

Introduction to Git

“The stupid¹ 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 / ...

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You

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

Obligatory XKCD

THIS IS GIT. IT TRACKS COLLABORATIVE WORK ON PROJECTS THROUGH A BEAUTIFUL DISTRIBUTED GRAPH THEORY TREE MODEL.

COOL. HOW DO WE USE IT?

NO IDEA. JUST MEMORIZIZE THESE SHELL COMMANDS AND TYPE THEM TO SYNC UP. IF YOU GET ERRORS, SAVE YOUR WORK ELSEWHERE, DELETE THE PROJECT, AND DOWNLOAD A FRESH COPY.



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

Table of Contents

1 The Problem

2 The Solution

3 The Implementation

4 Using Git

5 Extras (to flex)

6 Guided Tutorial

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.

Popular 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?

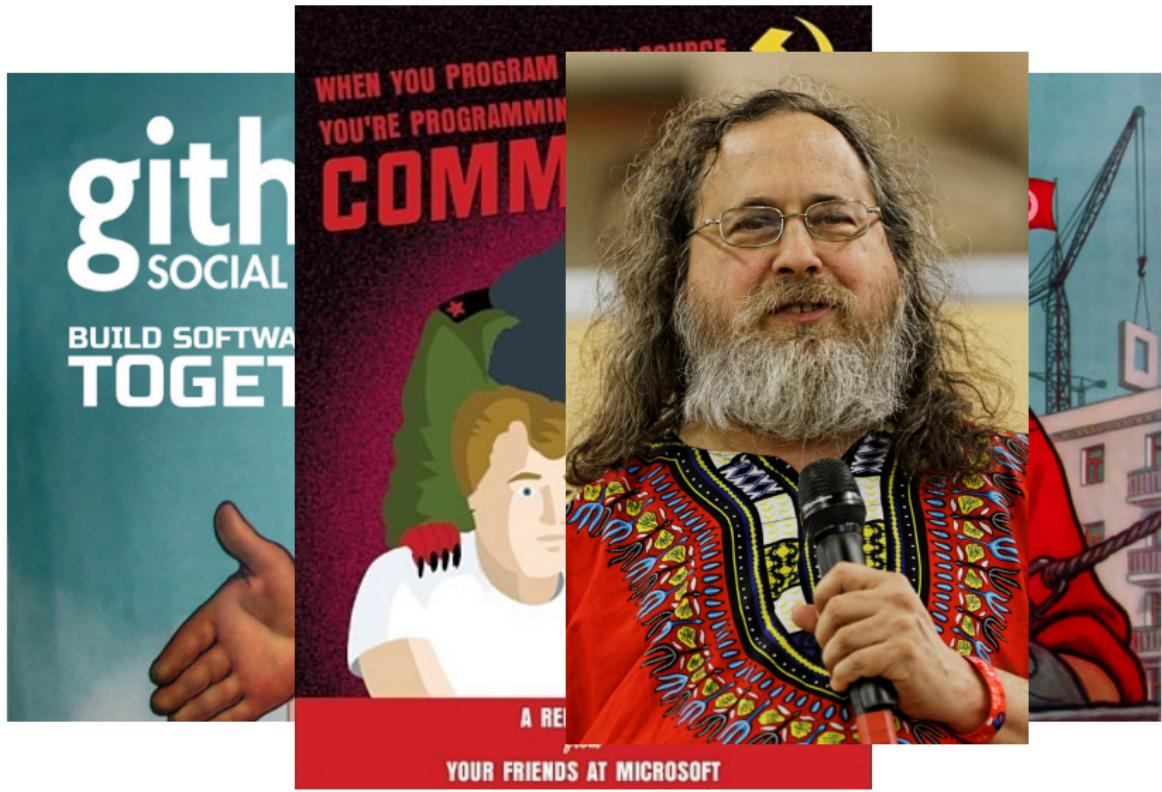
This is not a Political Event



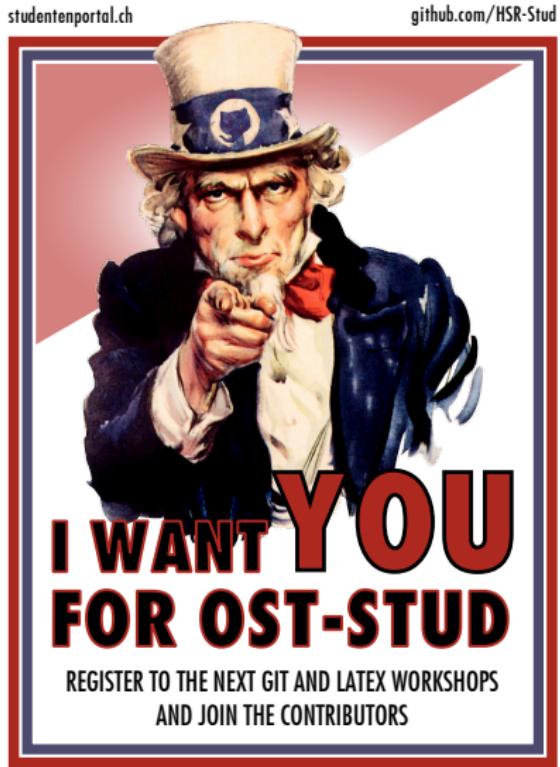
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This is not a Political Event



This poster's graphic design is artistically inspired by WW2 era propaganda, and it is not related to any current political events nor an endorsement of a political stance.

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This poster's graphic design is artistically 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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Fachschule Elektrotechnik

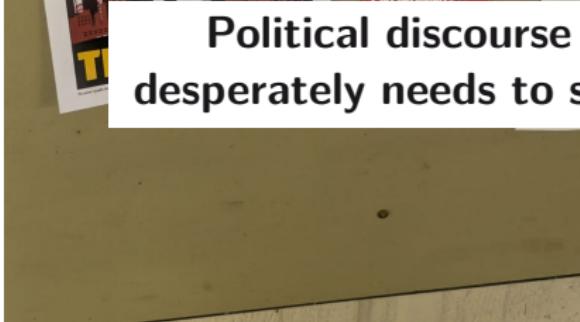
This is not a Political Event



How should I say it guys

Reactionary politics is bad

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

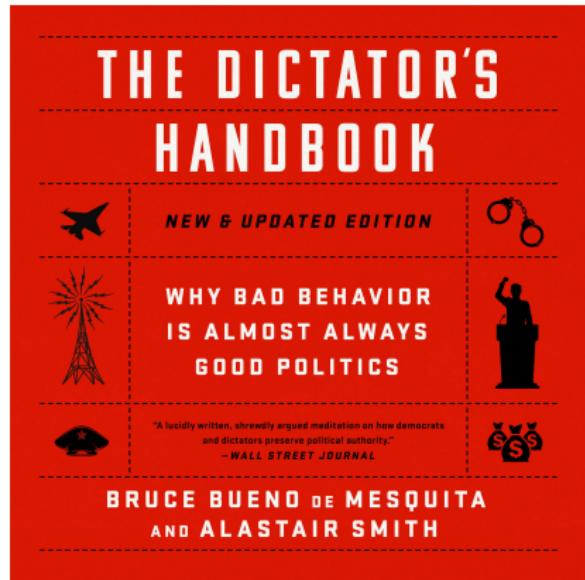


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Fachschule Elektrotechnik

This is not a Political Event



A recommendation
if you are interested
in politics

Simplified explanation 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, ...).

Table of Contents

1 The Problem

2 The Solution

- Commit Graph
- Blobs and Trees
- Branches
- Merging Strategies
- Remotes

3 The Implementation

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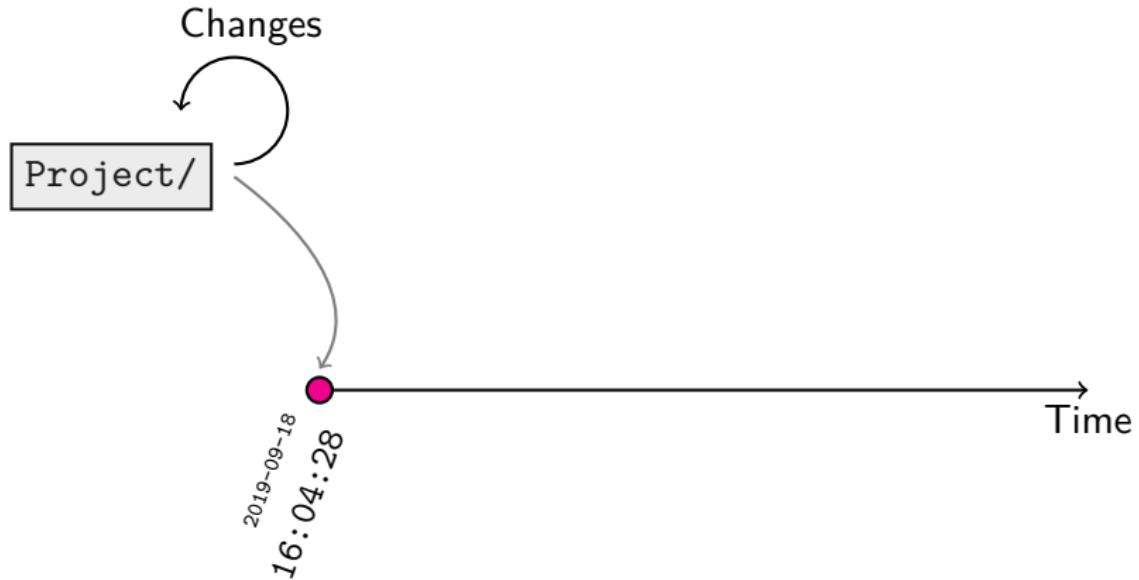
Solving the Problem: Snapshots

