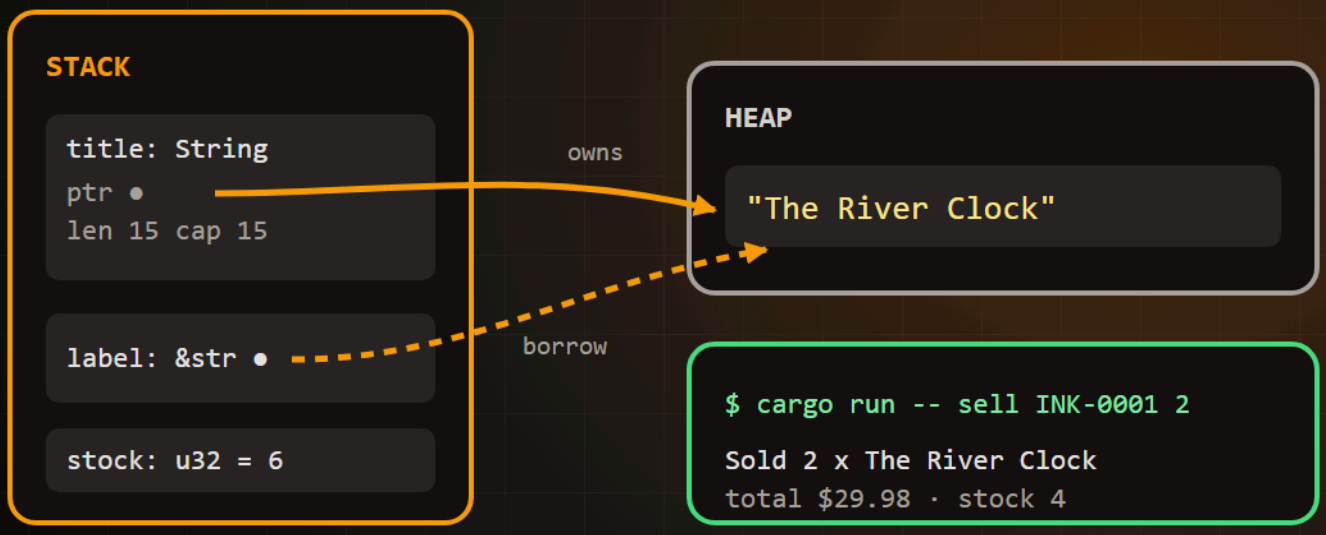



```
error[E0502]: cannot borrow `books` as mutable
because it is also borrowed as immutable
let first = &books[0]; // immutable borrow
books.push(new_book); // mutable borrow
help: finish using `first` before mutating
```

OWNERSHIP · BORROWING · TRAITS · ITERATORS · ASYNC

FROM YOUR FIRST LINE TO REAL PROJECTS

Rust Programming from Zero

A complete, practical guide to safe, fast, modern Rust

Ownership and borrowing explained clearly, real projects, and compiler errors treated as teachers — Rust 2024 edition

CARGO · SERDE · CLAP · TOKIO · AXUM

THENEXBOOKS

Rust Programming from Zero

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For the Rust 2024 edition

First Edition

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Rust Programming from Zero
A Complete, Practical Guide to Safe, Fast, Modern Rust

First Edition, 2026

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Preface

Rust has a reputation. People say it is hard, that the compiler argues with you, that ownership and lifetimes take months to understand. There is some truth in that: Rust asks you to think about things other languages let you ignore — who owns a piece of data, how long it lives, and who may change it. But that reputation leaves out the other half of the story. Once those ideas click, Rust gives you programs that are fast, that do not crash with null pointer errors or data races, and that you can change with confidence because the compiler checks so much for you.

This book is designed to make those ideas click. We start from zero — installing Rust and writing your first program — and build up one concept at a time, always explaining *why* Rust works the way it does. When the compiler rejects your code, we read the error together and treat it as a teacher rather than an obstacle. By the end, you will understand ownership, borrowing, lifetimes, traits, generics, iterators, error handling, smart pointers, concurrency, and async — and you will have built a complete, tested command-line application and a small web API.

Who This Book Is For

- **Developers new to Rust** who know another language — Python, JavaScript, Java, Go, C#, or C/C++ — and want to learn Rust properly.
- **Motivated beginners** with a little programming experience who want a language that teaches good habits.
- **Students and self-learners** curious about systems programming without the traditional pitfalls.
- **Engineers evaluating Rust** for their team who want a clear, honest picture of how it works.

