# Introduction to Git

**"The stupid[1] content tracker"**

Naoki Pross — np@0hm.ch

11. March 2025

[1] *git* (British) – a foolish or worthless person

# About Me, You and Polls

## Me

- BSc in Electrical Engineering OST FH (here)
- MSc in EE spec. Control Theory (Regelungstechnik) at ETHZ
- For today “Git connaisseur”
- Languages for questions: EN / DE / CH / IT / ...

# About Me, You and Polls

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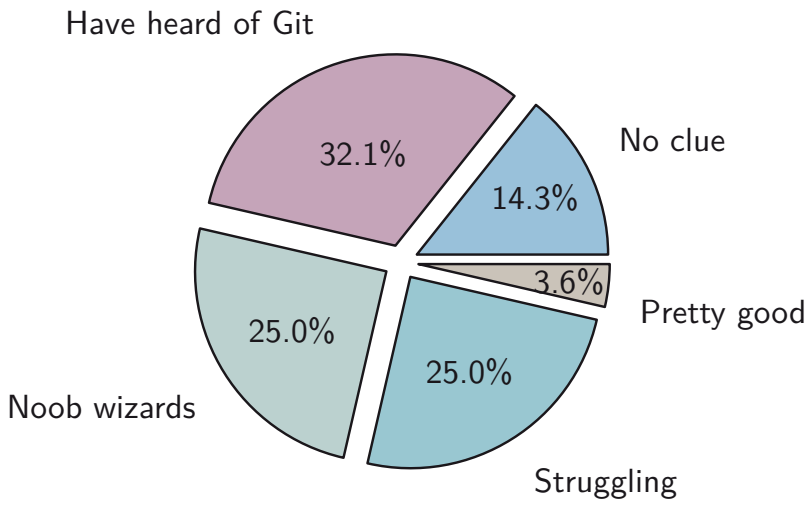
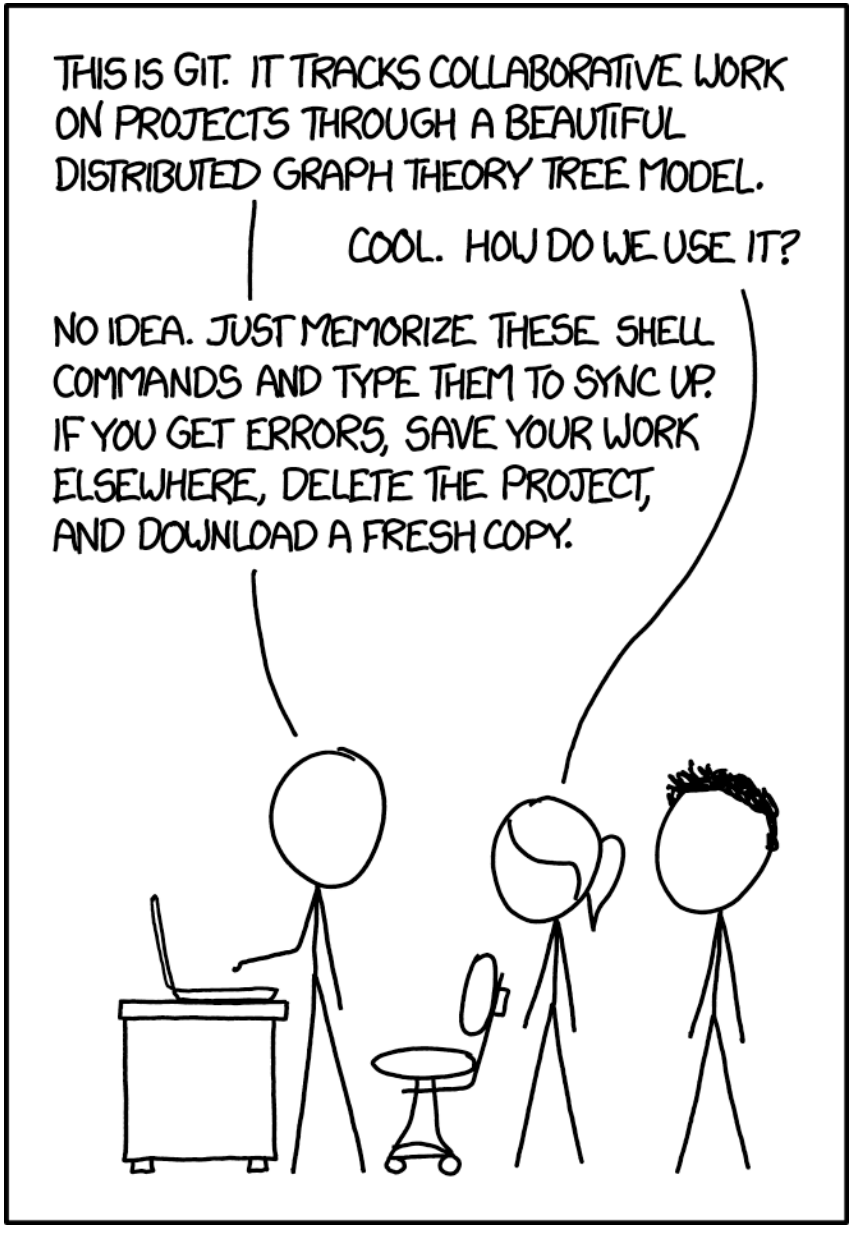
## You

- Background?
- Degree Programme?
- Ever used Git?



# Obligatory XKCD




## Plan for Today

1. A tiny bit of graph theory and even less cryptography
2. Understand (instead of memorizing) Git
3. Learn to actually use Git
4. Flex on your friends by finding what caused a bug using a logarithmic search over the directed acyclic graph that represents the change history
5. Put it on your CV and profit

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# What do we want?

## The Problem

Synchronize data across multiple computers, with multiple people working on (possibly the same) files.

# What do we want?

## The Problem

Synchronize data across multiple computers, with multiple people working on (possibly the same) files.

## Linus' Wishes (The guy who invented Git)

- Synchronization *always* works
- Teamwork is possible and efficient
- Works offline (and sync when online again)
- Fast
- Not centralized
- Open-source (btw. Linus also created Linux)

neither *intuitive nor easy to use* were not on his list!

# Other Solutions?

## Popular at Linus' Time

**CVS** Slow to synchronize. CVS requires a centralized server which can get overloaded, was usually set up by the company IT.

**E-Mail** People sent patch files to each other via email.

## Other Tools Today

**Cloud Storage** Does not work offline. Their whole business model is against you. You have no (real) control over when to sync. Also, sharepoint is garbage. No way to compare changes.

**Mercurial** (Much) less popular than Git, used by Mozilla.

**Jujitsu** Git-compatible VCS, even less popular and very new.

# This is not a Political Event

**Work *together*?**
**Open Source?**

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Almost all companies and research institutes use a Cloud service for data and / or Git (some stats put Git at $> 90\%$ market share for VCS).

So, no, Git and open source are not communism. Git is widely used in industry.


Richard Stallman



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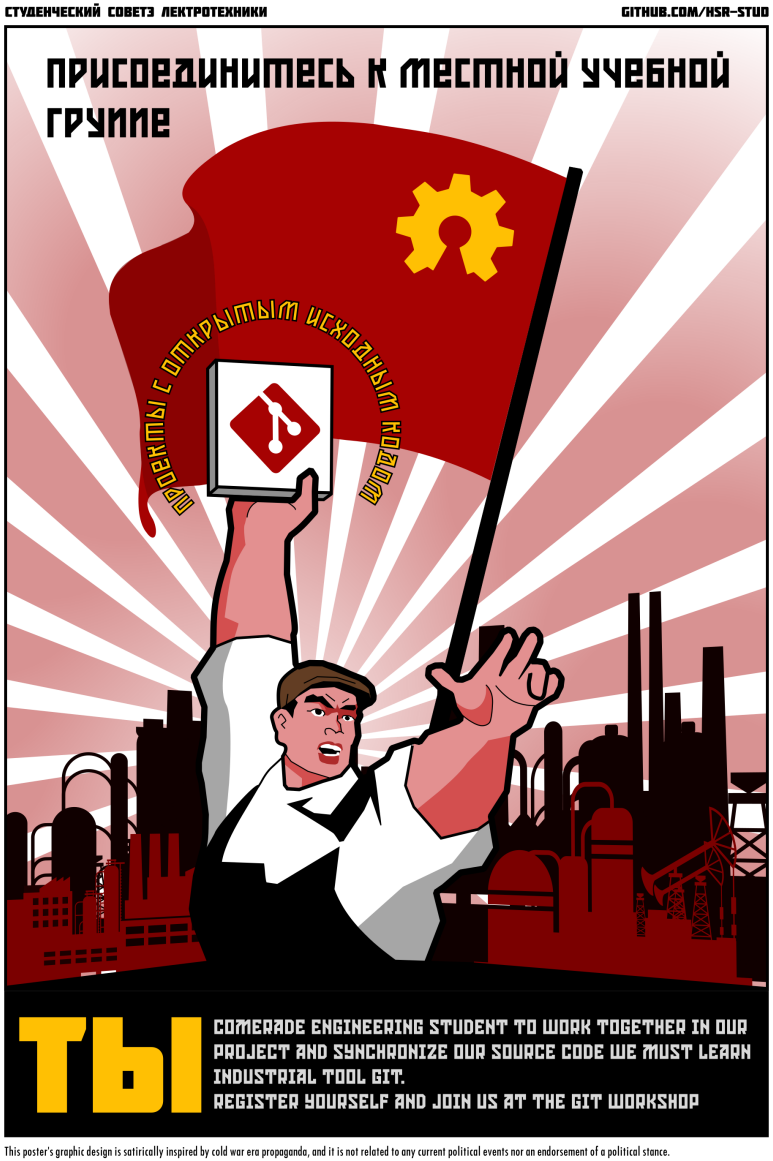
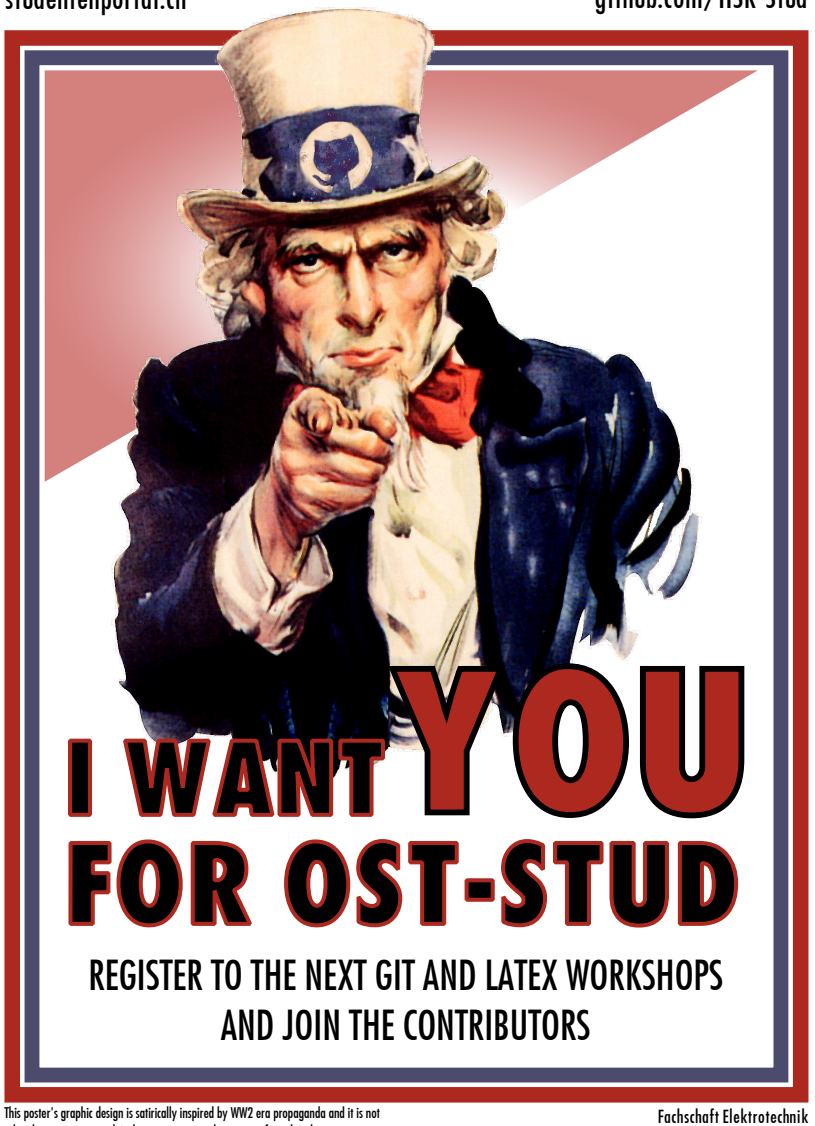



This poster's graphic design is satirically inspired by cold war era propaganda, and it is not related to any current political events nor an endorsement of a political stance.

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Fachschaft Elektrotechnik

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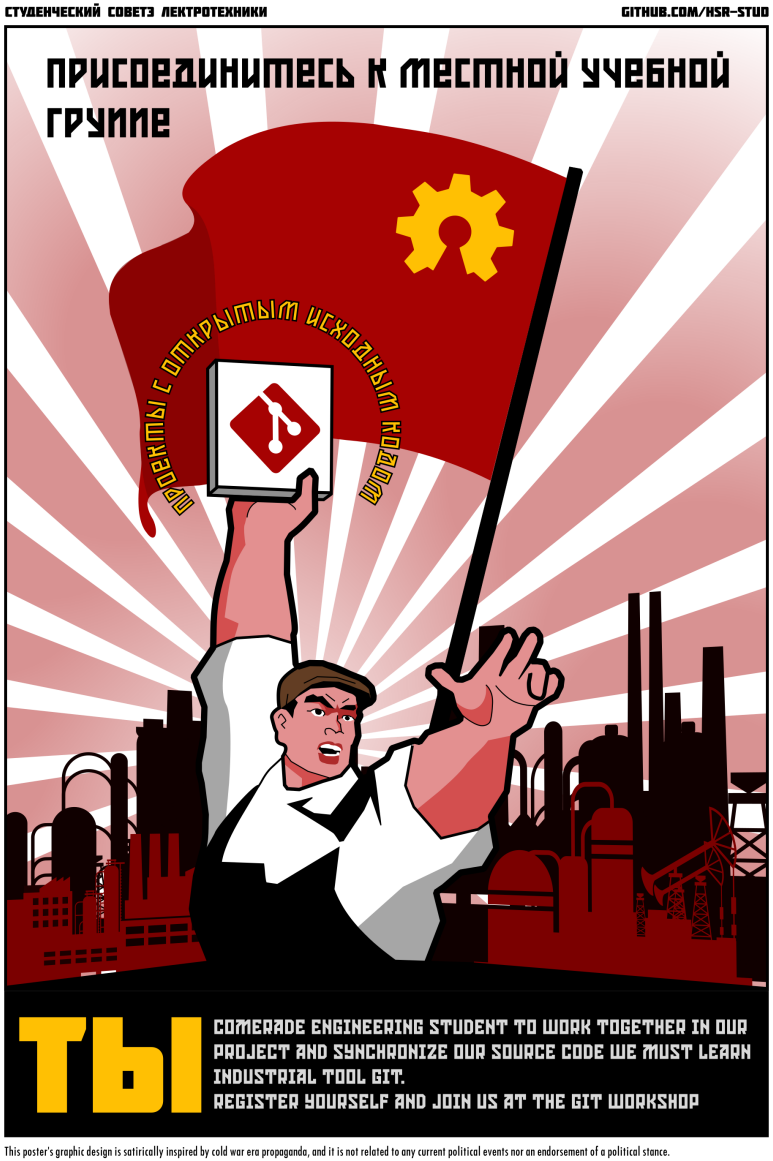


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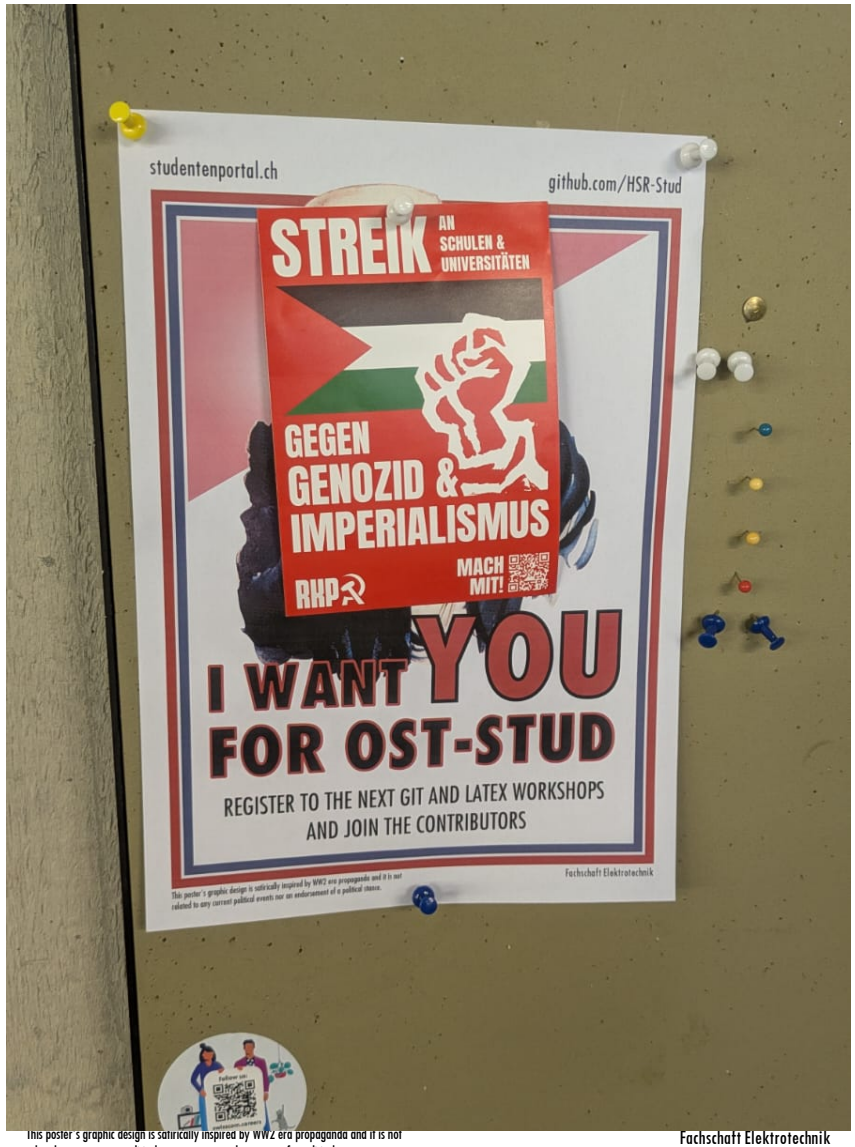


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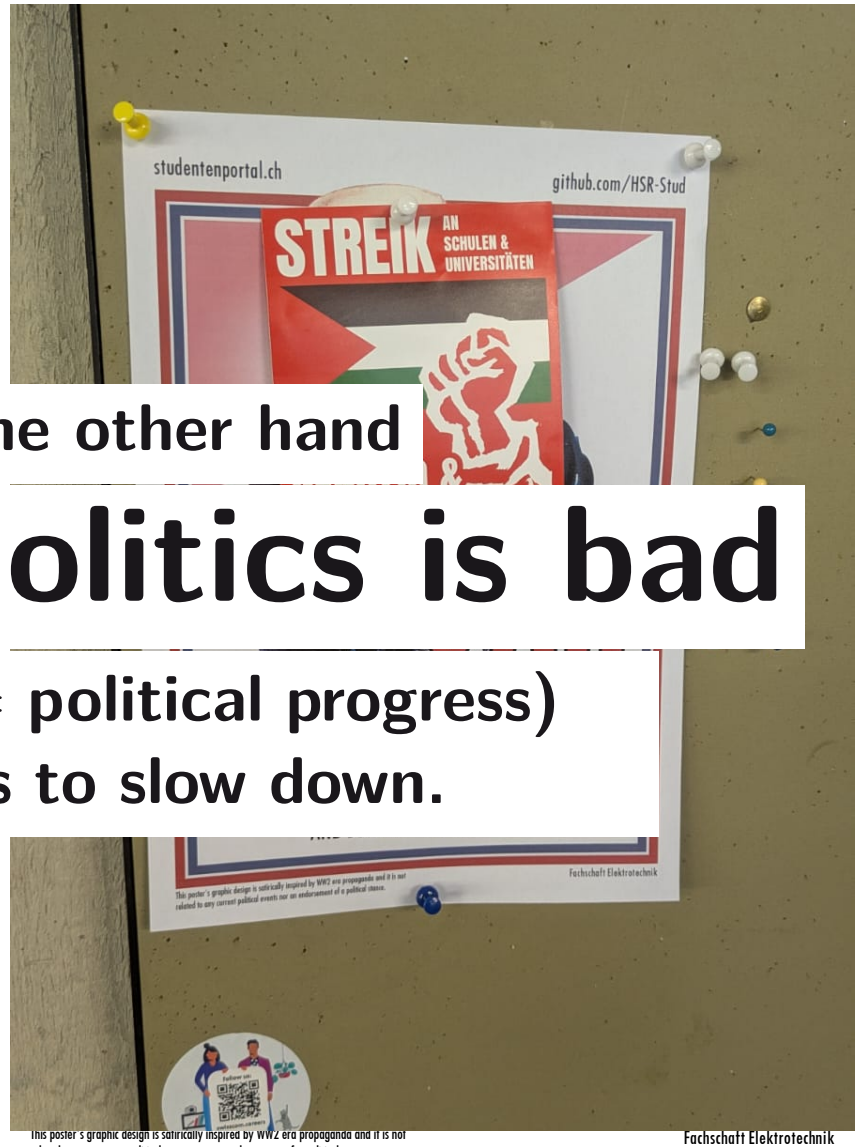


Funny but on the other hand

**Reactionary politics is bad**

Political discourse ($\neq$ political progress) desperately needs to slow down.

