

Updates



23 May 2021: Now available in Indonesian thanks to [Ariandy/1kb](#).

2 April 2021: Added BuyMeACoffee link for those who would like to buy me a coffee.

1 February 2021: Now available on YouTube! Two months later: all done as of 1 April 2021 for 186 videos in total (slightly over 23 hours).

22 December 2020: mdBook can be found [here](#).

28 November 2020: Now also available in simplified Chinese thanks to [kumakichi!](#)

27 November 2021: Videos for Easy Rust are now being recorded in Korean! 한국어판 비디오도 녹화 시작!

Introduction

Rust is a new language that already has good textbooks. But sometimes its textbooks are difficult because they are for native English speakers. Many companies and people now learn Rust, and they could learn faster with a book that has easy English. This textbook is for these companies and people to learn Rust with simple English.

Rust is a language that is quite new, but already very popular. It's popular because it gives you the speed and control of C or C++ but also the memory safety of other newer languages like Python. It does this with some new ideas that are sometimes different from other languages. That means that there are some new things to learn, and you can't just "figure it out as you go along". Rust is a language that you have to think about for a while to understand. But it still looks pretty familiar if you know another language and it is made to help you write good code.

Who am I?

I am a Canadian who lives in Korea, and I wrote Easy Rust while thinking of how to make it easy for companies here to start using it. I hope that other countries that don't use English as a first language can use it too.

Writing Rust in Easy English

Rust in Easy English was written from July to August 2020, and is over 400 pages long. You can contact me here or [on LinkedIn](#) or [on Twitter](#) if you have any questions. If you see anything wrong or have a pull request to make, go ahead. Over 20 people have already helped out by fixing typos and problems in the code, so you can too. I'm not the world's best Rust expert so I always like to hear new ideas or see where I can make the book better.

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Part 1 - Rust in your browser

This book has two parts. In Part 1, you will learn as much Rust as you can just in your browser. You can actually learn almost everything you need to know without installing Rust, so Part 1 is very long. Then at the end is Part 2. It is much shorter, and is about Rust on your computer. That's where you will learn everything else you need to know that you can only do outside of a browser. Some examples are: working with files, taking user input, graphics, and personal settings. Hopefully, by the end of Part 1 you will like Rust enough that you will install it. And if you don't, no problem - Part 1 teaches you so much that you won't mind.

Rust Playground

[See this chapter on YouTube](#)

Maybe you don't want to install Rust yet, and that's okay. You can go to <https://play.rust-lang.org/> and start writing Rust without leaving your browser. You can write your code there and click Run to see the results. You can run most of the samples in this book inside the Playground in your browser. Only near the end you will see samples that go beyond what you can do in the Playground (like opening files).

Here are some tips when using the Rust Playground:

- Run your code with Run
- Change Debug to Release if you want your code to be faster. Debug: compiles faster, runs slower, contains debug information. Release: compiles slower, runs much faster, removes debug information.
- Click on Share to get a url link. You can use that to share your code if you want help. After you click share, you can click on `Open a new thread in the Rust user forum` to ask people there for help right away.
- Tools: Rustfmt will format your code nicely.
- Tools: Clippy will give you extra information about how to make your code better.
- Config: here you can change your theme to dark mode so you can work at night, and many other configurations.

If you want to install Rust, go here <https://www.rust-lang.org/tools/install> and follow the instructions. Usually you will use `rustup` to install and update Rust.

and

Sometimes the code examples in the book don't work. If an example doesn't work, it will have a  or a  in it.  is like "under construction": it means that the code is not complete. Rust needs a `fn main()` (a main function) to run, but sometimes we just want to look at small pieces of code so it won't have a `fn main()`. Those examples are correct, but need a `fn main()` for you to run them. And some code examples show you a problem that we will fix. Those ones might have a  but generate an error, and so they will have a .

Comments

See this chapter on YouTube

Comments are made for programmers to read, not the computer. It's good to write comments to help other people understand your code. It's also good to help you understand your code later. (Many people write good code but then forget why they wrote it.) To write comments in Rust you usually use `//`:

```
fn main() {  
    // Rust programs start with fn main()  
    // You put the code inside a block. It starts with { and ends with }  
    let some_number = 100; // We can write as much as we want here and the compiler  
    won't look at it  
}
```

When you do this, the compiler won't look at anything to the right of the `//`.

There is another kind of comment that you write with `/*` to start and `*/` to end. This one is useful to write in the middle of your code.

```
fn main() {  
    let some_number/*: i16*/ = 100;  
}
```

To the compiler, `let some_number/*: i16*/ = 100;` looks like `let some_number = 100;`.

The `/* */` form is also useful for very long comments over more than one line. In this example you can see that you need to write `//` for every line. But if you type `/*`, it won't stop until you finish it with `*/`.

```
fn main() {  
    let some_number = 100; /* Let me tell you  
    a little about this number.  
    It's 100, which is my favourite number.  
    It's called some_number but actually I think that... */  
  
    let some_number = 100; // Let me tell you  
    // a little about this number.  
    // It's 100, which is my favourite number.  
    // It's called some_number but actually I think that...  
}
```

Types

Rust has many types that let you work with numbers, characters, and so on. Some are simple, others are more complicated, and you can even create your own.

Primitive types

See this chapter on YouTube

Rust has simple types that are called **primitive types** (primitive = very basic). We will start with integers and `char` (characters). Integers are whole numbers with no decimal point. There are two types of integers:

- Signed integers,
 - Unsigned integers.

Signed means + (plus sign) and - (minus sign), so signed integers can be positive or negative (e.g. +8, -8). But unsigned integers can only be positive, because they do not have a sign.

The signed integers are: `i8`, `i16`, `i32`, `i64`, `i128`, and `isize`. The unsigned integers are: `u8`, `u16`, `u32`, `u64`, `u128`, and `usize`.

The number after the i or the u means the number of bits for the number, so numbers with more bits can be larger. 8 bits = one byte, so `i8` is one byte, `i64` is 8 bytes, and so on. Number types with larger sizes can hold larger numbers. For example, a `u8` can hold up to 255, but a `u16` can hold up to 65535. And a `u128` can hold up to 340282366920938463463374607431768211455.

So what is `isize` and `usize`? This means the number of bits on your type of computer. (The number of bits on your computer is called the **architecture** of your computer.) So `isize` and `usize` on a 32-bit computer is like `i32` and `u32`, and `isize` and `usize` on a 64-bit computer is like `i64` and `u64`.

There are many reasons for the different types of integers. One reason is computer performance: a smaller number of bytes is faster to process. For example, the number -10 as an `i8` is `11110110`, but as an `i128` it is

But here are some other uses:

Characters in Rust are called `char`. Every `char` has a number: the letter `A` is number 65, while the character 友 ("friend" in Chinese) is number 21451. The list of numbers is called "Unicode". Unicode uses smaller numbers for characters that are used more, like A through Z, or digits 0 through 9, or space.

```
fn main() {
    let first_letter = 'A';
    let space = ' '; // A space inside '' is also a char
    let other_language_char = 'Ӄ'; // Thanks to Unicode, other languages like Cherokee
display just fine too
    let cat_face = '😺'; // Emojis are chars too
}
```

The characters that are used most have numbers less than 256, and they can fit into a `u8`. Remember, a `u8` is 0 plus all the numbers up to 255, for 256 in total. This means that Rust can safely **cast** a `u8` into a `char`, using `as`. ("Cast `u8` as `char`" means "pretend `u8` is a `char`")

Casting with `as` is useful because Rust is very strict. It always needs to know the type, and won't let you use two different types together even if they are both integers. For example, this will not work:

```
fn main() { // main() is where Rust programs start to run. Code goes inside {} (curly brackets)

    let my_number = 100; // We didn't write a type of integer,
    // so Rust chooses i32. Rust always
    // chooses i32 for integers if you don't
    // tell it to use a different type

    println!("{}", my_number as char); // ⚠
}
```

Here is the reason:

```
error[E0604]: only `u8` can be cast as `char`, not `i32`
--> src\main.rs:3:20
  |
3 |     println!("{}", my_number as char);
  |     ^^^^^^^^^^^^^^^^^^
```

Fortunately we can easily fix this with `as`. We can't cast `i32` as a `char`, but we can cast an `i32` as a `u8`. And then we can do the same from `u8` to `char`. So in one line we use `as` to make `my_number` a `u8`, and again to make it a `char`. Now it will compile:

```
fn main() {
    let my_number = 100;
    println!("{}", my_number as u8 as char);
}
```

It prints `d` because that is the `char` in place 100.

The easier way, however, is just to tell Rust that `my_number` is a `u8`. Here's how you do it:

```
fn main() {
    let my_number: u8 = 100; // change my_number to my_number: u8
    println!("{}", my_number as char);
}
```

So those are two reasons for all the different number types in Rust. Here is another reason: `usize` is the size that Rust uses for *indexing*. (Indexing means "which item is first", "which item is second", etc.) `usize` is the best size for indexing because:

- An index can't be negative, so it needs to be a number with a `u`
- It should be big, because sometimes you need to index many things, but
- It can't be a `u64` because 32-bit computers can't use `u64`.

So Rust uses `usize` so that your computer can get the biggest number for indexing that it can read.

Let's learn some more about `char`. You saw that a `char` is always one character, and uses `' '` instead of `""`.

All `chars` use 4 bytes of memory, since 4 bytes are enough to hold any kind of character:

- Basic letters and symbols usually need 1 out of 4 bytes: a b 1 2 + - = \$ @
- Other letters like German Umlauts or accents need 2 out of 4 bytes: ä ö ü ß è é à ñ
- Korean, Japanese or Chinese characters need 3 or 4 bytes: 国 안 네

When using characters as part of a string, the string is encoded to use the least amount of memory needed for each character.

We can use `.len()` to see this for ourselves:

```
fn main() {
    println!("Size of a char: {}", std::mem::size_of::<char>()); // 4 bytes
    println!("Size of string containing 'a': {}", "a".len()); // .len() gives the size
of the string in bytes
    println!("Size of string containing 'ß': {}", "ß".len());
    println!("Size of string containing '国': {}", "国".len());
    println!("Size of string containing '𠮶': {}", "𠮶".len());
}
```

This prints:

```
Size of a char: 4
Size of string containing 'a': 1
Size of string containing 'ß': 2
Size of string containing '国': 3
Size of string containing '𠮶': 4
```

You can see that `a` is one byte, the German `ß` is two, the Japanese `国` is three, and the ancient Egyptian `𠮶` is 4 bytes.

```
fn main() {
    let slice = "Hello!";
    println!("Slice is {} bytes.", slice.len());
    let slice2 = "안녕!"; // Korean for "hi"
    println!("Slice2 is {} bytes.", slice2.len());
}
```

This prints:

```
Slice is 6 bytes.
Slice2 is 7 bytes.
```

`slice` is 6 characters in length and 6 bytes, but `slice2` is 3 characters in length and 7 bytes.

If `.len()` gives the size in bytes, what about the size in characters? We will learn about these methods later, but you can just remember that `.chars().count()` will do it. `.chars().count()` turns what you wrote into characters and then counts how many there are.

```
fn main() {
    let slice = "Hello!";
    println!("Slice is {} bytes and also {} characters.", slice.len(),
slice.chars().count());
    let slice2 = "안녕!";
    println!("Slice2 is {} bytes but only {} characters.", slice2.len(),
slice2.chars().count());
}
```

This prints:

```
Slice is 6 bytes and also 6 characters.  
Slice2 is 7 bytes but only 3 characters.
```

Type inference

[See this chapter on YouTube](#)

Type inference means that if you don't tell the compiler the type, but it can decide by itself, it will decide. The compiler always needs to know the type of the variables, but you don't always need to tell it. Actually, usually you don't need to tell it. For example, for `let my_number = 8`, `my_number` will be an `i32`. That is because the compiler chooses `i32` for integers if you don't tell it. But if you say `let my_number: u8 = 8`, it will make `my_number` a `u8`, because you told it `u8`.

So usually the compiler can guess. But sometimes you need to tell it, for two reasons:

1. You are doing something very complex and the compiler doesn't know the type you want.
2. You want a different type (for example, you want an `i128`, not an `i32`).

To specify a type, add a colon after the variable name.

```
fn main() {
    let small_number: u8 = 10;
}
```

For numbers, you can say the type after the number. You don't need a space - just type it right after the number.

```
fn main() {
    let small_number = 10u8; // 10u8 = 10 of type u8
}
```

You can also add `_` if you want to make the number easy to read.

```
fn main() {
    let small_number = 10_u8; // This is easier to read
    let big_number = 100_000_000_i32; // 100 million is easy to read with _
}
```

The `_` does not change the number. It is only to make it easy for you to read. And it doesn't matter how many `_` you use:

```
fn main() {
    let number = 0_____u8;
    let number2 = 1____6____2____4____i32;
    println!("{} , {}", number, number2);
}
```

This prints `0 , 1624`.

Floats

Floats are numbers with decimal points. `5.5` is a float, and `6` is an integer. `5.0` is also a float, and even `5` is a float.

```
fn main() {
    let my_float = 5.; // Rust sees . and knows that it is a float
}
```

But the types are not called `float`, they are called `f32` and `f64`. It is the same as integers: the number after `f` shows the number of bits. If you don't write the type, Rust will choose `f64`.

Of course, only floats of the same type can be used together. So you can't add an `f32` to an `f64`.

```
fn main() {
    let my_float: f64 = 5.0; // This is an f64
    let my_other_float: f32 = 8.5; // This is an f32

    let third_float = my_float + my_other_float; // ▲
}
```

When you try to run this, Rust will say:

```
error[E0308]: mismatched types
--> src\main.rs:5:34
 |
5 |     let third_float = my_float + my_other_float;
 |                         ^^^^^^^^^^^^^^^^^ expected `f64`, found `f32`
```

The compiler writes "expected (type), found (type)" when you use the wrong type. It reads your code like this:

```
fn main() {
    let my_float: f64 = 5.0; // The compiler sees an f64
    let my_other_float: f32 = 8.5; // The compiler sees an f32. It is a different type.
    let third_float = my_float + // You want to add my_float to something, so it must
be an f64 plus another f64. Now it expects an f64...
    let third_float = my_float + my_other_float; // ▲ but it found an f32. It can't
add them.
}
```

So when you see "expected (type), found (type)", you must find why the compiler expected a different type.

Of course, with simple numbers it is easy to fix. You can cast the `f32` to an `f64` with `as`:

```
fn main() {
    let my_float: f64 = 5.0;
    let my_other_float: f32 = 8.5;

    let third_float = my_float + my_other_float as f64; // my_other_float as f64 = use
my_other_float like an f64
}
```

Or even more simply, remove the type declarations. ("to declare a type" = "to tell Rust to use the type") Rust will choose types that can add together.

```
fn main() {
    let my_float = 5.0; // Rust will choose f64
    let my_other_float = 8.5; // Here again it will choose f64

    let third_float = my_float + my_other_float;
}
```

The Rust compiler is smart and will not choose f64 if you need f32:

```
fn main() {
    let my_float: f32 = 5.0;
    let my_other_float = 8.5; // Usually Rust would choose f64,
                            // but now it knows that you need to
                            // add it to an f32. So it chooses f32 for my_other_float too
}
```

Printing 'hello, world!'

See this chapter on YouTube: [Video 1](#), [Video 2](#)

When you start a new Rust program, it always has this code:

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

- `fn` means function,
- `main` is the function that starts the program,
- `()` means that we didn't give the function any variables to start.

`{}` is called a **code block**. This is the space where code lives.

`println!` is a **macro** that prints to the console. A **macro** is like a function that writes code for you. Macros have a `!` after them. We will learn about making macros later. For now, remember that `!` means that it is a macro.

To learn about the `;`, we will create another function. First, in `main` we will print a number 8:

```
fn main() {
    println!("Hello, world number {}", 8);
}
```

The `{}` in `println!` means "put the variable inside here". This prints `Hello, world number 8!`.

We can put more in, just like we did before:

```
fn main() {
    println!("Hello, worlds number {} and {}", 8, 9);
}
```

This prints `Hello, worlds number 8 and 9!`.

Now let's create the function.

```
fn number() -> i32 {
    8
}

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

This also prints `Hello, world number 8!`. When Rust looks at `number()` it sees a function. This function:

- Does not take anything (because it has `()`)
- Returns an `i32`. The `->` (called a "skinny arrow") shows what the function returns.

Inside the function is just `8`. Because there is no `;`, this is the value it returns. If it had a `;`, it would not return anything (it would return a `()`). Rust will not compile this if it has a `;`, because the return is `i32` and `;` returns `()`, not `i32`:

```

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

fn number() -> i32 {
    8; // ⚠
}

```

5 | fn number() -> i32 {
| ----- ^^^ expected `i32`, found `()`
| |
| implicitly returns `()` as its body has no tail or `return` expression
6 | 8;
| - help: consider removing this semicolon

This means "you told me that `number()` returns an `i32`, but you added a `;` so it doesn't return anything". So the compiler suggests removing the semicolon.

You can also write `return 8;` but in Rust it is normal to just remove the `;` to `return`.

When you want to give variables to a function, put them inside the `()`. You have to give them a name and write the type.

```

fn multiply(number_one: i32, number_two: i32) { // Two i32s will enter the function. We
    will call them number_one and number_two.
    let result = number_one * number_two;
    println!("{} times {} is {}", number_one, number_two, result);
}

fn main() {
    multiply(8, 9); // We can give the numbers directly
    let some_number = 10; // Or we can declare two variables
    let some_other_number = 2;
    multiply(some_number, some_other_number); // and put them in the function
}

```

We can also return an `i32`. Just take out the semicolon at the end:

```

fn multiply(number_one: i32, number_two: i32) -> i32 {
    let result = number_one * number_two;
    println!("{} times {} is {}", number_one, number_two, result);
    result // this is the i32 that we return
}

fn main() {
    let multiply_result = multiply(8, 9); // We used multiply() to print and to give
    the result to multiply_result
}

```

Declaring variables and code blocks

Use `let` to declare a variable (declare a variable = tell Rust to make a variable).

```

fn main() {
    let my_number = 8;
    println!("Hello, number {}", my_number);
}

```

Variables start and end inside a code block `{}`. In this example, `my_number` ends before we call `println!`, because it is inside its own code block.

```
fn main() {
{
    let my_number = 8; // my_number starts here
                       // my_number ends here!
}

    println!("Hello, number {}", my_number); // ⚠ there is no my_number and
                                              // println!() can't find it
}
```

You can use a code block to return a value:

```
fn main() {
    let my_number = {
        let second_number = 8;
        second_number + 9 // No semicolon, so the code block returns 8 + 9.
                           // It works just like a function
    };

    println!("My number is: {}", my_number);
}
```

If you add a semicolon inside the block, it will return `()` (nothing):

```
fn main() {
    let my_number = {
        let second_number = 8; // declare second_number,
        second_number + 9; // add 9 to second_number
                           // but we didn't return it!
                           // second_number dies now
    };

    println!("My number is: {:?}", my_number); // my_number is ()
}
```

So why did we write `{:?:}` and not `{}`? We will talk about that now.

Display and debug

[See this chapter on YouTube](#)

Simple variables in Rust can be printed with `{}` inside `println!`. But some variables can't, and you need to **debug print**. Debug print is printing for the programmer, because it usually shows more information. Debug sometimes doesn't look pretty, because it has extra information to help you.

How do you know if you need `{:?:}` and not `{:?}`? The compiler will tell you. For example:

```
fn main() {
    let doesnt_print = ();
    println!("This will not print: {}", doesnt_print); // ⚠
}
```

When we run this, the compiler says:

```
error[E0277]: `()` doesn't implement `std::fmt::Display`
--> src\main.rs:3:41
   |
3 |     println!("This will not print: {}", doesnt_print);
   |     ^^^^^^^^^^^^^^ `()` cannot be formatted with
the default formatter
   |
   = help: the trait `std::fmt::Display` is not implemented for `()`
   = note: in format strings you may be able to use `{:?:}` (or `{:#:?}` for pretty-print)
instead
   = note: required by `std::fmt::Display::fmt`
   = note: this error originates in a macro (in Nightly builds, run with -Z macro-
backtrace for more info)
```

This is a lot of information. But the important part is: `you may be able to use {:?:} (or {:#:?} for pretty-print) instead`. This means that you can try `{:?:}`, and also `{:#:?}`. `{:#:?}` is called "pretty printing". It is like `{:?:}` but prints with different formatting over more lines.

So Display means printing with `{:?}", and Debug means printing with {:#:?".`

One more thing: you can also use `print!` without `\n` if you don't want a new line.

```
fn main() {
    print!("This will not print a new line");
    println!(" so this will be on the same line");
}
```

This prints `This will not print a new line so this will be on the same line.`

Smallest and largest numbers

If you want to see the smallest and biggest numbers, you can use MIN and MAX after the name of the type:

```
fn main() {
    println!("The smallest i8 is {} and the biggest i8 is {}.", i8::MIN, i8::MAX); // 
hint: printing std::i8::MIN means "print MIN inside of the i8 section in the standard
library"
    println!("The smallest u8 is {} and the biggest u8 is {}.", u8::MIN, u8::MAX);
    println!("The smallest i16 is {} and the biggest i16 is {}.", i16::MIN, i16::MAX);
    println!("The smallest u16 is {} and the biggest u16 is {}.", u16::MIN, u16::MAX);
    println!("The smallest i32 is {} and the biggest i32 is {}.", i32::MIN, i32::MAX);
    println!("The smallest u32 is {} and the biggest u32 is {}.", u32::MIN, u32::MAX);
    println!("The smallest i64 is {} and the biggest i64 is {}.", i64::MIN, i64::MAX);
    println!("The smallest u64 is {} and the biggest u64 is {}.", u64::MIN, u64::MAX);
    println!("The smallest i128 is {} and the biggest i128 is {}.", i128::MIN,
i128::MAX);
    println!("The smallest u128 is {} and the biggest u128 is {}.", u128::MIN,
u128::MAX);

}
```

This will print:

```
The smallest i8 is -128 and the biggest i8 is 127.
The smallest u8 is 0 and the biggest u8 is 255.
The smallest i16 is -32768 and the biggest i16 is 32767.
The smallest u16 is 0 and the biggest u16 is 65535.
The smallest i32 is -2147483648 and the biggest i32 is 2147483647.
The smallest u32 is 0 and the biggest u32 is 4294967295.
The smallest i64 is -9223372036854775808 and the biggest i64 is 9223372036854775807.
The smallest u64 is 0 and the biggest u64 is 18446744073709551615.
The smallest i128 is -170141183460469231731687303715884105728 and the biggest i128 is
170141183460469231731687303715884105727.
The smallest u128 is 0 and the biggest u128 is 340282366920938463463374607431768211455.
```

Mutability (changing)

[See this chapter on YouTube](#)

When you declare a variable with `let`, it is immutable (cannot be changed).

This will not work:

```
fn main() {
    let my_number = 8;
    my_number = 10; // ⚠
}
```

The compiler says: `error[E0384]: cannot assign twice to immutable variable my_number`. This is because variables are immutable if you only write `let`.

But sometimes you want to change your variable. To make a variable that you can change, add `mut` after `let`:

```
fn main() {
    let mut my_number = 8;
    my_number = 10;
}
```

Now there is no problem.

However, you cannot change the type: even `mut` doesn't let you do that. This will not work:

```
fn main() {
    let mut my_variable = 8; // it is now an i32. That can't be changed
    my_variable = "Hello, world!"; // ⚠
}
```

You will see the same "expected" message from the compiler: `expected integer, found &str`. `&str` is a string type that we will learn soon.

Shadowing

[See this chapter on YouTube](#)

Shadowing means using `let` to declare a new variable with the same name as another variable. It looks like mutability, but it is completely different. Shadowing looks like this:

```
fn main() {
    let my_number = 8; // This is an i32
    println!("{}", my_number); // prints 8
    let my_number = 9.2; // This is an f64 with the same name. But it's not the first
    // my_number - it is completely different!
    println!("{}", my_number) // Prints 9.2
}
```

Here we say that we "shadowed" `my_number` with a new "let binding".

So is the first `my_number` destroyed? No, but when we call `my_number` we now get `my_number` the `f64`. And because they are in the same scope block (the same `{}`), we can't see the first `my_number` anymore.

But if they are in different blocks, we can see both. For example:

```
fn main() {
    let my_number = 8; // This is an i32
    println!("{}", my_number); // prints 8
    {
        let my_number = 9.2; // This is an f64. It is not my_number - it is completely
        // different!
        println!("{}", my_number) // Prints 9.2
        // But the shadowed my_number only lives until here.
        // The first my_number is still alive!
    }
    println!("{}", my_number); // prints 8
}
```

So when you shadow a variable, you don't destroy it. You **block** it.

So what is the advantage of shadowing? Shadowing is good when you need to change a variable a lot. Imagine that you want to do a lot of simple math with a variable:

```
fn times_two(number: i32) -> i32 {
    number * 2
}

fn main() {
    let final_number = {
        let y = 10;
        let x = 9; // x starts at 9
        let x = times_two(x); // shadow with new x: 18
        let x = x + y; // shadow with new x: 28
        x // return x: final_number is now the value of x
    };
    println!("The number is now: {}", final_number)
}
```

Without shadowing you would have to think of different names, even though you don't care about x:

```
fn times_two(number: i32) -> i32 {
    number * 2
}

fn main() {
    // Pretending we are using Rust without shadowing
    let final_number = {
        let y = 10;
        let x = 9; // x starts at 9
        let x_twice = times_two(x); // second name for x
        let x_twice_and_y = x_twice + y; // third name for x!
        x_twice_and_y // too bad we didn't have shadowing - we could have just used x
    };
    println!("The number is now: {}", final_number)
}
```

In general, you see shadowing in Rust in this case. It happens where you want to quickly take variable, do something to it, and do something else again. And you usually use it for quick variables that you don't care too much about.

The stack, the heap, and pointers

The stack, the heap, and pointers are very important in Rust.

The stack and the heap are two places to keep memory in computers. The important differences are:

- The stack is very fast, but the heap is not so fast. It's not super slow either, but the stack is always faster. But you can't just use the stack all the time, because:
- Rust needs to know the size of a variable at compile time. So simple variables like `i32` go on the stack, because we know their exact size. You always know that an `i32` is going to be 4 bytes, because 32 bits = 4 bytes. So `i32` can always go on the stack.
- But some types don't know the size at compile time. But the stack needs to know the exact size. So what do you do? First you put the data in the heap, because the heap can have any size of data. And then to find it a pointer goes on the stack. This is fine because we always know the size of a pointer. So then the computer first goes to the stack, reads the pointer, and follows it to the heap where the data is.

Pointers sound complicated, but they are easy. Pointers are like a table of contents in a book.

Imagine this book:

MY BOOK	
TABLE OF CONTENTS	
Chapter	Page
Chapter 1: My life	1
Chapter 2: My cat	15
Chapter 3: My job	23
Chapter 4: My family	30
Chapter 5: Future plans	43

So this is like five pointers. You can read them and find the information they are talking about.

Where is the chapter "My life"? It's on page 1 (it *points* to page 1). Where is the chapter "My job?" It's on page 23.

The pointer you usually see in Rust is called a **reference**. This is the important part to know: a reference points to the memory of another value. A reference means you *borrow* the value, but you don't own it. It's the same as our book: the table of contents doesn't own the information. It's the chapters that own the information. In Rust, references have a `&` in front of them. So:

- `let my_variable = 8` makes a regular variable, but
- `let my_reference = &my_variable` makes a reference.

You read `my_reference = &my_variable` like this: "my_reference is a reference to my_variable". Or: "my_reference refers to my_variable".

This means that `my_reference` is only looking at the data of `my_variable`. `my_variable` still owns its data.

You can also have a reference to a reference, or any number of references.

```
fn main() {  
    let my_number = 15; // This is an i32  
    let single_reference = &my_number; // This is a &i32  
    let double_reference = &single_reference; // This is a &&i32  
    let five_references = &&&&&my_number; // This is a &&&&&i32  
}
```

These are all different types, just in the same way that "a friend of a friend" is different from "a friend".

More about printing

In Rust you can print things in almost any way you want. Here are some more things to know about printing.

Adding `\n` will make a new line, and `\t` will make a tab:

```
fn main() {
    // Note: this is print!, not println!
    print!("Start with a tab\nand move to a new line");
}
```

This prints:

```
Start with a tab
and move to a new line
```

Inside `""` you can write over many lines with no problem, but be careful with the spacing:

```
fn main() {
    // Note: After the first line you have to start on the far left.
    // If you write directly under println!, it will add the spaces
    println!("Inside quotes
you can write over
many lines
and it will print just fine.");

    println!("If you forget to write
on the left side, the spaces
will be added when you print.");
}
```

This prints:

```
Inside quotes
you can write over
many lines
and it will print just fine.
If you forget to write
    on the left side, the spaces
        will be added when you print.
```

If you want to print characters like `\n` (called "escape characters"), you can add an extra `\`:

```
fn main() {
    println!("Here are two escape characters: \\n and \\t");
}
```

This prints:

```
Here are two escape characters: \n and \t
```

Sometimes you have too many `"` and escape characters, and want Rust to ignore everything. To do this, you can add `r#` to the beginning and `#` to the end.

```
fn main() {
    println!("He said, \"You can find the file at c:\\\\files\\\\my_documents\\\\file.txt.\"");
    Then I found the file."); // We used \ five times here
    println!(r#"He said, "You can find the file at c:\\files\\\\my_documents\\\\file.txt."#);
    Then I found the file."#)
}
```

This prints the same thing, but using `r#` makes it easier for humans to read.

```
He said, "You can find the file at c:\\files\\\\my_documents\\\\file.txt." Then I found the
file.
He said, "You can find the file at c:\\files\\\\my_documents\\\\file.txt." Then I found the
file.
```

If you need to print with a `#` inside, then you can start with `r##` and end with `##`. And if you need more than one, you can add one more `#` on each side.

Here are four examples:

```
fn main() {
    let my_string = "'Ice to see you,' he said."; // single quotes
    let quote_string = r##"Ice to see you," he said."##; // double quotes
    let hashtag_string = r###"The hashtag #IceToSeeYou had become very popular."##; // Has one # so we need at least ##
    let many_hashtags = r#####"You don't have to type ### to use a hashtag. You can just use #."####; // Has three ### so we need at least ####

    println!("{}\\n{}\\n{}\\n{}", my_string, quote_string, hashtag_string,
many_hashtags);
}
```

This will print:

```
'Ice to see you,' he said.
"Ice to see you," he said.
The hashtag #IceToSeeYou had become very popular.
"You don't have to type ### to use a hashtag. You can just use #."
```

`r#` has another use: with it you can use a keyword (words like `let`, `fn`, etc.) as a variable name.

```
fn main() {
    let r#let = 6; // The variable's name is let
    let mut r#mut = 10; // This variable's name is mut
}
```

`r#` has this function because older versions of Rust had fewer keywords than Rust now. So with `r#` you can avoid mistakes with variable names that were not keywords before.

Or maybe for some reason you *really* need a function to have a name like `return`. Then you can write this:

```
fn r#return() -> u8 {
    println!("Here is your number.");
    8
}

fn main() {
    let my_number = r#return();
    println!("{}", my_number);
}
```

This prints:

Here is your number.
8

So you probably won't need it, but if you really need to use a keyword for a variable then you can use `r#`.

If you want to print the bytes of a `&str` or a `char`, you can just write `b` before the string. This works for all ASCII characters. These are all the ASCII characters:

So when you print this:

```
fn main() {
    println!("{:?}", b"This will look like numbers");
}
```

Here is the result:

[84, 104, 105, 115, 32, 119, 105, 108, 108, 32, 108, 111, 111, 107, 32, 108, 105, 107, 101, 32, 110, 117, 109, 98, 101, 114, 115]

For a `char` this is called a *byte*, and for a `&str` it's called a *byte string*.

You can also put **b** and **r** together if you need to:

```
fn main() {
    println!("{}:{}", br##"I like to write "#".##);
}
```

That will print [73, 32, 108, 105, 107, 101, 32, 116, 111, 32, 119, 114, 105, 116, 101, 32, 34, 35, 34, 46].

There is also a Unicode escape that lets you print any Unicode character inside a string: `\u{}`. A hexadecimal number goes inside the `{}` to print it. Here is a short example of how to get the Unicode number, and how to print it again.

```
fn main() {
    println!("{:X}", '행' as u32); // Cast char as u32 to get the hexadecimal value
    println!("{:X}", 'H' as u32);
    println!("{:X}", '居' as u32);
    println!("{:X}", 'い' as u32);

    println!("{}\u{D589}, \u{48}, \u{5C45}, \u{3044}"); // Try printing them with unicode
    escape \u
}
```

We know that `println!` can print with `{}` (for Display) and `{:?:}` (for Debug), plus `{:#?}` for pretty printing. But there are many other ways to print.

For example, if you have a reference, you can use `:p` to print the *pointer address*. Pointer address means the location in your computer's memory.

```
fn main() {
    let number = 9;
    let number_ref = &number;
    println!("{:p}", number_ref);
}
```

This prints `0xe2bc0ffcf` or some other address. It might be different every time, depending on where your computer stores it.

Or you can print binary, hexadecimal and octal:

```
fn main() {
    let number = 555;
    println!("Binary: {:b}, hexadecimal: {:x}, octal: {:o}", number, number, number);
}
```

This prints `Binary: 1000101011, hexadecimal: 22b, octal: 1053`.

Or you can add numbers to change the order. The first variable will be in index 0, the next in index 1, and so on.

```
fn main() {
    let father_name = "Vlad";
    let son_name = "Adrian Farenheit";
    let family_name = "Tepeş";
    println!("This is {1} {2}, son of {0} {2}.", father_name, son_name, family_name);
}
```

`father_name` is in position 0, `son_name` is in position 1, and `family_name` is in position 2. So it prints `This is Adrian Farenheit Tepeş, son of Vlad Tepeş`.

Maybe you have a very complex string to print with too many variables inside the `{}` curly brackets. Or maybe you need to print a variable more than one time. Then it can help to add names to the `{}`:

```
fn main() {
    println!(
        "{city1} is in {country} and {city2} is also in {country},
but {city3} is not in {country}.",
        city1 = "Seoul",
        city2 = "Busan",
        city3 = "Tokyo",
        country = "Korea"
    );
}
```

That will print:

```
Seoul is in Korea and Busan is also in Korea,
but Tokyo is not in Korea.
```

Very complex printing is also possible in Rust if you want to use it. Here is how to do it:

{variable:padding alignment minimum.maximum}

To understand this, look at the

1. Do you want a variable name? Write that first, like when we wrote {country} above. (Then add a `:` after it if you want to do more things)
2. Do you want a padding character? For example, 55 with three "padding zeros" looks like 00055.
3. What alignment (left / middle / right) for the padding?
4. Do you want a minimum length? (just write a number)
5. Do you want a maximum length? (write a number with a `.` in front)

For example, if I want to write "a" with five `<` characters on the left and five `>` characters on the right:

```
fn main() {
    let letter = "a";
    println!("{:<^11}", letter);
}
```

This prints `<<<<<a>>>>>`. Let's look at 1) to 5) for this to understand how the compiler reads it.

- Do you want a variable name? `{:<^11}` There is no variable name. There is nothing before `:`.
- Do you want a padding character? `{:<^11}` Yes. `<` comes after the `:` and has a `^`. `<` means padding with the character on the left, `>` means on the right, and `^` means in the middle.
- Do you want a minimum length? `{:<^11}` Yes: there is an 11 after.
- Do you want a maximum length? `{:<^11}` No: there is no number with a `.` before.

Here is an example of many types of formatting.

```
fn main() {
    let title = "TODAY'S NEWS";
    println!("{:~^30}", title); // no variable name, pad with -, put in centre, 30
    characters long
    let bar = "|";
    println!("{: <15}{: >15}", bar, bar); // no variable name, pad with space, 15
    characters each, one to the left, one to the right
    let a = "SEOUL";
    let b = "TOKYO";
    println!("{}{}-{}{}", city1 = a, city2 = b); // variable names city1
    and city2, pad with -, one to the left, one to the right
}
```

It prints:

```
-----TODAY'S NEWS-----
|                         |
SEOUL-----TOKYO
```

Strings

[See this chapter on YouTube](#)

Rust has two main types of strings: `String` and `&str`. What is the difference?

- `&str` is a simple string. When you write `let my_variable = "Hello, world!"`, you create a `&str`. A `&str` is very fast.
- `String` is a more complicated string. It is a bit slower, but it has more functions. A `String` is a pointer, with data on the heap.

Also note that `&str` has the `&` in front of it because you need a reference to use a `str`. That's because of the reason we saw above: the stack needs to know the size. So we give it a `&` that it knows the size of, and then it is happy. Also, because you use a `&` to interact with a `str`, you don't own it. But a `String` is an *owned* type. We will soon learn why that is important to know.

Both `&str` and `String` are UTF-8. For example, you can write:

```
fn main() {
    let name = "서태지"; // This is a Korean name. No problem, because a &str is UTF-8.
    let other_name = String::from("Adrian Farenheit Tepeş"); // Ł and ş are no problem
    in UTF-8.
}
```

You can see in `String::from("Adrian Farenheit Tepeş")` that it is easy to make a `String` from a `&str`. The two types are very closely linked together, even though they are different.

You can even write emojis, thanks to UTF-8.

```
fn main() {
    let name = "😊";
    println!("My name is actually {}", name);
}
```

On your computer that will print `My name is actually 😊` unless your command line can't print it. Then it will show `My name is actually ♦`. But Rust has no problem with emojis or any other Unicode.

Let's look at the reason for using a `&` for `str`s again to make sure we understand.

- `str` is a dynamically sized type (dynamically sized = the size can be different). For example, the names "서태지" and "Adrian Farenheit Tepeş" are not the same size:

```
fn main() {
    println!("A String is always {:?} bytes. It is Sized.", std::mem::size_of::<String>());
    // std::mem::size_of::<Type>() gives you the size in bytes of a type
    println!("And an i8 is always {:?} bytes. It is Sized.", std::mem::size_of::<i8>());
    println!("And an f64 is always {:?} bytes. It is Sized.", std::mem::size_of::<f64>());
    println!("But a &str? It can be anything. '서태지' is {:?} bytes. It is not Sized.",
    std::mem::size_of_val("서태지")); // std::mem::size_of_val() gives you the size in bytes
    // of a variable
    println!("And 'Adrian Fahrenheit Tepeş' is {:?} bytes. It is not Sized.",
    std::mem::size_of_val("Adrian Fahrenheit Tepeş"));
}
```

This prints:

```
A String is always 24 bytes. It is Sized.
And an i8 is always 1 bytes. It is Sized.
And an f64 is always 8 bytes. It is Sized.
But a &str? It can be anything. '서태지' is 9 bytes. It is not Sized.
And 'Adrian Fahrenheit Tepeş' is 25 bytes. It is not Sized.
```

That is why we need a `&`, because `&` makes a pointer, and Rust knows the size of the pointer. So the pointer goes on the stack. If we wrote `str`, Rust wouldn't know what to do because it doesn't know the size.

There are many ways to make a `String`. Here are some:

- `String::from("This is the string text");` This is a method for `String` that takes text and creates a `String`.
- `"This is the string text".to_string()`. This is a method for `&str` that makes it a `String`.
- The `format!` macro. This is like `println!` except it creates a `String` instead of printing. So you can do this:

```
fn main() {
    let my_name = "Billybrobby";
    let my_country = "USA";
    let my_home = "Korea";

    let together = format!(
        "I am {} and I come from {} but I live in {}.",
        my_name, my_country, my_home
    );
}
```

Now we have a `String` named `together`, but did not print it yet.

One other way to make a `String` is called `.into()` but it is a bit different because `.into()` isn't just for making a `String`. Some types can easily convert to and from another type using `From` and `.into()`. And if you have `From`, then you also have `.into()`. `From` is clearer because you already know the types: you know that `String::from("Some str")` is a `String` from a `&str`. But with `.into()`, sometimes the compiler doesn't know:

```
fn main() {
    let my_string = "Try to make this a String".into(); // ⚠
}
```

Rust doesn't know what type you want, because many types can be made from a `&str`. It says, "I can make a `&str` into a lot of things. Which one do you want?"

```
error[E0282]: type annotations needed
--> src\main.rs:2:9
 |
2 |     let my_string = "Try to make this a String".into();
 |           ^^^^^^ consider giving `my_string` a type
```

So you can do this:

```
fn main() {
    let my_string: String = "Try to make this a String".into();
}
```

And now you get a String.

const and static

[See this chapter on YouTube](#)

There are two other ways to declare values, not just with `let`. These are `const` and `static`. Also, Rust won't use type inference: you need to write the type for them. These are for values that don't change (`const` means constant). The difference is that:

- `const` is for values that don't change, the name is replaced with the value when it's used,
- `static` is similar to `const`, but has a fixed memory location and can act as a global variable.

So they are almost the same. Rust programmers almost always use `const`.

You write them with ALL CAPITAL LETTERS, and usually outside of `main` so that they can live for the whole program.

Two examples are: `const NUMBER_OF_MONTHS: u32 = 12;` and `static SEASONS: [&str; 4] = ["Spring", "Summer", "Fall", "Winter"];`

More on references

[See this chapter on YouTube](#)

References are very important in Rust. Rust uses references to make sure that all memory access is safe. We know that we use `&` to create a reference:

```
fn main() {
    let country = String::from("Austria");
    let ref_one = &country;
    let ref_two = &country;

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

This prints `Austria`.

In the code, `country` is a `String`. We then created two references to `country`. They have the type `&String`, which you say is a "reference to a String". We could create three references or one hundred references to `country` and it would be no problem.

But this is a problem:

```
fn return_str() -> &str {
    let country = String::from("Austria");
    let country_ref = &country;
    country_ref // ⚠
}

fn main() {
    let country = return_str();
}
```

The function `return_str()` creates a `String`, then it creates a reference to the `String`. Then it tries to return the reference. But the `String` `country` only lives inside the function, and then it dies. Once a variable is gone, the computer will clean up the memory and use it for something else. So after the function is over, `country_ref` is referring to memory that is already gone, and that's not okay. Rust prevents us from making a mistake with memory here.

This is the important part about the "owned" type that we talked about above. Because you own a `String`, you can pass it around. But a `&String` will die if its `String` dies, so you don't pass around "ownership" with it.

Mutable references

[See this chapter on YouTube](#)

If you want to use a reference to change data, you can use a mutable reference. For a mutable reference, you write `&mut` instead of `&`.

```
fn main() {
    let mut my_number = 8; // don't forget to write mut here!
    let num_ref = &mut my_number;
}
```

So what are the two types? `my_number` is an `i32`, and `num_ref` is `&mut i32` (we say a "mutable reference to an `i32`").

So let's use it to add 10 to `my_number`. But you can't write `num_ref += 10`, because `num_ref` is not the `i32` value, it is a `&i32`. The value is actually inside the `i32`. To reach the place where the value is, we use `* . *` means "I don't want the reference, I want the value behind the reference". In other words, one `*` is the opposite of `&`. Also, one `*` erases one `&`.

```
fn main() {
    let mut my_number = 8;
    let num_ref = &mut my_number;
    *num_ref += 10; // Use * to change the i32 value.
    println!("{}", my_number);

    let second_number = 800;
    let triple_reference = &&&second_number;
    println!("Second_number = triple_reference? {}", second_number ==
        ***triple_reference);
}
```

This prints:

```
18
Second_number = triple_reference? true
```

Because using `&` is called "referencing", using `*` is called "**dereferencing**".

Rust has two rules for mutable and immutable references. They are very important, but also easy to remember because they make sense.

- **Rule 1:** If you have only immutable references, you can have as many as you want. 1 is fine, 3 is fine, 1000 is fine. No problem.
- **Rule 2:** If you have a mutable reference, you can only have one. Also, you can't have an immutable reference **and** a mutable reference together.

This is because mutable references can change the data. You could get problems if you change the data when other references are reading it.

A good way to understand is to think of a Powerpoint presentation.

Situation one is about **only one mutable reference**.

Situation one: An employee is writing a Powerpoint presentation. He wants his manager to help him. The employee gives his login information to his manager, and asks him to help by making edits. Now the manager has a "mutable reference" to the employee's presentation. The manager can make any changes he wants, and give the computer back later. This is fine, because nobody else is looking at the presentation.

Situation two is about **only immutable references**.

Situation two: The employee is giving the presentation to 100 people. All 100 people can now see the employee's data. They all have an "immutable reference" to the employee's presentation. This is fine, because they can see it but nobody can change the data.

Situation three is **the problem situation**.

Situation three: The Employee gives his manager his login information. His manager now has a "mutable reference". Then the employee went to give the presentation to 100 people, but the manager can still log in. This is not fine, because the manager can log in and do anything. Maybe his manager will log into the computer and start typing an email to his mother! Now the 100 people have to watch the manager write an email to his mother instead of the presentation. That's not what they expected to see.

Here is an example of a mutable borrow with an immutable borrow:

```
fn main() {
    let mut number = 10;
    let number_ref = &number;
    let number_change = &mut number;
    *number_change += 10;
    println!("{}", number_ref); // ⚠
}
```

The compiler prints a helpful message to show us the problem.

```
error[E0502]: cannot borrow `number` as mutable because it is also borrowed as
immutable
--> src\main.rs:4:25
|
3 |     let number_ref = &number;
|             ----- immutable borrow occurs here
4 |     let number_change = &mut number;
|             ^^^^^^^^^^ mutable borrow occurs here
5 |     *number_change += 10;
6 |     println!("{}", number_ref);
|             ----- immutable borrow later used here
```

However, this code will work. Why?

```
fn main() {
    let mut number = 10;
    let number_change = &mut number; // create a mutable reference
    *number_change += 10; // use mutable reference to add 10
    let number_ref = &number; // create an immutable reference
    println!("{}", number_ref); // print the immutable reference
}
```

It prints 20 with no problem. It works because the compiler is smart enough to understand our code. It knows that we used `number_change` to change `number`, but didn't use it again. So here there is no problem. We are not using immutable and mutable references together.

Earlier in Rust this kind of code actually generated an error, but the compiler is smarter now. It can understand not just what we type, but how we use everything.

Shadowing again

Remember when we said that shadowing doesn't **destroy** a value but **blocks** it? Now we can use references to see this.

```
fn main() {  
    let country = String::from("Austria");  
    let country_ref = &country;  
    let country = 8;  
    println!("{} , {}", country_ref, country);  
}
```

Does this print `Austria, 8` or `8, 8`? It prints `Austria, 8`. First we declare a `String` called `country`. Then we create a reference `country_ref` to this string. Then we shadow `country` with `8`, which is an `i32`. But the first `country` was not destroyed, so `country_ref` still says "Austria", not "8". Here is the same code with some comments to show how it works:

```
fn main() {  
    let country = String::from("Austria"); // Now we have a String called country  
    let country_ref = &country; // country_ref is a reference to this data. It's not  
    // going to change  
    let country = 8; // Now we have a variable called country that is an i8. But it has  
    // no relation to the other one, or to country_ref  
    println!("{} , {}", country_ref, country); // country_ref still refers to the data  
    // of String::from("Austria") that we gave it.  
}
```

Giving references to functions

See this chapter on YouTube: [immutable references](#) and [mutable references](#)

References are very useful for functions. The rule in Rust on values is: a value can only have one owner.

This code will not work:

```
fn print_country(country_name: String) {
    println!("{}", country_name);
}

fn main() {
    let country = String::from("Austria");
    print_country(country); // We print "Austria"
    print_country(country); // ⚠ That was fun, let's do it again!
}
```

It does not work because `country` is destroyed. Here's how:

- Step 1: We create the `String` called `country`. `country` is the owner.
- Step 2: We give `country` to `print_country`. `print_country` doesn't have an `->`, so it doesn't return anything. After `print_country` finishes, our `String` is now dead.
- Step 3: We try to give `country` to `print_country`, but we already did that. We don't have `country` to give anymore.

We can make `print_country` give the `String` back, but it is a bit awkward.

```
fn print_country(country_name: String) -> String {
    println!("{}", country_name);
    country_name // return it here
}

fn main() {
    let country = String::from("Austria");
    let country = print_country(country); // we have to use let here now to get the
    String back
    print_country(country);
}
```

Now it prints:

```
Austria
Austria
```

The much better way to fix this is by adding `&`.

```

fn print_country(country_name: &String) {
    println!("{}", country_name);
}

fn main() {
    let country = String::from("Austria");
    print_country(&country); // We print "Austria"
    print_country(&country); // That was fun, let's do it again!
}

```

Now `print_country()` is a function that takes a reference to a `String`: a `&String`. Also, we give it a reference to `country` by writing `&country`. This says "you can look at it, but I will keep it".

Now let's do something similar with a mutable reference. Here is an example of a function that uses a mutable variable.

```

fn add_hungary(country_name: &mut String) { // first we say that the function takes a
    mutable reference
    country_name.push_str("-Hungary"); // push_str() adds a &str to a String
    println!("Now it says: {}", country_name);
}

fn main() {
    let mut country = String::from("Austria");
    add_hungary(&mut country); // we also need to give it a mutable reference.
}

```

This prints `Now it says: Austria-Hungary`.

So to conclude:

- `fn function_name(variable: String)` takes a `String` and owns it. If it doesn't return anything, then the variable dies inside the function.
- `fn function_name(variable: &String)` borrows a `String` and can look at it
- `fn function_name(variable: &mut String)` borrows a `String` and can change it

Here is an example that looks like a mutable reference, but it is different.

```

fn main() {
    let country = String::from("Austria"); // country is not mutable, but we are going
    to print Austria-Hungary. How?
    adds_hungary(country);
}

fn adds_hungary(mut country: String) { // Here's how: adds_hungary takes the String and
    declares it mutable!
    country.push_str("-Hungary");
    println!("{}", country);
}

```

How is this possible? It is because `mut country` is not a reference: `adds_hungary` owns `country` now. (Remember, it takes `String` and not `&String`). The moment you call `adds_hungary`, it becomes the full owner. `country` has nothing to do with `String::from("Austria")` anymore. So `adds_hungary` can take `country` as mutable, and it is perfectly safe to do so.

Remember our employee Powerpoint and manager situation above? In this situation it is like the employee just giving his whole computer to the manager. The employee won't ever touch it again, so the manager can do anything he wants to it.

Copy types

Some types in Rust are very simple. They are called **copy types**. These simple types are all on the stack, and the compiler knows their size. That means that they are very easy to copy, so the compiler always copies when you send it to a function. It always copies because they are so small and easy that there is no reason not to copy. So you don't need to worry about ownership for these types.

These simple types include: integers, floats, booleans (`true` and `false`), and `char`.

How do you know if a type **implements** copy? (implements = can use) You can check the documentation. For example, here is the documentation for `char`:

<https://doc.rust-lang.org/std/primitive.char.html>

On the left you can see **Trait Implementations**. You can see for example **Copy**, **Debug**, and **Display**. So you know that a `char`:

- is copied when you send it to a function (**Copy**)
- can use `{}` to print (**Display**)
- can use `{:?}` to print (**Debug**)

```
fn prints_number(number: i32) { // There is no -> so it's not returning anything
    // If number was not copy type, it would take it
    // and we couldn't use it again
    println!("{}", number);
}

fn main() {
    let my_number = 8;
    prints_number(my_number); // Prints 8. prints_number gets a copy of my_number
    prints_number(my_number); // Prints 8 again.
    // No problem, because my_number is copy type!
}
```

But if you look at the documentation for `String`, it is not copy type.

<https://doc.rust-lang.org/std/string/struct.String.html>

On the left in **Trait Implementations** you can look in alphabetical order. A, B, C... there is no **Copy** in C. But there is **Clone**. **Clone** is similar to **Copy**, but usually needs more memory. Also, you have to call it with `.clone()` - it won't clone just by itself.

In this example, `prints_country()` prints the country name, a `String`. We want to print it two times, but we can't:

```
fn prints_country(country_name: String) {
    println!("{}", country_name);
}

fn main() {
    let country = String::from("Kiribati");
    prints_country(country);
    prints_country(country); // ⚠
}
```

But now we understand the message.

```
error[E0382]: use of moved value: `country`
--> src\main.rs:4:20
  |
2 |     let country = String::from("Kiribati");
  |             ----- move occurs because `country` has type `std::string::String`, which
does not implement the `Copy` trait
3 |     prints_country(country);
  |             ----- value moved here
4 |     prints_country(country);
  |             ^^^^^^^^ value used here after move
```

The important part is `which does not implement the Copy trait`. But in the documentation we saw that `String` implements the `Clone` trait. So we can add `.clone()` to our code. This creates a clone, and we send the clone to the function. Now `country` is still alive, so we can use it.

```
fn prints_country(country_name: String) {
    println!("{}", country_name);
}

fn main() {
    let country = String::from("Kiribati");
    prints_country(country.clone()); // make a clone and give it to the function. Only
    // the clone goes in, and country is still alive
    prints_country(country);
}
```

Of course, if the `String` is very large, `.clone()` can use a lot of memory. One `String` can be a whole book in length, and every time we call `.clone()` it will copy the book. So using `&` for a reference is faster, if you can. For example, this code pushes a `&str` onto a `String` and then makes a clone every time it gets used in a function:

```
fn get_length(input: String) { // Takes ownership of a String
    println!("It's {} words long.", input.split_whitespace().count()); // splits to
    count the number of words
}

fn main() {
    let mut my_string = String::new();
    for _ in 0..50 {
        my_string.push_str("Here are some more words ");
        get_length(my_string.clone()); // gives it a clone every time
    }
}
```

It prints:

```
It's 5 words long.
It's 10 words long.
...
It's 250 words long.
```

That's 50 clones. Here it is using a reference instead, which is better:

```
fn get_length(input: &String) {
    println!("It's {} words long.", input.split_whitespace().count());
}

fn main() {
    let mut my_string = String::new();
    for _ in 0..50 {
        my_string.push_str("Here are some more words ");
        get_length(&my_string);
    }
}
```

Instead of 50 clones, it's zero.

Variables without values

A variable without a value is called an "uninitialized" variable. Uninitialized means "hasn't started yet". They are simple: just write `let` and the variable name:

```
fn main() {
    let my_variable; // ⚠
}
```

But you can't use it yet, and Rust won't compile if anything is uninitialized.