Project/

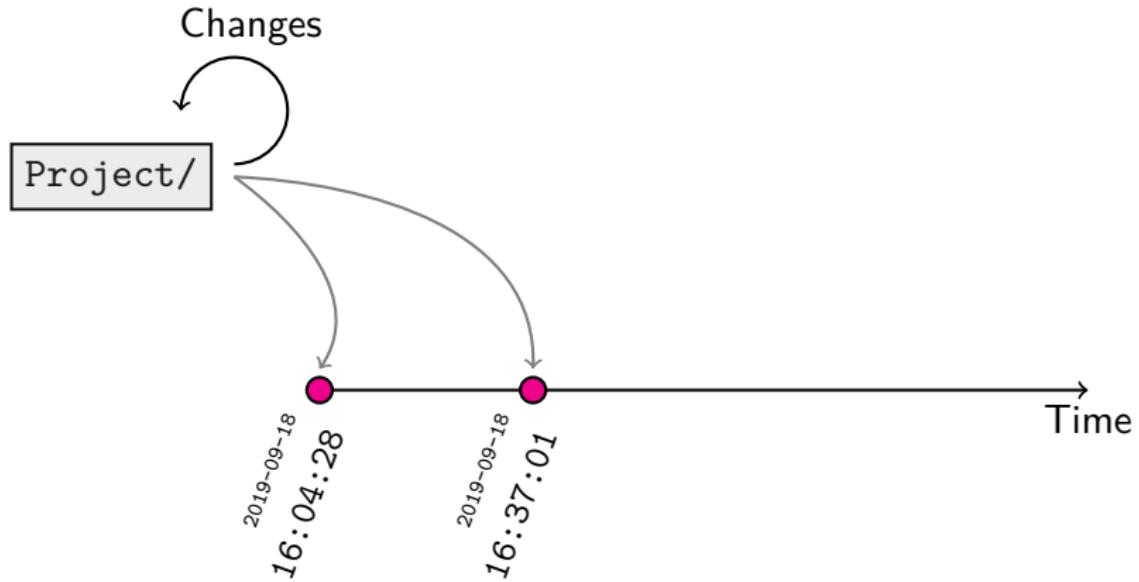
Solving the Problem: Snapshots



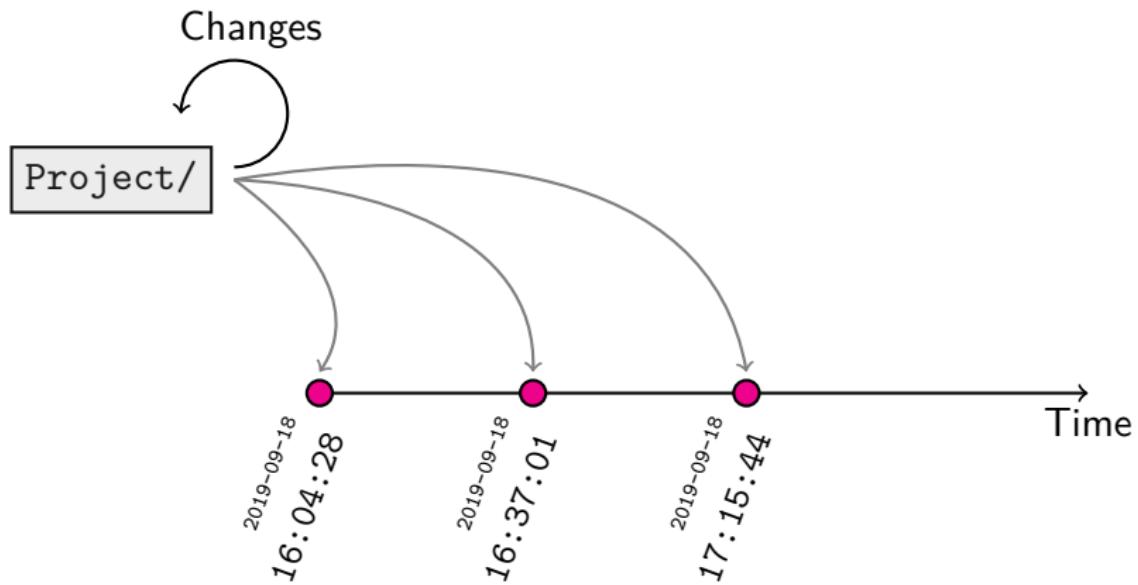
Solving the Problem: Snapshots



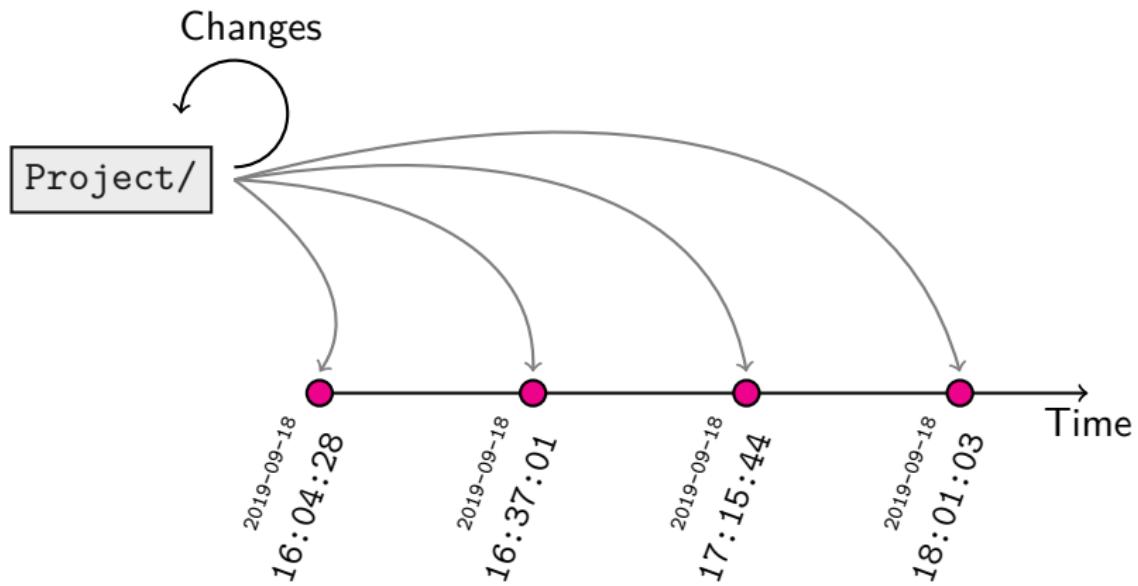
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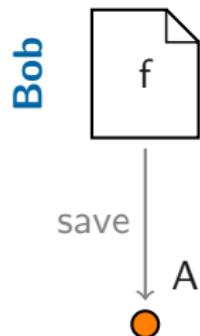
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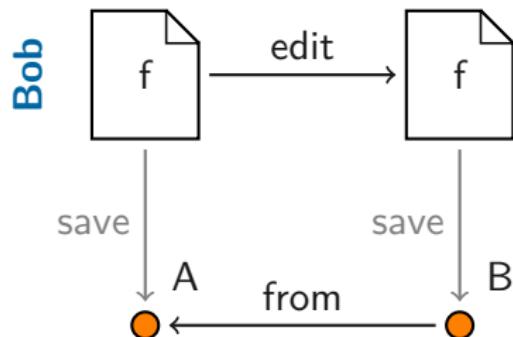
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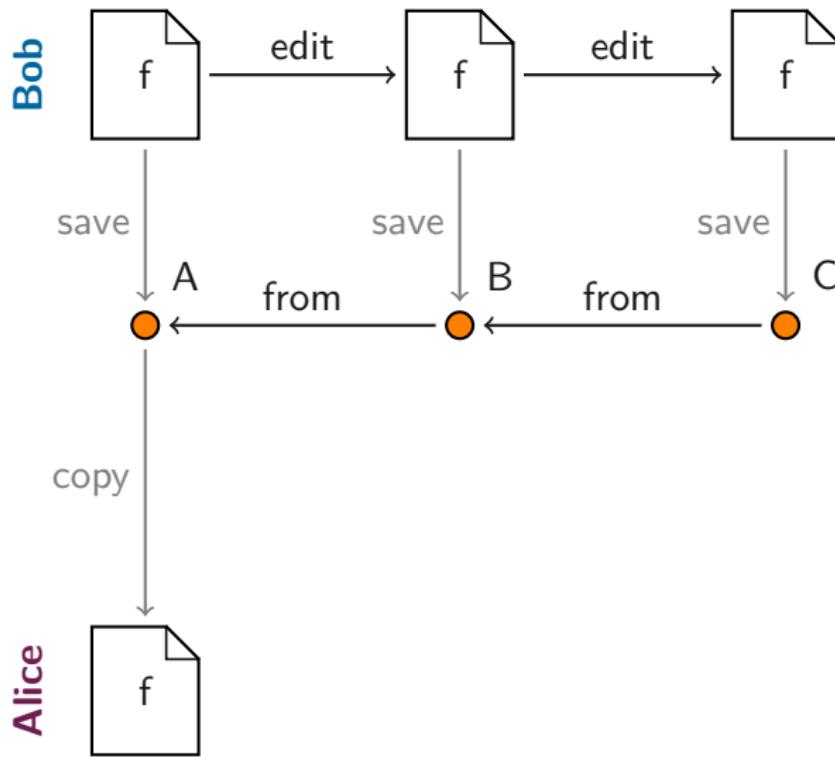
Solving the Problem: Concurrent Changes I



