The Rust Programming Language

Darth-Revan

https://github.com/Darth-Revan/rust-lang_Doc-LaTeX

March 30, 2016

Contents

1 Introduction

Welcome! This book will teach you about the Rust Programming Language. Rust is a systems programming language focused on three goals: safety, speed, and concurrency. It maintains these goals without having a garbage collector, making it a useful language for a number of use cases other languages aren't good at: embedding in other languages, programs with specific space and time requirements, and writing low-level code, like device drivers and operating systems. It improves on current languages targeting this space by having a number of compile-time safety checks that produce no runtime overhead, while eliminating all data races. Rust also aims to achieve 'zero-cost abstractions' even though some of these abstractions feel like those of a high-level language. Even then, Rust still allows precise control like a low-level language would.

"The Rust Programming Language" is split into chapters. This introduction is the first. After this:

- Getting Started - Set up your computer for Rust development.
- Tutorial: Guessing Game - Learn some Rust with a small project.
- Syntax and Semantics - Each bit of Rust, broken down into small chunks.
- Effective Rust - Higher-level concepts for writing excellent Rust code.
- Nightly Rust - Cutting-edge features that aren't in stable builds yet.
- Glossary - A reference of terms used in the book.
- Bibliography - Background on Rust's influences, papers about Rust.

Contributing

The source files from which this book is generated can be found on GitHub.

2 Getting Started

This first chapter of the book will get us going with Rust and its tooling. First, we'll install Rust. Then, the classic 'Hello World' program. Finally, we'll talk about Cargo, Rust's build system and package manager.

2.1 Installing Rust

The first step to using Rust is to install it. Generally speaking, you'll need an Internet connection to run the commands in this section, as we'll be downloading Rust from the internet.

We'll be showing off a number of commands using a terminal, and those lines all start with `$`. We don't need to type in the `$`s, they are there to indicate the start of each command. We'll see many tutorials and examples around the web that follow this convention: `$` for commands run as our regular user, and `#` for commands we should be running as an administrator.

Platform support

The Rust compiler runs on, and compiles to, a great number of platforms, though not all platforms are equally supported. Rust's support levels are organized into three tiers, each with a different set of guarantees.

Platforms are identified by their "target triple" which is the string to inform the compiler what kind of output should be produced. The columns below indicate whether the corresponding component works on the specified platform.

Tier 1

Tier 1 platforms can be thought of as "guaranteed to build and work". Specifically they will each satisfy the following requirements:

- Automated testing is set up to run tests for the platform.
- Landing changes to the `rust-lang/rust` repository's master branch is gated on tests passing.
- Official release artifacts are provided for the platform.
- Documentation for how to use and how to build the platform is available.

Target	std	rustc	cargo	notes
`x86_64-pc-windows-msvc`	✓	✓	✓	64-bit MSVC (Windows 7+)
`i686-pc-windows-gnu`	✓	✓	✓	32-bit MinGW (Windows 7+)
`x86_64-pc-windows-gnu`	✓	✓	✓	64-bit MinGW (Windows 7+)
`i686-apple-darwin`	✓	✓	✓	32-bit OSX (10.7+, Lion+)
`x86_64-apple-darwin`	✓	✓	✓	64-bit OSX (10.7+, Lion+)
`i686-unkown-linux-gnu`	✓	✓	✓	32-bit Linux (2.6.18+)
`x86_64-unkown-linux-gnu`	✓	✓	✓	64-bit Linux (2.6.18+)

Tier 2

Tier 2 platforms can be thought of as "guaranteed to build". Automated tests are not run so it's not guaranteed to produce a working build, but platforms often work to quite a good degree and patches are always welcome! Specifically, these platforms are required to have each of the following:

- Automated building is set up, but may not be running tests.
- Landing changes to the `rust-lang/rust` repository's master branch is gated on platforms **building**. Note that this means for some platforms only the standard library is compiled, but for others the full bootstrap is run.
- Official release artifacts are provided for the platform.

Target	std	rustc	cargo	notes
`i686-pc-windows-msvc`	✓	✓	✓	32-bit MSVC (Windows 7+)
`x86_64-unkown-linzux-musl`	✓			64-bit Linux with MUSL
`arm-linux-androideabi`	✓			ARM Android
`arm-unkown-linux-gnueabi`	✓	✓		ARM Linux (2.6.18+)
`arm-unkown-linux-gnueabihf`	✓	✓		ARM Linux (2.6.18+)
`aarch64-unkown-linux-gnu`	✓			ARM64 Linux (2.6.18+)
`mips-unkown-linux-gnu`	✓			MIPS Linux (2.6.18+)
`mipsel-unkown-linux-gnu`	✓			MIPS (LE) Linux (2.6.18+)

Tier 3

Tier 3 platforms are those which Rust has support for, but landing changes is not gated on the platform either building or passing tests. Working builds for these platforms may be spotty as their reliability is often defined in terms of community contributions. Additionally, release artifacts and installers are not provided, but there may be community infrastructure producing these in unofficial locations.

Target	std	rustc	cargo	notes
i686-linux-android	✓			32-bit x86 Android
aarch64-linux-android	✓			ARM64 Android
powerpc-unkown-linux-gnu	✓			PowerPC Linux (2.6.18+)
i386-apple-ios	✓			32-bit x86 iOS
x86_64-apple-ios	✓			64-bit x86 iOS
armv7-apple-ios	✓			ARM iOS
armv7s-apple-ios	✓			ARM iOS
aarch64-apple-ios	✓			ARM64 iOS
i686-unkown-freebsd	✓	✓		32-bit FreeBSD
x86_64-unkown-freebsd	✓	✓		64-bit FreeBSD
x86_64-unkown-openbsd	✓	✓		64-bit OpenBSD
x86_64-unkown-netbsd	✓	✓		64-bit NetBSD
x86_64-unkown-bitrig	✓	✓		64-bit Bitrig
x86_64-unkown-dragonfly	✓	✓		64-bit DragonFlyBSD
x86_64-rumprun-netbsd	✓			64-bit NetBDS Rump Kernel
i686-pc-windows-msvc (XP)	✓			Windows XP support
x86_64-pc-windows-msvc (XP)	✓			Windows XP support

Note that this table can be expanded over time, this isn't the exhaustive set of tier 3 platforms that will ever be!

Installing on Linux or Mac

If we're on Linux or a Mac, all we need to do is open a terminal and type this:

```
$ curl -sSf https://static.rust-lang.org/rustup.sh | sh
```

This will download a script, and stat the installation. If it all goes well, you'll see this appear:

```
Welcome to Rust.

This script will download the Rust compiler and its package manager,
Cargo, and install them to /usr/local. You may install elsewhere by
running this script with the --prefix=<path> option.

The installer will run under 'sudo' and may ask you for your password.
If you do not want the script to run 'sudo' then pass it the
--disable-sudo flag.

You may uninstall later by running /usr/local/lib/rustlib/uninstall.sh,
or by running this script again with the --uninstall flag.

Continue? (y/N)
```

From here, press `y` for 'yes', and then follow the rest of the prompts.

Installing on Windows

If you're on Windows, please download the appropriate installer.

Uninstalling

Uninstalling Rust is as easy as installing it. On Linux or Mac, run the uninstall script:

```
$ sudo /usr/local/lib/rustlib/uninstall.sh
```

If we used the Windows installer, we can re-run the `.msi` and it will give us an uninstall option.

Troubleshooting

If we've got Rust installed, we can open up a shell, and type this:

```
$ rustc --version
```

You should see the version number, commit hash, and commit date.

If you do, Rust has been installed successfully! Congrats!

If you don't and you're on Windows, check that Rust is in your %PATH% system variable. If it isn't, run the installer again, select "Change" on the "Change, repair, or remove installation" page and ensure "Add to PATH" is installed on the local hard drive.

If not, there are a number of places where we can get help. The easiest is the #rust IRC channel on irc.mozilla.org, which we can access through Mibbit. Click that link, and we'll be chatting with other Rustaceans (a silly nickname we call ourselves) who can help us out. Other great resources include the user's forum, and Stack Overflow.

This installer also installs a copy of the documentation locally, so we can read it offline. On UNIX systems, `/usr/local/share/doc/rust` is the location. On Windows, it's in a `share/doc directory`, inside the directory to which Rust was installed.

2.2 Hello, World!

Now that you have Rust installed, we'll help you write your first Rust program. It's traditional when learning a new language to write a little program to print the text "Hello, world!" to the screen, and in this section, we'll follow that tradition.

The nice thing about starting with such a simple program is that you can quickly verify that your compiler is installed, and that it's working properly. Printing information to the screen is also a pretty common thing to do, so practicing it early on is good.

> Note: This book assumes basic familiarity with the command line. Rust itself makes no specific demands about your editing, tooling, or where your code lives, so if you prefer an IDE to the command line, that's an option. You may want to check out SolidOak, which was built specifically with Rust in mind. There are a number of extensions in development by the community, and the Rust team ships plugins for various editors. Configuring your editor or IDE is out of the scope of this tutorial, so check the documentation for your specific setup.

Creating a Project File

First, make a file to put your Rust code in. Rust doesn't care where your code lives, but for this book, I suggest making a *projects* directory in your home directory, and keeping all your projects there. Open a terminal and enter the following commands to make a directory for this particular project:

```
$ mkdir ~/projects
$ cd ~/projects
$ mkdir hello_world
$ cd hello_world
```

> Note: If you're on Windows and not using PowerShell, the may not work. Consult the documentation for your shell for more details.

Writing and Running a Rust Program

Next, make a new source file and call it *main.rs*. Rust files always end in a *.rs* extension. If you're using more than one word in your filename, use an underscore to separate them; for example, you'd use *hello_world.rs* rather than *helloworld.rs*.

Now open the main.rs file you just created, and type the following code:

```rust
fn main() {
    println!("Hello, world!");
}
```

Save the file, and go back to your terminal window. On Linux or OSX, enter the following commands:

```
$ rustc main.rs
$ ./main
Hello, world!
```

In Windows, replace `main` with `main.exe`. Regardless of your operating system, you should see the string `Hello, world!` print to the terminal. If you did, then congratulations! You've officially written a Rust program. That makes you a Rust programmer! Welcome.