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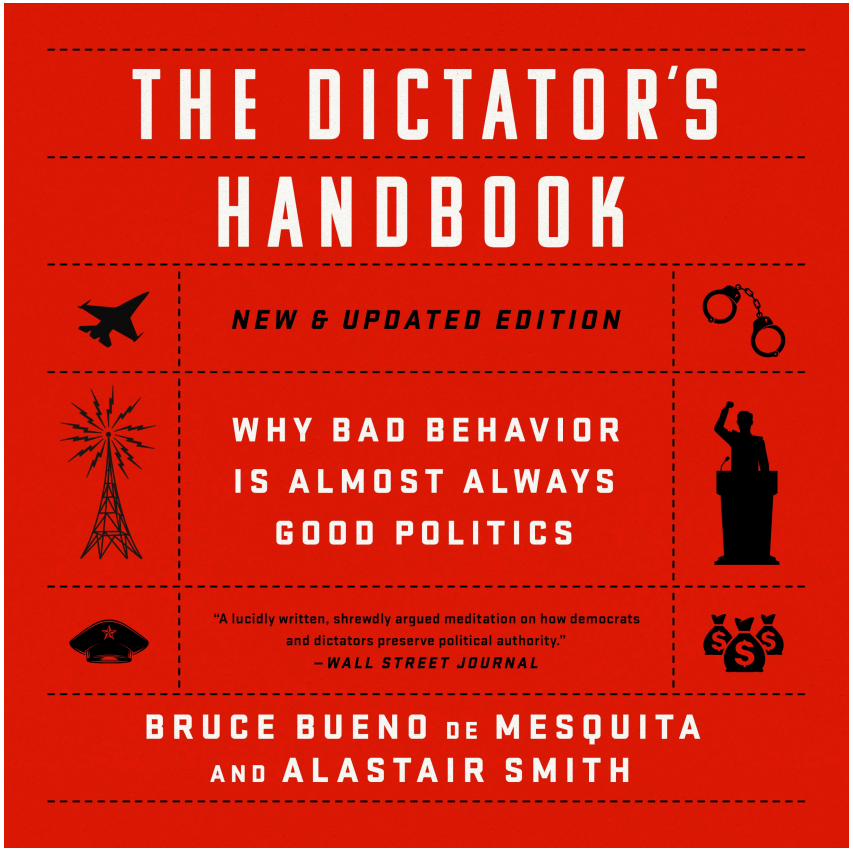


**A recommendation if you are interested in politics**

Simplified explaination of selectorate theory. Mostly about the *structures* of power in politics than politics itself.

Also: *Eristic Dialectic* (Schopenhauer) *Amusing Ourselves to Death* (Postman), *Animal Farm* (Orwell), *The Prince* (Machiavelli), and the many classics (Plato, Aristotle, Locke, Rousseau, Marx, Arendt, Rawls, Foucault, ...).

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# Solving the Problem: Snapshots

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Project/
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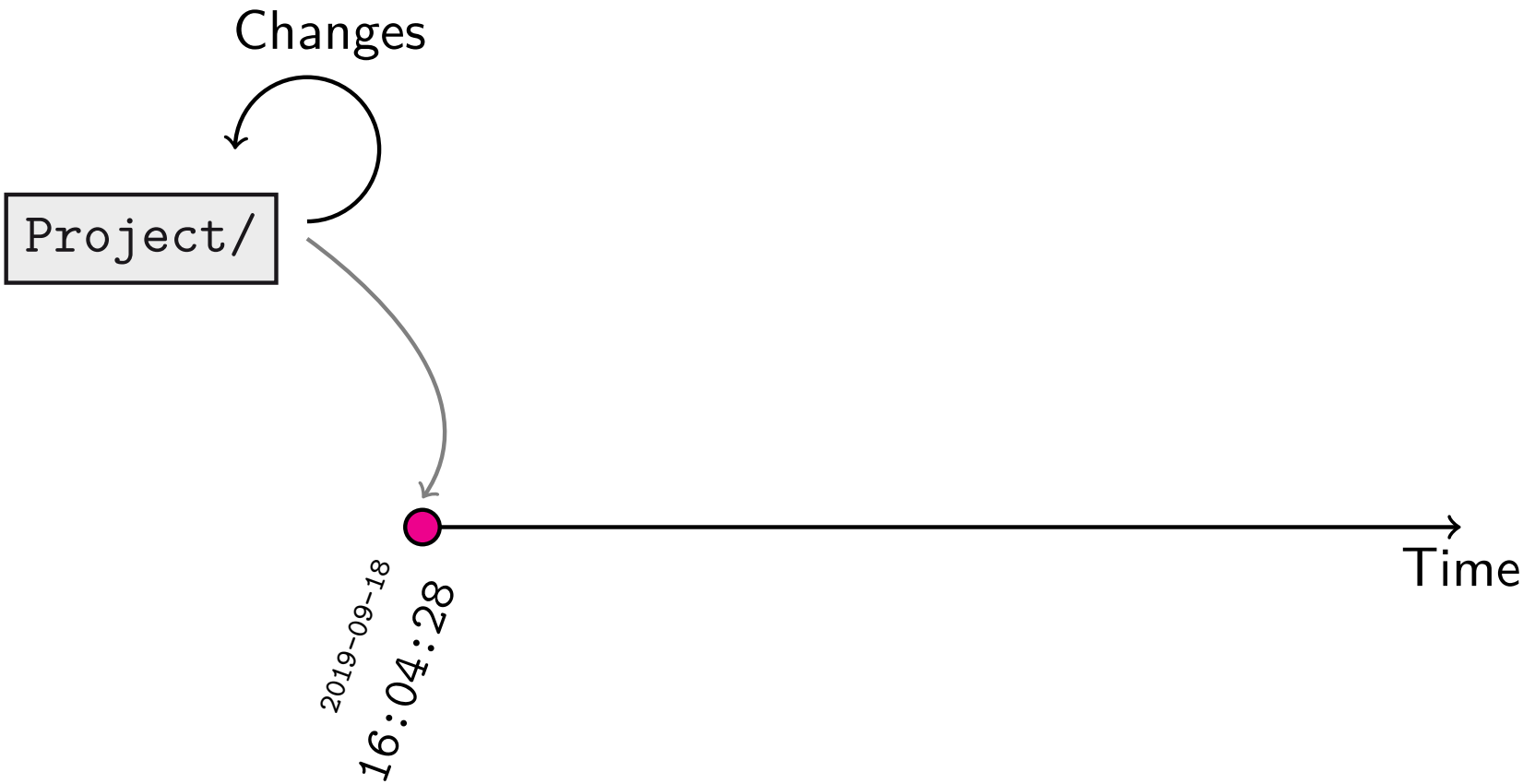

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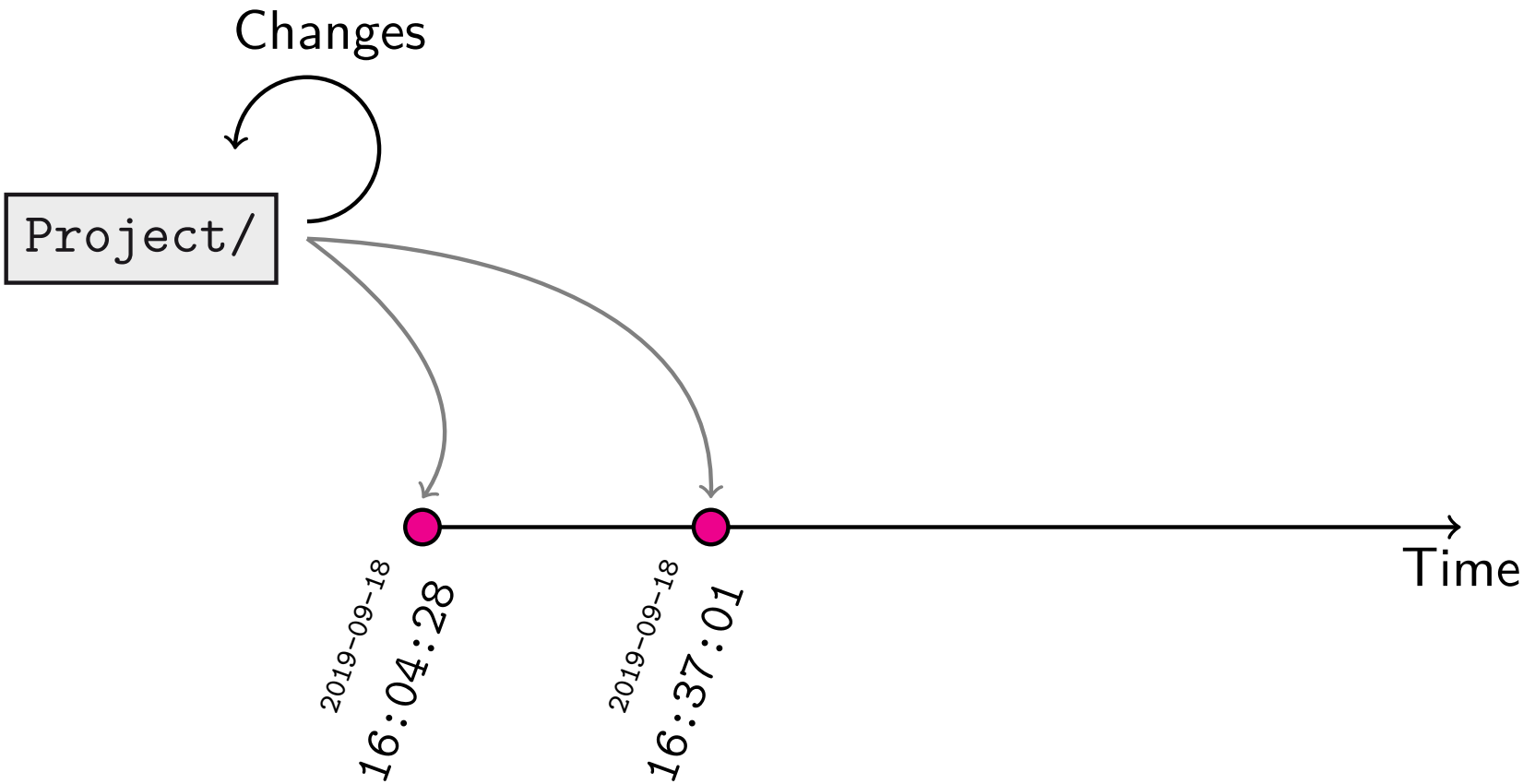

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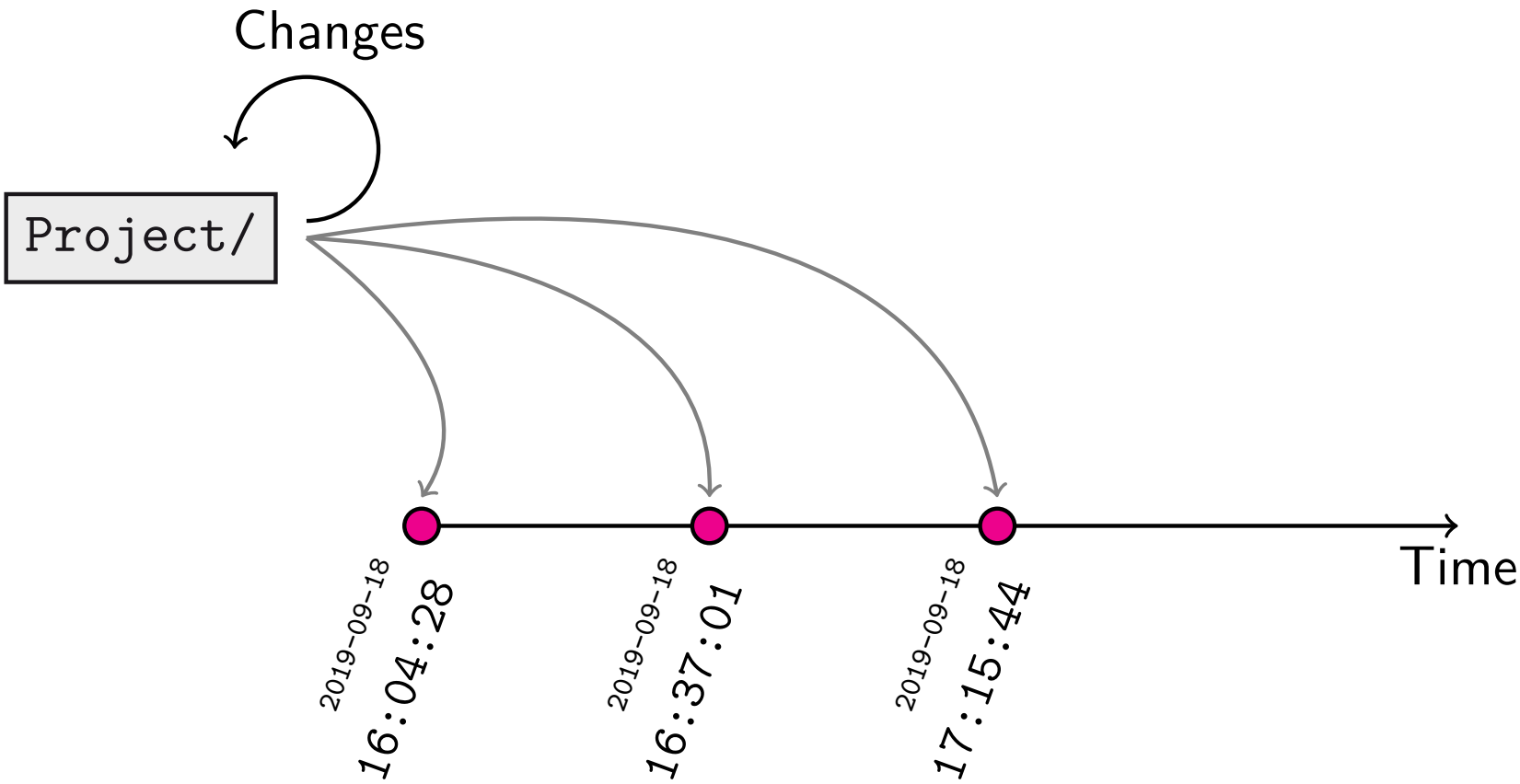

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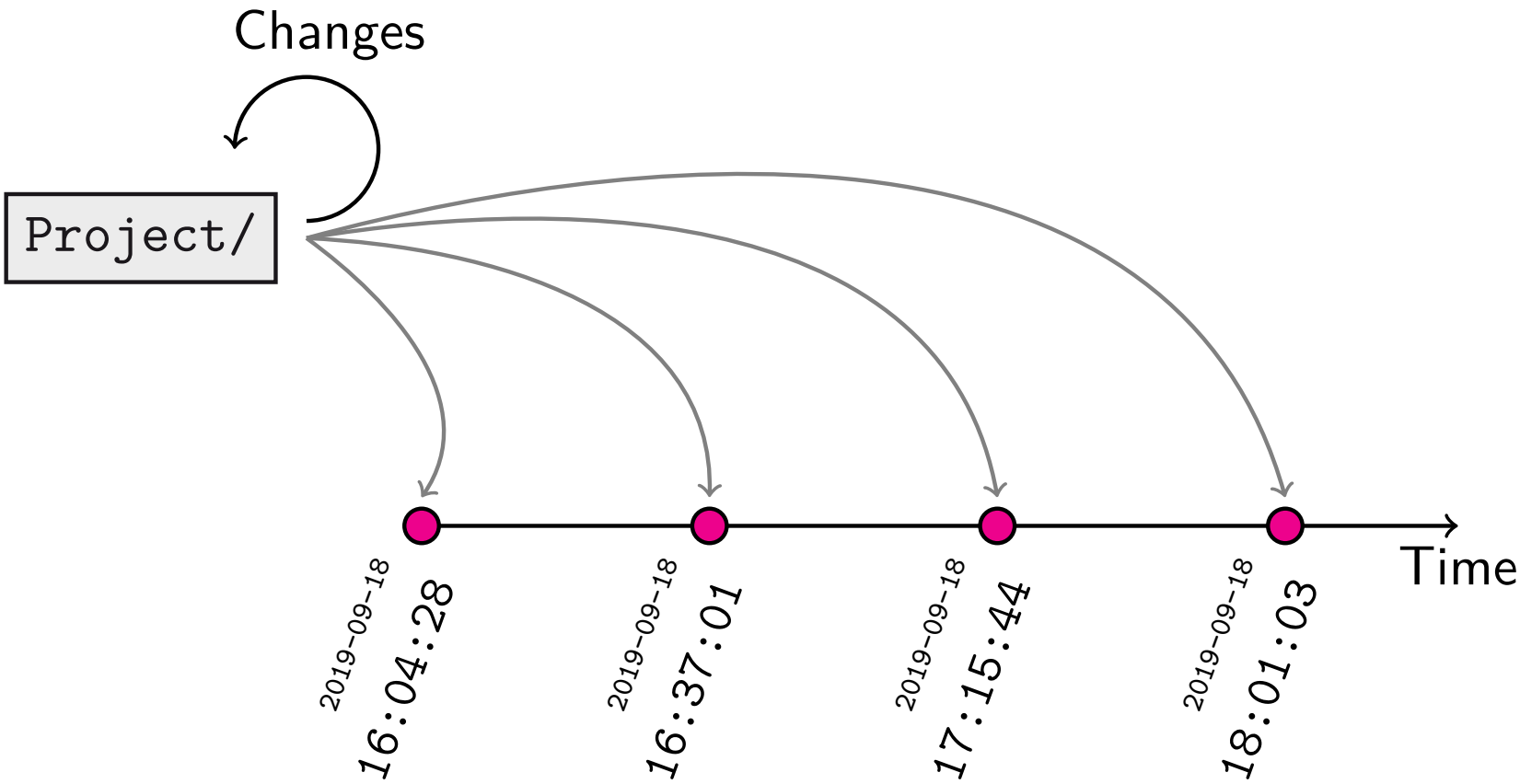