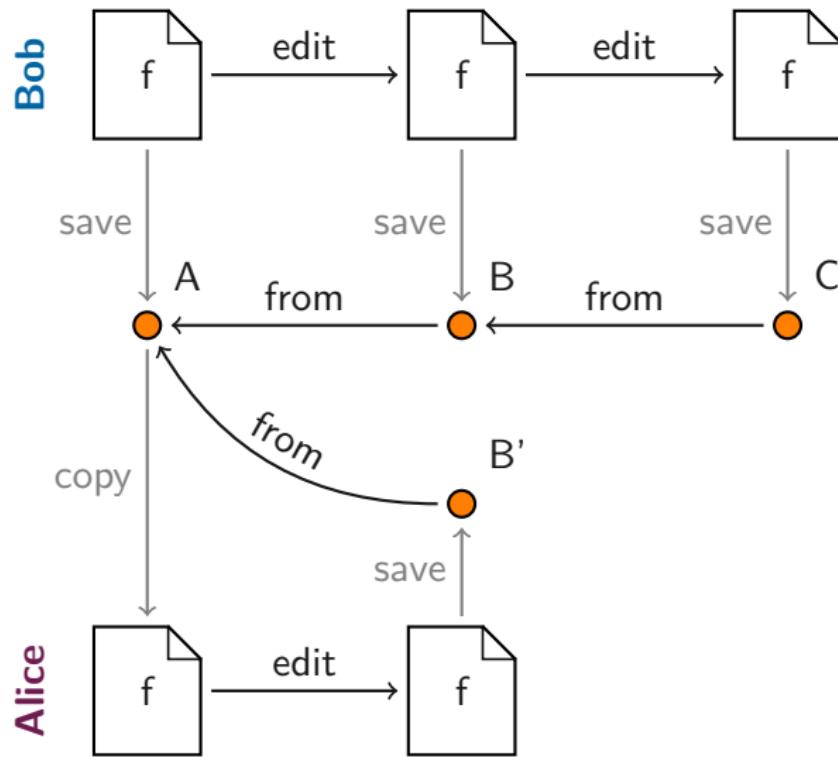
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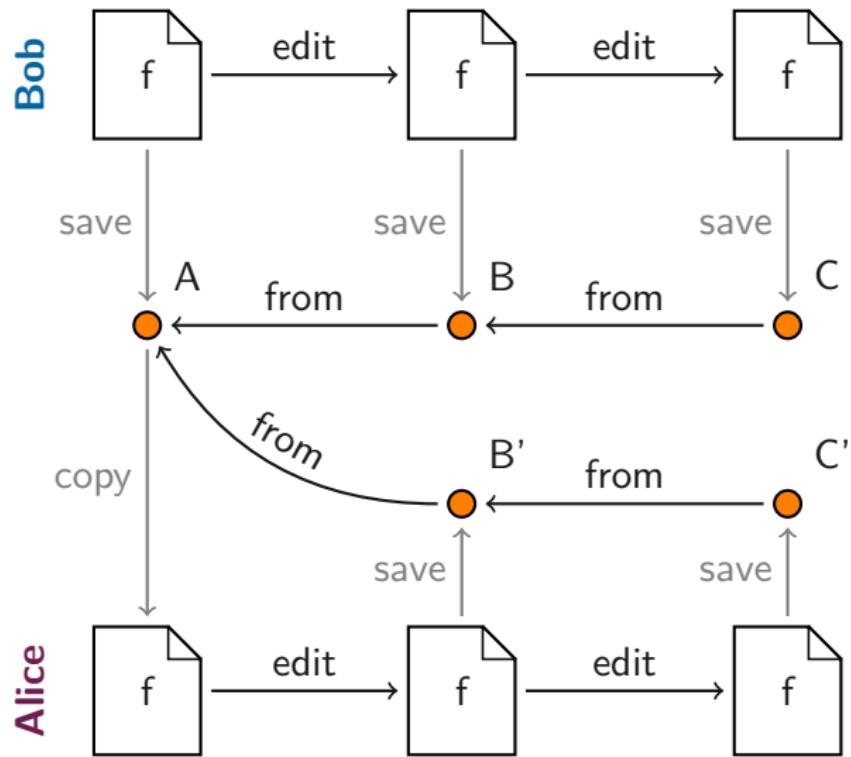
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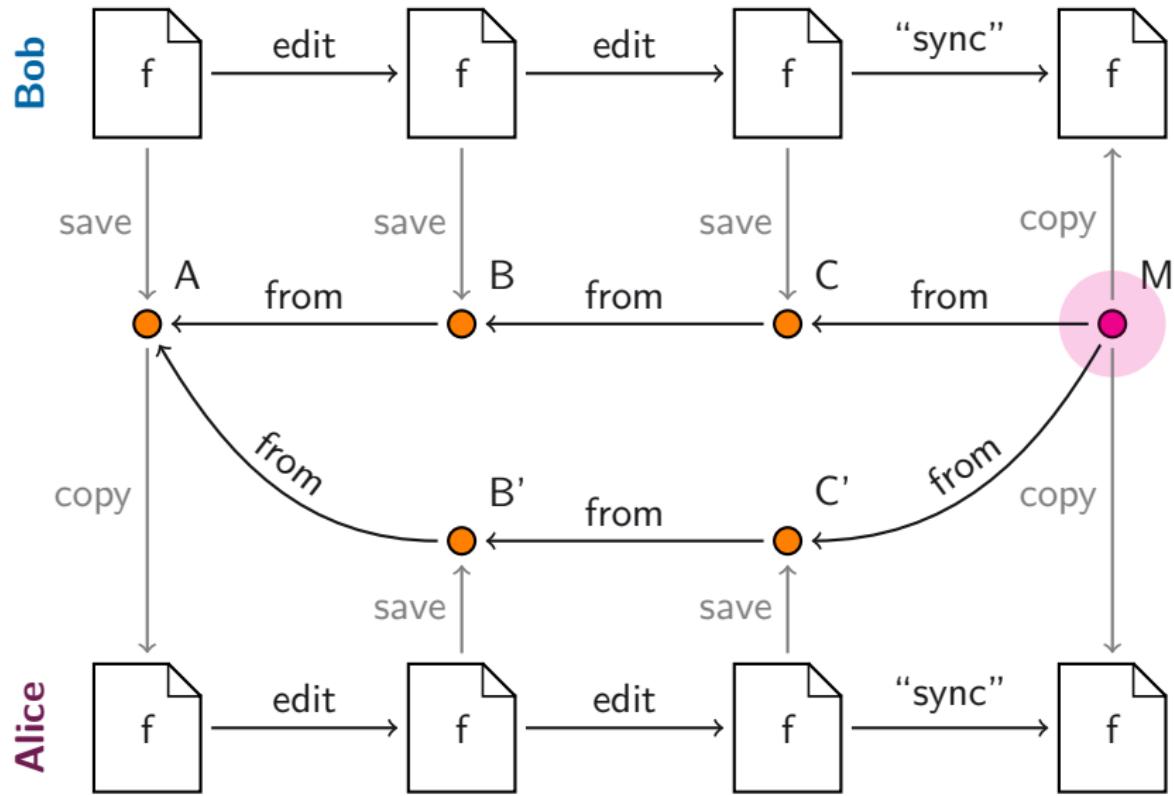
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Solving the Problem: Concurrent Changes I



Solving the Problem: Concurrent Changes I



Solving the Problem: Concurrent Changes II

High Level Overview

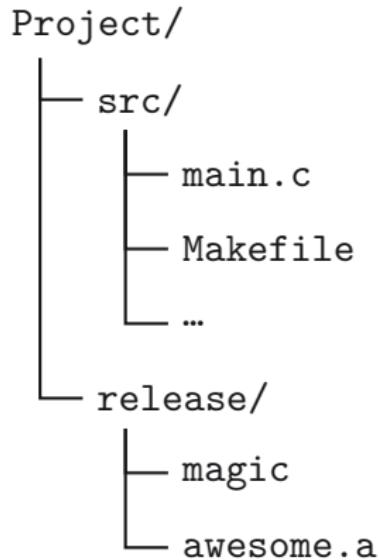
Store changes using a *directed acyclic graph* (DAG) called the *commit graph*.