What You Will Learn

- Rust's toolchain — `rustup`, Cargo, rust-analyzer, Clippy, and rustfmt — and how a Rust project is laid out.
- Variables, types, functions, control flow, and expressions.
- Ownership, borrowing, references, slices, and lifetimes — explained from first principles with diagrams.
- Structs, enums, pattern matching, modules, collections, and error handling with `Result` and the `?` operator.
- Generics, traits, closures, and iterators — the tools that make Rust code expressive.
- Testing, smart pointers, threads and channels, and async Rust with Tokio.
- Files and I/O, serialization with Serde, command-line tools with clap, macros, and unsafe Rust and FFI.
- Idiomatic style, performance basics, publishing crates, and where to go next.

How This Book Is Organized

Part I — Getting Started (Chapters 1–5) installs Rust and covers the basics, ending with ownership. **Part II — Core Language** (Chapters 6–10) covers borrowing, strings, structs, enums, and modules. **Part III — Building Real Programs** (Chapters 11–15) adds collections, error handling, generics, traits, lifetimes, closures, and iterators. **Part IV — Going Deeper** (Chapters 16–20) covers testing, smart pointers, concurrency, async, and advanced traits. **Part V — Practical Rust** (Chapters 21–25) covers files, Serde, command-line tools, macros, and unsafe code. **Part VI — Projects and Next Steps** (Chapters 26–28) brings everything together in two projects and a guide to writing idiomatic Rust. The appendices provide a cheat sheet, a tooling reference, a field guide to compiler errors, and a glossary.

Each chapter includes practice exercises and ends with a **Key Takeaways** box for quick review.

The Running Example: Inkwell

Throughout the book we write software for **Inkwell**, a small independent bookshop. Nia owns the shop, Felix works the counter and asks the practical questions, and Ravi — a friend learning Rust alongside you — helps build the tools. Chapter by chapter, you grow `inkwell`, a command-line program that tracks books, prices, stock, and sales: first as a few variables, then structs and enums, then modules, collections, and proper error handling, then saved to JSON and CSV, and finally as a complete, tested CLI with a small web API on top.

Versions and Conventions

Examples use the Rust 2024 edition on recent stable Rust. Third-party crates are shown with illustrative major versions; use the current versions when you add them. Compiler output is trimmed to fit the page and may differ slightly from what you see.

> **TIP**
> A recommended practice or a technique that saves you time.

> **NOTE**
> Background information, version details, or a useful aside.

> **WARNING**
> A common mistake, a compiler error you are likely to meet, or a habit to avoid.

File captions such as *inkwell/src/inventory.rs* tell you where a snippet belongs. If you later want to build production web services in Rust, the companion title *Rust for Backend Developers* picks up where this book leaves off.

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PART I

Getting Started

Why Rust exists and what makes it different, installing the toolchain, your first programs, the basic building blocks of the language, and the idea that everything else rests on: ownership.

1 · Why Rust?
2 · Installing Rust
3 · Variables and Basic Types
4 · Functions and Control Flow
5 · Ownership

CHAPTER 1 · PART I — GETTING STARTED

Why Rust? What Makes It Different and Who It Is For

Before we write a single line of code, this chapter explains what problem Rust was designed to solve, what makes it feel different from the languages you may already know, and what you will build as you work through this book: a real inventory tool for a small bookshop called Inkwell.

A Language With a Clear Promise

Every programming language is a set of trade-offs. Some languages make it easy to get a program running quickly but leave you to discover certain bugs at run time, sometimes in production, sometimes months later. Other languages give you precise control over memory and hardware but trust you completely to manage that control correctly, and they offer little help when you get it wrong. For decades, programmers were told they had to pick a side: **convenience and safety**, or **control and speed**.

Rust is an attempt to refuse that choice. Its promise can be summarized in one sentence: *you get low-level control over how your program uses memory and the machine, and the compiler checks, before the program ever runs, that you are using that control safely*. Rust programs do not need a garbage collector running in the background, yet whole categories of memory bugs — using memory after it has been freed, freeing the same memory twice, reading from a pointer that points nowhere, two threads racing to change the same data — are ruled out by the compiler in ordinary Rust code.

