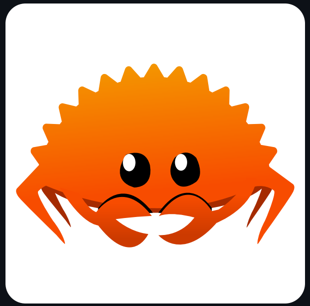
Introduction to the Rust programming Language



Following along The Rust Book from the official source

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For: **IFT-769** (Theoritical concepts CS)

📖 **Project overview -** Going through "The Rust Programming Language"

The Rust Programming Language by Steve Klabnik and Carol Nichols

Book overview:

- Official guide to the Rust programming language
- Covers the basics (syntax, types, functions) + toolchain
- Advanced and Rust-specific features:
  - Ownership, borrowing, lifetimes
  - Unique error handling
  - Concurrency

Klabnik, Steve, and Carol Nichols. The Rust Programming Language. 2nd ed., No Starch Press.

📚 **Theoretical concepts** - Key topics covered

1. Common Programming Concepts (*variables, types, control flow*)
2. Understanding Ownership (*memory management*)
3. Structs, Enums and Pattern Matching
4. Containers/Collections
5. Error Handling
6. Generics, Traits and Lifetimes
7. Functional and OO features
8. Smart pointers and Concurrency
9. Patterns and matching + Advanced features

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🦀 Rust Overview

- **Systems programming language** focused on **safety** and **performance**
- TODO

Currently known projects

TODO

Predicted use cases

TODO

📝 Pros and Cons of Rust

PROS:

- **Memory safety:** No null pointers, dangling pointers, or buffer overflows
- **Error handling**: With the `Result` and `Option` types
- **Concurrency**: Safe and efficient with the ownership system
- **Performance**: Comparable to C/C++ with zero-cost abstractions
- **Ecosystem**: Growing with a strong community and package manager (**Cargo**)
- **Helpful compiler**: Provides detailed error messages and warnings

CONS:

- **Learning curve**: Ownership, borrowing, and lifetimes can be challenging
- **Tooling and prevalence**: Not as mature as other languages (C/C++, Python, etc.)
- **Syntax**: Can be verbose and complex compared to other languages

⚙️ Installation and setup

<u>Installation</u>:

1. Install Rust using `rustup` (Rust toolchain installer)

<u>Included toolchain</u>:

- `rustc`: Rust compiler
- `rustup`: Rust toolchain manager
- `rustfmt`: Rust code formatter
- `cargo`: Rust package manager and build tool

Package and library management

- **Crates** are Rust packages that can be shared and reused
- Managed with **Cargo**, the Rust package manager

Development environment - Toolchain overview

Env setup and features:

- Easy install: `curl --proto '=https' --tlsv1.2 -sSf https://sh.rustup.rs | sh`
- Rustup for managing toolchains: `rustup update`
- Included formatter: `rustfmt --check src/main.rs` (dry-run mode)
- Cargo for building and managing projects: `cargo new project_name`
- Quality of life with `rust-analyzer`: LSP, build/debug IDE support etc.

Development environment - Cargo features

Useful Cargo commands when building a project:

- `cargo build` or `cargo run` to compile and run the project. Use `--release` flag for compilation with optimizations inside `target/release/`
- `cargo check`: Check the project for errors without building
- `cargo doc`: Generate documentation for the project
- `cargo clean`: Remove build artifacts
- `cargo update`: Update dependencies
- `cargo fmt`: Format the code according to the Rust style guidelines
- `cargo test`: Run tests in the project

🛠️ **Practical project #0 -** Guessing game

Great way to introduce to the development environment and basic concepts of Rust:

- Common programming concepts (types, funcs, control flow)
- Use of another crate (rand) inside the project
- I/O, String manipulation, error handling
- Compiler warnings and error messages
- `rust-analyzer` compiler FE for IDE support

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🚀 Demo Time!

