An Overview of the RUST Programming Language

Meet Your Presenter!

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What Will You Get Out Of Tonight's Presentation?

- Understanding of why Rust has become popular
- An introduction to the Rust programming language
- Ownership: Move, Clone, Copy
- References
- Borrowing

Image Credit: https://clipart-library.com

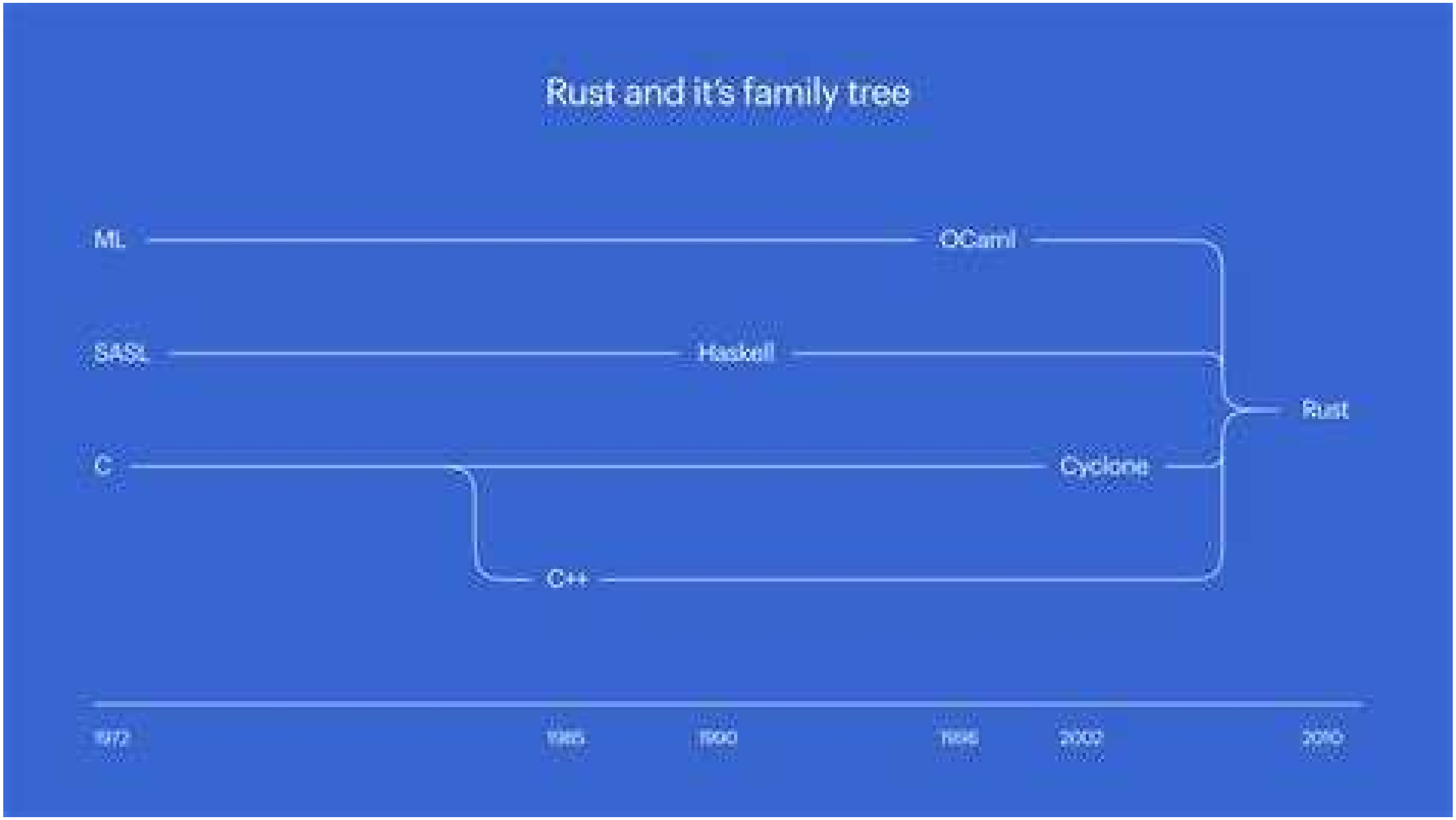
History Of Rust

- Rust started as a personal language that was developed by Graydon Hoare who worked for Mozilla in 2006.
- Rust was officially recognized as a Mozilla sponsored project in 2009 and was first publicly announced in 2010.
- The first pre-alpha version of Rust was released in January of 2012.
- The current stable version of Rust is version 1.16.
- The operating systems supported by Rust include: Linux, Windows, macOS, Android, IOS, etc.

What Is Rust?

- Graydon Hoare called Rust a "safe, concurrent, and practical language" that supports the functional and imperative paradigms.
- Rust’s syntax is comparable to that of the C++ programming language.
- Rust is free and open-source software, which means that anybody may use it for free, and the source code is openly provided so that anyone can enhance the product’s design.
- There is no such thing as direct memory management, such as calloc or malloc - Rust manages memory internally.
- Rust was developed to deliver excellent performance comparable to C and C++ while prioritizing code safety, which is the Achilles’ heel of the other two languages.

Rust Is Built On Other Langauges



Why Use Rust?

- Rust is a strongly typed programming language that prioritizes speed and safety and extraordinarily safe concurrency and memory management.
- Rust tackles two long-standing concerns for C/C++ developers: memory errors and concurrent programming.
- This is regarded as its primary advantage.
- Rust manages memory internally - trash collection is not required.
- In Rust, each reference has a lifespan, which specifies the scope for which that reference is valid.
- Over the last 12 years memory safety concerns have accounted for over 70% of all security flaws in Microsoft products, the necessity of proper memory management becomes instantly clear.

Why Use Rust?