That promise has a price, and it is better that you hear about it now rather than discover it on your own. The Rust compiler is strict. It will reject programs that would have compiled happily in C, Java, Python, or JavaScript. Early on, you will sometimes feel that you are arguing with it. The central goal of this book is to make that argument a conversation: to explain *why* the compiler insists on what it insists on, so that its messages start to read like advice from a careful colleague instead of a wall of red text.

Where Rust came from

Rust began as a personal project at Mozilla Research and was later sponsored by Mozilla as a language for writing safer browser components. Version 1.0 was released in 2015, and with it came a commitment to **stability**: code that compiles on one stable release of Rust should keep compiling on later stable releases. Since 2021 the language has been stewarded by the Rust Foundation, an independent non-profit, together with the open-source Rust project and its teams.

What Problem Does Rust Actually Solve?

To understand why Rust looks the way it does, it helps to understand the problem it was built to address. Almost every program needs memory to store data: the text a user typed, the list of books in a shop, the response that came back from a web server. A program asks for memory, uses it, and at some point must give it back. The question every language must answer is: **who decides when memory is given back, and how do we know nobody is still using it?**

There are three broad answers that languages have historically given.

Answer one: the programmer decides

In C and, to a large degree, C++, the programmer allocates memory and frees it explicitly. This gives excellent control and predictable performance, because nothing happens behind your back. But it is easy to get wrong. Forget to free memory and your program slowly leaks. Free it too early and some other part of the program may still read from it, getting garbage or crashing. Free it twice and you can corrupt the allocator. These are not hypothetical bugs; they are a long-standing source of crashes and security vulnerabilities in widely used software.

Answer two: a garbage collector decides

Java, C#, Go, Python, JavaScript, and many other languages use a **garbage collector** (or reference counting, or a mix). The runtime keeps track of which pieces of memory are still reachable and frees the rest automatically. This removes most memory bugs and makes these languages pleasant to use. The cost is that a runtime component must do this bookkeeping while your program runs. For most applications that cost is perfectly acceptable. For some — an operating system kernel, firmware on a tiny device, a game engine that must produce a frame on a tight schedule, a library that other languages call into — having a separate runtime is inconvenient or impossible.

Answer three: the compiler decides

Rust's answer is different. Every value in Rust has exactly one **owner**, and when the owner goes out of scope, the value is cleaned up. The rules about who owns what, and who may temporarily **borrow** a value, are checked by the compiler at compile time. Because the checks happen before the program runs, there is no garbage collector and no extra bookkeeping at run time for these rules. The compiler simply inserts the cleanup code in the right places, much as a careful C programmer would — except that the compiler never forgets and never frees too early.

This system is called **ownership**, and the part of the compiler that enforces borrowing rules is often called the **borrow checker**. Ownership is the single most important idea in Rust, and Chapter 5 is devoted entirely to it. Chapter 6 then covers references and borrowing. You do not need to understand it yet; for now, just keep in mind that most of what makes Rust feel different flows from this one design decision.

> **NOTE**
>
> Rust does not make every bug impossible. A Rust program can still have logic errors: it can add the wrong numbers, show the wrong book, or loop forever. What Rust's safety guarantees cover is a specific, important class of problems — invalid memory access and data races — in code that does not use the `unsafe` keyword. Chapter 25 explains exactly what `unsafe` allows and why you will rarely need it.

Five Things That Make Rust Feel Different

If you come to Rust from another language, a handful of features will stand out quickly. Here is a short tour, with tiny code fragments you do not need to type in yet. We will explain each properly in later chapters.

1. Variables are immutable unless you say otherwise

In Rust, a variable declared with `let` cannot be changed after it is set. If you want to change it, you must say so with `mut`. This small rule means that when you read someone else's code, you can tell at a glance which values might change.

```
let shop_name = "Inkwell";   // cannot be reassigned
let mut stock = 6;           // can be changed
stock = stock - 1;
```

Chapter 3 covers variables, mutability, and constants in detail.

2. Errors are values you must handle

Rust has no exceptions. A function that can fail returns a `Result`, which is either `Ok` with a value or `Err` with an error. A value that might be missing is an `Option`: either `Some` value or `None`. There is no `null` that can sneak into a variable that was supposed to hold a book. The compiler makes you deal with the missing case before you can use the value.

```
fn find_price(sku: &str) -> Option<u32> {
    if sku == "INK-0001" { Some(1499) } else { None }
}
```

That fragment already shows several things we will unpack later: `&str` is a borrowed piece of text (Chapter 7), `->` introduces a return type (Chapter 4), and `Option<u32>` means "maybe a `u32`" (Chapter 9). Error handling with `Result` and the `?` operator is the subject of Chapter 12.