But sometimes they can be useful. A good example is when:

- You have a code block and the value for your variable is inside it, and
- The variable needs to live outside of the code block.

```
fn loop_then_return(mut counter: i32) -> i32 {
    loop {
        counter += 1;
        if counter % 50 == 0 {
            break;
        }
    }
    counter
}

fn main() {
    let my_number;

    {
        // Pretend we need to have this code block
        let number = {
            // Pretend there is code here to make a number
            // Lots of code, and finally:
            57
        };
        my_number = loop_then_return(number);
    }

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

This prints `100`.

You can see that `my_number` was declared in the `main()` function, so it lives until the end. But it gets its value from inside a loop. However, that value lives as long as `my_number`, because `my_number` has

the value. And if you wrote `let my_number = loop_then_return(number)` inside the block, it would just die right away.

It helps to imagine if you simplify the code. `loop_then_return(number)` gives the result 100, so let's delete it and write `100` instead. Also, now we don't need `number` so we will delete it too. Now it looks like this:

```
fn main() {  
    let my_number;  
    {  
        my_number = 100;  
    }  
  
    println!("{}", my_number);  
}
```

So it's almost like saying `let my_number = { 100 };`.

Also note that `my_number` is not `mut`. We didn't give it a value until we gave it 50, so it never changed its value. In the end, the real code for `my_number` is just `let my_number = 100;`.

Collection types

Rust has a lot of types for making a collection. Collections are for when you need more than one value in one spot. For example, you could have information on all the cities in your country inside one variable. We will start with arrays, which are fastest but also have the least functionality. They are kind of like `&str` in that way.

Arrays

An array is data inside square brackets: `[]`. Arrays:

- must not change their size,
- must only contain the same type.

They are very fast, however.

The type of an array is: `[type; number]`. For example, the type of `["One", "Two"]` is `[&str; 2]`. This means that even these two arrays have different types:

```
fn main() {
    let array1 = ["One", "Two"]; // This one is type [&str; 2]
    let array2 = ["One", "Two", "Five"]; // But this one is type [&str; 3]. Different
type!
}
```

Here is a good tip: to know the type of a variable, you can "ask" the compiler by giving it bad instructions. For example:

```
fn main() {
    let seasons = ["Spring", "Summer", "Autumn", "Winter"];
    let seasons2 = ["Spring", "Summer", "Fall", "Autumn", "Winter"];
    seasons.ddd(); // ⚠️
    seasons2.thd(); // ⚠️ as well
}
```

The compiler says, "What? There's no `.ddd()` method for `seasons` and no `.thd()` method for `seasons2` either!!" as you can see:

```
error[E0599]: no method named `ddd` found for array `[&str; 4]` in the current scope
--> src\main.rs:4:13
 |
4 |     seasons.ddd(); //
|           ^^^ method not found in ` [&str; 4]`


error[E0599]: no method named `thd` found for array ` [&str; 5]` in the current scope
--> src\main.rs:5:14
 |
5 |     seasons2.thd(); //
|           ^^^ method not found in ` [&str; 5]`
```

So it tells you `method not found in ` [&str; 4]``, which is the type.

If you want an array with all the same value, you can declare it like this:

```
fn main() {
    let my_array = ["a"; 10];
    println!("{:?}", my_array);
}
```

This prints `["a", "a", "a", "a", "a", "a", "a", "a", "a", "a"]`.

This method is used a lot to create buffers. For example, `let mut buffer = [0; 640]` creates an array of 640 zeroes. Then we can change zero to other numbers in order to add data.

You can index (get) entries in an array with `[]`. The first entry is `[0]`, the second is `[1]`, and so on.

```
fn main() {
    let my_numbers = [0, 10, -20];
    println!("{}", my_numbers[1]); // prints 10
}
```

You can get a slice (a piece) of an array. First you need a `&`, because the compiler doesn't know the size. Then you can use `..` to show the range.

For example, let's use this array: `[1, 2, 3, 4, 5, 6, 7, 8, 9, 10]`.

```
fn main() {
    let array_of_ten = [1, 2, 3, 4, 5, 6, 7, 8, 9, 10];

    let three_to_five = &array_of_ten[2..5];
    let start_at_two = &array_of_ten[1..];
    let end_at_five = &array_of_ten[..5];
    let everything = &array_of_ten[..];

    println!("Three to five: {:?}, start at two: {:?}, end at five: {:?}, everything: {:?}",
            three_to_five, start_at_two, end_at_five, everything);
}
```

Remember that:

- Index numbers start at 0 (not 1)
- Index ranges are **exclusive** (they do not include the last number)

So `[0..2]` means the first index and the second index (0 and 1). Or you can call it the "zeroth and first" index. It doesn't have the third item, which is index 2.

You can also have an **inclusive** range, which means it includes the last number too. To do this, add `=` to write `..=` instead of `...`. So instead of `[0..2]` you can write `[0..=2]` if you want the first, second, and third item.

Vectors

See this chapter on YouTube

In the same way that we have `&str` and `String`, we have arrays and vectors. Arrays are faster with less functionality, and vectors are slower with more functionality. (Of course, Rust is always very fast so vectors are not slow, just slower than arrays.) The type is written `Vec`, and you can also just call it a "vec".

There are two main ways to declare a vector. One is like with `String` using `new`:

```
fn main() {
    let name1 = String::from("Windy");
    let name2 = String::from("Gomesy");

    let mut my_vec = Vec::new();
    // If we run the program now, the compiler will give an error.
    // It doesn't know the type of vec.

    my_vec.push(name1); // Now it knows: it's Vec<String>
    my_vec.push(name2);
}
```

You can see that a `Vec` always has something else inside it, and that's what the `<>` (angle brackets) are for. A `Vec<String>` is a vector with one or more `String`s. You can also have more types inside. For example:

- `Vec<(i32, i32)>` this is a `Vec` where each item is a tuple: `(i32, i32)`.
- `Vec<Vec<String>>` this is a `Vec` that has `Vec`s of `String`s. Say for example you wanted to save your favourite book as a `Vec<String>`. Then you do it again with another book, and get another `Vec<String>`. To hold both books, you would put them into another `Vec` and that would be a `Vec<Vec<String>>`.

Instead of using `.push()` to make Rust decide the type, you can just declare the type.

```
fn main() {
    let mut my_vec: Vec<String> = Vec::new(); // The compiler knows the type
                                                // so there is no error.
}
```

You can see that items in vectors must have the same type.

Another easy way to create a vector is with the `vec!` macro. It looks like an array declaration, but has `vec!` in front of it.

```
fn main() {
    let mut my_vec = vec![8, 10, 10];
}
```

The type is `Vec<i32>`. You call it a "Vec of i32s". And a `Vec<String>` is a "Vec of strings". And a `Vec<Vec<String>>` is a "Vec of a vec of strings".

You can slice a vector too, just like in an array.

```
fn main() {
    let vec_of_ten = vec![1, 2, 3, 4, 5, 6, 7, 8, 9, 10];
    // Everything is the same as above except we added vec!.
    let three_to_five = &vec_of_ten[2..5];
    let start_at_two = &vec_of_ten[1..];
    let end_at_five = &vec_of_ten[..5];
    let everything = &vec_of_ten[..];

    println!("Three to five: {:?}", three_to_five);
    start at two: {:?}
    end at five: {:?}
    everything: {:?}", three_to_five, start_at_two, end_at_five, everything);
}
```

Because a vec is slower than an array, we can use some methods to make it faster. A vec has a **capacity**, which means the space given to the vector. When you push a new item on the vector, it gets closer and closer to the capacity. Then if you go past the capacity, it will make its capacity double and copy the items into the new space. This is called reallocation. We'll use a method called `.capacity()` to look at the capacity of a vector as we add items to it.

For example:

```
fn main() {
    let mut num_vec = Vec::new();
    println!("{}", num_vec.capacity()); // 0 elements: prints 0
    num_vec.push('a'); // add one character
    println!("{}", num_vec.capacity()); // 1 element: prints 4. Vecs with 1 item always
start with capacity 4
    num_vec.push('a'); // add one more
    num_vec.push('a'); // add one more
    num_vec.push('a'); // add one more
    println!("{}", num_vec.capacity()); // 4 elements: still prints 4.
    num_vec.push('a'); // add one more
    println!("{}", num_vec.capacity()); // prints 8. We have 5 elements, but it doubled
4 to 8 to make space
}
```

This prints:

```
0
4
4
8
```

So this vector has two reallocations: 0 to 4, and 4 to 8. We can make it faster:

```
fn main() {
    let mut num_vec = Vec::with_capacity(8); // Give it capacity 8
    num_vec.push('a'); // add one character
    println!("{}", num_vec.capacity()); // prints 8
    num_vec.push('a'); // add one more
    println!("{}", num_vec.capacity()); // prints 8
    num_vec.push('a'); // add one more
    println!("{}", num_vec.capacity()); // prints 8.
    num_vec.push('a'); // add one more
    num_vec.push('a'); // add one more // Now we have 5 elements
    println!("{}", num_vec.capacity()); // Still 8
}
```

This vector has 0 reallocations, which is better. So if you think you know how many elements you need, you can use `Vec::with_capacity()` to make it faster.

You remember that you can use `.into()` to make a `&str` into a `String`. You can also use it to make an array into a `Vec`. You have to tell `.into()` that you want a `Vec`, but you don't have to choose the type of `Vec`. If you don't want to choose, you can write `Vec<_>`.

```
fn main() {
    let my_vec: Vec<u8> = [1, 2, 3].into();
    let my_vec2: Vec<_> = [9, 0, 10].into(); // Vec<_> means "choose the Vec type for
me"
                                                // Rust will choose Vec<i32>
}
```

Tuples

[See this chapter on YouTube](#)

Tuples in Rust use `()`. We have seen many empty tuples already, because *nothing* in a function actually means an empty tuple:

```
fn do_something() {}
```

is actually short for:

```
fn do_something() -> () {}
```

That function gets nothing (an empty tuple), and returns nothing (an empty tuple). So we have been using tuples a lot already. When you don't return anything in a function, you actually return an empty tuple.

```
fn just_prints() {
    println!("I am printing"); // Adding ; means we return an empty tuple
}

fn main() {}
```

But tuples can hold many things, and can hold different types too. Items inside a tuple are also indexed with numbers 0, 1, 2, and so on. But to access them, you use a `.` instead of a `[]`. Let's put a whole bunch of types into a single tuple.

```
fn main() {
    let random_tuple = ("Here is a name", 8, vec!['a'], 'b', [8, 9, 10], 7.7);
    println!(
        "Inside the tuple is: First item: {:?}", 
        Second item: {:?},
        Third item: {:?},
        Fourth item: {:?},
        Fifth item: {:?},
        Sixth item: {:?}",
        random_tuple.0,
        random_tuple.1,
        random_tuple.2,
        random_tuple.3,
        random_tuple.4,
        random_tuple.5,
    )
}
```

This prints:

```
Inside the tuple is: First item: "Here is a name"
Second item: 8
Third item: ['a']
Fourth item: 'b'
Fifth item: [8, 9, 10]
Sixth item: 7.7
```

That tuple is of type `(&str, i32, Vec<char>, char, [i32; 3], f64)`.

You can use a tuple to create multiple variables. Take a look at this code:

```
fn main() {  
    let str_vec = vec!["one", "two", "three"];  
}
```

`str_vec` has three items in it. What if we want to pull them out? That's where we can use a tuple.

```
fn main() {  
    let str_vec = vec!["one", "two", "three"];  
  
    let (a, b, c) = (str_vec[0], str_vec[1], str_vec[2]); // call them a, b, and c  
    println!("{}:{}:", b);  
}
```

That prints `"two"`, which is what `b` is. This is called *destructuring*. That is because first the variables are inside a structure, but then we made `a`, `b`, and `c` that are not inside a structure.

If you need to destructure but don't want all the variables, you can use `_`.

```
fn main() {  
    let str_vec = vec!["one", "two", "three"];  
  
    let (_, _, variable) = (str_vec[0], str_vec[1], str_vec[2]);  
}
```

Now it only creates a variable called `variable` but doesn't make a variable for the others.

There are many more collection types, and many more ways to use arrays,vecs, and tuples. We will learn more about them too, but first we will learn control flow.

Control flow

See this chapter on YouTube: [Part 1](#) and [Part 2](#)

Control flow means telling your code what to do in different situations. The simplest control flow is `if`.

```
fn main() {
    let my_number = 5;
    if my_number == 7 {
        println!("It's seven");
    }
}
```

Also note that you use `==` and not `=`. `==` is to compare, `=` is to *assign* (to give a value). Also note that we wrote `if my_number == 7` and not `if (my_number == 7)`. You don't need brackets with `if` in Rust.

`else if` and `else` give you more control:

```
fn main() {
    let my_number = 5;
    if my_number == 7 {
        println!("It's seven");
    } else if my_number == 6 {
        println!("It's six")
    } else {
        println!("It's a different number")
    }
}
```

This prints `It's a different number` because it's not equal to 7 or 6.

You can add more conditions with `&&` (and) and `||` (or).

```
fn main() {
    let my_number = 5;
    if my_number % 2 == 1 && my_number > 0 { // % 2 means the number that remains after
diving by two
        println!("It's a positive odd number");
    } else if my_number == 6 {
        println!("It's six")
    } else {
        println!("It's a different number")
    }
}
```

This prints `It's a positive odd number` because when you divide it by 2 you have a remainder of 1, and it's greater than 0.

You can see that too much `if`, `else`, and `else if` can be difficult to read. In this case you can use `match` instead, which looks much cleaner. But you must match for every possible result. For example, this will not work:

```
fn main() {
    let my_number: u8 = 5;
    match my_number {
        0 => println!("it's zero"),
        1 => println!("it's one"),
        2 => println!("it's two"),
        // ⚠
    }
}
```

The compiler says:

```
error[E0004]: non-exhaustive patterns: `3u8..=std::u8::MAX` not covered
--> src\main.rs:3:11
 |
3 |     match my_number {
|         ^^^^^^^^^^ pattern `3u8..=std::u8::MAX` not covered
```

This means "you told me about 0 to 2, but `u8`s can go up to 255. What about 3? What about 4? What about 5?" And so on. So you can add `_` which means "anything else".

```
fn main() {
    let my_number: u8 = 5;
    match my_number {
        0 => println!("it's zero"),
        1 => println!("it's one"),
        2 => println!("it's two"),
        _ => println!("It's some other number"),
    }
}
```

That prints `It's some other number.`

Remember this for match:

- You write `match` and then make a `{}` code block.
- Write the *pattern* on the left and use a `=>` fat arrow to say what to do when it matches.
- Each line is called an "arm".
- Put a comma between the arms (not a semicolon).

You can declare a value with a match:

```
fn main() {
    let my_number = 5;
    let second_number = match my_number {
        0 => 0,
        5 => 10,
        _ => 2,
    };
}
```

`second_number` will be 10. Do you see the semicolon at the end? That is because, after the match is over, we actually told the compiler this: `let second_number = 10;`

You can match on more complicated things too. You use a tuple to do it.

```
fn main() {
    let sky = "cloudy";
    let temperature = "warm";

    match (sky, temperature) {
        ("cloudy", "cold") => println!("It's dark and unpleasant today"),
        ("clear", "warm") => println!("It's a nice day"),
        ("cloudy", "warm") => println!("It's dark but not bad"),
        _ => println!("Not sure what the weather is."),
    }
}
```

This prints `It's dark but not bad` because it matches "cloudy" and "warm" for `sky` and `temperature`.

You can even put `if` inside of `match`. This is called a "match guard":

```
fn main() {
    let children = 5;
    let married = true;

    match (children, married) {
        (children, married) if married == false => println!("Not married with {} children", children),
        (children, married) if children == 0 && married == true => println!("Married but no children"),
        _ => println!("Married? {}. Number of children: {}", married, children),
    }
}
```

This will print `Married? true. Number of children: 5.`

You can use `_` as many times as you want in a match. In this match on colours, we have three but only check one at a time.

```
fn match_colours(rgb: (i32, i32, i32)) {
    match rgb {
        (r, _, _) if r < 10 => println!("Not much red"),
        (_, b, _) if b < 10 => println!("Not much blue"),
        (_, _, g) if g < 10 => println!("Not much green"),
        _ => println!("Each colour has at least 10"),
    }
}

fn main() {
    let first = (200, 0, 0);
    let second = (50, 50, 50);
    let third = (200, 50, 0);

    match_colours(first);
    match_colours(second);
    match_colours(third);
}
```

This prints:

```
Not much blue
Each colour has at least 10
Not much green
```

This also shows how `match` statements work, because in the first example it only printed `Not much blue`. But `first` also has not much green. A `match` statement always stops when it finds a match, and doesn't check the rest. This is a good example of code that compiles well but is not the code you want.

You can make a really big `match` statement to fix it, but it is probably better to use a `for` loop. We will talk about loops soon.

A match has to return the same type. So you can't do this:

```
fn main() {
    let my_number = 10;
    let some_variable = match my_number {
        10 => 8,
        _ => "Not ten", // ⚠
    };
}
```

The compiler tells you that:

```
error[E0308]: `match` arms have incompatible types
--> src\main.rs:17:14
|
15 |         let some_variable = match my_number {
16 |             10 => 8,
|                 - this is found to be of type `&str`
17 |             _ => "Not ten",
|                 ^^^^^^^^^ expected integer, found `&str`
18 |         };
|         `match` arms have incompatible types
```

This will also not work, for the same reason:

```
fn main() {
    let some_variable = if my_number == 10 { 8 } else { "something else" }; // ⚠
}
```

But this works, because it's not a `match` so you have a different `let` statement each time:

```
fn main() {
    let my_number = 10;

    if my_number == 10 {
        let some_variable = 8;
    } else {
        let some_variable = "Something else";
    }
}
```

You can also use `@` to give a name to the value of a `match` expression, and then you can use it. In this example we match an `i32` input in a function. If it's 4 or 13 we want to use that number in a `println!` statement. Otherwise, we don't need to use it.

```
fn match_number(input: i32) {
    match input {
        number @ 4 => println!("{} is an unlucky number in China (sounds close to 死)!", number),
        number @ 13 => println!("{} is unlucky in North America, lucky in Italy! In bocca al lupo!", number),
        _ => println!("Looks like a normal number"),
    }
}

fn main() {
    match_number(50);
    match_number(13);
    match_number(4);
}
```

This prints:

```
Looks like a normal number
13 is unlucky in North America, lucky in Italy! In bocca al lupo!
4 is an unlucky number in China (sounds close to 死)!
```

Structs

See this chapter on YouTube: [Part 1](#) and [Part 2](#)

With structs, you can create your own type. You will use structs all the time in Rust because they are so convenient. Structs are created with the keyword `struct`. The name of a struct should be in UpperCamelCase (capital letter for each word, no spaces). If you write a struct in all lowercase, the compiler will tell you.

There are three types of structs. One is a "unit struct". Unit means "doesn't have anything". For a unit struct, you just write the name and a semicolon.

```
struct FileDirectory;
fn main() {}
```

The next is a tuple struct, or an unnamed struct. It is "unnamed" because you only need to write the types, not the field names. Tuple structs are good when you need a simple struct and don't need to remember names.

```
struct Colour(u8, u8, u8);

fn main() {
    let my_colour = Colour(50, 0, 50); // Make a colour out of RGB (red, green, blue)
    println!("The second part of the colour is: {}", my_colour.1);
}
```

This prints `The second part of the colour is: 0.`

The third type is the named struct. This is probably the most common struct. In this struct you declare field names and types inside a `{}` code block. Note that you don't write a semicolon after a named struct, because there is a whole code block after it.

```
struct Colour(u8, u8, u8); // Declare the same Colour tuple struct

struct SizeAndColour {
    size: u32,
    colour: Colour, // And we put it in our new named struct
}

fn main() {
    let my_colour = Colour(50, 0, 50);

    let size_and_colour = SizeAndColour {
        size: 150,
        colour: my_colour
    };
}
```

You separate fields by commas in a named struct too. For the last field you can add a comma or not - it's up to you. `SizeAndColour` had a comma after `colour`:

```
struct Colour(u8, u8, u8); // Declare the same Colour tuple struct

struct SizeAndColour {
    size: u32,
    colour: Colour, // And we put it in our new named struct
}

fn main() {}
```

but you don't need it. But it can be a good idea to always put a comma, because sometimes you will change the order of the fields:

```
struct Colour(u8, u8, u8); // Declare the same Colour tuple struct

struct SizeAndColour {
    size: u32,
    colour: Colour // No comma here
}

fn main() {}
```

Then we decide to change the order...

```
struct SizeAndColour {
    colour: Colour // ⚠ Whoops! Now this doesn't have a comma.
    size: u32,
}

fn main() {}
```

But it is not very important either way so you can choose whether to use a comma or not.

Let's create a `Country` struct to give an example. The `Country` struct has the fields `population`, `capital`, and `leader_name`.

```
struct Country {
    population: u32,
    capital: String,
    leader_name: String
}

fn main() {
    let population = 500_000;
    let capital = String::from("Elista");
    let leader_name = String::from("Batu Khasikov");

    let kalmykia = Country {
        population: population,
        capital: capital,
        leader_name: leader_name,
    };
}
```

Did you notice that we wrote the same thing twice? We wrote `population: population`, `capital: capital`, and `leader_name: leader_name`. Actually, you don't need to do that. If the field name and variable name are the same, you don't have to write it twice.

```
struct Country {  
    population: u32,  
    capital: String,  
    leader_name: String  
}  
  
fn main() {  
    let population = 500_000;  
    let capital = String::from("Elista");  
    let leader_name = String::from("Batu Khasikov");  
  
    let kalmykia = Country {  
        population,  
        capital,  
        leader_name,  
    };  
}
```

Enums

See this chapter on YouTube: [Part 1](#), [Part 2](#), [Part 3](#) and [Part 4](#)

An `enum` is short for enumerations. They look very similar to a struct, but are different. Here is the difference:

- Use a `struct` when you want one thing **AND** another thing.
- Use an `enum` when you want one thing **OR** another thing.

So structs are for **many things** together, while enums are for **many choices** together.

To declare an enum, write `enum` and use a code block with the options, separated by commas. Just like a `struct`, the last part can have a comma or not. We will create an enum called `ThingsInTheSky`:

```
enum ThingsInTheSky {
    Sun,
    Stars,
}

fn main() {}
```

This is an enum because you can either see the sun, **or** the stars: you have to choose one. These are called **variants**.

```
// create the enum with two choices
enum ThingsInTheSky {
    Sun,
    Stars,
}

// With this function we can use an i32 to create ThingsInTheSky.
fn create_skystate(time: i32) -> ThingsInTheSky {
    match time {
        6..=18 => ThingsInTheSky::Sun, // Between 6 and 18 hours we can see the sun
        _ => ThingsInTheSky::Stars, // Otherwise, we can see stars
    }
}

// With this function we can match against the two choices in ThingsInTheSky.
fn check_skystate(state: &ThingsInTheSky) {
    match state {
        ThingsInTheSky::Sun => println!("I can see the sun!"),
        ThingsInTheSky::Stars => println!("I can see the stars!")
    }
}

fn main() {
    let time = 8; // it's 8 o'clock
    let skystate = create_skystate(time); // create_skystate returns a ThingsInTheSky
    check_skystate(&skystate); // Give it a reference so it can read the variable
    skystate
}
```

This prints `I can see the sun!`.

You can add data to an enum too.

```

enum ThingsInTheSky {
    Sun(String), // Now each variant has a string
    Stars(String),
}

fn create_skystate(time: i32) -> ThingsInTheSky {
    match time {
        6..=18 => ThingsInTheSky::Sun(String::from("I can see the sun!")), // Write the
strings here
        _ => ThingsInTheSky::Stars(String::from("I can see the stars!")),
    }
}

fn check_skystate(state: &ThingsInTheSky) {
    match state {
        ThingsInTheSky::Sun(description) => println!("{} {}", description), // Give the
string the name description so we can use it
        ThingsInTheSky::Stars(n) => println!("{} {}", n), // Or you can name it n. Or
anything else - it doesn't matter
    }
}

fn main() {
    let time = 8; // it's 8 o'clock
    let skystate = create_skystate(time); // create_skystate returns a ThingsInTheSky
    check_skystate(&skystate); // Give it a reference so it can read the variable
skystate
}

```

This prints the same thing: I can see the sun!

You can also "import" an enum so you don't have to type so much. Here's an example where we have to type `Mood::` every time we match on our mood:

```

enum Mood {
    Happy,
    Sleepy,
    NotBad,
    Angry,
}

fn match_mood(mood: &Mood) -> i32 {
    let happiness_level = match mood {
        Mood::Happy => 10, // Here we type Mood:: every time
        Mood::Sleepy => 6,
        Mood::NotBad => 7,
        Mood::Angry => 2,
    };
    happiness_level
}

fn main() {
    let my_mood = Mood::NotBad;
    let happiness_level = match_mood(&my_mood);
    println!("Out of 1 to 10, my happiness is {}", happiness_level);
}

```

It prints `Out of 1 to 10, my happiness is 7`. Let's import so we can type less. To import everything, write `*`. Note: it's the same key as `*` for dereferencing but is completely different.

```

enum Mood {
    Happy,
    Sleepy,
    NotBad,
    Angry,
}

fn match_mood(mood: &Mood) -> i32 {
    use Mood::*;

    // We imported everything in Mood. Now we can just write Happy,
    Sleepy, etc.
    let happiness_level = match mood {
        Happy => 10, // We don't have to write Mood:: anymore
        Sleepy => 6,
        NotBad => 7,
        Angry => 2,
    };
    happiness_level
}

fn main() {
    let my_mood = Mood::Happy;
    let happiness_level = match_mood(&my_mood);
    println!("Out of 1 to 10, my happiness is {}", happiness_level);
}

```

Parts of an `enum` can also be turned into an integer. That's because Rust gives each arm of an `enum` a number that starts with 0 for its own use. You can do things with it if your enum doesn't have any other data in it.

```

enum Season {
    Spring, // If this was Spring(String) or something it wouldn't work
    Summer,
    Autumn,
    Winter,
}

fn main() {
    use Season::*;

    let four_seasons = vec![Spring, Summer, Autumn, Winter];
    for season in four_seasons {
        println!("{}", season as u32);
    }
}

```

This prints:

```

0
1
2
3

```

Though you can give it a different number, if you want - Rust doesn't care and can use it in the same way. Just add an `=` and your number to the variant that you want to have a number. You don't have to give all of them a number. But if you don't, Rust will just add 1 from the arm before to give it a number.

```

enum Star {
    BrownDwarf = 10,
    RedDwarf = 50,
    YellowStar = 100,
    RedGiant = 1000,
    DeadStar, // Think about this one. What number will it have?
}

fn main() {
    use Star::*;

    let starvec = vec![BrownDwarf, RedDwarf, YellowStar, RedGiant];
    for star in starvec {
        match star as u32 {
            size if size <= 80 => println!("Not the biggest star."), // Remember: size
            doesn't mean anything. It's just a name we chose so we can print it
            size if size >= 80 => println!("This is a good-sized star."),
            _ => println!("That star is pretty big!"),
        }
    }
    println!("What about DeadStar? It's the number {}.", DeadStar as u32);
}

```

This prints:

```

Not the biggest star.
Not the biggest star.
This is a good-sized star.
This is a good-sized star.
What about DeadStar? It's the number 1001.

```

DeadStar would have been number 4, but now it's 1001.

Enums to use multiple types

You know that items in a `Vec`, array, etc. all need the same type (only tuples are different). But you can actually use an enum to put different types in. Imagine we want to have a `Vec` with `u32`s or `i32`s. Of course, you can make a `Vec<(u32, i32)>` (a vec with `(u32, i32)` tuples) but we only want one each time. So here you can use an enum. Here is a simple example:

```

enum Number {
    U32(u32),
    I32(i32),
}

fn main() {}

```

So there are two variants: the `U32` variant with a `u32` inside, and the `I32` variant with `i32` inside. `U32` and `I32` are just names we made. They could have been `UThirtyTwo` or `IThirtyTwo` or anything else.

Now, if we put them into a `Vec` we just have a `Vec<Number>`, and the compiler is happy because it's all the same type. The compiler doesn't care that we have either `u32` or `i32` because they are all inside a single type called `Number`. And because it's an enum, you have to pick one, which is what we want. We will use the `.is_positive()` method to pick. If it's `true` then we will choose `U32`, and if it's `false` then we will choose `I32`.

Now the code looks like this:

```
enum Number {
    U32(u32),
    I32(i32),
}

fn get_number(input: i32) -> Number {
    let number = match input.is_positive() {
        true => Number::U32(input as u32), // change it to u32 if it's positive
        false => Number::I32(input), // otherwise just give the number because it's
already i32
    };
    number
}

fn main() {
    let my_vec = vec![get_number(-800), get_number(8)];

    for item in my_vec {
        match item {
            Number::U32(number) => println!("It's a u32 with the value {}", number),
            Number::I32(number) => println!("It's an i32 with the value {}", number),
        }
    }
}
```

This prints what we wanted to see:

```
It's an i32 with the value -800
It's a u32 with the value 8
```

Loops

With loops you can tell Rust to continue something until you want it to stop. You use `loop` to start a loop that does not stop, unless you tell it when to `break`.

```
fn main() { // This program will never stop
    loop {
        }
}
```

So let's tell the compiler when it can break.

```
fn main() {
    let mut counter = 0; // set a counter to 0
    loop {
        counter +=1; // increase the counter by 1
        println!("The counter is now: {}", counter);
        if counter == 5 { // stop when counter == 5
            break;
        }
    }
}
```

This will print:

```
The counter is now: 1
The counter is now: 2
The counter is now: 3
The counter is now: 4
The counter is now: 5
```

If you have a loop inside of a loop, you can give them names. With names, you can tell Rust which loop to `break` out of. Use `'` (called a "tick") and a `:` to give it a name:

```

fn main() {
    let mut counter = 0;
    let mut counter2 = 0;
    println!("Now entering the first loop.");

    'first_loop: loop {
        // Give the first loop a name
        counter += 1;
        println!("The counter is now: {}", counter);
        if counter > 9 {
            // Starts a second loop inside this loop
            println!("Now entering the second loop");

            'second_loop: loop {
                // now we are inside 'second_loop
                println!("The second counter is now: {}", counter2);
                counter2 += 1;
                if counter2 == 3 {
                    break 'first_loop; // Break out of 'first_loop so we can exit the
program
                }
            }
        }
    }
}

```

This will print:

```

Now entering the first loop.
The counter is now: 1
The counter is now: 2
The counter is now: 3
The counter is now: 4
The counter is now: 5
The counter is now: 6
The counter is now: 7
The counter is now: 8
The counter is now: 9
The counter is now: 10
Now entering the second loop.
The second counter is now: 0
The second counter is now: 1
The second counter is now: 2

```

A `while` loop is a loop that continues while something is still `true`. Each loop, Rust will check if it is still `true`. If it becomes `false`, Rust will stop the loop.

```

fn main() {
    let mut counter = 0;

    while counter < 5 {
        counter += 1;
        println!("The counter is now: {}", counter);
    }
}

```

A `for` loop lets you tell Rust what to do each time. But in a `for` loop, the loop stops after a certain number of times. `for` loops use **ranges** very often. You use `..` and `..=` to create a range.

- `..` creates an **exclusive** range: `0..3` creates `0, 1, 2`.
- `..=` creates an **inclusive** range: `0..=3` = `0, 1, 2, 3`.

```
fn main() {
    for number in 0..3 {
        println!("The number is: {}", number);
    }

    for number in 0..=3 {
        println!("The next number is: {}", number);
    }
}
```

This prints:

```
The number is: 0
The number is: 1
The number is: 2
The next number is: 0
The next number is: 1
The next number is: 2
The next number is: 3
```

Also notice that `number` becomes the variable name for `0..3`. We could have called it `n`, or `ntod_het___hno_f`, or anything. We can then use that name in `println!`.

If you don't need a variable name, use `_`.

```
fn main() {
    for _ in 0..3 {
        println!("Printing the same thing three times");
    }
}
```

This prints:

```
Printing the same thing three times
Printing the same thing three times
Printing the same thing three times
```

because we didn't give it any number to print each time.

And actually, if you give a variable name and don't use it, Rust will tell you:

```
fn main() {
    for number in 0..3 {
        println!("Printing the same thing three times");
    }
}
```

This prints the same thing as above. The program compiles fine, but Rust will remind you that you didn't use `number`:

```
warning: unused variable: `number`
--> src\main.rs:2:9
 |
2 |     for number in 0..3 {
|         ^^^^^^ help: if this is intentional, prefix it with an underscore:
| '_number'
```

Rust suggests writing `_number` instead of `_`. Putting `_` in front of a variable name means "maybe I will use it later". But using just `_` means "I don't care about this variable at all". So you can put `_` in front of variable names if you will use them later and don't want the compiler to tell you about them.

You can also use `break` to return a value. You write the value right after `break` and use a `; .` Here is an example with a `loop` and a break that gives `my_number` its value.

```
fn main() {
    let mut counter = 5;
    let my_number = loop {
        counter +=1;
        if counter % 53 == 3 {
            break counter;
        }
    };
    println!("{}", my_number);
}
```

This prints `56`. `break counter;` means "break and return the value of counter". And because the whole block starts with `let`, `my_number` gets the value.

Now that we know how to use loops, here is a better solution to our `match` problem with colours from before. It is a better solution because we want to compare everything, and a `for` loop looks at every item.

```
fn match_colours(rgb: (i32, i32, i32)) {
    println!("Comparing a colour with {} red, {} blue, and {} green:", rbg.0, rbg.1, rbg.2);
    let new_vec = vec![(rbg.0, "red"), (rbg.1, "blue"), (rbg.2, "green")]; // Put the colours in a vec. Inside are tuples with the colour names
    let mut all_have_at_least_10 = true; // Start with true. We will set it to false if one colour is less than 10
    for item in new_vec {
        if item.0 < 10 {
            all_have_at_least_10 = false; // Now it's false
            println!("Not much {}.", item.1) // And we print the colour name.
        }
    }
    if all_have_at_least_10 { // Check if it's still true, and print if true
        println!("Each colour has at least 10.")
    }
    println!(); // Add one more line
}

fn main() {
    let first = (200, 0, 0);
    let second = (50, 50, 50);
    let third = (200, 50, 0);

    match_colours(first);
    match_colours(second);
    match_colours(third);
}
```

This prints:

```
Comparing a colour with 200 red, 0 blue, and 0 green:
Not much blue.
Not much green.
```

```
Comparing a colour with 50 red, 50 blue, and 50 green:
Each colour has at least 10.
```

```
Comparing a colour with 200 red, 50 blue, and 0 green:
Not much green.
```

Implementing structs and enums

This is where you can start to give your structs and enums some real power. To call functions on a `struct` or an `enum`, use an `impl` block. These functions are called **methods**. There are two kinds of methods in an `impl` block.

- Methods: these take `self` (or `&self` or `&mut self`). Regular methods use a `.` (a period). `.clone()` is an example of a regular method.
- Associated functions (known as "static" methods in some languages): these do not take self. Associated means "related to". They are written differently, using `::`. `String::from()` is an associated function, and so is `Vec::new()`. You see associated functions most often used to create new variables.

In our example we are going to create animals and print them.

For a new `struct` or `enum`, you need to give it **Debug** if you want to use `{:?}` to print, so we will do that. If you write `#[derive(Debug)]` above the struct or enum then you can print it with `{:?}`. These messages with `#[]` are called **attributes**. You can sometimes use them to tell the compiler to give your struct an ability like `Debug`. There are many attributes and we will learn about them later. But `derive` is probably the most common and you see it a lot above structs and enums.

```

#[derive(Debug)]
struct Animal {
    age: u8,
    animal_type: AnimalType,
}

#[derive(Debug)]
enum AnimalType {
    Cat,
    Dog,
}

impl Animal {
    fn new() -> Self {
        // Self means Animal.
        // You can also write Animal instead of Self

        Self {
            // When we write Animal::new(), we always get a cat that is 10 years old
            age: 10,
            animal_type: AnimalType::Cat,
        }
    }

    fn change_to_dog(&mut self) { // because we are inside Animal, &mut self means &mut
        Animal
            // use .change_to_dog() to change the cat to a dog
            // with &mut self we can change it
            println!("Changing animal to dog!");
            self.animal_type = AnimalType::Dog;
    }

    fn change_to_cat(&mut self) {
        // use .change_to_cat() to change the dog to a cat
        // with &mut self we can change it
        println!("Changing animal to cat!");
        self.animal_type = AnimalType::Cat;
    }

    fn check_type(&self) {
        // we want to read self
        match self.animal_type {
            AnimalType::Dog => println!("The animal is a dog"),
            AnimalType::Cat => println!("The animal is a cat"),
        }
    }
}

fn main() {
    let mut new_animal = Animal::new(); // Associated function to create a new animal
                                        // It is a cat, 10 years old
    new_animal.check_type();
    new_animal.change_to_dog();
    new_animal.check_type();
    new_animal.change_to_cat();
    new_animal.check_type();
}

```

This prints:

```
The animal is a cat
Changing animal to dog!
The animal is a dog
Changing animal to cat!
The animal is a cat
```

Remember that Self (the type Self) and self (the variable self) are abbreviations. (abbreviation = short way to write)

So in our code, Self = Animal. Also, `fn change_to_dog(&mut self)` means `fn change_to_dog(&mut Animal)`.

Here is one more small example. This time we will use `impl` on an `enum`:

```
enum Mood {
    Good,
    Bad,
    Sleepy,
}

impl Mood {
    fn check(&self) {
        match self {
            Mood::Good => println!("Feeling good!"),
            Mood::Bad => println!("Eh, not feeling so good"),
            Mood::Sleepy => println!("Need sleep NOW"),
        }
    }
}

fn main() {
    let my_mood = Mood::Sleepy;
    my_mood.check();
}
```

This prints `Need sleep NOW.`

Destructuring

Let's look at some more destructuring. You can get the values from a struct or enum by using `let` backwards. We learned that this is `destructuring`, because you get variables that are not part of a structure. Now you have the values separately. First a simple example:

```
struct Person { // make a simple struct for a person
    name: String,
    real_name: String,
    height: u8,
    happiness: bool
}

fn main() {
    let papa_doc = Person { // create variable papa_doc
        name: "Papa Doc".to_string(),
        real_name: "Clarence".to_string(),
        height: 170,
        happiness: false
    };

    let Person { // destructure papa_doc
        name: a,
        real_name: b,
        height: c,
        happiness: d
    } = papa_doc;

    println!("They call him {} but his real name is {}. He is {} cm tall and is he
    happy? {}", a, b, c, d);
}
```

This prints: They call him Papa Doc but his real name is Clarence. He is 170 cm tall and is he happy? false

You can see that it's backwards. First we say `let papa_doc = Person { fields }` to create the struct. Then we say `let Person { fields } = papa_doc` to destructure it.

You don't have to write `name: a` - you can just write `name`. But here we write `name: a` because we want to use a variable with the name `a`.

Now a bigger example. In this example we have a `City` struct. We give it a `new` function to make it. Then we have a `process_city_values` function to do things with the values. In the function we just create a `vec`, but you can imagine that we can do much more after we destructure it.

```
struct City {  
    name: String,  
    name_before: String,  
    population: u32,  
    date_founded: u32,  
}  
  
impl City {  
    fn new(name: String, name_before: String, population: u32, date_founded: u32) ->  
    Self {  
        Self {  
            name,  
            name_before,  
            population,  
            date_founded,  
        }  
    }  
}  
  
fn process_city_values(city: &City) {  
    let City {  
        name,  
        name_before,  
        population,  
        date_founded,  
    } = city;  
    // now we have the values to use separately  
    let two_names = vec![name, name_before];  
    println!("The city's two names are {:?}", two_names);  
}  
  
fn main() {  
    let tallinn = City::new("Tallinn".to_string(), "Reval".to_string(), 426_538, 1219);  
    process_city_values(&tallinn);  
}
```

This prints The city's two names are ["Tallinn", "Reval"] .

References and the dot operator

We learned that when you have a reference, you need to use `*` to get to the value. A reference is a different type, so this won't work:

```
fn main() {
    let my_number = 9;
    let reference = &my_number;

    println!("{}", my_number == reference); // ⚠
}
```

The compiler prints:

```
error[E0277]: can't compare '{integer}' with '&{integer}'
--> src\main.rs:5:30
|
5 |     println!("{}", my_number == reference);
|             ^^^ no implementation for '{integer} == &{integer}'
```

So we change line 5 to `println!("{}", my_number == *reference);` and now it prints `true` because it's now `i32 == i32`, not `i32 == &i32`. This is called dereferencing.

But when you use a method, Rust will dereference for you. The `.` in a method is called the dot operator, and it does dereferencing for free.

First, let's make a struct with one `u8` field. Then we will make a reference to it and try to compare. It will not work:

```
struct Item {
    number: u8,
}

fn main() {
    let item = Item {
        number: 8,
    };

    let reference_number = &item.number; // reference number type is &u8

    println!("{}", reference_number == 8); // ⚠ &u8 and u8 cannot be compared
}
```

To make it work, we need to dereference: `println!("{}", *reference_number == 8);`.

But with the dot operator, we don't need `*`. For example:

```

struct Item {
    number: u8,
}

fn main() {
    let item = Item {
        number: 8,
    };

    let reference_item = &item;

    println!("{}", reference_item.number == 8); // we don't need to write
*reference_item.number
}

```

Now let's create a method for `Item` that compares `number` to another number. We don't need to use `*` anywhere:

```

struct Item {
    number: u8,
}

impl Item {
    fn compare_number(&self, other_number: u8) { // takes a reference to self
        println!("Are {} and {} equal? {}", self.number, other_number, self.number ==
other_number);
            // We don't need to write *self.number
    }
}

fn main() {
    let item = Item {
        number: 8,
    };

    let reference_item = &item; // This is type &Item
    let reference_item_two = &&reference_item; // This is type &&Item

    item.compare_number(8); // the method works
    reference_item.compare_number(8); // it works here too
    reference_item_two.compare_number(8); // and here
}

```

So just remember: when you use the `.` operator, you don't need to worry about `*`.

Generics

In functions, you write what type to take as input:

```
fn return_number(number: i32) -> i32 {
    println!("Here is your number.");
    number
}

fn main() {
    let number = return_number(5);
}
```

But what if you want to take more than just `i32`? You can use generics for this. Generics means "maybe one type, maybe another type".

For generics, you use angle brackets with the type inside, like this: `<T>`. This means "any type you put into the function". Usually, generics uses types with one capital letter (T, U, V, etc.), though you don't have to just use one letter.

This is how you change the function to make it generic:

```
fn return_number<T>(number: T) -> T {
    println!("Here is your number.");
    number
}

fn main() {
    let number = return_number(5);
}
```

The important part is the `<T>` after the function name. Without this, Rust will think that `T` is a concrete (concrete = not generic) type, like `String` or `i8`.

This is easier to understand if we write out a type name. See what happens when we change `T` to `MyType`:

```
fn return_number(number: MyType) -> MyType { // ⚠
    println!("Here is your number.");
    number
}
```

As you can see, `MyType` is concrete, not generic. So we need to write this and so now it works:

```
fn return_number<MyType>(number: MyType) -> MyType {
    println!("Here is your number.");
    number
}

fn main() {
    let number = return_number(5);
}
```

So the single letter `T` is for human eyes, but the part after the function name is for the compiler's "eyes". Without it, it's not generic.

Now we will go back to type `T`, because Rust code usually uses `T`.

You will remember that some types in Rust are **Copy**, some are **Clone**, some are **Display**, some are **Debug**, and so on. With **Debug**, we can print with `{:?}`. So now you can see that we have a problem if we want to print `T`:

```
fn print_number<T>(number: T) {
    println!("Here is your number: {:?}", number); // ▲
}

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

`print_number` needs **Debug** to print `number`, but is `T` a type with `Debug`? Maybe not. Maybe it doesn't have `#[derive(Debug)]`, who knows. The compiler doesn't know either, so it gives an error:

```
error[E0277]: `T` doesn't implement `std::fmt::Debug`
--> src\main.rs:29:43
   |
29 |     println!("Here is your number: {:?}", number);
   |          ^^^^^^ `T` cannot be formatted using
   |          `{:?}` because it doesn't implement `std::fmt::Debug`
```

`T` doesn't implement **Debug**. So do we implement `Debug` for `T`? No, because we don't know what `T` is. But we can tell the function: "Don't worry, because any type `T` for this function will have `Debug`".

```
use std::fmt::Debug; // Debug is located at std::fmt::Debug. So now we can just write
'Debug'.

fn print_number<T: Debug>(number: T) { // <T: Debug> is the important part
    println!("Here is your number: {:?}", number);
}

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

So now the compiler knows: "Okay, this type `T` is going to have `Debug`". Now the code works, because `i32` has `Debug`. Now we can give it many types: `String`, `&str`, and so on, because they all have `Debug`.

Now we can create a struct and give it `Debug` with `#[derive(Debug)]`, so now we can print it too. Our function can take `i32`, the struct `Animal`, and more:

```
use std::fmt::Debug;

#[derive(Debug)]
struct Animal {
    name: String,
    age: u8,
}

fn print_item<T: Debug>(item: T) {
    println!("Here is your item: {:?}", item);
}

fn main() {
    let charlie = Animal {
        name: "Charlie".to_string(),
        age: 1,
    };

    let number = 55;

    print_item(charlie);
    print_item(number);
}
```

This prints:

```
Here is your item: Animal { name: "Charlie", age: 1 }
Here is your item: 55
```

Sometimes we need more than one type in a generic function. We have to write out each type name, and think about how we want to use it. In this example, we want two types. First we want to print a statement for type T. Printing with {} is nicer, so we will require `Display` for T.

Next is type U, and the two variables `num_1` and `num_2` have type U (U is some sort of number). We want to compare them, so we need `PartialOrd`. That trait lets us use things like `<`, `>`, `==`, and so on. We want to print them too, so we require `Display` for u as well.

```
use std::fmt::Display;
use std::cmp::PartialOrd;

fn compare_and_display<T: Display, U: Display + PartialOrd>(statement: T, num_1: U,
num_2: U) {
    println!("{}! Is {} greater than {}? {}", statement, num_1, num_2, num_1 > num_2);
}

fn main() {
    compare_and_display("Listen up!", 9, 8);
}
```

This prints `Listen up!! Is 9 greater than 8? true.`

So `fn compare_and_display<T: Display, U: Display + PartialOrd>(statement: T, num_1: U, num_2: U)` says:

- The function name is `compare_and_display`,
- The first type is T, and it is generic. It must be a type that can print with {}.
- The next type is U, and it is generic. It must be a type that can print with {}. Also, it must be a type that can compare (use `>`, `<`, and `==`).

Now we can give `compare_and_display` different types. `statement` can be a `String`, a `&str`, anything with `Display`.

To make generic functions easier to read, we can also write it like this with `where` right before the code block:

```
use std::cmp::PartialOrd;
use std::fmt::Display;

fn compare_and_display<T, U>(statement: T, num_1: U, num_2: U)
where
    T: Display,
    U: Display + PartialOrd,
{
    println!("{}! Is {} greater than {}? {}", statement, num_1, num_2, num_1 > num_2);
}

fn main() {
    compare_and_display("Listen up!", 9, 8);
}
```

Using `where` is a good idea when you have many generic types.

Also note:

- If you have one type T and another type T, they must be the same.
- If you have one type T and another type U, they can be different. But they can also be the same.

For example:

```
use std::fmt::Display;

fn say_two<T: Display, U: Display>(statement_1: T, statement_2: U) { // Type T needs
Display, type U needs Display
    println!("I have two things to say: {} and {}", statement_1, statement_2);
}

fn main() {

    say_two("Hello there!", String::from("I hate sand.")); // Type T is a &str, but
type U is a String.
    say_two(String::from("Where is Padme?"), String::from("Is she all right?")); // Both
types are String.
}
```

This prints:

```
I have two things to say: Hello there! and I hate sand.
I have two things to say: Where is Padme? and Is she all right?
```

Option and Result

We understand enums and generics now, so we can understand `option` and `Result`. Rust uses these two enums to make code safer.

We will start with `option`.

Option

You use `option` when you have a value that might exist, or might not exist. When a value exists it is `Some(value)` and when it doesn't it's just `None`, Here is an example of bad code that can be improved with `Option`.

```
// ⚠️
fn take_fifth(value: Vec<i32>) -> i32 {
    value[4]
}

fn main() {
    let new_vec = vec![1, 2];
    let index = take_fifth(new_vec);
}
```

When we run the code, it panics. Here is the message:

```
thread 'main' panicked at 'index out of bounds: the len is 2 but the index is 4',
src\main.rs:34:5
```

Panic means that the program stops before the problem happens. Rust sees that the function wants something impossible, and stops. It "unwinds the stack" (takes the values off the stack) and tells you "sorry, I can't do that".

So now we will change the return type from `i32` to `Option<i32>`. This means "give me a `Some(i32)` if it's there, and give me `None` if it's not". We say that the `i32` is "wrapped" in an `Option`, which means that it's inside an `Option`. You have to do something to get the value out.

```
fn take_fifth(value: Vec<i32>) -> Option<i32> {
    if value.len() < 5 { // .len() gives the length of the vec.
        // It must be at least 5.
        None
    } else {
        Some(value[4])
    }
}

fn main() {
    let new_vec = vec![1, 2];
    let bigger_vec = vec![1, 2, 3, 4, 5];
    println!("{:?}, {:?}", take_fifth(new_vec), take_fifth(bigger_vec));
}
```

This prints `None, Some(5)`. This is good, because now we don't panic anymore. But how do we get the value 5?

We can get the value inside an option with `.unwrap()`, but be careful with `.unwrap()`. It's just like unwrapping a present: maybe there's something good inside, or maybe there's an angry snake inside. You only want to `.unwrap()` if you are sure. If you unwrap a value that is `None`, the program will panic.

```
// ⚠️
fn take_fifth(value: Vec<i32>) -> Option<i32> {
    if value.len() < 5 {
        None
    } else {
        Some(value[4])
    }
}

fn main() {
    let new_vec = vec![1, 2];
    let bigger_vec = vec![1, 2, 3, 4, 5];
    println!("{:?}, {:?}", take_fifth(new_vec).unwrap(), // this one is None. .unwrap() will panic!
        take_fifth(bigger_vec).unwrap()
    );
}
```

The message is:

```
thread 'main' panicked at 'called `Option::unwrap()` on a `None` value',
src\main.rs:14:9
```

But we don't have to use `.unwrap()`. We can use a `match`. Then we can print the value we have `Some`, and not touch it if we have `None`. For example:

```
fn take_fifth(value: Vec<i32>) -> Option<i32> {
    if value.len() < 5 {
        None
    } else {
        Some(value[4])
    }
}

fn handle_option(my_option: Vec<Option<i32>>) {
    for item in my_option {
        match item {
            Some(number) => println!("Found a {}!", number),
            None => println!("Found a None!"),
        }
    }
}

fn main() {
    let new_vec = vec![1, 2];
    let bigger_vec = vec![1, 2, 3, 4, 5];
    let mut option_vec = Vec::new(); // Make a new vec to hold our options
                                    // The vec is type: Vec<Option<i32>>. That means a
                                    // vec of Option<i32>.

    option_vec.push(take_fifth(new_vec)); // This pushes "None" into the vec
    option_vec.push(take_fifth(bigger_vec)); // This pushes "Some(5)" into the vec

    handle_option(option_vec); // handle_option looks at every option in the vec.
                            // It prints the value if it is Some. It doesn't touch
                            // it if it is None.
}
```

This prints:

```
Found a None!
Found a 5!
```

Because we know generics, we are able to read the code for `Option`. It looks like this:

```
enum Option<T> {
    None,
    Some(T),
}

fn main() {}
```

The important point to remember: with `Some`, you have a value of type `T` (any type). Also note that the angle brackets after the `enum` name around `T` is what tells the compiler that it's generic. It has no trait like `Display` or anything to limit it, so it can be anything. But with `None`, you don't have anything.

So in a `match` statement for Option you can't say:

```
// 🚫
Some(value) => println!("The value is {}", value),
None(value) => println!("The value is {}", value),
```

because `None` is just `None`.

Of course, there are easier ways to use Option. In this code, we will use a method called `.is_some()` to tell us if it is `Some`. (Yes, there is also a method called `.is_none()`.) In this easier way, we don't need `handle_option()` anymore. We also don't need a vec for the Options.

```
fn take_fifth(value: Vec<i32>) -> Option<i32> {
    if value.len() < 5 {
        None
    } else {
        Some(value[4])
    }
}

fn main() {
    let new_vec = vec![1, 2];
    let bigger_vec = vec![1, 2, 3, 4, 5];
    let vec_of_vecs = vec![new_vec, bigger_vec];
    for vec in vec_of_vecs {
        let inside_number = take_fifth(vec);
        if inside_number.is_some() {
            // .is_some() returns true if we get Some, false if we get None
            println!("We got: {}", inside_number.unwrap()); // now it is safe to use
.unwrap() because we already checked
        } else {
            println!("We got nothing.");
        }
    }
}
```

This prints:

```
We got nothing.
We got: 5
```

Result

Result is similar to Option, but here is the difference:

- Option is about `Some` or `None` (value or no value),
- Result is about `Ok` or `Err` (okay result, or error result).

So `Option` is if you are thinking: "Maybe there will be something, and maybe there won't." But `Result` is if you are thinking: "Maybe it will fail."

To compare, here are the signatures for Option and Result.

```
enum Option<T> {
    None,
    Some(T),
}

enum Result<T, E> {
    Ok(T),
    Err(E),
}

fn main() {}
```

So Result has a value inside of `Ok`, and a value inside of `Err`. That is because errors usually contain information that describes the error.

`Result<T, E>` means you need to think of what you want to return for `Ok`, and what you want to return for `Err`. Actually, you can decide anything. Even this is okay:

```
fn check_error() -> Result<(), ()> {
    Ok(())
}

fn main() {
    check_error();
}
```

`check_error` says "return `()` if we get `Ok`, and return `()` if we get `Err`". Then we return `Ok` with a `()`.

The compiler gives us an interesting warning:

```
warning: unused `std::result::Result` that must be used
--> src\main.rs:6:5
  |
6 |     check_error();
  |     ^^^^^^^^^^^^^^
  |
= note: #[warn(unused_must_use)]` on by default
= note: this `Result` may be an `Err` variant, which should be handled
```

This is true: we only returned the `Result` but it could have been an `Err`. So let's handle the error a bit, even though we're still not really doing anything.