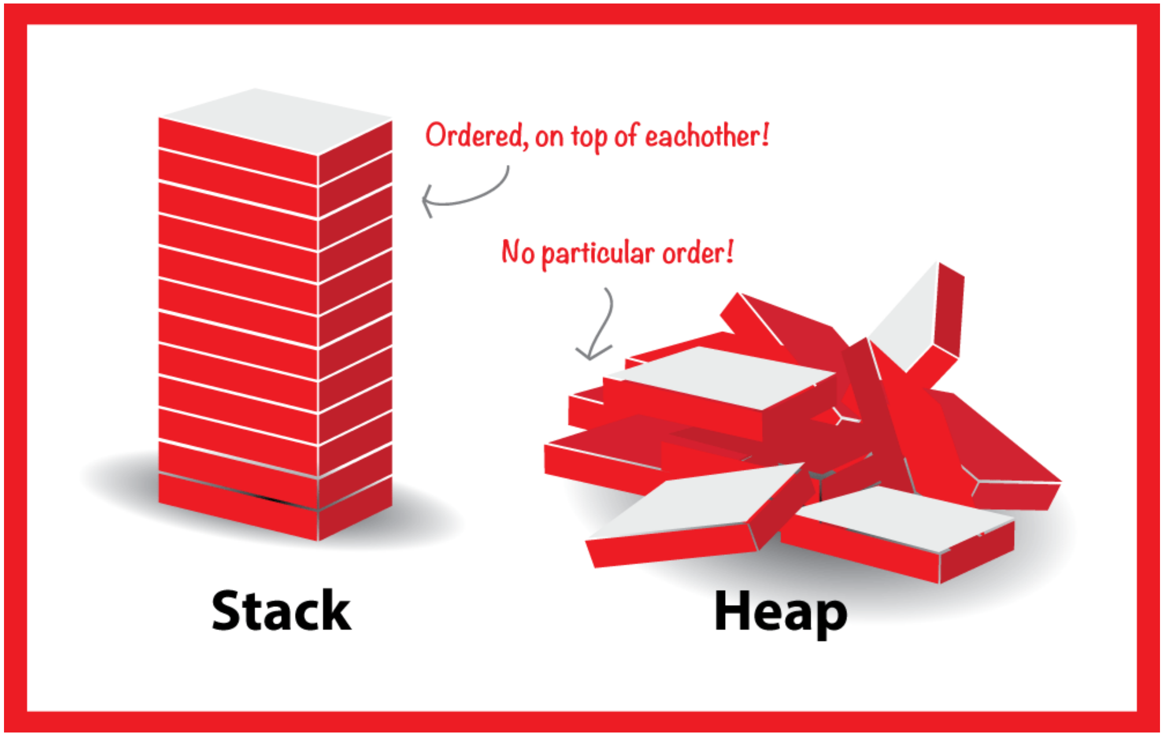
- Like C, Rust helps control low-level details as a systems programming language.
- Using Rust means that we're safe against resource leakage problems.
- Because Rust does not have an active garbage collector, other programming languages may utilize its projects as libraries via foreign-function interfaces.
- This is a good case for existing projects where high performance while preserving memory safety is crucial.
- In such cases, Rust code may replace select areas of software where speed is critical without rebuilding the entire product.

Why Use Rust – The NSA Memo

- On 11/10/22 the NSA released a memo entitled "Software Memory Safety" Cybersecurity Information Sheet
- In it they made the following statements:
  - Memory issues in software comprise a large portion of the exploitable vulnerabilities in existence.
  - NSA advises organizations to consider making a strategic shift from programming languages that provide little or no inherent memory protection, such as C/C++, to a memory safe language when possible.
  - Memory safe languages were identified as being: C#, Go, Java®, Ruby™, Rust®, and Swift®

The Stack & The Heap

All data stored on the stack must have a known fixed size at compile time. FIFO.



Data without a known size at compile time or with a size that may change will be stored on the heap.

- Rust stores variables on either its stack or its heap
- The behavior (speed, size, etc.) is different between the two options.
- We will discuss this in detail later on.

Image Credit: https://medium.com/@Miguel_Grillo/stack-vs-heap-and-the-virtual-memory-ea075ea6e3fc

HELLO WORLD AND VARIABLES

"Hello World" In Rust

- The Rust Hello World program looks like this:

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

```
> cargo run
    Finished dev [unoptimized + debuginfo] target(s) in 0.01s
     Running `target/debug/my-project`
Hello, world!
>
```

Picking Apart "Hello World"

- **fn**
  - The fn is short for "function." In Rust (and most other programming languages), a function means "tell me some information, and I'll do some things and give you an answer."
- **main**
  - The main function is a special function: just like in C, it's where your program starts.
- **()**
  - These parentheses are the parameter list for this function. It's empty right now, meaning there are no parameters. Every left parenthesis has a matching right.
- **{ }**
  - These are called curly braces or brackets. We actually need to give the main function a body. The body lives inside these braces. The body will say what the main function actually does. Every left curly brace has a matching right.

Picking Apart "Hello World"

- **println!**
  - This is a macro. It means "print and add a new line." Macros are very similar to functions - the difference is that it ends with an exclamation point (!). Rust has a print! Macro that stays on the same line after printing.
- **("Hello, world!")**
  - This is the parameter list for the macro call. We're saying "call this macro called **println** with these parameters."
- **"Hello, world!"**
  - This is a string. Just like in C strings are a bunch of letters (or characters) put together. We put them inside the double quotes (**"**) to mark them as strings.
- **;**
  - This is a semicolon. It completes a statement. Statements do something specific. In this case, it's calling the macro.

Rust Interpolation

- Def: **<u>interpolation</u>** - the insertion of something of a different nature into something else.
- In Rust, in order to include other values in what we are printing out, we can interpolate them.
- Example:

```
fn main() {
    println!("My name is {}", "Michael");
}
```

```
> cargo run
   Blocking waiting for file lock on build directory
  Compiling my-project v0.1.0 (/home/runner/Rust-Hello-World)
   Finished dev [unoptimized + debuginfo] target(s) in 1.88s
    Running `target/debug/my-project`
My name is Michael
>
```

Interpolation

- We now pass two parameters to the **println** macro: the first string is "**My name is {}**".
- The **println** macro has special support for the **{}** braces.
- It means: see that next parameter? Stick it in here.
- This program is going to print "**My name is Michael**".
- And we separate the parameters by putting a comma.

println! Macro

- The println! macro accepts two parameters:
  1. A unique syntax {}, which acts as a placeholder
  2. The name of a variable or a constant
- The variable's value will be used to replace the placeholder.
- Example:
  println!("company rating on level 5:{}",rating_float);

ANATOMY OF RUST

Variables In Rust

- Just like in C, a variable is a named storage location that programs may access.
- A variable is a type of data structure that allows programs to store values.
- In Rust, variables are always linked with a specific data type.
- The data type dictates both the variable’s memory size and layout, the range of values stored inside that memory, and the set of operations on the variable.