Simple guessing game CLI app 🎲 (Basics and dev environment features)

Demo reminders - P#0 (Guessing game)

- `Result` type with `.expect()` for error handling
- `cargo doc --open` to generate and view documentation
- `cargo fmt` to format the code
- Type annotations and `let` for variable declaration

📝 Variables and mutability

Variables are immutable by default

```
let x = 5;             // immutable variable
x = 10;                //!ERROR!

let mut y = 10;        // mutable variable
y = 15;                // Will compile (overwrite with same type)
let y = "hello";       // Will compile (shadowing)
```

Constants are always immutable within the scope

```
const MAX_POINTS: u32 = 100_000;
```

🧮 Statically typed + type inference

`rust-analyzer` provides type hints and suggestions

```
let secret_num = rand::thread_rng().gen_range(1..101); // Will infer i32 type
```

Explicit type annotations can or must be used

```
let mut num: String = String::new(); // Can be annotated or inferred
num = "42".to_string();

let guess = guess.trim().parse().expect("Please enter a number");  // Wont Compile
let guess: u32 = guess.trim().parse().expect("Please enter a number"); // Will compile
```

🧮 **Data types** - Scalars

Data type	Size	Specifity
int	8-128 bits	signed/unsigned
float	32/64 bits	simple/double precision
char	4 bytes	unicode
bool	1 byte	true/false

🧮 Data types - Compound

Data type	Size	Elements	Example	Access
tuple	fixed	mixed types	`(1, "hello", 3.14)`	`tuple.0`
array	fixed	same type	`[1, 2, 3, 4, 5]`	`array[0]`
vec	dynamic	same type	`vec![1, 2, 3, 4, 5]`	`vec[0]`

Access safety with runtime bounds checking. If using `array[10]` will panic at runtime instead of *undefined behavior like in C/C++*

⚙️ Functions - `main`

Functions are defined with the `fn` keyword. All programs start with a `main` function

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

    say_hello_back();
}

fn say_hello_back() {
    println!("Hello back!");
}
```

⚙️ **Functions** - Parameters and return

Function signatures and use:

- Parameters must have type annotations
- Return type must be specified with `->`
- Functions can return multiple values with tuples

```rust
fn main() {
    let num_sum = add(5, 10);
    println!("The sum is: {}", num_sum);
}

fn add(x: i32, y: i32) -> i32 {
    x + y
}
```

📜 Statements

- `let` is a statement, and `x + y` is an expression.
- Compared to C/C++, var assignment is an expression in Rust and **does not** return a value
- Statements must end with a semicolon `;`

```
let x = 5;              // statement
let y = z = 10;         // ERROR! z = 10 does not return a value
```

💡 Expressions

- Expressions **evaluate** to a value (*func calls, operations, blocks*)
- No `;` at the end of expressions
- **Blocks** `{}` are expressions and can be used to create new scopes + return values

```rust
fn main() {
    let x = 5; // whole line is statement, 5 is expression
    let y = {
        let x = 3;
        x + 1
    }; // an expression
    println!("The value of y is: {}", y); // Prints 4!
}
```

🧰 Control Flow - Conditionals

if/else: (Only takes boolean expressions)

```rust
// Classic if/else if/else
let mut condition = false;
if number < 5 {
    println!("Too small!");
} else if number > 5 {
    println!("Too big!");
} else {
    println!("Just right!");
    condition = true;
}

// Assignement with if/else
let result = if condition { 5 } else { 6 };
```

🧰 **Control Flow** - Loops overview

3 types of loops in Rust: `loop`, `while` and `for`

- `loop`: Infinite loop until `break` or return
- `while`: Loop while condition is true
- `for`: Loop over an iterator

```rust
// Conditional loop
let mut counter = 0;
while counter < 10 {
    println!("counter = {counter}");
    counter += 1;
}
```

🧰 Control Flow - Loop labels

Loop labels can be used to distinguish nested loops (*break* and *continue*)

```rust
fn main() {
    let mut count = 0;
    'counting_up: loop { // Label the outer loop
        println!("count = {count}");
        let mut remaining = 10;

        loop {
            println!("remaining = {remaining}");
            if remaining == 9 {
                break;
            }
            if count == 2 {
                break 'counting_up;    // Break the outer loop
            }
            remaining -= 1;
        }
        count += 1;
    }
    println!("End count = {count}");
}
```

🧰 **Control Flow** - Collection with `for`

No need for manual indexing, `for` loops iterate over collections

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

🔎 **Ranges**, use the `..` operator