3. Pattern matching is everywhere

Rust's `match` expression lets you inspect a value's shape and handle each case. The compiler checks that you have covered *every* possible case, so adding a new variant to an enum shows you every place in the program that needs updating.

```
match find_price("INK-0003") {
    Some(cents) => println!("Price: {cents} cents"),
    None => println!("No such book"),
}
```

4. Zero-cost abstractions

Rust lets you write high-level code — iterators, closures, generic functions — that the compiler turns into machine code comparable to what you would write by hand with loops. The phrase people use is **zero-cost abstractions**: you do not pay at run time for the abstraction itself. This does not mean every Rust program is fast; it means that choosing a clear, high-level style does not automatically make your program slower. The mechanism is **monomorphization** and aggressive inlining by the compiler, topics we touch on in Chapters 13 and 28.

5. A complete toolchain out of the box

When you install Rust, you get `cargo`, a single tool that creates projects, downloads dependencies, builds, runs, tests, generates documentation, and formats code (with `cargo fmt`) and lints it (with `cargo clippy`). There is no need to choose between competing build systems or package managers before writing your first line. Chapter 2 walks through installing and using all of this.

If You Come From Another Language

Most readers arrive with some experience in another language. Here are short notes on what will feel familiar and what will feel strange. Skip any that do not apply to you.

- **If you come from Python or JavaScript:** Rust is statically typed and compiled ahead of time. You will declare fewer types than you might fear, because the compiler infers most of them, but every value has a fixed type that is known before the program runs. You will also notice that there is no interactive interpreter in the standard toolchain; the edit–compile–run loop replaces the REPL, and Cargo makes it quick.
- **If you come from Java or C#:** there are no classes and no inheritance. Rust uses **structs** for data, **impl blocks** for methods, and **traits** for shared behavior (Chapters 8 and 13). Traits feel a bit like interfaces, but they are more flexible. There is no garbage collector, and no `null`.
- **If you come from C or C++:** much will feel familiar at the level of memory layout, stack and heap, and performance thinking. The difference is that rules you previously enforced by discipline and code review — who frees this, can this pointer dangle, is this shared across threads — are now checked by the compiler.

> **TIP**
>
> Try to approach Rust as a new language rather than as a variant of one you already know. Readers who try to write "Java in Rust" or "Python in Rust" often fight the compiler more than they need to. When the compiler rejects something, ask what it is trying to protect you from before looking for a way around it.

Who Is Rust For?

Rust is a general-purpose language, and people use it for a wide range of work. Some common areas:

- **Command-line tools.** Rust programs compile to a single executable with no runtime to install, start quickly, and can be distributed easily. Many popular developer tools are written in Rust. This is exactly the kind of program we build in this book.
- **Web services and back ends.** With async runtimes such as Tokio and frameworks such as Axum, Rust is used for APIs and network services where predictable latency and low memory use matter. Chapter 27 builds a small API; the companion book *Rust for Backend Developers* goes much deeper.
- **Systems programming.** Operating system components, file systems, networking stacks, databases, and browsers. The Linux kernel accepts Rust for some kinds of drivers and modules.
- **Embedded devices.** Rust can run without an operating system and without a heap, which makes it suitable for microcontrollers.

Rust is not the best tool for every job. If you need a quick one-off script to rename some files, a scripting language may get you there faster. If your team already has a large, healthy codebase in another language, rewriting it in Rust is a business decision, not a technical inevitability. Rust shines when correctness, performance, and long-term maintainability matter together, and when you are willing to invest some time up front in learning its rules.

Who this book is for

This book assumes you are new to Rust. It helps if you have written a little code in any language — you know roughly what a variable, a loop, and a function are — but we explain every Rust concept from scratch. Where Rust relies on a general computing idea that not every programmer has met, such as the difference between the **stack** and the **heap**, or what a compiler actually does, Part I explains that idea briefly before building on it.