Variable Naming Syntax

- When declaring a variable in Rust, the data type is optional.
- The value assigned to the variable determines the data type.
- The syntax for defining variables is as follows:
  - let variable_name = value; // no type-specified
  - let variable_name:dataType = value; //type-specified
- Example:

```
fn main() {
        let fees=35000;
        let salary:f64=45000.00;
        println!("fees is {} and salary is {}",fees,salary);
}
```

Rust Scalar Types

- A scalar type is a value that has just one value.
- For instance:
  10,
  3.14,
  ’c’
- Rust has four distinct scalar types.

1. Integer
2. Floating point
3. Booleans
4. Characters

Declaring Variables

- To declare a variable, we use the let keyword.
- Example:

```
fn main() {
    let company_string="Amazon"; // string type
    let rating_float=3.5; // float type
    let is_growing_boolean=true; // boolean type
    let icon_char='♥'; //unicode character type
    println!("company name:{}",company_string);
    println!("company rating on 5:{}",rating_float);
    println!("company is growing :{}",is_growing_boolean);
    println!("company icon:{}",icon_char);
}
```

- The data type of the variables in the example will deduce from the values assigned to them.
- Rust, for instance, will assign the string data type to the variable company string, the float data type to rating float, and so on.

Immutable

- By default, variables are immutable in Rust.
- In other words, the value of the variable cannot change once a value is bound to a variable name.
- Example:

```
fn main() {
        let fees=25_000;
        println!("fees is {} ",fees);
        fees=35_000;
        println!("fees changed is {}",fees);
}
```

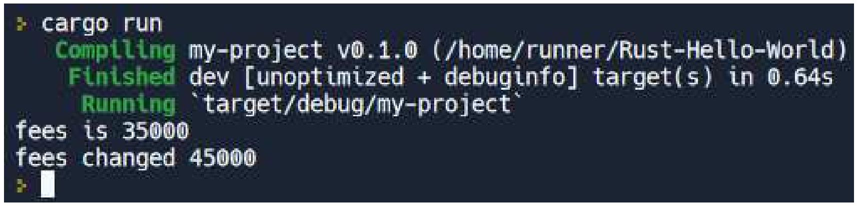
```
> cargo run
   Compiling my-project v0.1.0 (/home/runner/Rust-Hello-World)
error[E0384]: cannot assign twice to immutable variable `fees`
 --> src/main.rs:4:3
  |
2 |   let fees=25_000;
  |       ----
  |       |
  |       first assignment to `fees`
  |       help: consider making this binding mutable: `mut fees`
3 |   println!("fees is {} ",fees);
4 |   fees=35_000;
  |   ^^^^^^^^^^^ cannot assign twice to immutable variable
```

- Note we cannot set values to the immutable variable fees twice.
- This is just one of the numerous ways Rust allows programmers to write code while benefiting from the safety and ease of concurrency

Mutable

- By default, variables are immutable.
- To make a variable changeable, prefix it with the term **mut**.
- A mutable variable's value can be changed.
- The syntax for defining a mutable variable is:
  - let **mut** variable_name = value;
  - let **mut** variable_name:dataType = value;
- Example:

```
fn main() {
        let mut fees:i32=35_000;
        println!("fees is {} ",fees);
        fees=45_000;
        println!("fees changed {}",fees);
}
```



Number Types In Rust

- There's a little bit more to numbers to talk about.
- The first thing is about ***integers*** versus ***floating point***.
- Just as in C, integers are whole numbers, like 5, -2, 0, etc.
- They are numbers that don't have a decimal point or a fractional part.
- Floating point numbers can have decimal points.

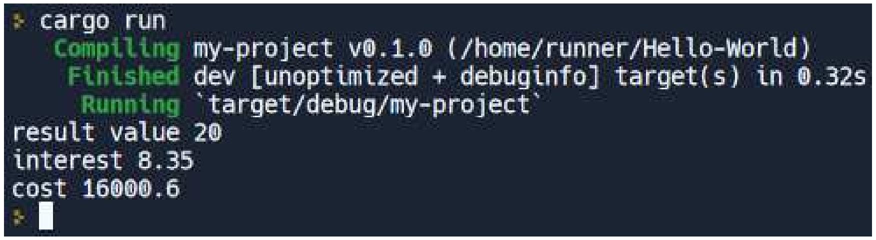
Math In Rust

- + : addition
- - : subtraction
- * : multiplication
- / : division
- % : Modulus/Remainder
- (5.0/3.0).floor() : floor division
- i32::pow(self, exp) : raise self to exp (u32) and return an integer (i32)
  f32::powi(self,exp) : raise self to exp (i32) and return a float (f32)
  f32::powf(self,exp) : raise self to exp (f32) and return a float (f32)

Float Data Type

- In Rust, float data types are categorized as f32 and f64.
- The f32 type is a single-precision float, whereas the f64 type is a double-precision float.
- The type that is used by default is f64.
- Example:

```
fn main() {
    let result=20.00;
    let interest:f32=8.35;
    let cost:f64=16000.600; // double precision
    println!("result value {}",result);
    println!("interest {}",interest);
    println!("cost {}",cost);
}
```



Printing Floats

- Just like in C, float (and integer) variables can be formatted as they are being printed.
- You have control over the size of the window that the number is printed in and the number of digits that will be displayed after the decimal point.
- You do NOT have the ability to have a comma printed after every three characters.
- Example:
  println!("The value is {0:12.2}",707.126456789);

Character Type

- Rust's character data type accepts integers, alphabets, Unicode, and special characters.
- To declare a variable of the character data type, use the char keyword.
- The char type in Rust represents a Unicode Scalar Value, which implies it may represent much more than simply ASCII.
- The Unicode Scalar Values span from U+0000 to U+D7FF [55,295] and from U+E000 [57,344] to U+10FFFF [1,114,111].
- Example:

```
fn main() {
        let special_character='@'; //default
        let alphabet:char='D';
        let emoji:char=' ';
        println!("special character {}",special_character);
        println!("alphabet {}",alphabet);
        println!("emoji {}",emoji);
}
```

Understanding Ownership:
Move, Clone, Copy

What Is Ownership In Rust?