```
for number in 1..4 {
    println!("The value is: {number}");
}
```

🔑 **Ownership** - Overview

Ownership is a key feature of Rust regarding the management of stack (*static, compile-time known, LIFO*) and heap memory (*allocated at runtime, dynamic, FIFO*).

It ensures memory safety without garbage collection.

The 3 rules of ownership:

1. Each value in Rust has a variable that's its owner
2. There can only be one owner at a time
3. When the owner goes out of scope, the value will be dropped

🔑 **Ownership** - String Type vs. literals

```rust
let s1: &str = "hello"; // string literal, immutable

{
    // s1 is still valid
    let mut s2 = String::from("hello"); // allocated on the heap
    s2.push_str(", world!"); // Mutable

} // calls drop(), s2 goes out of scope its memory is freed
```

- String literals hardcoded into binary. Immutable and fast.
- `String` type is allocated on the heap and is mutable. Memory freed when out of scope. Similar to smart pointers in C++.

🔑 **Ownership** - Move

```rust
// MOVE
let s1 = String::from("hello");
let s2 = s1; // s1 is moved to s2
println!("{s1}"); // ERROR! s1 is no longer valid

// DEEP COPY
let s3 = s2.clone(); // deep copy
println!("{s2}"); // s2 is still valid
```

No *double free* or *dangling pointers* with the **move** operation (first 3 lines of code).

🔑 Ownership - Copy

Types that implement the `Copy` trait are copied instead of moved. Stack-only data types (i.e. integers, booleans, char etc.) for speed and efficiency.

```
let x = 5;
let y = x; // x is copied to y

println!("{x}"); // x is still valid. Same as x.clone() but no needed
```

🔑 Taking ownership - Functions

```rust
fn main() {
    let s = String::from("hello");  // s comes into scope

    takes_ownership(s);             // s's value moves into the function...

    let x = 5;                      // x comes into scope
                                    // but i32 is Copy, so x available afterward

    println!("{s} world!");         // ERROR! s is no longer valid
}

fn takes_ownership(some_string: String) { // some_string comes into scope
    println!("{some_string}");
} // `some_string` goes out of scope, `drop` is called and memory is freed

fn makes_copy(some_integer: i32) { // some_integer comes into scope
    println!("{some_integer}");
} // `some_integer` goes out of scope, nothing happens.
```

🔑 **Transfer Ownership** - Function return and scope

A bit tedious, but ownership can be transferred back to the calling function with the return value.

```rust
fn main() {
    let s1 = gives_ownership();         // `gives_ownership` moves its return val into s1

    let s2 = String::from("hello");     // s2 comes into scope

    let s3 = takes_and_gives_back(s2);  // s2 is moved into `takes_and_gives_back` becomes invalid
                                        // `takes_and_gives_back` returns a new String that into s3
}

fn gives_ownership() -> String {             // `gives_ownership` move return val into the
                                             // function that calls it

    let some_string = String::from("yours"); // some_string comes into scope

    some_string                              // some_string is returned moves out of calling func
}

// This function takes a String and returns one
fn takes_and_gives_back(a_string: String) -> String { // a_string comes into scope

    a_string  // a_string is returned and moves out to the calling function
}
```

🤝 **References and Borrowing** - Overview

Kind of like passing by reference in C/C++ but with some key differences:

- **References** are immutable by default
- **Borrowing** allows multiple references to the same data
- **Mutable references** are exclusive and have strict rules

References are created with the `&` symbol, and borrowing is done with `&mut` for mutable references (see next slide).

🤝 References and Borrowing - Simple borrowing example

```rust
fn main() {
    let s1 = String::from("hello");

    let len = calculate_length(&s1);

    println!("The length of '{s1}' is {len}."); // s1 still valid because it is borrowed
}

fn calculate_length(s: &String) -> usize { // s is a reference to a String
    s.len()
} // s goes out of scope, but does not have ownership of what it refers to
```

🤝 Mutable references - General case

Borrowed references are not mutable by default. To allow mutation, use `&mut`