The Compiler as a Teacher

A large part of learning Rust is learning to read the compiler's messages. They are unusually detailed. A typical error tells you what went wrong, points at the exact code involved with arrows and labels, explains why it is a problem, and often suggests a fix. Here is an example of what you will see if you try to change a variable that was not declared `mut`:

```
error[E0384]: cannot assign twice to immutable variable `stock`
 --> src/main.rs:3:5
  |
2 |     let stock = 6;
  |         ----- first assignment to `stock`
3 |     stock = 5;
  |     ^^^^^^^^^ cannot assign twice to immutable variable
  |
help: consider making this binding mutable
  |
2 |     let mut stock = 6;
  |         +++
```

Look at the structure. The first line gives an error code (`E0384`) and a one-line summary. The arrow line gives the file, line, and column. The numbered lines reproduce your code with markers: dashes underline related code, carets underline the problem. The `help` section shows a concrete fix, with `+++` marking the characters to add. You can also run `rustc --explain E0384` to get a longer explanation with examples.

Throughout this book, chapters include a "Reading the compiler error" walkthrough like this one. The goal is not to memorize error codes but to build the habit of reading the whole message from top to bottom. Most beginners look only at the first line; the most useful information is often in the labels and the help text further down.

> **WARNING**
>
> Do not reach for the first fix you find online just to make an error disappear. Advice such as "add `.clone()` everywhere" or "wrap it in `unsafe`" can make code compile while hiding the real problem. When an error confuses you, slow down, read the labels, and try to restate in your own words what the compiler is protecting. The chapters on ownership, borrowing, and lifetimes give you the vocabulary to do this.

Editions, Stability, and Versions

Rust uses two related but separate ideas to evolve without breaking your code: **releases** and **editions**.

A **release** is a version of the compiler and toolchain, such as 1.85 or a later number. New stable releases arrive every six weeks. Each one is backward compatible with code written for earlier releases: if your program compiles today, it should compile on next year's compiler too. Updating is normally a single command, which you will see in Chapter 2.

An **edition** is a named set of language rules: 2015, 2018, 2021, and 2024 so far. Editions let the language make changes that would otherwise break existing code — for example, reserving a new keyword. Every crate (a Rust package) declares its edition in its `Cargo.toml` file, and crates of different

editions can be used together in the same program. A crate written for the 2018 edition keeps working on a new compiler; it just keeps the 2018 rules. New projects created with `cargo new` on a recent toolchain use the latest edition automatically.

Concept	What it is	How often it changes
Release	A compiler and toolchain version	Every six weeks
Edition	A set of language rules for a crate	Every few years
Channel	stable, beta, or nightly builds	Stable is what we use

This book uses the **2024 edition**, which became available in Rust 1.85. If you install Rust today, as Chapter 2 shows, you will get a compiler that is newer than that, and new projects will use the 2024 edition by default. Everything in this book works on stable Rust; you do not need the nightly channel.

Meet Inkwell

Learning a language through isolated examples is hard, because it is never clear how the pieces fit together. So this book follows one project from start to finish. It is set in a small independent bookshop called **Inkwell**.

Inkwell sits on a quiet street, with creaky shelves, a reading chair by the window, and a cash register older than some of its customers. It is run by **Nia**, the owner, who knows every book on the shelves but has been tracking stock in a paper notebook and a spreadsheet that nobody else understands. Nia wants a simple, reliable tool that tells her what is in stock, records sales, warns her before a popular book runs out, and produces a short report at the end of the week.

Felix is Inkwell's shop assistant. He is practical, a little impatient, and asks the questions real users ask: "What happens if I type the wrong code?" "Can it tell me what is running low?" "Why does the price say 1499 instead of $14.99?" Whenever Felix asks a question in this book, it usually points to a feature, an edge case, or a usability problem our code needs to handle.

Ravi is a friend of Nia's who is learning Rust alongside you. He has written some Python and a little JavaScript. Ravi makes the mistakes that every Rust learner makes, and we fix them together. When Ravi hits a compiler error, we read it with him.

The data we will work with

Inkwell identifies each book by an internal code called a **SKU** (stock keeping unit), such as `INK-0001`. We use SKUs rather than real ISBNs so that every identifier in the book is clearly fictional. Here are the four books that appear throughout the examples. All titles and authors are invented.

SKU	Title	Author	Price	Stock	Genre
INK-0001	The River Clock	Mara Quinn	$14.99	6	Fiction

INK-0002	Small Gardens, Big Harvests	Tomas Reyes	$22.50	2	Home
INK-0003	Night Trains of the North	Elin Sato	$18.00	0	Travel
INK-0004	A Practical Guide to Tea	Hugo Lambert	$12.95	11	Food

Notice that one book, *Night Trains of the North*, is out of stock, and another, *Small Gardens, Big Harvests*, is running low. That is deliberate: real data always contains edge cases, and our program will need to handle them gracefully.

