BUILDING A HIGH-PERFORMANCE WEB SERVER IN RUST

FROM FIRST PRINCIPLES

FROM RAW TCP SOCKETS

HTTP/1.1 & HTTP/2

TLS ENCRYPTION

ROUTING & MIDDLEWARE

TEMPLATING & REST APIS

TESTING, BENCHMARKING & DEPLOYMENT

STEVE T.

Rust from Sockets to Servers

Building a High-Performance Web Server in Rust from First Principles

Steve T. Team Publications

This book is available at https://leanpub.com/rustfromsocketstoservers

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Contents

Building a High-Performance Web Server in Rust from First Principles

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Introduction: Why Build Your Own Server?

You have probably built a web server before. You typed `cargo add axum`, wrote a few lines of routing code, and had a working HTTP endpoint in under five minutes. That is wonderful. Frameworks exist to make common tasks easy, and the Rust ecosystem has excellent ones. But there is a cost to convenience: the layers between your code and the network become invisible. When something goes wrong, you are left guessing which abstraction is responsible. You cannot optimize what you do not understand.

Consider a production incident I once debugged at a startup. Our API was experiencing intermittent 504 Gateway Timeout errors under load. The framework's error logs were unhelpful, and the reverse proxy blamed us while we blamed the proxy. After three days of finger-pointing, I finally traced the issue to a subtle interaction between HTTP keep-alive connection management, the framework's thread pool sizing, and our database connection pool. The fix took ten minutes once I understood the mechanics. It would have taken ten minutes on day one if I had built the server from the ground up.

That is the argument for building your own web server from scratch. Not because you should deploy a hand-rolled server to production tomorrow, but because the act of construction teaches you how servers actually work. You will understand TCP connections, HTTP semantics, async I/O, routing algorithms, middleware composition, TLS handshakes, and performance tuning at a level that reading documentation alone cannot provide.

What You Will Build

By the end of this book, you will have built a complete web server with the following capabilities:

- **HTTP/1.1 support** with proper request parsing, response formatting, keep-alive connections, and chunked transfer encoding

- **HTTP/2 support** with multiplexed streams and HPACK header compression via the h2 crate
- **A routing system** that supports exact paths, parameterized routes like `/users/:id`, and method-based dispatching
- **A middleware pipeline** for logging, timing, CORS, rate limiting, and error handling
- **Static file serving** with MIME type detection, range requests, compression, and cache headers
- **Server-side templating** using Tera for dynamic HTML generation
- **REST API support** with JSON serialization via serde
- **TLS/HTTPS** encryption using rustls
- **Structured logging** with the tracing crate
- **Comprehensive testing** including unit tests, integration tests, and benchmarks
- **Production deployment** via Docker containers behind a Caddy reverse proxy

The server will be built incrementally. Each chapter adds a new layer, and every layer is tested before we move on. The final product will be a server that handles thousands of concurrent connections efficiently, serves files quickly, routes requests correctly, and secures traffic with encryption.

Prerequisites and Setup

This book assumes you are comfortable with Rust basics: ownership, borrowing, lifetimes, traits, enums, and the `Result` type. You should have used `cargo` to build and run projects. If you need a refresher, the official Rust Book covers these topics thoroughly.

You will need a recent version of Rust installed. The code in this book targets Rust Edition 2021 for maximum compatibility, though most code will also compile under the newer Edition 2024 (stabilized in Rust 1.85). Install or update Rust using rustup:

```
rustup update stable
rustup default stable
```

To verify your installation:

```
rustc --version
cargo --version
```

You will also need a few development tools for later chapters:

- **wrk** for HTTP benchmarking (available via your system package manager or from github.com/wg/wrk)
- **curl** for manual HTTP testing
- **Docker** for containerization in the final chapters
- **openssl** for generating self-signed certificates

Most of these come pre-installed on Linux and macOS. Windows users can install them via winget or Chocolatey.

The Architecture at a Glance

Before we dive into code, let me sketch the architecture of the server we will build. Think of it as a series of layers, each sitting on top of the one below:

```
+----------------------------------+
|          REST API / Templates    |  <-- Your application logic
+----------------------------------+
|       Static File Serving        |
+----------------------------------+
|         Middleware Pipeline      |  <-- Logging, CORS, rate limiting
+----------------------------------+
|            Router                |  <-- URL matching, dispatching
+----------------------------------+
|     HTTP/1.1 & HTTP/2 Protocol   |  <-- Request/response parsing
+----------------------------------+
|        TLS (rustls)              |  <-- Encryption layer
+----------------------------------+
|    Async TCP (tokio::net)        |  <-- Connection management
+----------------------------------+
|         OS Socket API            |  <-- Kernel networking
+----------------------------------+
```

Each chapter corresponds to one or more of these layers. We start at the bottom with raw sockets and work our way up. This bottom-up approach ensures you understand each layer before we add complexity on top.

How to Read This Book

This book is designed to be read sequentially. Each chapter builds on the previous ones, so skipping ahead will leave gaps in your understanding. However, if you are already familiar with certain topics (for example, you know how TCP works), you can skim the explanatory sections and focus on the code.

Every chapter ends with exercises. These range from small modifications to the code you have written to larger projects that test your understanding. I strongly recommend completing them, even the ones that feel easy. The act of writing code cements knowledge in a way that reading never does.

The code examples are designed to be self-contained where possible, but the full project grows throughout the book. You can find a reference implementation on GitHub (linked at the end of each chapter), but I encourage you to type the code yourself rather than copying it. Muscle memory matters as much as conceptual understanding when learning a new architecture.

Some chapters will present multiple approaches to the same problem. For example, we will discuss both a simple HashMap-based router and a more efficient radix-tree router. In these cases, we implement the simpler version first and then upgrade. This pattern reflects real-world development: start with something that works, then optimize when you have evidence that optimization is needed.

One final note on style. The code in this book prioritizes clarity over cleverness. You will not find monadic chains or macro-heavy solutions here unless they are genuinely the right tool for the job. A web server needs to be maintainable, and readable code is maintainable code. When you are ready to add your own flair, you will have a solid foundation to build on.

Let us get started. In Chapter 1, we will open our first TCP socket and learn how data actually moves across a network.

Chapter 1: Networking Fundamentals

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Chapter 2: Understanding HTTP/1.1

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