- The primary aspect of Rust is ownership.
- Although the characteristic is simple to describe, it has deep implications for the rest of the language.
- All programs must manage how they use memory while running on a computer.
- Some languages offer **garbage collection** [i.e. Java], which searches for no longer utilized memory while the program runs; in others, the programmer must actively allocate and delete memory [i.e. C].
- Rust has a third approach: memory is controlled using an ownership system with rules that the compiler validates at compile time.
- While our software is running, none of the ownership aspects will slow it down.

Ownership Concepts

- The “owner” can modify the ownership value of a variable based on its mutability.
- The ownership of a variable can transfer to another variable.
- In Rust, ownership is just a matter of semantics.
- In addition, the ownership concept ensures safety

Rules Of Ownership

- In Rust, each value has a variable called its owner.
- At any one moment, there can only be one owner.
- When the owner exits the scope, the value is destroyed (also known as being freed).

Variable Scope

- Let's look at the scope of several variables as a first illustration of ownership.
- A scope is the range of items that are valid within a program.
- Assume we have a variable that looks something like this:
  let st=“hello”;
- The variable st refers to a literal string, the value of which is hardcoded into the program’s text.
- The variable is valid from the time it is declared until the current scope expires.

Variable Scope

- This example includes comments that indicate when the variable st is valid.

```
// st is not valid here, it's not yet declared
{
        let st="hello"; // st is valid from this point forward
        // do stuff with st
}
// this scope is now over, and st is no longer valid
```

- In other words, there are two critical time points here:

  1. It is valid when st enters the scope.
  2. It is still valid until it goes out of scope.

- The connection between the scope and when variables are valid is comparable to that of other programming languages at this stage.

How Variables and Data Interact: Move

- In Rust, several variables can interact with the same data in various ways.

- We now look at an example with an integer.
  let a=8;
  let x=a;
  let b=x;

- "Bind the value 8 to a; then make a copy of the value in x and bind it to b."

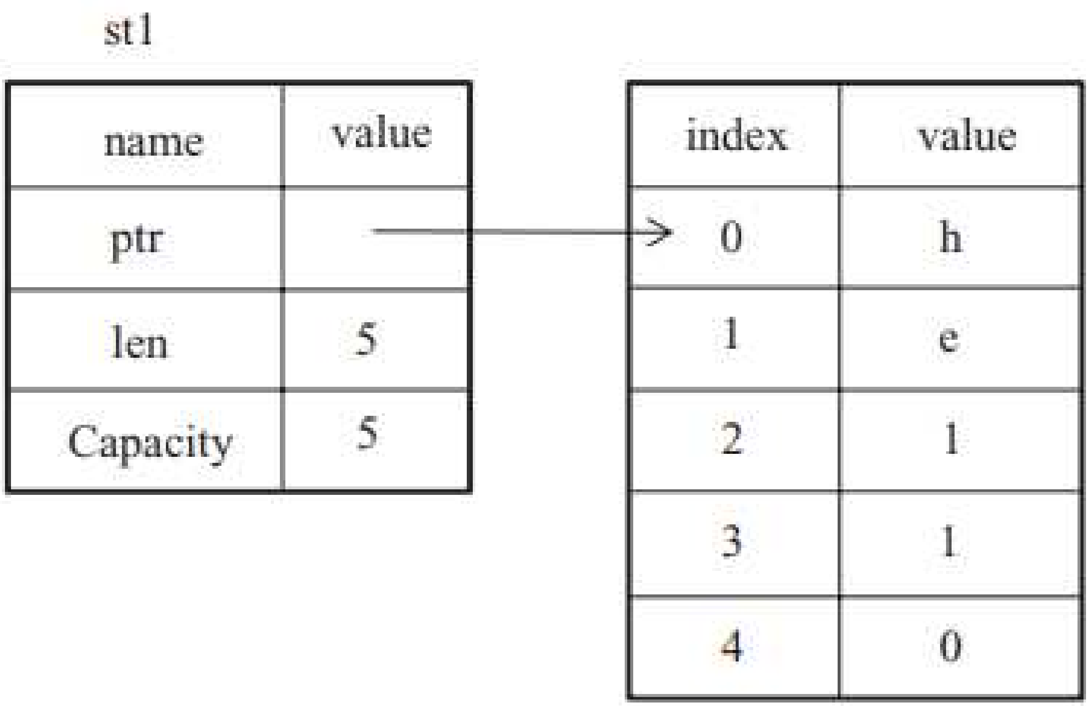
- We now have two variables, a and b, equal to 8.

- This is correct because integers are simple values with a known, defined size, and these two 8 values are placed into the stack.

- Let's have a look at the String version:
  let st1=String::from("hello");
  let st2=st1;

- This code appears to be quite similar to the preceding code, so we can conclude that the function is the same: the second line would duplicate the value in st1 and bind it to st2.