Anatomy of a Rust Program

Now, let's go over what just happened in your "Hello, world!" program in detail. Here's the first piece of the puzzle:

```
fn main() {

}
```

These lines define a *function* in Rust. The `main` function is special: it's the beginning of every Rust program. The first line says, "I'm declaring a function named `main` that takes no arguments and returns nothing." If there were arguments, they would go inside the parentheses (`(` and `)`), and because we aren't returning anything from this function, we can omit the return type entirely.

Also note that the function body is wrapped in curly braces (`{` and `}`). Rust requires these around all function bodies. It's considered good style to put the opening curly brace on the same line as the function declaration, with one space in between.

Inside the `main()` function:

```
println!("Hello, world!");
```

This line does all of the work in this little program: it prints text to the screen. There are a number of details that are important here. The first is that it's indented with four spaces, not tabs.

The second important part is the `println!()` line. This is calling a Rust *macro*, which is how metaprogramming is done in Rust. If it were calling a function instead, it would look like this: `println()` (without the !). We'll discuss Rust macros in more detail later, but for now you only need to know that when you see a `!` that means that you're calling a macro instead of a normal function.

Next is `"Hello, world!"` which is a *string*. Strings are a surprisingly complicated topic in a systems programming language, and this is a statically allocated string. We pass this string as an argument to `println!`, which prints the string to the screen. Easy enough!

The line ends with a semicolon (`;`). Rust is an Expression-Oriented Language, which means that most things are expressions, rather than statements. The `;` indicates that this expression is over, and the next one is ready to begin. Most lines of Rust code end with a `;`.

Compiling and Running are Separate Steps

In "Writing and Running a Rust Program", we showed you how to run a newly created program. We'll break that process down and examine each step now.

Before running a Rust program, you have to compile it. You can use the Rust compiler by entering the `rustc` command and passing it the name of your source file, like this:

```
$ rustc main.rs
```

If you come from a C or C++ background, you'll notice that this is similar to `gcc` or `clang`. After compiling successfully, Rust should output a binary executable, which you can see on Linux or OSX by entering the `ls` command in your shell as follows:

```
$ ls
main main.rs
```

On Windows, you'd enter:

```
$ dir
main.exe main.rs
```

This shows we have two files: the source code, with an `.rs` extension, and the executable (`main.exe` on Windows, `main` everywhere else). All that's left to do from here is run the `main` or `main.exe` file, like this:

```
$./main  # or main.exe on Windows
```

If *main.rs* were your "Hello, world!" program, this would print `Hello, world!` to your terminal.

If you come from a dynamic language like Ruby, Python, or JavaScript, you may not be used to compiling and running a program being separate steps. Rust is an *ahead-of-time compiled* language, which means that you can compile a program, give it to someone else, and they can run it even without Rust installed. If you give someone a `.rb` or `.py` or `.js` file, on the other hand, they need to have a Ruby, Python, or JavaScript implementation installed (respectively), but you only need one command to both compile and run your program. Everything is a tradeoff in language design.

Just compiling with `rustc` is fine for simple programs, but as your project grows, you'll want to be able to manage all of the options your project has, and make it easy to share your code with other people and projects. Next, I'll introduce you to a tool called Cargo, which will help you write real-world Rust programs.

2.3 Hello, Cargo!

Cargo is Rust's build system and package manager, and Rustaceans use Cargo to manage their Rust projects. Cargo manages three things: building your code, downloading the libraries your code depends on, and building those libraries. We call libraries your code needs 'dependencies' since your code depends on them.

The simplest Rust programs don't have any dependencies, so right now, you'd only use the first part of its functionality. As you write more complex Rust programs, you'll want to add dependencies, and if you start off using Cargo, that will be a lot easier to do.

As the vast, vast majority of Rust projects use Cargo, we will assume that you're using it for the rest of the book. Cargo comes installed with Rust itself, if you used the official installers. If you installed Rust through some other means, you can check if you have Cargo installed by typing:

```
$ cargo --version
```

into a terminal. If you see a version number, great! If you see an error like '`command not found`', then you should look at the documentation for the system in which you installed Rust, to determine if Cargo is separate.

Converting to Cargo

Let's convert the Hello World program to Cargo. To Cargo-fy a project, you need to do three things:

1. Put your source file in the right directory.
2. Get rid of the old executable (`main.exe` on Windows, `main` everywhere else) and make a new one.
3. Make a Cargo configuration file.

Let's get started!

Creating a new Executable and Source Directory

First, go back to your terminal, move to your *hello_world* directory, and enter the following commands:

```
$ mkdir src
$ mv main.rs src/main.rs
$ rm main  # or 'del main.exe' on Windows
```

Cargo expects your source files to live inside a *src* directory, so do that first. This leaves the top-level project directory (in this case, *hello_world*) for READMEs, license information, and anything else not related to your code. In this way, using Cargo helps you keep your projects nice and tidy. There's a place for everything, and everything is in its place.

Now, copy *main.rs* to the *src* directory, and delete the compiled file you created with `rustc`. As usual, replace `main` with `main.exe` if you're on Windows.

This example retains `main.rs` as the source filename because it's creating an executable. If you wanted to make a library instead, you'd name the file `lib.rs`. This convention is used by Cargo to successfully compile your projects, but it can be overridden if you wish.

Creating a Configuration File

Next, create a new file inside your *hello_world* directory, and call it `Cargo.toml`.

Make sure to capitalize the `C` in *Cargo.toml*, or Cargo won't know what to do with the configuration file.

This file is in the TOML (Tom's Obvious, Minimal Language) format. TOML is similar to INI, but has some extra goodies, and is used as Cargo's configuration format.

Inside this file, type the following information:

```
[package]

name = "hello_world"
version = "0.0.1"
authors = [ "Your name <you@example.com>" ]
```

The first line, `[package]`, indicates that the following statements are configuring a package. As we add more information to this file, we'll add other sections, but for now, we only have the package configuration.

The other three lines set the three bits of configuration that Cargo needs to know to compile your program: its name, what version it is, and who wrote it.

Once you've added this information to the *Cargo.toml* file, save it to finish creating the configuration file.

Building and Running a Cargo Project

With your *Cargo.toml* file in place in your project's root directory, you should be ready to build and run your Hello World program! To do so, enter the following commands:

```
$ cargo build
   Compiling hello_world v0.0.1 (file:///home/yourname/projects/hello_world)
$ ./target/debug/hello_world
Hello, world!
```

Bam! If all goes well, `Hello, world!` should print to the terminal once more.

You just built a project with `cargo build` and ran it with `./target/debug/hello_world`, but you can actually do both in one step with `cargo` run as follows:

```
$ cargo run
     Running ‘target/debug/hello_world‘
Hello, world!
```

Notice that this example didn't re-build the project. Cargo figured out that the file hasn't changed, and so it just ran the binary. If you'd modified your source code, Cargo would have rebuilt the project before running it, and you would have seen something like this:

```
$ cargo run
   Compiling hello_world v0.0.1 (file:///home/yourname/projects/hello_world)
     Running ‘target/debug/hello_world‘
Hello, world!
```

Cargo checks to see if any of your project's files have been modified, and only rebuilds your project if they've changed since the last time you built it.

With simple projects, Cargo doesn't bring a whole lot over just using `rustc`, but it will become useful in future. This is especially true when you start using crates; these are synonymous with a 'library' or 'package' in other programming languages. For complex projects composed of multiple crates, it's much easier to let Cargo coordinate the build. Using Cargo, you can run `cargo build`, and it should work the right way.

Building for Release

When your project is finally ready for release, you can use `cargo build -release` to compile your project with optimizations. These optimizations make your Rust code run faster, but turning them on makes your program take longer to compile. This is why there are two different profiles, one for development, and one for building the final program you'll give to a user.

Running this command also causes Cargo to create a new file called *Cargo.lock*, which looks like this:

```
[root]
name = "hello_world"
version = "0.0.1"
```

Cargo uses the *Cargo.lock* file to keep track of dependencies in your application. This is the Hello World project's *Cargo.lock* file. This project doesn't have dependencies, so the file is a bit sparse. Realistically, you won't ever need to touch this file yourself; just let Cargo handle it.

That's it! If you've been following along, you should have successfully built `hello_world` with Cargo.

Even though the project is simple, it now uses much of the real tooling you'll use for the rest of your Rust career. In fact, you can expect to start virtually all Rust projects with some variation on the following commands:

```
$ git clone someurl.com/foo
$ cd foo
$ cargo build
```

Making a new Cargo Project the Easy Way

You don't have to go through that previous process every time you want to start a new project! Cargo can quickly make a bare-bones project directory that you can start developing in right away.

To start a new project with Cargo, enter `cargo new` at the command line:

```
$ cargo new hello_world --bin
```

This command passes `-bin` because the goal is to get straight to making an executable application, as opposed to a library. Executables are often called binaries (as in `/usr/bin`, if you're on a Unix system).

Cargo has generated two files and one directory for us: a `Cargo.toml` and a *src* directory with a *main.rs* file inside. These should look familliar, they're exactly what we created by hand, above.

This output is all you need to get started. First, open `Cargo.toml`. It should look something like this:

```
[package]

name = "hello_world"
version = "0.1.0"
```

```
authors = ["Your Name <you@example.com>"]
```

Cargo has populated *Cargo.toml* with reasonable defaults based on the arguments you gave it and your `git` global configuration. You may notice that Cargo has also initialized the `hello_world` directory as a `git` repository.

Here's what should be in `src/main.rs`:

```
fn main() {
    println!("Hello, world!");
}
```

Cargo has generated a "Hello World!" for you, and you're ready to start coding!

> Note: If you want to look at Cargo in more detail, check out the official Cargo guide, which covers all of its features.

2.4 Closing Thoughts

This chapter covered the basics that will serve you well through the rest of this book, and the rest of your time with Rust. Now that you've got the tools down, we'll cover more about the Rust language itself.