Why money is stored as whole cents

In the table above, prices are shown as dollars and cents. Inside our program, however, we will always store money as a whole number of **cents**: *The River Clock* costs `1499`, not `14.99`. This is a deliberate design choice that many real systems make. Floating-point numbers (the kind with a decimal point) are stored in binary, and many decimal fractions such as 0.1 cannot be represented exactly. Adding prices as floating-point values can produce results like 0.30000000000000004 instead of 0.3. Integers have no such problem: 1499 plus 2250 is always exactly 3749. We only convert to a "$37.49" string when showing the value to a person. Chapter 3 introduces the integer types, and Chapter 4 writes the `format_price` function that does this conversion.

Your Roadmap: What You Will Build

The `inkwell` program grows chapter by chapter, and each stage uses the Rust features you have just learned. Here is the journey in outline.

Part	Chapters	What happens to inkwell
I — Getting Started	1–5	Create the project; store book data in variables; write helper functions
II — Core Language	6–10	Model `Book`, `Genre`, and `Inventory`; split code into modules
III — Real Programs	11–15	Store books in a `HashMap`; add error types; use iterators for reports
IV — Going Deeper	16–20	Add tests; share data safely between threads; try async
V — Practical Rust	21–25	Save to `inventory.json`; log sales to `sales.csv`; add a CLI
VI — Projects	26–28	Assemble the full CLI; expose a small read-only web API

In more concrete terms, here is what you will be able to type at the end of Chapter 26:

```
$ inkwell list
SKU       TITLE                       STOCK   PRICE
INK-0001  The River Clock                 6  $14.99
INK-0002  Small Gardens, Big Harvests     2  $22.50  (low)
INK-0003  Night Trains of the North       0  $18.00  (out)
INK-0004  A Practical Guide to Tea       11  $12.95
```

```
$ inkwell sell INK-0001 2
Sold 2 x The River Clock for $29.98. 4 left in stock.

$ inkwell sell INK-0003 1
error: "Night Trains of the North" is out of stock

$ inkwell report
Sales this week: 2 books, $29.98
```

The commands — `list`, `add`, `sell`, `restock`, and `report` — are built with the `clap` crate in Chapter 23. Books are saved between runs in a file called `inventory.json` using `serde` (Chapter 22), and every sale is appended to `sales.csv`. Along the way the core data types take shape. In Chapter 8 you will write something very close to this:

```
struct Book {
    sku: String,
    title: String,
    author: String,
    price_cents: u32,
    stock: u32,
    genre: Genre,
}
```

Do not worry about the syntax yet. The point is that by the time you see this struct, you will understand every word in it: why `sku` is a `String` rather than a `&str`, why `price_cents` is a `u32`, and what `Genre` is.

How the Inkwell code is presented

Code that belongs to the project is shown with a file caption above it, like this:

inkwell/src/main.rs

```
fn main() {
    println!("Welcome to Inkwell!");
}
```

The caption tells you which file the code lives in. When a chapter changes an existing file, it usually shows the whole function or block that changed, so you can find your place. Short snippets without a caption are standalone examples you can try in a scratch project; they are not part of `inkwell`.

How to Study With This Book

Rust rewards a particular style of learning. Here are a few habits that will make the journey smoother.

1. **Type the code yourself.** Copying and pasting is faster, but typing makes you notice details — a missing `&`, a semicolon at the end of a line, the difference between `.` and `::`. Those details matter in Rust.

2. **Break things on purpose.** When an example compiles, change one thing and see what the compiler says. Remove a `mut`. Use a variable after moving it. Pass the wrong type. Reading errors you caused deliberately is much less stressful than reading ones that surprise you.
3. **Read the full error message.** As shown above, the most useful hint is often at the bottom.
4. **Do not skip Part I and Chapter 5.** Ownership is the foundation for everything after it. Readers who rush through it tend to struggle in the middle of the book.

> **TIP**
>
> Keep a small "scratch" Cargo project next to `inkwell` for experiments. When a chapter shows a standalone snippet, paste it into the scratch project's `main` function and run it. That keeps your `inkwell` code clean and your experiments quick. Chapter 2 shows how to create one.