```

fn give_result(input: i32) -> Result<(), ()> {
    if input % 2 == 0 {
        return Ok(())
    } else {
        return Err(())
    }
}

fn main() {
    if give_result(5).is_ok() {
        println!("It's okay, guys")
    } else {
        println!("It's an error, guys")
    }
}

```

This prints `It's an error, guys`. So we just handled our first error.

Remember, the four methods to easily check are `.is_some()`, `is_none()`, `is_ok()`, and `is_err()`.

Sometimes a function with `Result` will use a `String` for the `Err` value. This is not the best method to use, but it is a little better than what we've done so far.

```

fn check_if_five(number: i32) -> Result<i32, String> {
    match number {
        5 => Ok(number),
        _ => Err("Sorry, the number wasn't five.".to_string()), // This is our error
message
    }
}

fn main() {
    let mut result_vec = Vec::new(); // Create a new vec for the results

    for number in 2..7 {
        result_vec.push(check_if_five(number)); // push each result into the vec
    }

    println!("{:?}", result_vec);
}

```

Our vec prints:

```
[Err("Sorry, the number wasn't five."), Err("Sorry, the number wasn't five."),
Err("Sorry, the number wasn't five."), Ok(5),
Err("Sorry, the number wasn't five.")]
```

Just like `Option`, `.unwrap()` on `Err` will panic.

```

// ▲
fn main() {
    let error_value: Result<i32, &str> = Err("There was an error"); // Create a Result
that is already an Err
    println!("{}", error_value.unwrap()); // Unwrap it
}

```

The program panics, and prints:

```
thread 'main' panicked at 'called `Result::unwrap()` on an `Err` value: "There was an
error"', src\main.rs:30:20
```

This information helps you fix your code. `src\main.rs:30:20` means "inside main.rs in directory src, on line 30 and column 20". So you can go there to look at your code and fix the problem.

You can also create your own error types. Result functions in the standard library and other people's code usually do this. For example, this function from the standard library:

```
// 📦
pub fn from_utf8(vec: Vec<u8>) -> Result<String, FromUtf8Error>
```

This function takes a vector of bytes (`u8`) and tries to make a `String`. So the success case for the `Result` is a `String` and the error case is `FromUtf8Error`. You can give your error type any name you want.

Using a `match` with `Option` and `Result` sometimes requires a lot of code. For example, the `.get()` method returns an `Option` on a `Vec`.

```
fn main() {
    let my_vec = vec![2, 3, 4];
    let get_one = my_vec.get(0); // 0 to get the first number
    let get_two = my_vec.get(10); // Returns None
    println!("{:?}", get_one);
    println!("{:?}", get_two);
}
```

This prints

```
Some(2)
None
```

So now we can match to get the values. Let's use a range from 0 to 10 to see if it matches the numbers in `my_vec`.

```
fn main() {
    let my_vec = vec![2, 3, 4];

    for index in 0..10 {
        match my_vec.get(index) {
            Some(number) => println!("The number is: {}", number),
            None => {}
        }
    }
}
```

This is good, but we don't do anything for `None` because we don't care. Here we can make the code smaller by using `if let`. `if let` means "do something if it matches, and don't do anything if it doesn't". `if let` is when you don't care about matching for everything.

```
fn main() {
    let my_vec = vec![2, 3, 4];

    for index in 0..10 {
        if let Some(number) = my_vec.get(index) {
            println!("The number is: {}", number);
        }
    }
}
```

Important to remember: `if let Some(number) = my_vec.get(index)` means "if you get `Some(number)` from `my_vec.get(index)`".

Also note: it uses one `=`. It is not a boolean.

`while let` is like a while loop for `if let`. Imagine that we have weather station data like this:

```
[ "Berlin", "cloudy", "5", "-7", "78"]
[ "Athens", "sunny", "not humid", "20", "10", "50"]
```

We want to get the numbers, but not the words. For the numbers, we can use a method called `parse::<i32>().parse()`. `parse()` is the method, and `::<i32>` is the type. It will try to turn the `&str` into an `i32`, and give it to us if it can. It returns a `Result`, because it might not work (like if you wanted it to parse "Billybobby" - that's not a number).

We will also use `.pop()`. This takes the last item off of the vector.

```
fn main() {
    let weather_vec = vec![
        vec![ "Berlin", "cloudy", "5", "-7", "78"],
        vec![ "Athens", "sunny", "not humid", "20", "10", "50"],
    ];
    for mut city in weather_vec {
        println!("For the city of {}: ", city[0]); // In our data, every first item is
the city name
        while let Some(information) = city.pop() {
            // This means: keep going until you can't pop anymore
            // When the vector reaches 0 items, it will return None
            // and it will stop.
            if let Ok(number) = information.parse::<i32>() {
                // Try to parse the variable we called information
                // This returns a result. If it's Ok(number), it will print it
                println!("The number is: {}", number);
            } // We don't write anything here because we do nothing if we get an
error. Throw them all away
        }
    }
}
```

This will print:

```
For the city of Berlin:
The number is: 78
The number is: -7
The number is: 5
For the city of Athens:
The number is: 50
The number is: 10
The number is: 20
```

Other collections

Rust has many more types of collections. You can see them at <https://doc.rust-lang.org/beta/std/collections/> in the standard library. That page has good explanations for why to use one type, so go there if you don't know what type you want. These collections are all inside `std::collections` in the standard library. The best way to use them is with a `use` statement, like we did with our `enums`. We will start with `HashMap`, which is very common.

HashMap (and BTreeMap)

A `HashMap` is a collection made out of *keys* and *values*. You use the key to look up the value that matches the key. You can create a new `HashMap` with just `HashMap::new()` and use `.insert(key, value)` to insert items.

A `HashMap` is not in order, so if you print every key in a `HashMap` together it will probably print differently. We can see this in an example:

```
use std::collections::HashMap; // This is so we can just write HashMap instead of std::collections::HashMap every time

struct City {
    name: String,
    population: HashMap<u32, u32>, // This will have the year and the population for the year
}

fn main() {
    let mut tallinn = City {
        name: "Tallinn".to_string(),
        population: HashMap::new(), // So far the HashMap is empty
    };

    tallinn.population.insert(1372, 3_250); // insert three dates
    tallinn.population.insert(1851, 24_000);
    tallinn.population.insert(2020, 437_619);

    for (year, population) in tallinn.population { // The HashMap is HashMap<u32, u32>
        so it returns a two items each time
        println!("In the year {} the city of {} had a population of {}.", year,
tallinn.name, population);
    }
}
```

This prints:

```
In the year 1372 the city of Tallinn had a population of 3250.
In the year 2020 the city of Tallinn had a population of 437619.
In the year 1851 the city of Tallinn had a population of 24000.
```

or it might print:

```
In the year 1851 the city of Tallinn had a population of 24000.
In the year 2020 the city of Tallinn had a population of 437619.
In the year 1372 the city of Tallinn had a population of 3250.
```

You can see that it's not in order.

If you want a `HashMap` that you can sort, you can use a `BTreeMap`. Actually they are very similar to each other, so we can quickly change our `HashMap` to a `BTreeMap` to see. You can see that it is almost the same code.

```
use std::collections::BTreeMap; // Just change HashMap to BTreeMap

struct City {
    name: String,
    population: BTreeMap<u32, u32>, // Just change HashMap to BTreeMap
}

fn main() {

    let mut tallinn = City {
        name: "Tallinn".to_string(),
        population: BTreeMap::new(), // Just change HashMap to BTreeMap
    };

    tallinn.population.insert(1372, 3_250);
    tallinn.population.insert(1851, 24_000);
    tallinn.population.insert(2020, 437_619);

    for (year, population) in tallinn.population {
        println!("In the year {} the city of {} had a population of {}.", year,
tallinn.name, population);
    }
}
```

Now it will always print:

```
In the year 1372 the city of Tallinn had a population of 3250.
In the year 1851 the city of Tallinn had a population of 24000.
In the year 2020 the city of Tallinn had a population of 437619.
```

Now we will go back to `HashMap`.

You can get a value in a `HashMap` by just putting the key in `[]` square brackets. In this next example we will bring up the value for the key `Bielefeld`, which is `Germany`. But be careful, because the program will crash if there is no key. If you write `println!("{}:?", city_hashmap["Bielefeld"]);` for example then it will crash, because `Bielefeld` doesn't exist.

If you are not sure that there will be a key, you can use `.get()` which returns an `Option`. If it exists it will be `Some(value)`, and if not you will get `None` instead of crashing the program. That's why `.get()` is the safer way to get a value from a `HashMap`.

```
use std::collections::HashMap;

fn main() {
    let canadian_cities = vec!["Calgary", "Vancouver", "Gimli"];
    let german_cities = vec!["Karlsruhe", "Bad Doberan", "Bielefeld"];

    let mut city_hashmap = HashMap::new();

    for city in canadian_cities {
        city_hashmap.insert(city, "Canada");
    }
    for city in german_cities {
        city_hashmap.insert(city, "Germany");
    }

    println!("{}: {:?}", city_hashmap["Bielefeld"]);
    println!("{}: {:?}", city_hashmap.get("Bielefeld"));
    println!("{}: {:?}", city_hashmap.get("Bielefeldd"));
}
```

This prints:

```
"Germany"
Some("Germany")
None
```

This is because *Bielefeld* exists, but *Bielefeldd* does not exist.

If a `HashMap` already has a key when you try to put it in, it will overwrite its value:

```
use std::collections::HashMap;

fn main() {
    let mut book_hashmap = HashMap::new();

    book_hashmap.insert(1, "L'Allemagne Moderne");
    book_hashmap.insert(1, "Le Petit Prince");
    book_hashmap.insert(1, "섀도우 오브 유어 스마일");
    book_hashmap.insert(1, "Eye of the World");

    println!("{}: {:?}", book_hashmap.get(&1));
}
```

This prints `Some("Eye of the World")`, because it was the last one you used `.insert()` for.

It is easy to check if an entry exists, because you can check with `.get()` which gives an `Option`:

```
use std::collections::HashMap;

fn main() {
    let mut book_hashmap = HashMap::new();

    book_hashmap.insert(1, "L'Allemagne Moderne");

    if book_hashmap.get(&1).is_none() { // is_none() returns a bool: true if it's None,
        book_hashmap.insert(1, "Le Petit Prince");
    }

    println!("{}: {:?}", book_hashmap.get(&1));
}
```

This prints `Some("L'\Allemagne Moderne")` because there was already a key for `1`, so we didn't insert `Le Petit Prince`.

`HashMap` has a very interesting method called `.entry()` that you definitely want to try out. With it you can try to make an entry and use another method like `.or_insert()` to insert the value if there is no key. The interesting part is that it also gives a mutable reference so you can change it if you want. First is an example where we just insert `true` every time we insert a book title into the `HashMap`.

Let's pretend that we have a library and want to keep track of our books.

```
use std::collections::HashMap;

fn main() {
    let book_collection = vec![ "L'Allemagne Moderne", "Le Petit Prince", "Eye of the World", "Eye of the World" ]; // Eye of the World appears twice

    let mut book_hashmap = HashMap::new();

    for book in book_collection {
        book_hashmap.entry(book).or_insert(true);
    }
    for (book, true_or_false) in book_hashmap {
        println!("Do we have {}? {}", book, true_or_false);
    }
}
```

This prints:

```
Do we have Eye of the World? true
Do we have Le Petit Prince? true
Do we have L'Allemagne Moderne? true
```

But that's not exactly what we want. Maybe it would be better to count the number of books so that we know that there are two copies of *Eye of the World*. First let's look at what `.entry()` does, and what `.or_insert()` does. `.entry()` actually returns an `enum` called `Entry`:

```
// 📄
pub fn entry(&mut self, key: K) -> Entry<K, V> // 📄
```

Here is the page for [Entry](#). Here is a simple version of its code. `K` means key and `V` means value.

```
// 📄
use std::collections::hash_map::*;

enum Entry<K, V> {
    Occupied(OccupiedEntry<K, V>),
    Vacant(VacantEntry<K, V>),
}
```

Then when we call `.or_insert()`, it looks at the enum and decides what to do.

```
fn or_insert(self, default: V) -> &mut V { // 🚧
    match self {
        Occupied(entry) => entry.into_mut(),
        Vacant(entry) => entry.insert(default),
    }
}
```

The interesting part is that it returns a `&mut` reference: `&mut V`. That means you can use `let` to attach it to a variable, and change the variable to change the value in the `HashMap`. So for every book we will insert a 0 if there is no entry. And if there is one, we will use `+= 1` on the reference to increase the number. Now it looks like this:

```
use std::collections::HashMap;

fn main() {
    let book_collection = vec!["L'Allemagne Moderne", "Le Petit Prince", "Eye of the World", "Eye of the World"];

    let mut book_hashmap = HashMap::new();

    for book in book_collection {
        let return_value = book_hashmap.entry(book).or_insert(0); // return_value is a mutable reference. If nothing is there, it will be 0
        *return_value += 1; // Now return_value is at least 1. And if there was another book, it will go up by 1
    }

    for (book, number) in book_hashmap {
        println!("{}: {}", book, number);
    }
}
```

The important part is `let return_value = book_hashmap.entry(book).or_insert(0);`. If you take out the `let`, you get `book_hashmap.entry(book).or_insert(0)`. Without `let` it does nothing: it inserts 0, and nobody takes the mutable reference to 0. So we bind it to `return_value` so we can keep the 0. Then we increase the value by 1, which gives at least 1 for every book in the `HashMap`. Then when `.entry()` looks at *Eye of the World* again it doesn't insert anything, but it gives us a mutable 1. Then we increase it to 2, and that's why it prints this:

```
L'Allemagne Moderne, 1
Le Petit Prince, 1
Eye of the World, 2
```

You can also do things with `.or_insert()` like insert a vec and then push into the vec. Let's pretend that we asked men and women on the street what they think of a politician. They give a rating from 0 to 10. Then we want to put the numbers together to see if the politician is more popular with men or women. It can look like this:

```

use std::collections::HashMap;

fn main() {
    let data = vec![ // This is the raw data
        ("male", 9),
        ("female", 5),
        ("male", 0),
        ("female", 6),
        ("female", 5),
        ("male", 10),
    ];

    let mut survey_hash = HashMap::new();

    for item in data { // This gives a tuple of (&str, i32)
        survey_hash.entry(item.0).or_insert(Vec::new()).push(item.1); // This pushes
        the number into the Vec inside
    }

    for (male_or_female, numbers) in survey_hash {
        println!("{}: {:?}", male_or_female, numbers);
    }
}

```

This prints:

```

"female", [5, 6, 5]
"male", [9, 0, 10]

```

The important line is: `survey_hash.entry(item.0).or_insert(Vec::new()).push(item.1);` So if it sees "female" it will check to see if there is "female" already in the `HashMap`. If not, it will insert a `Vec::new()`, then push the number in. If it sees "female" already in the `HashMap`, it will not insert a new `Vec`, and will just push the number into it.

HashSet and BTreeset

A `HashSet` is actually a `HashMap` that only has keys. On [the page for HashSet](#) it explains this on the top:

`A hash set implemented as a HashMap where the value is ()`. So it's a `HashMap` with keys, no values.

You often use a `HashSet` if you just want to know if a key exists, or doesn't exist.

Imagine that you have 100 random numbers, and each number between 1 and 100. If you do this, some numbers will appear more than once, while some won't appear at all. If you put them into a `HashSet` then you will have a list of all the numbers that appeared.

```

use std::collections::HashSet;

fn main() {
    let many_numbers = vec![
        94, 42, 59, 64, 32, 22, 38, 5, 59, 49, 15, 89, 74, 29, 14, 68, 82, 80, 56, 41,
        36, 81, 66,
        51, 58, 34, 59, 44, 19, 93, 28, 33, 18, 46, 61, 76, 14, 87, 84, 73, 71, 29, 94,
        10, 35, 20,
        35, 80, 8, 43, 79, 25, 60, 26, 11, 37, 94, 32, 90, 51, 11, 28, 76, 16, 63, 95,
        13, 60, 59,
        96, 95, 55, 92, 28, 3, 17, 91, 36, 20, 24, 0, 86, 82, 58, 93, 68, 54, 80, 56,
        22, 67, 82,
        58, 64, 80, 16, 61, 57, 14, 11];
    let mut number_hashset = HashSet::new();

    for number in many_numbers {
        number_hashset.insert(number);
    }

    let hashset_length = number_hashset.len(); // The length tells us how many numbers
    are in it
    println!("There are {} unique numbers, so we are missing {}.", hashset_length, 100
    - hashset_length);

    // Let's see what numbers we are missing
    let mut missing_vec = vec![];
    for number in 0..100 {
        if number_hashset.get(&number).is_none() { // If .get() returns None,
            missing_vec.push(number);
        }
    }

    print!("It does not contain: ");
    for number in missing_vec {
        print!("{} ", number);
    }
}

```

This prints:

```

There are 66 unique numbers, so we are missing 34.
It does not contain: 1 2 4 6 7 9 12 21 23 27 30 31 39 40 45 47 48 50 52 53 62 65 69 70
72 75 77 78 83 85 88 97 98 99

```

A `BTreeset` is similar to a `HashSet` in the same way that a `BTreeMap` is similar to a `HashMap`. If we print each item in the `HashSet`, we don't know what the order will be:

```

for entry in number_hashset { // 🚧
    print!("{} ", entry);
}

```

Maybe it will print this: 67 28 42 25 95 59 87 11 5 81 64 34 8 15 13 86 10 89 63 93 49 41 46
57 60 29 17 22 74 43 32 38 36 76 71 18 14 84 61 16 35 90 56 54 91 19 94 44 3 0 68 80 51
92 24 20 82 26 58 33 55 96 37 66 79 73. But it will almost never print it in the same way again.

Here as well, it is easy to change your `HashSet` to a `BTreeset` if you decide you need ordering. In our code, we only need to make two changes to switch from a `HashSet` to a `BTreeset`.

```
use std::collections::BTreeSet; // Change HashSet to BTreeSet

fn main() {
    let many_numbers = vec![
        94, 42, 59, 64, 32, 22, 38, 5, 59, 49, 15, 89, 74, 29, 14, 68, 82, 80, 56, 41,
        36, 81, 66,
        51, 58, 34, 59, 44, 19, 93, 28, 33, 18, 46, 61, 76, 14, 87, 84, 73, 71, 29, 94,
        10, 35, 20,
        35, 80, 8, 43, 79, 25, 60, 26, 11, 37, 94, 32, 90, 51, 11, 28, 76, 16, 63, 95,
        13, 60, 59,
        96, 95, 55, 92, 28, 3, 17, 91, 36, 20, 24, 0, 86, 82, 58, 93, 68, 54, 80, 56,
        22, 67, 82,
        58, 64, 80, 16, 61, 57, 14, 11];
}

let mut number_btreeset = BTreeSet::new(); // Change HashSet to BTreeSet

for number in many_numbers {
    number_btreeset.insert(number);
}
for entry in number_btreeset {
    print!("{} ", entry);
}
}
```

Now it will print in order: 0 3 5 8 10 11 13 14 15 16 17 18 19 20 22 24 25 26 28 29 32 33 34
 35 36 37 38 41 42 43 44 46 49 51 54 55 56 57 58 59 60 61 63 64 66 67 68 71 73 74 76 79 80
 81 82 84 86 87 89 90 91 92 93 94 95 96.

BinaryHeap

A `BinaryHeap` is an interesting collection type, because it is mostly unordered but has a bit of order. It keeps the largest item in the front, but the other items are in any order.

We will use another list of items for an example, but this time smaller.

```

use std::collections::BinaryHeap;

fn show_remainder(input: &BinaryHeap<i32>) -> Vec<i32> { // This function shows the
    remainder in the BinaryHeap. Actually an iterator would be
                                                // faster than a function - we
    will learn them later.
    let mut remainder_vec = vec![];
    for number in input {
        remainder_vec.push(*number)
    }
    remainder_vec
}

fn main() {
    let many_numbers = vec![0, 5, 10, 15, 20, 25, 30]; // These numbers are in order

    let mut my_heap = BinaryHeap::new();

    for number in many_numbers {
        my_heap.push(number);
    }

    while let Some(number) = my_heap.pop() { // .pop() returns Some(number) if a number
        is there, None if not. It pops from the front
        println!("Popped off {}. Remaining numbers are: {:?}", number,
        show_remainder(&my_heap));
    }
}

```

This prints:

```

Popped off 30. Remaining numbers are: [25, 15, 20, 0, 10, 5]
Popped off 25. Remaining numbers are: [20, 15, 5, 0, 10]
Popped off 20. Remaining numbers are: [15, 10, 5, 0]
Popped off 15. Remaining numbers are: [10, 0, 5]
Popped off 10. Remaining numbers are: [5, 0]
Popped off 5. Remaining numbers are: [0]
Popped off 0. Remaining numbers are: []

```

You can see that the number in the 0 index is always largest: 25, 20, 15, 10, 5, then 0. But the other ones are all different.

A good way to use a `BinaryHeap` is for a collection of things to do. Here we create a `BinaryHeap<(u8, &str)>` where the `u8` is a number for the importance of the task. The `&str` is a description of what to do.

```

use std::collections::BinaryHeap;

fn main() {
    let mut jobs = BinaryHeap::new();

    // Add jobs to do throughout the day
    jobs.push((100, "Write back to email from the CEO"));
    jobs.push((80, "Finish the report today"));
    jobs.push((5, "Watch some YouTube"));
    jobs.push((70, "Tell your team members thanks for always working hard"));
    jobs.push((30, "Plan who to hire next for the team"));

    while let Some(job) = jobs.pop() {
        println!("You need to: {}", job.1);
    }
}

```

This will always print:

```
You need to: Write back to email from the CEO
You need to: Finish the report today
You need to: Tell your team members thanks for always working hard
You need to: Plan who to hire next for the team
You need to: Watch some YouTube
```

VecDeque

A `VecDeque` is a `Vec` that is good at popping items both off the front and the back. Rust has `VecDeque` because a `Vec` is great for popping off the back (the last item), but not so great off the front. When you use `.pop()` on a `Vec`, it just takes off the last item on the right and nothing else is moved. But if you take it off another part, all the items to the right are moved over one position to the left. You can see this in the description for `.remove()`:

```
Removes and returns the element at position index within the vector, shifting all elements after it to the left.
```

So if you do this:

```
fn main() {
    let mut my_vec = vec![9, 8, 7, 6, 5];
    my_vec.remove(0);
}
```

it will remove `9`. `8` in index 1 will move to index 0, `7` in index 2 will move to index 1, and so on. Imagine a big parking lot where every time one car leaves all the cars on the right side have to move over.

This, for example, is a *lot* of work for the computer. In fact, if you run it on the Playground it will probably just give up because it's too much work.

```
fn main() {
    let mut my_vec = vec![0; 600_000];
    for i in 0..600000 {
        my_vec.remove(0);
    }
}
```

This is a `Vec` of 600,000 zeros. Every time you use `remove(0)` on it, it moves each zero left one space to the left. And then it does it 600,000 times.

You don't have to worry about that with a `VecDeque`. It is usually a bit slower than a `Vec`, but if you have to do things on both ends then it is much faster. You can just use `VecDeque::from` with a `Vec` to make one. Our code above then looks like this:

```
use std::collections::VecDeque;

fn main() {
    let mut my_vec = VecDeque::from(vec![0; 600000]);
    for i in 0..600000 {
        my_vec.pop_front(); // pop_front is like .pop but for the front
    }
}
```

It is now much faster, and on the Playground it finishes in under a second instead of giving up.

In this next example we have a `Vec` of things to do. Then we make a `VecDeque` and use `.push_front()` to put them at the front, so the first item we added will be on the right. But each item we push is a `(&str, bool)`: `&str` is the description and `false` means it's not done yet. We use our `done()` function to pop an item off the back, but we don't want to delete it. Instead, we change `false` to `true` and push it at the front so that we can keep it.

It looks like this:

```
use std::collections::VecDeque;

fn check_remaining(input: &VecDeque<(&str, bool)>) { // Each item is a (&str, bool)
    for item in input {
        if item.1 == false {
            println!("You must: {}", item.0);
        }
    }
}

fn done(input: &mut VecDeque<(&str, bool)>) {
    let mut task_done = input.pop_back().unwrap(); // pop off the back
    task_done.1 = true; // now it's done - mark as true
    input.push_front(task_done); // put it at the front now
}

fn main() {
    let mut my_vecdeque = VecDeque::new();
    let things_to_do = vec!["send email to customer", "add new product to list", "phone
Loki back"];

    for thing in things_to_do {
        my_vecdeque.push_front((thing, false));
    }

    done(&mut my_vecdeque);
    done(&mut my_vecdeque);

    check_remaining(&my_vecdeque);

    for task in my_vecdeque {
        print!("{:?}", task);
    }
}
```

This prints:

```
You must: phone Loki back
("add new product to list", true) ("send email to customer", true) ("phone Loki back",
false)
```

The ? operator

There is an even shorter way to deal with `Result` (and `Option`), shorter than `match` and even shorter than `if let`. It is called the "question mark operator", and is just `? .` After a function that returns a result, you can add `? .` This will:

- return what is inside the `Result` if it is `Ok`
- pass the error back if it is `Err`

In other words, it does almost everything for you.

We can try this with `.parse()` again. We will write a function called `parse_str` that tries to turn a `&str` into a `i32`. It looks like this:

```
use std::num::ParseIntError;

fn parse_str(input: &str) -> Result<i32, ParseIntError> {
    let parsed_number = input.parse::<i32>()?;
    Ok(parsed_number)
}

fn main() {}
```

This function takes a `&str`. If it is `Ok`, it gives an `i32` wrapped in `Ok`. If it is an `Err`, it returns a `ParseIntError`. Then we try to parse the number, and add `? .` That means "check if it is an error, and give what is inside the `Result` if it is okay". If it is not okay, it will return the error and end. But if it is okay, it will go to the next line. On the next line is the number inside of `Ok()`. We need to wrap it in `Ok` because the return is `Result<i32, ParseIntError>`, not `i32`.

Now, we can try out our function. Let's see what it does with a vec of `&str`s.

```
fn parse_str(input: &str) -> Result<i32, std::num::ParseIntError> {
    let parsed_number = input.parse::<i32>()?;
    Ok(parsed_number)
}

fn main() {
    let str_vec = vec!["Seven", "8", "9.0", "nice", "6060"];
    for item in str_vec {
        let parsed = parse_str(item);
        println!("{}: {:?}", item, parsed);
    }
}
```

This prints:

```
Err(ParseIntError { kind: InvalidDigit })
Ok(8)
Err(ParseIntError { kind: InvalidDigit })
Err(ParseIntError { kind: InvalidDigit })
Ok(6060)
```

How did we find `std::num::ParseIntError`? One easy way is to "ask" the compiler again.

```
fn main() {
    let failure = "Not a number".parse::<i32>();
    failure.rbrbrb(); // ⚠ Compiler: "What is rbrbrb()???""
}
```

The compiler doesn't understand, and says:

```
error[E0599]: no method named `rbrbrb` found for enum `std::result::Result<i32,
std::num::ParseIntError>` in the current scope
--> src\main.rs:3:13
 |
3 |     failure.rbrbrb();
 |     ^^^^^^ method not found in `std::result::Result<i32,
std::num::ParseIntError>`
```

So `std::result::Result<i32, std::num::ParseIntError>` is the signature we need.

We don't need to write `std::result::Result` because `Result` is always "in scope" (in scope = ready to use). Rust does this for all the types we use a lot so we don't have to write `std::result::Result`, `std::collections::Vec`, etc.

We aren't working with things like files yet, so the `?` operator doesn't look too useful yet. But here is a useless but quick example that shows how you can use it on a single line. Instead of making an `i32` with `.parse()`, we'll do a lot more. We'll make an `u16`, then turn it to a `String`, then a `u32`, then to a `String` again, and finally to a `i32`.

```
use std::num::ParseIntError;

fn parse_str(input: &str) -> Result<i32, ParseIntError> {
    let parsed_number = input.parse::<u16>()?.to_string().parse::<u32>()
        ?.to_string().parse::<i32>()?;
    Ok(parsed_number)
}

fn main() {
    let str_vec = vec!["Seven", "8", "9.0", "nice", "6060"];
    for item in str_vec {
        let parsed = parse_str(item);
        println!("{}:?", parsed);
    }
}
```

This prints the same thing, but this time we handled three `Results` in a single line. Later on we will do this with files, because they always return `Results` because many things can go wrong.

Imagine the following: you want to open a file, write to it, and close it. First you need to successfully find the file (that's a `Result`). Then you need to successfully write to it (that's a `Result`). With `?` you can do that on one line.

When panic and unwrap are good

Rust has a `panic!` macro that you can use to make it panic. It is easy to use:

```
fn main() {
    panic!("Time to panic!");
}
```

The message "Time to panic!" displays when you run the program: `thread 'main' panicked at 'Time to panic!', src\main.rs:2:3`

You will remember that `src\main.rs` is the directory and file name, and `2:3` is the line and column name. With this information, you can find the code and fix it.

`panic!` is a good macro to use to make sure that you know when something changes. For example, this function called `prints_three_things` always prints index [0], [1], and [2] from a vector. It is okay because we always give it a vector with three items:

```
fn prints_three_things(vector: Vec<i32>) {
    println!("{} {}, {}", vector[0], vector[1], vector[2]);
}

fn main() {
    let my_vec = vec![8, 9, 10];
    prints_three_things(my_vec);
}
```

It prints `8, 9, 10` and everything is fine.

But imagine that later on we write more and more code, and forget that `my_vec` can only be three things. Now `my_vec` in this part has six things:

```
fn prints_three_things(vector: Vec<i32>) {
    println!("{} {}, {}", vector[0], vector[1], vector[2]);
}

fn main() {
    let my_vec = vec![8, 9, 10, 10, 55, 99]; // Now my_vec has six things
    prints_three_things(my_vec);
}
```

No error happens, because [0] and [1] and [2] are all inside this longer `Vec`. But what if it was really important to only have three things? We wouldn't know that there was a problem because the program doesn't panic. We should have done this instead:

```
fn prints_three_things(vector: Vec<i32>) {
    if vector.len() != 3 {
        panic!("my_vec must always have three items") // will panic if the length is
not 3
    }
    println!("{} {}, {}", vector[0], vector[1], vector[2]);
}

fn main() {
    let my_vec = vec![8, 9, 10];
    prints_three_things(my_vec);
}
```

Now we will know if the vector has six items because it panics as it should:

```
// ⚠️
fn prints_three_things(vector: Vec<i32>) {
    if vector.len() != 3 {
        panic!("my_vec must always have three items")
    }
    println!("{} , {} , {}", vector[0], vector[1], vector[2]);
}

fn main() {
    let my_vec = vec![8, 9, 10, 10, 55, 99];
    prints_three_things(my_vec);
}
```

This gives us `thread 'main' panicked at 'my_vec must always have three items', src\main.rs:8:9`. Thanks to `panic!`, we now remember that `my_vec` should only have three items. So `panic!` is a good macro to create reminders in your code.

There are three other macros that are similar to `panic!` that you use a lot in testing. They are: `assert!`, `assert_eq!`, and `assert_ne!`.

Here is what they mean:

- `assert!()`: if the part inside `()` is not true, the program will panic.
- `assert_eq!()`: the two items inside `()` must be equal.
- `assert_ne!()`: the two items inside `()` must not be equal. (`ne` means not equal)

Some examples:

```
fn main() {
    let my_name = "Loki Laufeyson";

    assert!(my_name == "Loki Laufeyson");
    assert_eq!(my_name, "Loki Laufeyson");
    assert_ne!(my_name, "Mithridates");
}
```

This will do nothing, because all three assert macros are okay. (This is what we want)

You can also add a message if you want.

```
fn main() {
    let my_name = "Loki Laufeyson";

    assert!(
        my_name == "Loki Laufeyson",
        "{} should be Loki Laufeyson",
        my_name
    );
    assert_eq!(
        my_name, "Loki Laufeyson",
        "{} and Loki Laufeyson should be equal",
        my_name
    );
    assert_ne!(
        my_name, "Mithridates",
        "You entered {}. Input must not equal Mithridates",
        my_name
    );
}
```

These messages will only display if the program panics. So if you run this:

```
fn main() {
    let my_name = "Mithridates";

    assert_ne!(
        my_name, "Mithridates",
        "You enter {}. Input must not equal Mithridates",
        my_name
    );
}
```

It will display:

```
thread 'main' panicked at 'assertion failed: `(left != right)`
left: `\"Mithridates\"`,
right: `\"Mithridates\"`: You entered Mithridates. Input must not equal Mithridates',
src\main.rs:4:5
```

So it is saying "you said that left != right, but left == right". And it displays our message that says `You entered Mithridates. Input must not equal Mithridates`.

`unwrap` is also good when you are writing your program and you want it to crash when there is a problem. Later, when your code is finished it is good to change `unwrap` to something else that won't crash.

You can also use `expect`, which is like `unwrap` but a bit better because you give it your own message. Textbooks usually give this advice: "If you use `.unwrap()` a lot, at least use `.expect()` for better error messages."

This will crash:

```
// ⚠
fn get_fourth(input: &Vec<i32>) -> i32 {
    let fourth = input.get(3).unwrap();
    *fourth
}

fn main() {
    let my_vec = vec![9, 0, 10];
    let fourth = get_fourth(&my_vec);
}
```

The error message is `thread 'main' panicked at 'called Option::unwrap() on a None value', src\main.rs:7:18`.

Now we write our own message with `expect`:

```
// ⚠
fn get_fourth(input: &Vec<i32>) -> i32 {
    let fourth = input.get(3).expect("Input vector needs at least 4 items");
    *fourth
}

fn main() {
    let my_vec = vec![9, 0, 10];
    let fourth = get_fourth(&my_vec);
}
```

It crashes again, but the error is better: `thread 'main' panicked at 'Input vector needs at least 4 items', src\main.rs:7:18`. `.expect()` is a little better than `.unwrap()` because of this, but it will still panic on `None`. Now here is an example of a bad practice, a function that tries to

unwrap two times. It takes a `Vec<Option<i32>>`, so maybe each part will have a `Some<i32>` or maybe a `None`.

```
fn try_two_unwraps(input: Vec<Option<i32>>) {
    println!("Index 0 is: {}", input[0].unwrap());
    println!("Index 1 is: {}", input[1].unwrap());
}

fn main() {
    let vector = vec![None, Some(1000)]; // This vector has a None, so it will panic
    try_two_unwraps(vector);
}
```

The message is: `thread 'main' panicked at 'called `Option::unwrap()` on a `None` value'`, `src\main.rs:2:32`. We're not sure if it was the first `.unwrap()` or the second `.unwrap()` until we check the line. It would be better to check the length and also to not unwrap. But with `.expect()` at least it will be a *little* better. Here it is with `.expect()`:

```
fn try_two_unwraps(input: Vec<Option<i32>>) {
    println!("Index 0 is: {}", input[0].expect("The first unwrap had a None!"));
    println!("Index 1 is: {}", input[1].expect("The second unwrap had a None!"));
}

fn main() {
    let vector = vec![None, Some(1000)];
    try_two_unwraps(vector);
}
```

So that is a bit better: `thread 'main' panicked at 'The first unwrap had a None!',` `src\main.rs:2:32`. We have the line number as well so we can find it.

You can also use `unwrap_or` if you want to always have a value that you want to choose. If you do this it will never panic. That's:

- 1. good because your program won't panic, but
- 2. maybe not good if you want the program to panic if there's a problem.

But usually we don't want our program to panic, so `unwrap_or` is a good method to use.

```
fn main() {
    let my_vec = vec![8, 9, 10];

    let fourth = my_vec.get(3).unwrap_or(&0); // If .get doesn't work, we will make the
                                                // value &0.
                                                // .get returns a reference, so we need
                                                // &0 and not 0
                                                // You can write "let *fourth" with a *
                                                // a 0 and not a &0, but here we just
                                                // print so it doesn't matter

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

This prints `0` because `.unwrap_or(&0)` gives a 0 even if it is a `None`.

Traits

We have seen traits before: `Debug`, `Copy`, `Clone` are all traits. To give a type a trait, you have to implement it. Because `Debug` and the others are so common, we have attributes that automatically do it. That's what happens when you write `#[derive(Debug)]`: you are automatically implementing `Debug`.

```
#[derive(Debug)]
struct MyStruct {
    number: usize,
}

fn main() {}
```

But other traits are more difficult, so you need to implement them manually with `impl`. For example, `Add` (found at `std::ops::Add`) is used to add two things. But Rust doesn't know exactly how you want to add things, so you have to tell it.

```
struct ThingsToAdd {
    first_thing: u32,
    second_thing: f32,
}

fn main() {}
```

We can add `first_thing` and `second_thing`, but we need to give more information. Maybe we want an `f32`, so something like this:

```
// 🛡
let result = self.second_thing + self.first_thing as f32
```

But maybe we want an integer, so like this:

```
// 🛡
let result = self.second_thing as u32 + self.first_thing
```

Or maybe we want to just put `self.first_thing` next to `self.second_thing` and say that this is how we want to add. So if we add 55 to 33.4, we want to see 5533.4, not 88.4.

So first let's look at how to make a trait. The important thing to remember about `traits` is that they are about behaviour. To make a trait, write `trait` and then create some functions.

```

struct Animal { // A simple struct - an Animal only has a name
    name: String,
}

trait Dog { // The dog trait gives some functionality
    fn bark(&self) { // It can bark
        println!("Woof woof!");
    }
    fn run(&self) { // and it can run
        println!("The dog is running!");
    }
}

impl Dog for Animal {} // Now Animal has the trait Dog

fn main() {
    let rover = Animal {
        name: "Rover".to_string(),
    };

    rover.bark(); // Now Animal can use bark()
    rover.run(); // and it can use run()
}

```

This is okay, but we don't want to print "The dog is running". You can change the methods that a `trait` gives you if you want, but you have to have the same signature. That means that it needs to take the same things, and return the same things. For example, we can change the method `.run()`, but we have to follow the signature. The signature says:

```

// 🚫
fn run(&self) {
    println!("The dog is running!");
}

```

`fn run(&self)` means "`fn run()` takes `&self`, and returns nothing". So you can't do this:

```

fn run(&self) -> i32 { // ⚠️
    5
}

```

Rust will say:

```

= note: expected fn pointer `fn(&Animal)`
      found fn pointer `fn(&Animal) -> i32`

```

But we can do this:

```

struct Animal { // A simple struct - an Animal only has a name
    name: String,
}

trait Dog { // The dog trait gives some functionality
    fn bark(&self) { // It can bark
        println!("Woof woof!");
    }
    fn run(&self) { // and it can run
        println!("The dog is running!");
    }
}

impl Dog for Animal {
    fn run(&self) {
        println!("{} is running!", self.name);
    }
}

fn main() {
    let rover = Animal {
        name: "Rover".to_string(),
    };

    rover.bark(); // Now Animal can use bark()
    rover.run(); // and it can use run()
}

```

Now it prints `Rover is running!`. This is okay because we are returning `()`, or nothing, which is what the trait says.

When you are writing a trait, you can just write the function signature. But if you do that, the user will have to write the function. Let's try that. Now we change `bark()` and `run()` to just say `fn bark(&self);` and `fn run(&self);`. This is not a full function, so the user must write it.

```

struct Animal {
    name: String,
}

trait Dog {
    fn bark(&self); // bark() says it needs a &self and returns nothing
    fn run(&self); // run() says it needs a &self and returns nothing.
                    // So now we have to write them ourselves.
}

impl Dog for Animal {
    fn bark(&self) {
        println!("{}, stop barking!!", self.name);
    }
    fn run(&self) {
        println!("{} is running!", self.name);
    }
}

fn main() {
    let rover = Animal {
        name: "Rover".to_string(),
    };

    rover.bark();
    rover.run();
}

```

So when you create a trait, you must think: "Which functions should I write? And which functions should the user write?" If you think the user should use the function the same way every time, then write out the function. If you think the user will use it differently, then just write the function signature.

So let's try implementing the `Display` trait for our struct. First we will make a simple struct:

```
struct Cat {
    name: String,
    age: u8,
}

fn main() {
    let mr_mantle = Cat {
        name: "Reggie Mantle".to_string(),
        age: 4,
    };
}
```

Now we want to print `mr_mantle`. Debug is easy to derive:

```
#[derive(Debug)]
struct Cat {
    name: String,
    age: u8,
}

fn main() {
    let mr_mantle = Cat {
        name: "Reggie Mantle".to_string(),
        age: 4,
    };

    println!("Mr. Mantle is a {:?}", mr_mantle);
}
```

but Debug print is not the prettiest way to print, because it looks like this.

```
Mr. Mantle is a Cat { name: "Reggie Mantle", age: 4 }
```

So we need to implement `Display` for `Cat` if we want nicer printing. On <https://doc.rust-lang.org/std/fmt/trait.Display.html> we can see the information for `Display`, and one example. It says:

```
use std::fmt;

struct Position {
    longitude: f32,
    latitude: f32,
}

impl fmt::Display for Position {
    fn fmt(&self, f: &mut fmt::Formatter<'_>) -> fmt::Result {
        write!(f, "({}, {})", self.longitude, self.latitude)
    }
}

fn main() {}
```

Some parts of this we don't understand yet, like `<'_>` and what `f` is doing. But we understand the `Position` struct: it is just two `f32`s. We also understand that `self.longitude` and `self.latitude`

are the fields in the struct. So maybe we can just use this code for our struct, with `self.name` and `self.age`. Also, `write!` looks a lot like `println!` so it is pretty familiar. So we write this:

```
use std::fmt;

struct Cat {
    name: String,
    age: u8,
}

impl fmt::Display for Cat {
    fn fmt(&self, f: &mut fmt::Formatter<'_>) -> fmt::Result {
        write!(f, "{} is a cat who is {} years old.", self.name, self.age)
    }
}

fn main() {}
```

Let's add a `fn main()`. Now our code looks like this:

```
use std::fmt;

struct Cat {
    name: String,
    age: u8,
}

impl fmt::Display for Cat {
    fn fmt(&self, f: &mut fmt::Formatter<'_>) -> fmt::Result {
        write!(f, "{} is a cat who is {} years old.", self.name, self.age)
    }
}

fn main() {
    let mr_mantle = Cat {
        name: "Reggie Mantle".to_string(),
        age: 4,
    };

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

Success! Now when we use `{}` to print, we get `Reggie Mantle is a cat who is 4 years old.`. This looks much better.

By the way, if you implement `Display` then you get the `Tostring` trait for free. That's because you use the `format!` macro for the `.fmt()` function, which lets you make a `String` with `.to_string()`. So we could do something like this where we pass `reggie_mantle` to a function that wants a `String`, or anything else.

```

use std::fmt;
struct Cat {
    name: String,
    age: u8,
}

impl fmt::Display for Cat {
    fn fmt(&self, f: &mut fmt::Formatter<'_>) -> fmt::Result {
        write!(f, "{} is a cat who is {} years old.", self.name, self.age)
    }
}

fn print_cats(pet: String) {
    println!("{}", pet);
}

fn main() {
    let mr_mantle = Cat {
        name: "Reggie Mantle".to_string(),
        age: 4,
    };

    print_cats(mr_mantle.to_string()); // Turn him into a String here
    println!("{}'s String is {} letters long.", mr_mantle.to_string().chars().count()); // Turn him into chars and count them
}

```

This prints:

```

Reggie Mantle is a cat who is 4 years old.
Mr. Mantle's String is 42 letters long.

```

The thing to remember about traits is that they are about the behaviour of something. How does your `struct` act? What can it do? That's what traits are for. If you think of some of the traits we've seen so far, they are all about behaviour: `Copy` is something that a type can do. `Display` is also something that a type can do. `ToString` is another trait, and it's also something that a type can do: it can change into a `String`. In our `Dog` trait the word `dog` doesn't mean something you can do, but it gives some methods that let it do things. You could also implement it for a `struct Poodle` or `struct Beagle` and they would all get `Dog` methods.

Let's look at another example that is even more connected to just behaviour. We'll imagine a fantasy game with some simple characters. One is a `Monster`, the other two are `Wizard` and `Ranger`. The `Monster` just has `health` so we can attack it, the other two don't have anything yet. But we made two traits. One is called `FightClose`, and lets you fight up close. The other is `FightFromDistance`, and lets you fight from far away. Only `Ranger` can use `FightFromDistance`. Here's what it looks like:

```

struct Monster {
    health: i32,
}

struct Wizard {}
struct Ranger {}

trait FightClose {
    fn attack_with_sword(&self, opponent: &mut Monster) {
        opponent.health -= 10;
        println!(
            "You attack with your sword. Your opponent now has {} health left.",
            opponent.health
        );
    }
    fn attack_with_hand(&self, opponent: &mut Monster) {
        opponent.health -= 2;
        println!(
            "You attack with your hand. Your opponent now has {} health left.",
            opponent.health
        );
    }
}
impl FightClose for Wizard {}
impl FightClose for Ranger {}

trait FightFromDistance {
    fn attack_with_bow(&self, opponent: &mut Monster, distance: u32) {
        if distance < 10 {
            opponent.health -= 10;
            println!(
                "You attack with your bow. Your opponent now has {} health left.",
                opponent.health
            );
        }
    }
    fn attack_with_rock(&self, opponent: &mut Monster, distance: u32) {
        if distance < 3 {
            opponent.health -= 4;
        }
        println!(
            "You attack with your rock. Your opponent now has {} health left.",
            opponent.health
        );
    }
}
impl FightFromDistance for Ranger {}

fn main() {
    let radagast = Wizard {};
    let aragorn = Ranger {};

    let mut uruk_hai = Monster { health: 40 };

    radagast.attack_with_sword(&mut uruk_hai);
    aragorn.attack_with_bow(&mut uruk_hai, 8);
}

```

This prints:

```
You attack with your sword. Your opponent now has 30 health left.
You attack with your bow. Your opponent now has 20 health left.
```

We pass `self` inside our trait all the time, but we can't do much with it right now. That's because Rust doesn't know what type is going to use it. It could be a `Wizard`, it could be a `Ranger`, it could be

a new struct called `Toefocfgetobjtnode` or anything else. To give `self` some functionality, we can add necessary traits to the trait. If we want to print with `{:?}` for example then we need `Debug`. You can add it to the trait just by writing it after `:` (a colon). Now our code looks like this:

```

struct Monster {
    health: i32,
}

#[derive(Debug)] // Now Wizard has Debug
struct Wizard {
    health: i32, // Now Wizard has health
}
#[derive(Debug)] // So does Ranger
struct Ranger {
    health: i32, // So does Ranger
}

trait FightClose: std::fmt::Debug { // Now a type needs Debug to use FightClose
    fn attack_with_sword(&self, opponent: &mut Monster) {
        opponent.health -= 10;
        println!(
            "You attack with your sword. Your opponent now has {} health left. You are
now at: {}",
            // We can now print self with {:?} because we have Debug
            opponent.health, &self
        );
    }
    fn attack_with_hand(&self, opponent: &mut Monster) {
        opponent.health -= 2;
        println!(
            "You attack with your hand. Your opponent now has {} health left. You are
now at: {}",
            opponent.health, &self
        );
    }
}
impl FightClose for Wizard {}
impl FightClose for Ranger {}

trait FightFromDistance: std::fmt::Debug { // We could also do trait FightFromDistance:
FightClose because FightClose needs Debug
    fn attack_with_bow(&self, opponent: &mut Monster, distance: u32) {
        if distance < 10 {
            opponent.health -= 10;
            println!(
                "You attack with your bow. Your opponent now has {} health left. You
are now at: {}",
                opponent.health, self
            );
        }
    }
    fn attack_with_rock(&self, opponent: &mut Monster, distance: u32) {
        if distance < 3 {
            opponent.health -= 4;
        }
        println!(
            "You attack with your rock. Your opponent now has {} health left. You are
now at: {}",
            opponent.health, self
        );
    }
}
impl FightFromDistance for Ranger {}

fn main() {
    let radagast = Wizard { health: 60 };
    let aragorn = Ranger { health: 80 };

    let mut uruk_hai = Monster { health: 40 };

    radagast.attack_with_sword(&mut uruk_hai);
}

```

```
    aragorn.attack_with_bow(&mut uruk_hai, 8);  
}
```

Now this prints:

```
You attack with your sword. Your opponent now has 30 health left. You are now at:  
Wizard { health: 60 }  
You attack with your bow. Your opponent now has 20 health left. You are now at: Ranger  
{ health: 80 }
```

In a real game it might be better to rewrite this for each type, because `You are now at: Wizard { health: 60 }` looks funny. That's also why methods inside traits are usually simple, because you don't know what type is going to use it. You can't write things like `self.0 += 10` for example. But this example shows that we can use other traits inside a trait we are writing. And when we do that, we get some methods that we can use.

One other way to use a trait is with what are called `trait bounds`. That means "limitations by a trait". Trait bounds are easy because a trait actually doesn't need any methods, or anything at all. Let's rewrite our code with something similar but different. This time our trait doesn't have any methods, but we have other functions that require traits to use.

```

use std::fmt::Debug; // So we don't have to write std::fmt::Debug every time now

struct Monster {
    health: i32,
}

#[derive(Debug)]
struct Wizard {
    health: i32,
}
#[derive(Debug)]
struct Ranger {
    health: i32,
}

trait Magic{} // No methods for any of these traits. They are just trait bounds
trait FightClose {}
trait FightFromDistance {}

impl FightClose for Ranger{} // Each type gets FightClose,
impl FightClose for Wizard {}
impl FightFromDistance for Ranger{} // but only Ranger gets FightFromDistance
impl Magic for Wizard{} // and only Wizard gets Magic

fn attack_with_bow<T: FightFromDistance + Debug>(character: &T, opponent: &mut Monster, distance: u32) {
    if distance < 10 {
        opponent.health -= 10;
        println!(
            "You attack with your bow. Your opponent now has {} health left. You are now at: {}",
            opponent.health, character
        );
    }
}

fn attack_with_sword<T: FightClose + Debug>(character: &T, opponent: &mut Monster) {
    opponent.health -= 10;
    println!(
        "You attack with your sword. Your opponent now has {} health left. You are now at: {}",
        opponent.health, character
    );
}

fn fireball<T: Magic + Debug>(character: &T, opponent: &mut Monster, distance: u32) {
    if distance < 15 {
        opponent.health -= 20;
        println!("You raise your hands and cast a fireball! Your opponent now has {} health left. You are now at: {}",
            opponent.health, character);
    }
}

fn main() {
    let radagast = Wizard { health: 60 };
    let aragorn = Ranger { health: 80 };

    let mut uruk_hai = Monster { health: 40 };

    attack_with_sword(&radagast, &mut uruk_hai);
    attack_with_bow(&aragorn, &mut uruk_hai, 8);
    fireball(&radagast, &mut uruk_hai, 8);
}

```

This prints almost the same thing:

```
You attack with your sword. Your opponent now has 30 health left. You are now at:  
Wizard { health: 60 }  
You attack with your bow. Your opponent now has 20 health left. You are now at: Ranger  
{ health: 80 }  
You raise your hands and cast a fireball! Your opponent now has 0 health left. You are  
now at: Wizard { health: 60 }
```

So you can see there are many ways to do the same thing when you use traits. It all depends on what makes the most sense for the program that you are writing.

Now let's look at how to implement some of the main traits you will use in Rust.

The From trait

From is a very convenient trait to use, and you know this because you have seen it so much already. With *From* you can make a `String` from a `&str`, but you can make many types from many other types. For example, `Vec` uses *From* for the following:

```
From<&'_ [T]>  
From<&'_ mut [T]>  
From<&'_ str>  
From<&'a Vec<T>>  
From<[T; N]>  
From<BinaryHeap<T>>  
From<Box<[T]>>  
From<CString>  
From<Cow<'a, [T]>>  
From<String>  
From<Vec<NonZeroU8>>  
From<Vec<T>>  
From<VecDeque<T>>
```

That is a lot of `Vec::from()` that we have not tried yet. Let's make a few and see what happens.

```
use std::fmt::Display; // We will make a generic function to print them so we want  
Display  
  
fn print_vec<T: Display>(input: &Vec<T>) { // Take any Vec<T> if type T has Display  
    for item in input {  
        print!("{} ", item);  
    }  
    println!();  
}  
  
fn main() {  
  
    let array_vec = Vec::from([8, 9, 10]); // Try from an array  
    print_vec(&array_vec);  
  
    let str_vec = Vec::from("What kind of vec will I be?"); // An array from a &str?  
    This will be interesting  
    print_vec(&str_vec);  
  
    let string_vec = Vec::from("What kind of vec will a String be?".to_string()); //  
    Also from a String  
    print_vec(&string_vec);  
}
```

It prints the following:

```
8 9 10
87 104 97 116 32 107 105 110 100 32 111 102 32 118 101 99 32 119 105 108 108 32 73 32
98 101 63
87 104 97 116 32 107 105 110 100 32 111 102 32 118 101 99 32 119 105 108 108 32 97 32
83 116 114 105 110 103 32 98 101 63
```

If you look at the type, the second and third vectors are `Vec<u8>`, which means the bytes of the `&str` and the `String`. So you can see that `From` is very flexible and used a lot. Let's try it with our own types.

We'll make two structs and then implement `From` for one of them. One struct will be `City`, and the other will be `Country`. We want to be able to do this: `let country_name = Country::from(vector_of_cities)`.

It looks like this:

```
#[derive(Debug)] // So we can print City
struct City {
    name: String,
    population: u32,
}

impl City {
    fn new(name: &str, population: u32) -> Self { // just a new function
        Self {
            name: name.to_string(),
            population,
        }
    }
}
#[derive(Debug)] // Country also needs to be printed
struct Country {
    cities: Vec<City>, // Our cities go in here
}

impl From<Vec<City>> for Country { // Note: we don't have to write From<City>, we can
    // also do
    // From<Vec<City>>. So we can also implement on a
    type that
    // we didn't create
    fn from(cities: Vec<City>) -> Self {
        Self { cities }
    }
}

impl Country {
    fn print_cities(&self) { // function to print the cities in Country
        for city in &self.cities {
            // & because Vec<City> isn't Copy
            println!("{} has a population of {}.", city.name, city.population);
        }
    }
}

fn main() {
    let helsinki = City::new("Helsinki", 631_695);
    let turku = City::new("Turku", 186_756);

    let finland_cities = vec![helsinki, turku]; // This is the Vec<City>
    let finland = Country::from(finland_cities); // So now we can use From

    finland.print_cities();
}
```

This prints:

```
"Helsinki" has a population of 631695.  
"Turku" has a population of 186756.
```

You can see that `From` is easy to implement from types you didn't create like `Vec`, `i32`, and so on. Here is one more example where we create a vector that has two vectors. The first vector holds even numbers, and the second holds odd numbers. With `From` you can give it a vector of `i32`s and it will turn it into a `Vec<Vec<i32>>`: a vector that holds vectors of `i32`.