You have two options: Dive into a project with 'Learn Rust', or start from the bottom and work your way up with 'Syntax and Semantics'. More experienced systems programmers will probably prefer 'Learn Rust', while those from dynamic backgrounds may enjoy either. Different people learn differently! Choose whatever's right for you.

3 Tutorial: Guessing Game

Let's learn some Rust! For our first project, we'll implement a classic beginner programming problem: the guessing game. Here's how it works: Our program will generate a random integer between one and a hundred. It will then prompt us to enter a guess. Upon entering our guess, it will tell us if we're too low or too high. Once we guess correctly, it will congratulate us. Sounds good?

Along the way, we'll learn a little bit about Rust. The next chapter, 'Syntax and Semantics', will dive deeper into each part.

3.1 Set up

Let's set up a new project. Go to your projects directory. Remember how we had to create our directory structure and a `Cargo.toml` for `hello_world`? Cargo has a command that does that for us. Let's give it a shot:

```
$ cd ~/projects
$ cargo new guessing_game --bin
$ cd guessing_game
```

We pass the name of our project to `cargo new`, and then the `-bin` flag, since we're making a binary, rather than a library.

Check out the generated `Cargo.toml`:

```
[package]

name = "guessing_game"
version = "0.1.0"
authors = ["Your Name <you@example.com>"]
```

Cargo gets this information from your environment. If it's not correct, go ahead and fix that.

Finally, Cargo generated a 'Hello, world!' for us. Check out `src/main.rs`:

```
fn main() {
    println!("Hello, world!");
}
```

Let's try compiling what Cargo gave us:

```
$ cargo build
   Compiling guessing_game v0.1.0 (file:///home/you/projects/guessing_game)
```

Excellent! Open up your `src/main.rs` again. We'll be writing all of our code in this file.

Before we move on, let me show you one more Cargo command: `run`. `cargo run` is kind of like `cargo build`, but it also then runs the produced executable. Try it out:

```
$ cargo run
   Compiling guessing_game v0.1.0 (file:///home/you/projects/guessing_game)
     Running `target/debug/guessing_game`
Hello, world!
```

Great! The `run` command comes in handy when you need to rapidly iterate on a project. Our game is such a project, we need to quickly test each iteration before moving on to the next one.

3.2 Processing a Guess

Let's get to it! The first thing we need to do for our guessing game is allow our player to input a guess. Put this in your `src/main.rs`:

```
use std::io;

fn main() {
    println!("Guess the number!");

    println!("Please input your guess.");

    let mut guess = String::new();

    io::stdin().read_line(&mut guess)
        .expect("Failed to read line");

    println!("You guessed: {}", guess);
}
```

There's a lot here! Let's go over it, bit by bit.

```
use std::io;
```

We'll need to take user input, and then print the result as output. As such, we need the `io` library from the standard library. Rust only imports a few things by default into every program, the 'prelude'. If it's not in the prelude, you'll have to `use` it directly. There is also a second 'prelude', the io prelude, which serves a similar function: you import it, and it imports a number of useful, `io`-related things.

```
fn main() {
```

As you've seen before, the `main()` function is the entry point into your program. The `fn` syntax declares a new function, the `()`s indicate that there are no arguments, and `{` starts the body of the function. Because we didn't include a return type, it's assumed to be `()`, an empty tuple.

```
    println!("Guess the number!");

    println!("Please input your guess.");
```

We previously learned that `println!()` is a macro that prints a string to the screen.

```
    let mut guess = String::new();
```

Now we're getting interesting! There's a lot going on in this little line. The first thing to notice is that this is a let statement, which is used to create 'variable bindings'. They take this form:

```
let foo = bar;
```

This will create a new binding named `foo`, and bind it to the value `bar`. In many languages, this is called a 'variable', but Rust's variable bindings have a few tricks up their sleeves.

For example, they're immutable by default. That's why our example uses `mut`: it makes a binding mutable, rather than immutable. `let` doesn't take a name on the left hand side of the assignment, it actually accepts a 'pattern'. We'll use patterns later. It's easy enough to use for now:

```
let foo = 5; // immutable.
let mut bar = 5; // mutable
```

Oh, and `//` will start a comment, until the end of the line. Rust ignores everything in comments.

So now we know that `let mut guess` will introduce a mutable binding named `guess`, but we have to look at the other side of the `=` for what it's bound to: `String::new()`.

`String` is a string type, provided by the standard library. A String is a growable, UTF-8 encoded bit of text.

The `::new()` syntax uses `::` because this is an 'associated function' of a particular type. That is to say, it's associated with `String` itself, rather than a particular instance of a `String`. Some languages call this a 'static method'.

This function is named `new()`, because it creates a new, empty `String`. You'll find a `new()` function on many types, as it's a common name for making a new value of some kind.

Let's move forward:

```
    io::stdin().read_line(&mut guess)
        .expect("Failed to read line");
```

That's a lot more! Let's go bit-by-bit. The first line has two parts. Here's the first:

```
io::stdin()
```

Remember how we used `std::io` on the first line of the program? We're now calling an associated function on it. If we didn't `use std::io`, we could have written this line as `std::io::stdin()`.

This particular function returns a handle to the standard input for your terminal. More specifically, a std::io::Stdin.

The next part will use this handle to get input from the user:

```
.read_line(&mut guess)
```

Here, we call the read_line() method on our handle. Methods are like associated functions, but are only available on a particular instance of a type, rather than the type itself. We're also passing one argument to `read_line(): &mut guess`.

Remember how we bound `guess` above? We said it was mutable. However, `read_line` doesn't take a `String` as an argument: it takes a `&mut String`. Rust has a feature called 'references', which allows you to have multiple references to one piece of data, which can reduce copying. References are a complex feature, as one of Rust's major selling points is how safe and easy it is to use references. We don't need to know a lot of those details to finish our program right now, though. For now, all we need to know is that like `let` bindings, references are immutable by default. Hence, we need to write `&mut guess`, rather than `&guess`.

Why does `read_line()` take a mutable reference to a string? Its job is to take what the user types into standard input, and place that into a string. So it takes that string as an argument, and in order to add the input, it needs to be mutable.

But we're not quite done with this line of code, though. While it's a single line of text, it's only the first part of the single logical line of code:

```
        .expect("Failed to read line");
```

When you call a method with the `.foo()` syntax, you may introduce a newline and other whitespace. This helps you split up long lines. We *could* have done:

```
    io::stdin().read_line(&mut guess).expect("failed to read line");
```

But that gets hard to read. So we've split it up, three lines for three method calls. We already talked about `read_line()`, but what about `expect()`? Well, we already mentioned that `read_line()` puts what the user types into the `&mut String` we pass it. But it also returns a value: in this case, an io::Result. Rust has a number of types named `Result` in its standard library: a generic Result, and then specific versions for sub-libraries, like `io::Result`.

The purpose of these `Result` types is to encode error handling information. Values of the `Result` type, like any type, have methods defined on them. In this case, `io::Result` has an expect() method that takes a value it's called on, and if it isn't a successful one, panic!s with a message you passed it. A `panic!` like this will cause our program to crash, displaying the message.

If we leave off calling these two methods, our program will compile, but we'll get a warning:

```
$ cargo build
   Compiling guessing_game v0.1.0 (file:///home/you/projects/guessing_game)
src/main.rs:10:5: 10:39 warning: unused result which must be used,
#[warn(unused_must_use)] on by default
src/main.rs:10     io::stdin().read_line(&mut guess);
                   ^~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
```

Rust warns us that we haven't used the `Result` value. This warning comes from a special annotation that `io::Result` has. Rust is trying to tell you that you haven't handled a possible error. The right way to suppress the error is to actually write error handling. Luckily, if we want to crash if there's a problem, we can use these two little methods. If we can recover from the error somehow, we'd do something else, but we'll save that for a future project.

There's only one line of this first example left:

```
    println!("You guessed: {}", guess);
}
```

This prints out the string we saved our input in. The `{}`s are a placeholder, and so we pass it `guess` as an argument. If we had multiple `{}`s, we would pass multiple arguments:

```
let x = 5;
let y = 10;

println!("x and y: {} and {}", x, y);
```

Easy.

Anyway, that's the tour. We can run what we have with `cargo run`:

```
$ cargo run
   Compiling guessing_game v0.1.0 (file:///home/you/projects/guessing_game)
     Running ‘target/debug/guessing_game‘
Guess the number!
Please input your guess.
6
You guessed: 6
```

All right! Our first part is done: we can get input from the keyboard, and then print it back out.

3.3 Generating a secret number

Next, we need to generate a secret number. Rust does not yet include random number functionality in its standard library. The Rust team does, however, provide a rand crate. A ‘crate’ is a package of Rust code. We’ve been building a ‘binary crate’, which is an executable. `rand` is a ‘library crate’, which contains code that’s intended to be used with other programs.

Using external crates is where Cargo really shines. Before we can write the code using `rand`, we need to modify our `Cargo.toml`. Open it up, and add these few lines at the bottom:

```
[dependencies]

rand="0.3.0"
```

The `[dependencies]` section of `Cargo.toml` is like the `[package]` section: everything that follows it is part of it, until the next section starts. Cargo uses the dependencies section to know what dependencies on external crates you have, and what versions you require. In this case, we’ve specified version `0.3.0`, which Cargo understands to be any release that’s compatible with this specific version. Cargo understands Semantic Versioning, which is a standard for writing version numbers. A bare number like above is actually shorthand for `0̂.3.0`, meaning “anything compatible with 0.3.0”. If we wanted to use only `0.3.0` exactly, we could say `rand="=0.3.0"` (note the two equal signs). And if we wanted to use the latest version we could use `*`. We could also use a range of versions. Cargo’s documentation contains more details.

Now, without changing any of our code, let’s build our project:

```
$ cargo build
    Updating registry ‘https://github.com/rust-lang/crates.io-index‘
 Downloading rand v0.3.8
 Downloading libc v0.1.6
   Compiling libc v0.1.6
   Compiling rand v0.3.8
```

```
   Compiling guessing_game v0.1.0 (file:///home/you/projects/guessing_game)
```

(You may see different versions, of course.)