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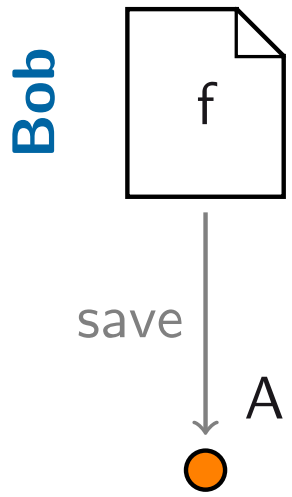

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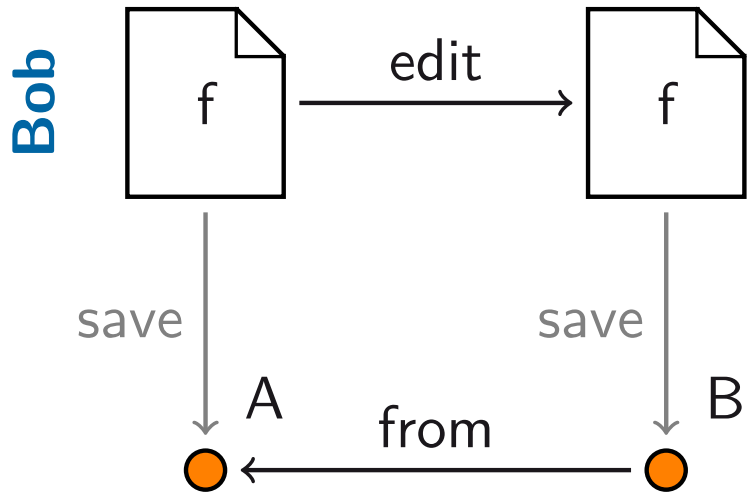

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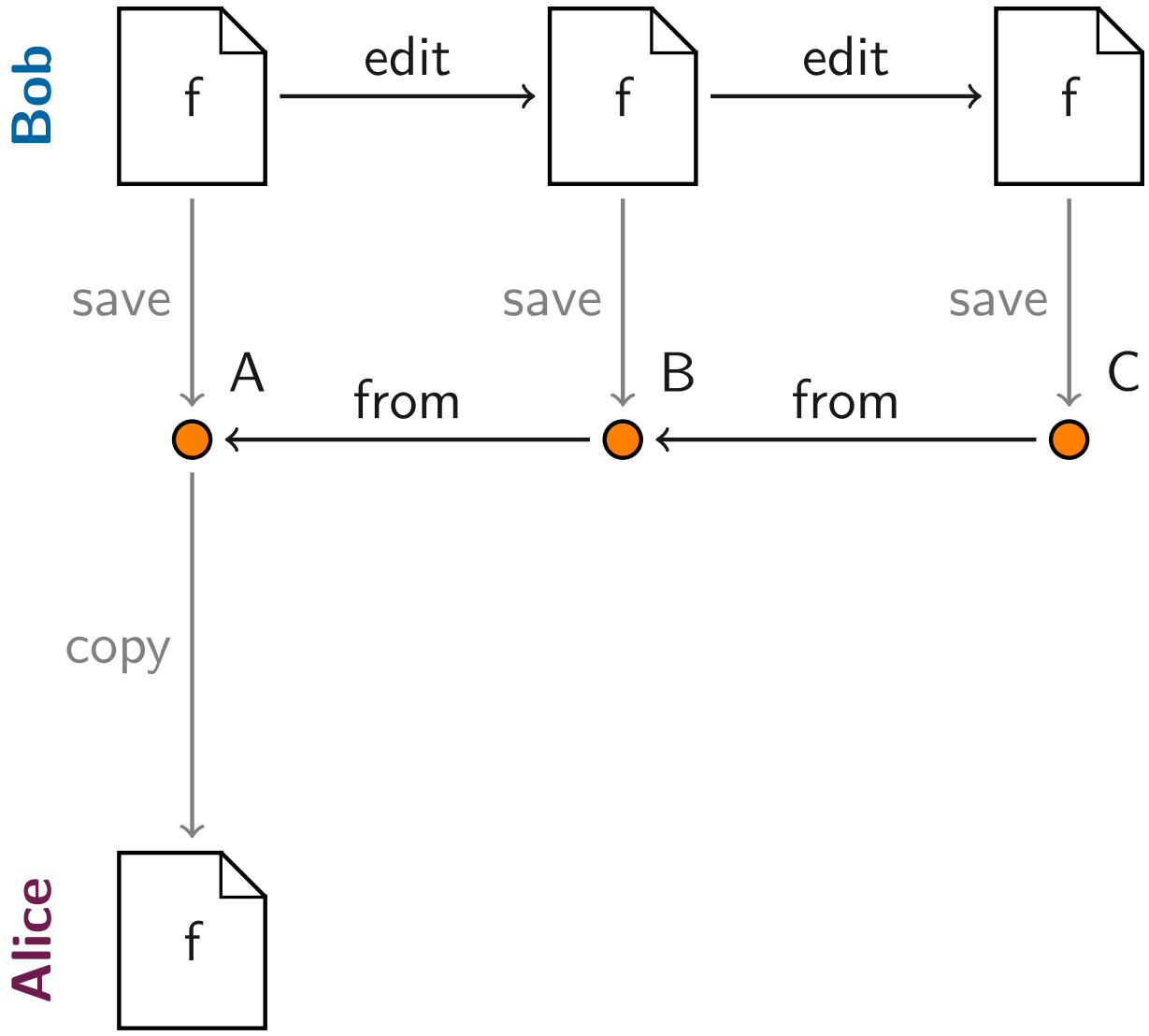

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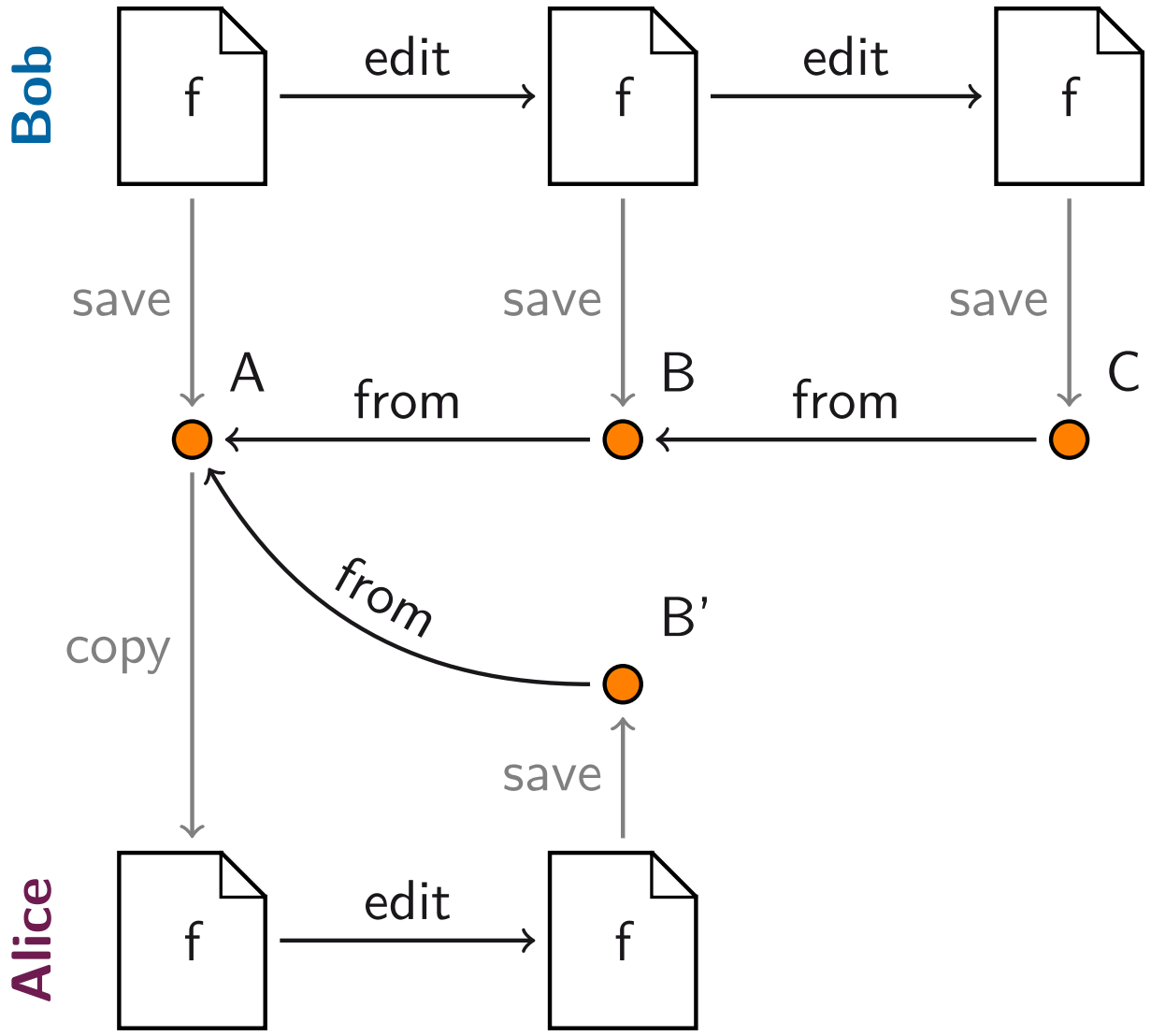

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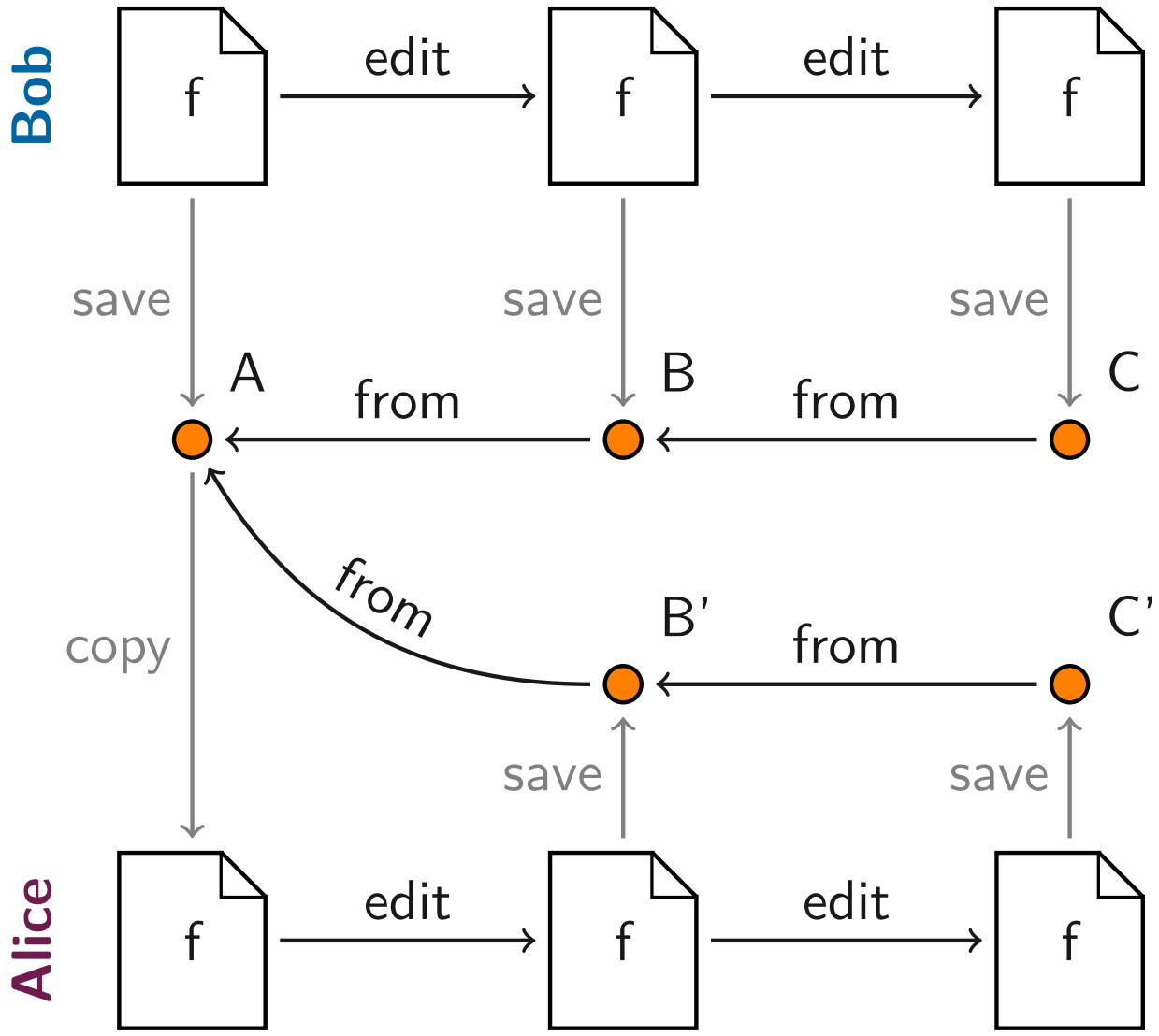

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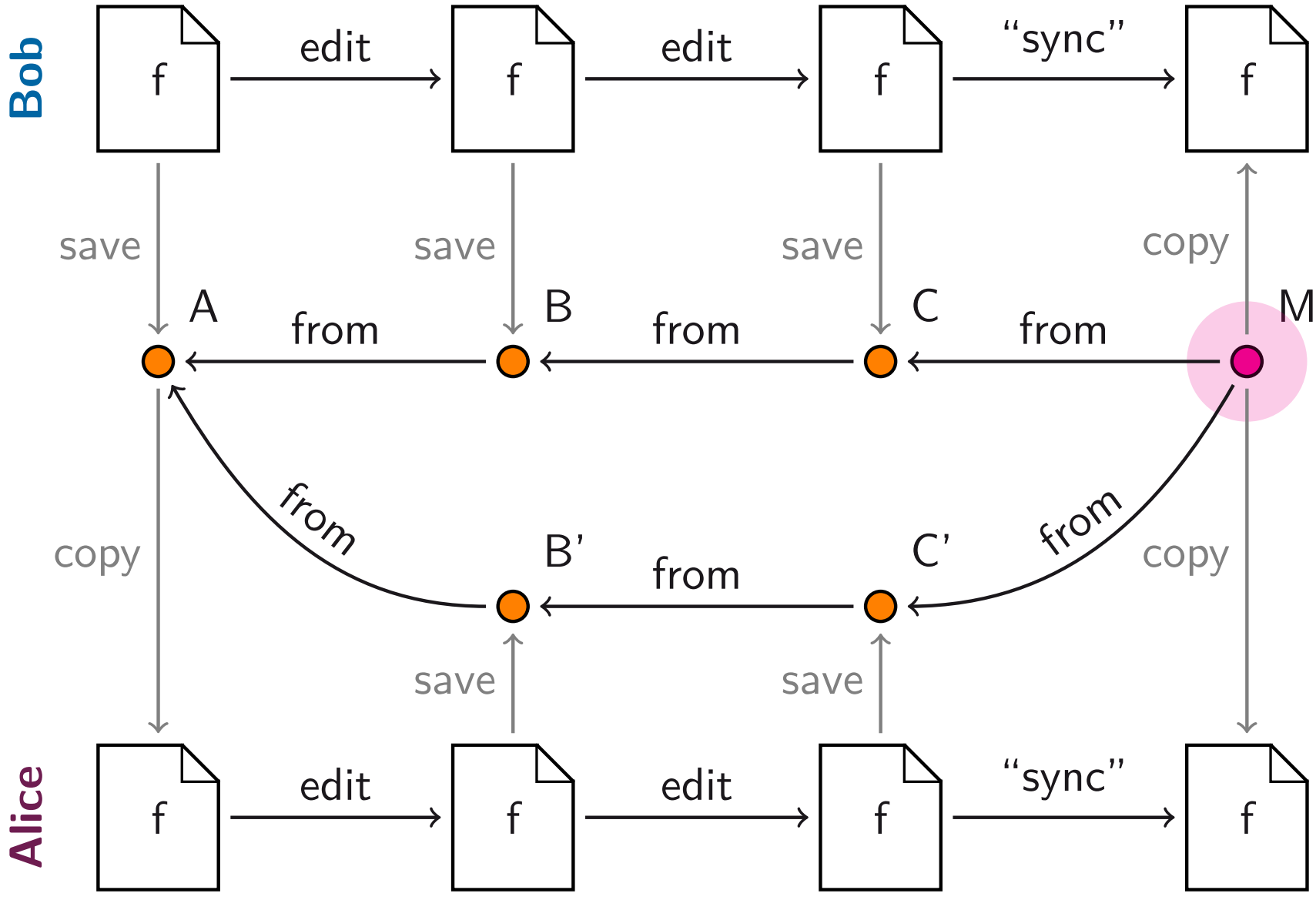


# Solving the Problem: Concurrent Changes II

## High Level Overview

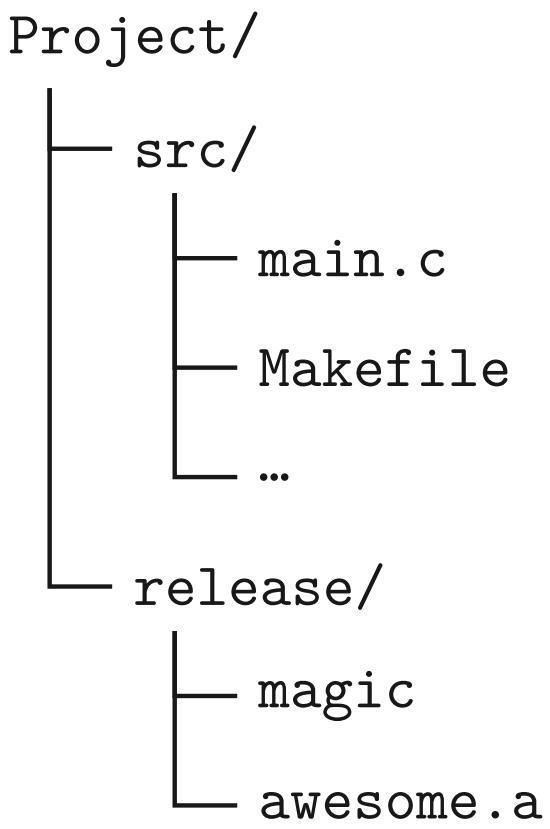
Store changes using a *directed acyclic graph* (DAG) called the *commit graph*.