```
use std::convert::From;

struct EvenOddVec(Vec<Vec<i32>>);

impl From<Vec<i32>> for EvenOddVec {
    fn from(input: Vec<i32>) -> Self {
        let mut even_odd_vec: Vec<Vec<i32>> = vec![vec![], vec![]]; // A vec with two
empty vecs inside                                                               // This is the
return value but first we must fill it
        for item in input {
            if item % 2 == 0 {
                even_odd_vec[0].push(item);
            } else {
                even_odd_vec[1].push(item);
            }
        }
        Self(even_odd_vec) // Now it is done so we return it as Self (Self =
EvenOddVec)
    }
}

fn main() {
    let bunch_of_numbers = vec![8, 7, -1, 3, 222, 9787, -47, 77, 0, 55, 7, 8];
    let new_vec = EvenOddVec::from(bunch_of_numbers);

    println!("Even numbers: {:?}", "\nOdd numbers: {:?}", new_vec.0[0], new_vec.0[1]);
}
```

This prints:

```
Even numbers: [8, 222, 0, 8]
Odd numbers: [7, -1, 3, 9787, -47, 77, 55, 7]
```

A type like `EvenOddVec` is probably better as a generic `T` so we can use many number types. You can try to make the example generic if you want for practice.

Taking a String and a &str in a function

Sometimes you want a function that can take both a `String` and a `&str`. You can do this with generics and the `AsRef` trait. `AsRef` is used to give a reference from one type to another type. If you look at the documentation for `String`, you can see that it has `AsRef` for many types:

<https://doc.rust-lang.org/std/string/struct.String.html>

Here are some function signatures for them.

```
AsRef<str> :
```

```
// 🛡
impl AsRef<str> for String
fn as_ref(&self) -> &str
```

AsRef<[u8]>:

```
// 🛡
impl AsRef<[u8]> for String
fn as_ref(&self) -> &[u8]
```

AsRef<OsStr>:

```
// 🛡
impl AsRef<OsStr> for String
fn as_ref(&self) -> &OsStr
```

You can see that it takes `&self` and gives a reference to the other type. This means that if you have a generic type `T`, you can say that it needs `AsRef<str>`. If you do that, it will be able to take a `&str` and a `String`.

Let's start with the generic function. This doesn't work yet:

```
fn print_it<T>(input: T) {
    println!("{}", input) // ⚠
}

fn main() {
    print_it("Please print me");
}
```

Rust says `error[E0277]: T doesn't implement std::fmt::Display`. So we will require `T` to implement `Display`.

```
use std::fmt::Display;

fn print_it<T: Display>(input: T) {
    println!("{}", input)
}

fn main() {
    print_it("Please print me");
}
```

Now it works and prints `Please print me`. That is good, but `T` can still be too many things. It can be an `i8`, an `f32` and anything else with just `Display`. So we add `AsRef<str>`, and now `T` needs both `AsRef<str>` and `Display`.

```
use std::fmt::Display;

fn print_it<T: AsRef<str> + Display>(input: T) {
    println!("{}", input)
}

fn main() {
    print_it("Please print me");
    print_it("Also, please print me".to_string());
    // print_it(7); <- This will not print
}
```

Now it won't take types like `i8`.

Don't forget that you can use `where` to write the function differently when it gets long. If we add `Debug` then it becomes `fn print_it<T: AsRef<str> + Display + Debug>(input: T)` which is long for one line. So we can write it like this:

```
use std::fmt::{Debug, Display}; // add Debug

fn print_it<T>(input: T) // Now this line is easy to read
where
    T: AsRef<str> + Debug + Display, // and these traits are easy to read
{
    println!("{}", input)
}

fn main() {
    print_it("Please print me");
    print_it("Also, please print me".to_string());
}
```

Chaining methods

Rust is a systems programming language like C and C++, and its code can be written as separate commands in separate lines, but it also has a functional style. Both styles are okay, but functional style is usually shorter. Here is an example of the non-functional style (called "imperative style") to make a `Vec` from 1 to 10:

```
fn main() {
    let mut new_vec = Vec::new();
    let mut counter = 1;

    while counter < 11 {
        new_vec.push(counter);
        counter += 1;
    }

    println!("{:?}", new_vec);
}
```

This prints `[1, 2, 3, 4, 5, 6, 7, 8, 9, 10]`.

And here is an example of functional style:

```
fn main() {
    let new_vec = (1..=10).collect::<Vec<i32>>();
    // Or you can write it like this:
    // let new_vec: Vec<i32> = (1..=10).collect();
    println!("{:?}", new_vec);
}
```

`.collect()` can make collections of many types, so we have to tell it the type.

With functional style you can chain methods. "Chaining methods" means to put many methods together in a single statement. Here is an example of many methods chained together:

```
fn main() {
    let my_vec = vec![0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10];

    let new_vec = my_vec.into_iter().skip(3).take(4).collect::<Vec<i32>>();

    println!("{:?}", new_vec);
}
```

This creates a `Vec` with `[3, 4, 5, 6]`. This is a lot of information for one line, so it can help to put each method on a new line. Let's do that to make it easier to read:

```
fn main() {
    let my_vec = vec![0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10];

    let new_vec = my_vec
        .into_iter() // "iterate" over the items (iterate = work with each item inside it). into_iter() gives us owned values, not references
        .skip(3) // skip over three items: 0, 1, and 2
        .take(4) // take the next four: 3, 4, 5, and 6
        .collect::<Vec<i32>>(); // put them in a new Vec<i32>

    println!("{:?}", new_vec);
}
```

You can use this functional style best when you understand closures and iterators. So we will learn them next.

Iterators

An iterator is a construct that can give you the items in the collection, one at a time. Actually, we have already used iterators a lot: the `for` loop gives you an iterator. When you want to use an iterator other times, you have to choose what kind:

- `.iter()` for an iterator of references
- `.iter_mut()` for an iterator of mutable references
- `.into_iter()` for an iterator of values (not references)

A `for` loop is actually just an iterator that owns its values. That's why it can make it mutable and then you can change the values when you use it.

We can use iterators like this:

```
fn main() {
    let vector1 = vec![1, 2, 3]; // we will use .iter() and .into_iter() on this one
    let vector1_a = vector1.iter().map(|x| x + 1).collect::<Vec<i32>>();
    let vector1_b = vector1.into_iter().map(|x| x * 10).collect::<Vec<i32>>();

    let mut vector2 = vec![10, 20, 30]; // we will use .iter_mut() on this one
    vector2.iter_mut().for_each(|x| *x += 100);

    println!("{:?}", vector1_a);
    println!("{:?}", vector2);
    println!("{:?}", vector1_b);
}
```

This prints:

```
[2, 3, 4]
[110, 120, 130]
[10, 20, 30]
```

The first two we used a method called `.map()`. This method lets you do something to every item, then pass it on. The last one we used is one called `.for_each()`. This method just lets you do something to every item. `.iter_mut()` plus `for_each()` is basically just a `for` loop. Inside each method we can give a name to every item (we just called it `x`) and use that to change it. These are called closures and we will learn about them in the next section.

Let's go over them again, one at a time.

First we used `.iter()` on `vector1` to get references. We added 1 to each, and made it into a new Vec. `vector1` is still alive because we only used references: we didn't take by value. Now we have `vector1`, and a new Vec called `vector1_a`. Because `.map()` just passes it on, we needed to use `.collect()` to make it into a `Vec`.

Then we used `into_iter` to get an iterator by value from `vector1`. This destroys `vector1`, because that's what `into_iter()` does. So after we make `vector1_b` we can't use `vector1` again.

Finally we used `.iter_mut()` for `vector2`. It is mutable, so we don't need to use `.collect()` to create a new Vec. Instead, we change the values in the same Vec with mutable references. So `vector2` is still there. Because we don't need a new Vec, we use `for_each`: it's just like a `for` loop.

How an iterator works

An iterator works by using a method called `.next()`, which gives an `Option`. When you use an iterator, Rust calls `next()` over and over again. If it gets `Some`, it keeps going. If it gets `None`, it stops.

Do you remember the `assert_eq!` macro? In documentation, you see it all the time. Here it is showing how an iterator works.

```
fn main() {
    let my_vec = vec!['a', 'b', '가', '柳']; // Just a regular Vec

    let mut my_vec_iter = my_vec.iter(); // This is an Iterator type now, but we
haven't called it yet

    assert_eq!(my_vec_iter.next(), Some(&'a')); // Call the first item with .next()
    assert_eq!(my_vec_iter.next(), Some(&'b')); // Call the next
    assert_eq!(my_vec_iter.next(), Some(&'가')); // Again
    assert_eq!(my_vec_iter.next(), Some(&'柳')); // Again
    assert_eq!(my_vec_iter.next(), None); // Nothing is left: just None
    assert_eq!(my_vec_iter.next(), None); // You can keep calling .next() but it
will always be None
}
```

Implementing `Iterator` for your own struct or enum is not too hard. First let's make a book library and think about it.

```

#[derive(Debug)] // we want to print it with {:?}
struct Library {
    library_type: LibraryType, // this is our enum
    books: Vec<String>, // list of books
}

#[derive(Debug)]
enum LibraryType { // libraries can be city libraries or country libraries
    City,
    Country,
}

impl Library {
    fn add_book(&mut self, book: &str) { // we use add_book to add new books
        self.books.push(book.to_string()); // we take a &str and turn it into a String,
        then add it to the Vec
    }

    fn new() -> Self { // this creates a new Library
        Self {
            library_type: LibraryType::City, // most are in the city so we'll choose
            City
                // most of the time
            books: Vec::new(),
        }
    }
}

fn main() {
    let mut my_library = Library::new(); // make a new library
    my_library.add_book("The Doom of the Darksword"); // add some books
    my_library.add_book("Demian - die Geschichte einer Jugend");
    my_library.add_book("구운몽");
    my_library.add_book("吾輩は猫である");

    println!("{:?}", my_library.books); // we can print our list of books
}

```

That works well. Now we want to implement `Iterator` for the library so we can use it in a `for` loop. Right now if we try a `for` loop, it doesn't work:

```

for item in my_library {
    println!("{}", item); // ▲
}

```

It says:

```

error[E0277]: `Library` is not an iterator
--> src\main.rs:47:16
|
47 |     for item in my_library {
|         ^^^^^^^^^ `Library` is not an iterator
|
= help: the trait `std::iter::Iterator` is not implemented for `Library`
= note: required by `std::iter::IntoIterator::into_iter`

```

But we can make library into an iterator with `impl Iterator for Library`. Information on the `Iterator` trait is here in the standard library: <https://doc.rust-lang.org/std/iter/trait.Iterator.html>

On the top left of the page it says: `Associated Types: Item` and `Required Methods: next`. An "associated type" means "a type that goes together". Our associated type will be `String`, because we want the iterator to give us Strings.

In the page it has an example that looks like this:

```
// an iterator which alternates between Some and None
struct Alternate {
    state: i32,
}

impl Iterator for Alternate {
    type Item = i32;

    fn next(&mut self) -> Option<i32> {
        let val = self.state;
        self.state = self.state + 1;

        // if it's even, Some(i32), else None
        if val % 2 == 0 {
            Some(val)
        } else {
            None
        }
    }
}

fn main() {}
```

You can see that under `impl Iterator for Alternate` it says `type Item = i32`. This is the associated type. Our iterator will be for our list of books, which is a `Vec<String>`. When we call `next`, it will give us a `String`. So we will write `type Item = String;`. That is the associated item.

To implement `Iterator`, you need to write the `fn next()` function. This is where you decide what the iterator should do. For our `Library`, we want it to give us the last books first. So we will `match` with `.pop()` which takes the last item off if it is `Some`. We also want to print " is found!" for each item. Now it looks like this:

```

#[derive(Debug, Clone)]
struct Library {
    library_type: LibraryType,
    books: Vec<String>,
}

#[derive(Debug, Clone)]
enum LibraryType {
    City,
    Country,
}

impl Library {
    fn add_book(&mut self, book: &str) {
        self.books.push(book.to_string());
    }

    fn new() -> Self {
        Self {
            library_type: LibraryType::City,
            // most of the time
            books: Vec::new(),
        }
    }
}

impl Iterator for Library {
    type Item = String;

    fn next(&mut self) -> Option<String> {
        match self.books.pop() {
            Some(book) => Some(book + " is found!"), // Rust allows String + &str
            None => None,
        }
    }
}

fn main() {
    let mut my_library = Library::new();
    my_library.add_book("The Doom of the Darksword");
    my_library.add_book("Demian - die Geschichte einer Jugend");
    my_library.add_book("구운몽");
    my_library.add_book("吾輩は猫である");

    for item in my_library.clone() { // we can use a for loop now. Give it a clone so
        Library won't be destroyed
        println!("{}", item);
    }
}

```

This prints:

```

吾輩は猫である is found!
구운몽 is found!
Demian - die Geschichte einer Jugend is found!
The Doom of the Darksword is found!

```

Closures

Closures are like quick functions that don't need a name. Sometimes they are called lambdas. Closures are easy to find because they use `||` instead of `()`. They are very common in Rust, and once you learn to use them you will wonder how you lived without them.

You can bind a closure to a variable, and then it looks exactly like a function when you use it:

```
fn main() {
    let my_closure = || println!("This is a closure");
    my_closure();
}
```

So this closure takes nothing: `||` and prints a message: `This is a closure`.

In between the `||` we can add input variables and types, like inside `()` for a function:

```
fn main() {
    let my_closure = |x: i32| println!("{}", x);

    my_closure(5);
    my_closure(5+5);
}
```

This prints:

```
5
10
```

When the closure becomes more complicated, you can add a code block. Then it can be as long as you want.

```
fn main() {
    let my_closure = || {
        let number = 7;
        let other_number = 10;
        println!("The two numbers are {} and {}.", number, other_number);
        // This closure can be as long as we want, just like a function.
    };

    my_closure();
}
```

But closures are special because they can take variables that are outside the closure even if you only write `||`. So you can do this:

```
fn main() {
    let number_one = 6;
    let number_two = 10;

    let my_closure = || println!("{} + {} = {}", number_one, number_two, number_one + number_two);
    my_closure();
}
```

So this prints `16`. You didn't need to put anything in `||` because it can just take `number_one` and `number_two` and add them.

By the way, that is where the name **closure** comes from, because they take variables and "enclose" them inside. And if you want to be very correct:

- a `||` that doesn't enclose a variable from outside is an "anonymous function". Anonymous means "doesn't have a name". It works more like a regular function.
- a `||` that does enclose a variable from outside is a "closure". It "encloses" the variables around it to use them.

But people will often call all `||` functions closures, so you don't have to worry about the name. We will just say "closure" for anything with a `||`, but remember that it can mean an "anonymous function".

Why is it good to know the difference? It's because an anonymous function actually makes the same machine code as a function with a name. They feel "high level", so sometimes people think that the machine code will be complicated. But the machine code that Rust makes from it is just as fast as a regular function.

So let's look at some more things that closures can do. You can also do this:

```
fn main() {
    let number_one = 6;
    let number_two = 10;

    let my_closure = |x: i32| println!("{}", number_one + number_two + x);
    my_closure(5);
}
```

This closure takes `number_one` and `number_two`. We also gave it a new variable `x` and said that `x` is 5. Then it adds all three together to print 21.

Usually you see closures in Rust inside of a method, because it is very convenient to have a closure inside. We saw closures in the last section with `.map()` and `.for_each()`. In that section we wrote `|x|` to bring in the next item in an iterator, and that was a closure.

Here is another example: the `unwrap_or` method that we know that you can use to give a value if `unwrap` doesn't work. Before, we wrote: `let fourth = my_vec.get(3).unwrap_or(&0);`. But there is also an `unwrap_or_else` method that has a closure inside. So you can do this:

```
fn main() {
    let my_vec = vec![8, 9, 10];

    let fourth = my_vec.get(3).unwrap_or_else(|| { // try to unwrap. If it doesn't
work,
        if my_vec.get(0).is_some() { // see if my_vec has something at
index [0]
            &my_vec[0] // Give the number at index 0 if
there is something
        } else {
            &0 // otherwise give a &0
        }
    });

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

Of course, a closure can be very simple. You can just write `let fourth = my_vec.get(3).unwrap_or_else(|| &0);` for example. You don't always need to use a `{}` and write complicated code just because there is a closure. As long as you put the `||` in, the compiler knows that you have put in the closure that you need.

The most frequent closure method is maybe `.map()`. Let's take a look at it again. Here is one way to use it:

```
fn main() {
    let num_vec = vec![2, 4, 6];

    let double_vec = num_vec
        .iter() // take num_vec
        .map(|number| number * 2) // for each item, multiply by two
        .collect::<Vec<i32>>(); // then make a new Vec from this
    println!("{:?}", double_vec);
}
```

Another good example is with `.for_each()` after `.enumerate()`. The `.enumerate()` method gives an iterator with the index number and the item. For example: `[10, 9, 8]` becomes `(0, 10), (1, 9), (2, 8)`. The type for each item here is `(usize, i32)`. So you can do this:

```
fn main() {
    let num_vec = vec![10, 9, 8];

    num_vec
        .iter() // iterate over num_vec
        .enumerate() // get (index, number)
        .for_each(|(index, number)| println!("Index number {} has number {}", index, number)); // do something for each one
}
```

This prints:

```
Index number 0 has number 10
Index number 1 has number 9
Index number 2 has number 8
```

In this case we use `for_each` instead of `map`. `map` is for **doing something to** each item and passing it on, and `for_each` is **doing something when you see each item**. Also, `map` doesn't do anything unless you use a method like `collect`.

Actually, this is the interesting thing about iterators. If you try to `map` without a method like `collect`, the compiler will tell you that it doesn't do anything. It won't panic, but the compiler will tell you that you didn't do anything.

```
fn main() {
    let num_vec = vec![10, 9, 8];

    num_vec
        .iter()
        .enumerate()
        .map(|(index, number)| println!("Index number {} has number {}", index, number));
}
```

It says:

```
warning: unused `std::iter::Map` that must be used
--> src\main.rs:4:5
  |
4 | /     num_vec
5 | |     .iter()
6 | |     .enumerate()
7 | |     .map(|(index, number)| println!("Index number {} has number {}", index,
number));
  |
|-----|
  |
= note: `#[warn(unused_must_use)]` on by default
= note: iterators are lazy and do nothing unless consumed
```

This is a **warning**, so it's not an error: the program runs fine. But why doesn't `num_vec` do anything? We can look at the types to see.

- `let num_vec = vec![10, 9, 8];` Right now it is a `Vec<i32>`.
- `.iter()` Now it is an `Iter<i32>`. So it is an iterator with items of `i32`.
- `.enumerate()` Now it is an `Enumerate<Iter<i32>>`. So it is a type `Enumerate` of type `Iter` of `i32`s.
- `.map()` Now it is a type `Map<Enumerate<Iter<i32>>>`. So it is a type `Map` of type `Enumerate` of type `Iter` of `i32`s.

All we did was make a more and more complicated structure. So this `Map<Enumerate<Iter<i32>>>` is a structure that is ready to go, but only when we tell it what to do. Rust does this because it needs to be fast. It doesn't want to do this:

- iterate over all the `i32`s in the `Vec`
- then enumerate over all the `i32`s from the iterator
- then map over all the enumerated `i32`s

Rust only wants to do one calculation, so it creates the structure and waits. Then if we say `.collect::<Vec<i32>>()` it knows what to do, and starts moving. This is what `iterators are lazy and do nothing unless consumed` means. The iterators don't do anything until you "consume" them (use them up).

You can even create complicated things like `HashMap` using `.collect()`, so it is very powerful. Here is an example of how to put twovecs into a `HashMap`. First we make the two vectors, and then we will use `.into_iter()` on them to get an iterator of values. Then we use the `.zip()` method. This method takes two iterators and attaches them together, like a zipper. Finally, we use `.collect()` to make the `HashMap`.

Here is the code:

```
use std::collections::HashMap;

fn main() {
    let some_numbers = vec![0, 1, 2, 3, 4, 5]; // a Vec<i32>
    let some_words = vec!["zero", "one", "two", "three", "four", "five"]; // a Vec<&str>

    let number_word_hashmap = some_numbers
        .into_iter() // now it is an iter
        .zip(some_words.into_iter()) // inside .zip() we put in the other iter. Now
        they are together.
        .collect::<HashMap<_, _>>();

    println!("For key {} we get {}", 2, number_word_hashmap.get(&2).unwrap());
}
```

This prints:

```
For key 2 we get two.
```

You can see that we wrote `<HashMap<_, _>>` because that is enough information for Rust to decide on the type `HashMap<i32, &str>`. You can write `.collect::<HashMap<i32, &str>>();` if you want, or you can write it like this if you prefer:

```
use std::collections::HashMap;

fn main() {
    let some_numbers = vec![0, 1, 2, 3, 4, 5]; // a Vec<i32>
    let some_words = vec!["zero", "one", "two", "three", "four", "five"]; // a Vec<&str>
    let number_word_hashmap: HashMap<_, _> = some_numbers // Because we tell it the
    type here...
        .into_iter()
        .zip(some_words.into_iter())
        .collect(); // we don't have to tell it here
}
```

There is another method that is like `.enumerate()` for `char s: char_indices()`. (`Indices` means "indexes"). You use it in the same way. Let's pretend we have a big string that made of 3-digit numbers.

```
fn main() {
    let numbers_together = "140399923481800622623218009598281";

    for (index, number) in numbers_together.char_indices() {
        match (index % 3, number) {
            (0..=1, number) => print!("{}", number), // just print the number if there
            is a remainder
            _ => print!("{}\t", number), // otherwise print the number with a tab space
        }
    }
}
```

This prints 140 399 923 481 800 622 623 218 009 598
281 .

|_| in a closure

Sometimes you see `|_|` in a closure. This means that the closure needs an argument (like `x`), but you don't want to use it. So `|_|` means "Okay, this closure takes an argument but I won't give it a

name because I don't care about it".

Here is an example of an error when you don't do that:

```
fn main() {
    let my_vec = vec![8, 9, 10];

    println!("{}:?", my_vec.iter().for_each(|| println!("We didn't use the variables at
all"))); // ⚠
}
```

Rust says that

```
error[E0593]: closure is expected to take 1 argument, but it takes 0 arguments
--> src\main.rs:28:36
|
28 |     println!("{}:?", my_vec.iter().for_each(|| println!("We didn't use the
variables at all")));
|                                     ^^^^^^^^^ -- takes 0 arguments
|                                     |
|                                     expected closure that takes 1 argument
```

The compiler actually gives you some help:

```
help: consider changing the closure to take and ignore the expected argument
|
28 |     println!("{}:?", my_vec.iter().for_each(|_| println!("We didn't use the
variables at all")));
```

This is good advice. If you change `||` to `|_|` then it will work.

Helpful methods for closures and iterators

Rust becomes a very fun language once you become comfortable with closures. With closures you can *chain* methods to each other and do a lot of things with very little code. Here are some closures and methods used with closures that we didn't see yet.

`.filter()` : This lets you keep the items in an iterator that you want to keep. Let's filter the months of the year.

```
fn main() {
    let months = vec!["January", "February", "March", "April", "May", "June", "July",
"August", "September", "October", "November", "December"];

    let filtered_months = months
        .into_iter()                      // make an iter
        .filter(|month| month.len() < 5)    // We don't want months more than 5 bytes
in length.                                // We know that each letter is one byte so
.month().is fine
        .filter(|month| month.contains("u")) // Also we only like months with the
letter u
        .collect::<Vec<&str>>();

    println!("{}:?", filtered_months);
}
```

This prints `["June", "July"]`.

.filter_map(). This is called `filter_map()` because it does `.filter()` and `.map()`. The closure must return an `Option<T>`, and then `filter_map()` takes the value out of each `Option` if it is `Some`. So for example if you were to `.filter_map()` a `vec![Some(2), None, Some(3)]`, it would return `[2, 3]`.

We will write an example with a `Company` struct. Each company has a `name` so that field is `String`, but the CEO might have recently quit. So the `ceo` field is `Option<String>`. We will `.filter_map()` over some companies to just keep the CEO names.

```
struct Company {
    name: String,
    ceo: Option<String>,
}

impl Company {
    fn new(name: &str, ceo: &str) -> Self {
        let ceo = match ceo {
            "" => None,
            ceo => Some(ceo.to_string()),
        }; // ceo is decided, so now we return Self
        Self {
            name: name.to_string(),
            ceo,
        }
    }

    fn get_ceo(&self) -> Option<String> {
        self.ceo.clone() // Just returns a clone of the CEO (struct is not Copy)
    }
}

fn main() {
    let company_vec = vec![
        Company::new("Umbrella Corporation", "Unknown"),
        Company::new("Ovintiv", "Doug Suttles"),
        Company::new("The Red-Headed League", ""),
        Company::new("Stark Enterprises", ""),
    ];
    let all_the_ceos = company_vec
        .into_iter()
        .filter_map(|company| company.get_ceo()) // filter_map needs Option<T>
        .collect::<Vec<String>>();

    println!("{:?}", all_the_ceos);
}
```

This prints `["Unknown", "Doug Suttles"]`.

Since `.filter_map()` needs an `Option`, what about `Result`? No problem: there is a method called `.ok()` that turns `Result` into `Option`. It is called `.ok()` because all it can send is the `Ok` result (the `Err` information is gone). You remember that `Option` is `Option<T>` while `Result` is `Result<T, E>` with information for both `Ok` and `Err`. So when you use `.ok()`, any `Err` information is lost and it becomes `None`.

Using `.parse()` is an easy example for this, where we try to parse some user input. `.parse()` here takes a `&str` and tries to turn it into an `f32`. It returns a `Result`, but we are using `filter_map()` so we just throw out the errors. Anything that is `Err` becomes `None` and is filtered out by `.filter_map()`.

```
fn main() {
    let user_input = vec!["8.9", "Nine point nine five", "8.0", "7.6", "eleventy-
twelve"];

    let actual_numbers = user_input
        .into_iter()
        .filter_map(|input| input.parse::<f32>().ok())
        .collect::<Vec<f32>>();

    println!("{}: {}", "actual_numbers");
}
```

This prints [8.9, 8.0, 7.6].

On the opposite side of `.ok()` is `.ok_or()` and `ok_or_else()`. This turns an `Option` into a `Result`. It is called `.ok_or()` because a `Result` gives an `Ok` or an `Err`, so you have to let it know what the `Err` value will be. That is because `None` in an `Option` doesn't have any information. Also, you can see now that the `else` part in the names of these methods means that it has a closure.

We can take our `Option` from the `Company` struct and turn it into a `Result` this way. For long-term error handling it is good to create your own type of error. But for now we just give it an error message, so it becomes a `Result<String, &str>`.

```
// Everything before main() is exactly the same
struct Company {
    name: String,
    ceo: Option<String>,
}

impl Company {
    fn new(name: &str, ceo: &str) -> Self {
        let ceo = match ceo {
            "" => None,
            ceo => Some(ceo.to_string()),
        };
        Self {
            name: name.to_string(),
            ceo,
        }
    }

    fn get_ceo(&self) -> Option<String> {
        self.ceo.clone()
    }
}

fn main() {
    let company_vec = vec![
        Company::new("Umbrella Corporation", "Unknown"),
        Company::new("Ovintiv", "Doug Suttles"),
        Company::new("The Red-Headed League", ""),
        Company::new("Stark Enterprises", ""),
    ];

    let mut results_vec = vec![]; // Pretend we need to gather error results too

    company_vec
        .iter()
        .for_each(|company| results_vec.push(company.get_ceo().ok_or("No CEO found")));

    for item in results_vec {
        println!("{}: {}", item);
    }
}
```

This line is the biggest change:

```
// 🚨
    .for_each(|company| results_vec.push(company.get_ceo().ok_or("No CEO found")));
```

It means: "For each company, use `get_ceo()`. If you get it, then pass on the value inside `ok`. And if you don't, pass on "No CEO found" inside `Err`. Then push this into the vec."

So when we print `results_vec` we get this:

```
Ok("Unknown")
Ok("Doug Suttles")
Err("No CEO found")
Err("No CEO found")
```

So now we have all four entries. Now let's use `.ok_or_else()` so we can use a closure and get a better error message. Now we have space to use `format!` to create a `String`, and put the company name in that. Then we return the `String`.

```
// Everything before main() is exactly the same
struct Company {
    name: String,
    ceo: Option<String>,
}

impl Company {
    fn new(name: &str, ceo: &str) -> Self {
        let ceo = match ceo {
            "" => None,
            name => Some(name.to_string()),
        };
        Self {
            name: name.to_string(),
            ceo,
        }
    }

    fn get_ceo(&self) -> Option<String> {
        self.ceo.clone()
    }
}

fn main() {
    let company_vec = vec![
        Company::new("Umbrella Corporation", "Unknown"),
        Company::new("Ovintiv", "Doug Suttles"),
        Company::new("The Red-Headed League", ""),
        Company::new("Stark Enterprises", ""),
    ];

    let mut results_vec = vec![];

    company_vec.iter().for_each(|company| {
        results_vec.push(company.get_ceo().ok_or_else(|| {
            let err_message = format!("No CEO found for {}", company.name);
            err_message
        }))
    });

    for item in results_vec {
        println!("{}: {}", item);
    }
}
```

This gives us:

```
Ok("Unknown")
Ok("Doug Suttles")
Err("No CEO found for The Red-Headed League")
Err("No CEO found for Stark Enterprises")
```

`.and_then()` is a helpful method that takes an `Option`, then lets you do something to its value and pass it on. So its input is an `Option`, and its output is also an `Option`. It is sort of like a safe "unwrap, then do something, then wrap again".

An easy example is a number that we get from a vec using `.get()`, because that returns an `Option`. Now we can pass it to `and_then()`, and do some math on it if it is `Some`. If it is `None`, then the `None` just gets passed through.

```
fn main() {
    let new_vec = vec![8, 9, 0]; // just a vec with numbers

    let number_to_add = 5; // use this in the math later
    let mut empty_vec = vec![]; // results go in here

    for index in 0..5 {
        empty_vec.push(
            new_vec
                .get(index)
                .and_then(|number| Some(number + 1))
                .and_then(|number| Some(number + number_to_add)))
    }
    println!("{:?}", empty_vec);
}
```

This prints `[Some(14), Some(15), Some(6), None, None]`. You can see that `None` isn't filtered out, just passed on.

`.and()` is sort of like a `bool` for `Option`. You can match many `Options` to each other, and if they are all `Some` then it will give the last one. And if one of them is a `None`, then it will give `None`.

First here is a `bool` example to help imagine. You can see that if you are using `&&` (and), even one `false` makes everything `false`.

```
fn main() {
    let one = true;
    let two = false;
    let three = true;
    let four = true;

    println!("{}", one & three); // prints true
    println!("{}", one && two && three && four); // prints false
}
```

Now here is the same thing with `.and()`. Imagine we did five operations and put the results in a `Vec<Option<&str>>`. If we get a value, we push `Some("success!")` to the vec. Then we do this two more times. After that we use `.and()` to only show the indexes that got `Some` every time.

```
fn main() {
    let first_try = vec![Some("success!"), None, Some("success!"), Some("success!"),
    None];
    let second_try = vec![None, Some("success!"), Some("success!"), Some("success!"),
    Some("success!")];
    let third_try = vec![Some("success!"), Some("success!"), Some("success!"),
    Some("success!"), None];

    for i in 0..first_try.len() {
        println!("{:?}", first_try[i].and(second_try[i]).and(third_try[i]));
    }
}
```

This prints:

```
None
None
Some("success!")
Some("success!")
None
```

The first one (index 0) is `None` because there is a `None` for index 0 in `second_try`. The second is `None` because there is a `None` in `first_try`. The next is `Some("success!")` because there is no `None` for `first_try`, `second_try`, or `third_try`.

`.any()` and `.all()` are very easy to use in iterators. They return a `bool` depending on your input. In this example we make a very large vec (about 20,000 items) with all the characters from `'a'` to `'働'`. Then we make a function to check if a character is inside it.

Next we make a smaller vec and ask it whether it is all alphabetic (with the `.is_alphabetic()` method). Then we ask it if all the characters are less than the Korean character `'행'`.

Also note that you put a reference in, because `.iter()` gives a reference and you need a `&` to compare with another `&`.

```
fn in_char_vec(char_vec: &Vec<char>, check: char) {
    println!("Is {} inside? {}", check, char_vec.iter().any(|&char| char == check));
}

fn main() {
    let char_vec = ('a'..'働').collect::<Vec<char>>();
    in_char_vec(&char_vec, 'i');
    in_char_vec(&char_vec, '뷁');
    in_char_vec(&char_vec, '鑿');

    let smaller_vec = ('A'..'z').collect::<Vec<char>>();
    println!("All alphabetic? {}", smaller_vec.iter().all(|&x| x.is_alphabetic()));
    println!("All less than the character 行? {}", smaller_vec.iter().all(|&x| x < '행'));
}
```

This prints:

```
Is i inside? true
Is 儕 inside? false
Is 鑿 inside? false
All alphabetic? false
All less than the character 行? true
```

By the way, `.any()` only checks until it finds one matching item, and then it stops. It won't check them all if it has already found a match. If you are going to use `.any()` on a `Vec`, it might be a good idea to push the items that might match near the front. Or you can use `.rev()` after `.iter()` to reverse the iterator. Here's one vec like that:

```
fn main() {
    let mut big_vec = vec![6; 1000];
    big_vec.push(5);
}
```

So this `Vec` has 1000 `6` followed by one `5`. Let's pretend that we want to use `.any()` to see if it contains 5. First let's make sure that `.rev()` is working. Remember, an `Iterator` always has `.next()` that lets you check what it does every time.

```
fn main() {
    let mut big_vec = vec![6; 1000];
    big_vec.push(5);

    let mut iterator = big_vec.iter().rev();
    println!("{:?}", iterator.next());
    println!("{:?}", iterator.next());
}
```

It prints:

```
Some(5)
Some(6)
```

We were right: there is one `Some(5)` and then the 1000 `Some(6)` start. So we can write this:

```
fn main() {
    let mut big_vec = vec![6; 1000];
    big_vec.push(5);

    println!("{}{:?}", big_vec.iter().rev().any(|&number| number == 5));
}
```

And because it's `.rev()`, it only calls `.next()` one time and stops. If we don't use `.rev()` then it will call `.next()` 1001 times before it stops. This code shows it:

```
fn main() {
    let mut big_vec = vec![6; 1000];
    big_vec.push(5);

    let mut counter = 0; // Start counting
    let mut big_iter = big_vec.into_iter(); // Make it an Iterator

    loop {
        counter += 1;
        if big_iter.next() == Some(5) { // Keep calling .next() until we get Some(5)
            break;
        }
    }
    println!("Final counter is: {}", counter);
}
```

This prints `Final counter is: 1001` so we know that it had to call `.next()` 1001 times before it found 5.

`.find()` tells you if an iterator has something, and `.position()` tells you where it is. `.find()` is different from `.any()` because it returns an `Option` with the value inside (or `None`). Meanwhile, `.position()` is also an `Option` with the position number, or `None`. In other words:

- `.find()` : "I'll try to get it for you"
- `.position()` : "I'll try to find where it is for you"

Here is a simple example:

```
fn main() {
    let num_vec = vec![10, 20, 30, 40, 50, 60, 70, 80, 90, 100];

    println!("{}?", num_vec.iter().find(|&number| number % 3 == 0)); // find takes a
    reference, so we give it &number
    println!("{}?", num_vec.iter().find(|&number| number * 2 == 30));

    println!("{}?", num_vec.iter().position(|&number| number % 3 == 0));
    println!("{}?", num_vec.iter().position(|&number| number * 2 == 30));

}
```

This prints:

```
Some(30) // This is the number itself
None // No number inside times 2 == 30
Some(2) // This is the position
None
```

With `.cycle()` you can create an iterator that loops forever. This type of iterator works well with `.zip()` to create something new, like this example which creates a `Vec<(i32, &str)>`:

```
fn main() {
    let even_odd = vec!["even", "odd"];

    let even_odd_vec = (0..6)
        .zip(even_odd.into_iter().cycle())
        .collect::<Vec<(i32, &str)>>();
    println!("{}?", even_odd_vec);
}
```

So even though `.cycle()` might never end, the other iterator only runs six times when zipping them together. That means that the iterator made by `.cycle()` doesn't get a `.next()` call again so it is done after six times. The output is:

```
[(0, "even"), (1, "odd"), (2, "even"), (3, "odd"), (4, "even"), (5, "odd")]
```

Something similar can be done with a range that doesn't have an ending. If you write `0..` then you create a range that never stops. You can use this very easily:

```
fn main() {
    let ten_chars = ('a'..).take(10).collect::<Vec<char>>();
    let skip_then_ten_chars = ('a'..).skip(1300).take(10).collect::<Vec<char>>();

    println!("{}?", ten_chars);
    println!("{}?", skip_then_ten_chars);
}
```

Both print ten characters, but the second one skipped 1300 places and prints ten letters in Armenian.

```
['a', 'b', 'c', 'd', 'e', 'f', 'g', 'h', 'i', 'j']
['j', 'u', 'z', 'n', 'g', 'g', 'n', 'u', 'u']
```

Another popular method is called `.fold()`. This method is used a lot to add together the items in an iterator, but you can also do a lot more. It is somewhat similar to `.for_each()`. In `.fold()`, you first add a starting value (if you are adding items together, then 0), then a comma, then the closure. The closure gives you two items: the total so far, and the next item. First here is a simple example showing `.fold()` to add items together.

```
fn main() {
    let some_numbers = vec![9, 6, 9, 10, 11];

    println!("{}",
        some_numbers
            .iter()
            .fold(0, |total_so_far, next_number| total_so_far + next_number)
    );
}
```

So:

- on step 1 it starts with 0 and adds the next number: 9.
- Then it takes that 9 and adds the 6: 15.
- Then it takes that 15, and adds the 9: 24.
- Then it takes that 24, and adds the 10: 34.
- Finally it takes that 34, and adds the 11: 45. So it prints 45.

But you don't just need to add things with it. Here is an example where we add a '-' to every character to make a `String`.

```
fn main() {
    let a_string = "I don't have any dashes in me.>";

    println!(
        "{}",
        a_string
            .chars() // Now it's an iterator
            .fold("-".to_string(), |mut string_so_far, next_char| { // Start with a
String "-". Bring it in as mutable each time along with the next char
                string_so_far.push(next_char); // Push the char on, then '-'
                string_so_far.push(' ');
                string_so_far} // Don't forget to pass it on to the next loop
    ));
}
```

This prints:

```
-I- -d-o-n-'-t- -h-a-v-e- -a-n-y- -d-a-s-h-e-s- -i-n- -m-e-.-
```

There are many other convenient methods like:

- `.take_while()` which takes into an iterator as long as it gets `true` (`take while x > 5` for example)
- `.cloned()` which makes a clone inside the iterator. This turns a reference into a value.
- `.by_ref()` which makes an iterator take a reference. This is good to make sure that you can use a `Vec` or something similar after you use it to make an iterator.
- Many other `_while` methods: `.skip_while()`, `.map_while()`, and so on
- `.sum()`: just adds everything together.

`.chunks()` and `.windows()` are two ways of cutting up a vector into a size you want. You put the size you want into the brackets. Let's say you have a vector with 10 items, and you want a size of 3. It will work like this:

- `.chunks()` will give you four slices: [0, 1, 2], then [3, 4, 5], then [6, 7, 8], and finally [9]. So it will try to make a slice of three items, but if it doesn't have three then it won't panic. It will just give you what is left.
- `.windows()` will first give you a slice of [0, 1, 2]. Then it will move over one and give you [1, 2, 3]. It will do that until it finally reaches the last slice of three and stop.

So let's use them on a simple vector of numbers. It looks like this:

```
fn main() {
    let num_vec = vec![1, 2, 3, 4, 5, 6, 7, 8, 9, 0];

    for chunk in num_vec.chunks(3) {
        println!("{:?}", chunk);
    }
    println!();
    for window in num_vec.windows(3) {
        println!("{:?}", window);
    }
}
```

This prints:

```
[1, 2, 3]
[4, 5, 6]
[7, 8, 9]
[0]

[1, 2, 3]
[2, 3, 4]
[3, 4, 5]
[4, 5, 6]
[5, 6, 7]
[6, 7, 8]
[7, 8, 9]
[8, 9, 0]
```

By the way, `.chunks()` will panic if you give it nothing. You can write `.chunks(1000)` for a vector with one item, but you can't write `.chunks()` with anything with a length of 0. You can see that right in the function if you click on [src] because it says `assert!(chunk_size != 0);`.

`.match_indices()` lets you pull out everything inside a `String` or `&str` that matches your input, and gives you the index too. It is similar to `.enumerate()` because it returns a tuple with two items.

```
fn main() {
    let rules = "Rule number 1: No fighting. Rule number 2: Go to bed at 8 pm. Rule
number 3: Wake up at 6 am.";
    let rule_locations = rules.match_indices("Rule").collect::<Vec<(_, _)>>(); // This
is Vec<usize, &str> but we just tell Rust to do it
    println!("{:?}", rule_locations);
}
```

This prints:

```
[(0, "Rule"), (28, "Rule"), (62, "Rule")]
```

`.peekable()` lets you make an iterator where you can see (peek at) the next item. It's like calling `.next()` (it gives an `Option`) except that the iterator doesn't move, so you can use it as many times as you want. You can actually think of peekable as "stoppable", because you can stop for as long as you want. Here is an example of us using `.peek()` three times for every item. We can use `.peek()` forever until we use `.next()` to move to the next item.

```
fn main() {
    let just_numbers = vec![1, 5, 100];
    let mut number_iter = just_numbers.iter().peekable(); // This actually creates a
    type of iterator called Peekable

    for _ in 0..3 {
        println!("I love the number {}", number_iter.peek().unwrap());
        println!("I really love the number {}", number_iter.peek().unwrap());
        println!("{} is such a nice number", number_iter.peek().unwrap());
        number_iter.next();
    }
}
```

This prints:

```
I love the number 1
I really love the number 1
1 is such a nice number
I love the number 5
I really love the number 5
5 is such a nice number
I love the number 100
I really love the number 100
100 is such a nice number
```

Here is another example where we use `.peek()` to match on an item. After we are done using it, we call `.next()`.

```
fn main() {
    let locations = vec![
        ("Nevis", 25),
        ("Taber", 8428),
        ("Markerville", 45),
        ("Cardston", 3585),
    ];
    let mut location_iter = locations.iter().peekable();
    while location_iter.peek().is_some() {
        match location_iter.peek() {
            Some((name, number)) if *number < 100 => { // .peek() gives us a reference
so we need *
                println!("Found a hamlet: {} with {} people", name, number)
            }
            Some((name, number)) => println!("Found a town: {} with {} people", name,
number),
            None => break,
        }
        location_iter.next();
    }
}
```

This prints:

```
Found a hamlet: Nevis with 25 people
Found a town: Taber with 8428 people
Found a hamlet: Markerville with 45 people
Found a town: Cardston with 3585 people
```

Finally, here is an example where we also use `.match_indices()`. In this example we put names into a `struct` depending on the number of spaces in the `&str`.

```

#[derive(Debug)]
struct Names {
    one_word: Vec<String>,
    two_words: Vec<String>,
    three_words: Vec<String>,
}

fn main() {
    let vec_of_names = vec![
        "Caesar",
        "Frodo Baggins",
        "Bilbo Baggins",
        "Jean-Luc Picard",
        "Data",
        "Rand Al'Thor",
        "Paul Atreides",
        "Barack Hussein Obama",
        "Bill Jefferson Clinton",
    ];
    let mut iter_of_names = vec_of_names.iter().peekable();

    let mut all_names = Names { // start an empty Names struct
        one_word: vec![],
        two_words: vec![],
        three_words: vec![],
    };

    while iter_of_names.peek().is_some() {
        let next_item = iter_of_names.next().unwrap(); // We can use .unwrap() because
we know it is Some
        match next_item.match_indices(' ').collect::<Vec<_>>().len() { // Create a
quick vec using .match_indices and check the length
            0 => all_names.one_word.push(next_item.to_string()),
            1 => all_names.two_words.push(next_item.to_string()),
            _ => all_names.three_words.push(next_item.to_string()),
        }
    }

    println!("{}: {:?}", all_names);
}

```

This will print:

```

Names { one_word: ["Caesar", "Data"], two_words: ["Frodo Baggins", "Bilbo Baggins",
"Jean-Luc Picard", "Rand Al'\Thor", "Paul Atreides"], three_words:
["Barack Hussein Obama", "Bill Jefferson Clinton"] }

```

The `dbg!` macro and `.inspect`

`dbg!` is a very useful macro that prints quick information. It is a good alternative to `println!` because it is faster to type and gives more information:

```
fn main() {
    let my_number = 8;
    dbg!(my_number);
}
```

This prints `[src\main.rs:4] my_number = 8`.

But actually, you can put `dbg!` in many other places, and even wrap code in it. Look at this code for example:

```
fn main() {
    let mut my_number = 9;
    my_number += 10;

    let new_vec = vec![8, 9, 10];

    let double_vec = new_vec.iter().map(|x| x * 2).collect::<Vec<i32>>();
}
```

This code creates a new mutable number and changes it. Then it creates a vec, and uses `iter` and `map` and `collect` to create a new vec. We can put `dbg!` almost everywhere in this code. `dbg!` asks the compiler: "What are you doing at this moment?" and tells you.

```
fn main() {
    let mut my_number = dbg!(9);
    dbg!(my_number += 10);

    let new_vec = dbg!(vec![8, 9, 10]);

    let double_vec = dbg!(new_vec.iter().map(|x| x * 2).collect::<Vec<i32>>());

    dbg!(double_vec);
}
```

So this prints:

```
[src\main.rs:3] 9 = 9
```

and:

```
[src\main.rs:4] my_number += 10 = ()
```

and:

```
[src\main.rs:6] vec![8, 9, 10] = [
    8,
    9,
    10,
]
```

and this one, which even shows you the value of the expression:

```
[src\main.rs:8] new_vec.iter().map(|x| x * 2).collect::<Vec<i32>>() = [
    16,
    18,
    20,
]
```

and:

```
[src\main.rs:10] double_vec = [
    16,
    18,
    20,
]
```

.inspect is a bit similar to `dbg!` but you use it like `map` in an iterator. It gives you the iterator item and you can print it or do whatever you want. For example, let's look at our `double_vec` again.

```
fn main() {
    let new_vec = vec![8, 9, 10];

    let double_vec = new_vec
        .iter()
        .map(|x| x * 2)
        .collect::<Vec<i32>>();
}
```

We want to know more information about what the code is doing. So we add `inspect()` in two places:

```
fn main() {
    let new_vec = vec![8, 9, 10];

    let double_vec = new_vec
        .iter()
        .inspect(|first_item| println!("The item is: {}", first_item))
        .map(|x| x * 2)
        .inspect(|next_item| println!("Then it is: {}", next_item))
        .collect::<Vec<i32>>();
}
```

This prints:

```
The item is: 8
Then it is: 16
The item is: 9
Then it is: 18
The item is: 10
Then it is: 20
```

And because `.inspect` takes a closure, we can write as much as we want:

```
fn main() {
    let new_vec = vec![8, 9, 10];

    let double_vec = new_vec
        .iter()
        .inspect(|first_item| {
            println!("The item is: {}", first_item);
            match **first_item % 2 { // first item is a &&i32 so we use **
                0 => println!("It is even."),
                _ => println!("It is odd."),
            }
            println!("In binary it is {:b}.", first_item);
        })
        .map(|x| x * 2)
        .collect::<Vec<i32>>();
}
```

This prints:

```
The item is: 8
It is even.
In binary it is 1000.
The item is: 9
It is odd.
In binary it is 1001.
The item is: 10
It is even.
In binary it is 1010.
```

Types of &str

There is more than one type of `&str`. We have:

- String literals: you make these when you write `let my_str = "I am a &str"`. They last for the whole program, because they are written directly into the binary. They have the type `&'static str`. '`'` means its lifetime, and string literal have a lifetime called `static`.
- Borrowed str: This is the regular `&str` form without a `static` lifetime. If you create a `String` and get a reference to it, Rust will convert it to a `&str` when you need it. For example:

```
fn prints_str(my_str: &str) { // it can use &String like a &str
    println!("{}", my_str);
}

fn main() {
    let my_string = String::from("I am a string");
    prints_str(&my_string); // we give prints_str a &String
}
```

So what is a lifetime? We will learn that now.

Lifetimes

A lifetime means "how long the variable lives". You only need to think about lifetimes with references. This is because references can't live longer than the object they come from. For example, this function does not work:

```
fn returns_reference() -> &str {
    let my_string = String::from("I am a string");
    &my_string // ⚠
}

fn main() {}
```

The problem is that `my_string` only lives inside `returns_reference`. We try to return `&my_string`, but `&my_string` can't exist without `my_string`. So the compiler says no.

This code also doesn't work:

```
fn returns_str() -> &str {
    let my_string = String::from("I am a string");
    "I am a str" // ⚠
}

fn main() {
    let my_str = returns_str();
    println!("{}", my_str);
}
```

But it almost works. The compiler says:

```
error[E0106]: missing lifetime specifier
--> src\main.rs:6:21
 |
6 | fn returns_str() -> &str {
|           ^ expected named lifetime parameter
|
|     = help: this function's return type contains a borrowed value, but there is no value
|     for it to be borrowed from
|     help: consider using the `<static` lifetime
|
6 | fn returns_str() -> &'static str {
|           ^^^^^^
```

`missing lifetime specifier` means that we need to add a '`'` with the lifetime. Then it says that it `contains a borrowed value, but there is no value for it to be borrowed from`. That means that `I am a str` isn't borrowed from anything. It says `consider using the 'static lifetime by writing &'static str`. So it thinks we should try saying that this is a string literal.

Now it works:

```
fn returns_str() -> &'static str {
    let my_string = String::from("I am a string");
    "I am a str"
}

fn main() {
    let my_str = returns_str();
    println!("{}", my_str);
}
```

That's because we returned a `&str` with a lifetime of `static`. Meanwhile, `my_string` can only be returned as a `String`: we can't return a reference to it because it is going to die in the next line.

So now `fn returns_str() -> &'static str` tells Rust: "don't worry, we will only return a string literal". String literals live for the whole program, so Rust is happy. You'll notice that this is similar to generics. When we tell the compiler something like `<T: Display>`, we promise that we will only use inputs with `Display`. Lifetimes are similar: we are not changing any variable lifetimes. We are just telling the compiler what the lifetimes of the inputs will be.

But `'static` is not the only lifetime. Actually, every variable has a lifetime, but usually we don't have to write it. The compiler is pretty smart and can usually figure out for itself. We only have to write the lifetime when the compiler doesn't know.

Here is an example of another lifetime. Imagine we want to create a `City` struct and give it a `&str` for the name. We might want to do that because it gives faster performance than with `String`. So we write it like this, but it won't work yet:

```
#[derive(Debug)]
struct City {
    name: &str, // ⚠️
    date_founded: u32,
}

fn main() {
    let my_city = City {
        name: "Ichinomiya",
        date_founded: 1921,
    };
}
```

The compiler says:

```
error[E0106]: missing lifetime specifier
--> src\main.rs:3:11
|
3 |     name: &str,
|         ^ expected named lifetime parameter
|
help: consider introducing a named lifetime parameter
|
2 | struct City<'a> {
3 |     name: &'a str,
```

Rust needs a lifetime for `&str` because `&str` is a reference. What happens when the value that `name` points to is dropped? That would be unsafe.

What about `'static`, will that work? We used it before. Let's try:

```
#[derive(Debug)]
struct City {
    name: &'static str, // change &str to &'static str
    date_founded: u32,
}

fn main() {
    let my_city = City {
        name: "Ichinomiya",
        date_founded: 1921,
    };

    println!("{} was founded in {}", my_city.name, my_city.date_founded);
}
```

Okay, that works. And maybe this is what you wanted for the struct. However, note that we can only take "string literals", so not references to something else. So this will not work:

```
#[derive(Debug)]
struct City {
    name: &'static str, // must live for the whole program
    date_founded: u32,
}

fn main() {
    let city_names = vec!["Ichinomiya".to_string(), "Kurume".to_string()]; // 
city_names does not live for the whole program

    let my_city = City {
        name: &city_names[0], // ▲ This is a &str, but not a &'static str. It is a
reference to a value inside city_names
        date_founded: 1921,
    };

    println!("{} was founded in {}", my_city.name, my_city.date_founded);
}
```

The compiler says:

```
error[E0597]: `city_names` does not live long enough
--> src\main.rs:12:16
  |
12 |     name: &city_names[0],
  |     ^^^^^^^^^^
  |
  |     borrowed value does not live long enough
  |     requires that `city_names` is borrowed for `static`
...
18 | } - `city_names` dropped here while still borrowed
```

This is important to understand, because the reference we gave it actually lives long enough. But we promised that we would only give it a `&'static str`, and that is the problem.