Lots of new output! Now that we have an external dependency, Cargo fetches the latest versions of everything from the registry, which is a copy of data from Crates.io. Crates.io is where people in the Rust ecosystem post their open source Rust projects for others to use.

After updating the registry, Cargo checks our `[dependencies]` and downloads any we don't have yet. In this case, while we only said we wanted to depend on `rand`, we've also grabbed a copy of `libc`. This is because `rand` depends on `libc` to work. After downloading them, it compiles them, and then compiles our project.

If we run `cargo build` again, we'll get different output:

```
$ cargo build
```

That's right, no output! Cargo knows that our project has been built, and that all of its dependencies are built, and so there's no reason to do all that stuff. With nothing to do, it simply exits. If we open up `src/main.rs` again, make a trivial change, and then save it again, we'll only see one line:

```
$ cargo build
   Compiling guessing_game v0.1.0 (file:///home/you/projects/guessing_game)
```

So, we told Cargo we wanted any `0.3.x` version of `rand`, and so it fetched the latest version at the time this was written, `v0.3.8`. But what happens when next week, version `v0.3.9` comes out, with an important bugfix? While getting bugfixes is important, what if `0.3.9` contains a regression that breaks our code?

The answer to this problem is the `Cargo.lock` file you'll now find in your project directory. When you build your project for the first time, Cargo figures out all of the versions that fit your criteria, and then writes them to the `Cargo.lock` file. When you build your project in the future, Cargo will see that the `Cargo.lock` file exists, and then use that specific version rather than do all the work of figuring out versions again. This lets you have a repeatable build automatically. In other words, we'll stay at `0.3.8` until we explicitly upgrade, and so will anyone who we share our code with, thanks to the lock file.

What about when we do want to use `v0.3.9`? Cargo has another command, `update`, which says 'ignore the lock, figure out all the latest versions that fit what we've specified. If that works, write those versions out to the lock file'. But, by default, Cargo will only look for versions larger than `0.3.0` and smaller than `0.4.0`. If we want to move to

`0.4.x`, we'd have to update the `Cargo.toml` directly. When we do, the next time we `cargo build`, Cargo will update the index and re-evaluate our `rand` requirements.

There's a lot more to say about Cargo and its ecosystem, but for now, that's all we need to know. Cargo makes it really easy to re-use libraries, and so Rustaceans tend to write smaller projects which are assembled out of a number of sub-packages.

Let's get on to actually *using* `rand`. Here's our next step:

```
extern crate rand;

use std::io;
use rand::Rng;

fn main() {
    println!("Guess the number!");

    let secret_number = rand::thread_rng().gen_range(1, 101);

    println!("The secret number is: {}", secret_number);

    println!("Please input your guess.");

    let mut guess = String::new();

    io::stdin().read_line(&mut guess)
        .expect("failed to read line");

    println!("You guessed: {}", guess);
}
```

The first thing we've done is change the first line. It now says `extern crate rand`. Because we declared `rand` in our `[dependencies]`, we can use `extern crate` to let Rust know we'll be making use of it. This also does the equivalent of a `use rand`; as well, so we can make use of anything in the `rand` crate by prefixing it with `rand::`.

Next, we added another `use` line: `use rand::Rng`. We're going to use a method in a moment, and it requires that `Rng` be in scope to work. The basic idea is this: methods are defined on something called 'traits', and for the method to work, it needs the trait to be in scope. For more about the details, read the traits section.

There are two other lines we added, in the middle:

```
    let secret_number = rand::thread_rng().gen_range(1, 101);

    println!("The secret number is: {}", secret_number);
```

We use the `rand::thread_rng()` function to get a copy of the random number generator, which is local to the particular thread of execution we're in. Because we `use` `rand::Rng`'d above, it has a `gen_range()` method available. This method takes two arguments, and generates a number between them. It's inclusive on the lower bound, but exclusive on the upper bound, so we need 1 and 101 to get a number ranging from one to a hundred.

The second line prints out the secret number. This is useful while we're developing our program, so we can easily test it out. But we'll be deleting it for the final version. It's not much of a game if it prints out the answer when you start it up!

Try running our new program a few times:

```
$ cargo run
   Compiling guessing_game v0.1.0 (file:///home/you/projects/guessing_game)
     Running `target/debug/guessing_game`
Guess the number!
The secret number is: 7
Please input your guess.
4
You guessed: 4
$ cargo run
     Running `target/debug/guessing_game`
Guess the number!
The secret number is: 83
Please input your guess.
5
You guessed: 5
```

Great! Next up: comparing our guess to the secret number.

3.4 Comparing guesses

Now that we've got user input, let's compare our guess to the secret number. Here's our next step, though it doesn't quite compile yet:

```
extern crate rand;

use std::io;
use std::cmp::Ordering;
use rand::Rng;

fn main() {
    println!("Guess the number!");

    let secret_number = rand::thread_rng().gen_range(1, 101);

    println!("The secret number is: {}", secret_number);

    println!("Please input your guess.");

    let mut guess = String::new();

    io::stdin().read_line(&mut guess)
        .expect("failed to read line");

    println!("You guessed: {}", guess);

    match guess.cmp(&secret_number) {
        Ordering::Less    => println!("Too small!"),
        Ordering::Greater => println!("Too big!"),
        Ordering::Equal   => println!("You win!"),
    }
}
```

A few new bits here. The first is another `use`. We bring a type called `std::cmp::Ordering` into scope. Then, five new lines at the bottom that use it:

```
match guess.cmp(&secret_number) {
    Ordering::Less    => println!("Too small!"),
    Ordering::Greater => println!("Too big!"),
    Ordering::Equal   => println!("You win!"),
}
```

The `cmp()` method can be called on anything that can be compared, and it takes a reference to the thing you want to compare it to. It returns the `Ordering` type we `used` earlier. We use a match statement to determine exactly what kind of `Ordering` it is. `Ordering` is an enum, short for 'enumeration', which looks like this:

```
enum Foo {
  Bar,
  Baz,
}
```

With this definition, anything of type `Foo` can be either a `Foo::Bar` or a `Foo::Baz`. We use the `::` to indicate the namespace for a particular `enum` variant.

The Ordering `enum` has three possible variants: `Less`, `Equal`, and `Greater`. The `match` statement takes a value of a type, and lets you create an 'arm' for each possible value. Since we have three types of `Ordering`, we have three arms:

```
match guess.cmp(&secret_number) {
    Ordering::Less    => println!("Too small!"),
    Ordering::Greater => println!("Too big!"),
    Ordering::Equal   => println!("You win!"),
}
```

If it's `Less`, we print `Too small!`, if it's `Greater`, `Too big!`, and if `Equal`, `You win!`. `match` is really useful, and is used often in Rust.

I did mention that this won't quite compile yet, though. Let's try it:

```
$ cargo build
   Compiling guessing_game v0.1.0 (file:///home/you/projects/guessing_game)
src/main.rs:28:21: 28:35 error: mismatched types:
 expected `&collections::string::String`,
    found `&_`
(expected struct `collections::string::String`,
    found integral variable) [E0308]
src/main.rs:28     match guess.cmp(&secret_number) {
                                   ^~~~~~~~~~~~~~
error: aborting due to previous error
Could not compile `guessing_game`.
```

Whew! This is a big error. The core of it is that we have 'mismatched types'. Rust has a strong, static type system. However, it also has type inference. When we wrote `let guess = String::new()`, Rust was able to infer that `guess` should be a `String`, and so it doesn't make us write out the type. And with our `secret_number`, there are a number of types which can have a value between one and a hundred: `i32`, a thirty-two-bit number, or `u32`, an unsigned thirty-two-bit number, or `i64`, a sixty-four-bit number or others. So far, that hasn't mattered, and so Rust defaults to an `i32`. However, here, Rust doesn't know how to compare the `guess` and the `secret_number`. They need to be the same type. Ultimately, we want to convert the `String` we read as input into a real number type, for comparison. We can do that with three more lines. Here's our new program:

```
extern crate rand;

use std::io;
use std::cmp::Ordering;
use rand::Rng;

fn main() {
    println!("Guess the number!");

    let secret_number = rand::thread_rng().gen_range(1, 101);

    println!("The secret number is: {}", secret_number);

    println!("Please input your guess.");

    let mut guess = String::new();

    io::stdin().read_line(&mut guess)
        .expect("failed to read line");

    let guess: u32 = guess.trim().parse()
        .expect("Please type a number!");

    println!("You guessed: {}", guess);

    match guess.cmp(&secret_number) {
        Ordering::Less    => println!("Too small!"),
        Ordering::Greater => println!("Too big!"),
        Ordering::Equal   => println!("You win!"),
    }
}
```

The new three lines:

```
    let guess: u32 = guess.trim().parse()
        .expect("Please type a number!");
```

Wait a minute, I thought we already had a `guess`? We do, but Rust allows us to 'shadow' the previous `guess` with a new one. This is often used in this exact situation, where `guess` starts as a `String`, but we want to convert it to an `u32`. Shadowing lets us re-use the `guess` name, rather than forcing us to come up with two unique names like `guess_str` and `guess`, or something else.

We bind `guess` to an expression that looks like something we wrote earlier:

```
guess.trim().parse()
```

Here, `guess` refers to the old `guess`, the one that was a `String` with our input in it. The `trim()` method on `String`s will eliminate any white space at the beginning and end of our string. This is important, as we had to press the 'return' key to satisfy

read_line(). This means that if we type 5 and hit return, guess looks like this: 5
n. The
n represents 'newline', the enter key. trim() gets rid of this, leaving our string with only the 5. The parse() method on strings parses a string into some kind of number. Since it can parse a variety of numbers, we need to give Rust a hint as to the exact type of number we want. Hence, let guess: u32. The colon (:) after guess tells Rust we're going to annotate its type. u32 is an unsigned, thirty-two bit integer. Rust has a number of built-in number types, but we've chosen u32. It's a good default choice for a small positive number.

Just like read_line(), our call to parse() could cause an error. What if our string contained A%? There'd be no way to convert that to a number. As such, we'll do the same thing we did with read_line(): use the expect() method to crash if there's an error.

