



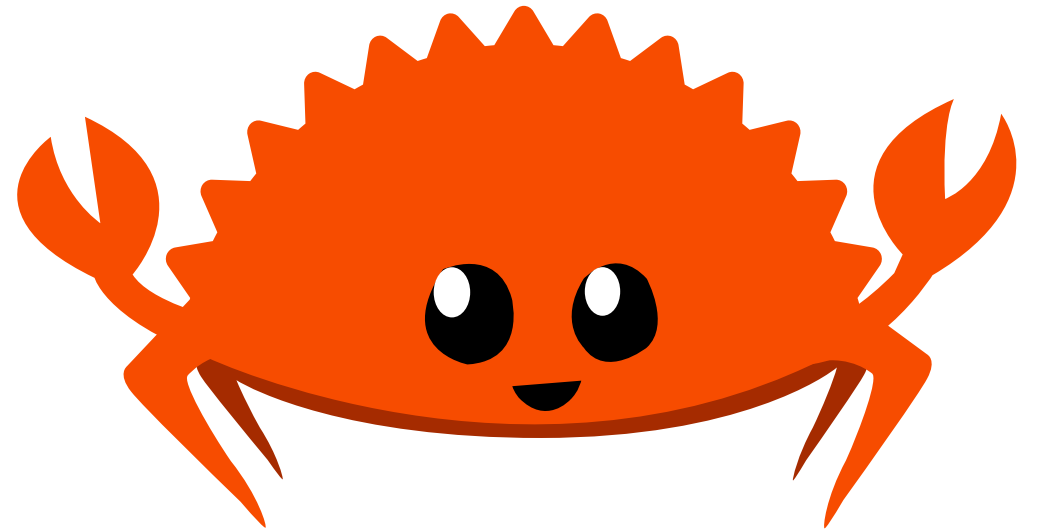
# INTRO TO RUST LANG INTRODUCTION

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**Welcome!**

# Meet Ferris!

- Ferris is Rust's mascot, and ours too!



# Why Rust?

# Why Rust?

- What is Rust?
- How does Rust compare to other languages?
- What are the biggest advantages of Rust?
- What are the pitfalls of Rust?
- Who is Rust for?

# What is Rust?

- Rust started as a personal project of Graydon Hoare, a Mozilla Research employee, in 2006
- Mozilla sponsored the project in 2009, and released the source code in 2010
- The first stable release, Rust 1.0, was announced in 2015
- From the official rust [website](#), Rust is:
  - Fast
  - Reliable
  - Productive

# What is Rust?

- Compiled language
- No runtime (no garbage collector)
- Imperative, but with functional features
- Strong static typing

# Rust vs Python

- Significantly faster
- Much lower memory use
- Multi-threaded
- Comprehensive type system



# Rust vs Java

- No runtime overhead from the JVM or a garbage collector
- Much lower memory use
- Zero-cost abstractions
- First-class support for modern paradigms

# Rust vs C/C++

- No segfaults!
- No null pointers!
- No buffer overflows!
- No data races!
- Memory safety as a guarantee through the type checker
- Robust type system with functional patterns
- Unified build system and dependency management

# Rust Is Memory Safe

- *"C makes it easy to shoot yourself in the foot; C++ makes it harder, but when you do it blows your whole leg off"* - Bjarne Stroustrup, creator of C++
- Safety by default makes it much harder to shoot yourself in the foot
- Memory accesses checked at compile-time
- Powerful type system supports thread safety

# Rust Is Low-Level

- Compiles to machine code
- No runtime (no garbage collector)
- Memory can be allocated deliberately
- Support for raw pointers
- Support for inline assembly
- Zero-overhead FFI

# Rust Is Modern

- Rust is only 8 years old
- Algebraic and generic data types
- Modern developer tooling
- Included build system and dependency management
- Macros / metaprogramming support

# Pitfall: Learning curve

- Writing Rust *feels* very different
- The borrow checker can get in your way
- No object oriented programming
- **That is what we are here for!**

# Pitfall: Ecosystem

- Rust is only 8 years old
- Smaller and less mature ecosystem compared to some older languages
  - *There is a lot of momentum here*

# Other pitfalls

- Compile time is slow
- Using established C++ libraries requires complicated bindings
- Programming in a systems language still takes more time than in a higher-level language



# Who is Rust for?

- Rust is for those who benefit from its great features, and do not suffer from its pitfalls
- **Which means Rust is *not* for everyone.**

# Course Goals

By the end of the semester, we want you all to:

- Be able to read, write, and reason about Rust code
- Become an intermediate to advanced Rust developer
- Understand the importance of the Rust language
- Be confident that you can use Rust going forward!