- Nodes are saved points in time called *commits*
- Arcs point to state from which change was made
- Commits with multiple children (A) are *branching commits*
- Commits with multiple parents (M) are *merge commits*

## Problems

1. We care about file content not the files itself
2. How do we merge changes?
3. Alice and Bob are not working on the same computer

# Solving the Problem: Multiple Files




## Filesystem Jargon

**Tree** Folder / Directory

**Blob** Binary Large OBject, raw data (bits) of file content[a]

**File** Blob + Metadata (Name, Date, …)

## Solution

Treat all blobs as single entity with metadata. Examples:

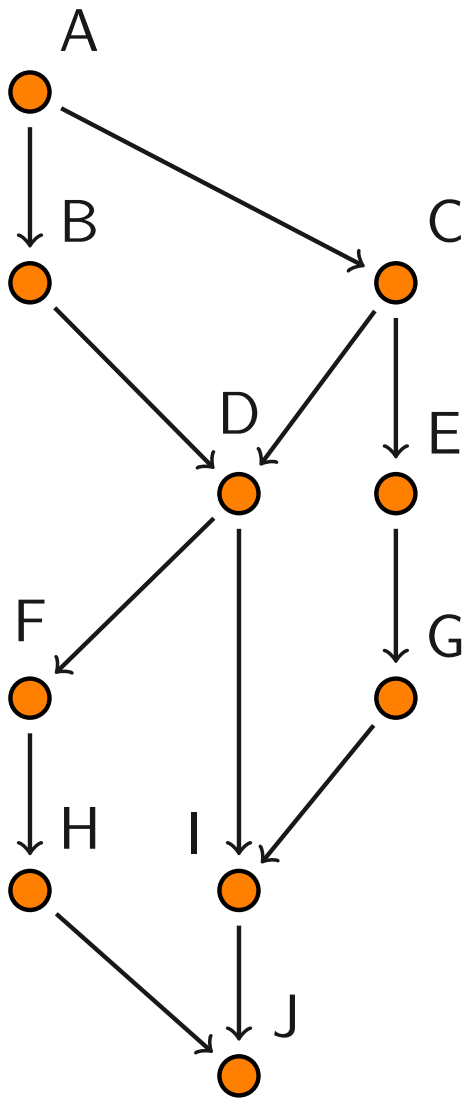
- Rename file ⇒ Same blob, commit name change
- Move file ⇒ Same blob, commit change tree

[a] Demo: `hexdump` vs `stat`

# Mathematical Digression I: DAG

## Directed Acyclic Graph

A DAG $G = (V, A)$ is defined by a finite set of vertices $V$ and a finite set of *arcs* $A$ and may not contain loops.



# Mathematical Digression I: DAG

## Directed Acyclic Graph

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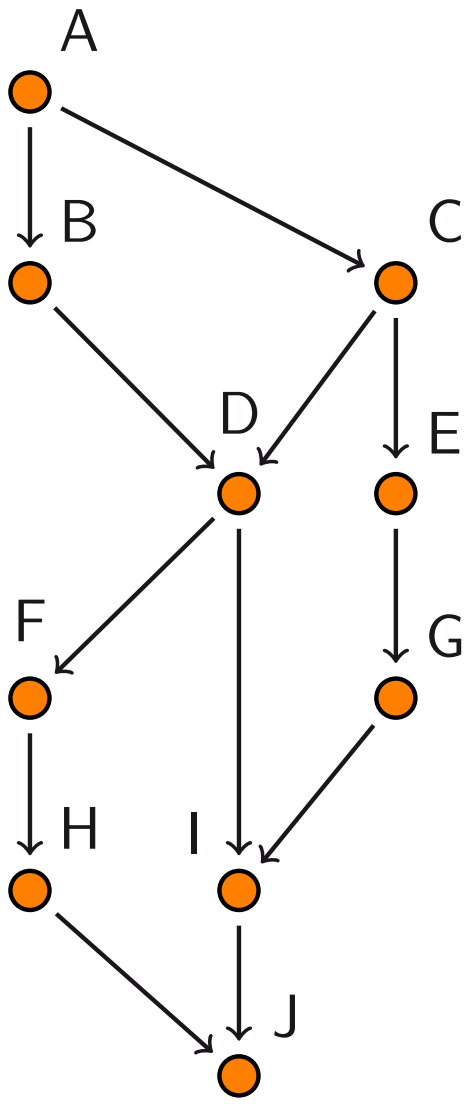
## Partial Order

DAG have a partial order relation $u \succ v$ for comparable $u, v \in V$.



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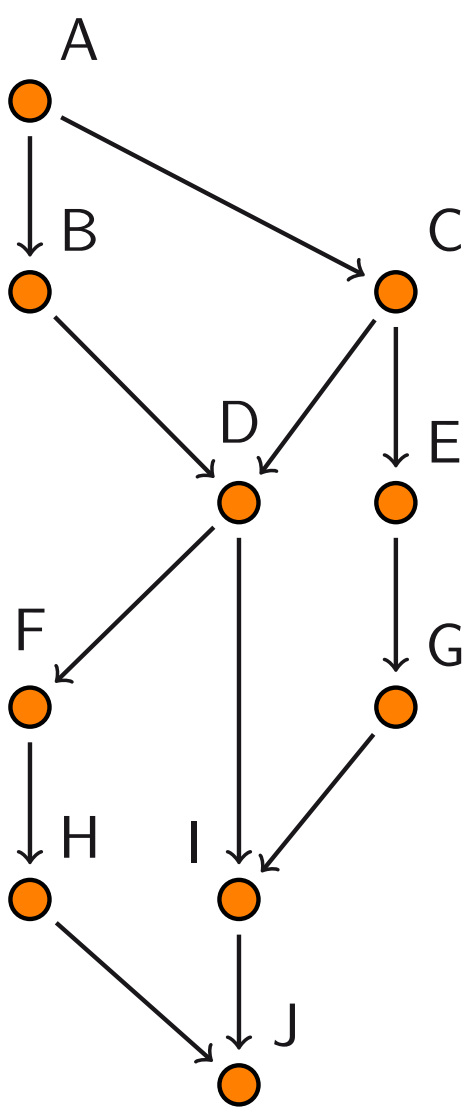
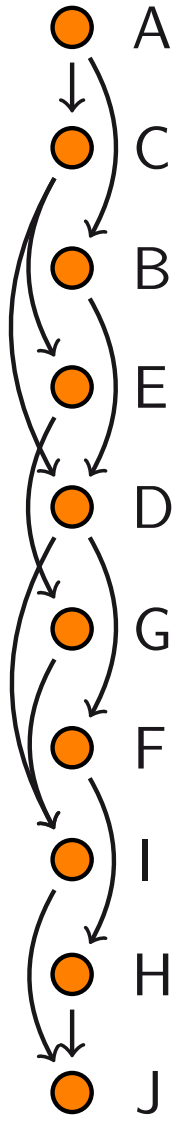
## Partial Order

DAG have a partial order relation $u \succ v$ for comparable $u, v \in V$.

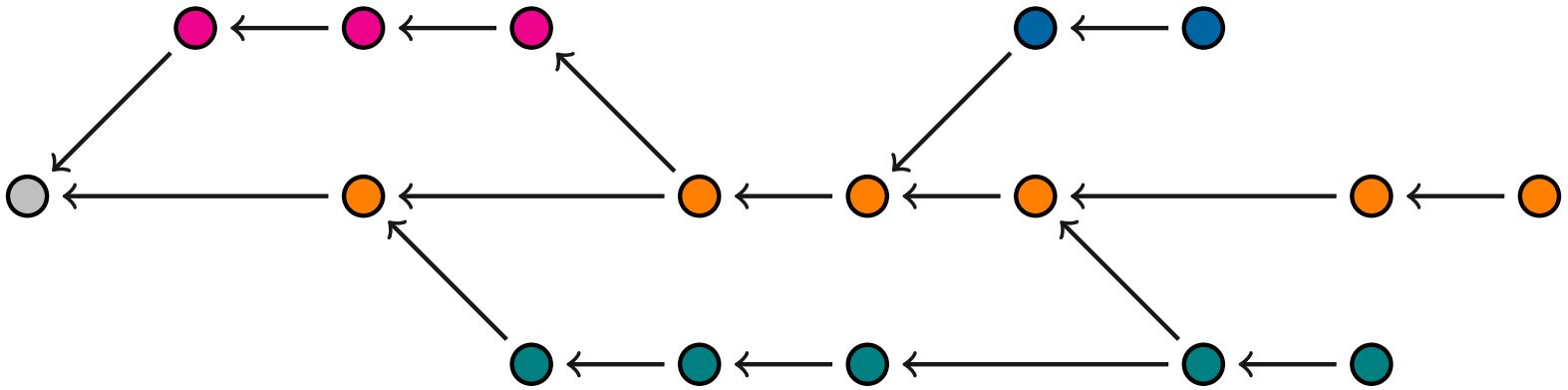
## Topological Order

A DAG $G = (V, A)$ has a total order $\succ^*$ by having that for all $(u, v) \in A$ $u \succ^* v$. If $G$ has a Hamiltonian path $\succ^*$ is unique.



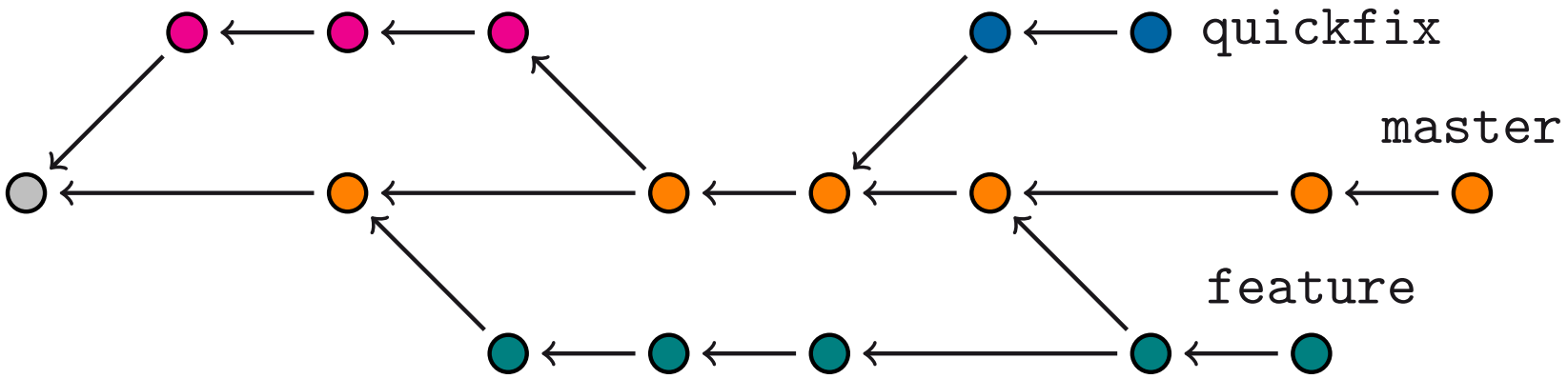
# Solving the Problem: Concurrent Changes III



**Branch (informal)**

Branches are subgraphs (subtrees) from a common anchestor in the commit graph.

# Solving the Problem: Concurrent Changes III



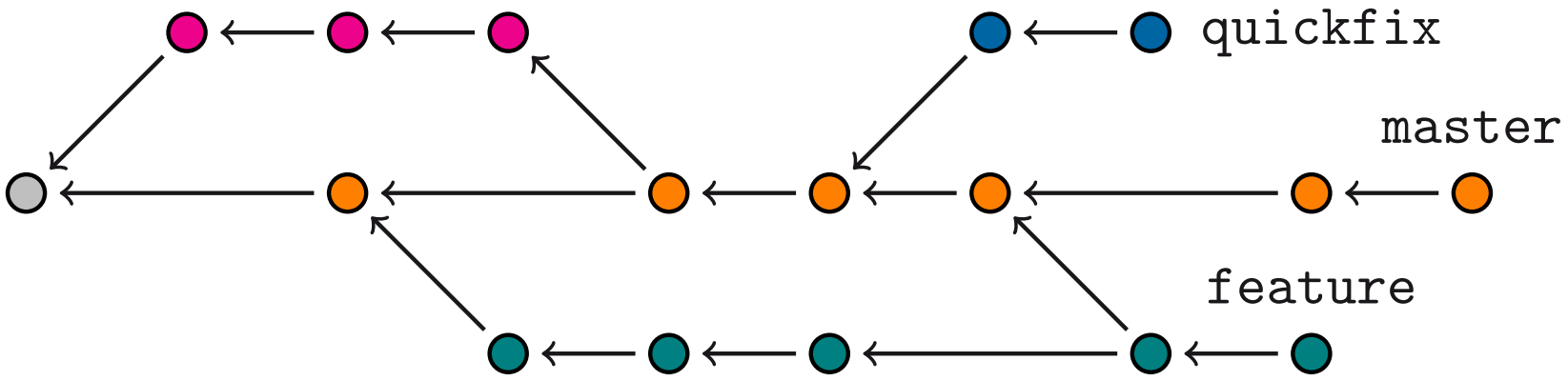

## Branch (informal)

Branches are subgraphs (subtrees) from a common anchestor in the commit graph.

## Naming Branches

Branch names are labels on their most recent commit.

# Solving the Problem: Concurrent Changes III




## Branch (informal)

Branches are subgraphs (subtrees) from a common anchestor in the commit graph.

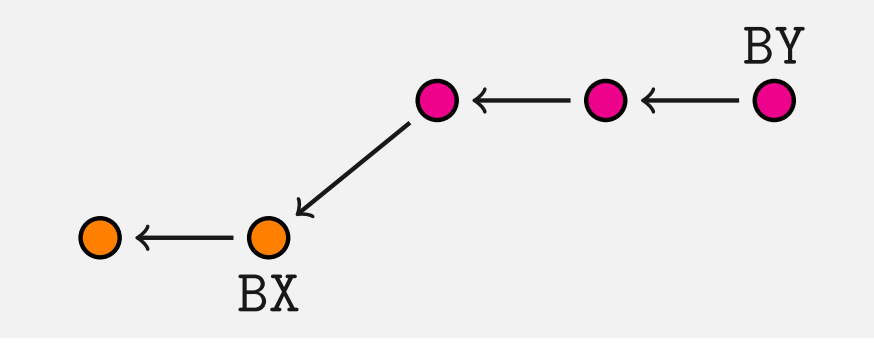
## Naming Branches

Branch names are labels on their most recent commit.

## Examples

- `quickfix` branch is from `master`
- Magenta (no name) branch was merged into `master`
- `master` branch was merged into `feature`

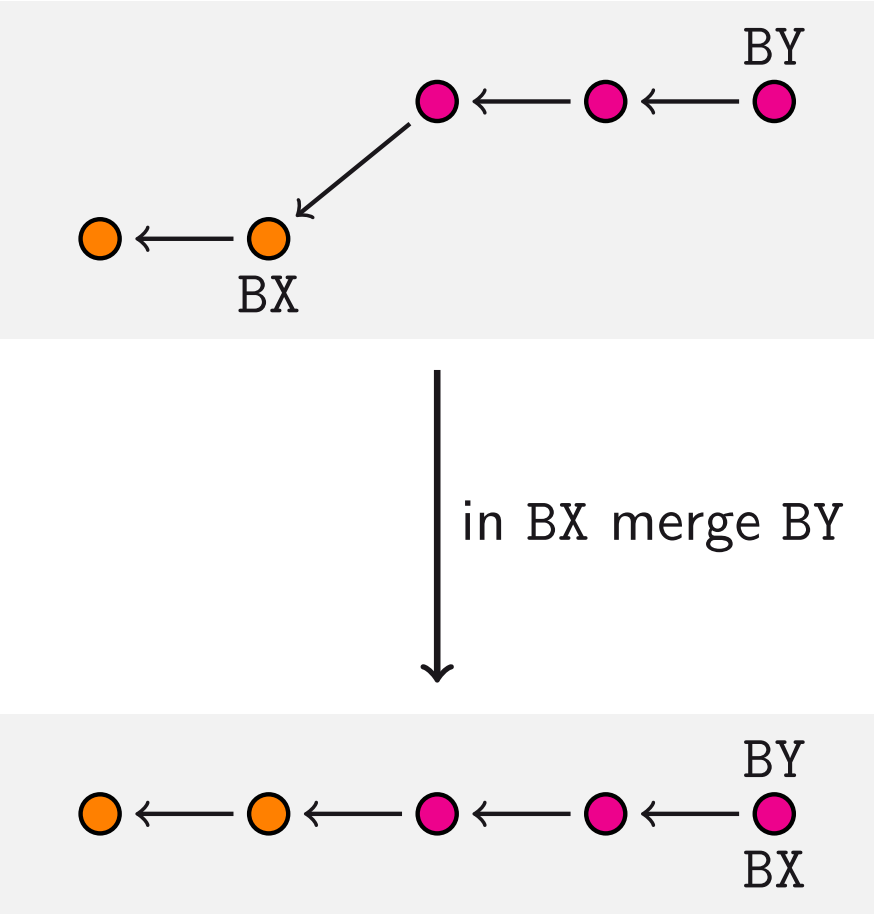
# Solving the Problem: Fast-Forward-Merge




## History

1. From an existing branch `BX` (with orange commits) a branch `BY` added new commits (magenta)
2. We merge `BY` into `BX`

# Solving the Problem: Fast-Forward-Merge



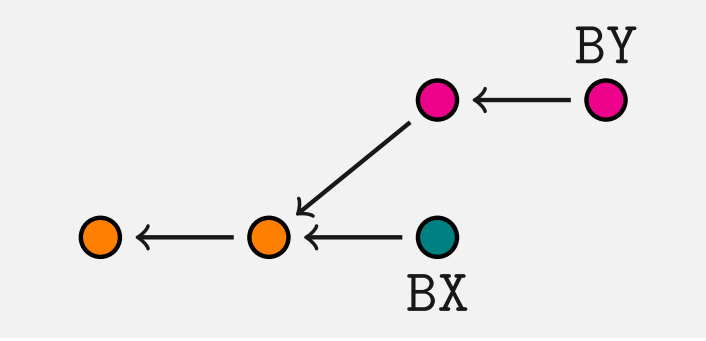

## History

1. From an existing branch BX (with orange commits) a branch BY added new commits (magenta)
2. We merge BY into BX

## FF-Merge

Apply changes of commits in BY starting at BX until you get to BY. Or BX just needs to "catch up" to BY. No new commits are created.