Let's try our program out!

```
$ cargo run
   Compiling guessing_game v0.1.0 (file:///home/you/projects/guessing_game)
     Running 'target/guessing_game'
Guess the number!
The secret number is: 58
Please input your guess.
  76
You guessed: 76
Too big!
```

Nice! You can see I even added spaces before my guess, and it still figured out that I guessed 76. Run the program a few times, and verify that guessing the number works, as well as guessing a number too small.

Now we've got most of the game working, but we can only make one guess. Let's change that by adding loops!

3.5 Looping

The loop keyword gives us an infinite loop. Let's add that in:

```
extern crate rand;

use std::io;
use std::cmp::Ordering;
use rand::Rng;

fn main() {
    println!("Guess the number!");

    let secret_number = rand::thread_rng().gen_range(1, 101);

    println!("The secret number is: {}", secret_number);

    loop {
        println!("Please input your guess.");

        let mut guess = String::new();

        io::stdin().read_line(&mut guess)
            .expect("failed to read line");

        let guess: u32 = guess.trim().parse()
            .expect("Please type a number!");

        println!("You guessed: {}", guess);

        match guess.cmp(&secret_number) {
            Ordering::Less    => println!("Too small!"),
            Ordering::Greater => println!("Too big!"),
            Ordering::Equal   => println!("You win!"),
        }
    }
}
```

And try it out. But wait, didn't we just add an infinite loop? Yup. Remember our discussion about `parse()`? If we give a non-number answer, we'll `panic!` and quit. Observe:

```
$ cargo run
   Compiling guessing_game v0.1.0 (file:///home/you/projects/guessing_game)
     Running ‘target/guessing_game‘
Guess the number!
The secret number is: 59
Please input your guess.
45
You guessed: 45
Too small!
Please input your guess.
60
You guessed: 60
Too big!
```

```
Please input your guess.
59
You guessed: 59
You win!
Please input your guess.
quit
thread '<main>' panicked at 'Please type a number!'
```

Ha! `quit` actually quits. As does any other non-number input. Well, this is suboptimal to say the least. First, let's actually quit when you win the game:

```
extern crate rand;

use std::io;
use std::cmp::Ordering;
use rand::Rng;

fn main() {
    println!("Guess the number!");

    let secret_number = rand::thread_rng().gen_range(1, 101);

    println!("The secret number is: {}", secret_number);

    loop {
        println!("Please input your guess.");

        let mut guess = String::new();

        io::stdin().read_line(&mut guess)
            .expect("failed to read line");

        let guess: u32 = guess.trim().parse()
            .expect("Please type a number!");

        println!("You guessed: {}", guess);

        match guess.cmp(&secret_number) {
            Ordering::Less    => println!("Too small!"),
            Ordering::Greater => println!("Too big!"),
            Ordering::Equal   => {
                println!("You win!");
                break;
            }
        }
    }
}
```

By adding the `break` line after the `You win!`, we'll exit the loop when we win. Exiting the loop also means exiting the program, since it's the last thing in `main()`. We have only one more tweak to make: when someone inputs a non-number, we don't want to quit, we want to ignore it. We can do that like this:

```
extern crate rand;

use std::io;
use std::cmp::Ordering;
use rand::Rng;

fn main() {
    println!("Guess the number!");

    let secret_number = rand::thread_rng().gen_range(1, 101);

    println!("The secret number is: {}", secret_number);

    loop {
        println!("Please input your guess.");

        let mut guess = String::new();

        io::stdin().read_line(&mut guess)
            .expect("failed to read line");

        let guess: u32 = match guess.trim().parse() {
            Ok(num) => num,
            Err(_) => continue,
        };

        println!("You guessed: {}", guess);

        match guess.cmp(&secret_number) {
            Ordering::Less    => println!("Too small!"),
            Ordering::Greater => println!("Too big!"),
            Ordering::Equal   => {
                println!("You win!");
                break;
            }
        }
    }
}
```

These are the lines that changed:

```
let guess: u32 = match guess.trim().parse() {
    Ok(num) => num,
    Err(_) => continue,
};
```

This is how you generally move from 'crash on error' to 'actually handle the returned by `parse()` is an `enum` like `Ordering`, but in this case, each variant has some data associated with it: `Ok` is a success, and `Err` is a failure. Each contains more information: the successfully parsed integer, or an error type. In this case, we `match` on `Ok(num)`, which sets the inner value of the `Ok` to the name `num`, and then we return it on the right-hand side. In the `Err` case, we don't care what kind of error it is, so we use `_` instead of a name. This ignores the error, and `continue` causes us to go to the next iteration of the `loop`.

Now we should be good! Let's try:

```
$ cargo run
   Compiling guessing_game v0.1.0 (file:///home/you/projects/guessing_game)
     Running 'target/guessing_game'
Guess the number!
The secret number is: 61
Please input your guess.
10
You guessed: 10
Too small!
Please input your guess.
99
You guessed: 99
Too big!
Please input your guess.
foo
Please input your guess.
61
You guessed: 61
You win!
```

Awesome! With one tiny last tweak, we have finished the guessing game. Can you think of what it is? That's right, we don't want to print out the secret number. It was good for testing, but it kind of ruins the game. Here's our final source:

```
extern crate rand;

use std::io;
use std::cmp::Ordering;
use rand::Rng;

fn main() {
    println!("Guess the number!");

    let secret_number = rand::thread_rng().gen_range(1, 101);

    loop {
        println!("Please input your guess.");

        let mut guess = String::new();

        io::stdin().read_line(&mut guess)
            .expect("failed to read line");

        let guess: u32 = match guess.trim().parse() {
            Ok(num) => num,
            Err(_) => continue,
        };

        println!("You guessed: {}", guess);

        match guess.cmp(&secret_number) {
            Ordering::Less    => println!("Too small!"),
            Ordering::Greater => println!("Too big!"),
            Ordering::Equal   => {
                println!("You win!");
                break;
            }
        }
    }
}
```

3.6 Complete

At this point, you have successfully built the Guessing Game! Congratulations!

This first project showed you a lot: `let`, `match`, methods, associated functions, using external crates, and more. Our next project will show off even more.

4 Syntax and Semantics

This chapter breaks Rust down into small chunks, one for each concept.

If you'd like to learn Rust from the bottom up, reading this in order is a great way to do that.

These sections also form a reference for each concept, so if you're reading another tutorial and find something confusing, you can find it explained somewhere in here.

4.1 Variable Bindings

Virtually every non-'Hello World' Rust program uses *variable bindings*. They bind some value to a name, so it can be used later. `let` is used to introduce a binding, like this:

```
fn main() {
    let x = 5;
}
```

Putting `fn main() {` in each example is a bit tedious, so we'll leave that out in the future. If you're following along, make sure to edit your `main()` function, rather than leaving it off. Otherwise, you'll get an error.

Patterns

In many languages, a variable binding would be called a *variable*, but Rust's variable bindings have a few tricks up their sleeves. For example the left-hand side of a `let` expression is a 'pattern', not a variable name. This means we can do things like:

```
let (x, y) = (1, 2);
```

After this expression is evaluated, `x` will be one, and `y` will be two. Patterns are really powerful, and have their own section in the book. We don't need those features for now, so we'll keep this in the back of our minds as we go forward.

Type annotations

Rust is a statically typed language, which means that we specify our types up front, and they're checked at compile time. So why does our first example compile? Well, Rust has this thing called 'type inference'. If it can figure out what the type of something is, Rust doesn't require you to actually type it out.

We can add the type if we want to, though. Types come after a colon (`:`):

```
let x: i32 = 5;
```

If I asked you to read this out loud to the rest of the class, you'd say "`x` is a binding with the type `i32` and the value `five`."

In this case we chose to represent `x` as a 32-bit signed integer. Rust has many different primitive integer types. They begin with `i` for signed integers and u for unsigned integers. The possible integer sizes are 8, 16, 32, and 64 bits.

In future examples, we may annotate the type in a comment. The examples will look like this:

```
fn main() {
    let x = 5; // x: i32
}
```

Note the similarities between this annotation and the syntax you use with `let`. Including these kinds of comments is not idiomatic Rust, but we'll occasionally include them to help you understand what the types that Rust infers are.

Mutability

By default, bindings are *immutable*. This code will not compile:

```
let x = 5;
x = 10;
```

It will give you this error:

```
error: re-assignment of immutable variable ‘x‘
     x = 10;
     ^~~~~~~
```

If you want a binding to be mutable, you can use `mut`:

```
let mut x = 5; // mut x: i32
x = 10;
```

There is no single reason that bindings are immutable by default, but we can think about it through one of Rust's primary focuses: safety. If you forget to say `mut`, the compiler will catch it, and let you know that you have mutated something you may not have intended to mutate. If bindings were mutable by default, the compiler would not be able to tell you this. If you *did* intend mutation, then the solution is quite easy: add `mut`.

There are other good reasons to avoid mutable state when possible, but they're out of the scope of this guide. In general, you can often avoid explicit mutation, and so it is preferable in Rust. That said, sometimes, mutation is what you need, so it's not verboten.

Initializing bindings

Rust variable bindings have one more aspect that differs from other languages: bindings are required to be initialized with a value before you're allowed to use them.

Let's try it out. Change your `src/main.rs` file to look like this:

```
fn main() {
    let x: i32;

    println!("Hello world!");
}
```

You can use `cargo build` on the command line to build it. You'll get a warning, but it will still print "Hello, world!":

```
   Compiling hello_world v0.0.1 (file:///home/you/projects/hello_world)
src/main.rs:2:9: 2:10 warning: unused variable: ‘x‘, #[warn(unused_variable)]
   on by default
src/main.rs:2     let x: i32;
                      ^
```

Rust warns us that we never use the variable binding, but since we never use it, no harm, no foul. Things change if we try to actually use this `x`, however. Let's do that. Change your program to look like this:

```
fn main() {
    let x: i32;

    println!("The value of x is: {}", x);
}
```

And try to build it. You'll get an error:

```
$ cargo build
   Compiling hello_world v0.0.1 (file:///home/you/projects/hello_world)
src/main.rs:4:39: 4:40 error: use of possibly uninitialized variable: ‘x‘
src/main.rs:4     println!("The value of x is: {}", x);
                                                    ^

note: in expansion of format_args!
<std macros>:2:23: 2:77 note: expansion site
<std macros>:1:1: 3:2 note: in expansion of println!
src/main.rs:4:5: 4:42 note: expansion site
error: aborting due to previous error
Could not compile ‘hello_world‘.
```

Rust will not let us use a value that has not been initialized. Next, let's talk about this stuff we've added to `println!`.