- 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:

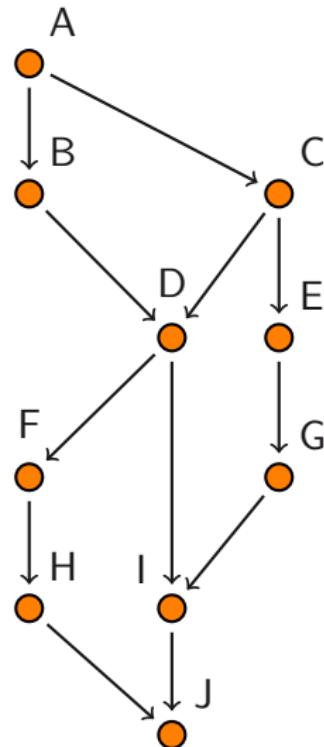
- Rename file ⇒ Same blob, commit name change
- Move file ⇒ Same blob, commit change tree

^aDemo: 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.



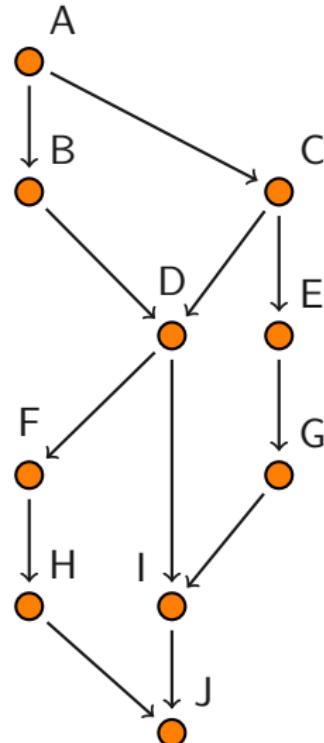
Mathematical Digression I: DAG

Directed Acyclic Graph

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Partial Order

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



Mathematical Digression I: DAG

Directed Acyclic Graph

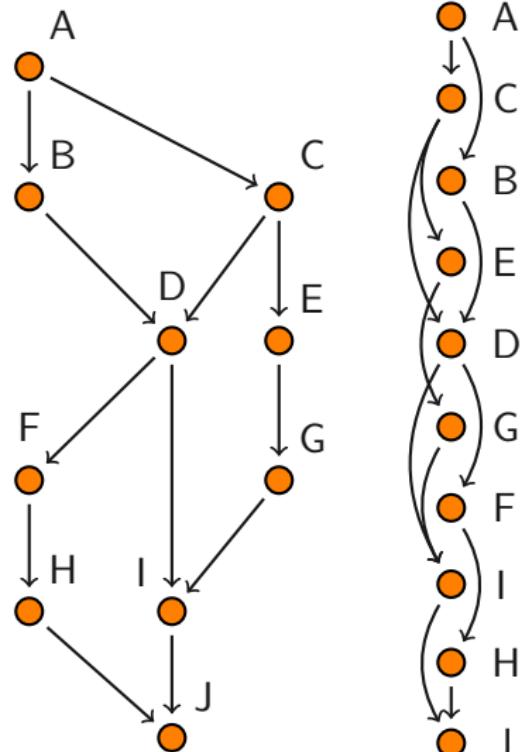
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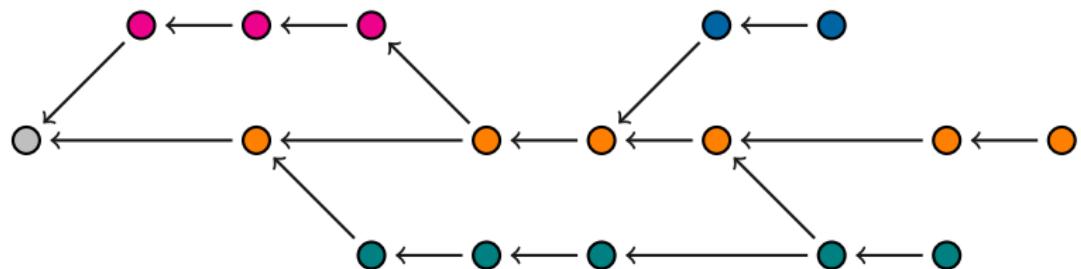
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Topological Order

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.



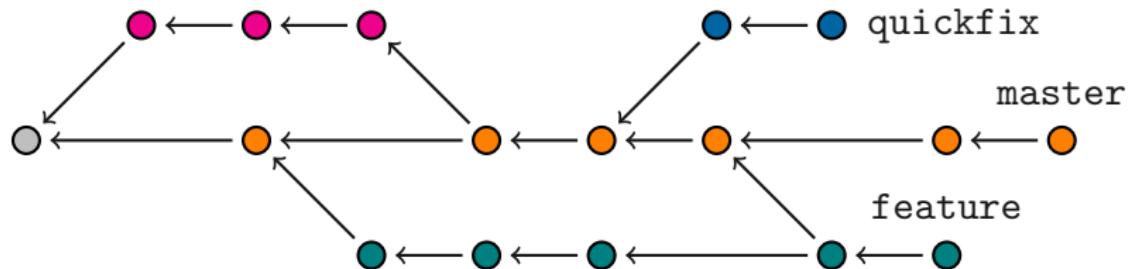
Solving the Problem: Concurrent Changes III



Branch (informal)

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

Solving the Problem: Concurrent Changes III



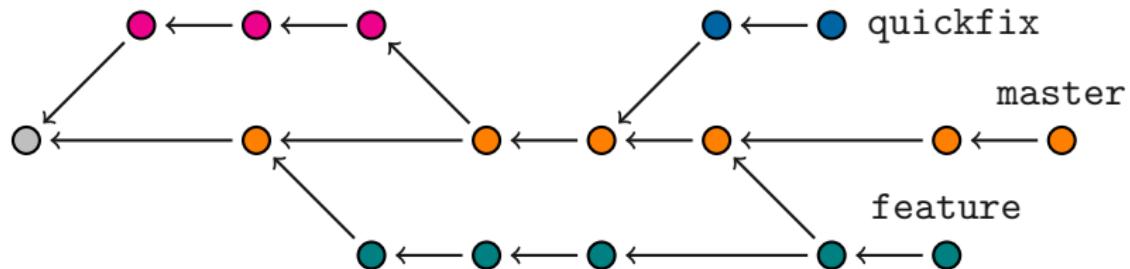
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Naming Branches

Branch names are labels on their
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Solving the Problem: Concurrent Changes III



Branch (informal)

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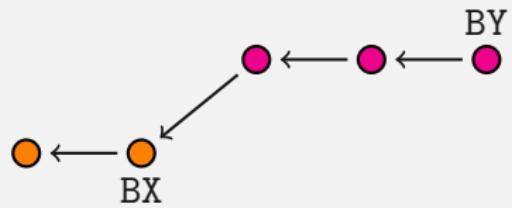
Naming Branches

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

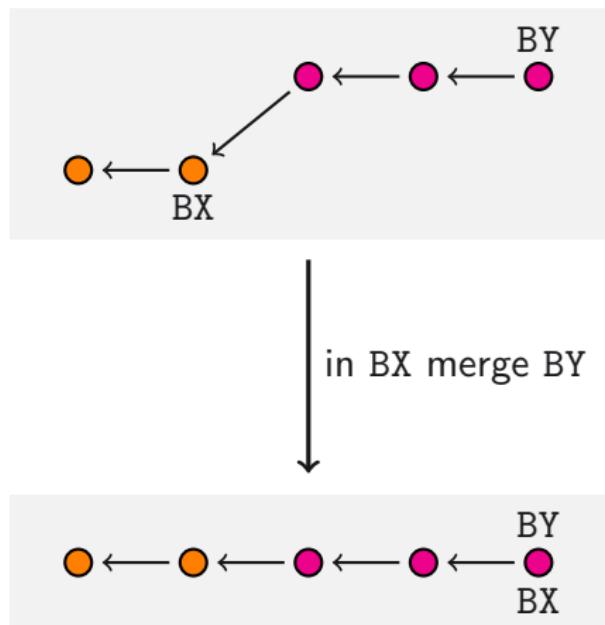
Solving the Problem: Fast-Forward-Merge



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



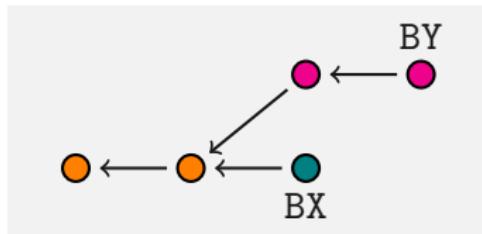
History

- 1 From an existing branch BX (with orange commits) a branch BY added new commits (magenta)
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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.

