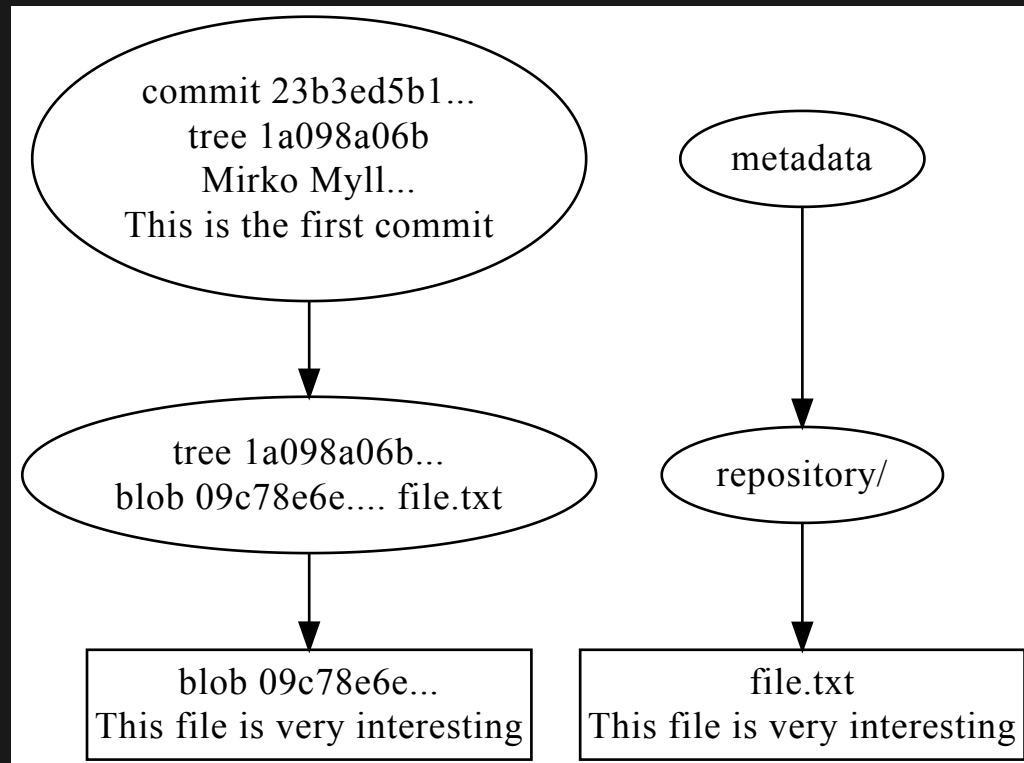
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author Mirko Myllykoski <....@gmail.com> 1600867851 +0200
committer Mirko Myllykoski <....@gmail.com> 1600867851 +0200

This is the first commit
```

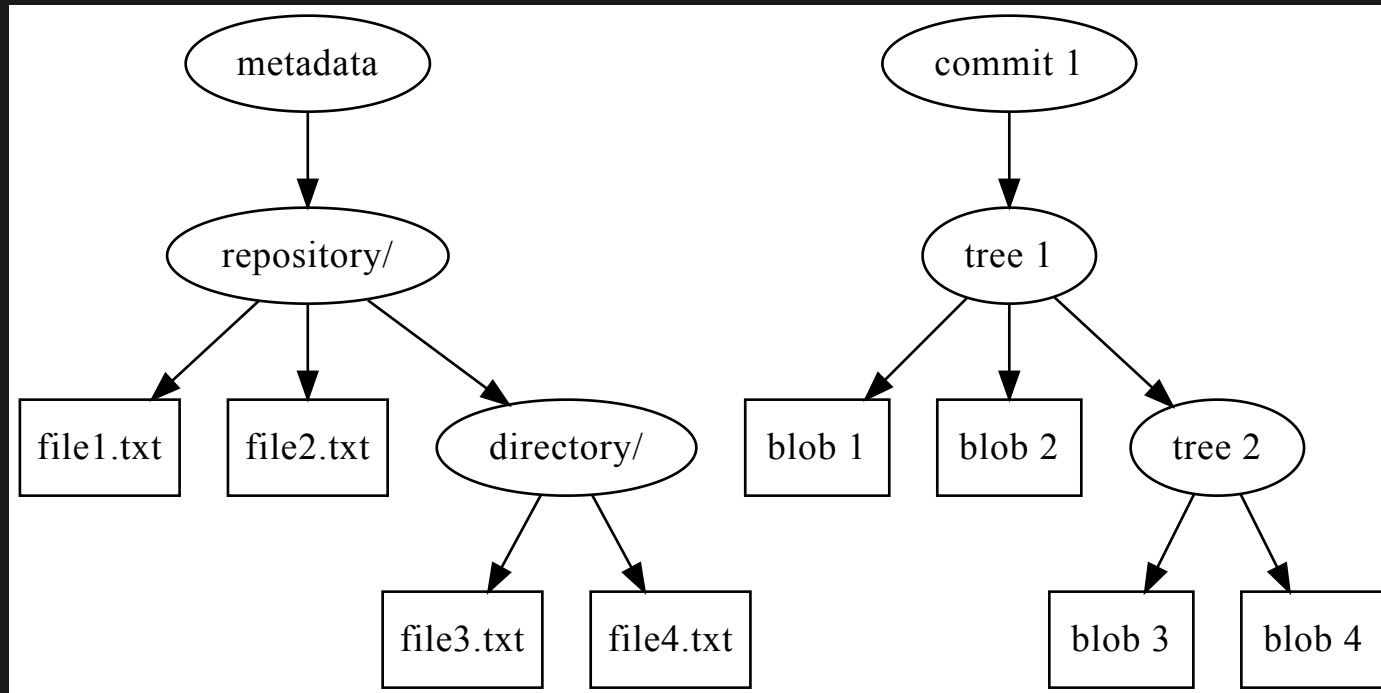
- The type of the object is **commit**. It contains
  - a pointer to a tree,
  - an author and a committer (+time), and
  - a commit message

A commit stores the state of the project in a given point of time.

In this case, the commit points to a tree that has one level and one blob:

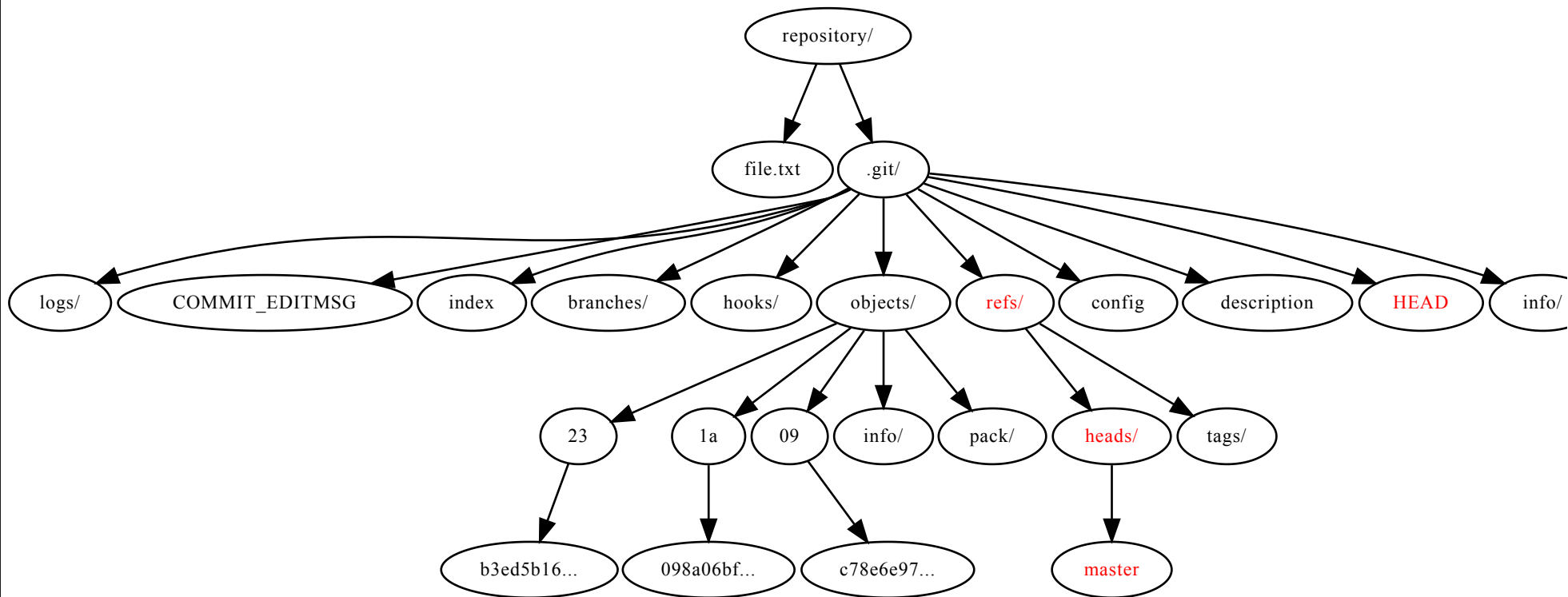


In a more general case, the associated tree can contain **several** levels and **multiple** blobs:



# Working with Git

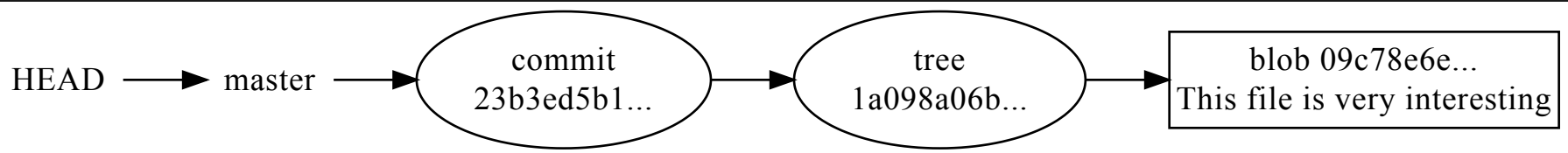
# Let's see what else we can find...



# HEAD and other references

- HEAD points (indirectly) to 23b3ed5b1:

```
$ cat ../.git/HEAD
ref: refs/heads/master
$ cat ../.git/refs/heads/master
23b3ed5b16095bb84b18d06734fdd614c8982841
```





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- HEAD determines “most recent” commit.

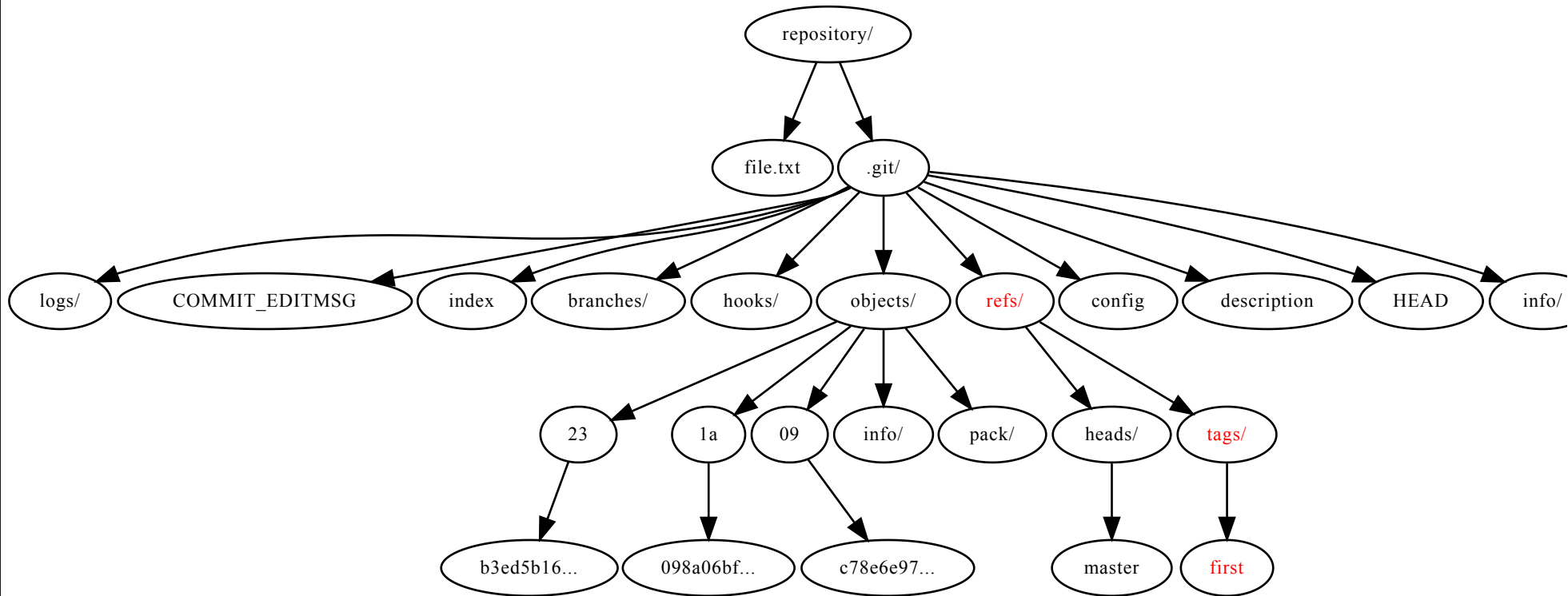
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  - More on this later

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  - A reference points to commits and another reference.
- HEAD determines “most recent” commit.
  - Many commands **act on the current HEAD**.
  - More on this later
- master is the current branch (more later).

- You can create a reference yourself:

```
$ git tag first  
$ find
```



first

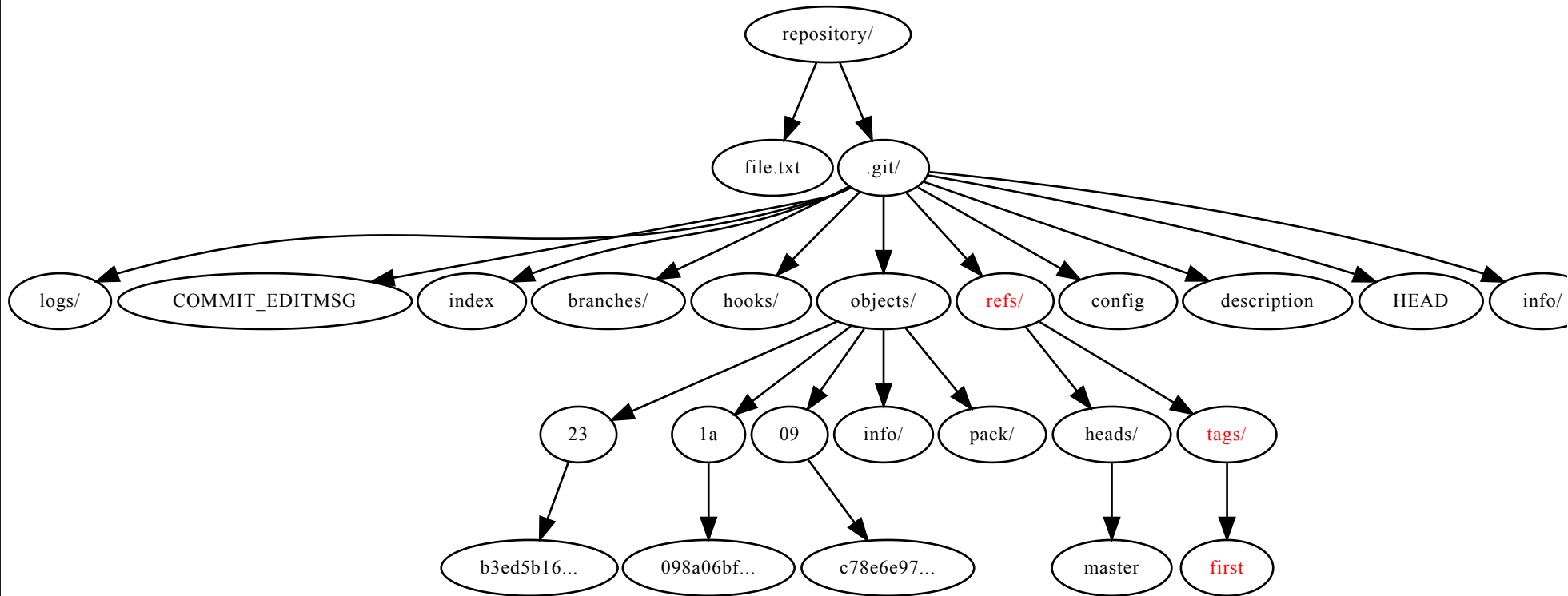
commit  
23b3ed5b1...

tree  
1a098a06b...

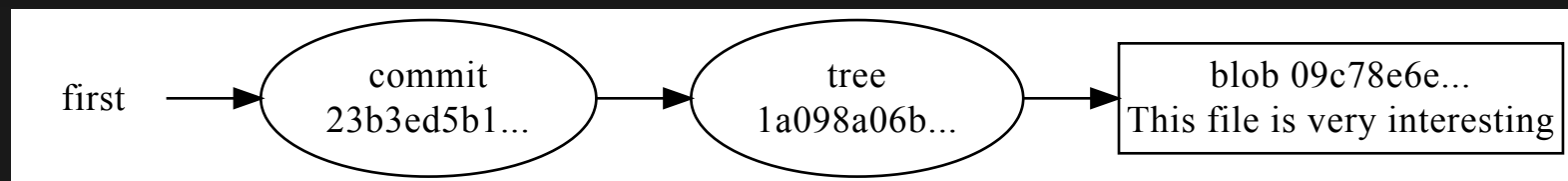
blob 09c78e6e...  
This file is very interesting

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```



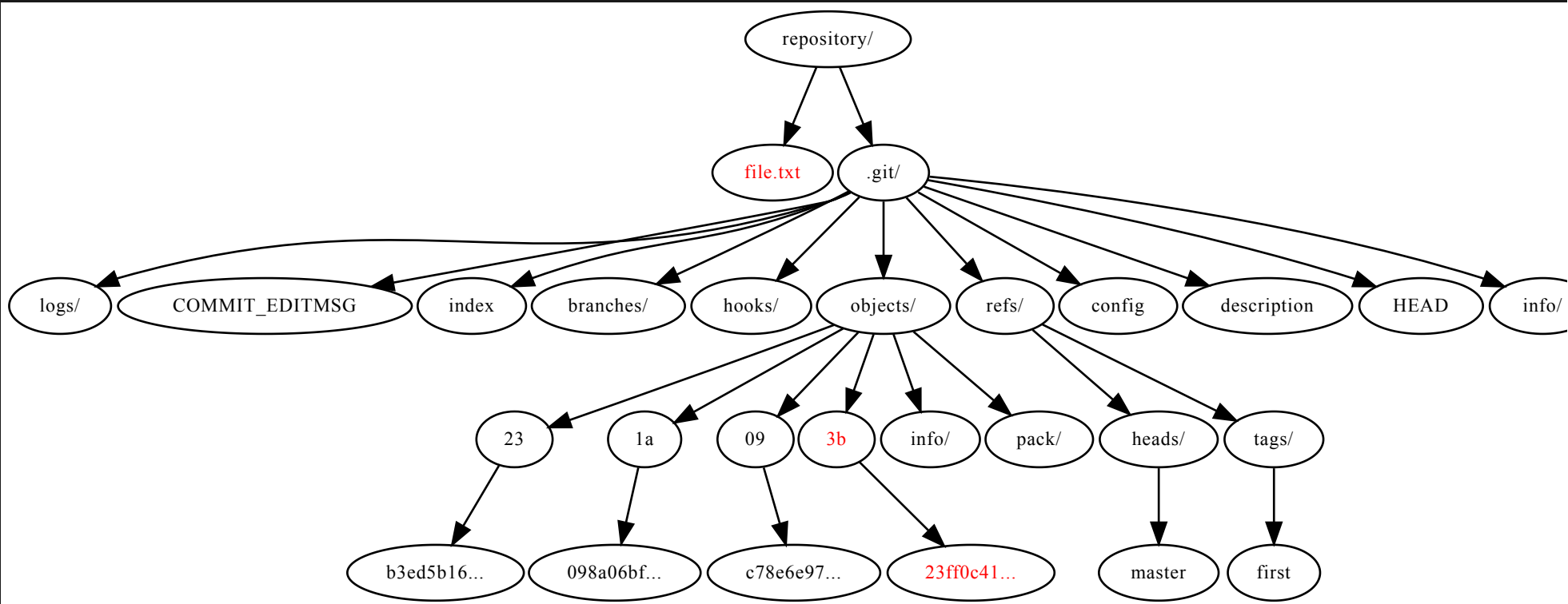
```
$ git rev-parse first  
23b3ed5b16095bb84b18d06734fdd614c8982841
```





# Index (staging area)

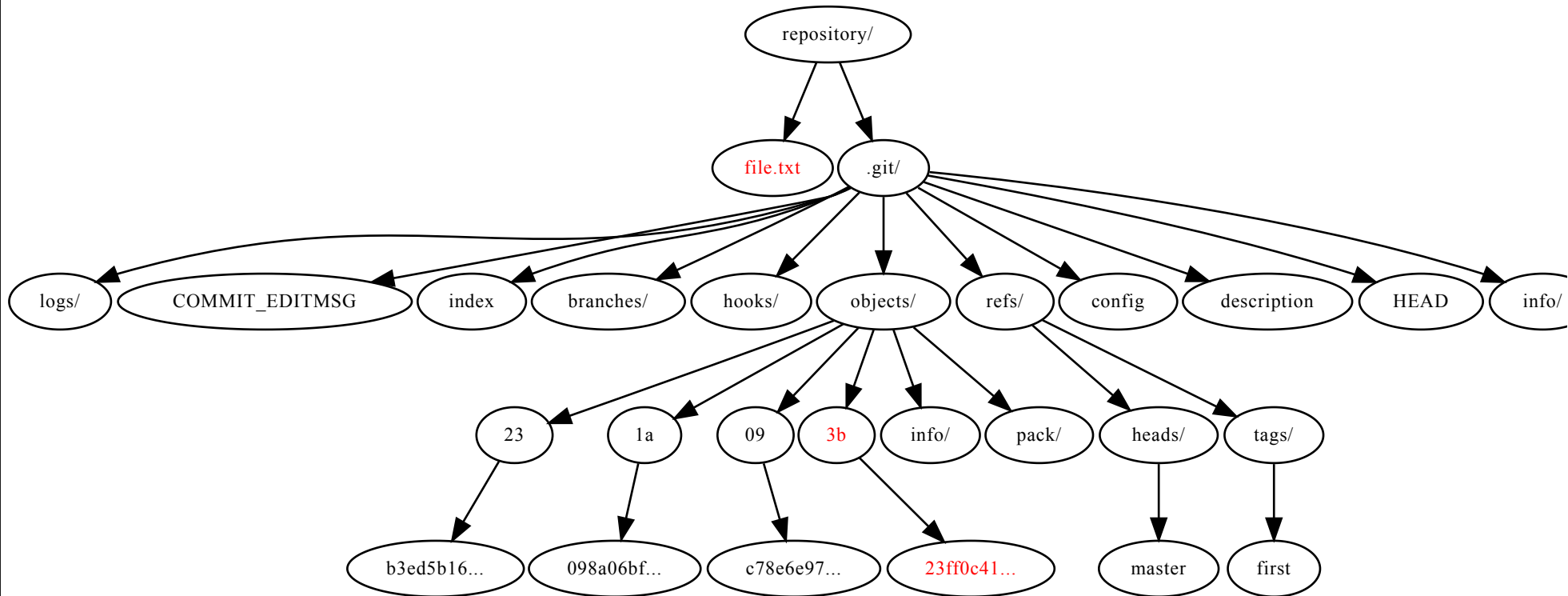
Let's repeat some of the earlier steps:



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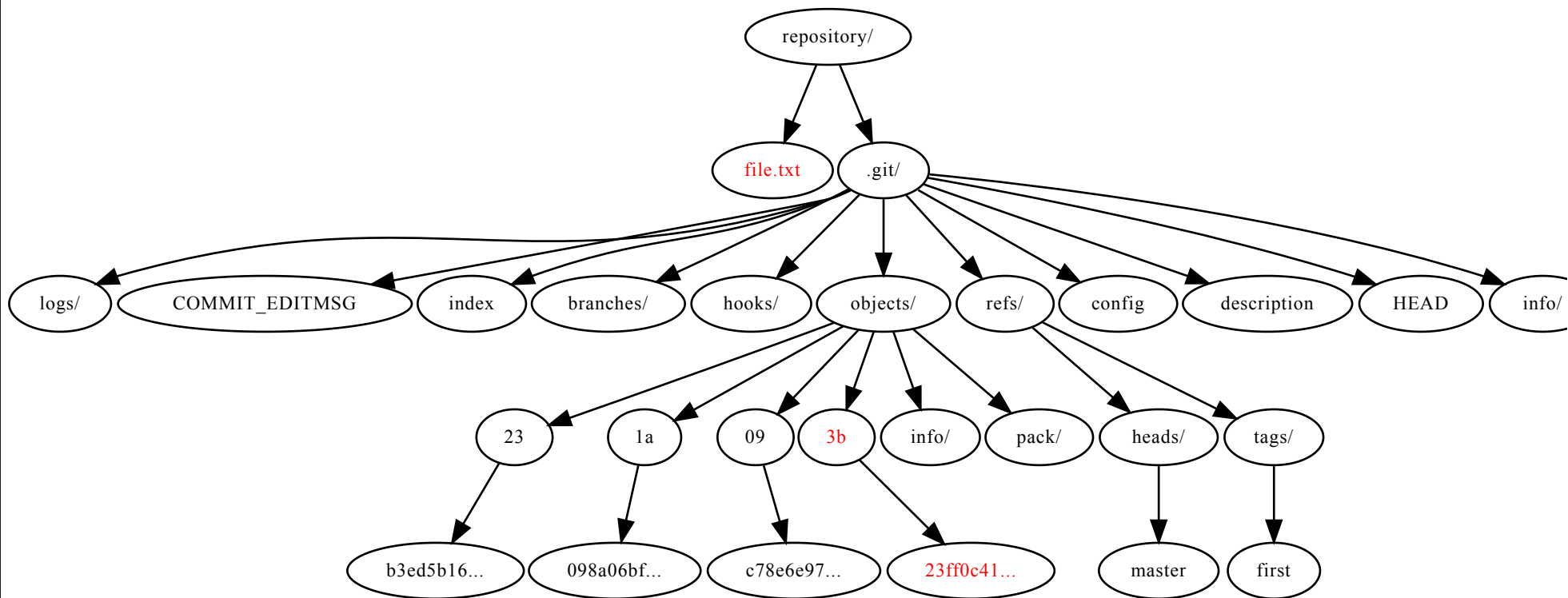
```
$ echo "More content" >> file.txt  
$ git add file.txt  
$ find
```



# Index (staging area)

Let's repeat some of the earlier steps:

```
$ echo "More content" >> file.txt  
$ git add file.txt  
$ find
```



```
$ git cat-file -p 3b23ff0c  
This file is very interesting  
More content
```

- The `git add` command creates a blob that correspond to the `update file.txt` file.

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  - No other object are created yet.

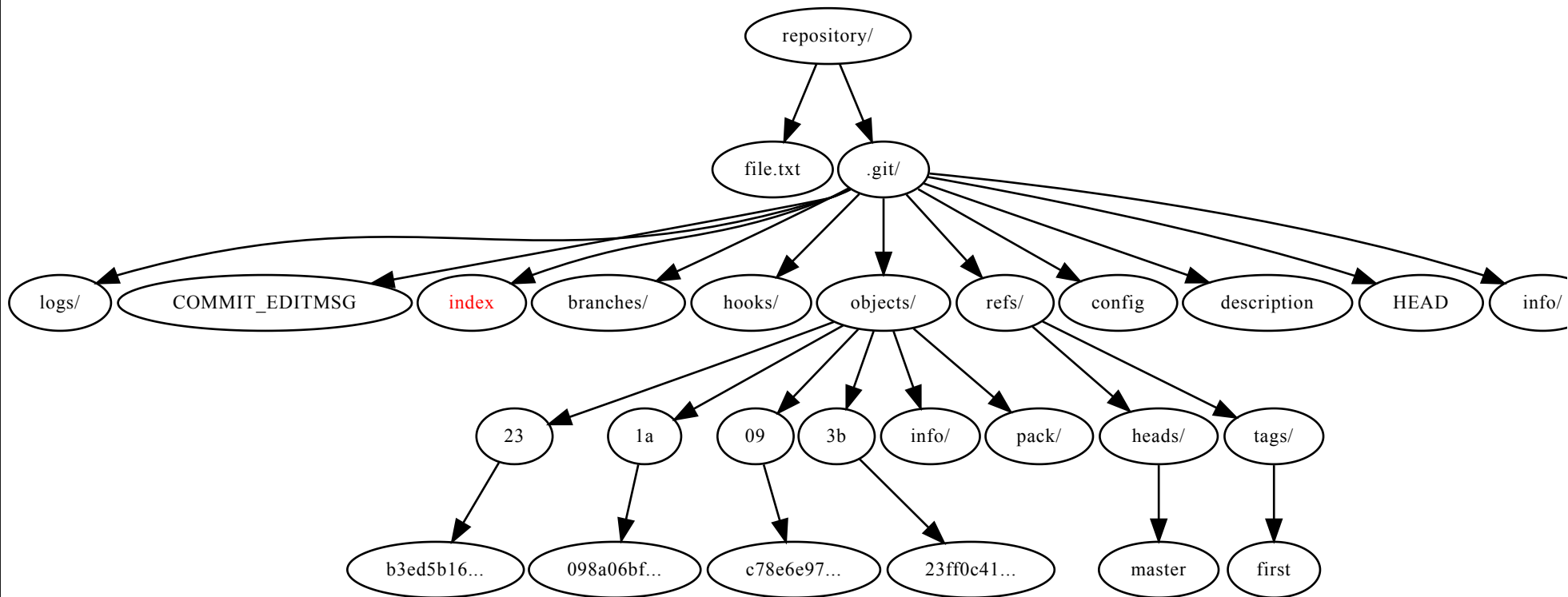
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  - No other object are created yet.
- The command also adds the file to the **index**.
- The index will become the **next commit**.
  - Contains a representation of the tree object.

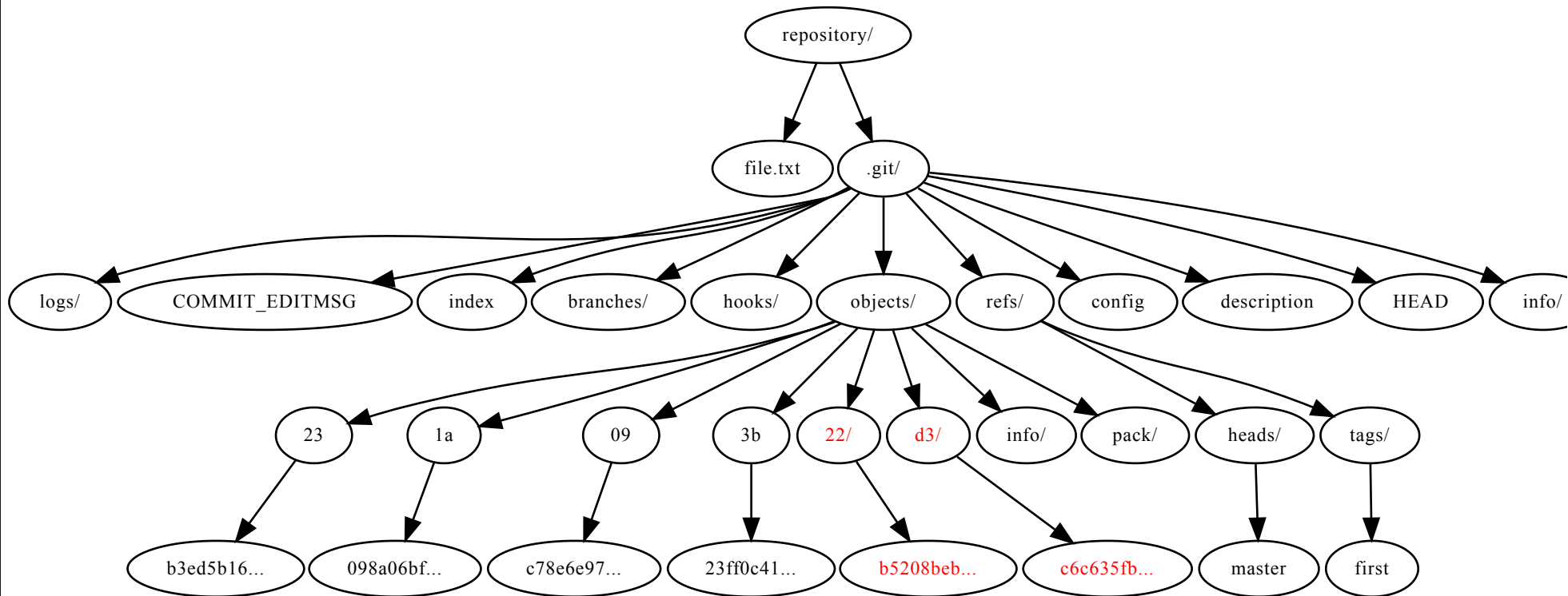


# The index is a binary file:



# We can now turn the index to the next commit:

```
$ git commit -m "This is the second commit"  
[master d3c6c63] This is the second commit  
1 file changed, 1 insertion(+)  
$ find
```



- Just as before, we have a tree object that describes the directory structure:

```
$ git cat-file -p 22b5208b
100644 blob 3b23ff0c411faf22c9253ed0....    file.txt
```

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```
$ git cat-file -p 22b5208b
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```

- And a commit, that describes the state of the repository:

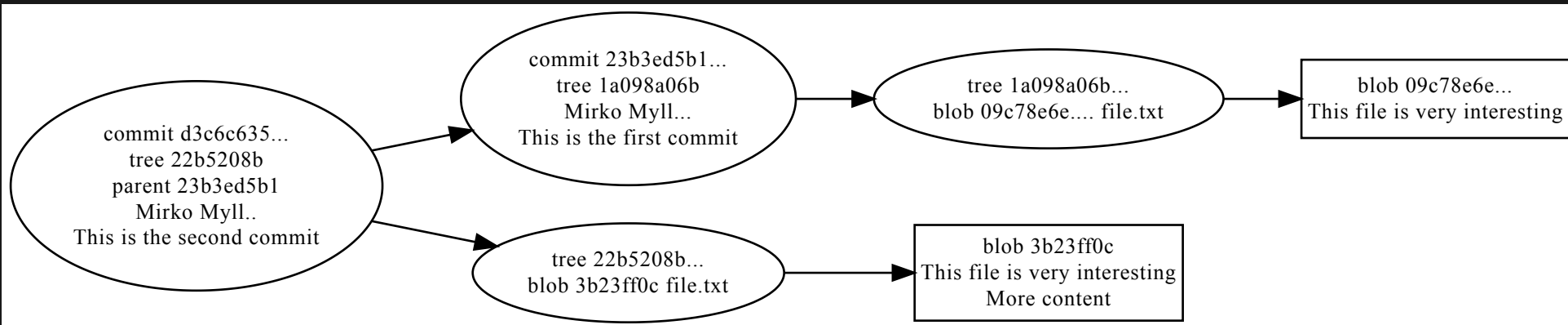
```
$ git cat-file -p d3c6c635
tree 22b5208bebacfcf745691f799b08df492b2a7da9
parent 23b3ed5b16095bb84b18d06734fdd614c8982841
author Mirko Myllykoski <mirko...> 1601228824 +0200
committer Mirko Myllykoski <mirko....> 1601228824 +0200
```

```
This is the second commit
```

# Parent

- The major difference is that the commit contains a pointer to a **parent**:

```
parent 23b3ed5b16095bb84b18d06734fdd614c8982841
```

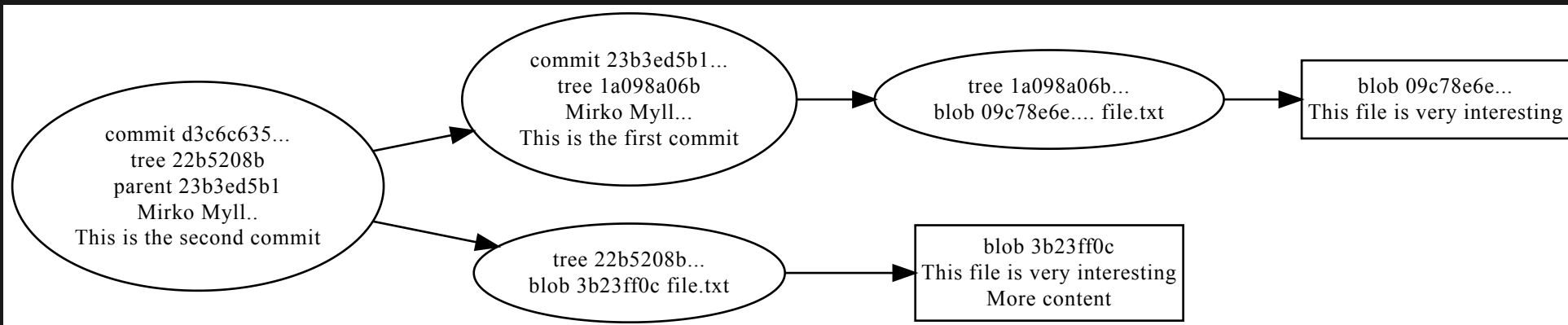


# Parent

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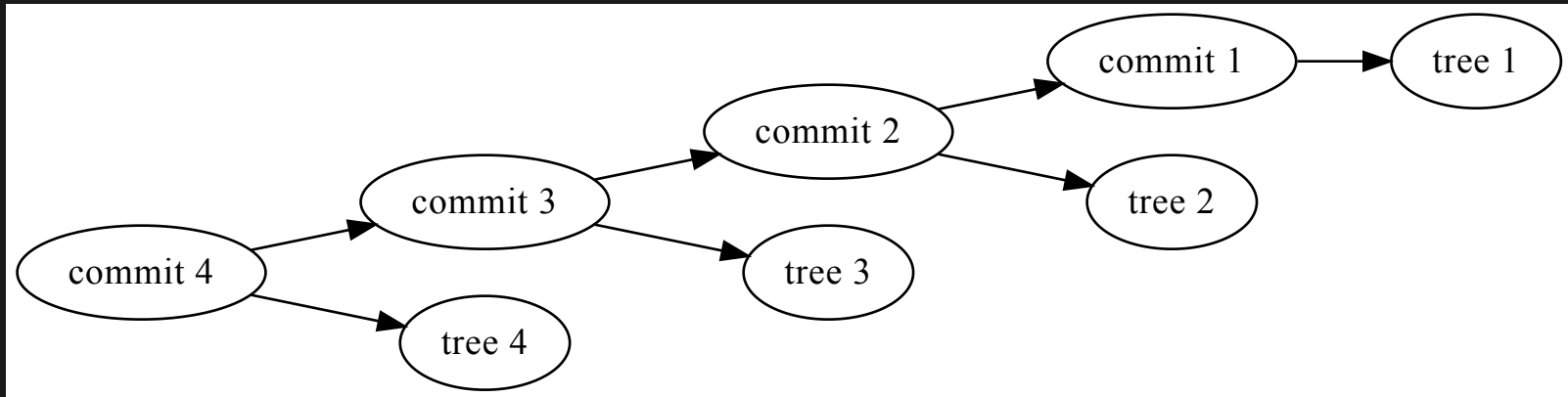
```
parent 23b3ed5b16095bb84b18d06734fdd614c8982841
```

- The parent pointer points to the previous commit:



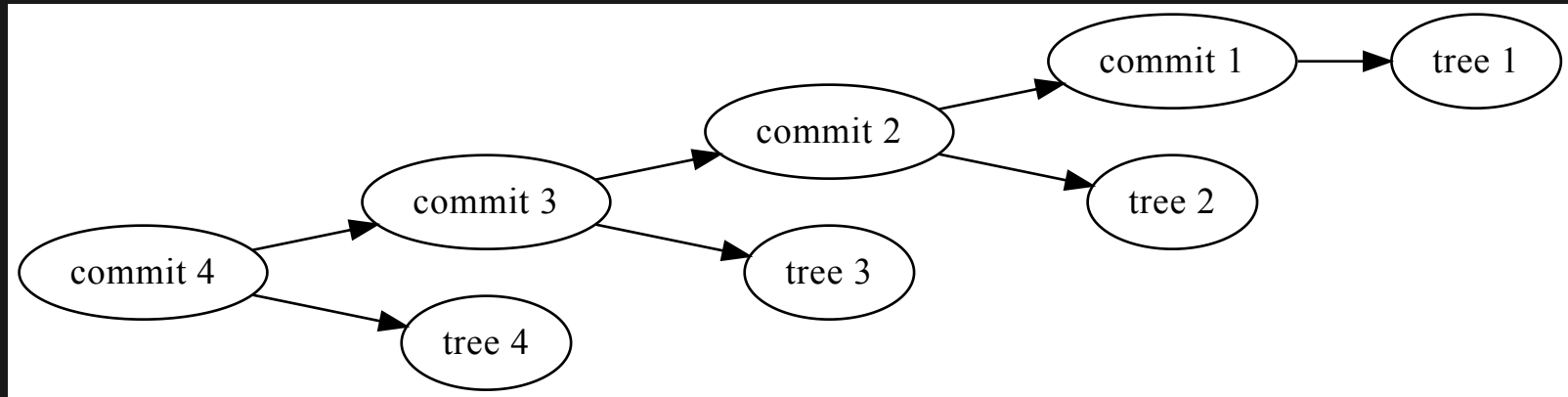
# Commit tree

- Usually, we have a complete tree of commits (**commit tree**):



# Commit tree

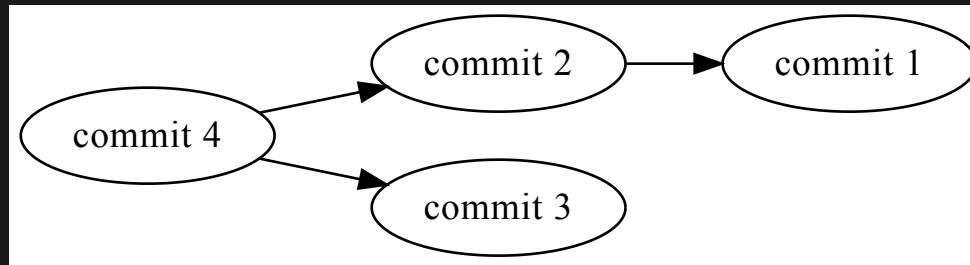
- Usually, we have a complete tree of commits (**commit tree**):



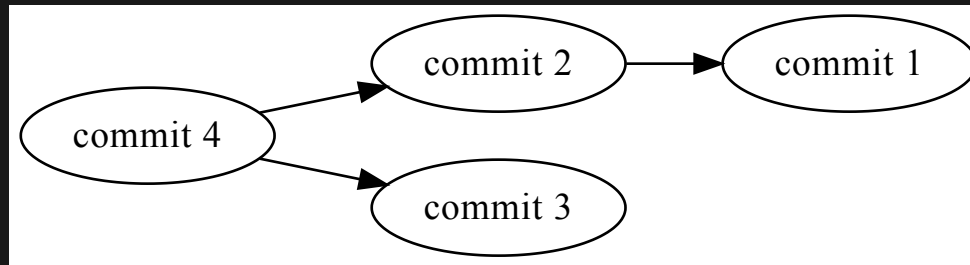
- Each commit represents the state of the repository at a given point of time.



- Each commit is allowed to have **multiple** parents:



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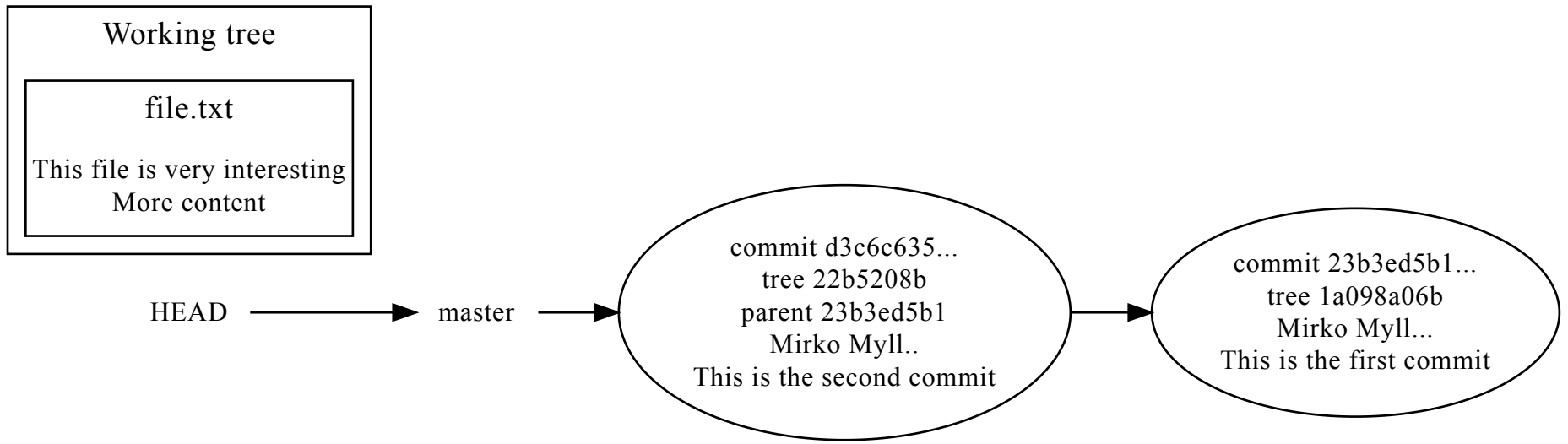


- These parents appear when two (or more) *branches* are **merged**.
  - More on this later...

# HEAD and other references (again)

- Let's investigate HEAD and master:

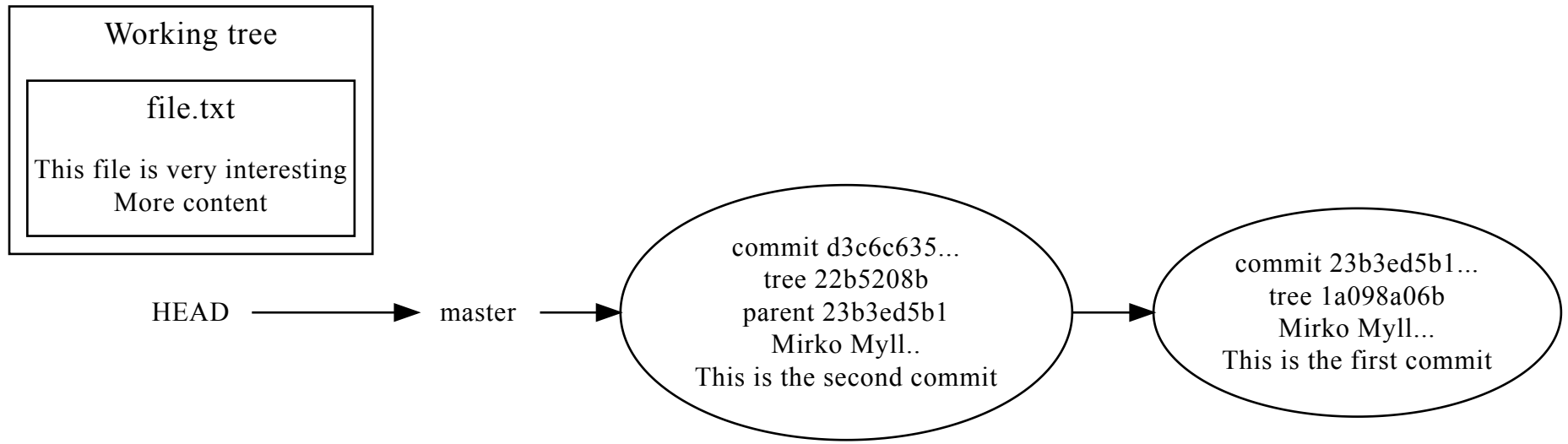
```
$ cat .git/HEAD
ref: refs/heads/master
$ cat .git/refs/heads/master
d3c6c635fb44c7084797d47050bff7961853c19b
```



# HEAD and other references (again)

- Let's investigate HEAD and master:

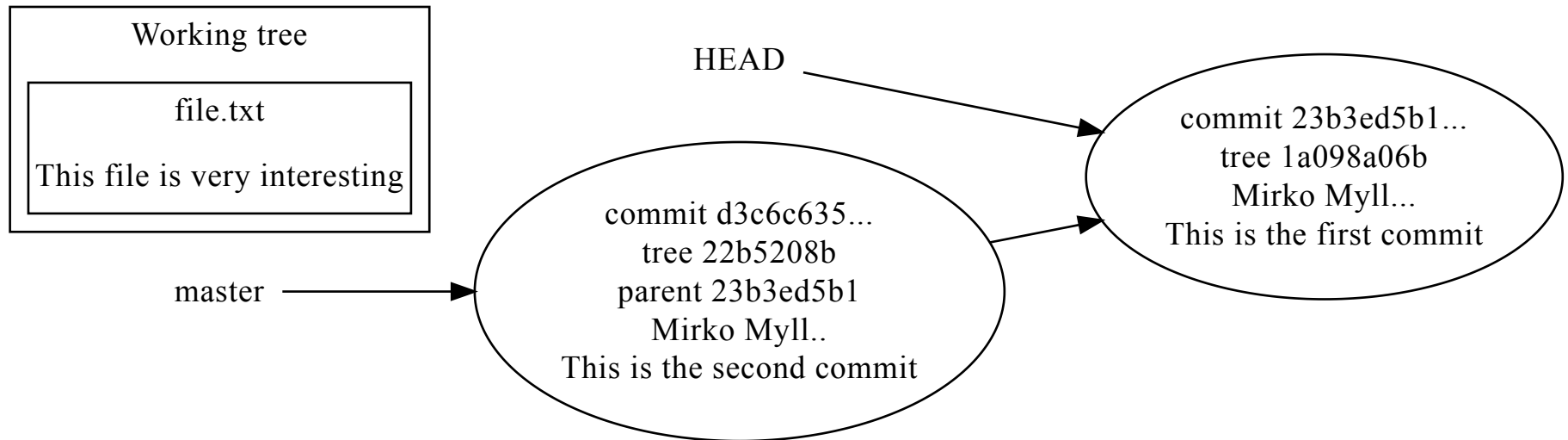
```
$ cat .git/HEAD
ref: refs/heads/master
$ cat .git/refs/heads/master
d3c6c635fb44c7084797d47050bff7961853c19b
```



- Remember, many Git commands act on the current HEAD.

- We can change the HEAD to something else:

```
$ git checkout 23b3ed5b
....
HEAD is now at 23b3ed5 This is the first commit
$ cat .git/HEAD
23b3ed5b16095bb84b18d06734fdd614c8982841
$ cat file.txt
This file is very interesting
```



# Branches

- We can modify the working tree and create a new commit:

```
$ echo "Different content" >> file.txt
$ git commit -a -m "This is the third commit"
[detached HEAD a118ae8] This is the third commit
1 file changed, 1 insertion(+)
```

# Branches

- We can modify the working tree and create a new commit:

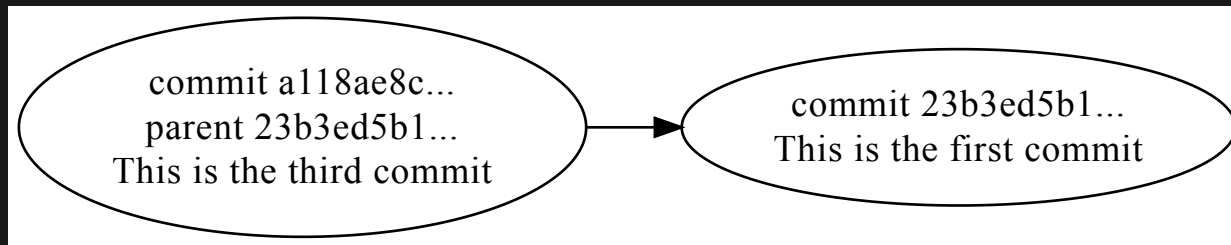
```
$ echo "Different content" >> file.txt
$ git commit -a -m "This is the third commit"
[detached HEAD a118ae8] This is the third commit
1 file changed, 1 insertion(+)
```

- Let's investigate the newly created commit:

```
$ git cat-file -p a118ae8c
tree 5fcc4f83fedf5a94cd773704bdb1ab2cdcadc6fd
parent 23b3ed5b16095bb84b18d06734fdd614c8982841
author Mirko Myllykoski <mirko....> 1601286412 +0200
committer Mirko Myllykoski <mirko....> 1601286412 +0200

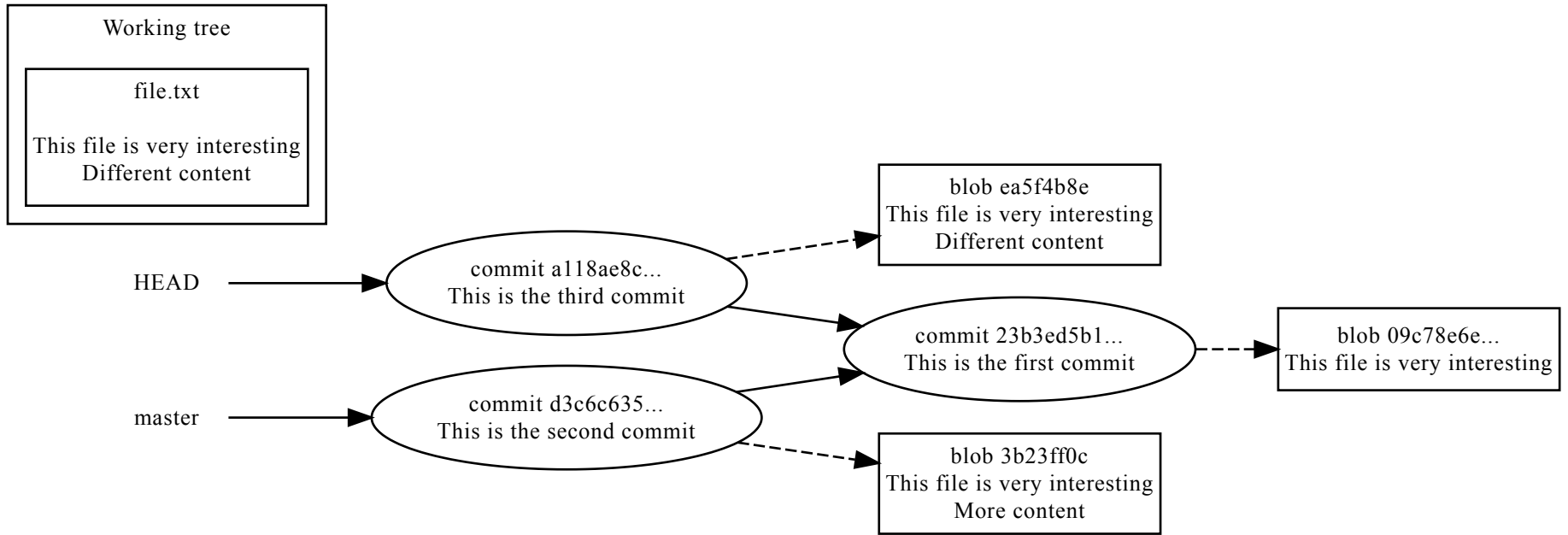
This is the third commit
```

- First, the parent points to the **first commit**:



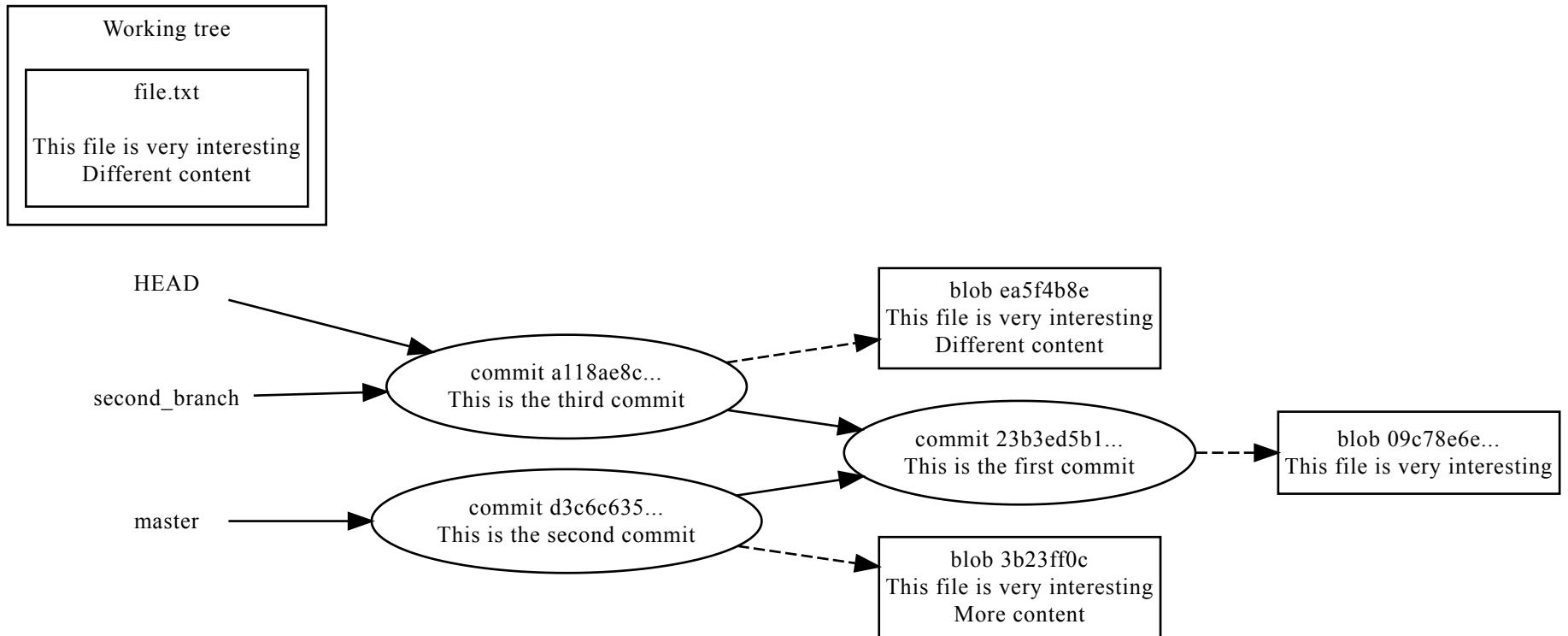


- Second, the commit tree now has **two** branches:



## We can give the second branch a name:

```
$ git checkout -b second_branch
Switched to a new branch 'second_branch'
$ cat .git/HEAD
ref: refs/heads/second_branch
$ cat .git/refs/heads/second_branch
a118ae8cda10a8f0a966ab7b9158b4a6d3b48cfc
```



# Merging

We can **merge** the two branches together:

```
$ git checkout master
$ git merge --no-ff second_branch
Auto-merging file.txt
CONFLICT (content): Merge conflict in file.txt
Automatic merge failed; fix conflicts and then commit the
result.
$ vim file.txt
```

We fix some **conflicts** at this point...

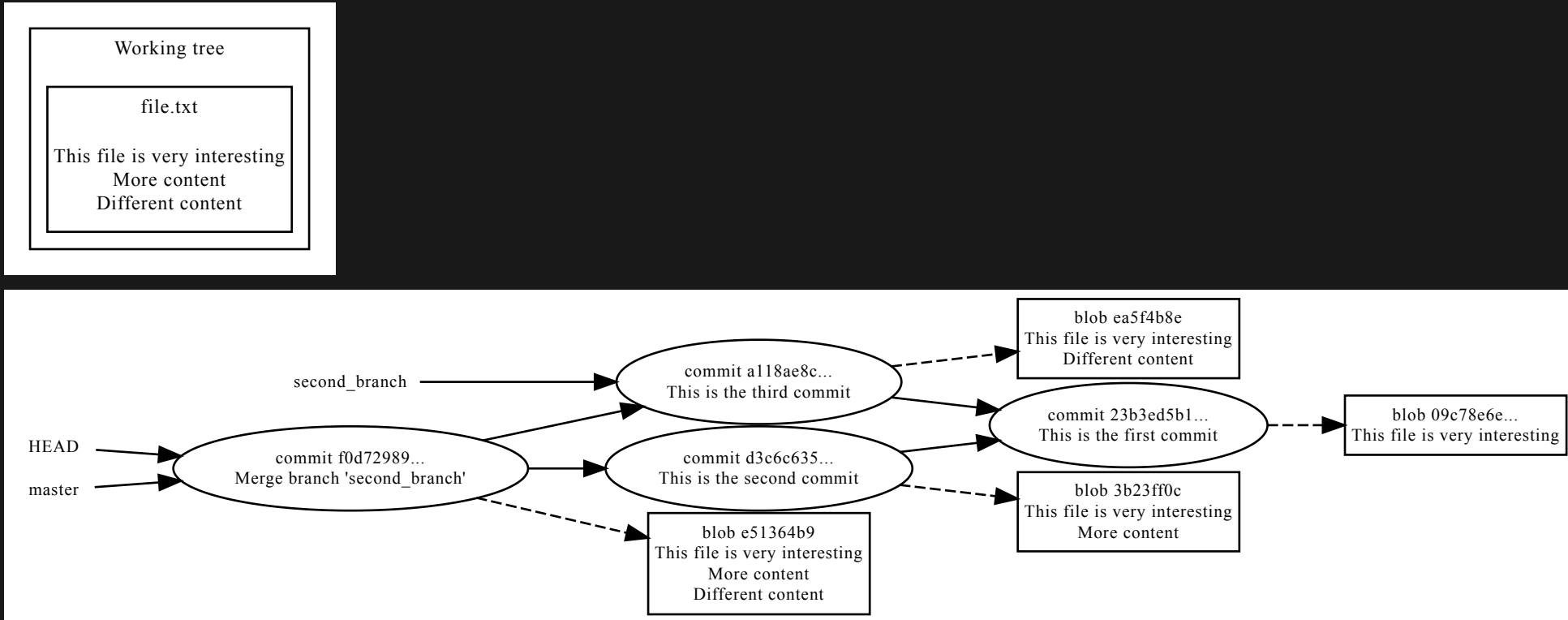
```
$ git add file.txt
$ git merge --continue
[master f0d7298] Merge branch 'second_branch'
```

## The created commit has **two** parents:

```
$ git cat-file -p f0d72989
tree f63f3a4c548f5065cee598bed4ae189bd2c099d8
parent d3c6c635fb44c7084797d47050bfff7961853c19b
parent a118ae8cda10a8f0a966ab7b9158b4a6d3b48cfc
author Mirko Myllykoski <mirko....> 1601288485 +0200
committer Mirko Myllykoski <mirko....> 1601288485 +0200

Merge branch 'second_branch'
```

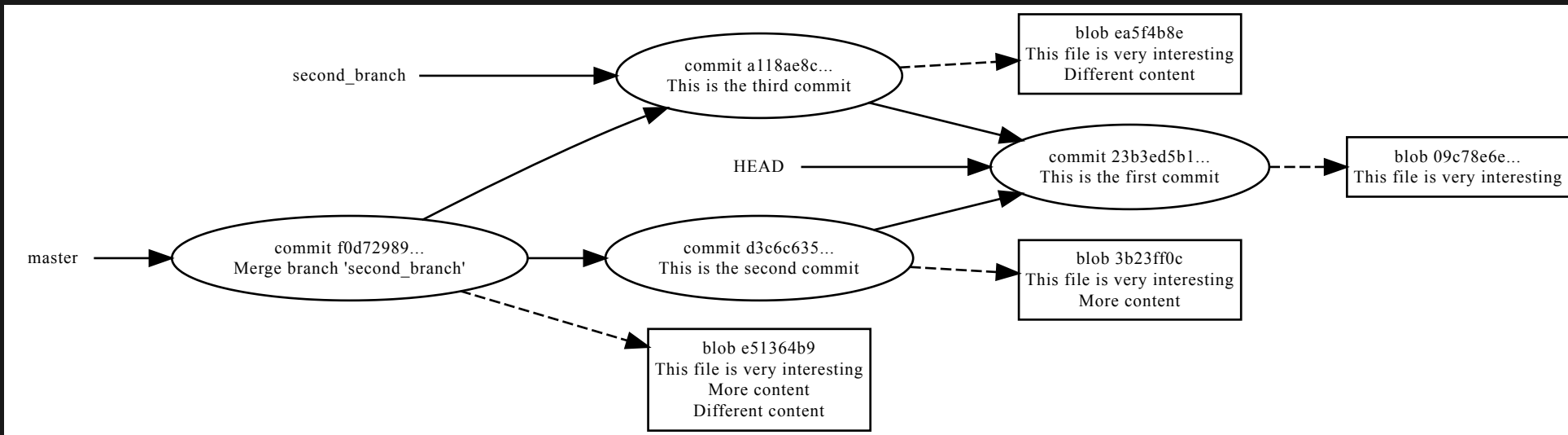
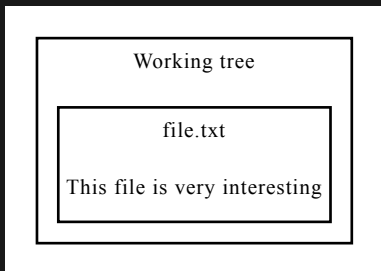
Finally, the tree looks like follows:



# Switching to a specific commit

We can always move back to any of the previous commits:

```
$ git checkout 23b3ed5b1
....
HEAD is now at 23b3ed5 This is the first commit
$ cat file.txt
This file is very interesting
```



The end.

An idea: Try to play with different commands. See what happens to the `.git/` directory.