# Cargo Basics

# Hello World!

To create an executable, we need a `main` function:

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

To compile `main.rs`, use `rustc`.

```
$ rustc main.rs
```

# Cargo

Rust has its own build system and package manager called **Cargo**.

- Cargo is included with all Rust distributions, so no `make` files or third-party build systems
- Manages packages similar to `pip` for `python` or `npm` for `node.js`

# Creating a new project

To create a new cargo project called `hello_cargo`, use `cargo new`.

```
$ cargo new hello_cargo  
$ cd hello_cargo
```

- You will find a few important things
  - `.git` repository and `.gitignore`
  - `Cargo.toml`
  - `src/main.rs`
- We will come back `Cargo.toml` in future weeks

# Building your project

To build your project, use `cargo build`.

```
$ cargo build
  Compiling hello_cargo v0.1.0 (<path>/hello_cargo)
  Finished dev [unoptimized + debuginfo] target(s) in 1.00s
```

- This creates an executable file at `target/debug/hello_cargo`
- What if we want to actually run this executable?
  - We could run `./target/debug/hello_cargo`, but this is a lot to type...

# Running your project

To run your project, use `cargo run`.

```
$ cargo run
  Compiling hello_cargo v0.1.0 (file:///projects/hello_cargo)
  Finished dev [unoptimized + debuginfo] target(s) in 0.42s
  Running `target/debug/hello_cargo`
Hello, world!
```

- Note that if you compiled with `cargo build` right before, you wouldn't see the `Compiling hello_cargo ...` line



# Check if your project compiles

To check your code for syntax and type errors, use `cargo check`

```
$ cargo check
  Checking hello_cargo v0.1.0 (file:///projects/hello_cargo)
    Finished dev [unoptimized + debuginfo] target(s) in 0.42s
```

- Much faster than `cargo build` since it doesn't build the executable
- Useful when programming to check if your code still compiles

# Cargo recap

- We can create a project using `cargo new`
- We can build a project using `cargo build`
- We can build and run a project in one step using `cargo run`
- We can check a project for errors using `cargo check`
- Cargo stores our executable in the `target/debug` directory

# Variables and Mutability

# Variables

Variables are values bound to a name. We define variables with the `let` keyword.

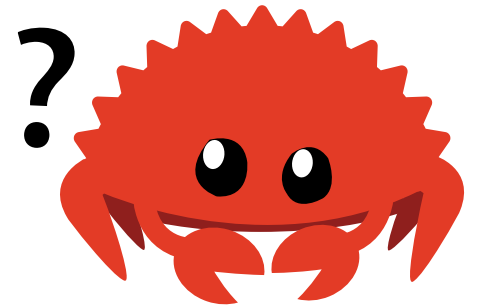
```
fn main() {  
    let x = 5;  
    println!("The value of x is: {}", x);  
}
```

# Immutability

All variables in Rust are *immutable* by default.

```
fn main() {  
    let x = 5;  
    println!("The value of x is: {}", x);  
    x = 6;  
    println!("The value of x is: {}", x);  
}
```

- What happens when we try to compile this?



# Immutability

When we try to compile, we get this error message:

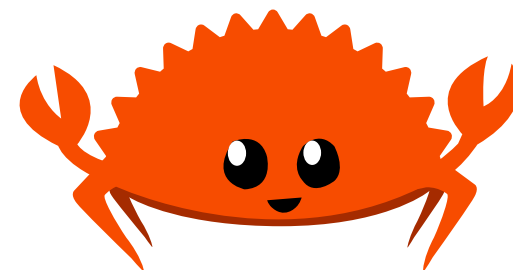
```
$ cargo run
  Compiling variables v0.1.0 (file:///projects/variables)
error[E0384]: cannot assign twice to immutable variable `x`
  --> src/main.rs:4:5
   |
2  |     let x = 5;
   |         -
   |         |
   |         first assignment to `x`
   |         help: consider making this binding mutable: `mut x`
3  |     println!("The value of x is: {}", x);
4  |     x = 6;
   |     ^^^^^ cannot assign twice to immutable variable
```

- Let's follow the compiler's advice!