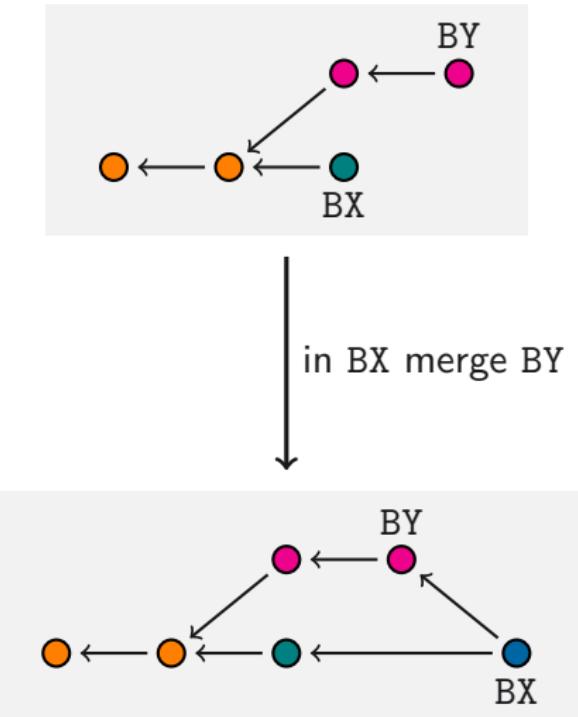
Solving the Problem: 3-Way-Merge I



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

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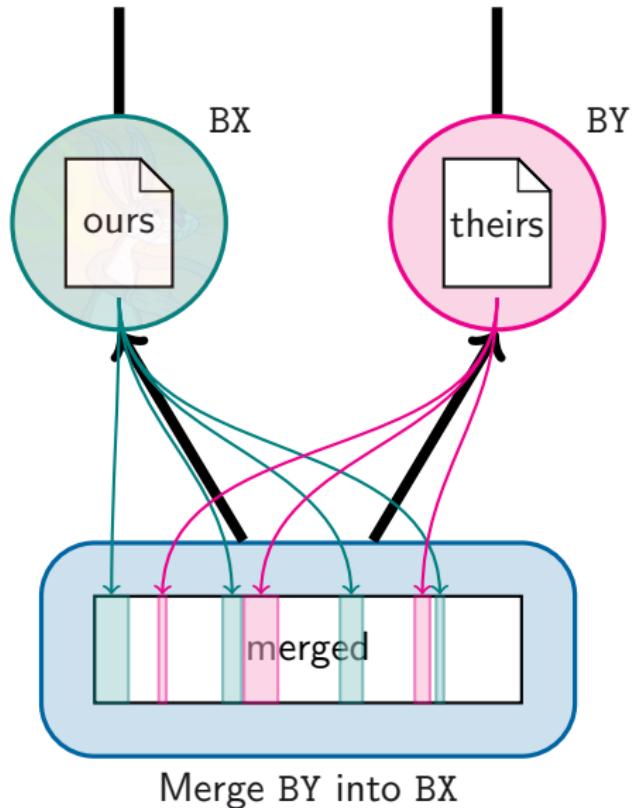
Observations

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



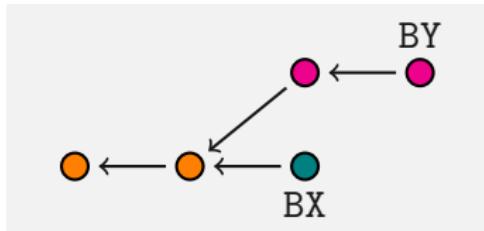
3-Way-Merge

- 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*.

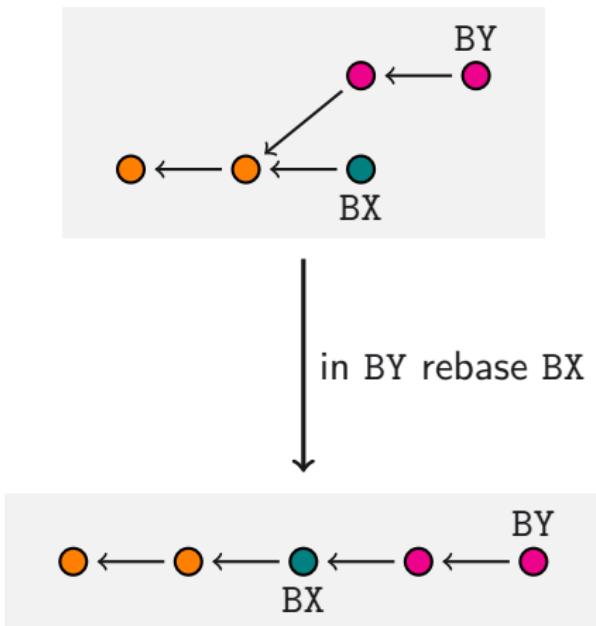
Solving the Problem: Rebase



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

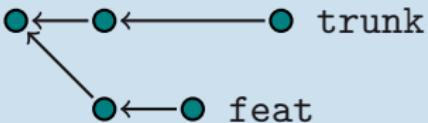
- 1 Branches BX and BY have new commits (magenta and green resp.) and share a common history (orange)
- 2 We rebase BY onto BX

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

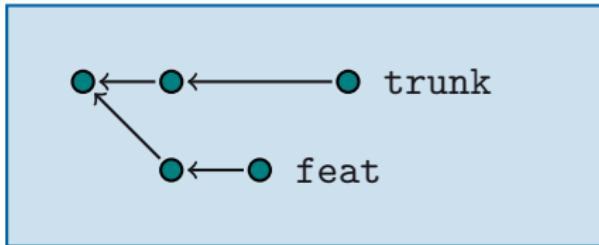
Other computers are called *remotes*. Clone means you copy the commit graph on the remote machine onto yours.

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

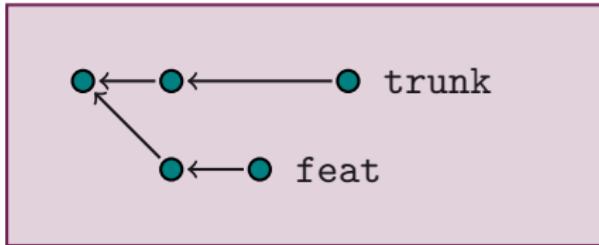
Solving the Problem: Multiple Computers I

Bob's PC



clone

Alice's PC



Remotes and Clone

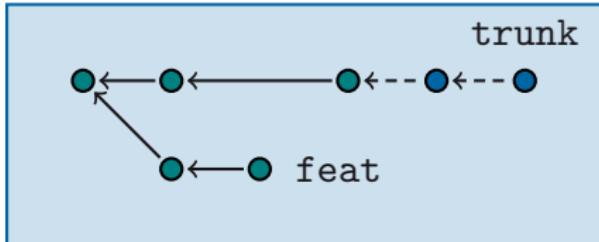
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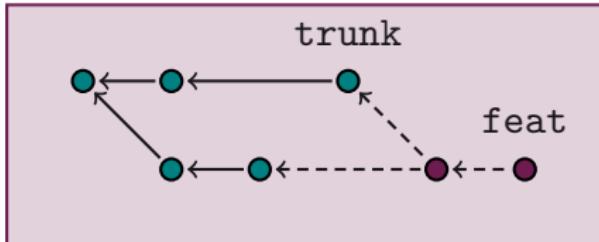
Solving the Problem: Multiple Computers I

Bob's PC



clone

Alice's PC



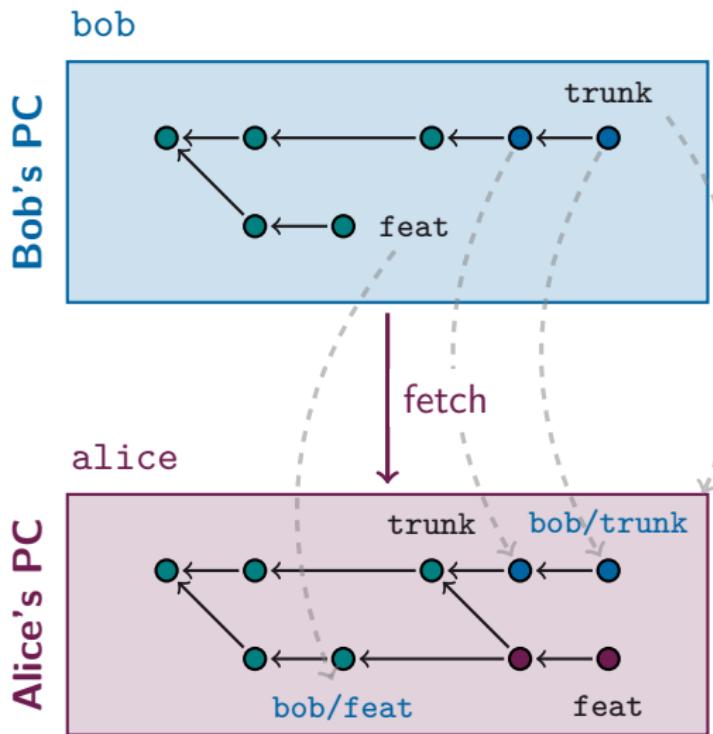
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Example

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Solving the Problem: Multiple Computers II



Fetch

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

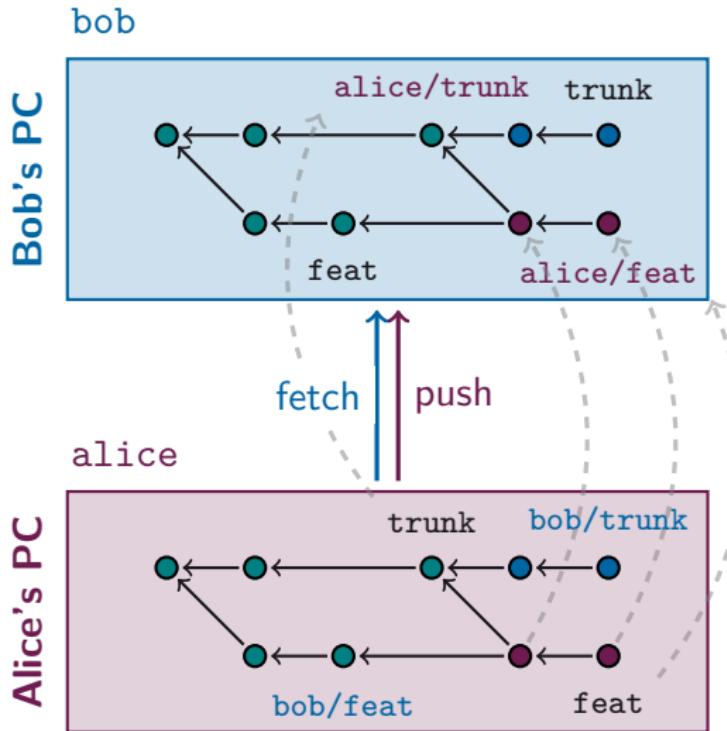
Running Example

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 the remote branch with the same name as the current one.