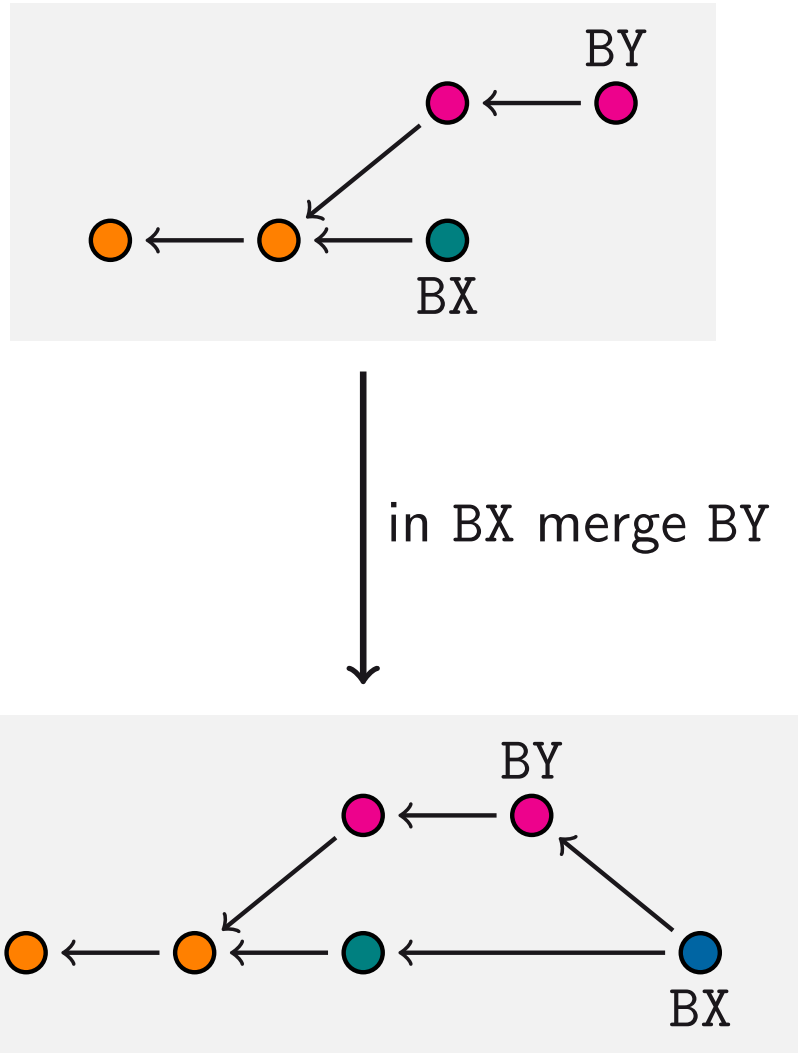
# Solving the Problem: 3-Way-Merge I




## History

1. Branches `BX` and `BY` have new commits (magenta and green resp.) and share a common history (orange)
2. We merge `BY` into `BX`

# Solving the Problem: 3-Way-Merge I




## History

1. Branches BX and BY have new commits (magenta and green resp.) and share a common history (orange)
2. We merge BY into BX

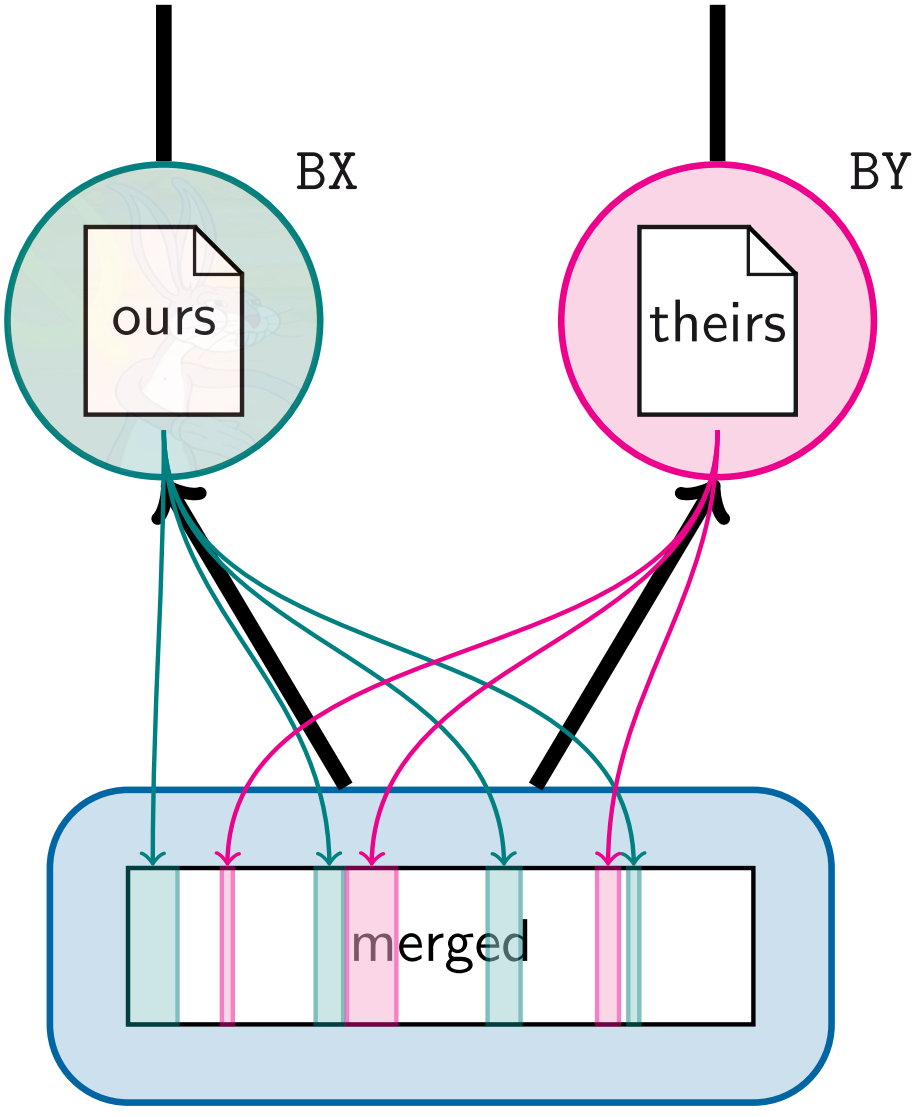
## Observations

When you merge you are in BX importing changes from BY

- "our" changes are from BX
- "their" changes are from BY

Need to make choices, which get saved in a new merge commit.

# Solving the Problem: 3-Way-Merge II




Merge BY into BX

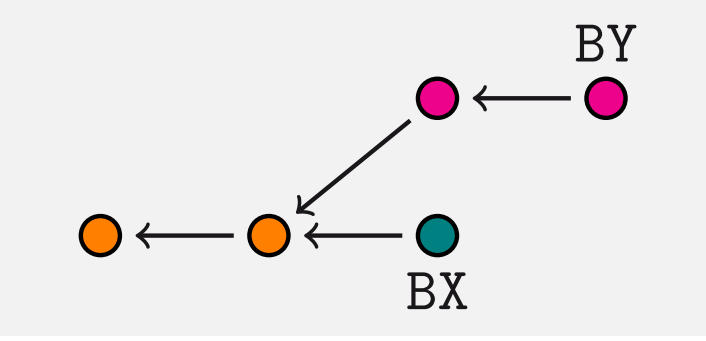
## 3-Way-Merge

- Use a (3-way-merge) algorithm to merge trees and blobs from each commit
- If not possible the user has to choose between 'our' changes and 'their' changes

## Merge Conflict

When the algorithm cannot merge the file automatically it is called *merge conflict*.

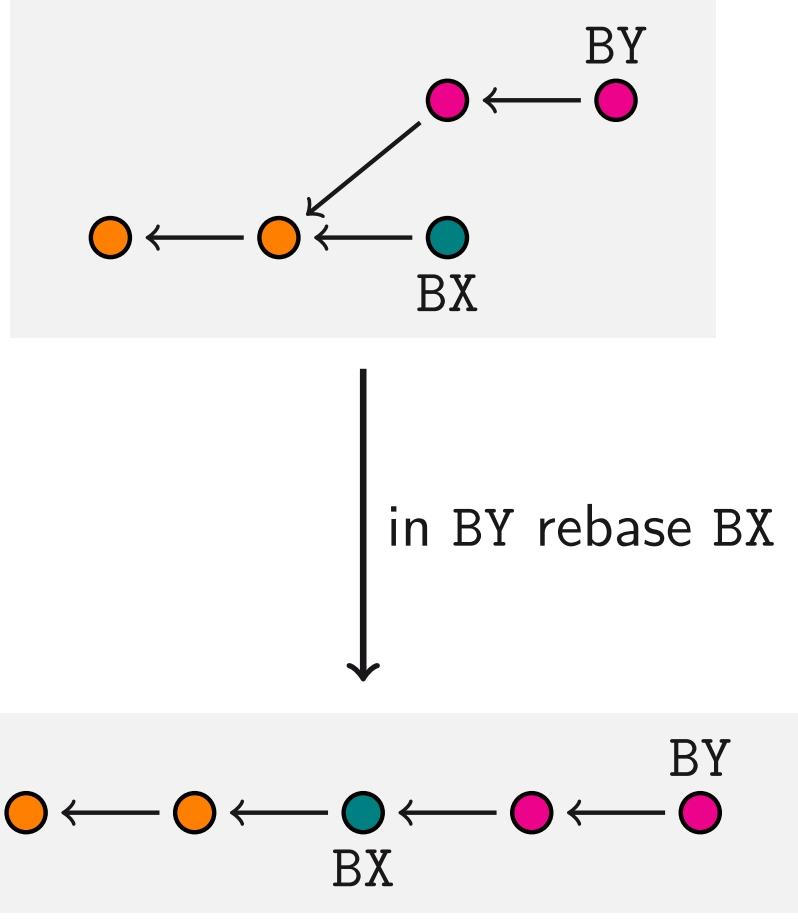
# Solving the Problem: Rebase




## History

1. Branches `BX` and `BY` have new commits (magenta and green resp.) and share a common history (orange)
2. We rebase `BY` onto `BX`

# Solving the Problem: Rebase




## History

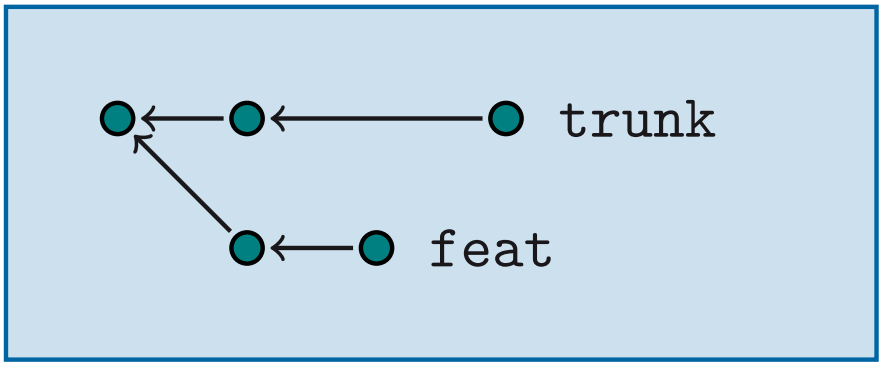
1. Branches BX and BY have new commits (magenta and green resp.) and share a common history (orange)
2. We rebase BY onto BX

## Observations

When you rebase you need to reapply your changes on the newer versions of the files. Hence you may need to resolve some conflicts during this process. But then there not a merge commit.

# Solving the Problem: Multiple Computers I

Bob's PC




## Remotes and Clone

Other computers are called *remotes*. Clone means you copy the commit graph on the remote machine onto yours.

## Example

1. Alice has cloned Bob's (green) commit graph
2. Alice has merged `trunk` onto `feat` and made changes
3. Bob has also made changes on `trunk`

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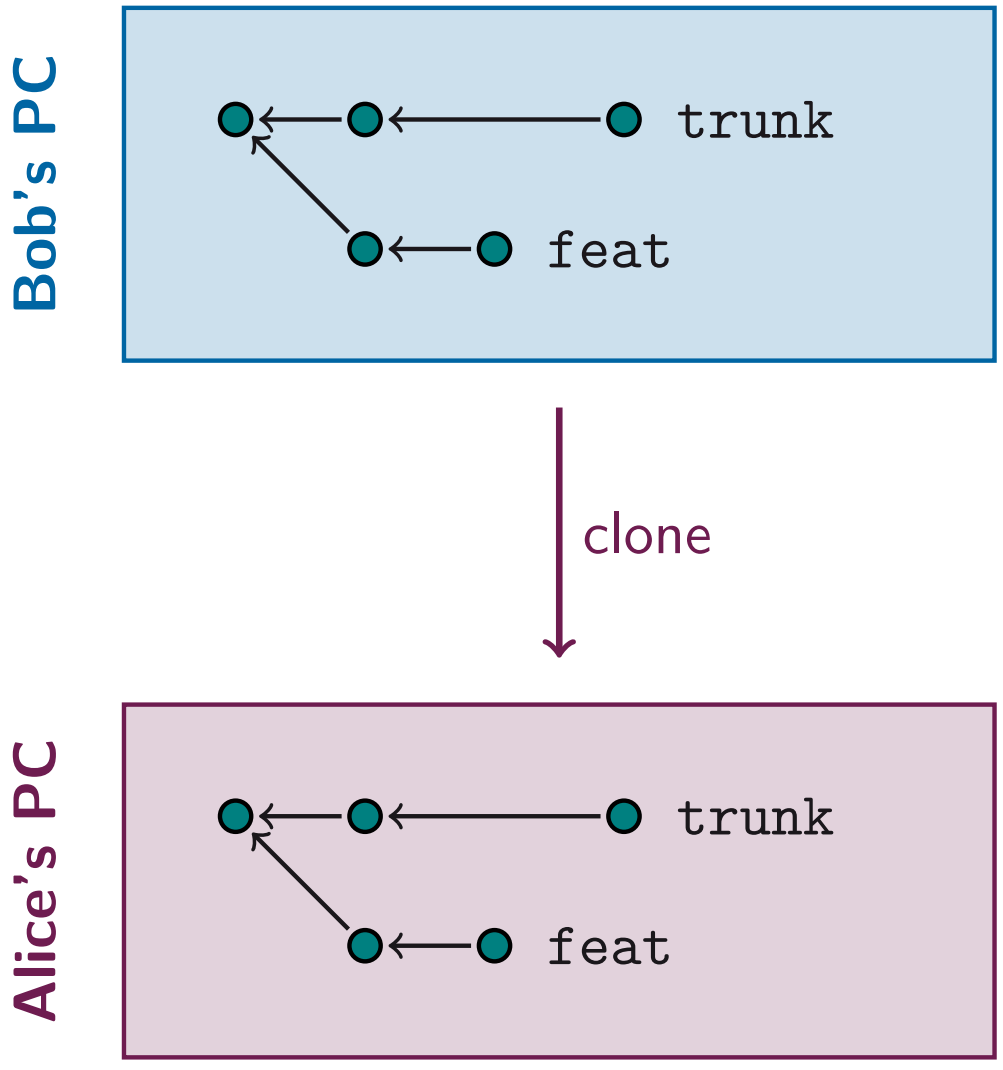


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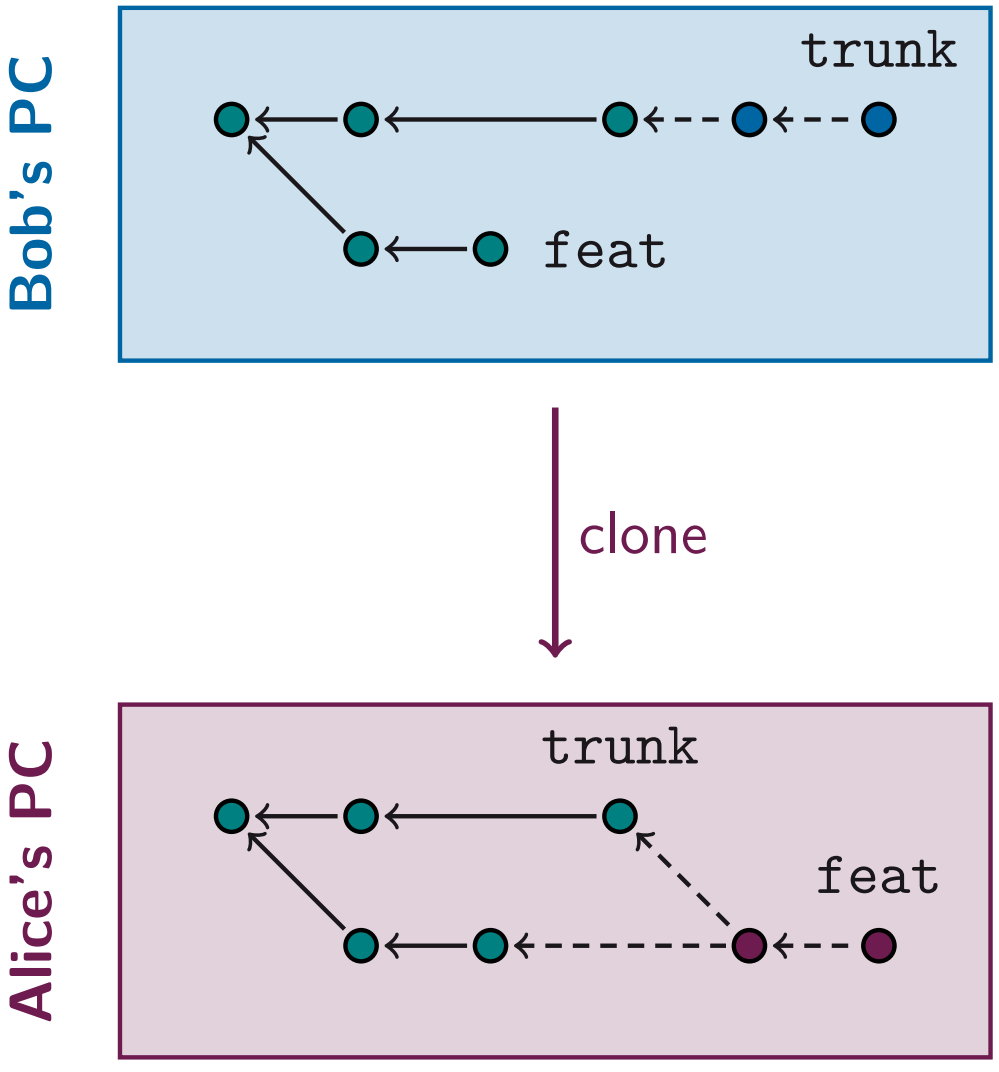
# Solving the Problem: Multiple Computers I



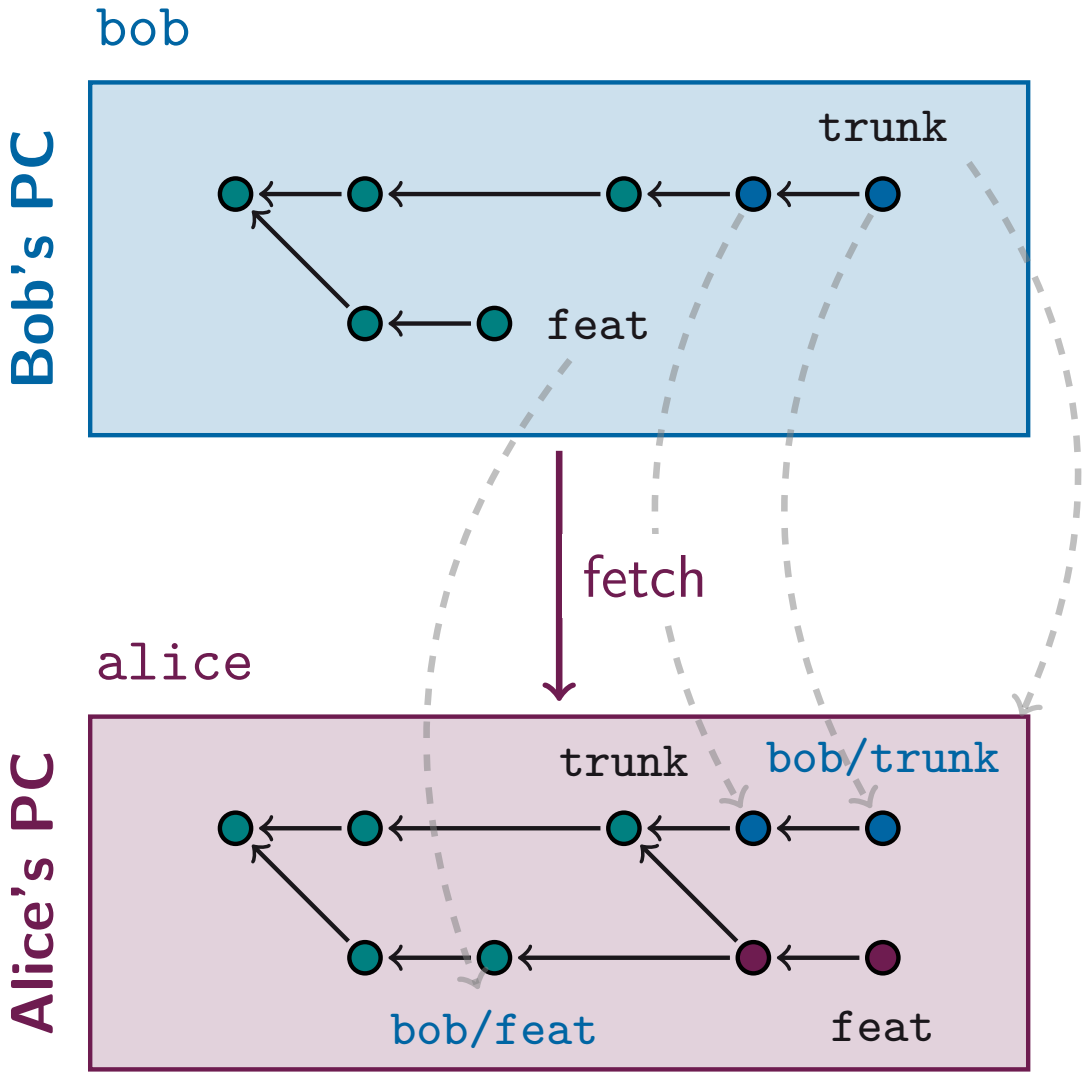

## Remotes and Clone

Other computers are called *remotes*. Clone means you copy the commit graph on the remote machine onto yours.