So now we will try what the compiler suggested before. It said to try writing `struct City<'a>` and `name: &'a str`. This means that it will only take a reference for `name` if it lives as long as `City`.

```
#[derive(Debug)]
struct City<'a> { // City has lifetime 'a
    name: &'a str, // and name also has lifetime 'a.
    date_founded: u32,
}

fn main() {
    let city_names = vec!["Ichinomiya".to_string(), "Kurume".to_string()];

    let my_city = City {
        name: &city_names[0],
        date_founded: 1921,
    };

    println!("{} was founded in {}", my_city.name, my_city.date_founded);
}
```

Also remember that you can write anything instead of `'a` if you want. This is also similar to generics where we write `T` and `U` but can actually write anything.

```
#[derive(Debug)]
struct City<'city> { // The lifetime is now called 'city
    name: &'city str, // and name has the 'city lifetime
    date_founded: u32,
}

fn main() {}
```

So usually you will write `'a`, `'b`, `'c` etc. because it is quick and the usual way to write. But you can always change it if you want. One good tip is that changing the lifetime to a "human-readable" name can help you read code if it is very complicated.

Let's look at the comparison to traits for generics again. For example:

```
use std::fmt::Display;

fn prints<T: Display>(input: T) {
    println!("T is {}", input);
}

fn main() {}
```

When you write `T: Display`, it means "please only take T if it has Display". It does not mean: "I am giving Display to T".

The same is true for lifetimes. When you write `'a` here:

```
#[derive(Debug)]
struct City<'a> {
    name: &'a str,
    date_founded: u32,
}

fn main() {}
```

It means "please only take an input for `name` if it lives at least as long as `City`". It does not mean: "I will make the input for `name` live as long as `City`".

Now we can learn about `<'_>` that we saw before. This is called the "anonymous lifetime" and is an indicator that references are being used. Rust will suggest it to you when you are implementing structs, for example. Here is one struct that almost works, but not yet:

```
// ⚠️
struct Adventurer<'a> {
    name: &'a str,
    hit_points: u32,
}

impl Adventurer {
    fn take_damage(&mut self) {
        self.hit_points -= 20;
        println!("{} has {} hit points left!", self.name, self.hit_points);
    }
}

fn main() {}
```

So we did what we needed to do for the `struct`: first we said that `name` comes from a `&str`. That means we need a lifetime, so we gave it `<'a>`. Then we had to do the same for the `struct` to show that they are at least as long as this lifetime. But then Rust tells us to do this:

```
error[E0726]: implicit elided lifetime not allowed here
--> src\main.rs:6:6
 |
6 | impl Adventurer {
|     ^^^^^^^^^^ help: indicate the anonymous lifetime: `'_`
```

It wants us to add that anonymous lifetime to show that there is a reference being used. So if we write that, it will be happy:

```
struct Adventurer<'a> {
    name: &'a str,
    hit_points: u32,
}

impl Adventurer<'_> {
    fn take_damage(&mut self) {
        self.hit_points -= 20;
        println!("{} has {} hit points left!", self.name, self.hit_points);
    }
}

fn main() {}
```

This lifetime was made so that you don't always have to write things like `impl<'a> Adventurer<'a>`, because the struct already shows the lifetime.

Lifetimes can be difficult in Rust, but here are some tips to avoid getting too stressed about them:

- You can stay with owned types, use clones etc. if you want to avoid them for the time being.
- Much of the time, when the compiler wants a lifetime you will just end up writing `<'a>` here and there and then it will work. It's just a way of saying "don't worry, I won't give you anything that doesn't live long enough".
- You can explore lifetimes just a bit at a time. Write some code with owned values, then make one a reference. The compiler will start to complain, but also give some suggestions. And if it gets too complicated, you can undo it and try again next time.

Let's do this with our code and see what the compiler says. First we'll go back and take the lifetimes out, and also implement `Display`. `Display` will just print the `Adventurer`'s name.

```
// ⚠️
struct Adventurer {
    name: &str,
    hit_points: u32,
}

impl Adventurer {
    fn take_damage(&mut self) {
        self.hit_points -= 20;
        println!("{} has {} hit points left!", self.name, self.hit_points);
    }
}

impl std::fmt::Display for Adventurer {
    fn fmt(&self, f: &mut std::fmt::Formatter<'_>) -> std::fmt::Result {
        write!(f, "{} has {} hit points.", self.name, self.hit_points)
    }
}

fn main() {}
```

First complaint is this:

```
error[E0106]: missing lifetime specifier
--> src\main.rs:2:11
|
2 |     name: &str,
|         ^ expected named lifetime parameter
|
help: consider introducing a named lifetime parameter
|
1 | struct Adventurer<'a> {
2 |     name: &'a str,
```

It suggests what to do: `<'a>` after `Adventurer`, and `&'a str`. So we do that:

```
// ⚠️
struct Adventurer<'a> {
    name: &'a str,
    hit_points: u32,
}

impl Adventurer {
    fn take_damage(&mut self) {
        self.hit_points -= 20;
        println!("{} has {} hit points left!", self.name, self.hit_points);
    }
}

impl std::fmt::Display for Adventurer {
    fn fmt(&self, f: &mut std::fmt::Formatter<'_>) -> std::fmt::Result {
        write!(f, "{} has {} hit points.", self.name, self.hit_points)
    }
}

fn main() {}
```

Now it's happy with those parts, but is wondering about the `impl` blocks. It wants us to mention that it's using references:

```

error[E0726]: implicit elided lifetime not allowed here
--> src\main.rs:6:6
|
6 | impl Adventurer {
|     ^^^^^^^^^^ help: indicate the anonymous lifetime: `'_`>

error[E0726]: implicit elided lifetime not allowed here
--> src\main.rs:12:28
|
12 | impl std::fmt::Display for Adventurer {
|     ^^^^^^^^^^ help: indicate the anonymous lifetime:
|     `'_`>

```

Okay, so we will write those in...and now it works! Now we can make an `Adventurer` and do some things with it.

```

struct Adventurer<'a> {
    name: &'a str,
    hit_points: u32,
}

impl Adventurer<'_> {
    fn take_damage(&mut self) {
        self.hit_points -= 20;
        println!("{} has {} hit points left!", self.name, self.hit_points);
    }
}

impl std::fmt::Display for Adventurer<'_> {

    fn fmt(&self, f: &mut std::fmt::Formatter<'_>) -> std::fmt::Result {
        write!(f, "{} has {} hit points.", self.name, self.hit_points)
    }
}

fn main() {
    let mut billy = Adventurer {
        name: "Billy",
        hit_points: 100_000,
    };
    println!("{}", billy);
    billy.take_damage();
}

```

This prints:

```

Billy has 100000 hit points.
Billy has 99980 hit points left!

```

So you can see that lifetimes are often just the compiler wanting to make sure. And it is usually smart enough to almost guess at what lifetimes you want, and just needs you to tell it so it can be certain.

Interior mutability

Cell

Interior mutability means having a little bit of mutability on the inside. Remember how in Rust you need to use `mut` to change a variable? There are also some ways to change them without the word `mut`. This is because Rust has some ways to let you safely change values inside of a struct that is immutable. Each one of them follows some rules that make sure that changing the values is still safe.

First, let's look at a simple example where we would want this. Imagine a `struct` called `PhoneModel` with many fields:

```
struct PhoneModel {
    company_name: String,
    model_name: String,
    screen_size: f32,
    memory: usize,
    date_issued: u32,
    on_sale: bool,
}

fn main() {
    let super_phone_3000 = PhoneModel {
        company_name: "YY Electronics".to_string(),
        model_name: "Super Phone 3000".to_string(),
        screen_size: 7.5,
        memory: 4_000_000,
        date_issued: 2020,
        on_sale: true,
    };
}
```

It is better for the fields in `PhoneModel` to be immutable, because we don't want the data to change. The `date_issued` and `screen_size` never change, for example.

But inside is one field called `on_sale`. A phone model will first be on sale (`true`), but later the company will stop selling it. Can we make just this one field mutable? Because we don't want to write `let mut super_phone_3000`. If we do, then every field will become mutable.

Rust has many ways to allow some safe mutability inside of something that is immutable. The most simple way is called `Cell`. First we use `use std::cell::Cell` so that we can just write `Cell` instead of `std::cell::Cell` every time.

Then we change `on_sale: bool` to `on_sale: Cell<bool>`. Now it isn't a bool: it's a `Cell` that holds a `bool`.

`Cell` has a method called `.set()` where you can change the value. We use `.set()` to change `on_sale: true` to `on_sale: Cell::new(true)`.

```

use std::cell::Cell;

struct PhoneModel {
    company_name: String,
    model_name: String,
    screen_size: f32,
    memory: usize,
    date_issued: u32,
    on_sale: Cell<bool>,
}

fn main() {
    let super_phone_3000 = PhoneModel {
        company_name: "YY Electronics".to_string(),
        model_name: "Super Phone 3000".to_string(),
        screen_size: 7.5,
        memory: 4_000_000,
        date_issued: 2020,
        on_sale: Cell::new(true),
    };

    // 10 years later, super_phone_3000 is not on sale anymore
    super_phone_3000.on_sale.set(false);
}

```

`Cell` works for all types, but works best for simple Copy types because it gives values, not references. `Cell` has a method called `get()` for example that only works on Copy types.

Another type you can use is `RefCell`.

RefCell

A `RefCell` is another way to change values without needing to declare `mut`. It means "reference cell", and is like a `Cell` but uses references instead of copies.

We will create a `User` struct. So far you can see that it is similar to `Cell`:

```

use std::cell::RefCell;

#[derive(Debug)]
struct User {
    id: u32,
    year_registered: u32,
    username: String,
    active: RefCell<bool>,
    // Many other fields
}

fn main() {
    let user_1 = User {
        id: 1,
        year_registered: 2020,
        username: "User 1".to_string(),
        active: RefCell::new(true),
    };

    println!("{:?}", user_1.active);
}

```

This prints `RefCell { value: true }`.

There are many methods for `RefCell`. Two of them are `.borrow()` and `.borrow_mut()`. With these methods, you can do the same thing you do with `&` and `&mut`. The rules are the same:

- Many borrows is fine,
- one mutable borrow is fine,
- but mutable and immutable together is not fine.

So changing the value in a `RefCell` is very easy:

```
// 🚨
user_1.active.replace(false);
println!("{:?}", user_1.active);
```

And there are many other methods like `replace_with` that uses a closure:

```
// 🚨
let date = 2020;

user_1
    .active
    .replace_with(|_| if date < 2000 { true } else { false });
println!("{:?}", user_1.active);
```

But you have to be careful with a `RefCell`, because it checks borrows at runtime, not compilation time. Runtime means when the program is actually running (after compilation). So this will compile, even though it is wrong:

```
use std::cell::RefCell;

#[derive(Debug)]
struct User {
    id: u32,
    year_registered: u32,
    username: String,
    active: RefCell<bool>,
    // Many other fields
}

fn main() {
    let user_1 = User {
        id: 1,
        year_registered: 2020,
        username: "User 1".to_string(),
        active: RefCell::new(true),
    };

    let borrow_one = user_1.active.borrow_mut(); // first mutable borrow - okay
    let borrow_two = user_1.active.borrow_mut(); // second mutable borrow - not okay
}
```

But if you run it, it will immediately panic.

```
thread 'main' panicked at 'already borrowed: BorrowMutError',
C:\Users\mithr\.rustup\toolchains\stable-x86_64-pc-windows-
msvc\lib\rustlib\src\rust\src\libcore\cell.rs:877:9
note: run with `RUST_BACKTRACE=1` environment variable to display a backtrace
error: process didn't exit successfully: 'target\debug\rust_book.exe' (exit code: 101)
```

`already borrowed: BorrowMutError` is the important part. So when you use a `RefCell`, it is good to compile **and** run to check.

Mutex

`Mutex` is another way to change values without declaring `mut`. `Mutex` means `mutual exclusion`, which means "only one at a time". This is why a `Mutex` is safe, because it only lets one process change it at a time. To do this, it uses `.lock()`. `Lock` is like locking a door from the inside. You go into a room, lock the door, and now you can change things inside the room. Nobody else can come in and stop you, because you locked the door.

A `Mutex` is easier to understand through examples.

```
use std::sync::Mutex;

fn main() {
    let my_mutex = Mutex::new(5); // A new Mutex<i32>. We don't need to say mut
    let mut mutex_changer = my_mutex.lock().unwrap(); // mutex_changer is a MutexGuard
                                                    // It has to be mut because we
    will change it
                                                    // Now it has access to the Mutex
                                                    // Let's print my_mutex to see:

    println!("{:?}", my_mutex); // This prints "Mutex { data: <locked> }"
                                // So we can't access the data with my_mutex now,
                                // only with mutex_changer

    println!("{:?}", mutex_changer); // This prints 5. Let's change it to 6.

    *mutex_changer = 6; // mutex_changer is a MutexGuard<i32> so we use * to change the
    i32

    println!("{:?}", mutex_changer); // Now it says 6
}
```

But `mutex_changer` still has a lock after it is done. How do we stop it? A `Mutex` is unlocked when the `MutexGuard` goes out of scope. "Go out of scope" means the code block is finished. For example:

```
use std::sync::Mutex;

fn main() {
    let my_mutex = Mutex::new(5);
    {
        let mut mutex_changer = my_mutex.lock().unwrap();
        *mutex_changer = 6;
    } // mutex_changer goes out of scope - now it is gone. It is not locked anymore

    println!("{:?}", my_mutex); // Now it says: Mutex { data: 6 }
}
```

If you don't want to use a different `{}` code block, you can use `std::mem::drop(mutex_changer)`. `std::mem::drop` means "make this go out of scope".

```
use std::sync::Mutex;

fn main() {
    let my_mutex = Mutex::new(5);
    let mut mutex_changer = my_mutex.lock().unwrap();
    *mutex_changer = 6;
    std::mem::drop(mutex_changer); // drop mutex_changer - it is gone now
                                    // and my_mutex is unlocked

    println!("{}: {}", my_mutex); // Now it says: Mutex { data: 6 }
}
```

You have to be careful with a `Mutex` because if another variable tries to `lock` it, it will wait:

```
use std::sync::Mutex;

fn main() {
    let my_mutex = Mutex::new(5);
    let mut mutex_changer = my_mutex.lock().unwrap(); // mutex_changer has the lock
    let mut other_mutex_changer = my_mutex.lock().unwrap(); // other_mutex_changer
wants the lock
                                                // the program is waiting
                                                // and waiting
                                                // and will wait forever.

    println!("This will never print...");
}
```

One other method is `try_lock()`. Then it will try once, and if it doesn't get the lock it will give up. Don't do `try_lock().unwrap()`, because it will panic if it doesn't work. `if let` or `match` is better:

```
use std::sync::Mutex;

fn main() {
    let my_mutex = Mutex::new(5);
    let mut mutex_changer = my_mutex.lock().unwrap();
    let mut other_mutex_changer = my_mutex.try_lock(); // try to get the lock

    if let Ok(value) = other_mutex_changer {
        println!("The MutexGuard has: {}", value)
    } else {
        println!("Didn't get the lock")
    }
}
```

Also, you don't need to make a variable to change the `Mutex`. You can just do this:

```
use std::sync::Mutex;

fn main() {
    let my_mutex = Mutex::new(5);

    *my_mutex.lock().unwrap() = 6;

    println!("{}: {}", my_mutex);
}
```

`*my_mutex.lock().unwrap() = 6;` means "unlock my_mutex and make it 6". There is no variable that holds it so you don't need to call `std::mem::drop`. You can do it 100 times if you want - it doesn't matter:

```
use std::sync::Mutex;

fn main() {
    let my_mutex = Mutex::new(5);

    for _ in 0..100 {
        *my_mutex.lock().unwrap() += 1; // locks and unlocks 100 times
    }

    println!("{:?}", my_mutex);
}
```

RwLock

`RwLock` means "read write lock". It is like a `Mutex` but also like a `RefCell`. You use `.write().unwrap()` instead of `.lock().unwrap()` to change it. But you can also use `.read().unwrap()` to get read access. It is like `RefCell` because it follows the rules:

- many `.read()` variables is okay,
- one `.write()` variable is okay,
- but more than one `.write()` or `.read()` together with `.write()` is not okay.

The program will run forever if you try to `.write()` when you can't get access:

```
use std::sync::RwLock;

fn main() {
    let my_rwlock = RwLock::new(5);

    let read1 = my_rwlock.read().unwrap(); // one .read() is fine
    let read2 = my_rwlock.read().unwrap(); // two .read()s is also fine

    println!("{:?}, {:?}", read1, read2);

    let write1 = my_rwlock.write().unwrap(); // uh oh, now the program will wait
    forever
}
```

So we use `std::mem::drop`, just like in a `Mutex`.

```
use std::sync::RwLock;
use std::mem::drop; // We will use drop() many times

fn main() {
    let my_rwlock = RwLock::new(5);

    let read1 = my_rwlock.read().unwrap();
    let read2 = my_rwlock.read().unwrap();

    println!("{:?}, {:?}", read1, read2);

    drop(read1);
    drop(read2); // we dropped both, so we can use .write() now

    let mut write1 = my_rwlock.write().unwrap();
    *write1 = 6;
    drop(write1);
    println!("{:?}", my_rwlock);
}
```

And you can use `try_read()` and `try_write()` too.

```
use std::sync::RwLock;

fn main() {
    let my_rwlock = RwLock::new(5);

    let read1 = my_rwlock.read().unwrap();
    let read2 = my_rwlock.read().unwrap();

    if let Ok(mut number) = my_rwlock.try_write() {
        *number += 10;
        println!("Now the number is {}", number);
    } else {
        println!("Couldn't get write access, sorry!")
    };
}
```

Cow

Cow is a very convenient enum. It means "clone on write" and lets you return a `&str` if you don't need a `String`, and a `String` if you need it. (It can also do the same with arrays vs. Vecs, etc.)

To understand it, let's look at the signature. It says:

```
pub enum Cow<'a, B>
where
    B: 'a + ToOwned + ?Sized,
{
    Borrowed(&'a B),
    Owned(<B as ToOwned>::Owned),
}
fn main() {}
```

You know right away that `'a` means it works with references. The `ToOwned` trait means that it is a type that can be turned into an owned type. For example, `str` is usually a reference (`&str`) and you can turn it into an owned `String`.

Next is `?sized`. This means "maybe Sized, but maybe not". Almost every type in Rust is Sized, but types like `str` are not. That is why we need a `&` for a `str`, because the compiler doesn't know the size. So if you want a trait that can use something like a `str`, you add `?sized`.

Next are the `enum` variants. They are `Borrowed` and `Owned`.

Imagine that you have a function that returns `Cow<'static, str>`. If you tell the function to return `"My message".into()`, it will look at the type: "My message" is a `str`. This is a `Borrowed` type, so it chooses `Borrowed(&'a B)`. So it becomes `Cow::Borrowed(&'static str)`.

And if you give it a `format!("{}", "My message").into()` then it will look at the type. This time it is a `String`, because `format!` makes a `String`. So this time it will select "Owned".

Here is an example to test `Cow`. We will put a number into a function that returns a `Cow<'static, str>`. Depending on the number, it will create a `&str` or a `String`. Then it uses `.into()` to turn it into a `Cow`. When you do that, it will choose either `Cow::Borrowed` or `Cow::Owned`. Then we will match to see which one it chose.

```
use std::borrow::Cow;

fn modulo_3(input: u8) -> Cow<'static, str> {
    match input % 3 {
        0 => "Remainder is 0".into(),
        1 => "Remainder is 1".into(),
        remainder => format!("Remainder is {}", remainder).into(),
    }
}

fn main() {
    for number in 1..=6 {
        match modulo_3(number) {
            Cow::Borrowed(message) => println!("{} went in. The Cow is borrowed with this message: {}", number, message),
            Cow::Owned(message) => println!("{} went in. The Cow is owned with this message: {}", number, message),
        }
    }
}
```

This prints:

```
1 went in. The Cow is borrowed with this message: Remainder is 1
2 went in. The Cow is owned with this message: Remainder is 2
3 went in. The Cow is borrowed with this message: Remainder is 0
4 went in. The Cow is borrowed with this message: Remainder is 1
5 went in. The Cow is owned with this message: Remainder is 2
6 went in. The Cow is borrowed with this message: Remainder is 0
```

Cow has some other methods like `into_owned` or `into_borrowed` so you can change it if you need to.

Type aliases

A type alias means "giving a new name to another type". Type aliases are very easy. Usually you use them when you have a very long type and don't want to write it every time. It is also good when you want to give a type a better name that is easy to remember. Here are two examples of type aliases.

Here is a type that is not difficult, but you want to make your code easier to understand for other people (or for you):

```
type CharacterVec = Vec<char>;
fn main() {}
```

Here's a type that is very difficult to read:

```
// this return type is extremely long
fn returns<'a>(input: &'a Vec<char>) ->
    std::iter::Take<std::iter::Skip<std::slice::Iter<'a, char>>> {
    input.iter().skip(4).take(5)
}

fn main() {}
```

So you can change it to this:

```
type SkipFourTakeFive<'a> = std::iter::Take<std::iter::Skip<std::slice::Iter<'a,
char>>>;
fn returns<'a>(input: &'a Vec<char>) -> SkipFourTakeFive {
    input.iter().skip(4).take(5)
}

fn main() {}
```

Of course, you can also import items to make the type shorter:

```
use std::iter::{Take, Skip};
use std::slice::Iter;

fn returns<'a>(input: &'a Vec<char>) -> Take<Skip<Iter<'a, char>>> {
    input.iter().skip(4).take(5)
}

fn main() {}
```

So you can decide what looks best in your code depending on what you like.

Note that this doesn't create an actual new type. It's just a name to use instead of an existing type. So if you write `type File = String;`, the compiler just sees a `String`. So this will print `true`:

```
type File = String;

fn main() {
    let my_file = File::from("I am file contents");
    let my_string = String::from("I am file contents");
    println!("{}", my_file == my_string);
}
```

So what if you want an actual new type?

If you want a new file type that the compiler sees as a `File`, you can put it in a struct. (This is actually called the `newtype` idiom)

```
struct File(String); // File is a wrapper around String

fn main() {
    let my_file = File(String::from("I am file contents"));
    let my_string = String::from("I am file contents");
}
```

Now this will not work, because they are two different types:

```
struct File(String); // File is a wrapper around String

fn main() {
    let my_file = File(String::from("I am file contents"));
    let my_string = String::from("I am file contents");
    println!("{}", my_file == my_string); // ⚠ cannot compare File with String
}
```

If you want to compare the String inside, you can use `my_file.0`:

```
struct File(String);

fn main() {
    let my_file = File(String::from("I am file contents"));
    let my_string = String::from("I am file contents");
    println!("{}", my_file.0 == my_string); // my_file.0 is a String, so this prints
true
}
```

And now this type doesn't have any traits, so you can implement them yourself. This is not too surprising:

```
#[derive(Clone, Debug)]
struct File(String);
```

So when you use the `File` type here you can clone it and Debug print it, but it doesn't have the traits of `String` unless you use `.0` to get to the `String` inside it. But in other people's code you can only use `.0` if it's marked `pub` for public. And that's why these sorts of types use the `Deref` trait a lot. We will learn about both `pub` and `Deref` later.

Importing and renaming inside a function

Usually you write `use` at the top of the program, like this:

```
use std::cell::{Cell, RefCell};

fn main() {}
```

But we saw that you can do this anywhere, especially in functions with enums that have long names. Here is an example.

```
enum MapDirection {
    North,
    NorthEast,
    East,
    SouthEast,
    South,
    SouthWest,
    West,
    NorthWest,
}

fn main() {}

fn give_direction(direction: &MapDirection) {
    match direction {
        MapDirection::North => println!("You are heading north."),
        MapDirection::NorthEast => println!("You are heading northeast."),
        // So much more left to type...
        // ⚠ because we didn't write every possible variant
    }
}
```

So now we will import MapDirection inside the function. That means that inside the function you can just write `North` and so on.

```
enum MapDirection {
    North,
    NorthEast,
    East,
    SouthEast,
    South,
    SouthWest,
    West,
    NorthWest,
}

fn main() {}

fn give_direction(direction: &MapDirection) {
    use MapDirection::*;

    let m = "You are heading";

    match direction {
        North => println!("{} north.", m),
        NorthEast => println!("{} northeast.", m),
        // This is a bit better
        // ⚠
    }
}
```

We've seen that `::*` means "import everything after the `::`". In our case, that means `North`, `NorthEast` ...and all the way to `NorthWest`. When you import other people's code you can do that too, but if the code is very large you might have problems. What if it has some items that are the same as your code? So it's usually best to not use `::*` all the time unless you're sure. A lot of times you see a section called `prelude` in other people's code with all the main items you probably need.

So then you will usually use it like this: `name::prelude::*`. We will talk about this more in the sections for `modules` and `crates`.

You can also use `as` to change the name. For example, maybe you are using someone else's code and you can't change the names in an enum:

```
enum FileState {
    CannotAccessFile,
    FileOpenedAndReady,
    NoSuchFileExists,
    SimilarFileNameInNextDirectory,
}

fn main() {}
```

So then you can 1) import everything and 2) change the names:

```
enum FileState {
    CannotAccessFile,
    FileOpenedAndReady,
    NoSuchFileExists,
    SimilarFileNameInNextDirectory,
}

fn give_filestate(input: &FileState) {
    use FileState::{
        CannotAccessFile as NoAccess,
        FileOpenedAndReady as Good,
        NoSuchFileExists as NoFile,
        SimilarFileNameInNextDirectory as OtherDirectory
    };
    match input {
        NoAccess => println!("Can't access file."),
        Good => println!("Here is your file"),
        NoFile => println!("Sorry, there is no file by that name."),
        OtherDirectory => println!("Please check the other directory."),
    }
}

fn main() {}
```

So now you can write `OtherDirectory` instead of `FileState::SimilarFileNameInNextDirectory`.

The todo! macro

Sometimes you want to write code in general to help you imagine your project. For example, imagine a simple project to do something with books. Here's what you think as you write it:

```
struct Book {} // Okay, first I need a book struct.  
               // Nothing in there yet - will add later  
  
enum BookType { // A book can be hardcover or softcover, so add an enum  
    HardCover,  
    SoftCover,  
}  
  
fn get_book(book: &Book) -> Option<String> {} // ⚠️ get_book should take a &Book and  
return an Option<String>  
  
fn delete_book(book: Book) -> Result<(), String> {} // delete_book should take a Book  
and return a Result...  
                                                       // TODO: impl block and make these  
functions methods...  
fn check_book_type(book_type: &BookType) { // Let's make sure the match statement works  
    match book_type {  
        BookType::HardCover => println!("It's hardcover"),  
        BookType::SoftCover => println!("It's softcover"),  
    }  
}  
  
fn main() {  
    let book_type = BookType::HardCover;  
    check_book_type(&book_type); // Okay, let's check this function!  
}
```

But Rust is not happy with `get_book` and `delete_book`. It says:

```
error[E0308]: mismatched types
--> src\main.rs:32:29
|
32 | fn get_book(book: &Book) -> Option<String> {}
|      -----                                ^^^^^^^^^^ expected enum `std::option::Option`,
found `()``                                implicitly returns `()` as its body has no tail or `return` expression
|
= note:    expected enum `std::option::Option<std::string::String>`
          found unit type `()``
```



```
error[E0308]: mismatched types
--> src\main.rs:34:31
|
34 | fn delete_book(book: Book) -> Result<(), String> {}
|      -----                                ^^^^^^^^^^ expected enum
`std::result::Result`, found `()``          implicitly returns `()` as its body has no tail or `return` expression
|
= note:    expected enum `std::result::Result<(), std::string::String>`
          found unit type `()``
```

But you don't care about `get_book` and `delete_book` right now. This is where you can use `todo!()`. If you add that to the function, Rust will not complain, and will compile.

```

struct Book {}

fn get_book(book: &Book) -> Option<String> {
    todo!() // todo means "I will do it later, please be quiet"
}

fn delete_book(book: Book) -> Result<(), String> {
    todo!()
}

fn main() {}

```

So now the code compiles and you can see the result of `check_book_type`: It's `hardcover`.

But careful, because it only compiles - you can't use the function. If you call a function with `todo!()` inside it, it will panic.

Also, `todo!()` functions still need real input and output types. If you just write this, it will not compile:

```

struct Book {}

fn get_book(book: &Book) -> WorldsBestType { // ⚠
    todo!()
}

fn main() {}

```

It will say:

```

error[E0412]: cannot find type `WorldsBestType` in this scope
--> src\main.rs:32:29
 |
32 | fn get_book(book: &Book) -> WorldsBestType {
|                                ^^^^^^^^^^^^^^ not found in this scope

```

`todo!()` is actually the same as another macro: `unimplemented!()`. Programmers were using `unimplemented!()` a lot but it was long to type, so they created `todo!()` which is shorter.

Rc

Rc means "reference counter". You know that in Rust, every variable can only have one owner. That is why this doesn't work:

```
fn takes_a_string(input: String) {
    println!("It is: {}", input)
}

fn also_takes_a_string(input: String) {
    println!("It is: {}", input)
}

fn main() {
    let user_name = String::from("User MacUserson");

    takes_a_string(user_name);
    also_takes_a_string(user_name); // ⚠
}
```

After `takes_a_string` takes `user_name`, you can't use it anymore. Here that is no problem: you can just give it `user_name.clone()`. But sometimes a variable is part of a struct, and maybe you can't clone the struct. Or maybe the `String` is really long and you don't want to clone it. These are some reasons for `Rc`, which lets you have more than one owner. An `Rc` is like a good office worker: `Rc` writes down who has ownership, and how many. Then once the number of owners goes down to 0, the variable can disappear.

Here's how you use an `Rc`. First imagine two structs: one called `City`, and another called `CityData`. `City` has information for one city, and `CityData` puts all the cities together in `Vec`s.

```

#[derive(Debug)]
struct City {
    name: String,
    population: u32,
    city_history: String,
}

#[derive(Debug)]
struct CityData {
    names: Vec<String>,
    histories: Vec<String>,
}

fn main() {
    let calgary = City {
        name: "Calgary".to_string(),
        population: 1_200_000,
            // Pretend that this string is very very long
        city_history: "Calgary began as a fort called Fort Calgary
that...".to_string(),
    };

    let canada_cities = CityData {
        names: vec![calgary.name], // This is using calgary.name, which is short
        histories: vec![calgary.city_history], // But this String is very long
    };

    println!("Calgary's history is: {}", calgary.city_history); // ⚠
}

```

Of course, it doesn't work because `canada_cities` now owns the data and `calgary` doesn't. It says:

```

error[E0382]: borrow of moved value: `calgary.city_history`
--> src\main.rs:27:42
|
24 |     histories: vec![calgary.city_history], // But this String is very long
|                         ----- value moved here
...
27 |     println!("Calgary's history is: {}", calgary.city_history); // ⚠
|                         ^^^^^^^^^^^^^^^^^^^^^ value borrowed here
after move
|
= note: move occurs because `calgary.city_history` has type `std::string::String`,
which does not implement the `Copy` trait

```

We can clone the name: `names: vec![calgary.name.clone()]` but we don't want to clone the `city_history`, which is long. So we can use an `Rc`.

Add the `use` declaration:

```

use std::rc::Rc;

fn main() {}

```

Then put `Rc` around `String`.

```
use std::rc::Rc;

#[derive(Debug)]
struct City {
    name: String,
    population: u32,
    city_history: Rc<String>,
}

#[derive(Debug)]
struct CityData {
    names: Vec<String>,
    histories: Vec<Rc<String>>,
}

fn main() {}
```

To add a new reference, you have to `clone` the `Rc`. But hold on, didn't we want to avoid using `.clone()`? Not exactly: we didn't want to clone the whole `String`. But a clone of an `Rc` just clones the pointer - it's basically free. It's like putting a name sticker on a box of books to show that two people own it, instead of making a whole new box.

You can clone an `Rc` called `item` with `item.clone()` or with `Rc::clone(&item)`. So `calgary.city_history` has 2 owners. We can check the number of owners with `Rc::strong_count(&item)`. Also let's add a new owner. Now our code looks like this:

```
use std::rc::Rc;

#[derive(Debug)]
struct City {
    name: String,
    population: u32,
    city_history: Rc<String>, // String inside an Rc
}

#[derive(Debug)]
struct CityData {
    names: Vec<String>,
    histories: Vec<Rc<String>>, // A Vec of Strings inside Rcs
}

fn main() {
    let calgary = City {
        name: "Calgary".to_string(),
        population: 1_200_000,
        // Pretend that this string is very very long
        city_history: Rc::new("Calgary began as a fort called Fort Calgary
that...".to_string()), // Rc::new() to make the Rc
    };

    let canada_cities = CityData {
        names: vec![calgary.name],
        histories: vec![calgary.city_history.clone()], // .clone() to increase the
        count
    };

    println!("Calgary's history is: {}", calgary.city_history);
    println!("{} {}", Rc::strong_count(&calgary.city_history));
    let new_owner = calgary.city_history.clone();
}
```

This prints 2. And `new_owner` is now an `Rc<String>`. Now if we use `println!("{}", Rc::strong_count(&calgary.city_history));`, we get 3.

So if there are strong pointers, are there weak pointers? Yes, there are. Weak pointers are useful because if two `Rc`s point at each other, they can't die. This is called a "reference cycle". If item 1 has an `Rc` to item 2, and item 2 has an `Rc` to item 1, they can't get to 0. In this case you want to use weak references. Then `Rc` will count the references, but if it only has weak references then it can die. You use `Rc::downgrade(&item)` instead of `Rc::clone(&item)` to make weak references. Also, you use `Rc::weak_count(&item)` to see the weak count.

Multiple threads

If you use multiple threads, you can do many things at the same time. Modern computers have more than one core so they can do more than one thing at the same time, and Rust lets you use them. Rust uses threads that are called "OS threads". OS thread means the operating system creates the thread on a different core. (Some other languages use "green threads", which are less powerful)

You create threads with `std::thread::spawn` and then a closure to tell it what to do. Threads are interesting because they run at the same time, and you can test it to see what happens. Here is a simple example:

```
fn main() {
    std::thread::spawn(|| {
        println!("I am printing something");
    });
}
```

If you run this, it will be different every time. Sometimes it will print, and sometimes it won't print (this depends on your computer speed too). That is because sometimes `main()` finishes before the thread finishes. And when `main()` finishes, the program is over. This is easier to see in a `for` loop:

```
fn main() {
    for _ in 0..10 { // set up ten threads
        std::thread::spawn(|| {
            println!("I am printing something");
        });
    } // Now the threads start.
} // How many can finish before main() ends here?
```

Usually about four threads will print before `main` ends, but it is always different. If your computer is faster then it might not print any. Also, sometimes the threads will panic:

```
thread 'thread 'I am printing something
thread '<unnamed><unnamed>thread '' panicked at '<unnamed>I am printing something
' panicked at 'thread '<unnamed>cannot access stdout during shutdown' panicked at
'<unnamed>thread 'cannot access stdout during
shutdown'
```

This is the error when the thread tries to do something right when the program is shutting down.

You can give the computer something to do so it won't shut down right away:

```
fn main() {
    for _ in 0..10 {
        std::thread::spawn(|| {
            println!("I am printing something");
        });
    }
    for _ in 0..1_000_000 { // make the program declare "let x = 9" one million times
                           // It has to finish this before it can exit the main
    function
        let _x = 9;
    }
}
```

But that is a silly way to give the threads time to finish. The better way is to bind the threads to a variable. If you add `let`, then you will create a `JoinHandle`. You can see this in the signature for `spawn`:

```
pub fn spawn<F, T>(f: F) -> JoinHandle<T>
where
    F: FnOnce() -> T,
    F: Send + 'static,
    T: Send + 'static,
```

(`f` is the closure - we will learn how to put closures into our functions later)

So now we have a `JoinHandle` every time.

```
fn main() {
    for _ in 0..10 {
        let handle = std::thread::spawn(|| {
            println!("I am printing something");
        });
    }
}
```

`handle` is now a `JoinHandle`. What do we do with it? We use a method called `.join()`. This method means "wait until all the threads are done" (it waits for the threads to join it). So now just write `handle.join()` and it will wait for each of the threads to finish.

```
fn main() {
    for _ in 0..10 {
        let handle = std::thread::spawn(|| {
            println!("I am printing something");
        });

        handle.join(); // Wait for the threads to finish
    }
}
```

Now we will learn about the three types of closures. The three types are:

- `FnOnce`: takes the whole value
- `FnMut`: takes a mutable reference
- `Fn`: takes a regular reference

A closure will try to use `Fn` if it can. But if it needs to change the value it will use `FnMut`, and if it needs to take the whole value, it will use `FnOnce`. `FnOnce` is a good name because it explains what it does: it takes the value once, and then it can't take it again.

Here is an example:

```
fn main() {
    let my_string = String::from("I will go into the closure");
    let my_closure = || println!("{}", my_string);
    my_closure();
    my_closure();
}
```

`String` is not `Copy`, so `my_closure()` is `Fn`: it takes a reference.

If we change `my_string`, it will be `FnMut`.

```
fn main() {
    let mut my_string = String::from("I will go into the closure");
    let mut my_closure = || {
        my_string.push_str(" now");
        println!("{}", my_string);
    };
    my_closure();
    my_closure();
}
```

This prints:

```
I will go into the closure now
I will go into the closure now now
```

And if you take by value, then it will be `FnOnce`.

```
fn main() {
    let my_vec: Vec<i32> = vec![8, 9, 10];
    let my_closure = || {
        my_vec
            .into_iter() // into_iter takes ownership
            .map(|x| x as u8) // turn it into u8
            .map(|x| x * 2) // multiply by 2
            .collect::<Vec<u8>>() // collect into a Vec
    };
    let new_vec = my_closure();
    println!("{}:", new_vec);
}
```

We took by value, so we can't run `my_closure()` more than once. That is where the name comes from.

So now back to threads. Let's try to use a value from outside:

```
fn main() {
    let mut my_string = String::from("Can I go inside the thread?");

    let handle = std::thread::spawn(|| {
        println!("{}:", my_string); // ⚠️
    });

    handle.join();
}
```

The compiler says that this won't work.

```
error[E0373]: closure may outlive the current function, but it borrows `my_string`,  
which is owned by the current function  
--> src\main.rs:28:37  
|  
28 |     let handle = std::thread::spawn(|| {  
|           ^^^ may outlive borrowed value `my_string`  
29 |         println!("{}", my_string);  
|                 ----- `my_string` is borrowed here  
|  
note: function requires argument type to outlive ``static``  
--> src\main.rs:28:18  
|  
28 |     let handle = std::thread::spawn(|| {  
|           ^-----  
29 |         println!("{}", my_string);  
30 |     });  
|     |-----^  
help: to force the closure to take ownership of `my_string` (and any other referenced  
variables), use the `move` keyword  
-->  
28 |     let handle = std::thread::spawn(move || {  
|           ^^^^^^
```

It is a long message, but helpful: it says to `use` the `'move'` keyword. The problem is that we can do anything to `my_string` while the thread is using it, but it doesn't own it. That would be unsafe.

Let's try something else that doesn't work:

```
fn main() {
    let mut my_string = String::from("Can I go inside the thread?");

    let handle = std::thread::spawn(|| {
        println!("{}", my_string); // now my_string is being used as a reference
    });

    std::mem::drop(my_string); // ⚠ We try to drop it here. But the thread still
    needs it.

    handle.join();
}
```

So you have to take the value with `move`. Now it is safe:

```
fn main() {
    let mut my_string = String::from("Can I go inside the thread?");

    let handle = std::thread::spawn(move|| {
        println!("{}", my_string);
    });

    std::mem::drop(my_string); // ⚠️ we can't drop, because handle has it. So this
    won't work

    handle.join();
}
```

So we delete the `std::mem::drop`, and now it is okay. `handle` takes `my_string` and our code is safe.

```
fn main() {
    let my_string = String::from("Can I go inside the thread?");

    let handle = std::thread::spawn(move|| {
        println!("{}", my_string);
    });

    handle.join().unwrap();
}
```

So just remember: if you need a value in a thread from outside the thread, you need to use `move`.

Closures in functions

Closures are great. So how do we put them into our own functions?

You can make your own functions that take closures, but inside them it is less free and you have to decide the type. Outside a function a closure can decide by itself between `Fn`, `FnMut` and `FnOnce`, but inside you have to choose one. The best way to understand is to look at a few function signatures. Here is the one for `.all()`. We remember that it checks an iterator to see if everything is `true` (depending on what you decide is `true` or `false`). Part of its signature says this:

```
fn all<F>(&mut self, f: F) -> bool    // 🚧
where
    F: FnMut(Self::Item) -> bool,
```

`fn all`: this tells you that there is a generic type `F`. A closure is always generic because every time it is a different type.

`(&mut self, f: F)`: `&mut self` tells you that it's a method. `f: F` is usually what you see for a closure: this is the variable name and the type. Of course, there is nothing special about `f` and `F` and they could be different names. You could write `my_closure: Closure` if you wanted - it doesn't matter. But in signatures you almost always see `f: F`.

Next is the part about the closure: `F: FnMut(Self::Item) -> bool`. Here it decides that the closure is `FnMut`, so it can change the values. It changes the values of `Self::Item`, which is the iterator that it takes. And it has to return `true` or `false`.

Here is a much simpler signature with a closure:

```
fn do_something<F>(f: F)    // 🚧
where
    F: FnOnce(),
{
    f();
}
```

This just says that it takes a closure, takes the value (`FnOnce` = takes the value), and doesn't return anything. So now we can call this closure that takes nothing and do whatever we like. We will create a `Vec` and then iterate over it just to show what we can do now.

```
fn do_something<F>(f: F)
where
    F: FnOnce(),
{
    f();
}

fn main() {
    let some_vec = vec![9, 8, 10];
    do_something(|| {
        some_vec
            .into_iter()
            .for_each(|x| println!("The number is: {}", x));
    })
}
```

For a more real example, we will create a `City` struct again. This time the `City` struct has more data about years and populations. It has a `Vec<u32>` for all the years, and another `Vec<u32>` for all the populations.

`City` has two functions: `new()` to create a new `City`, and `.city_data()` which has a closure. When we use `.city_data()`, it gives us the years and the populations and a closure, so we can do what we want with the data. The closure type is `FnMut` so we can change the data. It looks like this:

```

#[derive(Debug)]
struct City {
    name: String,
    years: Vec<u32>,
    populations: Vec<u32>,
}

impl City {
    fn new(name: &str, years: Vec<u32>, populations: Vec<u32>) -> Self {
        Self {
            name: name.to_string(),
            years,
            populations,
        }
    }

    fn city_data(&mut self, mut f: F) // We bring in self, but only f is generic F.
    f is the closure

        where
            F: FnMut(&mut Vec<u32>, &mut Vec<u32>), // The closure takes mutable vectors of
u32
                                                // which are the year and population
data
{
    f(&mut self.years, &mut self.populations) // Finally this is the actual
function. It says
                                                // "use a closure on self.years and
self.populations"
                                                // We can do whatever we want with
the closure
}
}

fn main() {
    let years = vec![
        1372, 1834, 1851, 1881, 1897, 1925, 1959, 1989, 2000, 2005, 2010, 2020,
    ];
    let populations = vec![
        3_250, 15_300, 24_000, 45_900, 58_800, 119_800, 283_071, 478_974, 400_378,
401_694,
        406_703, 437_619,
    ];
    // Now we can create our city
    let mut tallinn = City::new("Tallinn", years, populations);

    // Now we have a .city_data() method that has a closure. We can do anything we
want.

    // First let's put the data for 5 years together and print it.
    tallinn.city_data(|city_years, city_populations| { // We can call the input
anything we want
        let new_vec = city_years
            .into_iter()
            .zip(city_populations.into_iter()) // Zip the two together
            .take(5) // but only take the first 5
            .collect::<Vec<(_, _)>>(); // Tell Rust to decide the type inside the tuple
        println!("{}: {:?}", new_vec);
    });

    // Now let's add some data for the year 2030
    tallinn.city_data(|x, y| { // This time we just call the input x and y
        x.push(2030);
        y.push(500_000);
    });
}

```

```
// We don't want the 1834 data anymore
tallinn.city_data(|x, y| {
    let position_option = x.iter().position(|x| *x == 1834);
    if let Some(position) = position_option {
        println!(
            "Going to delete {} at position {} now.",
            x[position], position
        ); // Confirm that we delete the right item
        x.remove(position);
        y.remove(position);
    }
});

println!(
    "Years left are {}\nPopulations left are {}",
    tallinn.years, tallinn.populations
);
}
```

This will print the result of all the times we called `.city_data()`. It is:

```
[(1372, 3250), (1834, 15300), (1851, 24000), (1881, 45900), (1897, 58800)]
Going to delete 1834 at position 1 now.
Years left are [1372, 1851, 1881, 1897, 1925, 1959, 1989, 2000, 2005, 2010, 2020, 2030]
Populations left are [3250, 24000, 45900, 58800, 119800, 283071, 478974, 400378,
401694, 406703, 437619, 500000]
```

impl Trait

`impl Trait` is similar to generics. You remember that generics use a type `T` (or any other name) which then gets decided when the program compiles. First let's look at a concrete type:

```
fn gives_higher_i32(one: i32, two: i32) {
    let higher = if one > two { one } else { two };
    println!("{} is higher.", higher);
}

fn main() {
    gives_higher_i32(8, 10);
}
```

This prints: `10 is higher..`

But this only takes `i32`, so now we will make it generic. We need to compare and we need to print with `{}`, so our type `T` needs `PartialOrd` and `Display`. Remember, this means "only take types that already have `PartialOrd` and `Display`".

```
use std::fmt::Display;

fn gives_higher_i32<T: PartialOrd + Display>(one: T, two: T) {
    let higher = if one > two { one } else { two };
    println!("{} is higher.", higher);
}

fn main() {
    gives_higher_i32(8, 10);
}
```

Now let's look at `impl Trait`, which is similar. Instead of a type `T`, we can bring in a type `impl Trait`. Then it will take in a type that implements that trait. It is almost the same:

```
fn prints_it(input: impl Into<String> + std::fmt::Display) { // Takes anything that can
turn into a String and has Display
    println!("You can print many things, including {}", input);
}

fn main() {
    let name = "Tuon";
    let string_name = String::from("Tuon");
    prints_it(name);
    prints_it(string_name);
}
```

However, the more interesting part is that we can return `impl Trait`, and that lets us return closures because their function signatures are traits. You can see this in the signatures for methods that have them. For example, this is the signature for `.map()`:

```
fn map<B, F>(self, f: F) -> Map<Self, F>      // 🚧
    where
        Self: Sized,
        F: FnMut(Self::Item) -> B,
{
    Map::new(self, f)
}
```

`fn map<B, F>(self, f: F)` mean that it takes two generic types. `F` is a function that takes one item from the container implementing `.map()` and `B` is the return type of that function. Then after the `where` we see the trait bounds. ("Trait bound" means "it must have this trait".) One is `Sized`, and the next is the closure signature. It must be an `FnMut`, and do the closure on `Self::Item`, which is the iterator that you give it. Then it returns `B`.

So we can do the same thing to return a closure. To return a closure, use `impl` and then the closure signature. Once you return it, you can use it just like a function. Here is a small example of a function that gives you a closure depending on the text you put in. If you put "double" or "triple" in then it multiplies it by 2 or 3, and otherwise it gives you the same number. Because it's a closure we can do anything we want, so we also print a message.

```
fn returns_a_closure(input: &str) -> impl FnMut(i32) -> i32 {
    match input {
        "double" => |mut number| {
            number *= 2;
            println!("Doubling number. Now it is {}", number);
            number
        },
        "triple" => |mut number| {
            number *= 3;
            println!("Tripling number. Now it is {}", number);
            number
        },
        _ => |number| {
            println!("Sorry, it's the same: {}.", number);
            number
        },
    }
}

fn main() {
    let my_number = 10;

    // Make three closures
    let mut doubles = returns_a_closure("double");
    let mut triples = returns_a_closure("triple");
    let mut quadruples = returns_a_closure("quadruple");

    doubles(my_number);
    triples(my_number);
    quadruples(my_number);
}
```

Here is a bit longer example. Let's imagine a game where your character is facing monsters that are stronger at night. We can make an enum called `TimeOfDay` to keep track of the day. Your character is named Simon and has a number called `character_fear`, which is an `f64`. It goes up at night and down during the day. We will make a `change_fear` function that changes his fear, but also does other things like write messages. It could look like this:

```

enum TimeOfDay { // just a simple enum
    Dawn,
    Day,
    Sunset,
    Night,
}

fn change_fear(input: TimeOfDay) -> impl FnMut(f64) -> f64 { // The function takes a
TimeOfDay. It returns a closure.
    > f64 to say that it needs to
                                                // We use impl FnMut(64) -
also gives the same type back.
    use TimeOfDay::*;

    match input {
        Dawn => |x| { // This is the variable character_fear that we give it later
            println!("The morning sun has vanquished the horrible night. You no longer
feel afraid.");
            println!("Your fear is now {}", x * 0.5);
            x * 0.5
        },
        Day => |x| {
            println!("What a nice day. Maybe put your feet up and rest a bit.");
            println!("Your fear is now {}", x * 0.2);
            x * 0.2
        },
        Sunset => |x| {
            println!("The sun is almost down! This is no good.");
            println!("Your fear is now {}", x * 1.4);
            x * 1.4
        },
        Night => |x| {
            println!("What a horrible night to have a curse.");
            println!("Your fear is now {}", x * 5.0);
            x * 5.0
        },
    }
}

fn main() {
    use TimeOfDay::*;
    let mut character_fear = 10.0; // Start Simon with 10

    let mut daytime = change_fear(Day); // Make four closures here to call every time
we want to change Simon's fear.
    let mut sunset = change_fear(Sunset);
    let mut night = change_fear(Night);
    let mut morning = change_fear(Dawn);

    character_fear = daytime(character_fear); // Call the closures on Simon's fear.
They give a message and change the fear number.
                                                // In real life we would have a Character
struct and use it as a method instead,
                                                // like this: character_fear.daytime()
    character_fear = sunset(character_fear);
    character_fear = night(character_fear);
    character_fear = morning(character_fear);
}

```

This prints:

What a nice day. Maybe put your feet up and rest a bit.
Your fear is now 2
The sun is almost down! This is no good.
Your fear is now 2.8
What a horrible night to have a curse.
Your fear is now 14
The morning sun has vanquished the horrible night. You no longer feel afraid.
Your fear is now 7

Arc

You remember that we used an `Rc` to give a variable more than one owner. If we are doing the same thing in a thread, we need an `Arc`. `Arc` means "atomic reference counter". Atomic means that it uses the computer's processor so that data only gets written once each time. This is important because if two threads write data at the same time, you will get the wrong result. For example, imagine if you could do this in Rust:

```
// 🚨
let mut x = 10;

for i in 0..10 { // Thread 1
    x += 1
}
for i in 0..10 { // Thread 2
    x += 1
}
```

If Thread 1 and Thread 2 just start together, maybe this will happen:

- Thread 1 sees 10, writes 11. Then Thread 2 sees 11, writes 12. No problem so far.
- Thread 1 sees 12. At the same time, Thread 2 sees 12. Thread 1 writes 13. And Thread 2 writes 13. Now we have 13, but it should be 14. That's a big problem.

An `Arc` uses the processor to make sure this doesn't happen, so it is the method you must use when you have threads. You don't want an `Arc` for just one thread though, because `Rc` is a bit faster.

You can't change data with just an `Arc` though. So you wrap the data in a `Mutex`, and then you wrap the `Mutex` in an `Arc`.

So let's use a `Mutex` inside an `Arc` to change the value of a number. First let's set up one thread:

```
fn main() {
    let handle = std::thread::spawn(|| {
        println!("The thread is working!") // Just testing the thread
    });

    handle.join().unwrap(); // Make the thread wait here until it is done
    println!("Exiting the program");
}
```

So far this just prints:

```
The thread is working!
Exiting the program
```

Good. Now let's put it in a `for` loop for `0..5`:

```
fn main() {
    let handle = std::thread::spawn(|| {
        for _ in 0..5 {
            println!("The thread is working!")
        }
    });

    handle.join().unwrap();
    println!("Exiting the program");
}
```

This works too. We get the following:

```
The thread is working!
Exiting the program
```

Now let's make one more thread. Each thread will do the same thing. You can see that the threads are working at the same time. Sometimes it will say `Thread 1 is working!` first, but other times `Thread 2 is working!` is first. This is called **concurrency**, which means "running together".

```
fn main() {
    let thread1 = std::thread::spawn(|| {
        for _ in 0..5 {
            println!("Thread 1 is working!")
        }
    });

    let thread2 = std::thread::spawn(|| {
        for _ in 0..5 {
            println!("Thread 2 is working!")
        }
    });

    thread1.join().unwrap();
    thread2.join().unwrap();
    println!("Exiting the program");
}
```

This will print:

```
Thread 1 is working!
Thread 2 is working!
Exiting the program
```

Now we want to change the value of `my_number`. Right now it is an `i32`. We will change it to an `Arc<Mutex<i32>>`: an `i32` that can be changed, protected by an `Arc`.

```
// 🛡
let my_number = Arc::new(Mutex::new(0));
```

Now that we have this, we can clone it. Each clone can go into a different thread. We have two threads, so we will make two clones:

```
// 🛡
let my_number = Arc::new(Mutex::new(0));

let my_number1 = Arc::clone(&my_number); // This clone goes into Thread 1
let my_number2 = Arc::clone(&my_number); // This clone goes into Thread 2
```

Now that we have safe clones attached to `my_number`, we can `move` them into other threads with no problem.

```
use std::sync::{Arc, Mutex};

fn main() {
    let my_number = Arc::new(Mutex::new(0));

    let my_number1 = Arc::clone(&my_number);
    let my_number2 = Arc::clone(&my_number);

    let thread1 = std::thread::spawn(move || { // Only the clone goes into Thread 1
        for _ in 0..10 {
            *my_number1.lock().unwrap() += 1; // Lock the Mutex, change the value
        }
    });

    let thread2 = std::thread::spawn(move || { // Only the clone goes into Thread 2
        for _ in 0..10 {
            *my_number2.lock().unwrap() += 1;
        }
    });

    thread1.join().unwrap();
    thread2.join().unwrap();
    println!("Value is: {:?}", my_number);
    println!("Exiting the program");
}
```

The program prints:

```
Value is: Mutex { data: 20 }
Exiting the program
```

So it was a success.

Then we can join the two threads together in a single `for` loop, and make the code smaller.