How Variables and Data Interact: Move

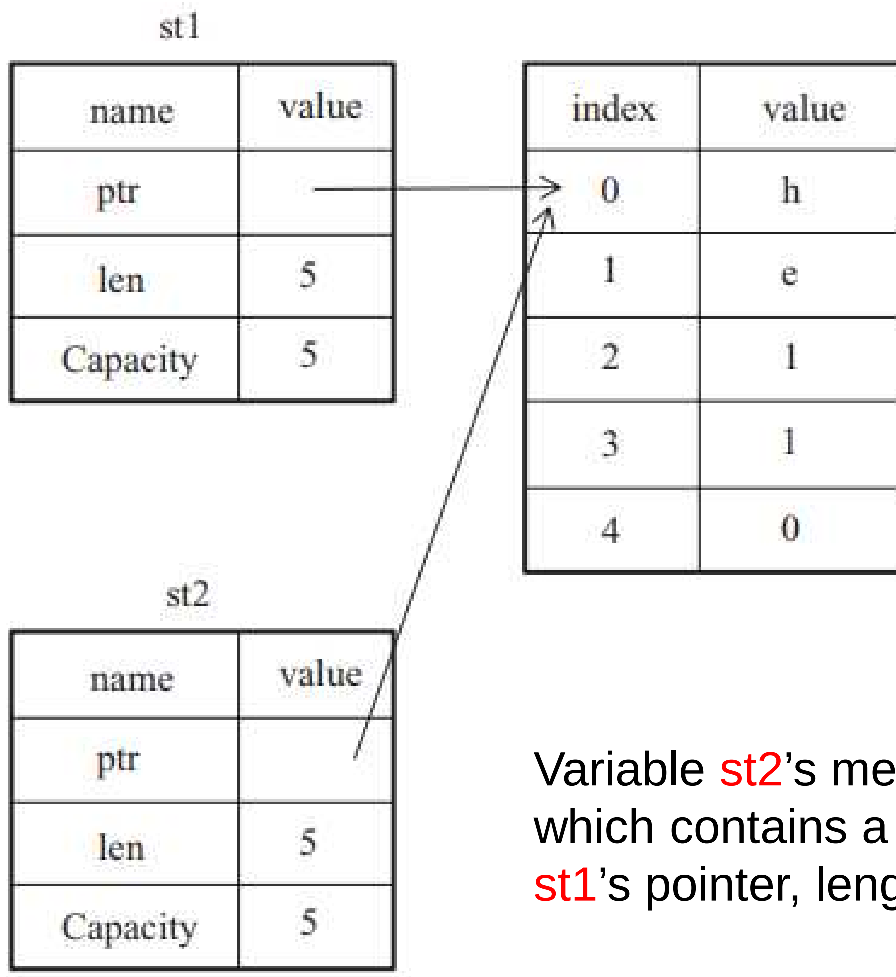


Memory representation of a String with the value “hello” linked to st1.

How Variables and Data Interact: Move

- However, this is not the case.
- The length specifies how much memory (in bytes) the String's contents presently occupy.
- The capacity is the entire amount of memory that the allocator gives the String in bytes.
- The distinction between length and capacity is essential, but not in this context, so ignore the capacity for the time being.
- When we assign st1 to st2, the String data is duplicated, which means we copy the stack's pointer, length, and capacity.

How Variables and Data Interact: Move



Variable st2's memory representation, which contains a duplicate of st1's pointer, length, and capacity.

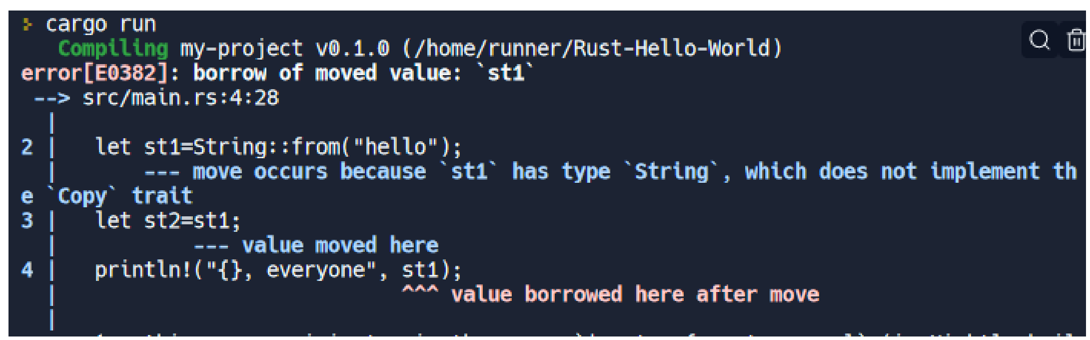
How Variables and Data Interact: Move

- We do not replicate the data on the heap to which the pointer points.
- Rust automatically executes the drop function when a variable exits scope and cleans away the heap memory for that variable.
- However, in the figure both st1 and st2 data pointers point to the same place.
- This is an issue because when st2 and st1 exit scope, they will attempt to free the same memory.
- This is referred to as a **double free mistake**.
- Memory corruption can result from freeing memory twice, leading to security vulnerabilities.

How Variables and Data Interact: Move

- There is one additional element to what occurs in this circumstance in Rust to ensure memory safety.
- Rust considers st1 invalid after letting st2 = st1.
- As a result, when st1 exits scope, Rust does not need to release anything.
- Examine what happens if we try to utilize st1 after st2 is generated; it will not work:

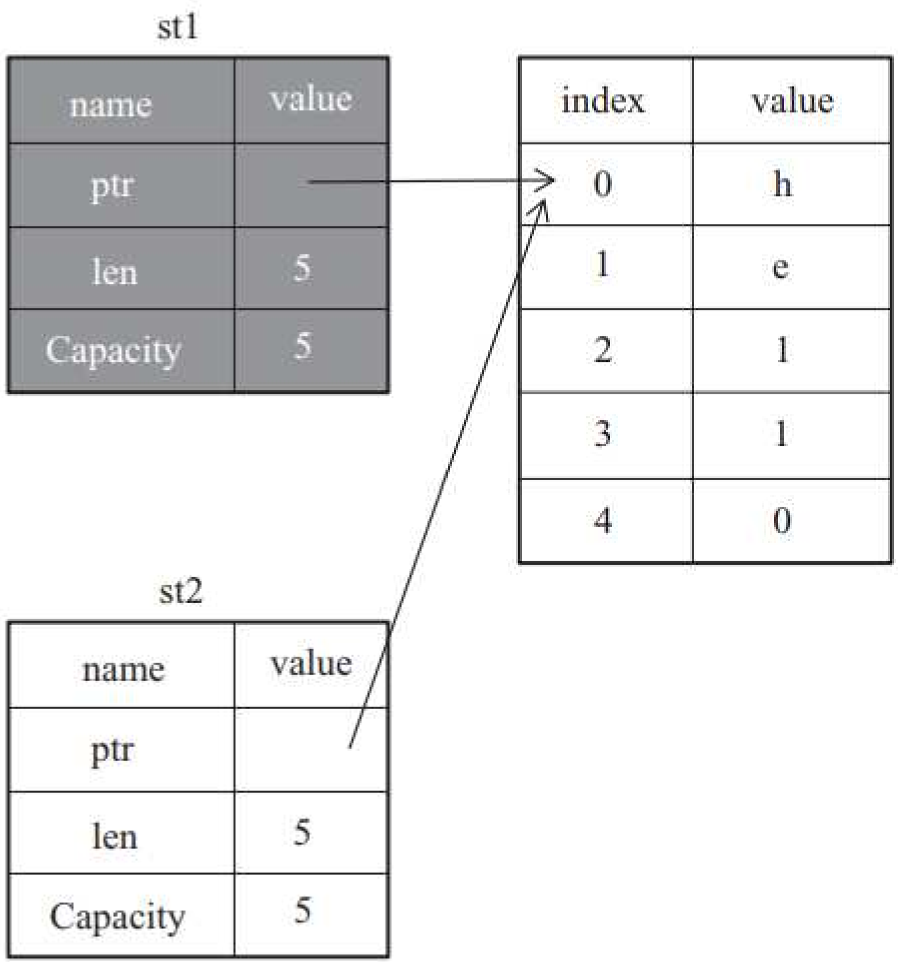
```
let st1=String::from("hello");
let st2=st1;
println!("{}, everyone", st1);
```