If you include two curly braces (`{}`, some call them moustaches...) in your string to print, Rust will interpret this as a request to interpolate some sort of value. *String* *interpolation* is a computer science term that means "stick in the middle of a string." We add a comma, and then x, to indicate that we want x to be the value we're interpolating. The comma is used to separate arguments we pass to functions and macros, if you're passing more than one.

When you use the curly braces, Rust will attempt to display the value in a meaningful way by checking out its type. If you want to specify the format in a more detailed manner, there are a wide number of options available. For now, we'll stick to the default: integers aren't very complicated to print.

Scope and shadowing

Let's get back to bindings. Variable bindings have a scope - they are constrained to live in a block they were defined in. A block is a collection of statements enclosed by { and }. Function definitions are also blocks! In the following example we define two variable bindings, x and y, which live in different blocks. x can be accessed from inside the fn main() {} block, while y can be accessed only from inside the inner block:

```
fn main() {
    let x: i32 = 17;
    {
        let y: i32 = 3;
        println!("The value of x is {} and value of y is {}", x, y);
    }
    println!("The value of x is {} and value of y is {}", x, y); // This won't work
}
```

The first println! would print "The value of x is 17 and the value of y is 3", but this example cannot be compiled successfully, because the second println! cannot access the value of y, since it is not in scope anymore. Instead we get this error:

```
$ cargo build
   Compiling hello v0.1.0 (file:///home/you/projects/hello_world)
main.rs:7:62: 7:63 error: unresolved name `y`. Did you mean `x`? [E0425]
main.rs:7     println!("The value of x is {} and value of y is {}", x, y); // This won't work
                                                                       ^

note: in expansion of format_args!
<std macros>:2:25: 2:56 note: expansion site
<std macros>:1:1: 2:62 note: in expansion of print!
<std macros>:3:1: 3:54 note: expansion site
<std macros>:1:1: 3:58 note: in expansion of println!
main.rs:7:5: 7:65 note: expansion site
main.rs:7:62: 7:63 help: run `rustc --explain E0425` to see a detailed explanation
error: aborting due to previous error
Could not compile `hello`.

To learn more, run the command again with --verbose.
```

Additionally, variable bindings can be shadowed. This means that a later variable binding with the same name as another binding, that's currently in scope, will override the previous binding.

```
let x: i32 = 8;
{
    println!("{}", x); // Prints "8"
    let x = 12;
    println!("{}", x); // Prints "12"
}
println!("{}", x); // Prints "8"
let x =  42;
println!("{}", x); // Prints "42"
```

Shadowing and mutable bindings may appear as two sides of the same coin, but they are two distinct concepts that can't always be used interchangeably. For one, shadowing enables us to rebind a name to a value of a different type. It is also possible to change the mutability of a binding.

```
let mut x: i32 = 1;
x = 7;
let x = x; // x is now immutable and is bound to 7

let y = 4;
let y = "I can also be bound to text!"; // y is now of a different type
```

4.2 Functions

Every Rust program has at least one function, the `main` function:

```
fn main() {
}
```

This is the simplest possible function declaration. As we mentioned before, `fn` says 'this is a function', followed by the name, some parentheses because this function takes no arguments, and then some curly braces to indicate the body. Here's a function named `foo`:

```
fn foo() {
}
```

So, what about taking arguments? Here's a function that prints a number:

```
fn print_number(x: i32) {
  println!("x is: {}", x);
}
```

Here's a complete program that uses `print_number`:

```
fn main() {
    print_number(5);
}

fn print_number(x: i32) {
    println!("x is: {}", x);
}
```

As you can see, function arguments work very similar to `let` declarations: you add a type to the argument name, after a colon.

Here's a complete program that adds two numbers together and prints them:

```
fn main() {
    print_sum(5, 6);
}

fn print_sum(x: i32, y: i32) {
    println!("sum is: {}", x + y);
}
```

You separate arguments with a comma, both when you call the function, as well as when you declare it.

Unlike `let`, you must declare the types of function arguments. This does not work:

```
fn print_sum(x, y) {
    println!("sum is: {}", x + y);
}
```

You get this error:

```
expected one of '!', ':', or '@', found ')'
fn print_number(x, y) {
```

This is a deliberate design decision. While full-program inference is possible, languages which have it, like Haskell, often suggest that documenting your types explicitly is a best-practice. We agree that forcing functions to declare types while allowing for inference inside of function bodies is a wonderful sweet spot between full inference and no inference.

What about returning a value? Here's a function that adds one to an integer:

```
fn add_one(x: i32) -> i32 {
    x + 1
}
```

Rust functions return exactly one value, and you declare the type after an 'arrow', which is a dash (`-`) followed by a greater-than sign (`>`). The last line of a function determines what it returns. You'll note the lack of a semicolon here. If we added it in:

```
fn add_one(x: i32) -> i32 {
    x + 1;
}
```

We would get an error:

```
error: not all control paths return a value
fn add_one(x: i32) -> i32 {
     x + 1;
}

help: consider removing this semicolon:
     x + 1;
          ^
```

This reveals two interesting things about Rust: it is an expression-based language, and semicolons are different from semicolons in other 'curly brace and semicolon'-based languages. These two things are related.

Expressions vs. Statements

Rust is primarily an expression-based language. There are only two kinds of statements, and everything else is an expression.

So what's the difference? Expressions return a value, and statements do not. That's why we end up with 'not all control paths return a value' here: the statement `x + 1;` doesn't return a value. There are two kinds of statements in Rust: 'declaration statements' and 'expression statements'. Everything else is an expression. Let's talk about declaration statements first.

In some languages, variable bindings can be written as expressions, not statements. Like Ruby:

```
x = y = 5
```

In Rust, however, using `let` to introduce a binding is *not* an expression. The following will produce a compile-time error:

```
let x = (let y = 5); // expected identifier, found keyword 'let'
```

The compiler is telling us here that it was expecting to see the beginning of an expression, and a `let` can only begin a statement, not an expression.

Note that assigning to an already-bound variable (e.g. `y = 5`) is still an expression, although its value is not particularly useful. Unlike other languages where an assignment evaluates to the assigned value (e.g. `5` in the previous example), in Rust the value of an assignment is an empty tuple `()` because the assigned value can have only one owner, and any other returned value would be too surprising:

```
let mut y = 5;

let x = (y = 6);  // x has the value `()`, not `6`
```

The second kind of statement in Rust is the *expression statement*. Its purpose is to turn any expression into a statement. In practical terms, Rust's grammar expects statements to follow other statements. This means that you use semicolons to separate expressions from each other. This means that Rust looks a lot like most other languages that require you to use semicolons at the end of every line, and you will see semicolons at the end of almost every line of Rust code you see.

What is this exception that makes us say "almost"? You saw it already, in this code:

```
fn add_one(x: i32) -> i32 {
    x + 1
}
```

Our function claims to return an `i32`, but with a semicolon, it would return `()` instead. Rust realizes this probably isn't what we want, and suggests removing the semicolon in the error we saw before.

Early returns

But what about early returns? Rust does have a keyword for that, `return`:

```
fn foo(x: i32) -> i32 {
    return x;

    // we never run this code!
    x + 1
}
```

Using a `return` as the last line of a function works, but is considered poor style:

```
fn foo(x: i32) -> i32 {
    return x + 1;
}
```

The previous definition without `return` may look a bit strange if you haven't worked in an expression-based language before, but it becomes intuitive over time.

Diverging functions

Rust has some special syntax for 'diverging functions', which are functions that do not return:

```
fn diverges() -> ! {
    panic!("This function never returns!");
}
```

`panic!` is a macro, similar to `println!()` that we've already seen. Unlike `println!()`, `panic!()` causes the current thread of execution to crash with the given message. Because this function will cause a crash, it will never return, and so it has the type '`!`', which is read 'diverges'.

If you add a main function that calls `diverges()` and run it, you'll get some output that looks like this:

```
thread '<main>' panicked at 'This function never returns!', hello.rs:2
```

If you want more information, you can get a backtrace by setting the `RUST_BACKTRACE` environment variable:

```
$ RUST_BACKTRACE=1 ./diverges
thread '<main>' panicked at 'This function never returns!', hello.rs:2
stack backtrace:
   1:     0x7f402773a829 - sys::backtrace::write::h0942de78b6c02817K8r
   2:     0x7f402773d7fc - panicking::on_panic::h3f23f9d0b5f4c91bu9w
   3:     0x7f402773960e - rt::unwind::begin_unwind_inner::h2844b8c5e81e79558Bw
   4:     0x7f4027738893 - rt::unwind::begin_unwind::h4375279447423903650
   5:     0x7f4027738809 - diverges::h2266b4c4b850236beaa
   6:     0x7f40277389e5 - main::h19bb1149c2f00ecfBaa
   7:     0x7f402773f514 - rt::unwind::try::try_fn::h1318688347910438223 1
   8:     0x7f402773d1d8 - __rust_try
   9:     0x7f402773f201 - rt::lang_start::ha172a3ce74bb453aK5w
  10:     0x7f4027738a19 - main
  11:     0x7f402694ab44 - __libc_start_main
  12:     0x7f40277386c8 - <unknown>
  13:                0x0 - <unknown>
```