# Mutability

To declare a variable as mutable, we use the `mut` keyword.

```
fn main() {  
    let mut x = 5;  
    println!("The value of x is: {}", x);  
    x = 6;  
    println!("The value of x is: {}", x);  
}
```



When we run the program now, we now get this:

```
$ cargo run  
  <-- snip -->  
The value of x is: 5  
The value of x is: 6
```

# Constants

Like immutable variables, constants are values bound to a name.

```
const THREE_HOURS_IN_SECONDS: u32 = 60 * 60 * 3;
```

- Constants cannot be `mut`
- Constants must have an explicit type
  - We will talk about types like `u32` in a few slides



# Scopes and Shadowing

You can create nested scopes within functions with curly braces `{}`.

```
fn main() {  
    let x = 5;  
  
    let x = x + 1;  
  
    {  
        let x = x * 2;  
        println!("The value of x in the inner scope is: {}", x);  
    }  
  
    println!("The value of x is: {}", x);  
}
```

- Let's dissect this!

```
let x = 5;
let x = x + 1;
{
  let x = x * 2;
  println!("The value of x in the inner scope is: {}", x);
}
println!("The value of x is: {}", x);
```

- `x` is bound to `5` first
- A new variable `x` is created and bound to `x + 1`, i.e. `6`
- An inner scope is created with the opening curly brace `{`
- The third `let` statement shadows `x`
- The shadowed `x` is set to `x * 2 = 12`
- The inner scope ends with the closing curly brace `}`
- `x` returns to being `6` again

```
let x = 5;
let x = x + 1;
{
    let x = x * 2;
    println!("The value of x in the inner scope is: {}", x);
}
println!("The value of x is: {}", x);
```

Let's run this now!

```
$ cargo run
  <-- snip -->
The value of x in the inner scope is: 12
The value of x is: 6
```

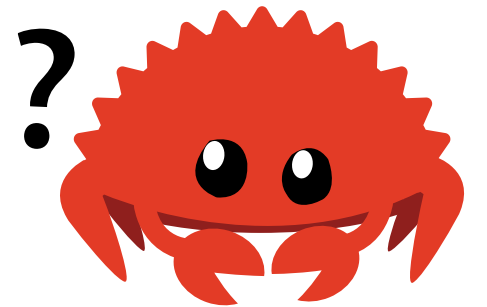
# Aside: Shadowing vs Mutability

Mutability:

```
let mut spaces = "  ";  
spaces = spaces.len();
```

```
2 | let mut spaces = "  ";  
   |                   ----- expected due to this value  
3 | spaces = spaces.len();  
   |                   ^^^^^^^^^^^^^^^^^ expected `&str`, found `usize`
```

- Expected one *type*, got something else
  - We'll talk about types in a few slides!

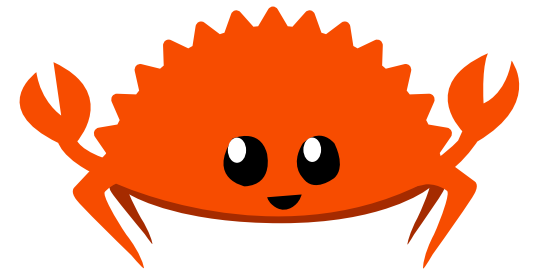


# Aside: Shadowing vs Mutability

Shadowing:

```
let spaces = "  ";  
let spaces = spaces.len();
```

- Even though the types are different, the `let` keyword allows us to redefine the `spaces` variable



# Shadowing vs Mutability

- Mutability lets us change the value of a variable
  - We get a compile time error if we try to modify a non-`mut` variable
- Shadowing allows us to change what a variable's name refers to
  - In addition to changing the value, it can also change types

# Types

# Types

Like most languages, there are two main categories of Data Types.