We need to save the handles so we can call `.join()` on each one outside of the loop. If we do this inside the loop, it will wait for the first thread to finish before starting the new one.

```
use std::sync::{Arc, Mutex};

fn main() {
    let my_number = Arc::new(Mutex::new(0));
    let mut handle_vec = vec![]; // JoinHandles will go in here

    for _ in 0..2 { // do this twice
        let my_number_clone = Arc::clone(&my_number); // Make the clone before starting
        the thread
        let handle = std::thread::spawn(move || { // Put the clone in
            for _ in 0..10 {
                *my_number_clone.lock().unwrap() += 1;
            }
        });
        handle_vec.push(handle); // save the handle so we can call join on it outside
        of the loop
                                // If we don't push it in the vec, it will just die
        here
    }

    handle_vec.into_iter().for_each(|handle| handle.join().unwrap()); // call join on
    all handles
    println!("{}: {}", my_number);
}
```

Finally this prints `Mutex { data: 20 }`.

This looks complicated but `Arc<Mutex<SomeType>>>` is used very often in Rust, so it becomes natural. Also, you can always write your code to make it cleaner. Here is the same code with one more `use` statement and two functions. The functions don't do anything new, but they move some code out of `main()`. You can try rewriting code like this if it is hard to read.

```
use std::sync::{Arc, Mutex};
use std::thread::spawn; // Now we just write spawn

fn make_arc(number: i32) -> Arc<Mutex<i32>> { // Just a function to make a Mutex in an
Arc
    Arc::new(Mutex::new(number))
}

fn new_clone(input: &Arc<Mutex<i32>>) -> Arc<Mutex<i32>> { // Just a function so we can
write new_clone
    Arc::clone(&input)
}

// Now main() is easier to read
fn main() {
    let mut handle_vec = vec![]; // each handle will go in here
    let my_number = make_arc(0);

    for _ in 0..2 {
        let my_number_clone = new_clone(&my_number);
        let handle = spawn(move || {
            for _ in 0..10 {
                let mut value_inside = my_number_clone.lock().unwrap();
                *value_inside += 1;
            }
        });
        handle_vec.push(handle); // the handle is done, so put it in the vector
    }

    handle_vec.into_iter().for_each(|handle| handle.join().unwrap()); // Make each one
wait

    println!("{}:{}", my_number);
}
```

Channels

A channel is an easy way to use many threads that send to one place. They are fairly popular because they are pretty simple to put together. You can create a channel in Rust with `std::sync::mpsc`. `mpsc` means "multiple producer, single consumer", so "many threads sending to one place". To start a channel, you use `channel()`. This creates a `Sender` and a `Receiver` that are tied together. You can see this in the function signature:

```
// 🚧
pub fn channel<T>() -> (Sender<T>, Receiver<T>)
```

So you have to choose one name for the sender and one for the receiver. Usually you see something like `let (sender, receiver) = channel();` to start. Because it's generic, Rust won't know the type if that is all you write:

```
use std::sync::mpsc::channel;

fn main() {
    let (sender, receiver) = channel(); // ⚠️
}
```

The compiler says:

```
error[E0282]: type annotations needed for `(std::sync::mpsc::Sender<T>,
std::sync::mpsc::Receiver<T>)`
--> src\main.rs:30:30
|
30 |     let (sender, receiver) = channel();
|     ----- ^^^^^^^ cannot infer type for type parameter `T`
declared on the function `channel`
|
|     consider giving this pattern the explicit type
`(<std::sync::mpsc::Sender<T>, std::sync::mpsc::Receiver<T>)>`, where
the type parameter `T` is specified
```

It suggests adding a type for the `Sender` and `Receiver`. You can do that if you want:

```
use std::sync::mpsc::{channel, Sender, Receiver}; // Added Sender and Receiver here

fn main() {
    let (sender, receiver): (Sender<i32>, Receiver<i32>) = channel();
}
```

but you don't have to. Once you start using the `Sender` and `Receiver`, Rust can guess the type.

So let's look at the simplest way to use a channel.

```
use std::sync::mpsc::channel;

fn main() {
    let (sender, receiver) = channel();

    sender.send(5);
    receiver.recv(); // recv = receive, not "rec v"
}
```

Now the compiler knows the type. `sender` is a `Result<(), SendError<i32>` and `receiver` is a `Result<i32, RecvError>`. So you can use `.unwrap()` to see if the sending works, or use better error handling. Let's add `.unwrap()` and also `println!` to see what we get:

```
use std::sync::mpsc::channel;

fn main() {
    let (sender, receiver) = channel();

    sender.send(5).unwrap();
    println!("{}", receiver.recv().unwrap());
}
```

This prints 5.

A `channel` is like an `Arc` because you can clone it and send the clones into other threads. Let's make two threads and send values to `receiver`. This code will work, but it is not exactly what we want.

```
use std::sync::mpsc::channel;

fn main() {
    let (sender, receiver) = channel();
    let sender_clone = sender.clone();

    std::thread::spawn(move|| { // move sender in
        sender.send("Send a &str this time").unwrap();
    });

    std::thread::spawn(move|| { // move sender_clone in
        sender_clone.send("And here is another &str").unwrap();
    });

    println!("{}", receiver.recv().unwrap());
}
```

The two threads start sending, and then we `println!`. It might say `Send a &str this time` or `And here is another &str`, depending on which thread finished first. Let's make a join handle to make them wait.

```
use std::sync::mpsc::channel;

fn main() {
    let (sender, receiver) = channel();
    let sender_clone = sender.clone();
    let mut handle_vec = vec![]; // Put our handles in here

    handle_vec.push(std::thread::spawn(move|| { // push this into the vec
        sender.send("Send a &str this time").unwrap();
    }));

    handle_vec.push(std::thread::spawn(move|| { // and push this into the vec
        sender_clone.send("And here is another &str").unwrap();
    }));

    for _ in handle_vec { // now handle_vec has 2 items. Let's print them
        println!("{:?}", receiver.recv().unwrap());
    }
}
```

This prints:

```
"Send a &str this time"
"And here is another &str"
```

Now let's make a `results_vec` instead of printing.

```
use std::sync::mpsc::channel;

fn main() {
    let (sender, receiver) = channel();
    let sender_clone = sender.clone();
    let mut handle_vec = vec![];
    let mut results_vec = vec![];

    handle_vec.push(std::thread::spawn(move|| {
        sender.send("Send a &str this time").unwrap();
    }));

    handle_vec.push(std::thread::spawn(move|| {
        sender_clone.send("And here is another &str").unwrap();
    }));

    for _ in handle_vec {
        results_vec.push(receiver.recv().unwrap());
    }

    println!("{:?}", results_vec);
}
```

Now the results are in our vec: `["Send a &str this time", "And here is another &str"]`.

Now let's pretend that we have a lot of work to do, and want to use threads. We have a big vec with 1 million items, all 0. We want to change each 0 to a 1. We will use ten threads, and each thread will do one tenth of the work. We will create a new vec and use `.extend()` to put the work in.

```

use std::sync::mpsc::channel;
use std::thread::spawn;

fn main() {
    let (sender, receiver) = channel();
    let hugevec = vec![0; 1_000_000];
    let mut newvec = vec![];
    let mut handle_vec = vec![];

    for i in 0..10 {
        let sender_clone = sender.clone();
        let mut work: Vec<u8> = Vec::with_capacity(hugevec.len() / 10); // new vec to
put the work in. 1/10th the size
        work.extend(&hugevec[i*100_000..(i+1)*100_000]); // first part gets 0..100_000,
next gets 100_000..200_000, etc.
        let handle = spawn(move || { // make a handle

            for number in work.iter_mut() { // do the actual work
                *number += 1;
            };
            sender_clone.send(work).unwrap(); // use the sender_clone to send the work
to the receiver
        });
        handle_vec.push(handle);
    }

    for handle in handle_vec { // stop until the threads are done
        handle.join().unwrap();
    }

    while let Ok(results) = receiver.try_recv() {
        newvec.push(results); // push the results from receiver.recv() into the vec
    }

    // Now we have a Vec<Vec<u8>>. To put it together we can use .flatten()
    let newvec = newvec.into_iter().flatten().collect::<Vec<u8>>(); // Now it's one vec
of 1_000_000 u8 numbers

    println!("{}:{}, {}:{}, total length: {}", // Let's print out some numbers to make
sure they are all 1
        &newvec[0..10], &newvec[newvec.len()-10..newvec.len()], newvec.len() // And
show that the length is 1_000_000 items
    );

    for number in newvec { // And let's tell Rust that it can panic if even one number
is not 1
        if number != 1 {
            panic!();
        }
    }
}

```

Reading Rust documentation

It's important to know how to read documentation in Rust so you can understand what other people wrote. Here are some things to know in Rust documentation:

assert_eq!

You saw that `assert_eq!` is used when doing testing. You put two items inside the function and the program will panic if they are not equal. Here is a simple example where we need an even number.

```
fn main() {
    prints_number(56);
}

fn prints_number(input: i32) {
    assert_eq!(input % 2, 0); // number must be equal.
                           // If number % 2 is not 0, it panics
    println!("The number is not odd. It is {}", input);
}
```

Maybe you don't have any plans to use `assert_eq!` in your code, but it is everywhere in Rust documentation. This is because in a document you would need a lot of room to `println!` everything. Also, you would require `Display` or `Debug` for the things you want to print. That's why documentation has `assert_eq!` everywhere. Here is an example from here <https://doc.rust-lang.org/std/vec/struct.Vec.html> showing how to use a Vec:

```
fn main() {
    let mut vec = Vec::new();
    vec.push(1);
    vec.push(2);

    assert_eq!(vec.len(), 2);
    assert_eq!(vec[0], 1);

    assert_eq!(vec.pop(), Some(2));
    assert_eq!(vec.len(), 1);

    vec[0] = 7;
    assert_eq!(vec[0], 7);

    vec.extend([1, 2, 3].iter().copied());

    for x in &vec {
        println!("{}", x);
    }
    assert_eq!(vec, [7, 1, 2, 3]);
}
```

In these examples, you can just think of `assert_eq!(a, b)` as saying "a is b". Now look at the same example with comments on the right. The comments show what it actually means.

```

fn main() {
    let mut vec = Vec::new();
    vec.push(1);
    vec.push(2);

    assert_eq!(vec.len(), 2); // "The vec length is 2"
    assert_eq!(vec[0], 1); // "vec[0] is 1"

    assert_eq!(vec.pop(), Some(2)); // "When you use .pop(), you get Some()"
    assert_eq!(vec.len(), 1); // "The vec length is now 1"

    vec[0] = 7;
    assert_eq!(vec[0], 7); // "Vec[0] is 7"

    vec.extend([1, 2, 3].iter().copied());

    for x in &vec {
        println!("{}: {}", x);
    }
    assert_eq!(vec, [7, 1, 2, 3]); // "The vec now has [7, 1, 2, 3]"
}

```

Searching

The top bar of a Rust document is the search bar. It shows you results as you type. When you go down a page you can't see the search bar anymore, but if you press the **s** key on the keyboard you can search again. So pressing **s** anywhere lets you search right away.

[src] button

Usually the code for a method, struct, etc. will not be complete. This is because you don't usually need to see the full source to know how it works, and the full code can be confusing. But if you want to know more, you can click on [src] and see everything. For example, on the page for `String` you can see this signature for `.with_capacity()`:

```
// 📄
pub fn with_capacity(capacity: usize) -> String
```

Okay, so you put a number in and it gives you a `String`. That's easy, but maybe we are curious and want to see more. If you click on [src] you can see this:

```
// 📄
pub fn with_capacity(capacity: usize) -> String {
    String { vec: Vec::with_capacity(capacity) }
}
```

Interesting! Now you can see that a `String` is a kind of `Vec`. And actually a `String` is a vector of `u8` bytes, which is interesting to know. You didn't need to know that to use the `with_capacity` method so you only see it if you click [src]. So clicking on [src] is a good idea if the document doesn't have much detail and you want to know more.

Information on traits

The important part of the documentation for a trait is "Required Methods" on the left. If you see Required Methods, it probably means that you have to write the method yourself. For example, for `Iterator` you need to write the `.next()` method. And for `From` you need to write the `.from()` method. But some traits can be implemented with just an **attribute**, like we see in `#[derive(Debug)]`. `Debug` needs the `.fmt()` method, but usually you just use `##[derive(Debug)]` unless you want to do it yourself. That's why the page on `std::fmt::Debug` says that "Generally speaking, you should just derive a `Debug` implementation."

Attributes

You have seen code like `#[derive(Debug)]` before: this type of code is called an *attribute*. These attributes are small pieces of code that give information to the compiler. They are not easy to create, but they are very easy to use. If you write an attribute with just `#` then it will affect the code on the next line. But if you write it with `#!` then it will affect everything in its own space.

Here are some attributes you will see a lot:

`#[allow(dead_code)]` and `#[allow(unused_variables)]`. If you write code that you don't use, Rust will still compile but it will let you know. For example, here is a struct with nothing in it and one variable. We don't use either of them.

```
struct JustAStruct {}

fn main() {
    let some_char = 'ʌ';
}
```

If you write this, Rust will remind you that you didn't use them:

```
warning: unused variable: `some_char`
--> src\main.rs:4:9
  |
4 |     let some_char = 'ʌ';
  |           ^^^^^^^^ help: if this is intentional, prefix it with an underscore:
'_some_char'
  |
  = note: `#[warn(unused_variables)]` on by default

warning: struct is never constructed: `JustAStruct`
--> src\main.rs:1:8
  |
1 | struct JustAStruct {}
  |           ^^^^^^^^^^
  |
  = note: `#[warn(dead_code)]` on by default
```

We know that you can write a `_` before the name to make the compiler be quiet:

```
struct _JustAStruct {}

fn main() {
    let _some_char = 'ʌ';
}
```

but you can also use attributes. You'll notice in the message that it uses `#[warn(unused_variables)]` and `#[warn(dead_code)]`. In our code, `JustAStruct` is dead code, and `some_char` is an unused variable. The opposite of `warn` is `allow`, so we can write this and it will not say anything:

```
#![allow(dead_code)]
#![allow(unused_variables)]

struct Struct1 {};
struct Struct2 {};
struct Struct3 {};
struct Struct4 {};
struct Struct5 {}

fn main() {
    let char1 = 'ʌ'; // and four variables. We don't use any of them but the compiler
is quiet
    let char2 = ';';
    let some_str = "I'm just a regular &str";
    let some_vec = vec!["I", "am", "just", "a", "vec"];
}
```

Of course, dealing with dead code and unused variables is important. But sometimes you want the compiler to be quiet for a while. Or you might need to show some code or teach people Rust and don't want to confuse them with compiler messages.

`#[derive(TraitName)]` lets you derive some traits for structs and enums that you create. This works with many common traits that can be automatically derived. Some like `Display` can't be automatically derived, because for `Display` you have to choose how to display:

```
// ▲
#[derive(Display)]
struct HoldsAString {
    the_string: String,
}

fn main() {
    let my_string = HoldsAString {
        the_string: "Here I am!".to_string(),
    };
}
```

The error message will tell you that.

```
error: cannot find derive macro `Display` in this scope
--> src\main.rs:2:10
 |
2 | #[derive(Display)]
 |
```

But for traits that you can automatically derive, you can put in as many as you like. Let's give `HoldsAString` seven traits in a single line, just for fun, even though it only needs one.

```
#[derive(Debug, PartialEq, Eq, Ord, PartialOrd, Hash, Clone)]
struct HoldsAString {
    the_string: String,
}

fn main() {
    let my_string = HoldsAString {
        the_string: "Here I am!".to_string(),
    };
    println!("{:?}", my_string);
}
```

Also, you can make a struct `Copy` if (and only if) its fields are all `Copy`. `HoldsAString` has `String` which is not `Copy` so you can't use `#[derive(Copy)]` for it. But for this struct you can:

```
#[derive(Clone, Copy)] // You also need Clone to use Copy
struct NumberAndBool {
    number: i32, // i32 is Copy
    true_or_false: bool // bool is also Copy. So no problem
}

fn does_nothing(input: NumberAndBool) {

}

fn main() {
    let number_and_bool = NumberAndBool {
        number: 8,
        true_or_false: true
};

    does_nothing(number_and_bool);
    does_nothing(number_and_bool); // If it didn't have copy, this would make an error
}
```

`#[cfg()]` means configuration and tells the compiler whether to run code or not. You see it usually like this: `#[cfg(test)]`. You use that when writing test functions so that it knows not to run them unless you are testing. Then you can have tests next to your code but the compiler won't run them unless you tell it to.

One other example using `cfg` is `#[cfg(target_os = "windows")]`. With that you can tell the compiler to only run the code on Windows, or Linux, or anything else.

`#![no_std]` is an interesting attribute that tells Rust not to bring in the standard library. That means you don't have `Vec`, `String`, and anything else in the standard library. You will see this in code for small devices that don't have much memory or space.

You can see many more attributes [here](#).

Box

`Box` is a very convenient type in Rust. When you use a `Box`, you can put a type on the heap instead of the stack. To make a new `Box`, just use `Box::new()` and put the item inside.

```
fn just_takes_a_variable<T>(item: T) {} // Takes anything and drops it.

fn main() {
    let my_number = 1; // This is an i32
    just_takes_a_variable(my_number);
    just_takes_a_variable(my_number); // Using this function twice is no problem,
    because it's Copy

    let my_box = Box::new(1); // This is a Box<i32>
    just_takes_a_variable(my_box.clone()); // Without .clone() the second function
    would make an error
    just_takes_a_variable(my_box); // because Box is not Copy
}
```

At first it is hard to imagine where to use it, but you use it in Rust a lot. You remember that `&` is used for `str` because the compiler doesn't know the size of a `str`: it can be any length. But the `&` reference is always the same length, so the compiler can use it. `Box` is similar. Also, you can use `*` on a `Box` to get to the value, just like with `&`:

```
fn main() {
    let my_box = Box::new(1); // This is a Box<i32>
    let an_integer = *my_box; // This is an i32
    println!("{:?}", my_box);
    println!("{:?}", an_integer);
}
```

This is why `Box` is called a "smart pointer", because it is like a `&` reference (a kind of pointer) but can do more things.

You can also use a `Box` to create structs with the same struct inside. These are called *recursive*, which means that inside Struct A is maybe another Struct A. Sometimes you can use Boxes to create linked lists, although these lists are not very popular in Rust. But if you want to create a recursive struct, you can use a `Box`. Here's what happens if you try without a `Box`:

```
struct List {
    item: Option<List>, // ▲
}
```

This simple `List` has one item, that may be `Some<List>` (another list), or `None`. Because you can choose `None`, it will not be recursive forever. But the compiler still doesn't know the size:

```
error[E0072]: recursive type `List` has infinite size
--> src\main.rs:16:1
16 | struct List {
| ^^^^^^^^^^^^ recursive type has infinite size
17 |     item: Option<List>,
|     ----- recursive without indirection
|
|= help: insert indirection (e.g., a `Box`, `Rc`, or `&`) at some point to make
`List` representable
```

You can see that it even suggests trying a `Box`. So let's put a `Box` around `List`:

```
struct List {
    item: Option<Box<List>>,
}
fn main() {}
```

Now the compiler is fine with the `List`, because everything is behind a `Box`, and it knows the size of a `Box`. Then a very simple list might look like this:

```
struct List {
    item: Option<Box<List>>,
}

impl List {
    fn new() -> List {
        List {
            item: Some(Box::new(List { item: None })),
        }
    }
}

fn main() {
    let mut my_list = List::new();
```

Even without data it is a bit complicated, and Rust does not use this type of pattern very much. This is because Rust has strict rules on borrowing and ownership, as you know. But if you want to start a list like this (a linked list), `Box` can help.

A `Box` also lets you use `std::mem::drop` on it, because it's on the heap. That can be convenient sometimes.

Box around traits

`Box` is very useful for returning traits. You know that you can write traits in generic functions like in this example:

```
use std::fmt::Display;

struct Doesn'tImplementDisplay {}

fn displays_it<T: Display>(input: T) {
    println!("{}", input);
}

fn main() {}
```

This only takes something with `Display`, so it can't accept our struct `DoesntImplementDisplay`. But it can take in a lot of others like `String`.

You also saw that we can use `impl Trait` to return other traits, or closures. `Box` can be used in a similar way. You can use a `Box` because otherwise the compiler won't know the size of the value. This example shows that a trait can be used on something of any size:

```

#![allow(dead_code)] // Tell the compiler to be quiet
use std::mem::size_of; // This gives the size of a type

trait JustATrait {} // We will implement this on everything

enum EnumOfNumbers {
    I8(i8),
    AnotherI8(i8),
    OneMoreI8(i8),
}
impl JustATrait for EnumOfNumbers {}

struct StructOfNumbers {
    an_i8: i8,
    another_i8: i8,
    one_more_i8: i8,
}
impl JustATrait for StructOfNumbers {}

enum EnumOfOtherTypes {
    I8(i8),
    AnotherI8(i8),
    Collection(Vec<String>),
}
impl JustATrait for EnumOfOtherTypes {}

struct StructOfOtherTypes {
    an_i8: i8,
    another_i8: i8,
    a_collection: Vec<String>,
}
impl JustATrait for StructOfOtherTypes {}

struct ArrayAndI8 {
    array: [i8; 1000], // This one will be very large
    an_i8: i8,
    in_u8: u8,
}
impl JustATrait for ArrayAndI8 {}

fn main() {
    println!(
        "{} {}, {}, {}, {}, {}",
        size_of::<EnumOfNumbers>(),
        size_of::<StructOfNumbers>(),
        size_of::<EnumOfOtherTypes>(),
        size_of::<StructOfOtherTypes>(),
        size_of::<ArrayAndI8>(),
    );
}

```

When we print the size of these, we get 2, 3, 32, 32, 1002. So if you were to do this, it would give an error:

```

// ⚠️
fn returns_just_a_trait() -> JustATrait {
    let some_enum = EnumOfNumbers::I8(8);
    some_enum
}
```

It says:

```
error[E0746]: return type cannot have an unboxed trait object
--> src\main.rs:53:30
|
53 | fn returns_just_a_trait() -> JustATrait {
|                                ^^^^^^^^^^ doesn't have a size known at compile-time
```

And this is true, because the size could be 2, 3, 32, 1002, or anything else. So we put it in a `Box` instead. Here we also add the keyword `dyn`. `dyn` is a word that shows you that you are talking about a trait, not a struct or anything else.

So you can change the function to this:

```
// 🚧
fn returns_just_a_trait() -> Box<dyn JustATrait> {
    let some_enum = EnumOfNumbers::I8(8);
    Box::new(some_enum)
}
```

And now it works, because on the stack is just a `Box` and we know the size of `Box`.

You see this a lot in the form `Box<dyn Error>`, because sometimes you can have more than one possible error.

We can quickly create two error types to show this. To make an official error type, you have to implement `std::error::Error` for it. That part is easy: just write `impl std::error::Error {}`. But errors also need `Debug` and `Display` so they can give information on the problem. `Debug` is easy with `#[derive(Debug)]` but `Display` needs the `.fmt()` method. We did this once before.

The code looks like this:

```

use std::error::Error;
use std::fmt;

#[derive(Debug)]
struct ErrorOne;

impl Error for ErrorOne {} // Now it is an error type with Debug. Time for Display:

impl fmt::Display for ErrorOne {
    fn fmt(&self, f: &mut fmt::Formatter) -> fmt::Result {
        write!(f, "You got the first error!") // All it does is write this message
    }
}

#[derive(Debug)] // Do the same thing with ErrorTwo
struct ErrorTwo;

impl Error for ErrorTwo {}

impl fmt::Display for ErrorTwo {
    fn fmt(&self, f: &mut fmt::Formatter) -> fmt::Result {
        write!(f, "You got the second error!")
    }
}

// Make a function that just returns a String or an error
fn returns_errors(input: u8) -> Result<String, Box<dyn Error>> { // With Box<dyn Error>
    you can return anything that has the Error trait

    match input {
        0 => Err(Box::new(ErrorOne)), // Don't forget to put it in a box
        1 => Err(Box::new(ErrorTwo)),
        _ => Ok("Looks fine to me".to_string()), // This is the success type
    }
}

fn main() {
    let vec_of_u8s = vec![0_u8, 1, 80]; // Three numbers to try out

    for number in vec_of_u8s {
        match returns_errors(number) {
            Ok(input) => println!("{}: {}", number, input),
            Err(message) => println!("{}: {}", number, message),
        }
    }
}

```

This will print:

```

You got the first error!
You got the second error!
Looks fine to me

```

If we didn't have a `Box<dyn Error>` and wrote this, we would have a problem:

```
// ⚠️
fn returns_errors(input: u8) -> Result<String, Error> {
    match input {
        0 => Err(ErrorOne),
        1 => Err(ErrorTwo),
        _ => Ok("Looks fine to me".to_string()),
    }
}
```

It will tell you:

```
21 | fn returns_errors(input: u8) -> Result<String, Error> {
|                                     ^^^^^^^^^^^^^^^^^ doesn't have a size known
at compile-time
```

This is not surprising, because we know that a trait can work on many things, and they each have different sizes.

Default and the builder pattern

You can implement the `Default` trait to give values to a `struct` or `enum` that you think will be most common. The builder pattern works nicely with this to let users easily make changes when they want. First let's look at `Default`. Actually, most general types in Rust already have `Default`. They are not surprising: 0, "" (empty strings), `false`, etc.

```
fn main() {
    let default_i8: i8 = Default::default();
    let default_str: String = Default::default();
    let default_bool: bool = Default::default();

    println!("{} {}, {}", default_i8, default_str, default_bool);
}
```

This prints `'0'`, `" "`, `'false'`.

So `Default` is like the `new` function except you don't have to enter anything. First we will make a `struct` that doesn't implement `Default` yet. It has a `new` function which we use to make a character named Billy with some stats.

```
struct Character {
    name: String,
    age: u8,
    height: u32,
    weight: u32,
    lifestate: LifeState,
}

enum LifeState {
    Alive,
    Dead,
    NeverAlive,
    Uncertain
}

impl Character {
    fn new(name: String, age: u8, height: u32, weight: u32, alive: bool) -> Self {
        Self {
            name,
            age,
            height,
            weight,
            lifestate: if alive { LifeState::Alive } else { LifeState::Dead },
        }
    }
}

fn main() {
    let character_1 = Character::new("Billy".to_string(), 15, 170, 70, true);
}
```

But maybe in our world we want most of the characters to be named Billy, age 15, height 170, weight 70, and alive. We can implement `Default` so that we can just write `Character::default()`. It looks like this:

```

#[derive(Debug)]
struct Character {
    name: String,
    age: u8,
    height: u32,
    weight: u32,
    lifestate: LifeState,
}

#[derive(Debug)]
enum LifeState {
    Alive,
    Dead,
    NeverAlive,
    Uncertain,
}

impl Character {
    fn new(name: String, age: u8, height: u32, weight: u32, alive: bool) -> Self {
        Self {
            name,
            age,
            height,
            weight,
            lifestate: if alive {
                LifeState::Alive
            } else {
                LifeState::Dead
            },
        }
    }
}

impl Default for Character {
    fn default() -> Self {
        Self {
            name: "Billy".to_string(),
            age: 15,
            height: 170,
            weight: 70,
            lifestate: LifeState::Alive,
        }
    }
}

fn main() {
    let character_1 = Character::default();

    println!(
        "The character {:#?} is {:#?} years old.",
        character_1.name, character_1.age
    );
}

```

It prints `The character "Billy" is 15 years old.` Much easier!

Now comes the builder pattern. We will have many Billys, so we will keep the default. But a lot of other characters will be only a bit different. The builder pattern lets us chain very small methods to change one value each time. Here is one such method for `Character`:

```
fn height(mut self, height: u32) -> Self {    // 🚧  
    self.height = height;  
    self  
}
```

Make sure to notice that it takes a `mut self`. We saw this once before, and it is not a mutable reference (`&mut self`). It takes ownership of `self` and with `mut` it will be mutable, even if it wasn't mutable before. That's because `.height()` has full ownership and nobody else can touch it, so it is safe to be mutable. Then it just changes `self.height` and returns `Self` (which is `Character`).

So let's have three of these builder methods. They are almost the same:

```
fn height(mut self, height: u32) -> Self {    // 🚧  
    self.height = height;  
    self  
}  
  
fn weight(mut self, weight: u32) -> Self {  
    self.weight = weight;  
    self  
}  
  
fn name(mut self, name: &str) -> Self {  
    self.name = name.to_string();  
    self  
}
```

Each one of those changes one variable and gives `Self` back: this is what you see in the builder pattern. So now we can write something like this to make a character: `let character_1 = Character::default().height(180).weight(60).name("Bobby");`. If you are building a library for someone else to use, this can make it easy for them. It's easy for the end user because it almost looks like natural English: "Give me a default character but with height of 180, weight of 60, and name of Bobby." So far our code looks like this:

```

#[derive(Debug)]
struct Character {
    name: String,
    age: u8,
    height: u32,
    weight: u32,
    lifestate: LifeState,
}

#[derive(Debug)]
enum LifeState {
    Alive,
    Dead,
    NeverAlive,
    Uncertain,
}

impl Character {
    fn new(name: String, age: u8, height: u32, weight: u32, alive: bool) -> Self {
        Self {
            name,
            age,
            height,
            weight,
            lifestate: if alive {
                LifeState::Alive
            } else {
                LifeState::Dead
            },
        }
    }

    fn height(&mut self, height: u32) -> Self {
        self.height = height;
        self
    }

    fn weight(&mut self, weight: u32) -> Self {
        self.weight = weight;
        self
    }

    fn name(&mut self, name: &str) -> Self {
        self.name = name.to_string();
        self
    }
}

impl Default for Character {
    fn default() -> Self {
        Self {
            name: "Billy".to_string(),
            age: 15,
            height: 170,
            weight: 70,
            lifestate: LifeState::Alive,
        }
    }
}

fn main() {
    let character_1 = Character::default().height(180).weight(60).name("Bobby");

    println!("{}: {} is {} years old, {} cm tall, and weighs {} kg.", character_1.name, character_1.name, character_1.age, character_1.height, character_1.weight);
}

```

One last method to add is usually called `.build()`. This method is a sort of final check. When you give a user a method like `.height()` you can make sure that they only put in a `u32()`, but what if they enter 5000 for height? That might not be okay in the game you are making. We will use a final method called `.build()` that returns a `Result`. Inside it we will check if the user input is okay, and if it is, we will return an `Ok(Self)`.

First though let's change the `.new()` method. We don't want users to be free to create any kind of character anymore. So we'll move the values from `impl Default` to `.new()`. And now `.new()` doesn't take any input.

```
fn new() -> Self {    // █
    Self {
        name: "Billy".to_string(),
        age: 15,
        height: 170,
        weight: 70,
        lifestate: LifeState::Alive,
    }
}
```

That means we don't need `impl Default` anymore, because `.new()` has all the default values. So we can delete `impl Default`.

Now our code looks like this:

```

#[derive(Debug)]
struct Character {
    name: String,
    age: u8,
    height: u32,
    weight: u32,
    lifestate: LifeState,
}

#[derive(Debug)]
enum LifeState {
    Alive,
    Dead,
    NeverAlive,
    Uncertain,
}

impl Character {
    fn new() -> Self {
        Self {
            name: "Billy".to_string(),
            age: 15,
            height: 170,
            weight: 70,
            lifestate: LifeState::Alive,
        }
    }

    fn height(mut self, height: u32) -> Self {
        self.height = height;
        self
    }

    fn weight(mut self, weight: u32) -> Self {
        self.weight = weight;
        self
    }

    fn name(mut self, name: &str) -> Self {
        self.name = name.to_string();
        self
    }
}

fn main() {
    let character_1 = Character::new().height(180).weight(60).name("Bobby");

    println!("{:?}", character_1);
}

```

This prints the same thing: `Character { name: "Bobby", age: 15, height: 180, weight: 60, lifestate: Alive }`.

We are almost ready to write the method `.build()`, but there is one problem: how do we make the user use it? Right now a user can write `let x = Character::new().height(76767);` and get a `Character`. There are many ways to do this, and maybe you can imagine your own. But we will add a `can_use: bool` value to `Character`.

```

#[derive(Debug)]           // 🚧
struct Character {
    name: String,
    age: u8,
    height: u32,
    weight: u32,
    lifestate: LifeState,
    can_use: bool, // Set whether the user can use the character
}

\\ Cut other code

fn new() -> Self {
    Self {
        name: "Billy".to_string(),
        age: 15,
        height: 170,
        weight: 70,
        lifestate: LifeState::Alive,
        can_use: true, // .new() always gives a good character, so it's true
    }
}

```

And for the other methods like `.height()`, we will set `can_use` to `false`. Only `.build()` will set it to `true` again, so now the user has to do a final check with `.build()`. We will make sure that `height` is not above 200 and `weight` is not above 300. Also, in our game there is a bad word called `smurf` that we don't want characters to use.

Our `.build()` method looks like this:

```

fn build(mut self) -> Result<Character, String> {           // 🚧
    if self.height < 200 && self.weight < 300 &&
!self.name.to_lowercase().contains("smurf") {
        self.can_use = true;
        Ok(self)
    } else {
        Err("Could not create character. Characters must have:
1) Height below 200
2) Weight below 300
3) A name that is not Smurf (that is a bad word)"
            .to_string())
    }
}

```

`!self.name.to_lowercase().contains("smurf")` makes sure that the user doesn't write something like "SMURF" or "IamSmurf". It makes the whole `String` lowercase (small letters), and checks for `.contains()` instead of `==`. And the `!` in front means "not".

If everything is okay, we set `can_use` to `true`, and give the character to the user inside `Ok`.

Now that our code is done, we will create three characters that don't work, and one character that does work. The final code looks like this:

```

#[derive(Debug)]
struct Character {
    name: String,
    age: u8,
    height: u32,
    weight: u32,
    lifestate: LifeState,
    can_use: bool, // Here is the new value
}

#[derive(Debug)]
enum LifeState {
    Alive,
    Dead,
    NeverAlive,
    Uncertain,
}

impl Character {
    fn new() -> Self {
        Self {
            name: "Billy".to_string(),
            age: 15,
            height: 170,
            weight: 70,
            lifestate: LifeState::Alive,
            can_use: true, // .new() makes a fine character, so it is true
        }
    }

    fn height(mut self, height: u32) -> Self {
        self.height = height;
        self.can_use = false; // Now the user can't use the character
        self
    }

    fn weight(mut self, weight: u32) -> Self {
        self.weight = weight;
        self.can_use = false;
        self
    }

    fn name(mut self, name: &str) -> Self {
        self.name = name.to_string();
        self.can_use = false;
        self
    }

    fn build(&mut self) -> Result<Character, String> {
        if self.height < 200 && self.weight < 300 &&
!self.name.to_lowercase().contains("smurf") {
            self.can_use = true; // Everything is okay, so set to true
            Ok(self) // and return the character
        } else {
            Err("Could not create character. Characters must have:
1) Height below 200
2) Weight below 300
3) A name that is not Smurf (that is a bad word)"
                .to_string())
        }
    }

    fn main() {
        let character_with_smurf = Character::new().name("Lol I am Smurf!!").build(); //
This one contains "smurf" - not okay
        let character_too_tall = Character::new().height(400).build(); // Too tall - not
    }
}

```

```

okay
let character_too_heavy = Character::new().weight(500).build(); // Too heavy - not
okay
let okay_character = Character::new()
    .name("Billybrobby")
    .height(180)
    .weight(100)
    .build(); // This character is okay. Name is fine, height and weight are fine

// Now they are not Character, they are Result<Character, String>. So let's put
them in a Vec so we can see them:
let character_vec = vec![character_with_smurf, character_too_tall,
character_too_heavy, okay_character];

for character in character_vec { // Now we will print the character if it's Ok, and
print the error if it's Err
    match character {
        Ok(character_info) => println!("{}:", character_info),
        Err(err_info) => println!("{}:", err_info),
    }
    println!(); // Then add one more line
}
}

```

This will print:

```

Could not create character. Characters must have:
1) Height below 200
2) Weight below 300
3) A name that is not Smurf (that is a bad word)

```

```

Could not create character. Characters must have:
1) Height below 200
2) Weight below 300
3) A name that is not Smurf (that is a bad word)

```

```

Could not create character. Characters must have:
1) Height below 200
2) Weight below 300
3) A name that is not Smurf (that is a bad word)

```

```

Character { name: "Billybrobby", age: 15, height: 180, weight: 100, lifestate: Alive,
can_use: true }

```

Deref and DerefMut

`Deref` is the trait that lets you use `*` to dereference something. We saw the word `Deref` before when using a tuple struct to make a new type, and now it's time to learn it.

We know that a reference is not the same as a value:

```
// ⚠️
fn main() {
    let value = 7; // This is an i32
    let reference = &7; // This is a &i32
    println!("{}", value == reference);
}
```

And Rust won't even give a `false` because it won't even compare the two.

```
error[E0277]: can't compare `{:integer}` with `&{:integer}`
--> src\main.rs:4:26
 |
4 |     println!("{}", value == reference);
 |             ^^^ no implementation for `{:integer} == &{:integer}`
```

Of course, the solution here is `*`. So this will print `true`:

```
fn main() {
    let value = 7;
    let reference = &7;
    println!("{}", value == *reference);
}
```

Now let's imagine a simple type that just holds a number. It will be like a `Box`, and we have some ideas for some extra functions for it. But if we just give it a number, it won't be able to do much with it.

We can't use `*` like we can with `Box`:

```
// ⚠️
struct HoldsANumber(u8);

fn main() {
    let my_number = HoldsANumber(20);
    println!("{}", *my_number + 20);
}
```

The error is:

```
error[E0614]: type `HoldsANumber` cannot be dereferenced
--> src\main.rs:24:22
 |
24 |     println!("{}?", *my_number + 20);
```

We can of course do this: `println!("{}?", my_number.0 + 20)`. But then we are just adding a separate `u8` to the 20. It would be nice if we could just add them together. The message `cannot be dereferenced` gives us a clue: we need to implement `Deref`. Something simple that implements `Deref` is sometimes called a "smart pointer". A smart pointer can point to its item, has information

about it, and can use its methods. Because right now we can add `my_number.0`, which is a `u8`, but we can't do much else with a `HoldsANumber`: all it has so far is `Debug`.

Interesting fact: `String` is actually a smart pointer to `&str` and `Vec` is a smart pointer to array (or other types). So we have actually been using smart pointers since the beginning.

Implementing `Deref` is not too hard and the examples in the standard library are easy. [Here's the sample code from the standard library](#):

```
use std::ops::Deref;

struct DerefExample<T> {
    value: T
}

impl<T> Deref for DerefExample<T> {
    type Target = T;

    fn deref(&self) -> &Self::Target {
        &self.value
    }
}

fn main() {
    let x = DerefExample { value: 'a' };
    assert_eq!('a', *x);
}
```

So we follow that and now our `Deref` looks like this:

```
// 🛡
impl Deref for HoldsANumber {
    type Target = u8; // Remember, this is the "associated type": the type that goes
                      // together.
                      // You have to use the right type Target = (the type you want to
                      // return)

    fn deref(&self) -> &Self::Target { // Rust calls .deref() when you use *. We just
        defined Target as a u8 so this is easy to understand
        &self.0 // We chose &self.0 because it's a tuple struct. In a named struct it
                // would be something like "&self.number"
    }
}
```

So now we can do this with `*`:

```
use std::ops::Deref;
#[derive(Debug)]
struct HoldsANumber(u8);

impl Deref for HoldsANumber {
    type Target = u8;

    fn deref(&self) -> &Self::Target {
        &self.0
    }
}

fn main() {
    let my_number = HoldsANumber(20);
    println!("{} + 20 = {}", my_number, my_number + 20);
}
```

So that will print `40` and we didn't need to write `my_number.0`. That means we get the methods of `u8` and we can write our own methods for `HoldsANumber`. We will add our own simple method and use another method we get from `u8` called `.checked_sub()`. The `.checked_sub()` method is a safe subtraction that returns an `Option`. If it can do the subtraction then it gives it to you inside `Some`, and if it can't do it then it gives a `None`. Remember, a `u8` can't be negative so it's safer to do `.checked_sub()` so we don't panic.

```
use std::ops::Deref;

struct HoldsANumber(u8);

impl HoldsANumber {
    fn prints_the_number_times_two(&self) {
        println!("{} * 2 = {}", self.0, self.0 * 2);
    }
}

impl Deref for HoldsANumber {
    type Target = u8;

    fn deref(&self) -> &Self::Target {
        &self.0
    }
}

fn main() {
    let my_number = HoldsANumber(20);
    println!("{} - 100 = {}", my_number, my_number.checked_sub(100)); // This method comes from u8
    my_number.prints_the_number_times_two(); // This is our own method
}
```

This prints:

```
None
40
```

We can also implement `DerefMut` so we can change the values through `*`. It looks almost the same. You need `Deref` before you can implement `DerefMut`.

```

use std::ops::{Deref, DerefMut};

struct HoldsANumber(u8);

impl HoldsANumber {
    fn prints_the_number_times_two(&self) {
        println!("{}", self.0 * 2);
    }
}

impl Deref for HoldsANumber {
    type Target = u8;

    fn deref(&self) -> &Self::Target {
        &self.0
    }
}

impl DerefMut for HoldsANumber { // You don't need type Target = u8; here because it
already knows thanks to Deref
    fn deref_mut(&mut self) -> &mut Self::Target { // Everything else is the same
except it says mut everywhere
        &mut self.0
    }
}

fn main() {
    let mut my_number = HoldsANumber(20);
    *my_number = 30; // DerefMut lets us do this
    println!("{:?}", my_number.checked_sub(100));
    my_number.prints_the_number_times_two();
}

```

So you can see that `Deref` gives your type a lot of power.

This is also why the standard library says: `Deref` should only be implemented for smart pointers to avoid confusion. That's because you can do some strange things with `Deref` for a complicated type. Let's imagine a really confusing example to understand what they mean. We'll start with `Character` struct for a game. A new `Character` needs some stats like intelligence and strength. So here is our first character:

```

struct Character {
    name: String,
    strength: u8,
    dexterity: u8,
    health: u8,
    intelligence: u8,
    wisdom: u8,
    charm: u8,
    hit_points: i8,
    alignment: Alignment,
}

impl Character {
    fn new(
        name: String,
        strength: u8,
        dexterity: u8,
        health: u8,
        intelligence: u8,
        wisdom: u8,
        charm: u8,
        hit_points: i8,
        alignment: Alignment,
    ) -> Self {
        Self {
            name,
            strength,
            dexterity,
            health,
            intelligence,
            wisdom,
            charm,
            hit_points,
            alignment,
        }
    }
}

enum Alignment {
    Good,
    Neutral,
    Evil,
}

fn main() {
    let billy = Character::new("Billy".to_string(), 9, 8, 7, 10, 19, 19, 5,
Alignment::Good);
}

```

Now let's imagine that we want to keep character hit points in a big vec. Maybe we'll put monster data in there too, and keep it all together. Since `hit_points` is an `i8`, we implement `Deref` so we can do all sorts of math on it. But look at how strange it looks in our `main()` function now:

```

use std::ops::Deref;

// All the other code is the same until after the enum Alignment
struct Character {
    name: String,
    strength: u8,
    dexterity: u8,
    health: u8,
    intelligence: u8,
    wisdom: u8,
    charm: u8,
    hit_points: i8,
    alignment: Alignment,
}

impl Character {
    fn new(
        name: String,
        strength: u8,
        dexterity: u8,
        health: u8,
        intelligence: u8,
        wisdom: u8,
        charm: u8,
        hit_points: i8,
        alignment: Alignment,
    ) -> Self {
        Self {
            name,
            strength,
            dexterity,
            health,
            intelligence,
            wisdom,
            charm,
            hit_points,
            alignment,
        }
    }
}

enum Alignment {
    Good,
    Neutral,
    Evil,
}

impl Deref for Character { // impl Deref for Character. Now we can do any integer math
we want!
    type Target = i8;

    fn deref(&self) -> &Self::Target {
        &self.hit_points
    }
}
}

fn main() {
    let billy = Character::new("Billy".to_string(), 9, 8, 7, 10, 19, 19, 5,
Alignment::Good); // Create two characters, billy and brandy
    let brandy = Character::new("Brandy".to_string(), 9, 8, 7, 10, 19, 19, 5,
Alignment::Good);

    let mut hit_points_vec = vec![]; // Put our hit points data in here
    hit_points_vec.push(*billy); // Push *billy?
    hit_points_vec.push(*brandy); // Push *brandy?
}

```

```
    println!("{:?}", hit_points_vec);
}
```

This just prints `[5, 5]`. Our code is now very strange for someone to read. We can read `Deref` just above `main()` and figure out that `*billy` means `i8`, but what if there was a lot of code? Maybe our code is 2000 lines long, and suddenly we have to figure out why we are `.push()` ing `*billy`. `Character` is certainly more than just a smart pointer for `i8`.

Of course, it is not illegal to write `hit_points_vec.push(*billy)`, but it makes the code look very strange. Probably a simple `.get_hp()` method would be much better, or another struct that holds the characters. Then you could iterate through and push the `hit_points` for each one. `Deref` gives a lot of power but it's good to make sure that the code is logical.

Crates and modules

Every time you write code in Rust, you are writing it in a `crate`. A `crate` is the file, or files, that go together for your code. Inside the file you write you can also make a `mod`. A `mod` is a space for functions, structs, etc. and is used for a few reasons:

- Building your code: it helps you think about the general structure of your code. This can be important as your code gets larger and larger.
- Reading your code: people can understand your code more easily. For example, the name `std::collections::HashMap` tells you that it's in `std` inside the module `collections`. This gives you a hint that maybe there are more collection types inside `collections` that you can try.
- Privacy: everything starts out as private. That lets you keep users from using functions directly.

To make a `mod`, just write `mod` and start a code block with `{}`. We will make a mod called `print_things` that has some printing-related functions.

```
mod print_things {
    use std::fmt::Display;

    fn prints_one_thing<T: Display>(input: T) { // Print anything that implements
        Display
            println!("{}", input)
    }
}

fn main() {}
```

You can see that we wrote `use std::fmt::Display;` inside `print_things`, because it is a separate space. If you wrote `use std::fmt::Display;` inside `main()` it wouldn't help. Also, we can't call it from `main()` right now. Without the `pub` keyword in front of `fn` it will stay private. Let's try to call it without `pub`. Here's one way to write it:

```
// 🚧
fn main() {
    crate::print_things::prints_one_thing(6);
}
```

`crate` means "inside this project", but for our simple example it's the same as "inside this file". Inside that is the mod `print_things`, then finally the `prints_one_thing()` function. You can write that every time, or you can write `use` to import it. Now we can see the error that says that it's private:

```
// ⚠️
mod print_things {
    use std::fmt::Display;

    fn prints_one_thing<T: Display>(input: T) {
        println!("{}", input)
    }
}

fn main() {
    use crate::print_things::prints_one_thing;

    prints_one_thing(6);
    prints_one_thing("Trying to print a string...".to_string());
}
```

Here's the error:

```
error[E0603]: function `prints_one_thing` is private
--> src\main.rs:10:30
|
10 |     use crate::print_things::prints_one_thing;
|           ^^^^^^^^^^^^^^^^^^ private function
|
note: the function `prints_one_thing` is defined here
--> src\main.rs:4:5
|
4 |     fn prints_one_thing<T: Display>(input: T) {
|           ^^^^^^^^^^^^^^^^^^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^
```

It's easy to understand that function `prints_one_thing` is private. It also shows us with `src\main.rs:4:5` where to find the function. This is helpful because you can write `mod`s not just in one file, but over a lot of files as well.

Now we just write `pub fn` instead of `fn` and everything works.

```
mod print_things {
    use std::fmt::Display;

    pub fn prints_one_thing<T: Display>(input: T) {
        println!("{}", input)
    }
}

fn main() {
    use crate::print_things::prints_one_thing;

    prints_one_thing(6);
    prints_one_thing("Trying to print a string...".to_string());
}
```

This prints:

```
6
Trying to print a string...
```

How about `pub` for a struct, enum, trait, or module? `pub` works like this for them:

- `pub` for a struct: it makes the struct public, but the items are not public. To make an item public, you have to write `pub` for each one too.
- `pub` for an enum or trait: everything becomes public. This makes sense because traits are about giving the same behaviour to something. And enums are about choosing between items,

and you need to see them all to choose them.

- `pub` for a module: a top level module will be `pub` because if it isn't pub then nobody can touch anything in it at all. But modules inside modules need `pub` to be public.

So let's put a struct named `Billy` inside `print_things`. This struct will be almost all public, but not quite. The struct is public so it will say `pub struct Billy`. Inside it will have a `name` and `times_to_print`. `name` will not be public, because we only want the user to create structs named `"Billy".to_string()`. But the user can select the number of times to print, so that will be public. It looks like this:

```
mod print_things {
    use std::fmt::{Display, Debug};

    #[derive(Debug)]
    pub struct Billy { // Billy is public
        name: String, // but name is private.
        pub times_to_print: u32,
    }

    impl Billy {
        pub fn new(times_to_print: u32) -> Self { // That means the user needs to use
            new to create a Billy. The user can only change the number of times_to_print
            Self {
                name: "Billy".to_string(), // We choose the name - the user can't
                times_to_print,
            }
        }

        pub fn print_billy(&self) { // This function prints a Billy
            for _ in 0..self.times_to_print {
                println!("{:?}", self.name);
            }
        }
    }

    pub fn prints_one_thing<T: Display>(input: T) {
        println!("{}", input)
    }
}

fn main() {
    use crate::print_things::*;

    let my_billy = Billy::new(3);
    my_billy.print_billy();
}
```

This will print:

```
"Billy"
"Billy"
"Billy"
```

By the way, the `*` to import everything is called the "glob operator". Glob means "global", so it means everything.

Inside a `mod` you can create other mods. A child mod (a mod inside of a mod) can always use anything inside a parent mod. You can see this in the next example where we have a `mod city` inside a `mod province` inside a `mod country`.

You can think of the structure like this: even if you are in a country, you might not be in a province. And even if you are in a province, you might not be in a city. But if you are in a city, you are in its province and you are in its country.

```
mod country { // The main mod doesn't need pub
    fn print_country(country: &str) { // Note: this function isn't public
        println!("We are in the country of {}", country);
    }
    pub mod province { // Make this mod public

        fn print_province(province: &str) { // Note: this function isn't public
            println!("in the province of {}", province);
        }

        pub mod city { // Make this mod public
            pub fn print_city(country: &str, province: &str, city: &str) { // This
                function is public though
                    crate::country::print_country(country);
                    crate::country::province::print_province(province);
                    println!("in the city of {}", city);
                }
            }
        }
    }

    fn main() {
        crate::country::province::city::print_city("Canada", "New Brunswick", "Moncton");
    }
}
```

The interesting part is that `print_city` can access `print_province` and `print_country`. That's because `mod city` is inside the other mods. It doesn't need `pub` in front of `print_province` to use it. And that makes sense: a city doesn't need to do anything to be inside a province and inside a country.

You probably noticed that `crate::country::province::print_province(province);` is very long. When we are inside a module we can use `super` to bring in items from above. Actually the word `super` itself means "above", like in "superior". In our example we only used the function once, but if you use it more then it is a good idea to import. It can also be a good idea if it makes your code easier to read, even if you only use the function once. The code is almost the same now, but a bit easier to read:

```
mod country {
    fn print_country(country: &str) {
        println!("We are in the country of {}", country);
    }
    pub mod province {
        fn print_province(province: &str) {
            println!("in the province of {}", province);
        }
        pub mod city {
            use super::super::*; // use everything in "above above": that means mod
country
            use super::*;

            pub fn print_city(country: &str, province: &str, city: &str) {
                print_country(country);
                print_province(province);
                println!("in the city of {}", city);
            }
        }
    }
}

fn main() {
    use crate::country::province::city::print_city; // bring in the function

    print_city("Canada", "New Brunswick", "Moncton");
    print_city("Korea", "Gyeonggi-do", "Gwangju"); // Now it's less work to use it
again
}
```

Testing

Testing is a good subject to learn now that we understand modules. Testing your code is very easy in Rust, because you can write tests right next to your code.

The easiest way to start testing is to add `#[test]` above a function. Here is a simple one:

```
#[test]
fn two_is_two() {
    assert_eq!(2, 2);
}
```

But if you try to run it in the Playground, it gives an error: `error[E0601]: `main` function not found in crate `playground``. That's because you don't use *Run* for tests, you use *Test*. Also, you don't use a `main()` function for tests - they go outside. To run this in the Playground, click on `...` next to *RUN* and change it to *Test*. Now if you click on it, it will run the test. (If you have Rust installed already, you will type `cargo test` to do this)

Here is the output:

```
running 1 test
test two_is_two ... ok

test result: ok. 1 passed; 0 failed; 0 ignored; 0 measured; 0 filtered out
```

Let's change `assert_eq!(2, 2)` to `assert_eq!(2, 3)` and see what we get. When a test fails you get a lot more information:

```
running 1 test
test two_is_two ... FAILED

failures:

---- two_is_two stdout ----
thread 'two_is_two' panicked at 'assertion failed: `(left == right)`
  left: `2`,
  right: `3`, src/lib.rs:3:5
note: run with `RUST_BACKTRACE=1` environment variable to display a backtrace

failures:
  two_is_two

test result: FAILED. 0 passed; 1 failed; 0 ignored; 0 measured; 0 filtered out
```

`assert_eq!(left, right)` is the main way to test a function in Rust. If it doesn't work, it will show the different values: left has 2, but right has 3.