`RUST_BACKTRACE` also works with Cargo's `run` command:

```
$ RUST_BACKTRACE=1 cargo run
     Running 'target/debug/diverges'
thread '<main>' panicked at 'This function never returns!', hello.rs:2
stack backtrace:
   1:     0x7f402773a829 - sys::backtrace::write::h0942de78b6c02817K8r
   2:     0x7f402773d7fc - panicking::on_panic::h3f23f9d0b5f4c91bu9w
   3:     0x7f402773960e - rt::unwind::begin_unwind_inner::h2844b8c5e81e79558Bw
   4:     0x7f4027738893 - rt::unwind::begin_unwind::h4375279447423903650
   5:     0x7f4027738809 - diverges::h2266b4c4b850236beaa
   6:     0x7f40277389e5 - main::h19bb1149c2f00ecfBaa
   7:     0x7f402773f514 - rt::unwind::try::try_fn::h13186883479104382231
   8:     0x7f402773d1d8 - __rust_try
   9:     0x7f402773f201 - rt::lang_start::ha172a3ce74bb453aK5w
  10:     0x7f4027738a19 - main
  11:     0x7f402694ab44 - __libc_start_main
  12:     0x7f40277386c8 - <unknown>
  13:                0x0 - <unknown>
```

A diverging function can be used as any type:

```
let x: i32 = diverges();
let x: String = diverges();
```

Function pointers

We can also create variable bindings which point to functions:

```
let f: fn(i32) -> i32;
```

`f` is a variable binding which points to a function that takes an `i32` as an argument and returns an `i32`. For example:

```
fn plus_one(i: i32) -> i32 {
    i + 1
}

// without type inference
let f: fn(i32) -> i32 = plus_one;

// with type inference
let f = plus_one;
```

We can then use `f` to call the function:

```
let six = f(5);
```

4.3 Primitive Types

The Rust language has a number of types that are considered 'primitive'. This means that they're built-in to the language. Rust is structured in such a way that the standard library also provides a number of useful types built on top of these ones, as well, but these are the most primitive.

Booleans

Rust has a built in boolean type, named `bool`. It has two values, `true` and `false`:

```
let x = true;

let y: bool = false;
```

A common use of booleans is in if conditionals.

You can find more documentation for `bool`s in the standard library documentation.

char

The `char` type represents a single Unicode scalar value. You can create `char`s with a single tick: (`'`)

```
let x = 'x';
```

Unlike some other languages, this means that Rust's `char` is not a single byte, but four.

You can find more documentation for `char`s in the standard library documentation.

Numeric types

Rust has a variety of numeric types in a few categories: signed and unsigned, fixed and variable, floating-point and integer.

These types consist of two parts: the category, and the size. For example, `u16` is an unsigned type with sixteen bits of size. More bits lets you have bigger numbers.

If a number literal has nothing to cause its type to be inferred, it defaults:

```
let x = 42; // x has type i32

let y = 1.0; // y has type f64
```

Here's a list of the different numeric types, with links to their documentation in the standard library:

- i8
- i16
- i32
- i64
- u8
- u16
- u32
- u64
- isize
- usize

- f32
- f64

Let's go over them by category:

Signed and Unsigned

Integer types come in two varieties: signed and unsigned. To understand the difference, let's consider a number with four bits of size. A signed, four-bit number would let you store numbers from `-8` to `+7`. Signed numbers use "two's complement representation". An unsigned four bit number, since it does not need to store negatives, can store values from `0` to `+15`.

Unsigned types use a `u` for their category, and signed types use `i`. The `i` is for 'integer'. So `u8` is an eight-bit unsigned number, and `i8` is an eight-bit signed number.

Fixed size types

Fixed size types have a specific number of bits in their representation. Valid bit sizes are `8`, `16`, `32`, and `64`. So, `u32` is an unsigned, 32-bit integer, and `i64` is a signed, 64-bit integer.

Variable sized types

Rust also provides types whose size depends on the size of a pointer of the underlying machine. These types have 'size' as the category, and come in signed and unsigned varieties. This makes for two types: `isize` and `usize`.

Floating-point types

Rust also has two floating point types: `f32` and `f64`. These correspond to IEEE-754 single and double precision numbers.

Arrays

Like many programming languages, Rust has list types to represent a sequence of things. The most basic is the *array*, a fixed-size list of elements of the same type. By default, arrays are immutable.

```
let a = [1, 2, 3]; // a: [i32; 3]
let mut m = [1, 2, 3]; // m: [i32; 3]
```

Arrays have type `[T; N]`. We'll talk about this `T` notation in the generics section. The `N` is a compile-time constant, for the length of the array.

There's a shorthand for initializing each element of an array to the same value. In this example, each element of a will be initialized to `0`:

```
let a = [0; 20]; // a: [i32; 20]
```

You can get the number of elements in an array `a` with `a.len()`:

```
let a = [1, 2, 3];

println!("a has {} elements", a.len());
```

You can access a particular element of an array with *subscript notation*:

```
let names = ["Graydon", "Brian", "Niko"]; // names: [&str; 3]

println!("The second name is: {}", names[1]);
```

Subscripts start at zero, like in most programming languages, so the first name is `names[0]` and the second name is `names[1]`. The above example prints `The second name is:  Brian`. If you try to use a subscript that is not in the array, you will get an error: array access is bounds-checked at run-time. Such errant access is the source of many bugs in other systems programming languages.

You can find more documentation for `array`s in the standard library documentation.

Slices

A 'slice' is a reference to (or "view" into) another data structure. They are useful for allowing safe, efficient access to a portion of an array without copying. For example, you might want to reference only one line of a file read into memory. By nature, a slice is not created directly, but from an existing variable binding. Slices have a defined length, can be mutable or immutable.

Slicing syntax

You can use a combo of `&` and `[]` to create a slice from various things. The `&` indicates that slices are similar to references, which we will cover in detail later in this section. The `[]`s, with a range, let you define the length of the slice:

```
let a = [0, 1, 2, 3, 4];
let complete = &a[..]; // A slice containing all of the elements in a
let middle = &a[1..4]; // A slice of a: only the elements 1, 2, and 3
```

Slices have type `&[T]`. We'll talk about that `T` when we cover generics.

You can find more documentation for slices in the standard library documentation.

str

Rust's `str` type is the most primitive string type. As an unsized type, it's not very useful by itself, but becomes useful when placed behind a reference, like `&str`. We'll elaborate further when we cover Strings and references.

You can find more documentation for `str` in the standard library documentation.

Tuples

A tuple is an ordered list of fixed size. Like this:

```
let x = (1, "hello");
```

The parentheses and commas form this two-length tuple. Here's the same code, but with the type annotated:

```
let x: (i32, &str) = (1, "hello");
```

As you can see, the type of a tuple looks like the tuple, but with each position having a type name rather than the value. Careful readers will also note that tuples are heterogeneous: we have an `i32` and a `&str` in this tuple. In systems programming languages, strings are a bit more complex than in other languages. For now, read `&str` as a *string slice*, and we'll learn more soon.

You can assign one tuple into another, if they have the same contained types and Arity. Tuples have the same arity when they have the same length.

```
let mut x = (1, 2); // x: (i32, i32)
let y = (2, 3); // y: (i32, i32)

x = y;
```

You can access the fields in a tuple through a *destructuring let*. Here's an example:

```
let (x, y, z) = (1, 2, 3);

println!("x is {}", x);
```

Remember before when I said the left-hand side of a `let` statement was more powerful than assigning a binding? Here we are. We can put a pattern on the left-hand side of the `let`, and if it matches up to the right-hand side, we can assign multiple bindings at once. In this case, `let` "destructures" or "breaks up" the tuple, and assigns the bits to three bindings.

This pattern is very powerful, and we'll see it repeated more later.

You can disambiguate a single-element tuple from a value in parentheses with a comma:

```
(0,); // single-element tuple
(0); // zero in parentheses
```

Tuple Indexing

You can also access fields of a tuple with indexing syntax:

```
let tuple = (1, 2, 3);

let x = tuple.0;
let y = tuple.1;
let z = tuple.2;

println!("x is {}", x);
```

Like array indexing, it starts at zero, but unlike array indexing, it uses a `.`, rather than `[]`s.

You can find more documentation for tuples in the standard library documentation.

Functions

Functions also have a type! They look like this:

```
fn foo(x: i32) -> i32 { x }

let x: fn(i32) -> i32 = foo;
```

In this case, `x` is a 'function pointer' to a function that takes an `i32` and returns an `i32`.

4.4 Comments

Now that we have some functions, it's a good idea to learn about comments. Comments are notes that you leave to other programmers to help explain things about your code. The compiler mostly ignores them.

Rust has two kinds of comments that you should care about: *line comments* and *doc comments*.

```
// Line comments are anything after '//' and extend to the end of the line.

let x = 5; // this is also a line comment.

// If you have a long explanation for something, you can put line comments next
// to each other. Put a space between the // and your comment so that it's
// more readable.
```

The other kind of comment is a doc comment. Doc comments use `///` instead of `//`, and support Markdown notation inside:

```
/// Adds one to the number given.
///
/// # Examples
///
/// ```
/// let five = 5;
///
/// assert_eq!(6, add_one(5));
/// # fn add_one(x: i32) -> i32 {
/// #     x + 1
/// # }
/// ```
fn add_one(x: i32) -> i32 {
    x + 1
}
```

There is another style of doc comment, `//!`, to comment containing items (e.g. crates, modules or functions), instead of the items following it. Commonly used inside crates root (lib.rs) or modules root (mod.rs):

```
//! # The Rust Standard Library
//!
//! The Rust Standard Library provides the essential runtime
//! functionality for building portable Rust software.
```

When writing doc comments, providing some examples of usage is very, very helpful. You'll notice we've used a new macro here: `assert_eq!`. This compares two values, and `panic!`s if they're not equal to each other. It's very helpful in documentation. There's another macro, `assert!`, which `panic!`s if the value passed to it is `false`.

You can use the rustdoc tool to generate HTML documentation from these doc comments, and also to run the code examples as tests!

4.5 If

Rust's take on `if` is not particularly complex, but it's much more like the `if` you'll find in a dynamically typed language than in a more traditional systems language. So let's talk about it, to make sure you grasp the nuances.