How Variables and Data Interact: Move

- Because Rust invalidates the first variable, it is referred to as a **move**.
- In this case, we would state that st1 was relocated to st2.
- That takes care of our issue!
- With just st2 valid, when it exits scope, it will release the memory on its own, and we're done.
- Furthermore, this implies a design choice: any automated copying may be presumed to be low cost in terms of runtime performance.

How Variables and Data Interact: Move



Memory representation after s1 has been invalidated.

Ownership And Moving

- Blocks can also be owners.
- Example:

```
fn main() {
        {
                let x: i32 = 5;
                println!("{}", x);
        }
}
```

- **main** owns that block, and the block owns the value 5.
- And values can even own other values.
- Remember that you can only have one owner for a value at a time.

No Ownership Problem: Copy

- Example:

```
fn count(apples: i32) {
        println!("You have {} apples", apples);
}
fn price(apples: i32) -> i32 {
        apples * 8
}
fn main() {
        let apples: i32 = 10;
        count(apples);
        let price = price(apples);
        println!("The apples are worth {} cents", price);
}
```

```
> cargo run
   Compiling my-project v0.1.0 (/home/runner/Rust-Hello-World)
    Finished dev [unoptimized + debuginfo] target(s) in 0.67s
     Running `target/debug/my-project`
You have 10 apples
The apples are worth 80 cents
>
```

Why Don't We Have A Problem?

- **Copy** is a trait in Rust that says "this thing is so incredibly cheap to make a copy of, that each time you try to move it, it’s fine to just make a copy and move that new copy instead."
- And i32 is an example of a type which is so cheap.
- Therefore, in our code here, count(apples) doesn’t **move** the value into count.
- Instead, it makes a **copy** of the value 10, and moves that copy into count.
- But the original 10 inside the apples variable remains unchanged.

Stack-Only Data: Copy

- The Rust annotation Copy trait may be applied to types like integers stored on the stack.
- If a type has the Copy trait, an older variable can still be used after the assignment has been performed.
- Rust will not allow us to annotate a type with the Copy trait if the type or any of its components has the Drop trait implemented.
- If we add the Copy annotation to a type that requires anything specific to happen when the value is out of scope, we will get a compile-time error.

Variables and Data Interactions: Clone

- We may use the clone method to thoroughly duplicate the String’s heap data rather than merely the stack data. [also called a "deep copy"]
- Here’s an example of how to use the clone method:

```
let st1=String::from(“hello”);
let st2=st1.clone();
println!(“st1={}, st2={}”, st1, st2);
```

- This works well and generates the behavior in the previous example, where the heap data is explicitly copied: both st1 and st2 now contain the string "hello".
- Performing a clone call might be costly to perform depending on the variable that is being duplicated.

Stack-Only Data: Copy vs Clone

- This code use integers:
  ```
  let a=8;
  let b=a;
  println!("a={}, b={}", a, b);
  ```
- However, this code appears to contradict what we have just learned: there is no call to clone, but a is still valid and was not transferred into b.
- This is because types with known sizes at build time, like integers, floats, Booleans, characters, and tuples (depending on what they contain) are wholly stored on the stack; thus, copies of the actual values are quickly produced.
- There is no reason to prevent a from being valid after we have created the variable b.
- In this case, there is no distinction between deep and shallow copying.
- Therefore, invoking clone would perform nothing more than shallow copying so that we can leave it out.

Ownership and Functions

- Passing a value to a function has semantics comparable to giving a value to a variable.
- Passing a variable to a function will cause it to move or copy much like an assignment.
- The following example has annotations indicating where variables enter and exit their scope.

Ownership and Functions

```
fn main() {
        let st=String::from("hello"); // st comes into scope
        takes_ownership(st); // st's value moves into the function... and so is no longer valid
        let a=5; // a comes into scope
        makes_copy(a); // move into the function, but a (i32) is Copy, so okay to still use afterward
}
        // Here, a goes out of scope, then st. But because st's value was moved, nothing
        // special happens.

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

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

Return Values and Scope

- Ownership can also be transferred by returning values.
- Every time, the ownership of a variable follows the same pattern: assigning a value to another variable changes it.
- When a variable that includes heap data exits scope, the value is destroyed unless the data has been transferred to be held by another variable.
- Example:

Return Values and Scope

```
fn main() {
        let st1=gives_ownership(); // gives_ownership moves its return value into st1
        let st2=String::from(“hello”); // st2 comes into the scope
        let st3=takes_and_gives_back(st2);
        // st2 is moved into takes_and_gives_back, which also moves its return value into st3.
}
        // Here, st3  goes out of the scope and is dropped. st2 was moved, so nothing happens.
        // st1 goes out of the scope and is dropped.

fn gives_ownership() ->String { // gives_ownership will move its return the value into function that calls it
        let some_string=String::from(“yours”);  // the some_string comes into scope
        some_string        // the some_string is returned and moves out to calling function
        }

// This function takes 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 a function
}
```

Return Values and Scope

- Taking ownership and then restoring ownership with each function is time-consuming.
- What if we want a function to utilize a value but not own it?
- It is inconvenient because whatever we send data to a function, in addition to any data originating from the function's body that we might want to return, it must be sent back if we want to use it again.
- A tuple can be used to return many values:

```
fn main() {
        let st1=String::from("hello");
        let (st2, len)=calculate_length(st1);
        println!("length of '{}' is {}.", st2, len);
}
fn calculate_length(st: String) ->(String, usize) {
        let length=st.len(); // len() returns the length of a String
        (st, length)
}
```

References & Borrowing

References And Borrowing In Rust

- A reference is an address passed as an argument to a function.
- Borrowing is similar to when we borrow something and then return it after we are through with it.
- Borrowing and references are mutually exclusive, which means that when a reference is released, the borrowing also ends.

References - Borrow

- Example:

```
fn increase_fruit(mut numFruit: Fruit) -> Fruit {
        numFruit *= 2;
        numFruit
}
fn print_fruit(numFruit: Fruit) -> Fruit {
        println!("You have {} pieces of fruit", numFruit.apples+numFruit.bananas);
        numFruit
}
fn main() {
        let fruit = 10;
        let fruit = print_fruit(fruit);
        let fruit = increase_fruit(fruit);
        print_fruit(fruit);
}
```

Problem: we have to create another fruit variable because we have to move the value of fruit both in and out of the routine print_fruit.

Borrowed References

- The problem with this code:
  let fruit **= print_fruit**(fruit);
- We don't want to have to move the value in and back out.
- Instead, we'd like to be able to let print_fruit borrow the value we own in main, without moving it completely.
- Good news - Rust supports exactly that!
- Instead of passing print_fruit the fruit value itself, we need to pass it a **borrowed reference**.
- There's a new unary operator to learn for this: &.

Borrowed References

- It turns out that when you borrow a value of type Fruit, you don't get back a Fruit. Instead, you get a &Fruit.
- That & at the beginning of the type means "a reference to."
- In other words, & has two different but related meanings:
  - When on a value: borrow a reference to this value
  - When on a type: a reference to this type
- Right now, the type of the parameter to print_fruit is Fruit. This requires that the value be moved into print_fruit.
- Instead, let's change that so that it's a reference to a Fruit, or &Fruit:
  fn print_fruit(numFruit: **&**Fruit) **->** Fruit

Borrowed References

- Error: the only reason we were returning a Fruit in the first place was to deal with moving and ownership.
- But we don't actually need that anymore!
- So instead, let's get rid of the return value entirely:

```
fn print_fruit(numFruit: &Fruit) {
        println!("You have {} pieces of fruit",
        numFruit.apples+numFruit.bananas);
}
```

- We now replace:

```
let fruit = print_fruit(&fruit);
```

with:

```
print_fruit(&fruit);
```

Fixed Code

- Example:

```
fn increase_fruit(mut fruit: Fruit) -> Fruit {
	fruit.apples *= 2;
	fruit.bananas *= 3;
	fruit
}
fn print_fruit(numFruit: &Fruit) {
	println!("You have {} pieces of fruit", numFruit.apples+numFruit.bananas);
}
fn main() {
	let fruit = Fruit {
			apples: 10,
			bananas: 5,
	};
	print_fruit(&fruit);
	let fruit = increase_fruit(fruit);
	print_fruit(&fruit);
}
```

Mutable References

- We still want to be able to modify the fruit using the increase_fruit function.
- To make this work, we need to introduce a second kind of reference: **a mutable reference**.
- While an immutable reference is &, a mutable reference is &mut.
- It looks like:

```
fn increase_fruit(numFruit: &mut Fruit) {
        numFruit *= 2;
}
```

Mutable References

- It turns out that &Fruit and &mut Fruit are really different types.
- Therefore, we need a different operator to borrow a mutable reference than an immutable reference.
- And this operator is &mut.
- So we rewrite our function call from our original:

  let fruit **= increase_fruit**(fruit);

  updated:

  increase_fruit(**&mut** fruit);
- One final change to make it all work:

  ```
  let mut fruit = Fruit {
          apples: 10,
          bananas: 5,
  };
  ```

References

- Just like in C, every value in Rust lives somewhere in your computer's memory.
- And every place in computer memory has an address.
- It's possible to use println and the special {:p} syntax to display the address itself:

```
fn main() {
        let x: i32 = 5;
        println!("x == {}, located at {:p}", x, &x);
}
```

```
> cargo run
   Compiling my-project v0.1.0 (/home/runner/Rust-Hello-World)
    Finished dev [unoptimized + debuginfo] target(s) in 0.78s
     Running `target/debug/my-project`
x == 5, located at 0x7ffd60977afc
> 
```

References

- Just like in C, a reference can be thought of as a ***pointer***: it's an address pointing at a value that lives somewhere else.
- That's also why we use the letter p in the format string to print the address.
- When you have a variable like let y: &i32 = &x, what this means is:
  - y is an immutable variable
  - That variable holds an address
  - That address points to an i32
  - The reference is immutable, so we **can't** change the value of y
- On the other hand, let y: &mut i32 = &mut x is almost exactly the same thing, except for the last point.
- Since the reference is mutable, we **can** change the y value.

Dereferences

- Example:

```
fn main() {
        let x: i32 = 5;
        let mut y: i32 = 6;
        let z: &mut i32 = &mut y;
        z -= 1;
        assert_eq!(x, y);
        println!("Success");
}
```

- Does not work,
- The problem is that we're trying to use the -= operator on a &mut i32 value.
- The reference is really just an address, not an i32.
- We don't want to subtract 1 from an address.
- We want to subtract 1 from the value *behind* the reference.

Dereferences

- Just like in C, Rust provides another unary operator to talk about the thing behind a reference.
- It’s called the deref—short for dereference —operator, and is *.
- Example:

```
fn main() {
        let x: i32 = 5; let mut y: i32 = 6;
        let z: &mut i32 = &mut y;
        *z -= 1;
        assert_eq!(x, y);
        println!("Success");
}
```

```
> cargo run
   Compiling my-project v0.1.0 (/home/runner/Rust-Hello-World)
    Finished dev [unoptimized + debuginfo] target(s) in 0.34s
     Running `target/debug/my-project`
Success
>
```

Lifetimes Of References

- There's an important restriction on references, both mutable and immutable: they cannot live longer than the values they are referencing.

- Example:

```
fn main() {
        let x: &i32 = {
                let y = 5;
                &y
        };
        println!("x == {}", x);
}
```

- This program fails to compile.

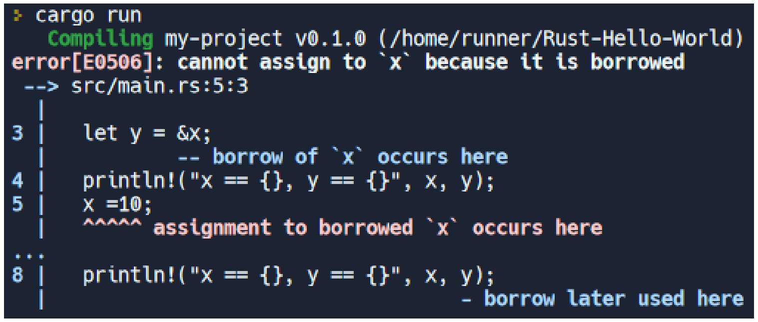
Lifetimes Of References

- The problem here is that y is *dropped* as soon as the block finishes.
- The block itself was the owner for y.
- And when an owner goes away, the value is dropped, and cannot be used anymore.
- However, we return a reference to y, which would allow us to keep using y after it's gone.
- That would be really dangerous, and so Rust doesn't let that happen.
- All values and references in Rust have a *lifetime*.
- When Rust is able to figure out the lifetime of a value, it will.

Mutating And Borrowing

- A lot of problems in software come about from things changing when you don't expect them to.
- That's why Rust defaults to having immutable variables: it's easier to think about things when they can't change.
- It means that if I have an immutable value, and I print it twice, I know it will give me the same value.
- This applies to immutable references too.
- As long as a value is borrowed, it can't be mutated:
- Example:

```
fn main() {
        let mut x = 5;
        let y = &x;
        println!("x == {}, y == {}", x, y);
        x =10;
        // I can do anything I want here...
        // And then this will produce the same output
        println!("x == {}, y == {}", x, y);
}
```



Single Mutable Reference

- Rust is picky about mutation stuff.
- We already mentioned that you can't mutate a value that's borrowed.
- This same basic logic extends to mutable references.
- If you have a mutable reference to a value, you can't mutate *or read* that value anywhere else in your program.
- We call this ***freezing***.
- Example:

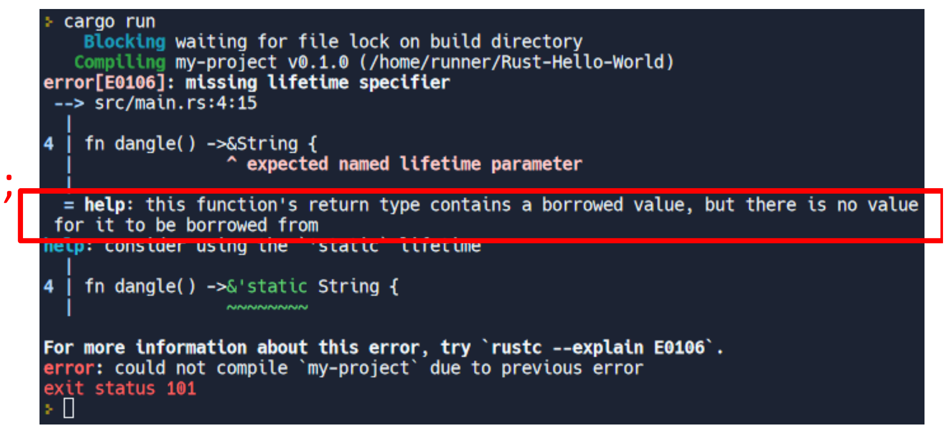
```
fn main() {
        let mut x = 5;
         let y = &mut x; // freeze
         x *= 2;
         *y *= 2; // unfreeze
         println!("x == {}", x);
}
```

```
> cargo run
   Compiling my-project v0.1.0 (/home/runner/Rust-Hello-World)
error[E0503]: cannot use `x` because it was mutably borrowed
 --> src/main.rs:3:12
  |
2 |             let y = &mut x; // freeze
  |                     ------ borrow of `x` occurs here
3 |             x *= 2;
  |             ^^^^^^ use of borrowed `x`
4 |             *y *= 2; // unfreeze
  |             ------- borrow later used here
```

Dangling References

- In pointer-based languages, it's possible to construct a dangling pointer, which refers to a place in memory that may have been passed to someone else, by releasing some memory while retaining a pointer to that region.
- In contrast, the compiler in Rust ensures that references are never dangling: if we have a reference to some data, the compiler will ensure that the data does not go out of the scope before the reference to the data does.
- Let's attempt making a dangling reference, which Rust will reject with a compile-time error:
- Example:

```
fn main() {
        let reference_to_nothing=dangle();
}
fn dangle() ->&String {
        let st=String::from("hello");
        &st
}
```



Dangling References

- Because st is generated within dangle, after dangle's code is complete, st will be deallocated.
- However, we attempted to return a reference to it.
- As a result, this reference would link to an incorrect String.
- That is not acceptable; Rust will not allow us to do so.
- The approach here is to just return the String:

```
fn no_dangle() ->String {
        let st=String::from("hello");
        st
}
```

- This works without a problem.
- Nothing has been deallocated, and ownership has been transferred.

Summary

- You are allowed to borrow references to values
- Borrowing a reference does not move ownership
- Borrowing is the preferred way to solve the "move in move out" problem with functions.
- References have their own type, and i32 is different than &i32.
- We also have mutable references such as &mut i32, which allow the values behind the reference to be changed.
- Mutable references can only be borrowed from mutable values
- References are essentially addresses for where the original value lives in memory
- If you want to operate directly on the value behind a reference, you can dereference using the * operator.

Summary

- A reference cannot outlive the value it refers to
- To avoid insanity around mutation and references, Rust has some rules you need to abide by
  - You cannot mutate a value if there is a reference to it
  - You can have multiple immutable references to a value
  - You can only have one mutable reference to a value, and then no other immutable references to it, or access the value directly
- You can create an immutable reference from a mutable reference, but not the other way around

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