What does `RUST_BACKTRACE=1` mean? This is a setting on your computer to give a lot more information about errors. Luckily the Playground has it too: click on `...` next to `STABLE` and set backtrace to `ENABLED`. If you do that, it will give you *a lot* of information:

```
running 1 test
test two_is_two ... FAILED

failures:

---- two_is_two stdout ----
thread 'two_is_two' panicked at 'assertion failed: 2 == 3', src/lib.rs:3:5
stack backtrace:
  0: backtrace::backtrace::libunwind::trace
    at /cargo/registry/src/github.com-1ecc6299db9ec823/backtrace-0.3.46/src/backtrace/libunwind.rs:86
  1: backtrace::backtrace::trace_unsynchronized
    at /cargo/registry/src/github.com-1ecc6299db9ec823/backtrace-0.3.46/src/backtrace/mod.rs:66
  2: std::sys_common::backtrace::_print_fmt
    at src/libstd/sys_common/backtrace.rs:78
  3: <std::sys_common::backtrace::_print::DisplayBacktrace as core::fmt::Display>::fmt
    at src/libstd/sys_common/backtrace.rs:59
  4: core::fmt::write
    at src/libcore/fmt/mod.rs:1076
  5: std::io::Write::write_fmt
    at
/rustc/c367798cf3817ca6ae908ce675d1d99242af148/src/libstd/io/mod.rs:1537
  6: std::io::impls::<impl std::io::Write for alloc::boxed::Box<W>>::write_fmt
    at src/libstd/io/impls.rs:176
  7: std::sys_common::backtrace::_print
    at src/libstd/sys_common/backtrace.rs:62
  8: std::sys_common::backtrace::print
    at src/libstd/sys_common/backtrace.rs:49
  9: std::panicking::default_hook::{closure}
    at src/libstd/panicking.rs:198
 10: std::panicking::default_hook
    at src/libstd/panicking.rs:215
 11: std::panicking::rust_panic_with_hook
    at src/libstd/panicking.rs:486
 12: std::panicking::begin_panic
    at
/rustc/c367798cf3817ca6ae908ce675d1d99242af148/src/libstd/panicking.rs:410
 13: playground::two_is_two
    at src/lib.rs:3
 14: playground::two_is_two::{closure}
    at src/lib.rs:2
 15: core::ops::function::FnOnce::call_once
    at
/rustc/c367798cf3817ca6ae908ce675d1d99242af148/src/libcore/ops/function.rs:232
 16: <alloc::boxed::Box<F> as core::ops::function::FnOnce<A>>::call_once
    at
/rustc/c367798cf3817ca6ae908ce675d1d99242af148/src/liballoc/boxed.rs:1076
 17: <std::panic::AssertUnwindSafe<F> as core::ops::function::FnOnce<()>>::call_once
    at /rustc/c367798cf3817ca6ae908ce675d1d99242af148/src/libstd/panic.rs:318
 18: std::panicking::try::do_call
    at
/rustc/c367798cf3817ca6ae908ce675d1d99242af148/src/libstd/panicking.rs:297
 19: std::panicking::try
    at
/rustc/c367798cf3817ca6ae908ce675d1d99242af148/src/libstd/panicking.rs:274
 20: std::panic::catch_unwind
    at /rustc/c367798cf3817ca6ae908ce675d1d99242af148/src/libstd/panic.rs:394
 21: test::run_test_in_process
    at src/libtest/lib.rs:541
 22: test::run_test::run_test_inner::{closure}
    at src/libtest/lib.rs:450
note: Some details are omitted, run with `RUST_BACKTRACE=full` for a verbose backtrace.

failures:
  two_is_two
```

```
test result: FAILED. 0 passed; 1 failed; 0 ignored; 0 measured; 0 filtered out
```

You don't need to use a backtrace unless you really can't find where the problem is. But luckily you don't need to understand it all either. If you keep reading, you will eventually see line 13 where it says `playground` - that's where it talks about your code. Everything else is about what Rust is doing in other libraries to run your program. But these two lines show you that it looked at line 2 and line 3 of `playground`, which is a hint to check there. Here's that part again:

```
13: playground::two_is_two
    at src/lib.rs:3
14: playground::two_is_two::{{closure}}
    at src/lib.rs:2
```

Edit: Rust improved its backtrace messages in early 2021 to only show the most meaningful information. Now it's much easier to read:

```
failures:

---- two_is_two stdout ----
thread 'two_is_two' panicked at 'assertion failed: `(left == right)`
  left: `2`,
  right: `3`, src/lib.rs:3:5
stack backtrace:
  0: rust_begin_unwind
    at
/rustc/cb75ad5db02783e8b0222fee363c5f63f7e2cf5b/library/std/src/panicking.rs:493:5
  1: core::panicking::panic_fmt
    at
/rustc/cb75ad5db02783e8b0222fee363c5f63f7e2cf5b/library/core/src/panicking.rs:92:14
  2: playground::two_is_two
    at ./src/lib.rs:3:5
  3: playground::two_is_two::{{closure}}
    at ./src/lib.rs:2:1
  4: core::ops::function::FnOnce::call_once
    at
/rustc/cb75ad5db02783e8b0222fee363c5f63f7e2cf5b/library/core/src/ops/function.rs:227:5
  5: core::ops::function::FnOnce::call_once
    at
/rustc/cb75ad5db02783e8b0222fee363c5f63f7e2cf5b/library/core/src/ops/function.rs:227:5
note: Some details are omitted, run with `RUST_BACKTRACE=full` for a verbose backtrace.

failures:
    two_is_two

test result: FAILED. 0 passed; 1 failed; 0 ignored; 0 measured; 0 filtered out;
finished in 0.02s
```

Now let's turn backtrace off again and return to regular tests. Now we'll write some other functions, and use test functions to test them. Here are a few:

```

fn return_two() -> i8 {
    2
}
#[test]
fn it_returns_two() {
    assert_eq!(return_two(), 2);
}

fn return_six() -> i8 {
    4 + return_two()
}
#[test]
fn it_returns_six() {
    assert_eq!(return_six(), 6)
}

```

Now it runs both:

```

running 2 tests
test it_returns_two ... ok
test it_returns_six ... ok

test result: ok. 2 passed; 0 failed; 0 ignored; 0 measured; 0 filtered out

```

That's not too hard.

Usually you will want to put your tests in their own module. To do this, use the same `mod` keyword and add `#[cfg(test)]` above it (remember: `cfg` means "configure"). You also want to continue to write `#[test]` above each test. This is because later on when you install Rust, you can do more complicated testing. You will be able to run one test, or all of them, or run a few. Also don't forget to write `use super::*`; because the test module needs to use the functions above it. Now it will look like this:

```

fn return_two() -> i8 {
    2
}
fn return_six() -> i8 {
    4 + return_two()
}

#[cfg(test)]
mod tests {
    use super::*;

    #[test]
    fn it_returns_six() {
        assert_eq!(return_six(), 6)
    }
    #[test]
    fn it_returns_two() {
        assert_eq!(return_two(), 2);
    }
}

```

Test-driven development

You might see the words "test-driven development" when reading about Rust or another language. It's one way to write programs, and some people like it while others prefer something else. "Test-

"driven development" means "writing tests first, then writing the code". When you do this, you will have a lot of tests for everything you want your code to do. Then you start writing the code, and run the tests to see if you did it right. Then the tests are always there to show you if something goes wrong when you add to and rewrite your code. This is pretty easy in Rust because the compiler gives a lot of information about what to fix. Let's write a small example of test-driven development and see what it looks like.

Let's imagine a calculator that takes user input. It can add (+) and it can subtract (-). If the user writes "5 + 6" it should return 11, if the user writes "5 + 6 - 7" it should return 4, and so on. So we'll start with test functions. You can also see that function names in tests are usually quite long. That is because you might run a lot of tests, and you want to understand which tests have failed.

We'll imagine that a single function called `math()` will do everything. It will return an `i32` (we won't use floats). Because it needs to return something, we'll just return `6` every time. Then we will write three test functions. They will all fail, of course. Now the code looks like this:

```
fn math(input: &str) -> i32 {
    6
}

#[cfg(test)]
mod tests {
    use super::*;

    #[test]
    fn one_plus_one_is_two() {
        assert_eq!(math("1 + 1"), 2);
    }
    #[test]
    fn one_minus_two_is_minus_one() {
        assert_eq!(math("1 - 2"), -1);
    }
    #[test]
    fn one_minus_minus_one_is_two() {
        assert_eq!(math("1 - -1"), 2);
    }
}
```

It gives us this information:

```
running 3 tests
test tests::one_minus_minus_one_is_two ... FAILED
test tests::one_minus_two_is_minus_one ... FAILED
test tests::one_plus_one_is_two ... FAILED
```

and all the information about `thread 'tests::one_plus_one_is_two' panicked at 'assertion failed: `(left == right)`'`. We don't need to print it all here.

Now to think about how to make the calculator. We will accept any number, and the symbols `+-`. We will allow spaces, but nothing else. So let's start with a `const` that contains all the values. Then we will use `.chars()` to iterate by character, and `.all()` to make sure they are all inside.

Then we will add a test that should panic. To do that, add `#[should_panic]` attribute: now if it panics the test will succeed.

Now the code looks like this:

```

const OKAY_CHARACTERS: &str = "1234567890+- "; // Don't forget the space at the end

fn math(input: &str) -> i32 {
    if !input.chars().all(|character| OKAY_CHARACTERS.contains(character)) {
        panic!("Please only input numbers, +-, or spaces");
    }
    6 // we still return a 6 for now
}

#[cfg(test)]
mod tests {
    use super::*;

    #[test]
    fn one_plus_one_is_two() {
        assert_eq!(math("1 + 1"), 2);
    }

    #[test]
    fn one_minus_two_is_minus_one() {
        assert_eq!(math("1 - 2"), -1);
    }

    #[test]
    fn one_minus_minus_one_is_two() {
        assert_eq!(math("1 - -1"), 2);
    }

    #[test]
    #[should_panic] // Here is our new test - it should panic
    fn panics_when_characters_not_right() {
        math("7 + seven");
    }
}

```

Now when we run the tests we get this result:

```

running 4 tests
test tests::one_minus_two_is_minus_one ... FAILED
test tests::one_minus_minus_one_is_two ... FAILED
test tests::panics_when_characters_not_right ... ok
test tests::one_plus_one_is_two ... FAILED

```

One succeeded! Our `math()` function will only accept good input now.

The next step is to write the actual calculator. This is the interesting part about having tests first: the actual code starts much later. First we will put the logic together for the calculator. We want the following:

- All empty spaces should be removed. This is easy with `.filter()`
- The input should turn into a `Vec` with all the inputs. `+` doesn't need to be an input, but when the program sees `+` it should know that the number is done. For example, the input `11+1` should do something like this: 1) See `1`, push it into an empty string. 2) See another `1`, push it into the string (it is now "11"). 3) See a `+`, know the number has ended. It will push the string into the vec, then clear the string.
- The program must count the number of `-`. An odd number (1, 3, 5...) will mean subtract, an even number (2, 4, 6...) will mean add. So "1--9" should give 10, not -8.
- The program should remove anything after the last number. `5+5++++++` is made out of all the characters in `OKAY_CHARACTERS`, but it should turn to `5+5`. This is easy with `.trim_end_matches()`, where you remove anything that matches at the end of a `&str`.

(By the way, `.trim_end_matches()` and `.trim_start_matches()` used to be `trim_right_matches()` and `trim_left_matches()`. But then people noticed that some languages go from right to left (Persian, Hebrew, etc.) so right and left were wrong. You might still see the older names in some code but they are the same thing.)

First we just want to pass all the tests. After we pass the tests, we can "refactor". Refactor means to make code better, usually through things like structs and enums and methods. Here is our code to make the tests pass:

```

const OKAY_CHARACTERS: &str = "1234567890+- ";

fn math(input: &str) -> i32 {
    if !input.chars().all(|character| OKAY_CHARACTERS.contains(character)) ||
        !input.chars().take(2).any(|character| character.is_numeric())
    {
        panic!("Please only input numbers, +-, or spaces.");
    }

    let input = input.trim_end_matches(|x| "+- ".contains(x)).chars().filter(|x| *x != '+').collect::<String>(); // Remove + and - at the end, and all spaces
    let mut result_vec = vec![]; // Results go in here
    let mut push_string = String::new(); // This is the string we push in every time.
    We will keep reusing it in the loop.
    for character in input.chars() {
        match character {
            '+' => {
                if !push_string.is_empty() { // If the string is empty, we don't want
                    to push "" into result_vec
                    result_vec.push(push_string.clone()); // But if it's not empty, it
                    will be a number. Push it into the vec
                    push_string.clear(); // Then clear the string
                }
            },
            '-' => { // If we get a -
                if push_string.contains('-') || push_string.is_empty() { // check to
                    see if it's empty or has a -
                    push_string.push(character) // if so, then push it in
                } else { // otherwise, it will contain a number
                    result_vec.push(push_string.clone()); // so push the number into
                    result_vec, clear it and then push -
                    push_string.clear();
                    push_string.push(character);
                }
            },
            number => { // number here means "anything else that matches". We selected
                the name here
                if push_string.contains('-') { // We might have some - characters to
                    push in first
                    result_vec.push(push_string.clone());
                    push_string.clear();
                    push_string.push(number);
                } else { // But if we don't, that means we can push the number in
                    push_string.push(number);
                }
            },
        }
    }
    result_vec.push(push_string); // Push one last time after the loop is over. Don't
    need to .clone() because we don't use it anymore

    let mut total = 0; // Now it's time to do math. Start with a total
    let mut adds = true; // true = add, false = subtract
    let mut math_iter = result_vec.into_iter();
    while let Some(entry) = math_iter.next() { // Iter through the items
        if entry.contains('-') { // If it has a - character, check if it's even or odd
            if entry.chars().count() % 2 == 1 {
                adds = match adds {
                    true => false,
                    false => true
                };
                continue; // Go to the next item
            } else {
                continue;
            }
        }
    }
}

```

```

        if adds == true {
            total += entry.parse::<i32>().unwrap(); // If there is no '-', it must be a
number. So we are safe to unwrap
        } else {
            total -= entry.parse::<i32>().unwrap();
            adds = true; // After subtracting, reset adds to true.
        }
    }
    total // Finally, return the total
}
/// We'll add a few more tests just to make sure

#[cfg(test)]
mod tests {
    use super::*;

    #[test]
    fn one_plus_one_is_two() {
        assert_eq!(math("1 + 1"), 2);
    }
    #[test]
    fn one_minus_two_is_minus_one() {
        assert_eq!(math("1 - 2"), -1);
    }
    #[test]
    fn one_minus_minus_one_is_two() {
        assert_eq!(math("1 - -1"), 2);
    }
    #[test]
    fn nine_plus_nine_minus_nine_minus_nine_is_zero() {
        assert_eq!(math("9+9-9-9"), 0); // This is a new test
    }
    #[test]
    fn eight_minus_nine_plus_nine_is_eight_even_with_characters_on_the_end() {
        assert_eq!(math("8 - 9 +9-----++++"), 8); // This is a new test
    }
    #[test]
    #[should_panic]
    fn panics_when_characters_not_right() {
        math("7 + seven");
    }
}
}

```

And now the tests pass!

```

running 6 tests
test tests::one_minus_minus_one_is_two ... ok
test tests::nine_plus_nine_minus_nine_minus_nine_is_zero ... ok
test tests::one_minus_two_is_minus_one ... ok
test tests::eight_minus_nine_plus_nine_is_eight_even_with_characters_on_the_end ... ok
test tests::one_plus_one_is_two ... ok
test tests::panics_when_characters_not_right ... ok

test result: ok. 6 passed; 0 failed; 0 ignored; 0 measured; 0 filtered out

```

You can see that there is a back and forth process in test-driven development. It's something like this:

- First you write all the tests you can think of.
- Then you start writing the code.
- As you write the code, you get ideas for other tests.
- You add the tests, and your tests grow as you go. The more tests you have, the more times your code gets checked.

Of course, tests don't check everything and it is wrong to think that "passing all tests = the code is perfect". But tests are great for when you change your code. If you change your code later on and run the tests, if one of them doesn't work you will know what to fix.

Now we can rewrite (refactor) the code a bit. One good way to start is with clippy. If you installed Rust then you can type `cargo clippy`, and if you're using the Playground then click on `TOOLS` and select Clippy. Clippy will look at your code and give you tips to make it simpler. Our code doesn't have any mistakes, but it could be better.

Clippy tells us two things:

```
warning: this loop could be written as a `for` loop
--> src/lib.rs:44:5
|
44 |     while let Some(entry) = math_iter.next() { // Iter through the items
|     ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^ help: try: `for entry in math_iter`
|
|     = note: `#[warn(clippy::while_let_on_iterator)]` on by default
|     = help: for further information visit https://rust-lang.github.io/rust-
clippy/master/index.html#while_let_on_iterator

warning: equality checks against true are unnecessary
--> src/lib.rs:53:12
|
53 |         if adds == true {
|         ^^^^^^^^^^^ help: try simplifying it as shown: `adds`
|
|     = note: `#[warn(clippy::bool_comparison)]` on by default
|     = help: for further information visit https://rust-lang.github.io/rust-
clippy/master/index.html#bool_comparison
```

This is true: `for entry in math_iter` is much simpler than `while let Some(entry) = math_iter.next()`. And a `for` loop is actually an iterator so we don't have any reason to write `.iter()`. Thanks, clippy! And also we didn't need to make `math_iter`: we can just write `for entry in result_vec`.

Now we'll start some real refactoring. Instead of separate variables, we will create a `calculator` struct. This will have all the variables we used together. We will change two names to make it more clear. `result_vec` will become `results`, and `push_string` will become `current_input` (`current` means "now"). And so far it only has one method: `new`.

```
// 📐
#[derive(Clone)]
struct Calculator {
    results: Vec<String>,
    current_input: String,
    total: i32,
    adds: bool,
}

impl Calculator {
    fn new() -> Self {
        Self {
            results: vec![],
            current_input: String::new(),
            total: 0,
            adds: true,
        }
    }
}
```

Now our code is actually a bit longer, but easier to read. For example, `if adds` is now `if calculator.adds`, which is exactly like reading English. It looks like this:

```

#[derive(Clone)]
struct Calculator {
    results: Vec<String>,
    current_input: String,
    total: i32,
    adds: bool,
}

impl Calculator {
    fn new() -> Self {
        Self {
            results: vec![], 
            current_input: String::new(),
            total: 0,
            adds: true,
        }
    }
}

const OKAY_CHARACTERS: &str = "1234567890+- ";

fn math(input: &str) -> i32 {
    if !input.chars().all(|character| OKAY_CHARACTERS.contains(character)) ||
       !input.chars().take(2).any(|character| character.is_numeric()) {
        panic!("Please only input numbers, +-, or spaces");
    }

    let input = input.trim_end_matches(|x| "+- ".contains(x)).chars().filter(|x| *x != ' ')
        .collect::<String>();
    let mut calculator = Calculator::new();

    for character in input.chars() {
        match character {
            '+' => {
                if !calculator.current_input.is_empty() {
                    calculator.results.push(calculator.current_input.clone());
                    calculator.current_input.clear();
                }
            },
            '-' => {
                if calculator.current_input.contains('>') || calculator.current_input.is_empty() {
                    calculator.current_input.push(character)
                } else {
                    calculator.results.push(calculator.current_input.clone());
                    calculator.current_input.clear();
                    calculator.current_input.push(character);
                }
            },
            number => {
                if calculator.current_input.contains('>') {
                    calculator.results.push(calculator.current_input.clone());
                    calculator.current_input.clear();
                    calculator.current_input.push(number);
                } else {
                    calculator.current_input.push(number);
                }
            },
        }
    }
    calculator.results.push(calculator.current_input);

    for entry in calculator.results {
        if entry.contains('>') {
            if entry.chars().count() % 2 == 1 {
                calculator.adds = match calculator.adds {

```

```

        true => false,
        false => true
    };
    continue;
} else {
    continue;
}
}
if calculator.adds {
    calculator.total += entry.parse::<i32>().unwrap();
} else {
    calculator.total -= entry.parse::<i32>().unwrap();
    calculator.adds = true;
}
calculator.total
}

#[cfg(test)]
mod tests {
    use super::*;

    #[test]
    fn one_plus_one_is_two() {
        assert_eq!(math("1 + 1"), 2);
    }
    #[test]
    fn one_minus_two_is_minus_one() {
        assert_eq!(math("1 - 2"), -1);
    }
    #[test]
    fn one_minus_minus_one_is_two() {
        assert_eq!(math("1 - -1"), 2);
    }
    #[test]
    fn nine_plus_nine_minus_nine_minus_nine_is_zero() {
        assert_eq!(math("9+9-9-9"), 0);
    }
    #[test]
    fn eight_minus_nine_plus_nine_is_eight_even_with_characters_on_the_end() {
        assert_eq!(math("8 - 9      +9-----++++"), 8);
    }
    #[test]
    #[should_panic]
    fn panics_when_characters_not_right() {
        math("7 + seven");
    }
}
}

```

Finally we add two new methods. One is called `.clear()` and clears the `current_input()`. The other one is called `push_char()` and pushes the input onto `current_input()`. Here is our refactored code:

```
#[derive(Clone)]
struct Calculator {
    results: Vec<String>,
    current_input: String,
    total: i32,
    adds: bool,
}

impl Calculator {
    fn new() -> Self {
        Self {
            results: vec![],
            current_input: String::new(),
            total: 0,
            adds: true,
        }
    }

    fn clear(&mut self) {
        self.current_input.clear();
    }

    fn push_char(&mut self, character: char) {
        self.current_input.push(character);
    }
}

const OKAY_CHARACTERS: &str = "1234567890+- ";

fn math(input: &str) -> i32 {
    if !input.chars().all(|character| OKAY_CHARACTERS.contains(character)) ||
       !input.chars().take(2).any(|character| character.is_numeric()) {
        panic!("Please only input numbers, +-, or spaces");
    }

    let input = input.trim_end_matches(|x| "+- ".contains(x)).chars().filter(|x| *x != '+').collect::<String>();
    let mut calculator = Calculator::new();

    for character in input.chars() {
        match character {
            '+' => {
                if !calculator.current_input.is_empty() {
                    calculator.results.push(calculator.current_input.clone());
                    calculator.clear();
                }
            },
            '-' => {
                if calculator.current_input.contains('-') ||
                   calculator.current_input.is_empty() {
                    calculator.push_char(character)
                } else {
                    calculator.results.push(calculator.current_input.clone());
                    calculator.clear();
                    calculator.push_char(character);
                }
            },
            number => {
                if calculator.current_input.contains('-') {
                    calculator.results.push(calculator.current_input.clone());
                    calculator.clear();
                    calculator.push_char(number);
                } else {
                    calculator.push_char(number);
                }
            },
        }
    }
}
```

```

        }
    }
    calculator.results.push(calculator.current_input);

    for entry in calculator.results {
        if entry.contains('-') {
            if entry.chars().count() % 2 == 1 {
                calculator.adds = match calculator.adds {
                    true => false,
                    false => true
                };
                continue;
            } else {
                continue;
            }
        }
        if calculator.adds {
            calculator.total += entry.parse::<i32>().unwrap();
        } else {
            calculator.total -= entry.parse::<i32>().unwrap();
            calculator.adds = true;
        }
    }
    calculator.total
}

#[cfg(test)]
mod tests {
    use super::*;

    #[test]
    fn one_plus_one_is_two() {
        assert_eq!(math("1 + 1"), 2);
    }
    #[test]
    fn one_minus_two_is_minus_one() {
        assert_eq!(math("1 - 2"), -1);
    }
    #[test]
    fn one_minus_minus_one_is_two() {
        assert_eq!(math("1 - -1"), 2);
    }
    #[test]
    fn nine_plus_nine_minus_nine_minus_nine_is_zero() {
        assert_eq!(math("9+9-9-9"), 0);
    }
    #[test]
    fn eight_minus_nine_plus_nine_is_eight_even_with_characters_on_the_end() {
        assert_eq!(math("8 - 9 +9-----++++"), 8);
    }
    #[test]
    #[should_panic]
    fn panics_when_characters_not_right() {
        math("7 + seven");
    }
}
}

```

This is probably good enough for now. We could write more methods but lines like `calculator.results.push(calculator.current_input.clone());` are already very clear. Refactoring is best when you can still easily read the code after you are done. You don't want to just refactor to make the code short: `clc.clr()` is much worse than `calculator.clear()`, for example.

External crates

An external crate means "someone else's crate".

For this section you *almost* need to install Rust, but we can still use just the Playground. Now we are going to learn how to import crates that other people have written. This is important in Rust because of two reasons:

- It is very easy to import other crates, and
- The Rust standard library is quite small.

That means that it is normal in Rust to bring in an external crate for a lot of basic functions. The idea is that if it is easy to use external crates, then you can choose the best one. Maybe one person will make a crate for one function, and then someone else will make a better one.

In this book we will only look at the most popular crates, the crates that everyone who uses Rust knows.

To begin learning external crates, we will start with the most common one: `rand`.

rand

Did you notice that we didn't use any random numbers yet? That's because random numbers aren't in the standard library. But there are a lot of crates that are "almost standard library" because everybody uses them. In any case, it's very easy to bring in a crate. If you have Rust on your computer, there is a file called `Cargo.toml` that has this information. A `Cargo.toml` file looks like this when you start:

```
[package]
name = "rust_book"
version = "0.1.0"
authors = ["David MacLeod"]
edition = "2018"

# See more keys and their definitions at https://doc.rust-
lang.org/cargo/reference/manifest.html

[dependencies]
```

Now if you want to add the `rand` crate, search for it on `crates.io`, which is where all the crates go. That takes you to <https://crates.io/crates/rand>. And when you click on that, you can see a screen that says `Cargo.toml` `rand = "0.7.3"`. All you do is add that under `[dependencies]` like this:

```
[package]
name = "rust_book"
version = "0.1.0"
authors = ["David MacLeod"]
edition = "2018"

# See more keys and their definitions at https://doc.rust-lang.org/cargo/reference/manifest.html

[dependencies]
rand = "0.7.3"
```

And then Cargo will do the rest for you. Then you can start writing code like [this example code](#) on the `rand` document website. To get to the documents you can click on the `docs` button in [the page on crates.io](#).

So that's enough about Cargo: we are still using just the Playground. Luckily, the Playground already has the top 100 crates installed. So you don't need to write in `Cargo.toml` yet. On the Playground you can imagine that it has a long list like this with 100 crates:

```
[dependencies]
rand = "0.7.3"
some_other_crate = "0.1.0"
another_nice_crate = "1.7"
```

That means that to use `rand`, you can just do this.

```
use rand; // This means the whole crate rand
          // On your computer you can't just write this;
          // you need to write in the Cargo.toml file first

fn main() {
    for _ in 0..5 {
        let random_u16 = rand::random::<u16>();
        print!("{} ", random_u16);
    }
}
```

It will print a different `u16` number every time, like `42266 52873 56528 46927 6867`.

The main functions in `rand` are `random` and `thread_rng` (`rng` means "random number generator"). And actually if you look at `random` it says: "This is simply a shortcut for `thread_rng().gen()`". So it's actually just `thread_rng` that does almost everything.

Here is a simple example of numbers from 1 to 10. To get those numbers, we use `.gen_range()` between 1 and 11.

```
use rand::{thread_rng, Rng}; // Or just use rand::*; if we are lazy

fn main() {
    let mut number_maker = thread_rng();
    for _ in 0..5 {
        print!("{} ", number_maker.gen_range(1, 11));
    }
}
```

This will print something like `7 2 4 8 6`.

With random numbers we can do fun things like make characters for a game. We will use `rand` and some other things we know to make them. In this game our characters have six stats, and you use a

d6 for them. A d6 is a cube that gives 1, 2, 3, 4, 5, or 6 when you throw it. Each character rolls a d6 three times, so each stat is between 3 and 18.

But sometimes it can be unfair if your character has something low like a 3 or 4. If your strength is 3 you can't carry anything, for example. So there is one more method that uses a d6 four times. You roll it four times, and throw away the lowest number. So if you roll 3, 3, 1, 6 then you keep 3, 3, 6 = 12. We will make this method too so the owner of the game can decide.

Here is our simple character creator. We created a `Character` struct for the stats, and even implemented `Display` to print it the way we want.

```

use rand::thread_rng, Rng; // Or just use rand::*; if we are lazy
use std::fmt; // Going to impl Display for our character


struct Character {
    strength: u8,
    dexterity: u8,      // This means "body quickness"
    constitution: u8,   // This means "health"
    intelligence: u8,
    wisdom: u8,
    charisma: u8,      // This means "popularity with people"
}

fn three_die_six() -> u8 { // A "die" is the thing you throw to get the number
    let mut generator = thread_rng(); // Create our random number generator
    let mut stat = 0; // This is the total
    for _ in 0..3 {
        stat += generator.gen_range(1..=6); // Add each time
    }
    stat // Return the total
}

fn four_die_six() -> u8 {
    let mut generator = thread_rng();
    let mut results = vec![]; // First put the numbers in a vec
    for _ in 0..4 {
        results.push(generator.gen_range(1..=6));
    }
    results.sort(); // Now a result like [4, 3, 2, 6] becomes [2, 3, 4, 6]
    results.remove(0); // Now it would be [3, 4, 6]
    results.iter().sum() // Return this result
}

enum Dice {
    Three,
    Four
}

impl Character {
    fn new(dice: Dice) -> Self { // true for three dice, false for four
        match dice {
            Dice::Three => Self {
                strength: three_die_six(),
                dexterity: three_die_six(),
                constitution: three_die_six(),
                intelligence: three_die_six(),
                wisdom: three_die_six(),
                charisma: three_die_six(),
            },
            Dice::Four => Self {
                strength: four_die_six(),
                dexterity: four_die_six(),
                constitution: four_die_six(),
                intelligence: four_die_six(),
                wisdom: four_die_six(),
                charisma: four_die_six(),
            },
        }
    }
    fn display(&self) { // We can do this because we implemented Display below
        println!("{}: {}", self);
        println!();
    }
}

impl fmt::Display for Character { // Just follow the code for in https://doc.rust-lang.org/std/fmt/trait.Display.html and change it a bit
}

```

```

fn fmt(&self, f: &mut fmt::Formatter<'_>) -> fmt::Result {
    write!(f,
        "Your character has these stats:
strength: {}
dexterity: {}
constitution: {}
intelligence: {}
wisdom: {}
charisma: {}",
        self.strength,
        self.dexterity,
        self.constitution,
        self.intelligence,
        self.wisdom,
        self.charisma
    )
}
}

fn main() {
    let weak_billy = Character::new(Dice::Three);
    let strong_billy = Character::new(Dice::Four);
    weak_billy.display();
    strong_billy.display();
}

```

It will print something like this:

```

Your character has these stats:
strength: 9
dexterity: 15
constitution: 15
intelligence: 8
wisdom: 11
charisma: 9

Your character has these stats:
strength: 9
dexterity: 13
constitution: 14
intelligence: 16
wisdom: 16
charisma: 10

```

The character with four dice is usually a bit better at most things.

rayon

`rayon` is a popular crate that lets you speed up your Rust code. It's popular because it creates threads without needing things like `thread::spawn`. In other words, it is popular because it is effective but easy to write. For example:

- `.iter()`, `.iter_mut()`, `into_iter()` in rayon is written like this:
- `.par_iter()`, `.par_iter_mut()`, `par_into_iter()`. So you just add `par_` and your code becomes much faster. (par means "parallel")

Other methods are the same: `.chars()` is `.par_chars()`, and so on.

Here is an example of a simple piece of code that is making the computer do a lot of work:

```
fn main() {
    let mut my_vec = vec![0; 200_000];
    my_vec.iter_mut().enumerate().for_each(|(index, number)| *number+=index+1);
    println!("{}:{}..{}", index, number, &my_vec[5000..5005]);
}
```

It creates a vector with 200,000 items: each one is 0. Then it calls `.enumerate()` to get the index for each number, and changes the 0 to the index number. It's too long to print so we only print items 5000 to 5004. This is still very fast in Rust, but if you want you can make it faster with Rayon. The code is almost the same:

```
use rayon::prelude::*;

fn main() {
    let mut my_vec = vec![0; 200_000];
    my_vec.par_iter_mut().enumerate().for_each(|(index, number)| *number+=index+1); // add par_ to iter_mut
    println!("{}:{}..{}", index, number, &my_vec[5000..5005]);
}
```

And that's it. `rayon` has many other methods to customize what you want to do, but at its most simple it is just "add `_par` to make your program faster".

serde

`serde` is a popular crate that lets you convert to and from formats like JSON, YAML, etc. The most common way to use it is by creating a `struct` with two attributes on top. [It looks like this:](#)

```
#[derive(Serialize, Deserialize, Debug)]
struct Point {
    x: i32,
    y: i32,
}
```

The `Serialize` and `Deserialize` traits are what make the conversion easy. (That's also where the name `serde` comes from) If you have them on your struct, then you can just call a method to turn it into and from JSON or anything else.

regex

The `regex` crate lets you search through text using [regular expressions](#). With that you can get matches for something like `colour`, `color`, `colours` and `colors` through a single search. Regular expressions are a whole other language have to learn that too if you want to use them.

chrono

[chrono](#) is the main crate for people who need more functionality for time. We will look at the standard library now which has functions for time, but if you need more then this is a good crate to use.

A tour of the standard library

Now that you know a lot of Rust, you will be able to understand most things inside the standard library. The code inside it isn't so scary anymore. Let's take a look at some of the parts in it that we haven't learned yet. This tour will go over most parts of the standard library that you don't need to install Rust for. We will revisit a lot of items we already know so we can learn them with greater understanding.

Arrays

In the past (before Rust 1.53), arrays didn't implement `Iterator` and you needed to use methods like `.iter()` on them in for `loops`. (People also used `&` to get a slice in `for` loops). So this didn't work in the past:

```
fn main() {
    let my_cities = ["Beirut", "Tel Aviv", "Nicosia"];

    for city in my_cities {
        println!("{}", city);
    }
}
```

The compiler used to give this message:

```
error[E0277]: `[&str; 3]` is not an iterator
--> src\main.rs:5:17
 |
 |
 |         ^^^^^^^^^^ borrow the array with `&` or call `<T as Iterator>::iter()` on it to
 iterate over it
```

Luckily, that isn't a problem anymore! So all three of these work:

```
fn main() {
    let my_cities = ["Beirut", "Tel Aviv", "Nicosia"];

    for city in my_cities {
        println!("{}", city);
    }
    for city in &my_cities {
        println!("{}", city);
    }
    for city in my_cities.iter() {
        println!("{}", city);
    }
}
```

This prints:

```
Beirut
Tel Aviv
Nicosia
Beirut
Tel Aviv
Nicosia
Beirut
Tel Aviv
Nicosia
```

If you want to get variables from an array, you can put their names inside `[]` to destructure it. This is the same as using a tuple in `match` statements or to get variables from a struct.

```
fn main() {
    let my_cities = ["Beirut", "Tel Aviv", "Nicosia"];
    let [city1, city2, city3] = my_cities;
    println!("{} {}", city1);
}
```

This prints `Beirut`.

char

You can use the `.escape_unicode()` method to get the Unicode number for a `char`:

```
fn main() {
    let korean_word = "청춘예찬";
    for character in korean_word.chars() {
        print!("{} ", character.escape_unicode());
    }
}
```

This prints `\u{ccad} \u{cd98} \u{c608} \u{cc2c}`.

You can get a char from `u8` using the `From` trait, but for a `u32` you use `TryFrom` because it might not work. There are many more numbers in `u32` than characters in Unicode. We can see this with a simple demonstration.

```
use std::convert::TryFrom; // You need to bring TryFrom in to use it
use rand::prelude::*;

fn main() {
    let some_character = char::from(99); // This one is easy - no need for TryFrom
    println!("{} {}", some_character);

    let mut random_generator = rand::thread_rng();
    // This will try 40,000 times to make a char from a u32.
    // The range is 0 (std::u32::MIN) to u32's highest number (std::u32::MAX). If it
    doesn't work, we will give it '-'.
    for _ in 0..40_000 {
        let bigger_character =
            char::try_from(random_generator.gen_range(std::u32::MIN..std::u32::MAX)).unwrap_or('-');
        print!("{} {}", bigger_character)
    }
}
```

Almost every time it will generate a `-`. This is part of the sort of output you will see:

~~燒~~~~太~~~~☒~~

So it's a good thing you need to use `TryFrom`.

Also, as of late August 2020 you can now get a `String` from a `char`. (`String` implements `From<char>`) Just write `String::from()` and put a `char` inside.

Integers

There are a lot of math methods for these types, plus some others. Here are some of the most useful ones.

`.checked_add()`, `.checked_sub()`, `.checked_mul()`, `.checked_div()`. These are good methods if you think you might get a number that won't fit into a type. They return an `Option` so you can safely check that your math works without making the program panic.

```
fn main() {
    let some_number = 200_u8;
    let other_number = 200_u8;

    println!("{} + {} = {}", some_number, other_number, some_number.checked_add(other_number));
    println!("{} + 1 = {}", some_number, some_number.checked_add(1));
}
```

This prints:

None
Some(401)

You'll notice that on the page for integers it says `rhs` a lot. This means "right hand side", which is the right hand side when you do some math. For example, in `5 + 6`, `5` is on the left and `6` is on the right, so it's the `rhs`. This is not a keyword, but you will see it a lot so it's good to know.

While we are on the subject, let's learn how to implement `Add`. After you implement `Add`, you can use `+` on a type that you create. You need to implement `Add` yourself because `add` can mean a lot

of things. Here's the example in the standard library page:

```
use std::ops::Add; // first bring in Add

#[derive(Debug, Copy, Clone, PartialEq)] // PartialEq is probably the most important
part here. You want to be able to compare numbers
struct Point {
    x: i32,
    y: i32,
}

impl Add for Point {
    type Output = Self; // Remember, this is called an "associated type": a "type that
goes together".
                                // In this case it's just another Point

    fn add(self, other: Self) -> Self {
        Self {
            x: self.x + other.x,
            y: self.y + other.y,
        }
    }
}
```

Now let's implement `Add` for our own type. Let's imagine that we want to add two countries together so we can compare their economies. It looks like this:

```

use std::fmt;
use std::ops::Add;

#[derive(Clone)]
struct Country {
    name: String,
    population: u32,
    gdp: u32, // This is the size of the economy
}

impl Country {
    fn new(name: &str, population: u32, gdp: u32) -> Self {
        Self {
            name: name.to_string(),
            population,
            gdp,
        }
    }
}

impl Add for Country {
    type Output = Self;

    fn add(self, other: Self) -> Self {
        Self {
            name: format!("{} and {}", self.name, other.name), // We will add the names
            together,
            population: self.population + other.population, // and the population,
            gdp: self.gdp + other.gdp, // and the GDP
        }
    }
}

impl fmt::Display for Country {
    fn fmt(&self, f: &mut fmt::Formatter<'_>) -> fmt::Result {
        write!(f,
               "In {} are {} people and a GDP of ${}",
               self.name, self.population, self.gdp)
    }
}

fn main() {
    let nauru = Country::new("Nauru", 10_670, 160_000_000);
    let vanuatu = Country::new("Vanuatu", 307_815, 820_000_000);
    let micronesia = Country::new("Micronesia", 104_468, 367_000_000);

    // We could have given Country a &str instead of a String for the name. But we
    // would have to write lifetimes everywhere
    // and that would be too much for a small example. Better to just clone them when
    // we call println!.
    println!("{}", nauru.clone());
    println!("{} + {}", nauru.clone() + vanuatu.clone());
    println!("{} + {} + {}", nauru + vanuatu + micronesia);
}

```

This prints:

```

In Nauru are 10670 people and a GDP of $160000000
In Nauru and Vanuatu are 318485 people and a GDP of $980000000
In Nauru and Vanuatu and Micronesia are 422953 people and a GDP of $1347000000

```

Later on in this code we could change `.fmt()` to display a number that is easier to read.

The three others are called `sub`, `Mul`, and `Div`, and they are basically the same to implement. For `+=`, `-=`, `*=` and `/=`, just add `Assign`: `AddAssign`, `SubAssign`, `MulAssign`, and `DivAssign`. You can see the full list [here](#), because there are many more. `%` for example is called `Rem`, `_` is called `Neg`, and so on.

Floats

`f32` and `f64` have a very large number of methods that you use when doing math. We won't look at those, but here are some methods that you might use. They are: `.floor()`, `.ceil()`, `.round()`, and `.trunc()`. All of these return an `f32` or `f64` that is like an integer, with only `0` after the period. They do this:

- `.floor()` : gives you the next lowest integer.
- `.ceil()` : gives you the next highest integer.
- `.round()` : gives you a higher number if 0.5 or more, or the same number if less than 0.5. This is called rounding because it gives you a "round" number (a number that has a short, simple form).
- `.trunc()` : just cuts off the part after the period. Truncate means "to cut off".

Here is a simple function to print them.

```
fn four_operations(input: f64) {
    println!(
        "For the number {}:
    floor: {}
    ceiling: {}
    rounded: {}
    truncated: {}\\n",
        input,
        input.floor(),
        input.ceil(),
        input.round(),
        input.trunc()
    );
}

fn main() {
    four_operations(9.1);
    four_operations(100.7);
    four_operations(-1.1);
    four_operations(-19.9);
}
```

This prints:

```

For the number 9.1:
floor: 9
ceiling: 10
rounded: 9 // because less than 9.5
truncated: 9

For the number 100.7:
floor: 100
ceiling: 101
rounded: 101 // because more than 100.5
truncated: 100

For the number -1.1:
floor: -2
ceiling: -1
rounded: -1
truncated: -1

For the number -19.9:
floor: -20
ceiling: -19
rounded: -20
truncated: -19

```

`f32` and `f64` have a method called `.max()` and `.min()` that gives you the higher or the lower of two numbers. (For other types you can just use `std::cmp::max` and `std::cmp::min`.) Here is a way to use this with `.fold()` to get the highest or lowest number. You can see again that `.fold()` isn't just for adding numbers.

```

fn main() {
    let my_vec = vec![8.0_f64, 7.6, 9.4, 10.0, 22.0, 77.345, 10.22, 3.2, -7.77, -10.0];
    let maximum = my_vec.iter().fold(f64::MIN, |current_number, next_number|
        current_number.max(*next_number)); // Note: start with the lowest possible number for
        // an f64.
    let minimum = my_vec.iter().fold(f64::MAX, |current_number, next_number|
        current_number.min(*next_number)); // And here start with the highest possible number
        // println!("{} {}", maximum, minimum);
}

```

bool

In Rust you can turn a `bool` into an integer if you want, because it's safe to do that. But you can't do it the other way around. As you can see, `true` turns to 1 and `false` turns to 0.

```

fn main() {
    let true_false = (true, false);
    println!("{} {}", true_false.0 as u8, true_false.1 as i32);
}

```

This prints `1 0`. Or you can use `.into()` if you tell the compiler the type:

```

fn main() {
    let true_false: (i128, u16) = (true.into(), false.into());
    println!("{} {}", true_false.0, true_false.1);
}

```

This prints the same thing.

As of Rust 1.50 (released in February 2021), there is now a method called `then()`, which turns a `bool` into an `Option`. With `then()` you write a closure, and the closure is called if the item is `true`.

Also, whatever is returned from the closure goes inside the `Option`. Here's a small example:

```
fn main() {
    let (tru, fals) = (true.then(|| 8), false.then(|| 8));
    println!("{:?}", {:?})", tru, fals);
}
```

This just prints `Some(8), None`.

And now a bit larger example:

```
fn main() {
    let bool_vec = vec![true, false, true, false, false];

    let option_vec = bool_vec
        .iter()
        .map(|item| {
            item.then(|| { // Put this inside of map so we can pass it on
                println!("Got a {}!", item);
                "It's true, you know" // This goes inside Some if it's true
                // Otherwise it just passes on None
            })
        })
        .collect::<Vec<_>>();

    println!("Now we have: {:?}", option_vec);

    // That printed out the Nones too. Let's filter map them out in a new Vec.
    let filtered_vec = option_vec.into_iter().filter_map(|c| c).collect::<Vec<_>>();

    println!("And without the Nones: {:?}", filtered_vec);
}
```

And here's what this prints:

```
Got a true!
Got a true!
Now we have: [Some("It's true, you know"), None, Some("It's true, you know"), None, None]
And without the Nones: ["It's true, you know", "It's true, you know"]
```

Vec

`Vec` has a lot of methods that we haven't looked at yet. Let's start with `.sort()`. `.sort()` is not surprising at all. It uses a `&mut self` to sort a vector.

```
fn main() {
    let mut my_vec = vec![100, 90, 80, 0, 0, 0, 0, 0];
    my_vec.sort();
    println!("{:?}", my_vec);
}
```

This prints `[0, 0, 0, 0, 0, 80, 90, 100]`. But there is one more interesting way to sort called `.sort_unstable()`, and it is usually faster. It can be faster because it doesn't care about the order of numbers if they are the same number. In regular `.sort()`, you know that the last `0, 0, 0, 0, 0` will be in the same order after `.sort()`. But `.sort_unstable()` might move the last zero to index 0, then the third last zero to index 2, etc.

.dedup() means "de-duplicate". It will remove items that are the same in a vector, but only if they are next to each other. This next code will not just print "sun", "moon":

```
fn main() {
    let mut my_vec = vec!["sun", "sun", "moon", "moon", "sun", "moon", "moon"];
    my_vec.dedup();
    println!("{:?}", my_vec);
}
```

It only gets rid of "sun" next to the other "sun", then "moon" next to one "moon", and again with "moon" next to another "moon". The result is: ["sun", "moon", "sun", "moon"] .

If you want to remove every duplicate, just .sort() first:

```
fn main() {
    let mut my_vec = vec!["sun", "sun", "moon", "moon", "sun", "moon", "moon"];
    my_vec.sort();
    my_vec.dedup();
    println!("{:?}", my_vec);
}
```

Result: ["moon", "sun"] .

String

You will remember that a `String` is kind of like a `Vec`. It is so like a `Vec` that you can do a lot of the same methods. For example, you can start one with `String::with_capacity()` . You want that if you are always going to be pushing a `char` with `.push()` or pushing a `&str` with `.push_str()` . Here's an example of a `String` that has too many allocations.

```
fn main() {
    let mut push_string = String::new();
    let mut capacity_counter = 0; // capacity starts at 0
    for _ in 0..100_000 { // Do this 100,000 times
        if push_string.capacity() != capacity_counter { // First check if capacity is
            different now
            println!("{}", push_string.capacity()); // If it is, print it
            capacity_counter = push_string.capacity(); // then update the counter
        }
        push_string.push_str("I'm getting pushed into the string!"); // and push this
        in every time
    }
}
```

This prints:

```
35
70
140
280
560
1120
2240
4480
8960
17920
35840
71680
143360
286720
573440
1146880
2293760
4587520
```

We had to reallocate (copy everything over) 18 times. But now we know the final capacity. So we'll give it the capacity right away, and we don't need to reallocate: just one `String` capacity is enough.

```
fn main() {
    let mut push_string = String::with_capacity(4587520); // We know the exact number.
Some different big number could work too
    let mut capacity_counter = 0;
    for _ in 0..100_000 {
        if push_string.capacity() != capacity_counter {
            println!("{}", push_string.capacity());
            capacity_counter = push_string.capacity();
        }
        push_string.push_str("I'm getting pushed into the string!");
    }
}
```

And this prints `4587520`. Perfect! We never had to allocate again.

Of course, the actual length is certainly smaller than this. If you try 100,001 times, 101,000 times, etc., it'll still say `4587520`. That's because each time the capacity is two times what it was before. We can shrink it though with `.shrink_to_fit()` (same as for a `Vec`). Our `String` is very large and we don't want to add anything more to it, so we can make it a bit smaller. But only do this if you are sure. Here is why:

```
fn main() {
    let mut push_string = String::with_capacity(4587520);
    let mut capacity_counter = 0;
    for _ in 0..100_000 {
        if push_string.capacity() != capacity_counter {
            println!("{}", push_string.capacity());
            capacity_counter = push_string.capacity();
        }
        push_string.push_str("I'm getting pushed into the string!");
    }
    push_string.shrink_to_fit();
    println!("{}", push_string.capacity());
    push_string.push('a');
    println!("{}", push_string.capacity());
    push_string.shrink_to_fit();
    println!("{}", push_string.capacity());
}
```

This prints:

```
4587520
3500000
7000000
3500001
```

So first we had a size of `4587520`, but we weren't using it all. We used `.shrink_to_fit()` and got the size down to `3500000`. But then we forgot that we needed to push an `a` on. When we did that, Rust saw that we needed more space and gave us double: now it's `7000000`. Whoops! So we did `.shrink_to_fit()` again and now it's back down to `3500001`.

`.pop()` works for a `String`, just like for a `Vec`.

```
fn main() {
    let mut my_string = String::from("daer ot drah tib eltil a si gnirts sihT");
    loop {
        let pop_result = my_string.pop();
        match pop_result {
            Some(character) => print!("{}" , character),
            None => break,
        }
    }
}
```

This prints `This string is a little bit hard to read.` because it starts from the last character.

`.retain()` is a method that uses a closure, which is rare for `String`. It's just like `.filter()` for an iterator.

```
fn main() {
    let mut my_string = String::from("Age: 20 Height: 194 Weight: 80");
    my_string.retain(|character| character.is_alphabetic() || character == ' ');
    // Keep if a letter or a space
    dbg!(my_string); // Let's use dbg!() for fun this time instead of println!
}
```

This prints:

```
[src\main.rs:4] my_string = "Age Height Weight "
```

OsString and CString

`std::ffi` is the part of `std` that helps you use Rust with other languages or operating systems. It has types like `OsString` and `CString`, which are like `String` for the operating system or `String` for the language C. They each have their own `&str` type too: `OsStr` and `CStr`. `ffi` means "foreign function interface".

You can use `OsString` when you have to work with an operating system that doesn't have Unicode. All Rust strings are unicode, but not every operating system has it. Here is the simple English explanation from the standard library on why we have `OsString`:

- A string on Unix (Linux, etc.) might be lots of bytes together that don't have zeros. And sometimes you read them as Unicode UTF-8.
- A string on Windows might be made of random 16-bit values that don't have zeros. And sometimes you read them as Unicode UTF-16.
- In Rust, strings are always valid UTF-8, which may contain zeros.

So an `OsString` is made to be read by all of them.

You can do all the regular things with an `OsString` like `OsString::from("Write something here")`. It also has an interesting method called `.into_string()` that tries to make it into a regular `String`. It returns a `Result`, but the `Err` part is just the original `OsString`:

```
// 🛡
pub fn into_string(self) -> Result<String, OsString>
```

So if it doesn't work then you just get it back. You can't call `.unwrap()` because it will panic, but you can use `match` to get the `OsString` back. Let's test it out by calling methods that don't exist.

```
use std::ffi::OsString;

fn main() {
    // ⚠
    let os_string = OsString::from("This string works for your OS too.");
    match os_string.into_string() {
        Ok(valid) => valid.thth(),           // Compiler: "What's .thth()??"
        Err(not_valid) => not_valid.occg(),   // Compiler: "What's .occg()??"
    }
}
```

Then the compiler tells us exactly what we want to know:

```
error[E0599]: no method named `thth` found for struct `std::string::String` in the
current scope
--> src/main.rs:6:28
 |
6 |         Ok(valid) => valid.thth(),
|                         ^^^^^ method not found in `std::string::String`

error[E0599]: no method named `occg` found for struct `std::ffi::OsString` in the
current scope
--> src/main.rs:7:37
 |
7 |         Err(not_valid) => not_valid.occg(),
|                         ^^^^^ method not found in `std::ffi::OsString`
```

We can see that the type of `valid` is `String` and the type of `not_valid` is `OsString`.

mem

`std::mem` has some pretty interesting methods. We saw some of them already, such as `.size_of()`, `.size_of_val()` and `.drop()`:

```
use std::mem;

fn main() {
    println!("{}", mem::size_of::<i32>());
    let my_array = [8; 50];
    println!("{}", mem::size_of_val(&my_array));
    let mut some_string = String::from("You can drop a String because it's on the
heap");
    mem::drop(some_string);
    // some_string.clear(); If we did this it would panic
}
```

This prints:

```
4
200
```

Here are some other methods in `mem`:

`swap()` : with this you can change the values between two variables. You use a mutable reference for each to do it. This is helpful when you have two things you want to switch and Rust doesn't let you because of borrowing rules. Or just when you want to quickly switch two things.

Here's one example:

```
use std::mem, std::fmt;

struct Ring { // Create a ring from Lord of the Rings
    owner: String,
    former_owner: String,
    seeker: String, // seeker means "person looking for it"
}

impl Ring {
    fn new(owner: &str, former_owner: &str, seeker: &str) -> Self {
        Self {
            owner: owner.to_string(),
            former_owner: former_owner.to_string(),
            seeker: seeker.to_string(),
        }
    }
}

impl fmt::Display for Ring { // Display to show who has it and who wants it
    fn fmt(&self, f: &mut fmt::Formatter<'_>) -> fmt::Result {
        write!(f, "{} has the ring, {} used to have it, and {} wants it",
            self.owner, self.former_owner, self.seeker)
    }
}

fn main() {
    let mut one_ring = Ring::new("Frodo", "Gollum", "Sauron");
    println!("{}", one_ring);
    mem::swap(&mut one_ring.owner, &mut one_ring.former_owner); // Gollum got the ring back for a second
    println!("{}", one_ring);
}
```

This will print:

```
Frodo has the ring, Gollum used to have it, and Sauron wants it
Gollum has the ring, Frodo used to have it, and Sauron wants it
```

`replace()` : this is like swap, and actually uses swap inside it, as you can see:

```
pub fn replace<T>(dest: &mut T, mut src: T) -> T {
    swap(dest, &mut src);
    src
}
```

So it just does a swap and then returns the other item. With this you replace the value with something else you put in. And since it returns the old value, so you should use it with `let`. Here's a quick example.

```

use std::mem;

struct City {
    name: String,
}

impl City {
    fn change_name(&mut self, name: &str) {
        let old_name = mem::replace(&mut self.name, name.to_string());
        println!(
            "The city once called {} is now called {}.",
            old_name, self.name
        );
    }
}

fn main() {
    let mut capital_city = City {
        name: "Constantinople".to_string(),
    };
    capital_city.change_name("Istanbul");
}

```

This prints The city once called Constantinople is now called Istanbul..