## Example

1. Alice has cloned Bob's (green) commit graph
2. Alice has merged `trunk` onto `feat` and made changes
3. Bob has also made changes on `trunk`

# Solving the Problem: Multiple Computers II




## Fetch

Copy the changes of the remote git graph into your local git graph.

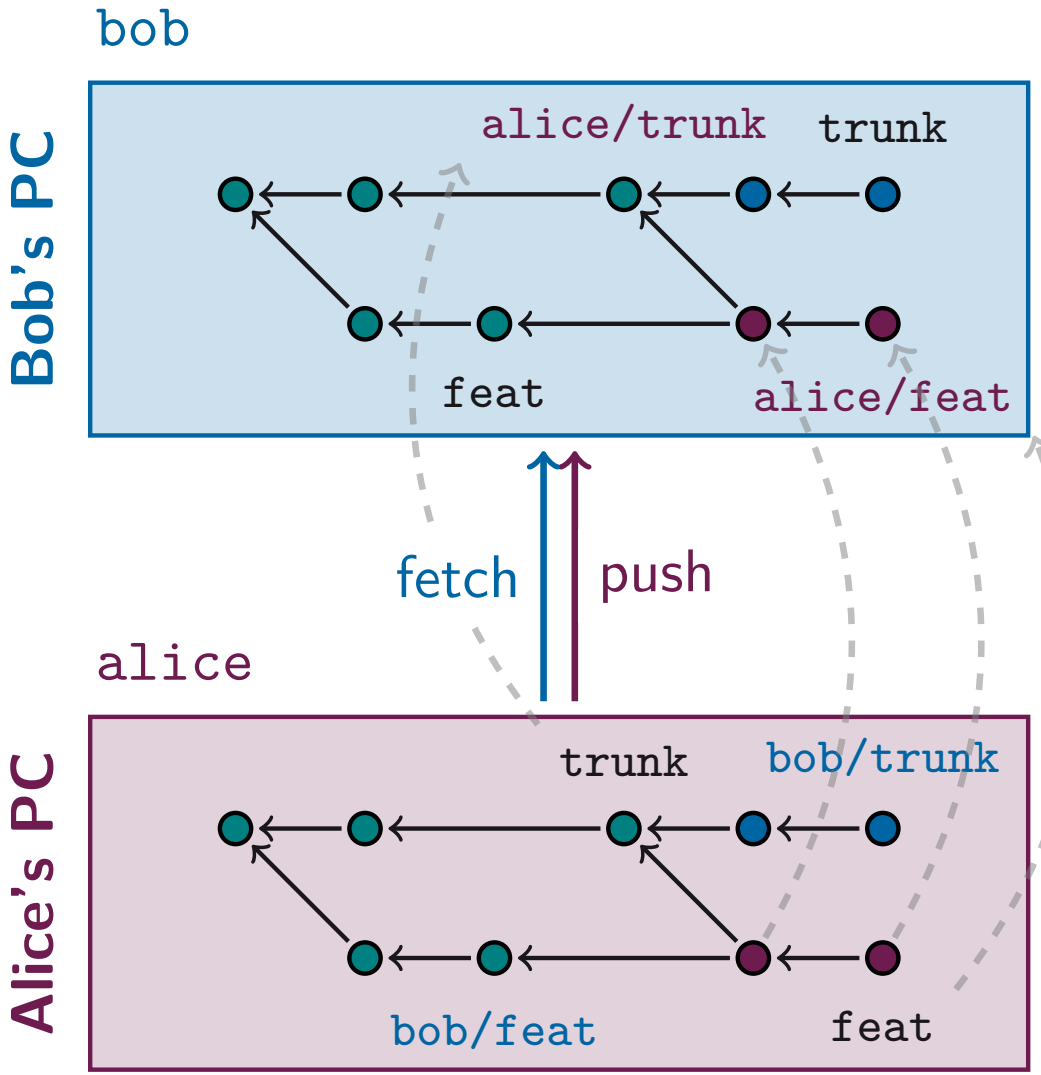
## Running Example

Alice fetches Bob's changes.

## Remote Branches

A branch that represents changes done in another machine. When a graph is cloned, the machine from which it was cloned has the default name `origin`.

# Solving the Problem: Multiple Computers III




## Push

Copy the changes of your local git graph to the remote machine.

## Running Example

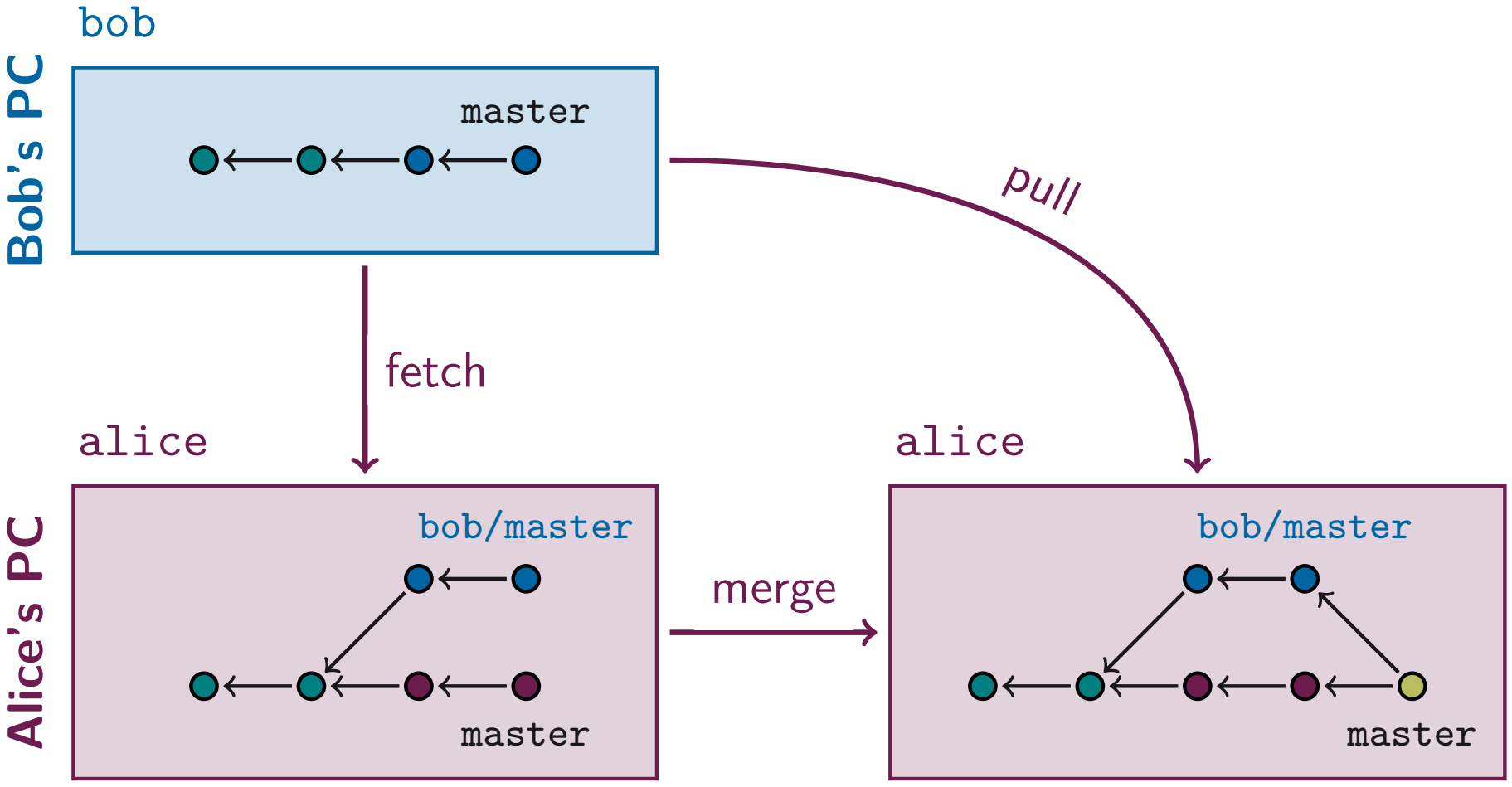
This is the same as if Bob had fetched Alice's changes.

## Network Access

In practice you cannot directly access other people's machines, so people use a third computer to which both parties have access (more later).

# Solving the Problem: Multiple Computers IV

Since it is very a common operation there is a shorthand to fetch and merge[a] the remote branch with the same name as the current one.




[a]Can also be configured to be rebase instead of merge.

# Table of Contents

# Mathematical Digression II: Hash and Merkle DAG

## "One-way fast" functions

### Hash Function

A (cryptographic) *hash* function is an $h : \Omega \to \{0,1\}^d$ for a fixed hash length $d$ such that:

1. Given $y = h(x)$ it is hard to find $x$
2. It is hard to find $x, y \in \Omega$ s.t. $h(x) = h(y)$
3. Given $h(x)$ it is hard to find $y$ s.t. $h(x) = h(y)$
4. Given $h(x)$ and a function $f$ it is hard to find $h(f(x))$

Hashes are *not* unique!

# Mathematical Digression II: Hash and Merkle DAG

**"One-way fast" functions**

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Hashes are *not* unique!

## Merkle DAG

A Merkle DAG is a DAG $G = (V, A)$ with a hash

$$h : V \times \{0,1\}^d \to \{0,1\}^d$$

that defines a label function

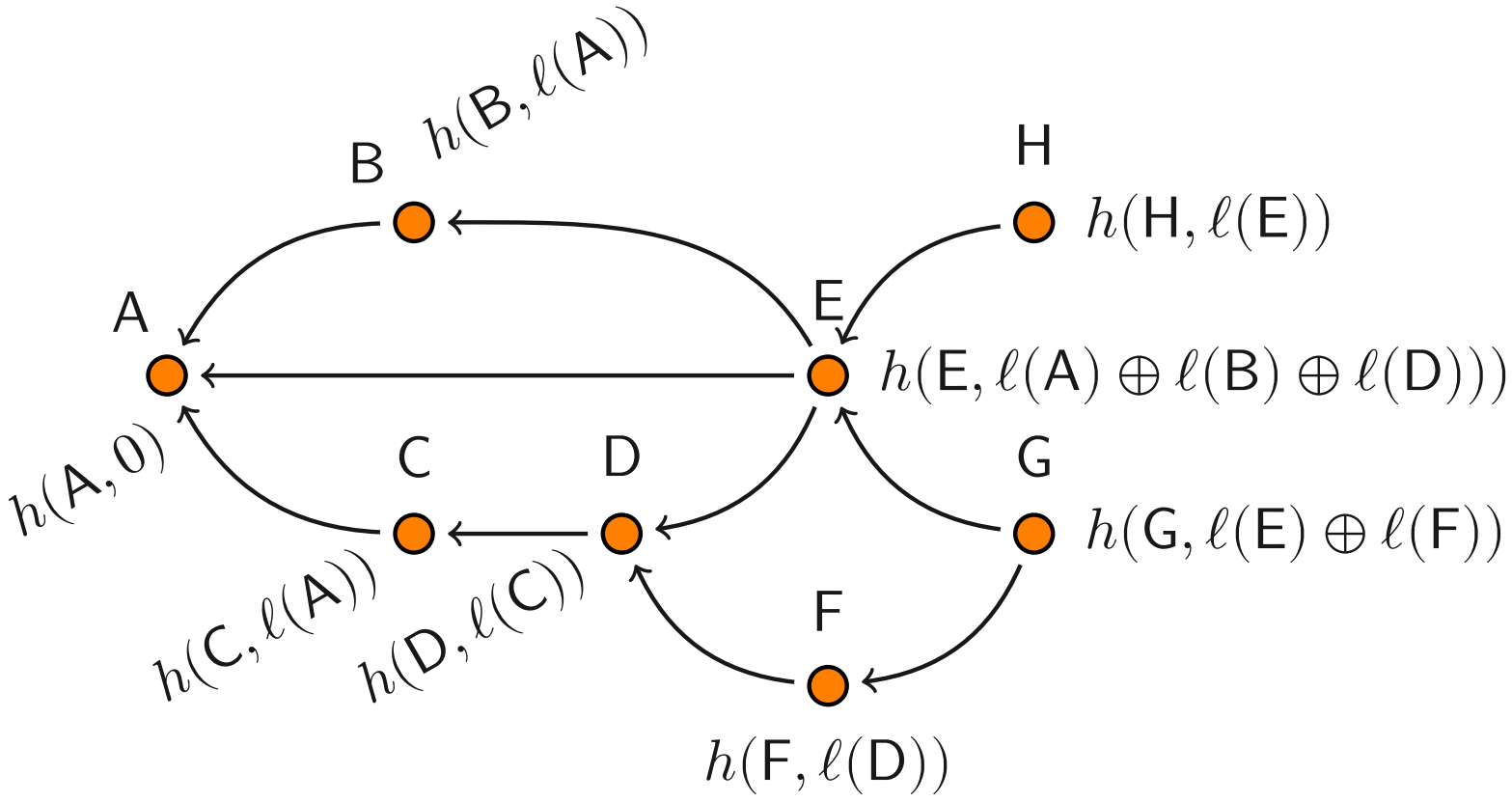
$$\ell(v) = h\left(v, \sum_{u \in \mathrm{n}^+(v)} \ell(u)\right)$$

## Properties

- Immutable data structure
- Cryptographic verification

# Mathematical Digression II: Merkle DAGs

To compute the label of a node, you need to first compute the label of all nodes on which it depends. Changing a label has a cascading effect on descendents.




Technicality: Sum symbol represents hash concatenation.

# Git Commits

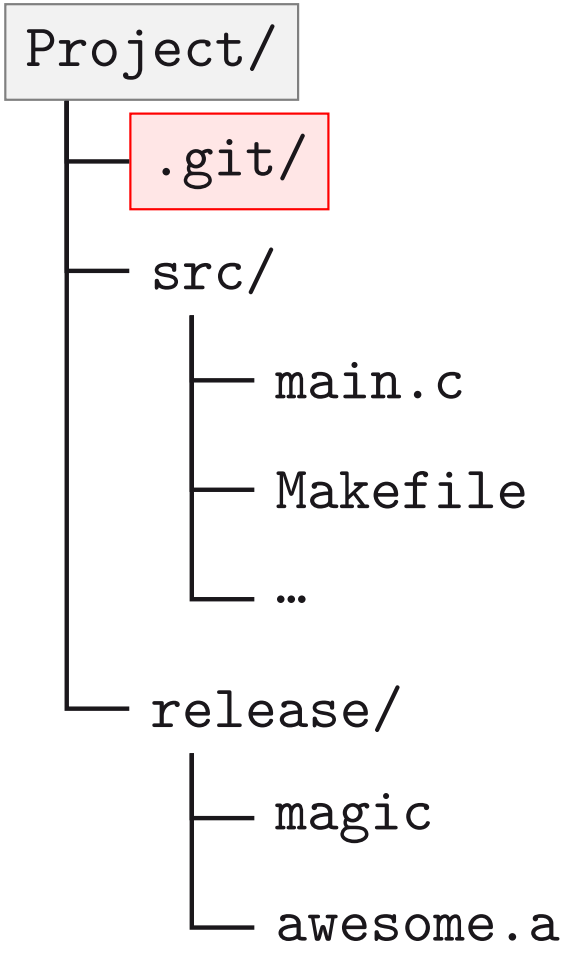
## Commit Contents

- Content (Blobs and Trees) hash
- Parent(s) commit(s) hash(es)
- Metadata: Author, Date, Message

## Example (Git's first git commit)

```
commit e83c5163316f89bfbde7d9ab23ca2e25604af290
Author: Linus Torvalds <torvalds@linux-foundation.org>
Date:   Thu Apr 7 15:13:13 2005 -0700

    Initial revision of "git", the information manager from hell

commit 8bc9a0c769ac1df7820f2dbf8f7b7d64835e3c68
Author: Linus Torvalds <torvalds@linux-foundation.org>
Date:   Thu Apr 7 15:16:10 2005 -0700

    Add copyright notices.

    The tool interface sucks (especially "committing" information, which is jus
```

# Git Repositories



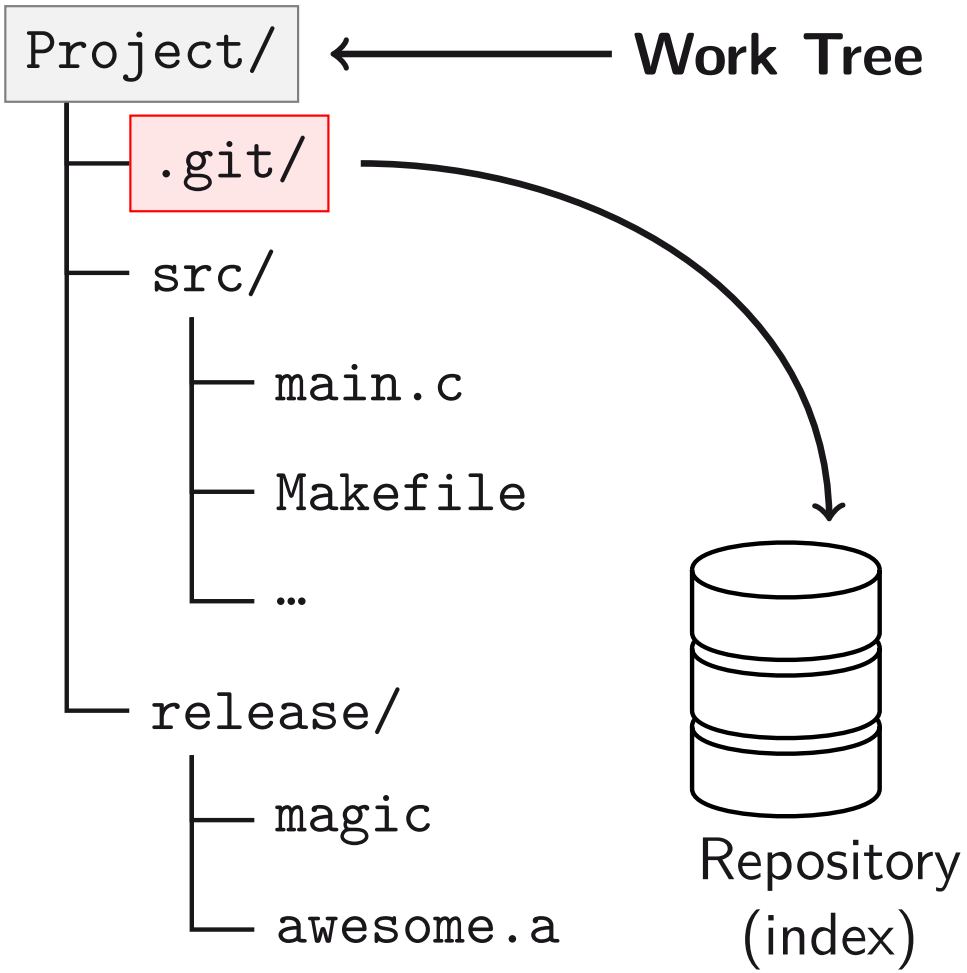

## Work Tree

Root of your project, contains (hidden) `.git`.
**Never delete `.git`.**

## Repository

- Commit graph (Blobs, …)
- Staging Area (will come next)