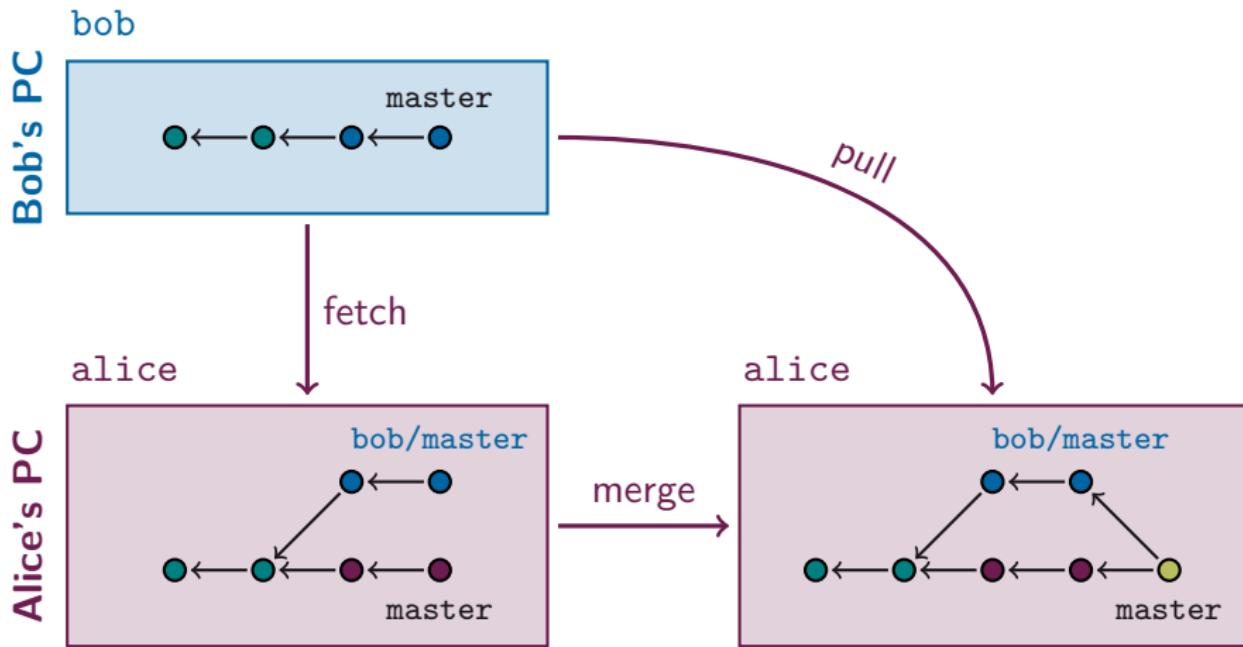


Table of Contents

1 The Problem

2 The Solution

3 The Implementation

- Hash and Merkle DAG
- Git Commits
- Git Repositories

4 Using Git

5 Extras (to flex)

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Mathematical Digression II: Hash and Merkle DAG

“One-way fast” functions

Hash Function

A (cryptographic) *hash* function is an $h : \Omega \rightarrow \{0, 1\}^d$ 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

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Hashes are *not* unique!

Merkle DAG

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

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

that defines a label function

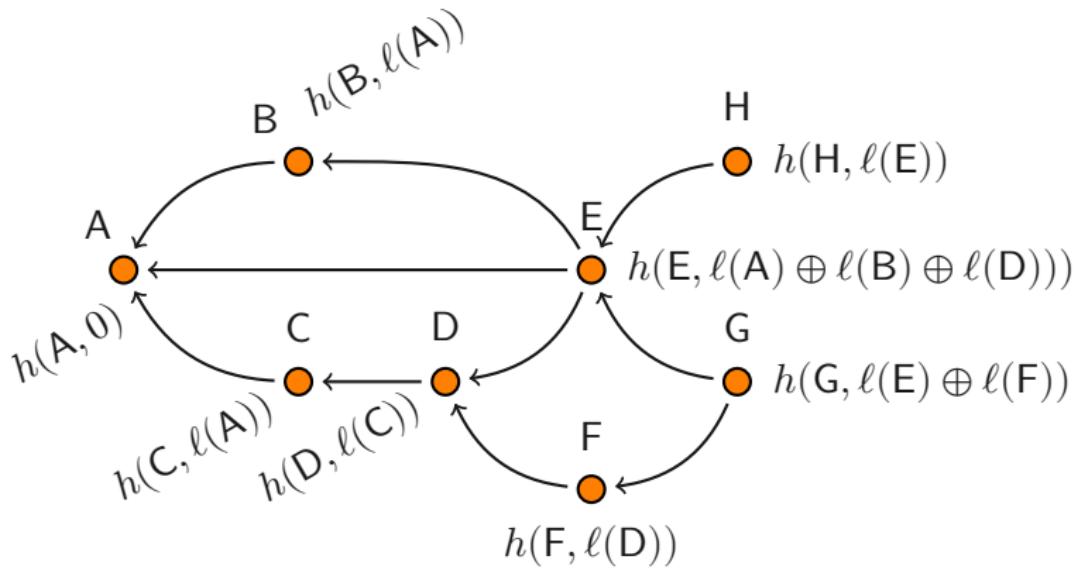
$$\ell(v) = h\left(v, \sum_{u \in \text{n}^+(v)} \ell(u)\right)$$

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 descendants.



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
```

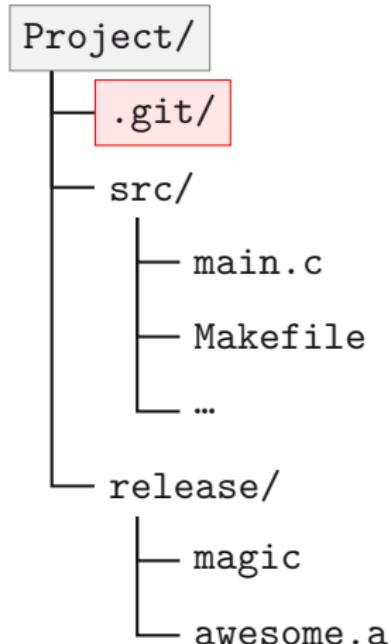
Initial revision of "git", the information manager from hell

```
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 just

Git Repositories



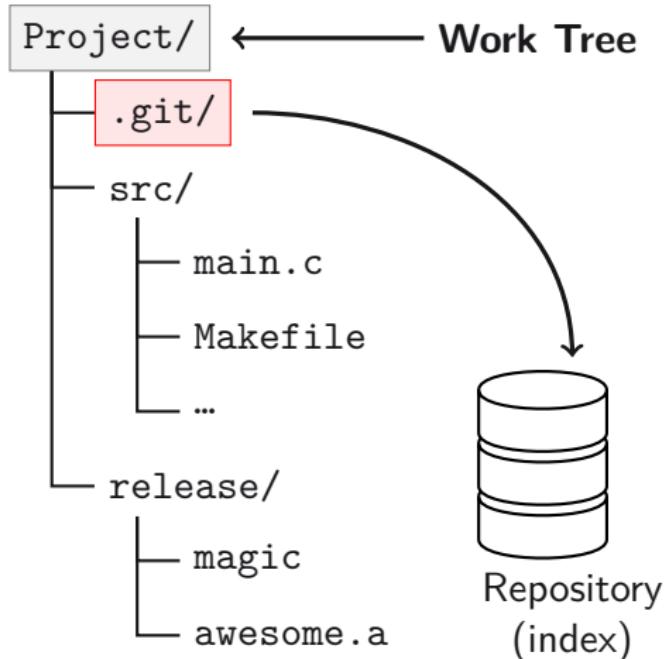
Work Tree

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

Repository

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

Git Repositories



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Root of your project,
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1 The Problem

2 The Solution

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4 Using Git

- The Conceptual Areas
- Branches and Merging
- Command Line vs GUI
- Best Practices
- GitHub and Others, Fork

