Git In

Engineering a Version Control System

"From ancient counting stones to quantum algorithms—
every data structure tells the story of human ingenuity."

Living First Edition

Updated December 31, 2025

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Git Internals: Software Engineering, Architecture, Design Patterns

A Living Architecture of Computing

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Preface

I HAD JUST FINISHED a project and wanted to start something new. I was working on gix—a Git wrapper I'd been thinking about—and realized I didn't actually understand Git well enough.

Sure, I could use it. I knew the commands. But how does it work? Why is it designed this way? What makes it different from other version control systems?

I read some articles. Looked at Pro Git's internals chapter. Found a small booklet on Git internals. But I wanted more. I wanted to see the actual code. The decisions. The trade-offs.

So I cloned the Git repository and started reading.

Why I'm Writing This

At first, I was just making notes for myself. Trying to understand the codebase. Mapping out how things connect.

Then I thought maybe I could write an article about it. Share what I learned.

But the more I read, the more I found. This wasn't article material. There was too much to say.

So here we are. A book about Git's internals from an engineering perspective.

What This Book Actually Is

This is me reading Git's source code and explaining what I find.

Not line by line—that would be boring and pointless. But the important parts. The clever solutions. The patterns that keep showing up. The reasons things are built the way they are.

I care about software engineering. How systems are designed. Why certain approaches work. What problems they solve. Git is interesting because it does things differently and those differences matter.

Who This Is For

You if you've used Git but want to understand how it works underneath.
You if you're interested in system design and want to see a real, mature codebase.
You if you like reading code and learning from it.
You don't need to be a C expert. I'll explain the tricky bits. You don't need to know Git internals already. That's what this book is about.

What This Isn't

This isn't a Git tutorial. I'm not teaching you how to use Git. There are better resources for that.
This isn't comprehensive. Git's codebase is massive. I'm focusing on the core ideas and the interesting engineering choices.
This isn't perfect. I'm still learning this stuff. I'll probably get some things wrong. That's okay.

How I'm Approaching This

I started with Git's first commit. The original implementation by Linus Torvalds. It's small and shows the core model clearly.
Then I worked forward, looking at how the codebase evolved. What got added. What got changed. Why.
I'm trying to explain not just what the code does but why it's designed that way. What problem was being solved? What alternatives existed? What trade-offs were made?

This Is Ongoing

I'm still reading the code. Still learning. This book reflects what I understand right now.
Maybe in six months I'll understand more and want to revise some sections. That's how learning works.
Consider this a snapshot of the journey, not the final destination.

Why Bother?

Because Git is everywhere and most people don't understand it.
Because understanding your tools makes you better at using them.
Because Git's design has lessons that apply beyond version control.

Because it's interesting.
Let's start.

Mahdi
2025

Introduction

EVERY DESIGN decision has a reason. Every data structure solves a problem. Every algorithm makes a trade-off.
When you look at mature software, you're seeing years of evolution. Hundreds of developers. Thousands of decisions. Some good, some less good, all made for specific reasons at specific times.
Git is like that. It's been around since 2005. It's used by millions. It's been optimized, refactored, extended. And understanding it teaches you about software engineering.

What You're Going To Learn

This book walks through Git's internals from an engineering perspective.
Not how to use Git. How Git is built.
We'll look at the data model and why it's clever. The codebase structure and how it evolved. The algorithms and their complexity. The design patterns that keep appearing. The performance optimizations. How it all fits together.
And more importantly—why. Why these choices? What problems do they solve? What are the trade-offs?

What This Book Isn't

This is not a Git tutorial. If you need to learn Git commands, read Pro Git or the official documentation.
This is not complete reference. Git has over 2000 files and hundreds of commands. I'm covering the important parts, the core insights, the interesting engineering.
This is not academic. I'll talk about algorithms and complexity, but I'm not writing proofs or formal specifications. This is practical engineering.
This is not flawless. I'll make mistakes. I'll miss things. That's fine. The goal is understanding, not perfection.

Why Git?

Because you probably use it every day. Most developers do.
Because it's well-designed at its core. The data model is elegant even if the command interface is messy.
Because it's mature. Twenty years of evolution. You can learn from that evolution—what worked, what didn't, what got changed and why.
Because it does things differently. Most version control systems work one way. Git works another way. Understanding why teaches you about design choices.

Prerequisites

You should know basic programming. Any language is fine. Concepts like variables, functions, data structures.
You should know basic Git usage. Add, commit, push, merge. Not expert level, just the basics.
You should know basic data structures. Trees, graphs, hash tables. Nothing fancy.
You don't need to know C deeply. I'll explain the important parts.
You don't need to know advanced Git internals. That's what this book teaches.
You don't need algorithm analysis background. I'll teach what matters.

How To Read This

Start with Part I if you want historical context. Skip it if you already know about version control evolution and why Git was created.
Parts II and III are essential. They cover architecture and the data model. Read those.
After that, jump around based on your interests. Want to understand merging? Go to Part VI. Curious about performance? Part IV. Interested in patterns? Part V.
Code examples are simplified for clarity but accurate in concept. When I show code, I'll tell you if I've simplified it.

The Core Ideas

Most version control systems think in terms of changes. They track what changed between versions. Git doesn't.
Git thinks in terms of snapshots. It stores the complete state of your project at each commit. Not the difference—the whole thing.

That one decision changes everything. It makes branching cheap. It makes merging easier. It makes Git fast. But it also creates challenges. How do you store thousands of snapshots efficiently? How do you transfer them over networks? How do you handle conflicts?
Git solves these problems in specific ways. We're going to look at how and why.

Content-Addressable Storage

Everything in Git is identified by its content hash. Files aren't named by their path. They're named by their SHA-1 hash.
If two files have the same content, they have the same hash. Git only stores them once. Automatic deduplication.
This seems weird at first but it's powerful. Git can tell if two things are identical by comparing hashes. It can detect corruption by verifying hashes. It can reference any object by its hash.
The entire system builds on this idea.

Starting Point

We'll start with foundations. What is version control? Why does Git exist? What problems does it solve?
Then architecture. How is the codebase organized? Where are things located?
Then the data model. This is the heart of Git. Objects, hashes, the DAG structure.
Then we go deeper. Storage, algorithms, patterns, performance.
By the end, you'll understand how Git works. Not just what commands do, but how they're implemented and why.

A Word on Engineering

Good engineering isn't about being clever. It's about solving problems effectively. Sometimes the best solution is simple. Sometimes it's complex because the problem is complex. Sometimes it's ugly because reality is messy.
Git has all of these. Simple elegant parts. Complex necessary parts. Ugly historical parts.
Learning to distinguish between them—to see which complexity is essential and which is accidental—that's what studying real systems teaches you.
Let's start.

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Before diving into Git's engineering, you need to understand why it exists and what problems it solves.

This part is quick. Just enough background to make sense of the decisions that follow.

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