# Git Repositories




## Work Tree

Root of your project, contains (hidden) `.git`.
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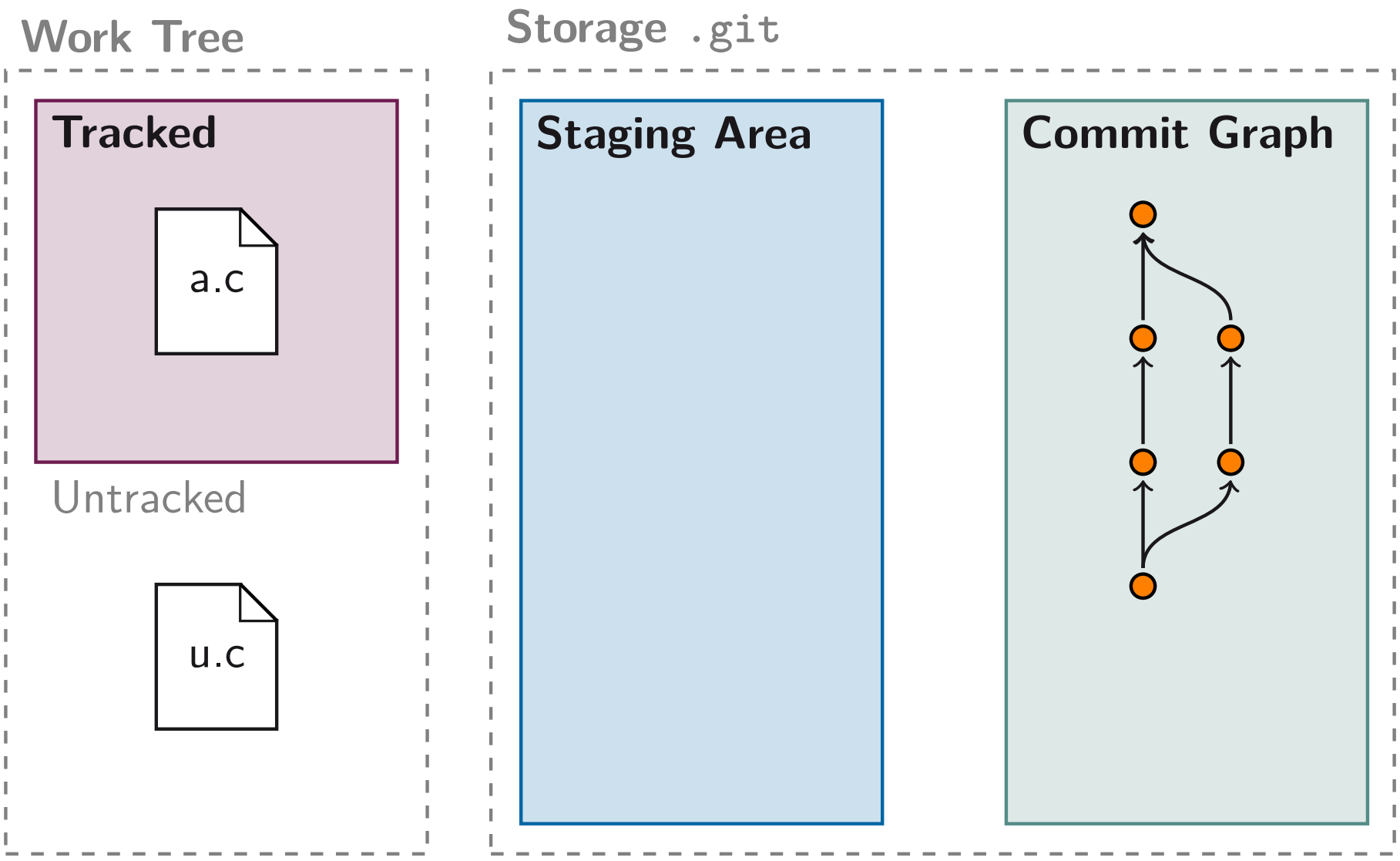
# The 3 (or 4) Conceptual Areas of Git



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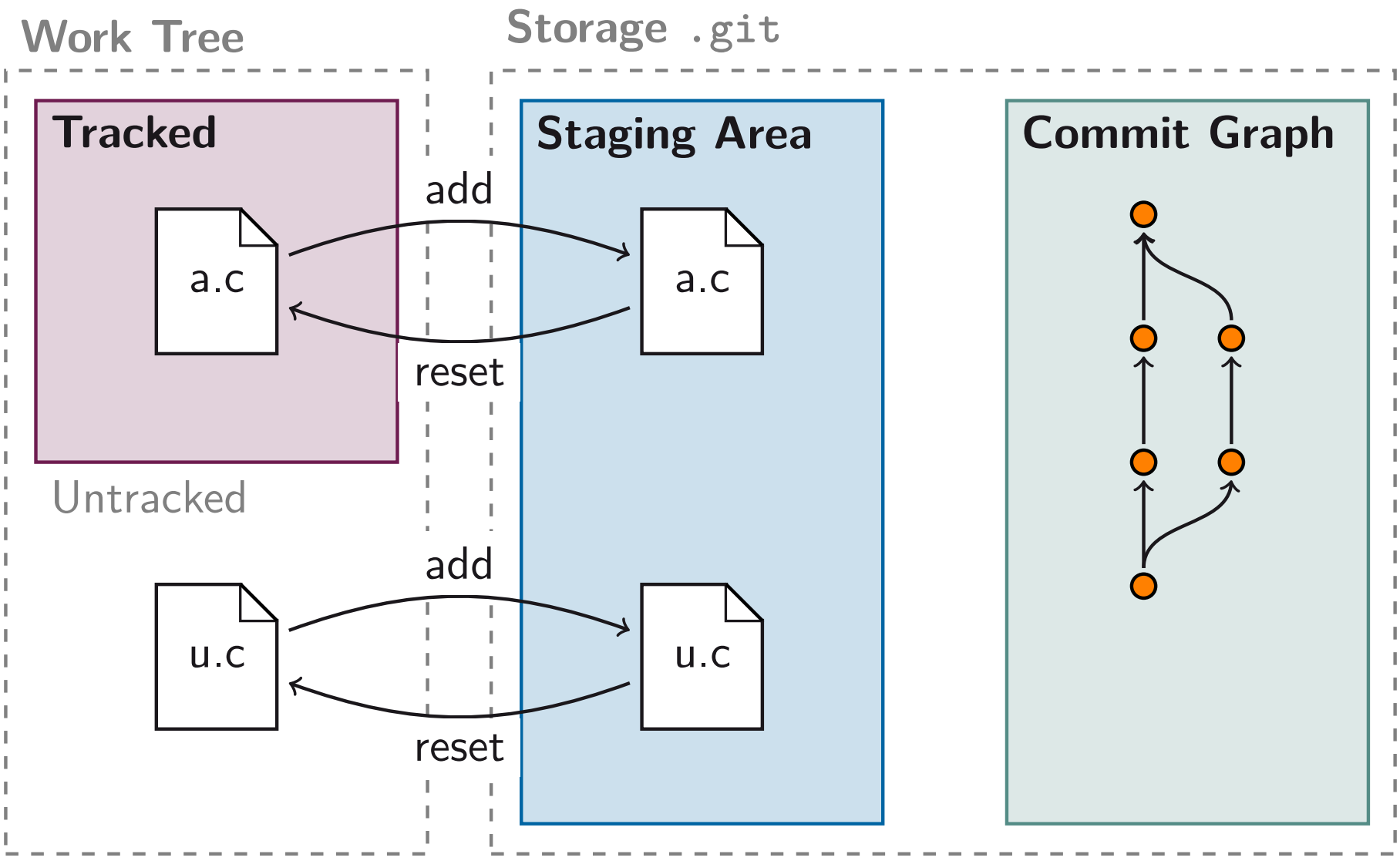

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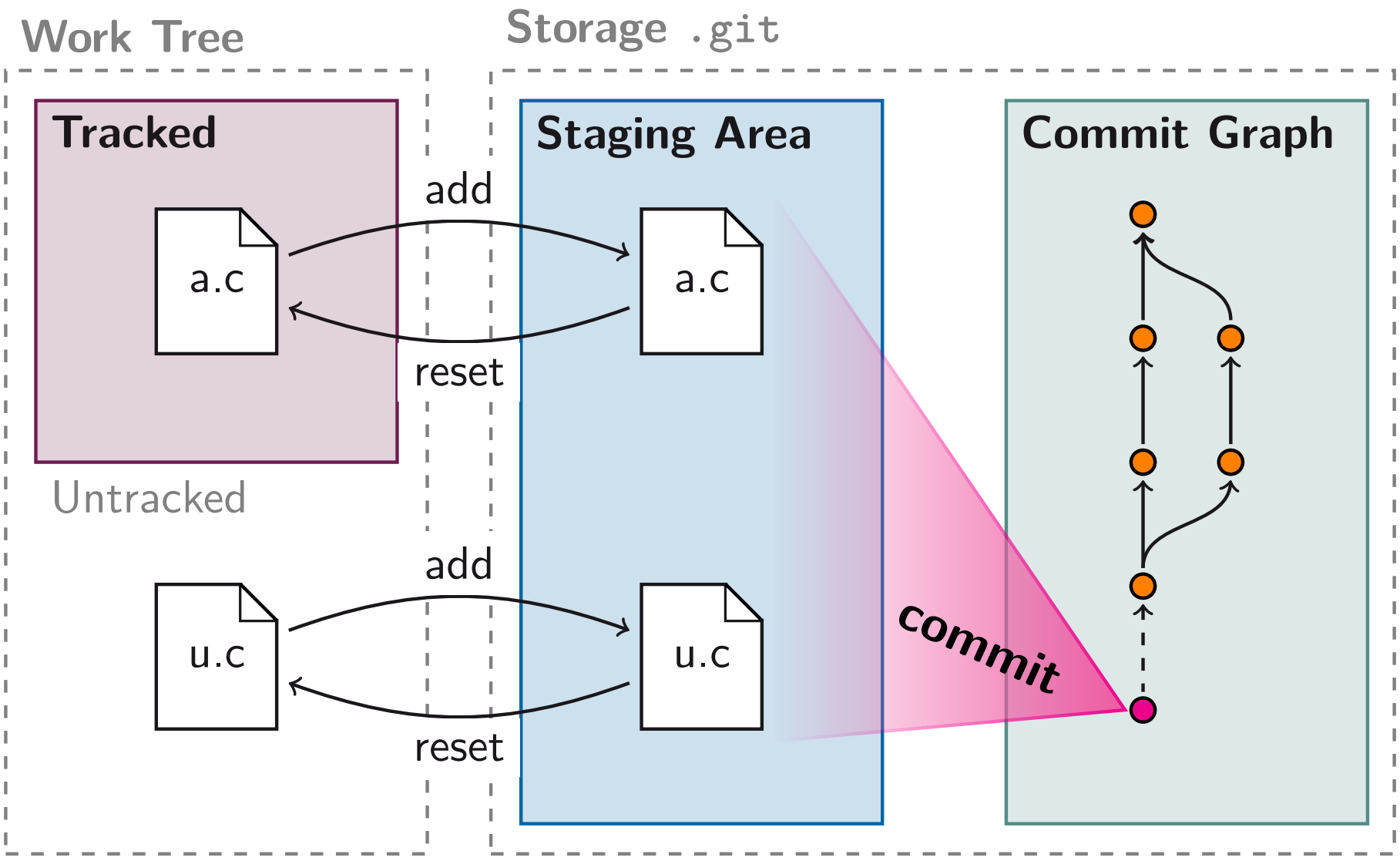
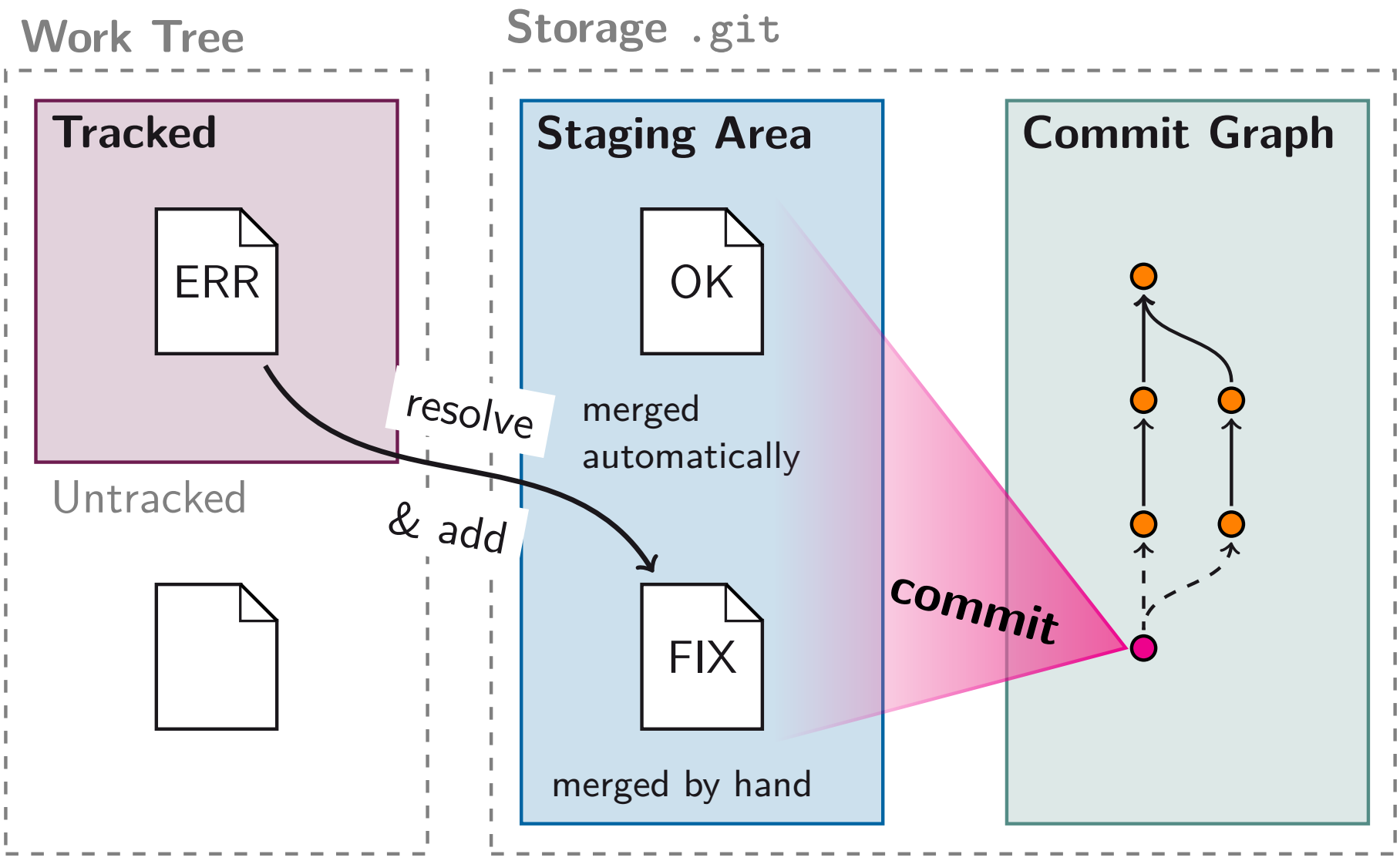


# The Command Line Interface (CLI)

- Setup git the first time
  - `git config --global user.name "Your Name"`
  - `git config --global user.email your@email`
  - `git config --global core.editor your-editor`
  - `git config --global alias.graph "log --all --decorate --graph --oneline"`
- Your work tree state is at commit where you have your HEAD
  - `git status`
  - `git log`
- Adding changes to the staging area and committing them
  - `git add [-u] [-p]`
  - `git commit [-a] [-v]`
- Branching and the detached HEAD state
  - `git branch`
  - `git switch / checkout`
  - `git merge / rebase`
- Managing remotes and Cloning
  - `git remote add / …`
  - `git clone`
  - `git fetch / push / pull`

# Automatic Merge Failed (Conflicts)



# Graphical User Interfaces

## Command Line Interface

If you learn to use Git on the terminal you are set forever, but

- you have to think (tip: abuse `git status` and read, always!)

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## Graphical Interfaces

A good GUI that does not hide complexity

- Sublime Merge

Alternatives

- SourceTree, GitKraken, lazygit (terminal UI)
- TortoiseGit (integrates with Windows Explorer)

Bad GUI (why? It tries to hide complexity until you inevitabily screw up something, and then you have no clue what is going on)

- GitHub Desktop

More at `https://git-scm.com/downloads/guis`

# What is a Commit Anyways?

When you work with git, a commit should be a

## Logical Unit of Work

i.e. you think of a specific thing you need to do, you do it, then immediately commit the changes, repeat. The more people in the team, the more commits you should do.

### Bad

- Huge commits that change multiple unrelated files / classes / functions / ...
- Meaningless messages like “fix”, “update”, “wip” or “misc”
- Messages in past tense

Demo: Browse Linux kernel git commits

### Good

- Small, modular changes, change only one file / class / function / ...
- Descriptive commit message, just title with bullet points are ok!
- Commit even if does not compile
- Message in imperative tense. Write as if you were the recipient of the commit: what will it do?

# Trunk, Feature Branches

This pertains software developement and project management.

## Simplest Workflow

- There is no team
- Commit everything on the same branch
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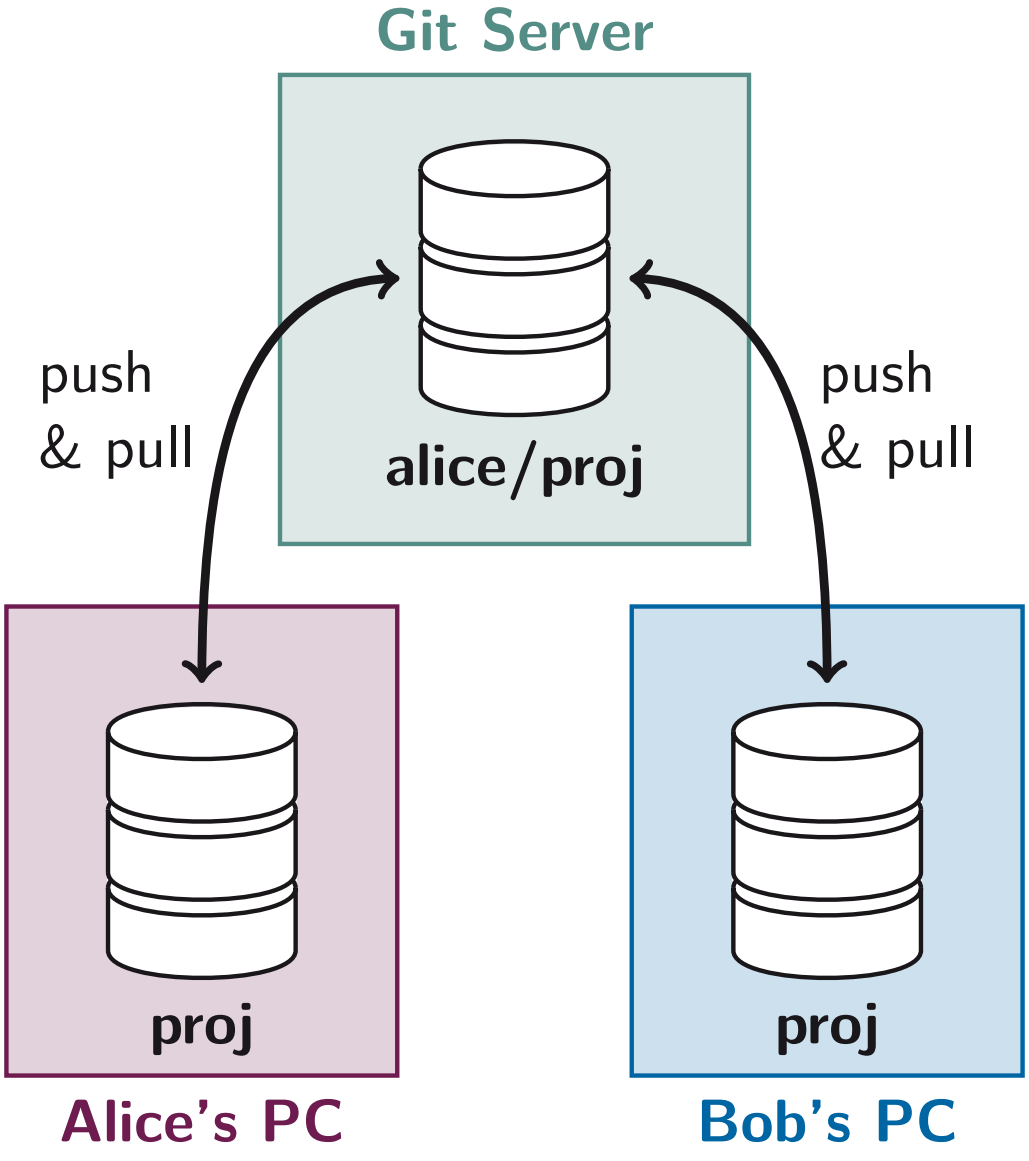
## Branching Workflow

Every time you want to add a feature, make changes in a short lived branch until feature is complete, then merge that branch into a “master” branch (also called “main” or “trunk”)

- For larger teams or organized people
- Changes are more organized
- Typically, master branch always compiles

# Git Services (GitHub, GitLab, ...)




## Git Server

Because of IPv4 NAT, Bob can't push directly to Alice's computer. So they use a third computer that hosts a *git server* that can be reached by both.