- Scalar Types
  - Integers
  - Floating-Points
  - Boolean
  - Character
- Compound Types
  - Tuples
  - Arrays



# Integers

Rust has similar integer types you would expect to see in C.

Length	Signed	Unsigned
8-bit	<code>i8</code>	<code>u8</code>
16-bit	<code>i16</code>	<code>u16</code>
32-bit	<code>i32</code>	<code>u32</code>
64-bit	<code>i64</code>	<code>u64</code>
128-bit	<code>i128</code>	<code>u128</code>
arch	<code>isize</code>	<code>usize</code>

# Floating-Points

Rust has both a 32-bit and 64-bit floating-point type.

```
fn main() {  
    let x = 2.0; // f64  
  
    let y: f32 = 3.0; // f32  
}
```

# Numeric Operations

```
fn main() {  
    // addition  
    let sum = 5 + 10;  
  
    // subtraction  
    let difference = 95.5 - 4.3;  
  
    // multiplication  
    let product = 4 * 30;  
  
    // division  
    let quotient = 56.7 / 32.2;  
    let truncated = -5 / 3; // Results in -1  
  
    // remainder / modulo  
    let remainder = 43 % 5;  
}
```

# Booleans

A *boolean* in Rust has two values `true` and `false` (as in most other languages).

```
fn main() {  
    let t = true;  
  
    let f: bool = false; // with explicit type annotation  
}
```

- Booleans are always 1 byte in size

# Characters

Rust has a UTF-32 character type `char`.

```
fn main() {  
    let c = 'z';  
    let z: char = 'Z'; // with explicit type annotation  
    let heart_eyed_cat = '😻';  
}
```

- Use `char` with single quotes ( `'a'` vs. `"a"` )
- Due to `char` being UTF-32, a `char` is always **4 bytes in length**
- We will talk more about this and UTF-8 / UTF-32 in the future!

# Tuples

A *tuple* is a way of grouping together a number of values with a variety of types.

```
fn main() {  
    let tup: (i32, f64, u8) = (500, 6.4, 1);  
}
```

# Tuples

You can destructure tuples like so:

```
fn main() {  
    let tup = (500, 6.4, 1);  
  
    let (x, y, z) = tup;  
  
    println!("The value of y is: {}", y);  
}
```

# Tuples

You can also access specific elements in the tuples like so:

```
fn main() {  
    let x: (i32, f64, u8) = (500, 6.4, 1);  
  
    let five_hundred = x.0;  
  
    let six_point_four = x.1;  
  
    let one = x.2;  
}
```



# Arrays

To store a collection of multiple values, we use *arrays*.

```
fn main() {  
    let a = [1, 2, 3, 4, 5];  
    let months = ["January", "February", "March", "April", "May", "June", "July",  
                 "August", "September", "October", "November", "December"];  
}
```

- Unlike tuples, all elements must be the same type
- The number of elements is always fixed at compile time
  - If you want a collection that grows and shrinks, use a vector (lecture 4)
- Similar to stack-allocated arrays you would see in C

# Arrays

We define an array's type by specifying the type of the elements and the length of the array.

```
let a: [i32; 5] = [1, 2, 3, 4, 5];
```

We can also initialize the array such that every element has the same value.

```
let a = [3; 5];  
// let a = [3, 3, 3, 3, 3];
```

# Arrays

To access an array element, we use square brackets.

```
fn main() {  
    let a = [1, 2, 3, 4, 5];  
  
    let first = a[0];  
    let second = a[1];  
}
```

- Rust will ensure that the index is within bounds at runtime
  - This is *not* done in C/C++

# Functions, Statements, and Expressions

# Functions

Like most programming languages, Rust has functions.

```
fn main() {  
    println!("Hello, world!");  
    another_function();  
}  
  
fn another_function() {  
    println!("Another function.");  
}
```

```
$ cargo run  
    <-- snip -->  
Hello, world!  
Another function.
```