5 Extras (to flex)

6 Guided Tutorial

The 3 (or 4) Conceptual Areas of Git

Work Tree

Tracked



Untracked



Storage .git

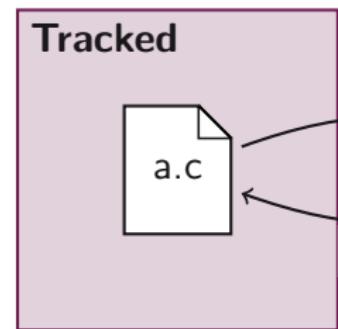
Staging Area

Commit Graph



The 3 (or 4) Conceptual Areas of Git

Work Tree



Untracked



Storage .git

Staging Area

add

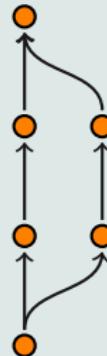
reset

add

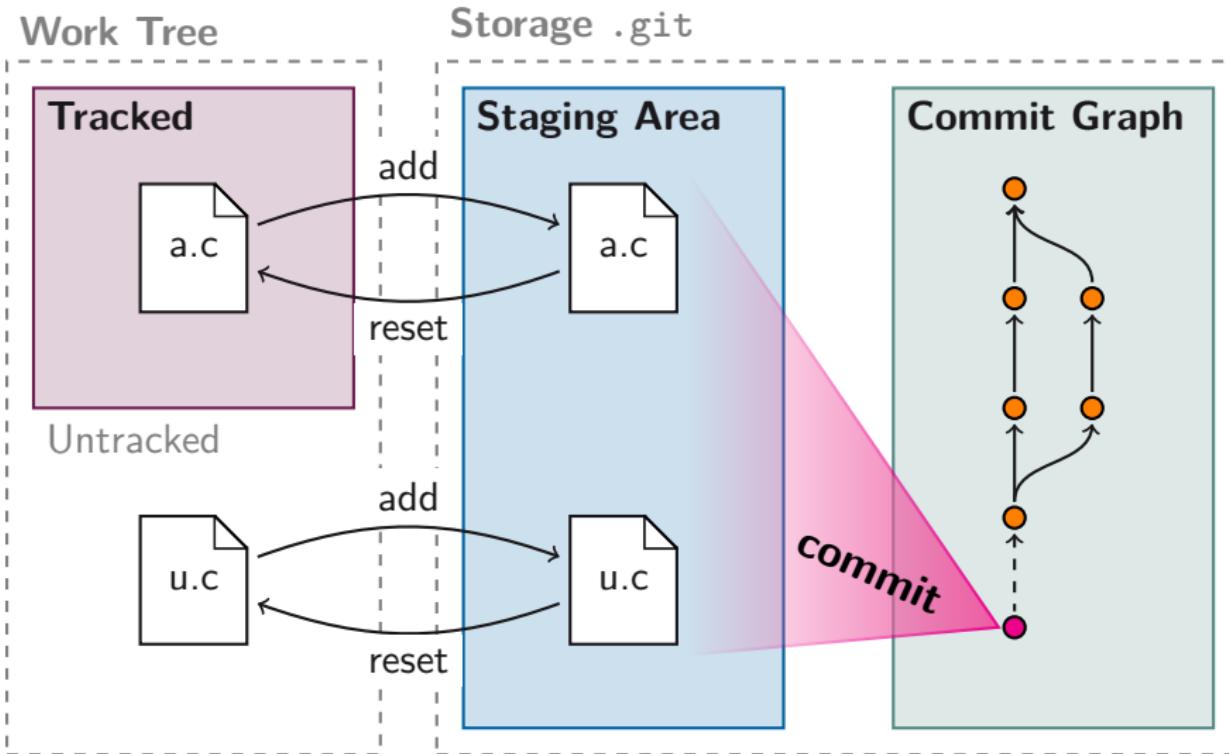
reset



Commit Graph



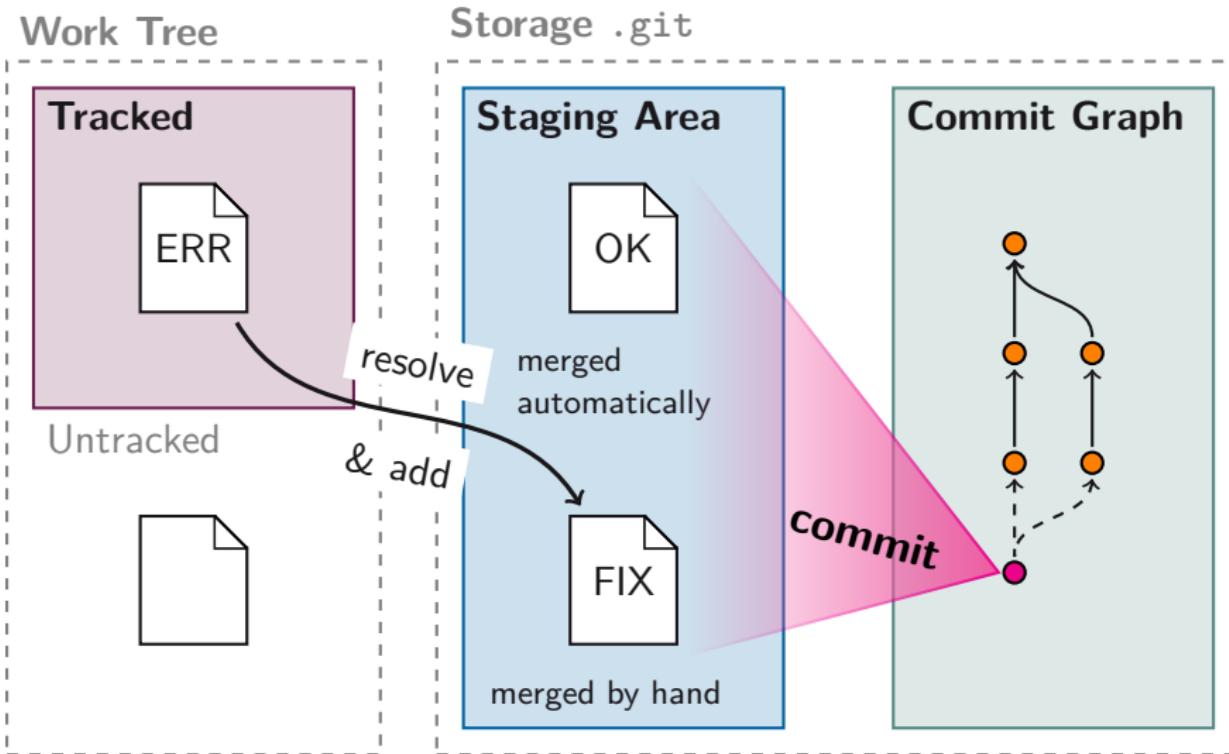
The 3 (or 4) Conceptual Areas of Git



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)



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!)

Graphical User Interfaces

Command Line Interface

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

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 inevitably 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

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?

Demo: Browse Linux kernel git commits

Trunk, Feature Branches

This pertains software development and project management.

Simplest Workflow

- There is no team
- Commit everything on the same branch
- Extremely easy

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People Workflow

- For very small teams
- Very easy
- Each person has a branch
- Avoids mixing work

Trunk, Feature Branches

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Simplest Workflow

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Branching Workflow

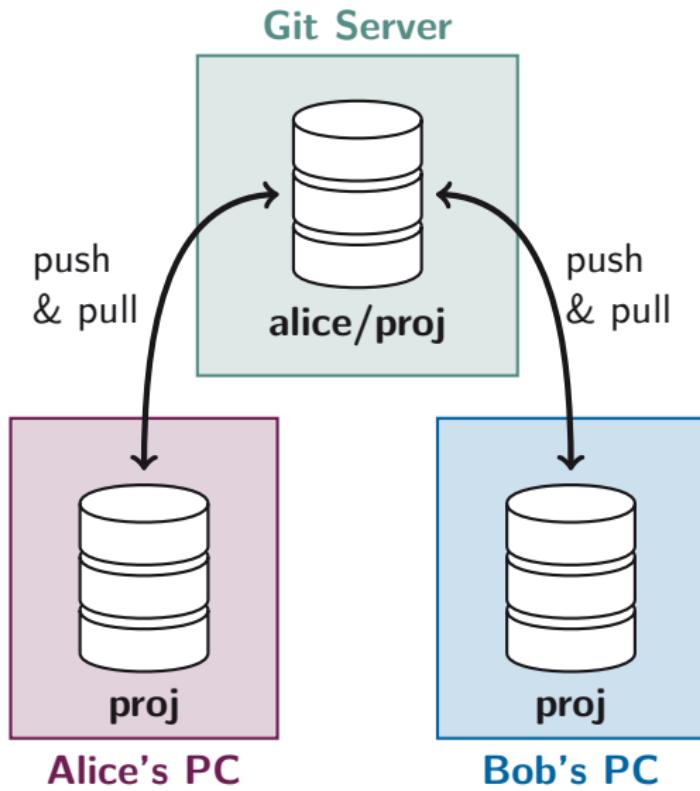
Every time you want to add a feature, make changes in a short lived branch until feature is complete, then merge that branch into a “master” branch (also called “main” or “trunk”)

People Workflow

- For very small teams
- Very easy
- Each person has a branch
- Avoids mixing work

- 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.