One function called `.take()` is like `.replace()` but it leaves the default value in the item. You will remember that default values are usually things like 0, "", and so on. Here is the signature:

```
// 🛡
pub fn take<T>(dest: &mut T) -> T
where
    T: Default,
```

So you can do something like this:

```

use std::mem;

fn main() {
    let mut number_vec = vec![8, 7, 0, 2, 49, 9999];
    let mut new_vec = vec![];

    number_vec.iter_mut().for_each(|number| {
        let taker = mem::take(number);
        new_vec.push(taker);
    });

    println!("{}:{}\n{}:{}", number_vec, new_vec);
}

```

And as you can see, it replaced all the numbers with 0: no index was deleted.

```
[0, 0, 0, 0, 0, 0]
[8, 7, 0, 2, 49, 9999]
```

Of course, for your own type you can implement `Default` to whatever you want. Let's look at an example where we have a `Bank` and a `Robber`. Every time he robs the `Bank`, he gets the money at the desk. But the desk can take money from the back any time, so it always has 50. We will make our own type for this so it will always have 50. Here is how it works:

```

use std::mem;
use std::ops::{Deref, DerefMut}; // We will use this to get the power of u32

struct Bank {
    money_inside: u32,
    money_at_desk: DeskMoney, // This is our "smart pointer" type. It has its own
default, but it will use u32
}

struct DeskMoney(u32);

impl Default for DeskMoney {
    fn default() -> Self {
        Self(50) // default is always 50, not 0
    }
}

impl Deref for DeskMoney { // With this we can access the u32 using *
type Target = u32;

fn deref(&self) -> &Self::Target {
    &self.0
}
}

impl DerefMut for DeskMoney { // And with this we can add, subtract, etc.
fn deref_mut(&mut self) -> &mut Self::Target {
    &mut self.0
}
}

impl Bank {
    fn check_money(&self) {
        println!(
            "There is ${} in the back and ${} at the desk.\n",
            self.money_inside, *self.money_at_desk // Use * so we can just print the
u32
        );
    }
}

struct Robber {
    money_in_pocket: u32,
}

impl Robber {
    fn check_money(&self) {
        println!("The robber has ${} right now.\n", self.money_in_pocket);
    }

    fn rob_bank(&mut self, bank: &mut Bank) {
        let new_money = mem::take(&mut bank.money_at_desk); // Here it takes the money,
and leaves 50 because that is the default
        self.money_in_pocket += *new_money; // Use * because we can only add u32.
        // DeskMoney can't add
        bank.money_inside -= *new_money; // Same here
        println!("She robbed the bank. She now has ${}!\n", self.money_in_pocket);
    }
}

fn main() {
    let mut bank_of_klezkavania = Bank { // Set up our bank
        money_inside: 5000,
        money_at_desk: DeskMoney(50),
    };
    bank_of_klezkavania.check_money();
}

```

```

let mut robber = Robber { // Set up our robber
    money_in_pocket: 50,
};

robber.check_money();

robber.rob_bank(&mut bank_of_klezkavania); // Rob, then check money
robber.check_money();
bank_of_klezkavania.check_money();

robber.rob_bank(&mut bank_of_klezkavania); // Do it again
robber.check_money();
bank_of_klezkavania.check_money();

}

```

This will print:

```

There is $5000 in the back and $50 at the desk.

The robber has $50 right now.

She robbed the bank. She now has $100!

The robber has $100 right now.

There is $4950 in the back and $50 at the desk.

She robbed the bank. She now has $150!

The robber has $150 right now.

There is $4900 in the back and $50 at the desk.

```

You can see that there is always \$50 at the desk.

prelude

The standard library has a prelude too, which is why you don't have to write things like `use std::vec::Vec` to create a `Vec`. You can see all the items [here](#), and will already know almost all of them:

- `std::marker::{Copy, Send, Sized, Sync, Unpin}`. You haven't seen `Unpin` before, because it is used for almost every type (like `Sized`, which is also very common). To "pin" means to not let something move. In this case a `Pin` means that it can't move in memory, but most items have `Unpin` so you can. That's why functions like `std::mem::replace` work, because they aren't pinned.
- `std::ops::{Drop, Fn, FnMut, FnOnce}`.
- `std::mem::drop`
- `std::boxed::Box`.
- `std::borrow::ToOwned`. You saw this before a bit with `Cow`, which can take borrowed content and make it owned. It uses `.to_owned()` to do this. You can also use `.to_owned()` on a `&str` to get a `String`, and the same for other borrowed values.
- `std::clone::Clone`
- `std::cmp::{PartialEq, PartialOrd, Eq, Ord}`.
- `std::convert::{AsRef, AsMut, Into, From}`.
- `std::default::Default`.

- `std::iter::Iterator, Extend, IntoIterator, DoubleEndedIterator, ExactSizeIterator`. We used `.rev()` for an iterator before: this actually makes a `DoubleEndedIterator`. An `ExactSizeIterator` is just something like `0..10`: it already knows that it has a `.len()` of 10. Other iterators don't know their length for sure.
- `std::option::Option::Some, None`.
- `std::result::Result::Ok, Err`.
- `std::string::String, ToString`.
- `std::vec::Vec`.

What if you don't want the prelude for some reason? Just add the attribute `#![no_implicit_prelude]`. Let's give it a try and watch the compiler complain:

```
// ⚠
#![no_implicit_prelude]
fn main() {
    let my_vec = vec![8, 9, 10];
    let my_string = String::from("This won't work");
    println!("{:?}", {}, my_vec, my_string);
}
```

Now Rust has no idea what you are trying to do:

```
error: cannot find macro `println` in this scope
--> src/main.rs:5:5
|     println!("{:?}", {}, my_vec, my_string);
|     ^^^^^^

error: cannot find macro `vec` in this scope
--> src/main.rs:3:18
|
3 |     let my_vec = vec![8, 9, 10];
|     ^^^

error[E0433]: failed to resolve: use of undeclared type or module `String`
--> src/main.rs:4:21
|
4 |     let my_string = String::from("This won't work");
|             ^^^^^^ use of undeclared type or module `String`

error: aborting due to 3 previous errors
```

So for this simple code you need to tell Rust to use the `extern` (external) crate called `std`, and then the items you want. Here is everything we have to do just to create a `Vec` and a `String` and print it:

```
#![no_implicit_prelude]

extern crate std; // Now you have to tell Rust that you want to use a crate called std
use std::vec; // We need the vec macro
use std::string::String; // and string
use std::convert::From; // and this to convert from a &str to the String
use std::println; // and this to print

fn main() {
    let my_vec = vec![8, 9, 10];
    let my_string = String::from("This won't work");
    println!("{:?}", {}, my_vec, my_string);
}
```

And now it finally works, printing `[8, 9, 10], This won't work`. So you can see why Rust uses the prelude. But if you want, you don't need to use it. And you can even use `#![no_std]` (we saw this

once) for when you can't even use something like stack memory. But most of the time you don't have to think about not using the prelude or `std` at all.

So why didn't we see the `extern` keyword before? It's because you don't need it that much anymore. Before, when bringing in an external crate you had to use it. So to use `rand` in the past, you had to write:

```
extern crate rand;
```

and then `use` statements for the mods, traits, etc. that you wanted to use. But the Rust compiler now doesn't need this help anymore - you can just use `use` and it knows where to find it. So you almost never need `extern crate` anymore, but in other people's Rust code you might still see it on the top.

time

`std::time` is where you can get functions for time. (If you want even more functions, a crate like `chrono` can work.) The simplest function is just getting the system time with `Instant::now()`.

```
use std::time::Instant;

fn main() {
    let time = Instant::now();
    println!("{}:{}", time);
}
```

If you print it, you'll get something like this: `Instant { tv_sec: 2738771, tv_nsec: 685628140 }`. That's talking about seconds and nanoseconds, but it's not very useful. If you look at 2738771 seconds for example (written in August), it is 31.70 days. That doesn't have anything to do with the month or the day of the year. But the page on `Instant` tells us that it isn't supposed to be useful on its own. It says that it is "opaque and useful only with Duration." Opaque means "you can't figure it out", and duration means "how much time passed". So it's only useful when doing things like comparing times.

If you look at the traits on the left, one of them is `Sub<Instant>`. That means we can use `-` to subtract one from another. And when we click on [src] to see what it does, it says:

```
impl Sub<Instant> for Instant {
    type Output = Duration;

    fn sub(self, other: Instant) -> Duration {
        self.duration_since(other)
    }
}
```

So it takes an `Instant` and uses `.duration_since()` to give a `Duration`. Let's try printing that. We'll make two `Instant::now()`s right next to each other, then we'll make the program busy for a while. Then we'll make one more `Instant::now()`. Finally, we'll see how long it took.

```
use std::time::Instant;

fn main() {
    let time1 = Instant::now();
    let time2 = Instant::now(); // These two are right next to each other

    let mut new_string = String::new();
    loop {
        new_string.push('გ'); // Make Rust push this Georgian letter onto the String
        if new_string.len() > 100_000 { // until it is 100,000 bytes long
            break;
        }
    }
    let time3 = Instant::now();
    println!("{:?}", time2 - time1);
    println!("{:?}", time3 - time1);
}
```

This will print something like this:

```
1.025µs
683.378µs
```

So that's just over 1 microsecond vs. 683 microseconds. We can see that Rust did take some time to do it.

There is one fun thing we can do with just a single `Instant` though. We can turn it into a `String` with `format!("{}")`, `Instant::now()`. It looks like this:

```
use std::time::Instant;

fn main() {
    let time1 = format!("{}", Instant::now());
    println!("{}", time1);
}
```

That prints something like `Instant { tv_sec: 2740773, tv_nsec: 632821036 }`. That's not useful, but if we use `.iter()` and `.rev()` and `.skip(2)`, we can skip the `}` and at the end. We can use it to make a random number generator.

```

use std::time::Instant;

fn bad_random_number(digits: usize) {
    if digits > 9 {
        panic!("Random number can only be up to 9 digits");
    }
    let now = Instant::now();
    let output = format!("{}:{}:", now);

    output
        .chars()
        .rev()
        .skip(2)
        .take(digits)
        .for_each(|character| print!("{}:", character));
    println!();
}

fn main() {
    bad_random_number(1);
    bad_random_number(1);
    bad_random_number(3);
    bad_random_number(3);
}

```

This will print something like:

```

6
4
967
180

```

The function is called `bad_random_number` because it's not a very good random number generator. Rust has better crates that make random numbers with less code than `rand` like `fastrand`. But it's a good example of how you can use your imagination to do something with `Instant`.

When you have a thread, you can use `std::thread::sleep` to make it stop for a while. When you do this, you have to give it a duration. You don't have to make more than one thread to do this because every program is on at least one thread. `sleep` needs a `Duration` though, so it can know how long to sleep. You can pick the unit like this: `Duration::from_millis()`, `Duration::from_secs`, etc. Here's one example:

```

use std::time::Duration;
use std::thread::sleep;

fn main() {
    let three_seconds = Duration::from_secs(3);
    println!("I must sleep now.");
    sleep(three_seconds);
    println!("Did I miss anything?");
}

```

This will just print

```

I must sleep now.
Did I miss anything?

```

but the thread will do nothing for three seconds. You usually use `.sleep()` when you have many threads that need to try something a lot, like connecting. You don't want the thread to use your processor to try 100,000 times in a second when you just want it to check sometimes. So then you can set a `Duration`, and it will try to do its task every time it wakes up.

Other macros

Let's take a look at some other macros.

```
unreachable!()
```

This macro is kind of like `todo!()` except it's for code that you will never do. Maybe you have a `match` in an enum that you know will never choose one of the arms, so the code can never be reached. If that's so, you can write `unreachable!()` so the compiler knows that it can ignore that part.

For example, let's say you have a program that writes something when you choose a place to live in. They are in Ukraine, and all of them are nice except Chernobyl. Your program doesn't let anyone choose Chernobyl, because it's not a good place to live right now. But the enum was made a long time ago in someone else's code, and you can't change it. So in the `match` arm you can use the macro here. It looks like this:

```
enum UkrainePlaces {
    Kiev,
    Kharkiv,
    Chernobyl, // Pretend we can't change the enum - Chernobyl will always be here
    Odesa,
    Dnipro,
}

fn choose_city(place: &UkrainePlaces) {
    use UkrainePlaces::*;

    match place {
        Kiev => println!("You will live in Kiev"),
        Kharkiv => println!("You will live in Kharkiv"),
        Chernobyl => unreachable!(),
        Odesa => println!("You will live in Odesa"),
        Dnipro => println!("You will live in Dnipro"),
    }
}

fn main() {
    let user_input = UkrainePlaces::Kiev; // Pretend the user input is made from some
    // other function. The user can't choose Chernobyl, no matter what
    choose_city(&user_input);
}
```

This will print `You will live in Kiev`.

`unreachable!()` is also nice for you to read because it reminds you that some part of the code is unreachable. You have to be sure that the code is actually unreachable though. If the compiler ever calls `unreachable!()`, the program will panic.

Also, if you ever have unreachable code that the compiler knows about, it will tell you. Here is a quick example:

```
fn main() {
    let true_or_false = true;

    match true_or_false {
        true => println!("It's true"),
        false => println!("It's false"),
        true => println!("It's true"), // Whoops, we wrote true again
    }
}
```

It will say:

```
warning: unreachable pattern
--> src/main.rs:7:9
7 |         true => println!("It's true"),
   |         ^^^^
```

But `unreachable!()` is for when the compiler can't know, like our other example.

```
column!, line!, file!, module_path!
```

These four macros are kind of like `dbg!()` because you just put them in to give you debug information. But they don't take any variables - you just use them with the brackets and nothing else. They are easy to learn together:

- `column!()` gives you the column where you wrote it,
- `file!()` gives you the name of the file where you wrote it,
- `line!()` gives you the line where you wrote it, and
- `module_path!()` gives you the module where it is.

The next code shows all three in a simple example. We will pretend there is a lot more code (mods inside mods), because that is why we would want to use these macros. You can imagine a big Rust program over many mods and files.

```

pub mod something {
    pub mod third_mod {
        pub fn print_a_country(input: &mut Vec<&str>) {
            println!(
                "The last country is {} inside the module {}",
                input.pop().unwrap(),
                module_path!()
            );
        }
    }
}

fn main() {
    use something::third_mod::*;

    let mut country_vec = vec!["Portugal", "Czechia", "Finland"];

    // do some stuff
    println!("Hello from file {}", file!());

    // do some stuff
    println!(
        "On line {} we got the country {}",
        line!(),
        country_vec.pop().unwrap()
    );

    // do some more stuff

    println!(
        "The next country is {} on line {} and column {}.",
        country_vec.pop().unwrap(),
        line!(),
        column!(),
    );

    // lots more code

    print_a_country(&mut country_vec);
}

```

It prints this:

```

Hello from file src/main.rs
On line 23 we got the country Finland
The next country is Czechia on line 32 and column 9.
The last country is Portugal inside the module rust_book::something::third_mod

```

`cfg!`

We know that you can use attributes like `#[cfg(test)]` and `#[cfg(windows)]` to tell the compiler what to do in certain cases. When you have `test`, it will run the code when you run Rust under testing mode (if it's on your computer you type `cargo test`). And when you use `windows`, it will run the code if the user is using Windows. But maybe you just want to change one tiny bit of code depending on the operating system, etc. That's when this macro is useful. It returns a `bool`.

```
fn main() {
    let helpful_message = if cfg!(target_os = "windows") { "backslash" } else { "slash" };

    println!(
        "...then in your hard drive, type the directory name followed by a {}. Then
you...", helpful_message
);
}
```

This will print differently, depending on your system. The Rust Playground runs on Linux, so it will print:

```
...then in your hard drive, type the directory name followed by a slash. Then you...
```

`cfg!()` works for any kind of configuration. Here is an example of a function that runs differently when you use it inside a test.

```
#[cfg(test)] // cfg! will know to look for the word test
mod testing {
    use super::*;

    fn check_if_five() {
        assert_eq!(bring_number(true), 5); // This bring_number() function should
return 5
    }
}

fn bring_number(should_run: bool) -> u32 { // This function takes a bool as to whether
it should run
    if cfg!(test) && should_run { // if it should run and has the configuration test,
return 5
        5
    } else if should_run { // if it's not a test but it should run, print something.
When you run a test it ignores println! statements
        println!("Returning 5. This is not a test");
        5
    } else {
        println!("This shouldn't run, returning 0."); // otherwise return 0
        0
    }
}

fn main() {
    bring_number(true);
    bring_number(false);
}
```

Now it will run differently depending on the configuration. If you just run the program, it will give you this:

```
Returning 5. This is not a test
This shouldn't run, returning 0.
```

But if you run it in test mode (`cargo test` for Rust on your computer), it will actually run the test. And because the test always returns 5 in this case, it will pass.

```
running 1 test
test testing::check_if_five ... ok

test result: ok. 1 passed; 0 failed; 0 ignored; 0 measured; 0 filtered out
```

Writing macros

Writing macros can be very complicated. You almost never need to write one, but sometimes you might want to because they are very convenient. Writing macros is interesting because they are almost a different language. To write one, you actually use another macro called `macro_rules!`. Then you add your macro name and open a `{}` block. Inside is sort of like a `match` statement.

Here's one that only takes `()`, then just returns 6:

```
macro_rules! give_six {
    () => {
        6
    };
}

fn main() {
    let six = give_six!();
    println!("{}", six);
}
```

But it's not the same as a `match` statement, because a macro actually doesn't compile anything. It just takes an input and gives an output. Then the compiler checks to see if it makes sense. That's why a macro is like "code that writes code". You will remember that a true `match` statement needs to give the same type, so this won't work:

```
fn main() {
// 
    let my_number = 10;
    match my_number {
        10 => println!("You got a ten"),
        _ => 10,
    }
}
```

It will complain that you want to return `()` in one case, and `i32` in the other.

```
error[E0308]: `match` arms have incompatible types
--> src\main.rs:5:14
|
3 | /     match my_number {
4 | |         10 => println!("You got a ten"),
4 | |             ----- this is found to be of type `()`
5 | |         _ => 10,
5 | |             ^^ expected `()`, found integer
6 | |     }
| |-----`match` arms have incompatible types
```

But a macro doesn't care, because it's just giving an output. It's not a compiler - it's code before code. So you can do this:

```
macro_rules! six_or_print {
    (6) => {
        6
    };
    () => {
        println!("You didn't give me 6.");
    };
}

fn main() {
    let my_number = six_or_print!(6);
    six_or_print!();
}
```

This is just fine, and prints `You didn't give me 6.`. You can also see that it's not a match arm because there's no `_` case. We can only give it `(6)`, or `()`. Anything else will make an error. And the `6` we give it isn't even an `i32`, it's just an input 6. You can actually set anything as the input for a macro, because it's just looking at input to see what it gets. For example:

```
macro_rules! might_print {
    (THis is strange input 하하하하하하 but it still works) => {
        println!("You guessed the secret message!")
    };
    () => {
        println!("You didn't guess it");
    };
}

fn main() {
    might_print!(THis is strange input 하하하하하하 but it still works);
    might_print!();
}
```

So this strange macro only responds to two things: `()` and `(THis is strange input 하하하하하하 but it still works)`. Nothing else. It prints:

```
You guessed the secret message!
You didn't guess it
```

So a macro isn't exactly Rust syntax. But a macro can also understand different types of input that you give it. Take this example:

```
macro_rules! might_print {
    ($input:expr) => {
        println!("You gave me: {}", $input);
    }
}

fn main() {
    might_print!(6);
}
```

This will print `You gave me: 6`. The `$input:expr` part is important. It means "for an expression, give it the variable name `$input`". In macros, variables start with a `$`. In this macro, if you give it one expression, it will print it. Let's try it out some more:

```

macro_rules! might_print {
    ($input:expr) => {
        println!("You gave me: {:?}", $input); // Now we'll use {:?} because we will
        give it different kinds of expressions
    }
}

fn main() {
    might_print!(()); // give it a ()
    might_print!(6); // give it a 6
    might_print!(vec![8, 9, 7, 10]); // give it a vec
}

```

This will print:

```

You gave me: ()
You gave me: 6
You gave me: [8, 9, 7, 10]

```

Also note that we wrote `{:?}",` but it won't check to see if `&input` implements `Debug`. It'll just write the code and try to make it compile, and if it doesn't then it gives an error.

So what can a macro see besides `expr`? They are: `block` | `expr` | `ident` | `item` | `lifetime` | `literal` | `meta` | `pat` | `path` | `stmt` | `tt` | `ty` | `vis`. This is the complicated part. You can see what each of them means [here](#), where it says:

```

item: an Item
block: a BlockExpression
stmt: a Statement without the trailing semicolon (except for item statements that
require semicolons)
pat: a Pattern
expr: an Expression
ty: a Type
ident: an IDENTIFIER_OR_KEYWORD
path: a TypePath style path
tt: a TokenTree (a single token or tokens in matching delimiters (), [], or {})
meta: an Attr, the contents of an attribute
lifetime: a LIFETIME_TOKEN
vis: a possibly empty Visibility qualifier
literal: matches -?LiteralExpression

```

There is another good site called `cheats.rs` that explains them [here](#) and gives examples for each.

However, for most macros you will use `expr`, `ident`, and `tt`. `ident` means identifier and is for variable or function names. `tt` means token tree and sort of means any type of input. Let's try a simple macro with both.

```

macro_rules! check {
    ($input1:ident, $input2:expr) => {
        println!(
            "Is {:#?} equal to {:#?} {:#?}",
            $input1,
            $input2,
            $input1 == $input2
        );
    };
}

fn main() {
    let x = 6;
    let my_vec = vec![7, 8, 9];
    check!(x, 6);
    check!(my_vec, vec![7, 8, 9]);
    check!(x, 10);
}

```

So this will take one `ident` (like a variable name) and an expression and see if they are the same. It prints:

```

Is 6 equal to 6? true
Is [7, 8, 9] equal to [7, 8, 9]? true
Is 6 equal to 10? false

```

And here's one macro that takes a `tt` and prints it. It uses a macro called `stringify!` to make a string first.

```

macro_rules! print_anything {
    ($input:tt) => {
        let output = stringify!($input);
        println!("{}", output);
    };
}

fn main() {
    print_anything!(ththdoetd);
    print_anything!(87575oehq75onth);
}

```

This prints:

```

ththdoetd
87575oehq75onth

```

But it won't print if we give it something with spaces, commas, etc. It will think that we are giving it more than one item or extra information, so it will be confused.

This is where macros start to get difficult.

To give a macro more than one item at a time, we have to use a different syntax. Instead of `$input`, it will be `$($input1),*`. This means zero or more (this is what `*` means), separated by a comma. If you want one or more, use `+` instead of `*`.

Now our macro looks like this:

```
macro_rules! print_anything {
    ($($input1:tt),*) => {
        let output = stringify!($($input1),*);
        println!("{}", output);
    };
}

fn main() {
    print_anything!(ththdoetd, rcofe);
    print_anything!();
    print_anything!(87575oehq75onth, ntohe, 987987o, 097);
}
```

So it takes any token tree separated by commas, and uses `stringify!` to make it into a string. Then it prints it. It prints:

```
ththdoetd, rcofe
87575oehq75onth, ntohe, 987987o, 097
```

If we used `+` instead of `*` it would give an error, because one time we gave it no input. So `*` is a bit safer option.

So now we can start to see the power of macros. In this next example we can actually make our own functions:

```
macro_rules! make_a_function {
    ($name:ident, $($input:tt),*) => { // First you give it one name for the function,
    then it checks everything else
        fn $name() {
            let output = stringify!($($input),*); // It makes everything else into a
        string
            println!("{}", output);
        }
    };
}

fn main() {
    make_a_function!(print_it, 5, 5, 6, I); // We want a function called print_it()
that prints everything else we give it
    print_it();
    make_a_function!(say_its_nice, this, is, really, nice); // Same here but we change
the function name
    say_its_nice();
}
```

This prints:

```
5, 5, 6, I
this, is, really, nice
```

So now we can start to understand other macros. You can see that some of the macros we've already been using are pretty simple. Here's the one for `write!` that we used to write to files:

```
macro_rules! write {
    ($dst:expr, $($arg:tt)*) => ($dst.write_fmt($crate::format_args!($($arg)*)));
}
```

So to use it, you enter this:

- an expression (`expr`) that gets the variable name `$dst`.
- everything after that. If it wrote `$arg:tt` then it would only take one, but because it wrote `$($arg:tt)*` it takes zero, one, or any number.

Then it takes `$dst` and uses a method called `write_fmt` on it. Inside that, it uses another macro called `format_args!` that takes all `$($arg)*`, or all the arguments we put in.

Now let's take a look at the `todo!` macro. That's the one you use when you want the program to compile but haven't written your code yet. It looks like this:

```
macro_rules! todo {
    () => (panic!("not yet implemented"));
    ($($arg:tt)+) => (panic!("not yet implemented: {}", $crate::format_args!(
        $($arg+))));
}
```

This one has two options: you can enter `()`, or a number of token trees (`tt`).

- If you enter `()`, it just uses `panic!` with a message. So you could actually just write `panic!("not yet implemented")` instead of `todo!` and it would be the same.
- If you enter some arguments, it will try to print them. You can see the same `format_args!` macro inside, which works like `println!`.

So if you write this, it will work too:

```
fn not_done() {
    let time = 8;
    let reason = "lack of time";
    todo!("Not done yet because of {}. Check back in {} hours", reason, time);
}

fn main() {
    not_done();
}
```

This will print:

```
thread 'main' panicked at 'not yet implemented: Not done yet because of lack of time.
Check back in 8 hours', src/main.rs:4:5
```

Inside a macro you can even call the same macro. Here's one:

```

macro_rules! my_macro {
    () => {
        println!("Let's print this.");
    };
    ($input:expr) => {
        my_macro!();
    };
    ($($input:expr),*) => {
        my_macro!();
    }
}

fn main() {
    my_macro!(vec![8, 9, 0]);
    my_macro!(toheteh);
    my_macro!(8, 7, 0, 10);
    my_macro!();
}

```

This one takes either `()`, or one expression, or many expressions. But it ignores all the expressions no matter what you put in, and just calls `my_macro!` on `()`. So the output is just `Let's print this`, four times.

You can see the same thing in the `dbg!` macro, which also calls itself.

```

macro_rules! dbg {
    () => {
        $crate::eprintln!("[{}:{}]", $crate::file!(), $crate::line!()); // $crate means
the crate that it's in.
    };
    ($val:expr) => {
        // Use of `match` here is intentional because it affects the lifetimes
        // of temporaries - https://stackoverflow.com/a/48732525/1063961
        match $val {
            tmp => {
                $crate::eprintln!("[{}:{}]: {} = {:?}", $crate::file!(), $crate::line!(),
$crate::stringify!($val), &tmp);
            }
        }
    };
    // Trailing comma with single argument is ignored
    ($val:expr,) => { $crate::dbg!($val) };
    ($($val:expr),+ $(,)? ) => {
        ($($crate::dbg!($val)),+,)
    };
}

```

(`eprintln!` is the same as `println!` except it prints to `io::stderr` instead of `io::stdout`. There is also `eprint!` that doesn't add a new line)

So we can try this out ourself.

```

fn main() {
    dbg!();
}

```

That matches the first arm, so it will print the file name and line name with the `file!` and `line!` macros. It prints `[src/main.rs:2]`.

Let's try it with this:

```
fn main() {
    dbg!(vec![8, 9, 10]);
}
```

This will match the next arm, because it's one expression. It will then call the input `tmp` and use this code: `$crate::eprintln!("[{}:{}]\n{} = {:?}", $crate::file!(), $crate::line!(), $crate::stringify!($val), &tmp);`. So it will print with `file!` and `line!`, then `$val` made into a `String`, and pretty print with `{:#?}` for `tmp`. So for our input it will write this:

```
[src/main.rs:2] vec![8, 9, 10] = [
    8,
    9,
    10,
]
```

And for the rest of it it just calls `dbg!` on itself even if you put in an extra comma.

As you can see, macros are very complicated! Usually you only want a macro to automatically do something that a simple function can't do very well. The best way to learn about macros is to look at other macro examples. Not many people can quickly write macros without problems. So don't think that you need to know everything about macros to know how to write in Rust. But if you read other macros, and change them a little, you can easily borrow their power. Then you might start to get comfortable with writing your own.

Part 2 - Rust on your computer

You saw that we can learn almost anything in Rust just using the Playground. But if you learned everything so far, you will probably want Rust on your computer now. There are always things that you can't do with the Playground like using files or code in more than just one file. Some other things you need Rust on your computer for are input and flags. But most important is that with Rust on your computer you can use crates. We already learned about crates, but in the Playground you could only use the most popular ones. But with Rust on your computer you can use any crate in your program.

cargo

`rustc` means Rust compiler, and it's what does the actual compiling. A rust file ends with an `.rs`. But most people don't write something like `rustc main.rs` to compile. They use something called `cargo`, which is the main package manager for Rust.

One note about the name: it's called `cargo` because when you put crates together, you get cargo. A crate is a wooden box that you see on ships or trucks, but you remember that every Rust project is also called a crate. Then when you put them together you get the whole cargo.

You can see this when you use cargo to run a project. Let's try something simple with `rand`: we'll just randomly choose between eight letters.

```
use rand::seq::SliceRandom; // Use this for .choose over slices

fn main() {

    let my_letters = vec!['a', 'b', 'c', 'd', 'e', 'f', 'g', 'h'];

    let mut rng = rand::thread_rng();
    for _ in 0..6 {
        print!("{} ", my_letters.choose(&mut rng).unwrap());
    }
}
```

This will print something like `b c g h e a`. But we want to see what `cargo` does first. To use `cargo` and run our program, usually we type `cargo run`. This will build our program and run it for us. But when it starts compiling, it does something like this:

```
Compiling getrandom v0.1.14
Compiling cfg-if v0.1.10
Compiling ppv-lite86 v0.2.8
Compiling rand_core v0.5.1
Compiling rand_chacha v0.2.2
Compiling rand v0.7.3
Compiling rust_book v0.1.0 (C:\Users\mithr\OneDrive\Documents\Rust\rust_book)
  Finished dev [unoptimized + debuginfo] target(s) in 13.13s
    Running
`C:\Users\mithr\OneDrive\Documents\Rust\rust_book\target\debug\rust_book.exe`
```

So it looks like it didn't just bring in `rand`, but some others too. That's because we need `rand` for our crate, but `rand` also has some code that needs other crates too. So `cargo` will find all the crates we need and put them together. In our case we only had seven, but on very big projects you may have 200 or more crates to bring in.

This is where you can see the tradeoff for Rust. Rust is extremely fast, because it compiles ahead of time. It does this by looking through the code and looking to see what the code you write actually does. For example, you might write this generic code:

```
use std::fmt::Display;

fn print_and_return_thing<T: Display>(input: T) -> T {
    println!("You gave me {} and now I will give it back.", input);
    input
}

fn main() {
    let my_name = print_and_return_thing("Windy");
    let small_number = print_and_return_thing(9.0);
}
```

This function can take anything with `Display`, so we gave it a `&str` and next gave it a `f64` and that is no problem for us. But the compiler doesn't look at generics, because it doesn't want to do anything at runtime. It wants to put together a program that can run by itself as fast as possible. So when it looks at the first part with `"Windy"`, it doesn't see `fn print_and_return_thing<T: Display>(input: T) -> T`. It sees something like `fn print_and_return_thing(input: &str) -> &str`. And next it sees `fn print_and_return_thing(input: f64) -> f64`. All the checking about traits and so on is done during compile time. That's why generics take longer to compile, because it needs to figure them out, and make it concrete.

One more thing: Rust in 2020 is working hard on compile time, because this part takes the longest. Every version of Rust is a little bit faster at compiling, and there are some other plans to speed it up. But in the meantime, here's what you should know:

- `cargo build` will build your program so you can run it
- `cargo run` will build your program and run it
- `cargo build --release` and `cargo run --release` will do the same but in release mode.
What's that? Release mode is for when your code is finally done. Then Rust will take even longer to compile, but it does this because it uses everything it knows to make it faster. Release mode is actually a *lot* faster than the regular mode, which is called debug mode. That's because it compiles quicker and has more debug information. The regular `cargo build` is called a "debug build" and `cargo build --release` is called a "release build".
- `cargo check` is a way to check your code. It's like compiling except that it won't actually make your program. This is a good way to check your code a lot because it doesn't take as long as `build` or `run`.

By the way, the `--release` part of the command is called a `flag`. That means extra information in a command.

Some other things you need to know are:

- `cargo new`. You do this to create a new Rust project. After `new`, write the name of the project and `cargo` will make the folder and all the files you need.
- `cargo clean`. When you add crates to `Cargo.toml`, the computer will download all the files it needs and they can take a lot of space. If you don't want them on your computer anymore, type `cargo clean`.

One more thing about the compiler: it only takes the most time when you use `cargo build` or `cargo run` the first time. After that it will remember, and it will compile fast again. But if you use `cargo clean` and then run `cargo build`, it will have to compile slowly one more time.

Taking user input

One easy way to take input from the user is with `std::io::stdin`. This means "standard in", which is the input from the keyboard. With `stdin()` you can get user input, but then you will want to put it in a `&mut String` with `.read_line()`. Here is a simple example of that, but it both works and doesn't work:

```
use std::io;

fn main() {
    println!("Please type something, or x to escape:");
    let mut input_string = String::new();

    while input_string != "x" { // This is the part that doesn't work right
        input_string.clear(); // First clear the String. Otherwise it will keep adding
        to it
        io::stdin().read_line(&mut input_string).unwrap(); // Get the stdin from the
        user, and put it in read_string
        println!("You wrote {}", input_string);
    }
    println!("See you later!");
}
```

Here is what an output looks like:

```
Please type something, or x to escape:
something
You wrote something

Something else
You wrote Something else

x
You wrote x

x
You wrote x

x
You wrote x
```

It takes our input and gives it back, and it even knows that we typed `x`. But it doesn't exit the program. The only way to get out is to close the window, or type ctrl and c. Let's change the `{}` to `{:?:}` in `println!` to get more information (or you could use `dbg!(&input_string)` if you like that macro). Now it says:

```
Please type something, or x to escape:
something
You wrote "something\r\n"
Something else
You wrote "Something else\r\n"
x
You wrote "x\r\n"
x
You wrote "x\r\n"
```

This is because the keyboard input is actually not just `something`, it is `something` and the `Enter` key. There is an easy method to fix this called `.trim()`, which removes all the whitespace.

Whitespace, by the way, is all these characters:

```
U+0009 (horizontal tab, '\t')
U+000A (line feed, '\n')
U+000B (vertical tab)
U+000C (form feed)
U+000D (carriage return, '\r')
U+0020 (space, ' ')
U+0085 (next line)
U+200E (left-to-right mark)
U+200F (right-to-left mark)
U+2028 (line separator)
U+2029 (paragraph separator)
```

So that will turn `x\r\n` into just `x`. Now it works:

```
use std::io;

fn main() {
    println!("Please type something, or x to escape:");
    let mut input_string = String::new();

    while input_string.trim() != "x" {
        input_string.clear();
        io::stdin().read_line(&mut input_string).unwrap();
        println!("You wrote {}", input_string);
    }
    println!("See you later!");
}
```

Now it will print:

```
Please type something, or x to escape:
something
You wrote something

Something
You wrote Something

x
You wrote x

See you later!
```

There is another kind of user input called `std::env::Args` (env means environment). `Args` is what the user types when starting the program. There is actually always at least one `Arg` in a program. Let's write a program that only prints them using `std::env::args()` to see what they are.

```
fn main() {
    println!("{:?}", std::env::args());
}
```

If we write `cargo run` then it prints something like this:

```
Args { inner: ["target\\debug\\rust_book.exe"] }
```

Let's give it more input and see what it does. We'll type `cargo run but with some extra words`. It gives us:

```
Args { inner: ["target\\debug\\rust_book.exe", "but", "with", "some", "extra", "words"] }
```

Interesting. And when we look at [the page for Args](#), we see that it implements `IntoIterator`. That means we can do all the things we know about iterators to read and change it. Let's try this:

```
use std::env::args;

fn main() {
    let input = args();

    for entry in input {
        println!("You entered: {}", entry);
    }
}
```

Now it says:

```
You entered: target\debug\rust_book.exe
You entered: but
You entered: with
You entered: some
You entered: extra
You entered: words
```

You can see that the first argument is always the program name, so you will often want to skip it, like this:

```
use std::env::args;

fn main() {
    let input = args();

    input.skip(1).for_each(|item| {
        println!("You wrote {}, which in capital letters is {}", item,
item.to_uppercase());
    })
}
```

That will print:

```
You wrote but, which in capital letters is BUT
You wrote with, which in capital letters is WITH
You wrote some, which in capital letters is SOME
You wrote extra, which in capital letters is EXTRA
You wrote words, which in capital letters is WORDS
```

One common use for `Args` is for user settings. You can make sure that the user writes the input you need, and only run the program if it's right. Here's a small program that either makes letters big (capital) or small (lowercase):

```

use std::env::args;

enum Letters {
    Capitalize,
    Lowercase,
    Nothing,
}

fn main() {
    let mut changes = Letters::Nothing;
    let input = args().collect::<Vec<_>>();

    if input.len() > 2 {
        match input[1].as_str() {
            "capital" => changes = Letters::Capitalize,
            "lowercase" => changes = Letters::Lowercase,
            _ => {}
        }
    }

    for word in input.iter().skip(2) {
        match changes {
            Letters::Capitalize => println!("{} {}", word.to_uppercase()),
            Letters::Lowercase => println!("{} {}", word.to_lowercase()),
            _ => println!("{} {}", word)
        }
    }
}

```

Here are some examples of what it gives:

Input: cargo run please make capitals:

```
make capitals
```

Input: cargo run capital:

```
// Nothing here...
```

Input: cargo run capital I think I understand now:

```
I
THINK
I
UNDERSTAND
NOW
```

Input: cargo run lowercase Does this work too?

```
does
this
work
too?
```

Besides `Args` given by the user, available in `std::env::args()`, there are also `Vars` which are the system variables. Those are the basic settings for the program that the user didn't type in. You can use `std::env::vars()` to see them all as a `(String, String)`. There are very many. For example:

```
fn main() {
    for item in std::env::vars() {
        println!("{}:{}", item);
    }
}
```

Just doing this shows you all the information about your user session. It will show information like this:

```
("CARGO", "/playground/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/bin/cargo")
("CARGO_HOME", "/playground/.cargo")
("CARGO_MANIFEST_DIR", "/playground")
("CARGO_PKG_AUTHORS", "The Rust Playground")
("CARGO_PKG_DESCRIPTION", "")
("CARGO_PKG_HOMEPAGE", "")
("CARGO_PKG_NAME", "playground")
("CARGO_PKG_REPOSITORY", "")
("CARGO_PKG_VERSION", "0.0.1")
("CARGO_PKG_VERSION_MAJOR", "0")
("CARGO_PKG_VERSION_MINOR", "0")
("CARGO_PKG_VERSION_PATCH", "1")
("CARGO_PKG_VERSION_PRE", "")
("DEBIAN_FRONTEND", "noninteractive")
("HOME", "/playground")
("HOSTNAME", "f94c15b8134b")
("LD_LIBRARY_PATH", "/playground/target/debug/build/backtrace-sys-3ec4c973f371c302/out:/playground/target/debug/build/sqlite3-sys-fbddfb9b241dacb/out:/playground/target/debug/build/ring-cadba5e583648abb/out:/playground/target/debug/deps:/playground/target/debug:/playground/.x86_64-unknown-linux-gnu/lib/rustlib/x86_64-unknown-linux-gnu/lib:/playground/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/lib")
("PATH",
"/playground/.cargo/bin:/playground/.cargo/bin:/usr/local/sbin:/usr/local/bin:/usr/sbin:/usr/bin")
("PLAYGROUND_EDITION", "2018")
("PLAYGROUND_TIMEOUT", "10")
("PWD", "/playground")
("RUSTUP_HOME", "/playground/.rustup")
("RUSTUP_TOOLCHAIN", "stable-x86_64-unknown-linux-gnu")
("RUST_RECURSION_COUNT", "1")
("SHLVL", "1")
("SSL_CERT_DIR", "/usr/lib/ssl/certs")
("SSL_CERT_FILE", "/usr/lib/ssl/certs/ca-certificates.crt")
("USER", "playground")
("_", "/usr/bin/timeout")
```

So if you need this information, `Vars` is what you want.

The easiest way to get a single `Var` is by using the `env!` macro. You just give it the name of the variable, and it will give you a `&str` with the value. It won't work if the variable is spelled wrong or does not exist, so if you aren't sure then use `option_env!` instead. If we write this on the Playgroud:

```
fn main() {
    println!("{}: {}", env!("USER"));
    println!("{}: {}", option_env!("ROOT").unwrap_or("Can't find ROOT"));
    println!("{}: {}", option_env!("CARGO").unwrap_or("Can't find CARGO"));
}
```

then we get the output:

```
playground  
Can't find ROOT  
/playground/.rustup/toolchains/stable-x86_64-unknown-linux-gnu/bin/cargo
```

So `option_env!` is always going to be the safer macro. `env!` is better if you actually want the program to crash when you can't find the environment variable.

Using files

Now that we are using Rust on the computer, we can start working with files. You will notice that now we will start to see more and more `Result`s in our code. That is because once you start working with files and similar things, many things can go wrong. A file might not be there, or maybe the computer can't read it.

You might remember that if you want to use the `?` operator, it has to return a `Result` in the function it is in. If you can't remember the error type, you can just give it nothing and let the compiler tell you. Let's try that with a function that tries to make a number with `.parse()`.

```
// ⚠
fn give_number(input: &str) -> Result<i32, ()> {
    input.parse::<i32>()
}

fn main() {
    println!("{}:?", give_number("88"));
    println!("{}:?", give_number("5"));
}
```

The compiler tells us exactly what to do:

```
error[E0308]: mismatched types
--> src\main.rs:4:5
|
3 | fn give_number(input: &str) -> Result<i32, ()> {
|                                     ----- expected `std::result::Result<i32,
()>` because of return type
4 |     input.parse::<i32>()
|     ^^^^^^^^^^^^^^^^^^^^^ expected `()` , found struct `std::num::ParseIntError`
|
= note: expected enum `std::result::Result<_, ()>`
         found enum `std::result::Result<_, std::num::ParseIntError>`
```

Great! So we just change the return to what the compiler says:

```
use std::num::ParseIntError;

fn give_number(input: &str) -> Result<i32, ParseIntError> {
    input.parse::<i32>()
}

fn main() {
    println!("{}:?", give_number("88"));
    println!("{}:?", give_number("5"));
}
```

Now the program works!

```
Ok(88)
Ok(5)
```

So now we want to use `?` to just give us the value if it works, and the error if it doesn't. But how to do this in `fn main()`? If we try to use `?` in `main`, it won't work.

```
// ⚠️
use std::num::ParseIntError;

fn give_number(input: &str) -> Result<i32, ParseIntError> {
    input.parse::<i32>()
}

fn main() {
    println!("{}?", give_number("88")?);
    println!("{}?", give_number("5")?);
}
```

It says:

```
error[E0277]: the `?` operator can only be used in a function that returns `Result` or
`Option` (or another type that implements `std::ops::Try`)
--> src\main.rs:8:22
   |
7 | / fn main() {
8 | |     println!("{}?", give_number("88")?);
   | |     ^^^^^^^^^^^^^^^^^ cannot use the `?` operator in a
function that returns `()`
9 | |     println!("{}?", give_number("5")?);
10| |
   |_- this function should return `Result` or `Option` to accept `?`
```

But actually `main()` can return a `Result`, just like any other function. If our function works, we don't want to return anything (`main()` isn't giving anything to anything else). And if it doesn't work, we will return the same error. So we can write it like this:

```
use std::num::ParseIntError;

fn give_number(input: &str) -> Result<i32, ParseIntError> {
    input.parse::<i32>()
}

fn main() -> Result<(), ParseIntError> {
    println!("{}?", give_number("88")?);
    println!("{}?", give_number("5")?);
    Ok(())
}
```

Don't forget the `Ok(())` at the end: this is very common in Rust. It means `Ok`, inside of which is `()`, which is our return value. Now it prints:

```
88
5
```

This wasn't very useful when just using `.parse()`, but it will be with files. That's because `?` also changes error types for us. Here's what [the page for the `?` operator](#) says in simple English:

If you get an `'Err'`, it will get the inner error. Then `'?'` does a conversion using `'From'`. With that it can change specialized errors to more general ones. The error it gets is then returned.

Also, Rust has a convenient `Result` type when using `Files` and similar things. It's called `std::io::Result`, and this is what you usually see in `main()` when you are using `?` to open and do things to files. It's actually a type alias. It looks like this:

```
type Result<T> = Result<T, Error>;
```

So it is a `Result<T, Error>`, but we only need to write the `Result<T>` part.

Now let's try working with files for the first time. `std::fs` is where the methods are for working with files, and with `std::io::Write` you can write in them. With that we can use `.write_all()` to write into the file.

```
use std::fs;
use std::io::Write;

fn main() -> std::io::Result<()> {
    let mut file = fs::File::create("myfilename.txt")?; // Create a file with this
    name. // CAREFUL! If you have a file
    with this name already, // it will delete everything in
    it. // Don't forget the b in front
    file.write_all(b"Let's put this in the file")?; // That's because files take bytes.
    Ok(())
}
```

Then if you click on the new file `myfilename.txt`, it will say `Let's put this in the file`.

We don't need to do this on two lines though, because we have the `?` operator. It will pass on the result we want if it works, kind of like when you use lots of methods on an iterator. This is when `?` becomes very convenient.

```
use std::fs;
use std::io::Write;

fn main() -> std::io::Result<()> {
    fs::File::create("myfilename.txt")?.write_all(b"Let's put this in the file")?;
    Ok(())
}
```

So this is saying "Please try to create a file and check if it worked. If it did, then use `.write_all()` and then check if that worked."

And in fact, there is also a function that does both of these things together. It's called `std::fs::write`. Inside it you give it the file name you want, and the content you want to put inside. Again, careful! It will delete everything in that file if it already exists. Also, it lets you write a `&str` without `b` in front, because of this:

```
pub fn write<P: AsRef<Path>, C: AsRef<[u8]>>(path: P, contents: C) -> Result<()>
```

`AsRef<[u8]>` is why you can give it either one.

It's very simple:

```
use std::fs;

fn main() -> std::io::Result<()> {
    fs::write("calvin_with_dad.txt",
    "Calvin: Dad, how come old photographs are always black and white? Didn't they have
    color film back then?
    Dad: Sure they did. In fact, those photographs *are* in color. It's just the *world*
    was black and white then.
    Calvin: Really?
    Dad: Yep. The world didn't turn color until sometimes in the 1930s...");;
    Ok(())
}
```

So that's the file we will use. It's a conversation with a comic book character named Calvin and his dad, who is not serious about his question. With this we can create a file to use every time.

Opening a file is just as easy as creating one. You just use `open()` instead of `create()`. After that (if it finds your file), you can do things like `read_to_string()`. To do that you can create a mutable `String` and read the file into there. It looks like this:

```
use std::fs;
use std::fs::File;
use std::io::Read; // this is to use the function .read_to_string()

fn main() -> std::io::Result<()> {
    fs::write("calvin_with_dad.txt",
    "Calvin: Dad, how come old photographs are always black and white? Didn't they have
    color film back then?
    Dad: Sure they did. In fact, those photographs *are* in color. It's just the *world*
    was black and white then.
    Calvin: Really?
    Dad: Yep. The world didn't turn color until sometimes in the 1930s...");;

    let mut calvin_file = File::open("calvin_with_dad.txt")?; // Open the file we just
made
    let mut calvin_string = String::new(); // This String will hold it
    calvin_file.read_to_string(&mut calvin_string)?; // Read the file into it

    calvin_string.split_whitespace().for_each(|word| print!("{} ", 
word.to_uppercase())); // Do things with the String now

    Ok(())
}
```

That will print:

```
CALVIN: DAD, HOW COME OLD PHOTOGRAPHS ARE ALWAYS BLACK AND WHITE? DIDN'T THEY HAVE
COLOR FILM BACK THEN? DAD: SURE THEY DID. IN
FACT, THOSE PHOTOGRAPHS *ARE* IN COLOR. IT'S JUST THE *WORLD* WAS BLACK AND WHITE THEN.
CALVIN: REALLY? DAD: YEP. THE WORLD DIDN'T TURN COLOR UNTIL SOMETIMES IN THE 1930S...
```

Okay, what if we want to create a file but not do it if there is already another file with the same name? Maybe you don't want to delete the other file if it's already there just to make a new one. To do this, there is a struct called `OpenOptions`. Actually, we've been using `OpenOptions` all this time and didn't know it. Take a look at the source for `File::open`:

```
pub fn open<P: AsRef<Path>>(path: P) -> io::Result<File> {
    OpenOptions::new().read(true).open(path.as_ref())
}
```

Interesting, that looks like the builder pattern that we learned. It's the same for `File::create`:

```
pub fn create<P: AsRef<Path>>(path: P) -> io::Result<File> {
    OpenOptions::new().write(true).create(true).truncate(true).open(path.as_ref())
}
```

If you go to [the page for OpenOptions](#), you can see all the methods that you can choose from. Most take a `bool`:

- `append()` : This means "add to the content that's already there instead of deleting".
- `create()` : This lets `OpenOptions` create a file.
- `create_new()` : This means it will only create a file if it's not there already.
- `read()` : Set this to `true` if you want it to be able to read a file.
- `truncate()` : Set this to true if you want to cut the file content to 0 (delete the contents) when you open it.
- `write()` : This lets it write to a file.

Then at the end you use `.open()` with the file name, and that will give you a `Result`. Let's look at one example:

```
// ⚠
use std::fs;
use std::fs::OpenOptions;

fn main() -> std::io::Result<()> {
    fs::write("calvin_with_dad.txt",
    "Calvin: Dad, how come old photographs are always black and white? Didn't they have
    color film back then?
    Dad: Sure they did. In fact, those photographs *are* in color. It's just the *world*
    was black and white then.
    Calvin: Really?
    Dad: Yep. The world didn't turn color until sometimes in the 1930s...")?;

    let calvin_file =
    OpenOptions::new().write(true).create_new(true).open("calvin_with_dad.txt")?;

    Ok(())
}
```

First we made an `openOptions` with `new` (always start with `new`). Then we gave it the ability to `write`. After that we set `create_new()` to `true`, and tried to open the file we made. It won't work, which is what we want:

```
Error: Os { code: 80, kind: AlreadyExists, message: "The file exists." }
```

Let's try using `.append()` so we can write to a file. To write to the file we can use `.write_all()`, which is a method that tries to write in everything you give it.

Also, we will use the `write!` macro to do the same thing. You will remember this macro from when we did `impl Display` for our structs. This time we are using it on a file though instead of a buffer.

```
use std::fs;
use std::fs::OpenOptions;
use std::io::Write;

fn main() -> std::io::Result<()> {
    fs::write("calvin_with_dad.txt",
    "Calvin: Dad, how come old photographs are always black and white? Didn't they have
    color film back then?
    Dad: Sure they did. In fact, those photographs *are* in color. It's just the *world*
    was black and white then.
    Calvin: Really?
    Dad: Yep. The world didn't turn color until sometimes in the 1930s...")?;

    let mut calvin_file = OpenOptions::new()
        .append(true) // Now we can write without deleting it
        .read(true)
        .open("calvin_with_dad.txt")?;
    calvin_file.write_all(b"And it was a pretty grainy color for a while too.\n")?;
    write!(&mut calvin_file, "That's really weird.\n")?;
    write!(&mut calvin_file, "Well, truth is stranger than fiction.")?;

    println!("{}", fs::read_to_string("calvin_with_dad.txt")?)?;
    Ok(())
}
```

This prints:

```
Calvin: Dad, how come old photographs are always black and white? Didn't they have
color film back then?
Dad: Sure they did. In fact, those photographs *are* in color. It's just the *world*
was black and white then.
Calvin: Really?
Dad: Yep. The world didn't turn color until sometimes in the 1930s...And it was a
pretty grainy color for a while too.
That's really weird.
Well, truth is stranger than fiction.
```

cargo doc

You might have noticed that Rust documentation always looks almost the same. On the left side you can see `structs` and `traits`, code examples are on the right, etc. This is because you can automatically make documentation just by typing `cargo doc`.

Even making a project with nothing can help you learn about traits in Rust. For example, here are two structs that do almost nothing, and a `fn main()` that also does nothing.

```
struct DoesNothing {}

struct PrintThing {}

impl PrintThing {
    fn prints_something() {
        println!("I am printing something");
    }
}

fn main() {}
```

But if you type `cargo doc --open`, you can see a lot more information than you expected. First it shows you this:

```
Crate rust_book

Structs
DoesNothing
PrintThing

Functions
main
```

But if you click on one of the structs, it will show you a lot of traits that you didn't think were there:

```

Struct rust_book::DoesNothing
[+] Show declaration
Auto Trait Implementations
impl RefUnwindSafe for DoesNothing
impl Send for DoesNothing
impl Sync for DoesNothing
impl Unpin for DoesNothing
impl UnwindSafe for DoesNothing
Blanket Implementations
impl<T> Any for T
where
    T: 'static + ?Sized,
[src]
[+]
impl<T> Borrow<T> for T
where
    T: ?Sized,
[src]
[+]
impl<T> BorrowMut<T> for T
where
    T: ?Sized,
[src]
[+]
impl<T> From<T> for T
[src]
[+]
impl<T, U> Into<U> for T
where
    U: From<T>,
[src]
[+]
impl<T, U> TryFrom<U> for T
where
    U: Into<T>,
[src]
[+]
impl<T, U> TryInto<U> for T
where
    U: TryFrom<T>,

```

This is because of all the traits that Rust automatically makes for every type.

Then if we add some documentation comments you can see them when you type `cargo doc`.

```

/// This is a struct that does nothing
struct DoesNothing {}
/// This struct only has one method.
struct PrintThing {}
/// It just prints the same message.
impl PrintThing {
    fn prints_something() {
        println!("I am printing something");
    }
}
fn main() {}

```

Now it will print:

```
Crate rust_book
Structs
DoesNothing This is a struct that does nothing
PrintThing This struct only has one method.
Functions
main
```

`cargo doc` is very nice when you use a lot of other people's crates. Because these crates are all on different websites, it can take some time to search them all. But if you use `cargo doc`, you will have them all in the same place on your hard drive.

The end?

This is the end of Rust in Easy English. But I am still here, and you can let me know if you have any questions. Feel free to [contact me on Twitter](#) or add a pull request, issue, etc. You can also tell me if some parts weren't easy to understand. Rust in Easy English needs to be very easy to understand, so please let me know where the English is too difficult. Of course, Rust itself can be difficult to understand, but we can at least make sure that the English is easy.