# Functions

All parameters / arguments to functions must be given an explicit type.

```
fn main() {  
    print_labeled_measurement(5, 'h');  
}  
  
fn print_labeled_measurement(value: i32, unit_label: char) {  
    println!("The measurement is: {}", value, unit_label);  
}
```

```
$ cargo run  
  <-- snip -->  
The measurement is: 5h
```

# Returning from Functions

You can return values back to the caller of a function with the `return` keyword.

```
fn main() {  
    let x = plus_one(5);  
    println!("The value of x is: {}", x);  
}  
  
fn plus_one(x: i32) -> i32 {  
    return x + 1;  
}
```

```
$ cargo run  
  <-- snip -->  
The value of x is: 6
```

# Returning from Functions

You can also omit the `return` keyword.

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

```
$ cargo run  
  <-- snip -->  
The value of x is: 6
```

- Why are we allowed do this?



# Statements and Expressions

All functions are a series of statements optionally ending in an expression.

```
fn main() {  
    let x = 6; // Statement  
    let y = 2 + 2; // Statement resulting from the expression "2 + 2"  
    2 + 2; // Expression ending in a semicolon,  
           // which turns the expression into a statement with no effect  
}
```

- **Statements** are instructions that do some action and don't return a value
- **Expressions** evaluate / return to a resultant value

# Statements and Expressions

- Statements
  - `let y = 6;` is a statement and does not return a value
  - You *cannot* write `x = y = 6`
- Expressions
  - `2 + 2` is an expression
  - Calling a function is an expression
  - A scope is also an expression
- If you add a semicolon to an expression, it turns into a statement
- If a scope is an expression, can scopes return values?

# Statements and Expressions

Observe the following code where a scope returns a value.

```
fn main() {  
    let y = {  
        let x = 3;  
        x + 1  
    };  
  
    println!("The value of y is: {}", y);  
}
```

- Notice that there is no semicolon after `x + 1`
- Scopes return the value of their last expression
- Since functions are scopes, they can also return values in this way!

# Function Return Types

Let's revisit this code snippet.

```
fn main() {  
    let x = plus_one(5);  
    println!("The value of x is: {}", x);  
}  
  
fn plus_one(x: i32) -> i32 {  
    x + 1  
}
```

- Functions must have a specific return value, or return nothing
  - No return type is equivalent to returning the unit type `()`
- Notice again that there is no semicolon after `x + 1`

Suppose we did add a semicolon:

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

We get this error:

```
error[E0308]: mismatched types  
  --> src/main.rs:7:24  
7 | | fn plus_one(x: i32) -> i32 {  
  | |  
  ---  
  
  ---  
  --      ^^^ expected `i32`, found `()`  
  |      |  
  |      | implicitly returns `()` as its body has no tail or `return` expression  
8 |      | x + 1;  
  |      | - help: remove this semicolon to return this value
```

# Control Flow

# if Expressions

We can define runtime control flow with `if`.

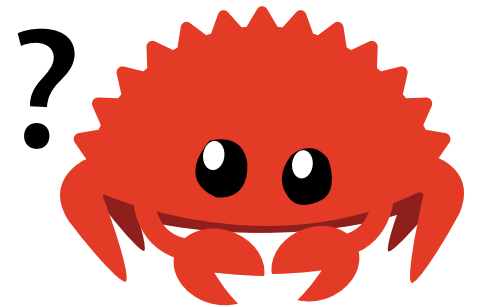
```
fn main() {  
    let number = 3;  
  
    if number < 5 {  
        println!("condition was true");  
    } else {  
        println!("condition was false");  
    }  
}
```

# if Expressions

if expressions must condition on a boolean expression.

```
fn main() {  
    let number = 3;  
  
    if number {  
        println!("number was three");  
    }  
}
```

```
error[E0308]: mismatched types  
--> src/main.rs:4:8  
4 | |     if number {  
  | |         ^^^^^ expected `bool`, found integer
```





# else if Branching

You can handle multiple conditions with `else if`

```
fn main() {  
    let number = 6;  
  
    if number % 4 == 0 {  
        println!("divisible by 4");  
    } else if number % 3 == 0 {  
        println!("divisible by 3");  
    } else if number % 2 == 0 {  
        println!("divisible by 2");  
    } else {  
        println!("not divisible by 4, 3, or 2");  
    }  
}
```

# if s are Expressions!

Since `if` expressions are expressions, we can bind the result of an `if` expression to a variable.

```
fn main() {  
    let condition = true;  
    let number = if condition { 5 } else { 6 };  
  
    println!("The value of number is: {}", number);  
}
```

- `if` expressions must always return the same type in all branches

# Loops

There are 3 kinds of loops in Rust.