`if` is a specific form of a more general concept, the 'branch'. The name comes from a branch in a tree: a decision point, where depending on a choice, multiple paths can be taken.

In the case of `if`, there is one choice that leads down two paths:

```
let x = 5;

if x == 5 {
    println!("x is five!");
}
```

If we changed the value of `x` to something else, this line would not print. More specifically, if the expression after the `if` evaluates to `true`, then the block is executed. If it's `false`, then it is not.

If you want something to happen in the `false` case, use an `else`:

```
let x = 5;

if x == 5 {
    println!("x is five!");
} else {
    println!("x is not five :(");
}
```

If there is more than one case, use an `else if`:

```
let x = 5;

if x == 5 {
    println!("x is five!");
} else if x == 6 {
    println!("x is six!");
} else {
    println!("x is not five or six :(");
}
```

This is all pretty standard. However, you can also do this:

```
let x = 5;

let y = if x == 5 {
    10
} else {
    15
}; // y: i32
```

Which we can (and probably should) write like this:

```
let x = 5;

let y = if x == 5 { 10 } else { 15 }; // y: i32
```

This works because `if` is an expression. The value of the expression is the value of the last expression in whichever branch was chosen. An `if` without an `else` always results in `()` as the value.

4.6 Loops

Rust currently provides three approaches to performing some kind of iterative activity. They are: `loop`, `while` and `for`. Each approach has its own set of uses.

loop

The infinite `loop` is the simplest form of loop available in Rust. Using the keyword `loop`, Rust provides a way to loop indefinitely until some terminating statement is reached. Rust's infinite `loop`s look like this:

```
loop {
    println!("Loop forever!");
}
```

while

Rust also has a `while` loop. It looks like this:

```
let mut x = 5; // mut x: i32
let mut done = false; // mut done: bool

while !done {
    x += x - 3;

    println!("{}", x);

    if x % 5 == 0 {
        done = true;
    }
}
```

`while` loops are the correct choice when you're not sure how many times you need to loop.

If you need an infinite loop, you may be tempted to write this:

```
while true {
```

However, `loop` is far better suited to handle this case:

```
loop {
```

Rust's control-flow analysis treats this construct differently than a `while true`, since we know that it will always loop. In general, the more information we can give to the compiler, the better it can do with safety and code generation, so you should always prefer `loop` when you plan to loop infinitely.

for

The `for` loop is used to loop a particular number of times. Rust's `for` loops work a bit differently than in other systems languages, however. Rust's `for` loop doesn't look like this "C-style" `for` loop:

```
for (x = 0; x < 10; x++) {
    printf( "%d\n", x );
}
```

Instead, it looks like this:

```
for x in 0..10 {
    println!("{}", x); // x: i32
}
```

In slightly more abstract terms,

```
for var in expression {
    code
}
```

The expression is an item that can be converted into an iterator using . The iterator gives back a series of elements. Each element is one iteration of the loop. That value is then bound to the name `var`, which is valid for the loop body. Once the body is over, the next value is fetched from the iterator, and we loop another time. When there are no more values, the for loop is over.

In our example, `0..10` is an expression that takes a start and an end position, and gives an iterator over those values. The upper bound is exclusive, though, so our loop will print `0` through `9`, not `10`.

Rust does not have the "C-style" `for` loop on purpose. Manually controlling each element of the loop is complicated and error prone, even for experienced C developers.

Enumerate

When you need to keep track of how many times you already looped, you can use the `.enumerate()` function.

On ranges:

```
for (i,j) in (5..10).enumerate() {
    println!("i = {} and j = {}", i, j);
}
```

Outputs:

```
i = 0 and j = 5
i = 1 and j = 6
i = 2 and j = 7
i = 3 and j = 8
i = 4 and j = 9
```

Don't forget to add the parentheses around the range.

On iterators:

```
for (linenumber, line) in lines.enumerate() {
    println!("{}: {}", linenumber, line);
}
```

Outputs:

```
0: Content of line one
1: Content of line two
2: Content of line three
3: Content of line four
```

Ending iteration early

Let's take a look at that `while` loop we had earlier:

```
let mut x = 5;
let mut done = false;

while !done {
    x += x - 3;

    println!("{}", x);

    if x % 5 == 0 {
        done = true;
    }
}
```

We had to keep a dedicated `mut` boolean variable binding, `done`, to know when we should exit out of the loop. Rust has two keywords to help us with modifying iteration: `break` and `continue`.

In this case, we can write the loop in a better way with `break`:

```
let mut x = 5;

loop {
    x += x - 3;

    println!("{}", x);

    if x % 5 == 0 { break; }
}
```

We now loop forever with `loop` and use `break` to break out early. Issuing an explicit `return` statement will also serve to terminate the loop early.

`continue` is similar, but instead of ending the loop, goes to the next iteration. This will only print the odd numbers:

```
for x in 0..10 {
    if x % 2 == 0 { continue; }

    println!("{}", x);
}
```

Loop labels

You may also encounter situations where you have nested loops and need to specify which one your `break` or `continue` statement is for. Like most other languages, by default a `break` or `continue` will apply to innermost loop. In a situation where you would like to a `break` or `continue` for one of the outer loops, you can use labels to specify which loop the `break` or `continue` statement applies to. This will only print when both `x` and `y` are odd:

```
'outer: for x in 0..10 {
    'inner: for y in 0..10 {
        if x % 2 == 0 { continue 'outer; } // continues the loop over x
        if y % 2 == 0 { continue 'inner; } // continues the loop over y
        println!("x: {}, y: {}", x, y);
    }
}
```

5 Effective Rust

6 Nightly Rust

7 Glossary

Not every Rustacean has a background in systems programming, nor in computer science, so we've added explanations of terms that might be unfamiliar.

Abstract Syntax Tree

When a compiler is compiling your program, it does a number of different things. One of the things that it does is turn the text of your program into an 'abstract syntax tree', or 'AST'. This tree is a representation of the structure of your program. For example, `2 + 3` can be turned into a tree:

```
  +
 / \
2   3
```

And `2 + (3 * 4)` would look like this:

```
  +
 / \
2   *
   / \
  3   4
```

Arity

Arity refers to the number of arguments a function or operation takes.

```rust
let x = (2, 3);
let y = (4, 6);
let z = (8, 2, 6);
```

In the example above `x` and `y` have arity 2. `z` has arity 3.

Bounds

Bounds are constraints on a type or trait. For example, if a bound is placed on the argument a function takes, types passed to that function must abide by that constraint.

DST (Dynamically Sized Type)

A type without a statically known size or alignment. (more info)

Expression

In computer programming, an expression is a combination of values, constants, variables, operators and functions that evaluate to a single value. For example, `2 + (3 * 4)` is an expression that returns the value 14. It is worth noting that expressions can have side-effects. For example, a function included in an expression might perform actions other than simply returning a value.

Expression-Oriented Language

In early programming languages, Expression and Statement were two separate syntactic categories: expressions had a value and statements did things. However, later languages blurred this distinction, allowing expressions to do things and statements to have a value. In an expression-oriented language, (nearly) every statement is an expression and therefore returns a value. Consequently, these expression statements can themselves form part of larger expressions.

Statement

In computer programming, a statement is the smallest standalone element of a programming language that commands a computer to perform an action.

8 Syntax Index

9 Bibliography

This is a reading list of material relevant to Rust. It includes prior research that has - at one time or another - influenced the design of Rust, as well as publications about Rust.

9.1 Type system

- Region based memory management in Cyclone
- Safe manual memory management in Cyclone
- Typeclasses: making ad-hoc polymorphism less ad hoc
- Macros that work together
- Traits: composable units of behavior
- Alias burying - We tried something similar and abandoned it.
- External uniqueness is unique enough
- Uniqueness and Reference Immutability for Safe Parallelism
- Region Based Memory Management

9.2 Concurrency

- Singularity: rethinking the software stack
- Language support for fast and reliable message passing in singularity OS
- Scheduling multithreaded computations by work stealing
- Thread scheduling for multiprogramming multiprocessors
- The data locality of work stealing
- Dynamic circular work stealing deque - The Chase/Lev deque
- Work-first and help-first scheduling policies for async-finish task parallelism - More general than fully-strict work stealing
- A Java fork/join calamity - critique of Java's fork/join library, particularly its application of work stealing to non-strict computation
- Scheduling techniques for concurrent systems
- Contention aware scheduling
- Balanced work stealing for time-sharing multicores

- Three layer cake for shared-memory programming
- Non-blocking steal-half work queues
- Reagents: expressing and composing fine-grained concurrency
- Algorithms for scalable synchronization of shared-memory multiprocessors
- Epoch-based reclamation.

9.3 Others

- Crash-only software
- Composing High-Performance Memory Allocators
- Reconsidering Custom Memory Allocation

9.4 Papers about Rust

- GPU Programming in Rust: Implementing High Level Abstractions in a Systems Level Language. Early GPU work by Eric Holk.
- Parallel closures: a new twist on an old idea
  - not exactly about Rust, but by nmatsakis
- Patina: A Formalization of the Rust Programming Language. Early formalization of a subset of the type system, by Eric Reed.
- Experience Report: Developing the Servo Web Browser Engine using Rust. By Lars Bergstrom.
- Implementing a Generic Radix Trie in Rust. Undergrad paper by Michael Sproul.
- Reenix: Implementing a Unix-Like Operating System in Rust. Undergrad paper by Alex Light.
- Evaluation of performance and productivity metrics of potential programming languages in the HPC environment. Bachelor's thesis by Florian Wilkens. Compares C, Go and Rust.
- Nom, a byte oriented, streaming, zero copy, parser combinators library in Rust. By Geoffroy Couprie, research for VLC.
- Graph-Based Higher-Order Intermediate Representation. An experimental IR implemented in Impala, a Rust-like language.
- Code Refinement of Stencil Codes. Another paper using Impala.

- Parallelization in Rust with fork-join and friends. Linus Farnstrand's master's thesis.
- Session Types for Rust. Philip Munksgaard's master's thesis. Research for Servo.
- Ownership is Theft: Experiences Building an Embedded OS in Rust - Amit Levy, et. al.