Common Misconceptions About Rust

Rust attracts strong opinions, and some of them reach beginners in distorted forms. Here are a few you can set aside.

"Rust is only for systems programmers"

Rust is excellent for systems work, but it is also a comfortable language for command-line tools, web services, data processing, and general application code. Its type system, pattern matching, and tooling help in any domain. This book's running example is a bookshop inventory tool precisely because ordinary business programs benefit from Rust too.

"Rust is always faster than other languages"

Rust gives you the *tools* to write fast programs: no garbage collector, control over memory layout, and abstractions that compile down to efficient code. But a poorly designed algorithm is slow in any language, and a well-written program in another language can easily outperform a careless Rust one. Performance comes from design and measurement, not from the language name. Chapter 28 introduces basic profiling and the habits that actually make programs faster.

Ravi's First Question

At the end of a slow afternoon at the shop, Ravi leans on the counter. "I've written a bit of Python," he says. "Why not just write Nia's tool in that? It would be done by Friday."

It is a fair question, and the honest answer is that a Python version would work. For a single shop with a few hundred books, almost any language would be fast enough. What Rust offers Inkwell is different: a program that, once it compiles, is much less likely to crash on a missing value or a typo in a field name; a single executable that Nia can copy to the shop computer without installing anything else; and

a codebase that Felix and future helpers can change with confidence because the compiler checks every change against every use. And for Ravi and for you, the real reason is that Inkwell is a friendly, realistic setting in which to learn a language whose ideas will change how you think about programs.

Felix, overhearing, adds his own requirement: "Whatever it is, it has to say *$14.99*, not *1499*." Noted, Felix. That is Chapter 4.

Practice

This chapter has no code to write yet, so these exercises are about building a mental model. Answer them in a notebook or a text file; brief answers follow each one.

1. **Memory strategies.** Name the three broad ways a language can decide when memory is freed, and give one advantage and one cost of each.
   Solution: Manual management (C): full control and predictability, but easy to leak or free too early. Garbage collection (Java, Python, Go): convenient and safe, but needs a runtime doing work while the program runs. Ownership checked by the compiler (Rust): safety without a garbage collector, but a stricter compiler and a learning curve.
2. **Read an error.** Look again at the `E0384` error shown in this chapter. Which line of code caused the error, which line is related to it, and what fix does the compiler suggest?
   Solution: Line 3 (`stock = 5;`) caused the error, marked with carets. Line 2 (`let stock = 6;`) is the first assignment, marked with dashes. The help suggests changing line 2 to `let mut stock = 6;`.
3. **Cents, not floats.** Felix sells one copy of *Small Gardens, Big Harvests* and two copies of *A Practical Guide to Tea*. Compute the total in cents, then write it as a dollar string.
   Solution: 2250 + 2 × 1295 = 2250 + 2590 = 4840 cents, shown as "$48.40".
4. **Edge cases.** Looking at the Inkwell table, list three situations the finished program must handle that a careless version might get wrong.
   Solution: Selling a book with stock 0 (`INK-0003`); selling more copies than are in stock (for example 3 of `INK-0002`); entering a SKU that does not exist (such as `INK-0099`). Others: a negative or zero quantity, or a price of zero.
5. **Editions.** A friend says, "If I update my compiler, my 2021-edition project will break because the new edition is 2024." Explain why this is not true.
   Solution: The edition is declared per crate in `Cargo.toml`. A new compiler still supports older editions, so a 2021-edition crate keeps compiling under 2021 rules. Changing to 2024 is a separate, deliberate step.

Key Takeaways

- Rust aims to give low-level control over memory and performance while having the compiler check that you use it safely.
- Instead of manual memory management or a garbage collector, Rust uses ownership and borrowing rules checked at compile time (Chapters 5 and 6).
- Variables are immutable by default, errors are values (`Result` , `Option`), and `match` checks that every case is handled.
- Rust ships a new stable release every six weeks; editions (2015, 2018, 2021, 2024) group larger language changes, and this book uses the 2024 edition.
- Compiler errors are detailed teachers: read the whole message, including the labels and the `help` section.
- Rust is not automatically faster or always the right choice; it shines where correctness, performance, and maintainability matter together.
- The running example is the `inkwell` inventory tool for Nia's bookshop, with money stored as integer cents and books identified by SKUs like `INK-0001` .