- `loop`
- `while`
- `for`

# Loop loops

`loop` will loop forever until you tell it to stop with `break`.

```
fn main() {  
    let mut counter = 0;  
  
    loop {  
        counter += 1;  
  
        if counter == 10 {  
            break;  
        }  
    }  
  
    println!("The counter is {}", counter);  
}
```

- `break` and `continue` apply to the innermost loop where they are called

# Loops are Expressions

Like everything else, you can return a value from a loop.

```
fn main() {  
    let mut counter = 0;  
  
    let result = loop {  
        counter += 1;  
  
        if counter == 10 {  
            break counter * 2;  
        }  
    };  
  
    println!("The result is {}", result);  
}
```

# Loop Labels

You can label loops to use with `break` and `continue` to specify which loop it applies to.

```
fn main() {
    'outer: loop {
        println!("Entered the outer loop");

        'inner: loop {
            println!("Entered the inner loop");
            // break; // <-- This would break only the inner loop

            // This breaks the outer loop
            break 'outer;
        }

        println!("This point will never be reached");
    }
    println!("Exited the outer loop");
}
```

```
fn main() {  
    'outer: loop {  
        println!("Entered the outer loop");  
        'inner: loop {  
            println!("Entered the inner loop");  
            break 'outer;  
        }  
        println!("This point will never be reached");  
    }  
    println!("Exited the outer loop");  
}
```

```
Entered the outer loop  
Entered the inner loop  
Exited the outer loop
```

- Applies to `while` and `for` loops too

# while loops

Just like other languages, we have `while` loops that stop after some condition.

```
fn main() {  
    let mut number = 3;  
  
    while number != 0 {  
        println!("{}", number);  
  
        number -= 1;  
    }  
  
    println!("LIFTOFF!!!");  
}
```



# for loops

We can also loop through collections with a `for` loop.

```
fn main() {  
    let a = [10, 20, 30, 40, 50];  
  
    for element in a {  
        println!("the value is: {}", element);  
    }  
}
```

# for loops and ranges

To loop over a range, use the `..` syntax to create a range.

```
fn main() {  
    for number in 1..4 {  
        println!("{}", number);  
    }  
    println!("SURPRISE!!!");  
}
```

# Recap

- Variables and Mutability
- Scalar and Compound Data Types
- Functions, Statements, and Expressions
- Control Flow

# Course Logistics

# Course Logistics: Grading

- Attendance is 50% of your grade
  - We have to take attendance every lecture
  - You only get 2 unexcused absences
- Programming assignments are the other 50%
- You need 60% to pass this course

# Course Logistics: Communication

- [Discord](#)
- [Piazza](#)
- Email
- Talk to us!
  - If you can't make it to lecture, tell us beforehand
  - If you have feedback for us, feel free to tell us!
  - Let us know of any ideas you have for this or future semesters!
  - If you have any sort of concern, talk to us!

# Course Logistics: Homework

- Homeworks are designed to take less than an hour per week
- If you are spending more than that, please let us know!
- Autograded assignments through Gradescope
- 7 late days
  - Can use them any time in the semester
  - Can use at most 7 late days for a specific assignment
  - *You can ask us for more late days if you ask in advance...*

# Installing Rust

- Go to [rust-lang.org/tools/install](https://rust-lang.org/tools/install)
- Read and follow the instructions for installing `rustup`
- Let us know if you run into trouble!



# Homework 1

- This first homework consists of 8 small puzzles and 4 simple function implementations
- The objective is to build confidence with Rust syntax and experience interpreting error messages
- Refer to `README.md` for further instructions
- Please let us know if you have any questions!

## Next Lecture: Ownership

Thanks for coming!