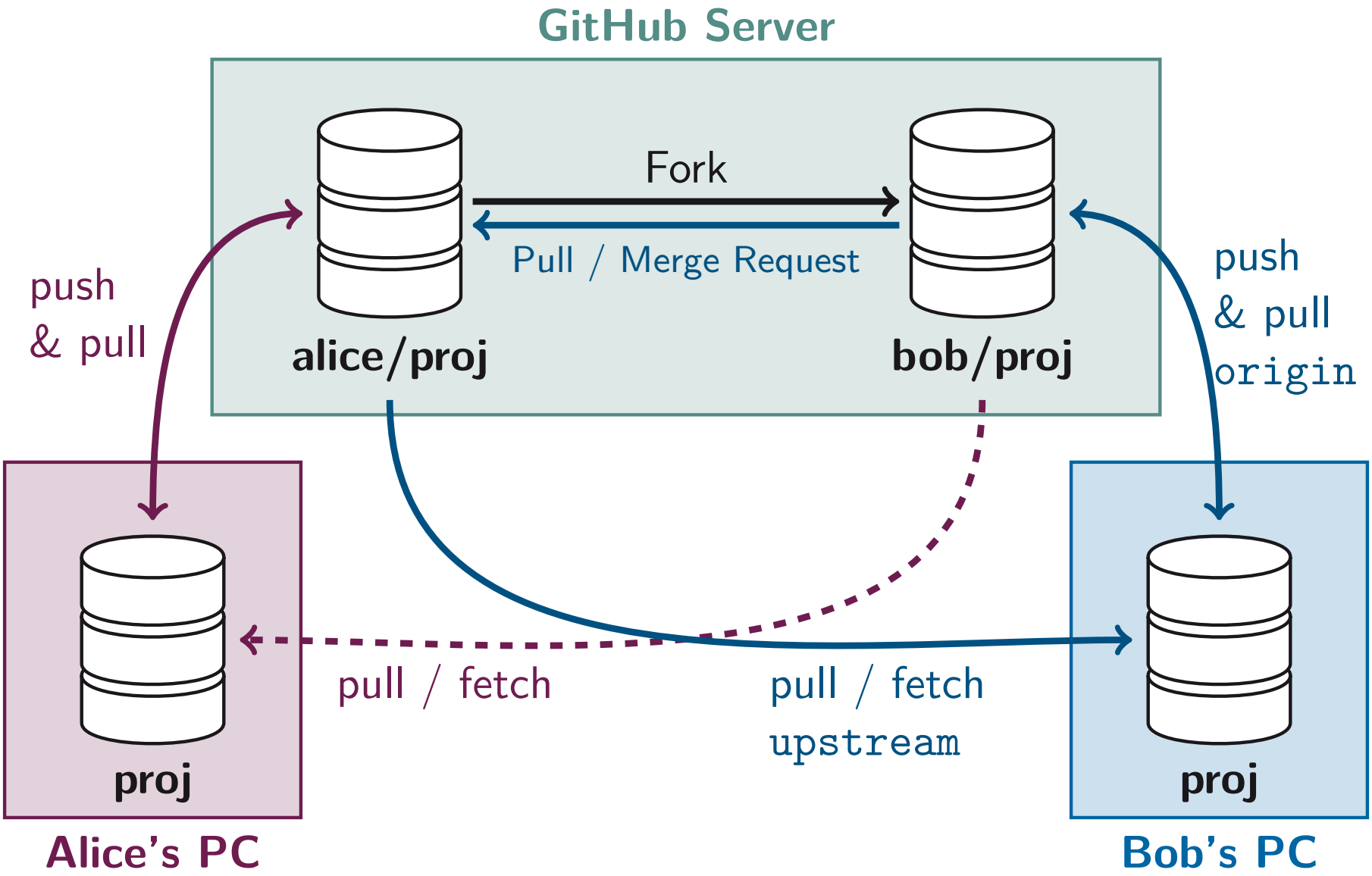
## Interface

The server (usually) has a web interface with a login to manage your hosted repositories. In this example Alice has a project **proj** under the username **alice**.

## Examples

GitHub, GitLab, Gitea, Codeberg, SourceHut, rgit.

# Forking and Pull / Merge Requests




Note: Actually the fork does not need to be on the same server, but let's keep this simple.

# Forking and Pull / Merge Requests

Most services provide a way to fetch the pull requests as if they were remote branches on your repository. Assuming the remote is named[2] `origin` for GitHub this can be achieved by running

1. `git config --add remote.origin.fetch '+refs/pull/*/head:refs/remotes/origin/pr/*'`
2. `git fetch origin`
3. `git switch pr/5`

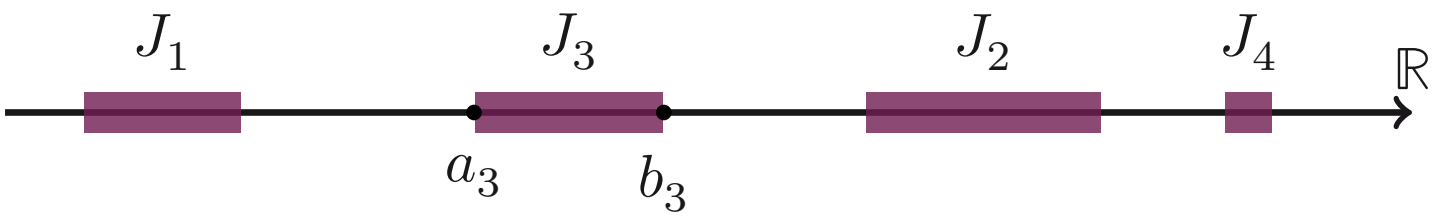
Then, you can check out any pull request using their ID, here for example #5. The same for GitLab:

1. `git config --add remote.origin.fetch '+refs/merge-requests/*/head:refs/remotes/origin/mr/*'`
2. `git fetch origin`
3. `git switch mr/5`

[2] If you remote has a different name, replace all occurences of `origin`.

# Table of Contents

# Mathematical Digression III: Logarithmic Search I



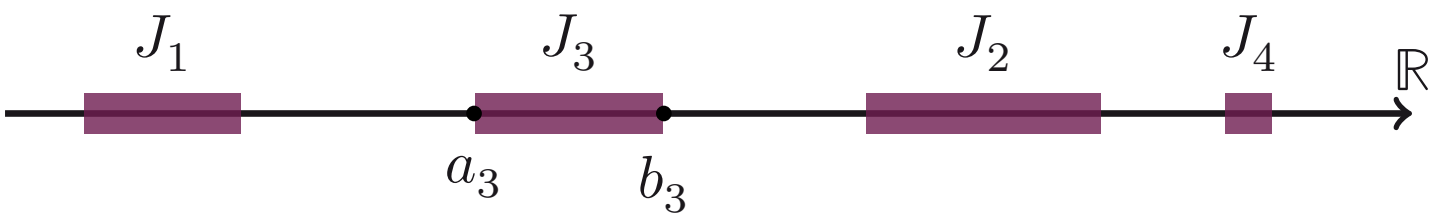

## Toy Problem

Given a set of disjoint intervals $S = \{J_1, \ldots, J_n\}$, $J_i \subset \mathbb{R}$, $\log_2(n) \in \mathbb{N}$ find to which interval belongs $q \in \bigcup_i J_i$.

## Naive Solution

For every $J \in S$ interval check if $q \in J$. This is $O(n)$.

# Mathematical Digression III: Logarithmic Search I

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## Total Order in $S$

Intervals $[a, b) \in S$ can be ordered. Define $J_i \succ J_j$ if $a_i > a_j$.

## Logarithmic Search Intuition

If $q \notin J = [a, b)$ then either

- $q > a$ so $q \in J' \succ J$
- $q < a$ and $q \in J' \prec J$

# Mathematical Digression III: Logarithmic Search II

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## Idea

Recursively apply intuition.

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## Logarithmic Search

Start with $Q = S$ then

1. take $J \in Q$ in the "middle" of $Q$ and if $q \in J$ we are done
2. otherwise
   1. if $q > a$ repeat with $Q := \{J' \in Q : J' \succ J\}$
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Does not check every $J \in S$ (fast for large $n$!).

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## Idea

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## Complexity (Landau)

Base $b$ logarithmic search is $O(\log_b(n))$. In this case $b = 2$ (two options $q > a$ or $q < a$), so it usually called *binary* search.

## Logarithmic Search

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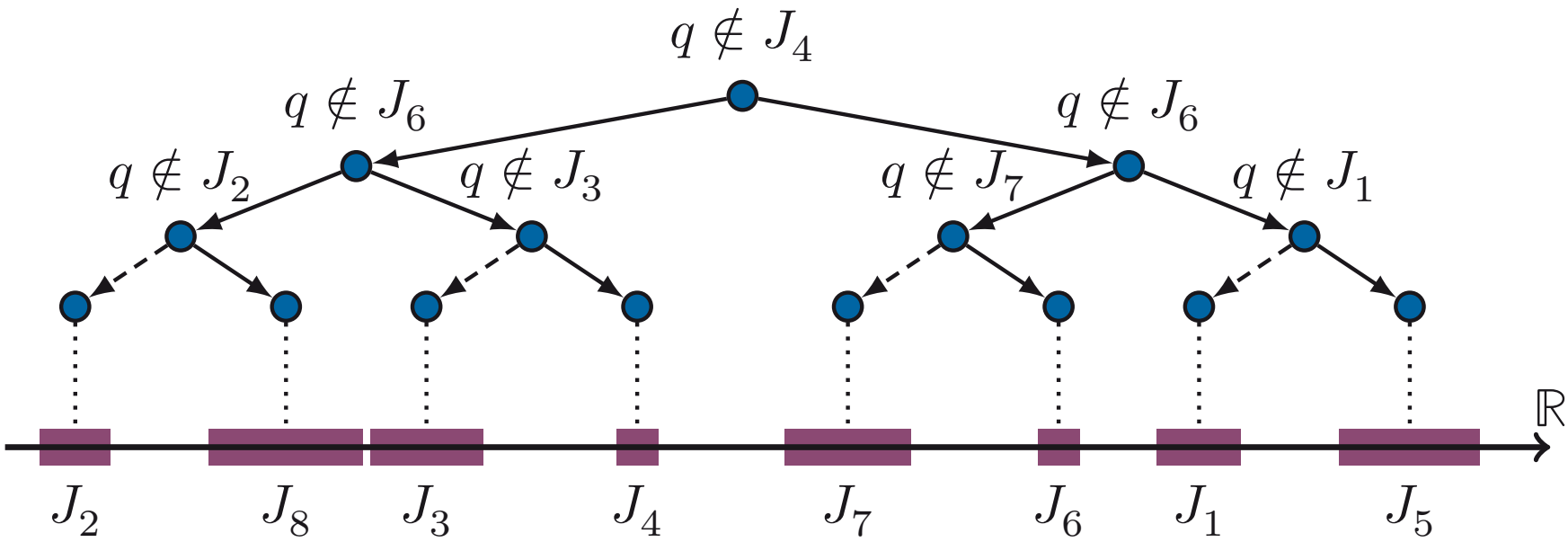
# Mathematical Digression III: Logarithmic Search III

We can visualize the decisions of logarithmic searching as a tree. The decision goes to the left or right branch depending on whether $q < a$ or $q > a$ respectively. Obseve that the tree has depth $3 = \log_2(8)$.

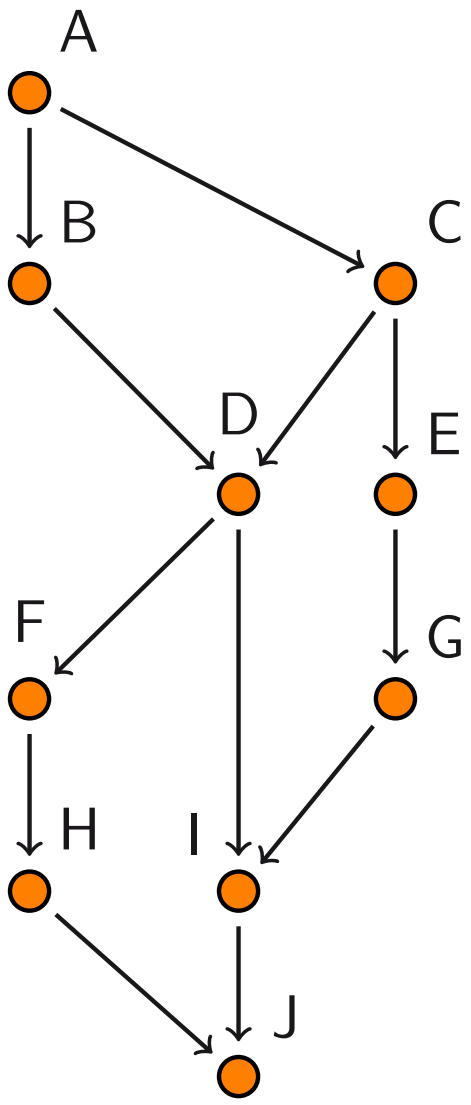


# Git Bisect: Search for something in the past

## Purpose

You are looking for a commit that caused something, e.g.

- Introduced a bug
- Deleted / added something
- Anything really



# Git Bisect: Search for something in the past

## Purpose

You are looking for a commit that caused something, e.g.

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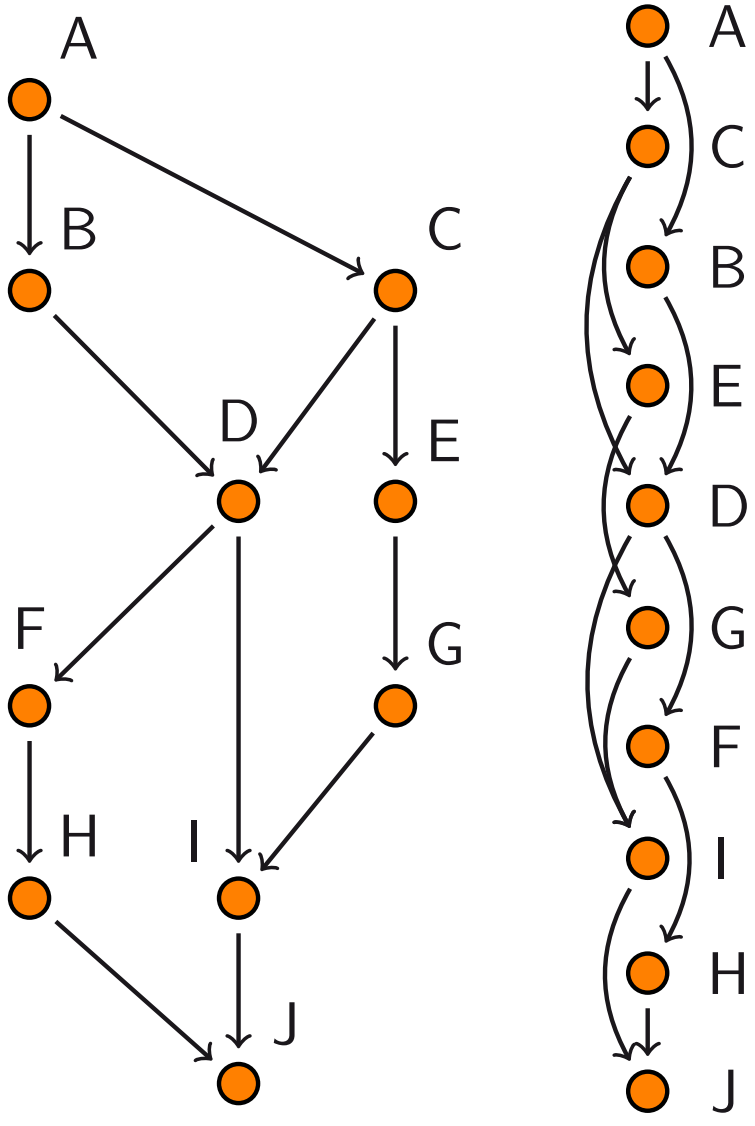
- Anything really

## Rough Idea

1. Take commit graph $G = (V, A)$ we want to find $\bar{v} \in V$ that did above
2. Topologically sort $G$, i.e. add order $\succ^*$ to $V$
3. Logarithmic search $\bar{v}$ in $G$



# Git Bisect Practice

You want to find the commit that did X. Initialization:

1. `git bisect start`
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- `git bisect skip` (cannot test this commit for X)

Process repeats a few time ($\approx$ log of # of commits between good and bad). If you have a script e.g. `check.py` that returns 0 for good, 125 for skip, any other number for bad, it can be automated

- `git bisect run check.py`

# Table of Contents

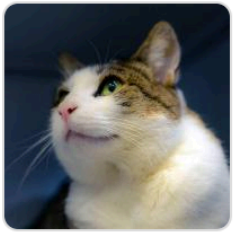
# That's (most of) it

## Further topics that were not covered

Git and its ecosystem have many more features

- Stash, Blame, Squash, Tag, Cherry-Pick, ...
- Submodules and subtrees
- LFS (Large File Storage) for big (gigabytes) files
- Email "old school" workflow (e.g. `sr.ht` and Linux Kernel)
- Integration with CI (e.g. GitHub Actions, GitLab Workers)

# OST Students Organization: Students, unite!



**OST - Studenten**

Wenn du das erste mal auf **@OST-Stud** bist, sieh dir das Repo Willkommen an. Bei Fragen, E-Mail an fachschaft-e@ost.ch

**34** followers · Switzerland · fachschaft-e@ost.ch

- Did you also take part in the LaTeX workshop?
- Do you take notes / write summaries using LaTeX?

$$- \mu \upsilon \quad \partial t$$

**LaTeX $2_\varepsilon$ Workshop**

Fachschaft Elektrotechnik

$$H = -\sum p(x$$

## Organization Goals

- Provide high-quality lecture summaries maintained by the community
- Teach LaTeX and Git
- Connect students to study together for exams

# Hands-On Phase (Groupwork)

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## Goals

- Set up Git on your PC
- Test your understanding
- **Fuck up here** with a toy project **instead of on real work**

## Your Tasks

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- Directly contribute to a repository
- Contribute as external via pull-request

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## Plan

1. Short introduction of tutorial
2. Form small groups 2 - 3 persons
3. Grab some beers & snacks
4. Install Git if you haven't already
5. Work through the tutorial with your group
6. Work with other groups (see tutorial part 4)

Ask questions if you get stuck.