```
// let s = String::from("hello"); // WOULD NOT COMPILE!
let mut s = String::from("hello");
change(&mut s);

fn change(some_string: &mut String) {
    some_string.push_str(", world");
}
```

🤝 Mutable references - Data races safety

Compile time checks for mutable refs

⚠️ **NO** multiple mutable references to the same data

```
let mut s = String::from("hello");
let r1 = &mut s;
let r2 = &mut s;    // ERROR! r1 is still active
println!("{}, {}", r1, r2);
```

⚠️ **NO** mutable references while immutable references are active

```
let mut s = String::from("hello");
let r1 = &s;         // OK
let r2 = &s;         // OK
let r3 = &mut s;     // ERROR! r1 and r2 are still active
println!("{}, {}, {}", r1, r2, r3);
```

🤝 **Mutable references** - Data races safety (2/2)

🔎 Use of scopes to limit mutable references

```rust
let mut s = String::from("hello");
{
    let r1 = &mut s;
} // r1 goes out of scope, allowing a new mutable reference
let r2 = &mut s; // OK!
```

🔎 Reference's scope ends after the last usage of the reference.

```rust
    let mut s = String::from("hello");

    let r1 = &s; // no problem
    let r2 = &s; // no problem
    println!("{r1} and {r2}");
    // variables r1 and r2 will not be used after this point

    let r3 = &mut s; // no problem because r1/r2 are no longer valid
    println!("{r3}");
```

⚠️ **Reference caution** - Fixing a state management problem

❗ Tedious or even problematic when working on a reference

```rust
let mut s = String::from("hello world");
let word_index = first_word(&s); // word_index will get the value 5

s.clear(); // empties the String, making it equal to ""
// `word_index` still has the value 5 here, but no more string tied because s is invalid
println!("the first word is: {s[..word_index]}"); // ERROR! s is empty
```

```rust
fn first_word(s: &String) -> usize {
    let bytes = s.as_bytes();
    for (i, &item) in bytes.iter().enumerate() {
        if item == b' ' {
            return i;
        }
    }
    s.len()
}
// Imagine implementing second_word() and managing state...
```

🔪 **String Slice Type** - A kind of reference

Slices are references to a contiguous sequence of elements in a collection. They are a reference to a part of a string or array.

```rust
let s = String::from("hello world");
let hello = &s[0..5];   // same as &s[..5]. Excludes the last index
let world = &s[6..11];  // same as &s[6..]. Includes the first index
```

🔪 String Slice - Refactoring `first_word()`

```rust
fn first_word(s: &String) -> &str {
    let bytes = s.as_bytes();
    for (i, &item) in bytes.iter().enumerate() {
        if item == b' ' {
            return &s[0..i]; // return a slice(ref) of the string
        }
    }
    &s[..]  // or return the slice of whole string
}
```

```rust
// Compiler assures that the slice is valid as long as the string is valid
fn main() {
    let mut s = String::from("hello world");
    let word = first_word(&s); // immutable borrow (return type is &str)

    s.clear(); // error! mutable borrow while immutable borrow is active
    println!("the first word is: {word}");
}
```

🔪 **Other Slice types** - Array example `first_word()`

Similar to strings, slices can be used with arrays

```
fn main() {
    let a = [1, 2, 3, 4, 5];
    let slice = &a[1..3]; // slice is of type &[i32]
    assert_eq!([2, 3], slice);
}
```

Useful for passing parts of arrays to functions without copying the data.

☠️ Dangling Pointers -

⚙️ TODO

🛠️ **Practical project #1** - Write an I/O CLI program

Halfway project for a `grep` clone CLI app covers:

1. Code organization (crates, modules)
2. Use of containers and strings
3. Error handling
4. Using traits and lifetimes
5. Testing and documentation

Klabnik, Steve, and Carol Nichols. The Rust Programming Language. 2nd ed., No Starch Press.

🛠️ **Practical project #2** - Building a Multithreaded Web Server

Final Project from the book includes :

1. Learn TCP/IP networking and HTTP
2. Listen to TCP connections on a socket
3. Parse HTTP requests
4. Generate HTTP responses
5. Handle multiple requests concurrently with a thread pool

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⚙️ THEORY STUFF

TODO