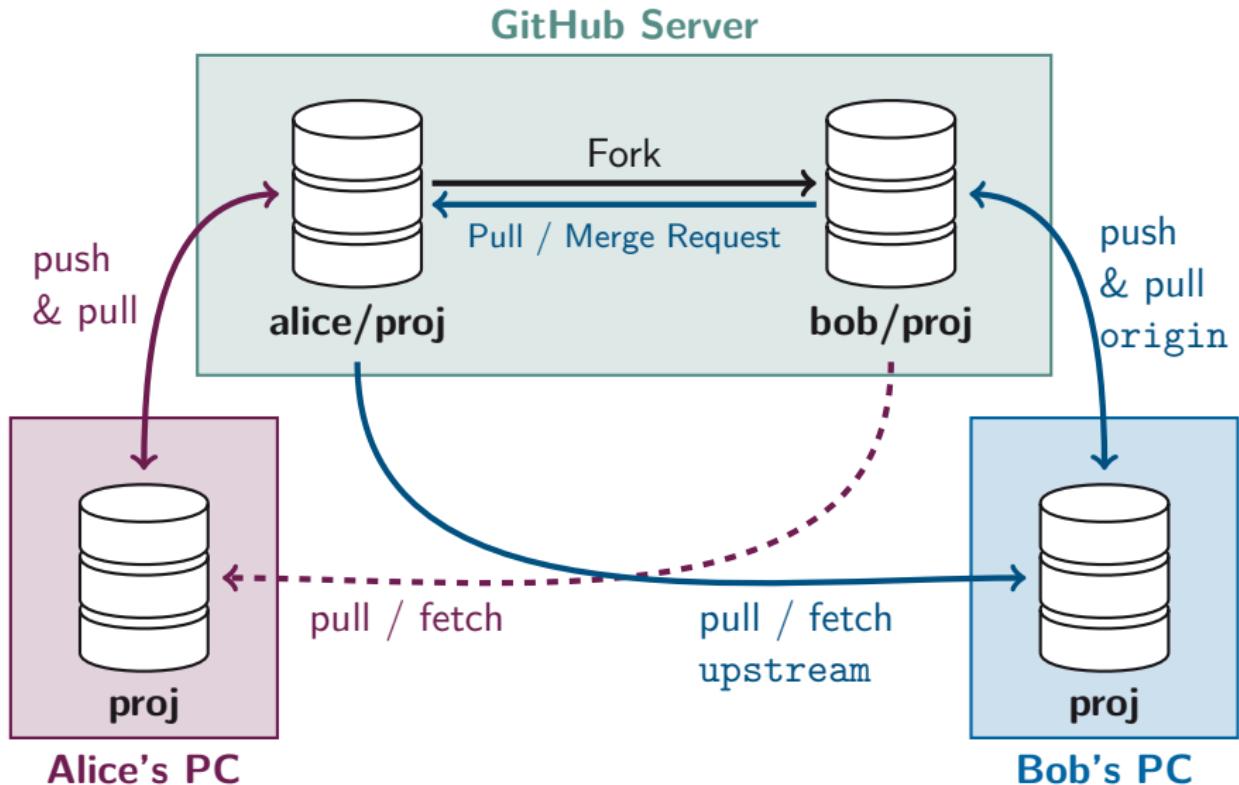
Interface

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 named² 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

²If your remote has a different name, replace all occurrences of origin.

Table of Contents

1 The Problem

2 The Solution

3 The Implementation

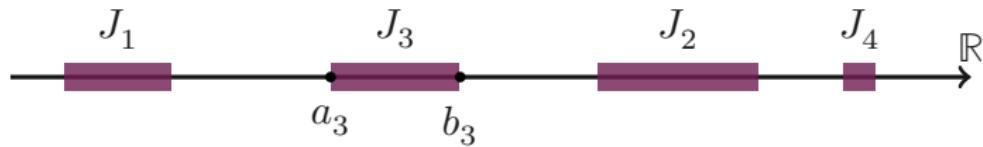
4 Using Git

5 Extras (to flex)

- Logarithmic Search
- Git bisect

6 Guided Tutorial

Mathematical Digression III: Logarithmic Search I



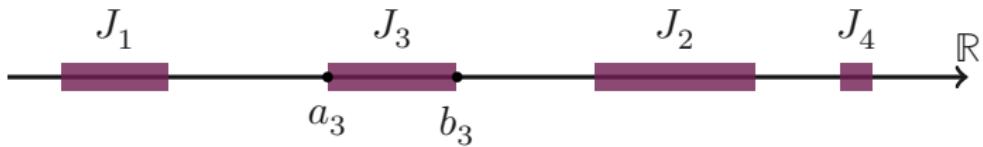
Toy Problem

Given a set of disjoint intervals $S = \{J_1, \dots, J_n\}$, $J_i \subset \mathbb{R}$, $\log_2(n) \in \mathbb{N}$ 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



Toy Problem

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Naive Solution

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

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

Logarithmic Search Intuition

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

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Idea

Recursively apply intuition.

Mathematical Digression III: Logarithmic Search II

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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 $Q := \{J' \in Q : J' \succ J\}$
 - 2 if $q < a$ repeat with $Q := \{J' \in Q : J' \prec J\}$

Does not check every $J \in S$ (fast for large $n!$).

Mathematical Digression III: Logarithmic Search II

Logarithmic Search Intuition

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

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Idea

Recursively apply intuition.

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

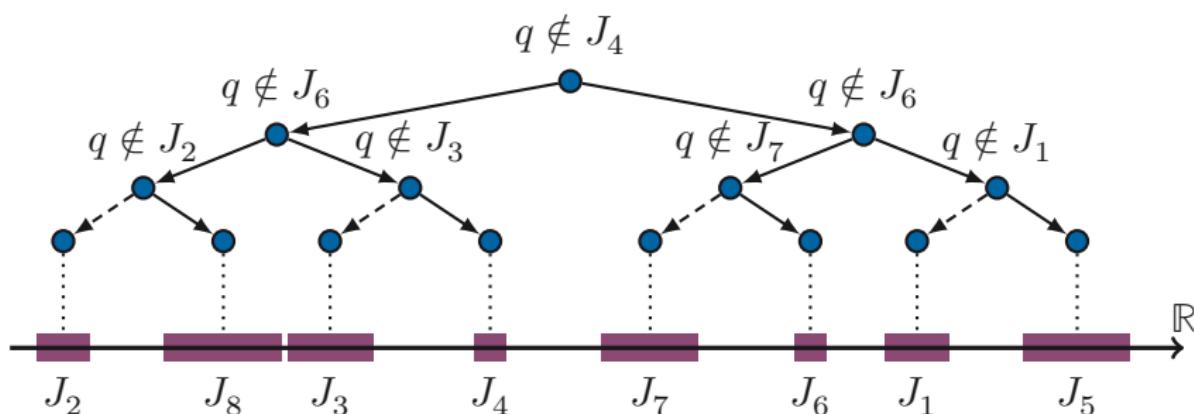
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Does not check every $J \in S$ (fast for large n !).

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. Observe that the tree has depth $3 = \log_2(8)$.

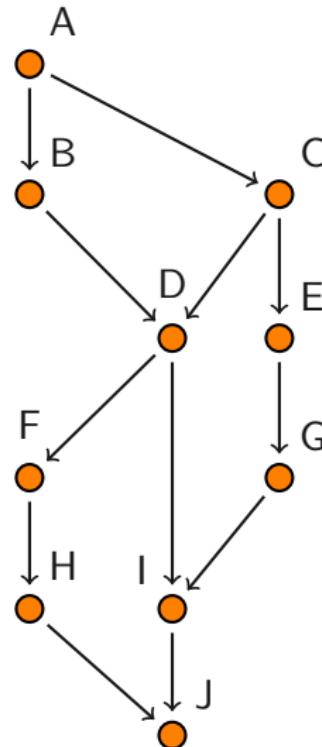


Git Bisect: Search for something in the past

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

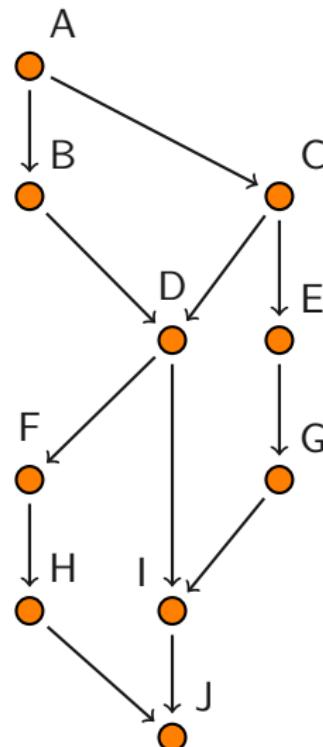
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Rough Idea

- 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
- 2 git bisect bad (current commit is bad, no X)
- 3 git bisect good 258dbc1 (commit 258dbc1... was good, has X)

Git Bisect Practice

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

- 1 git bisect start
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Git will checkout (go back in time to) a commit between the good one and the bad one and you have to say

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- git bisect bad
- git bisect skip (cannot test this commit for X)

Git Bisect Practice

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

- 1 git bisect start
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Git will checkout (go back in time to) a commit between the good one and the bad one and you have to say

- git bisect good
- git bisect bad
- 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

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- Outlook
- OST GitHub Organization
- Tutorial

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 L^AT_EX workshop?
- Do you take notes / write summaries using L^AT_EX?

- $\mu_0 \frac{\partial t}{\partial r}$

L^AT_EX 2 _{ϵ} Workshop

Fachschaft Elektrotechnik

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

Organization Goals

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

Hands-On Phase (Groupwork)



where beer

Hands-On Phase (Groupwork)

Goals

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

Sample Projects

- Import existing code into new repository
- Directly contribute to a repository
- Contribute as external via pull-request

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