Rust Fundamentals

Topics

- Basics of Rust
- Data types
- Functions
- Strings
- Ownership
- Traits
- Memory Management
- Control Flow
- Error Handling
- Concurrency
- Async and Await

Basics of Rust

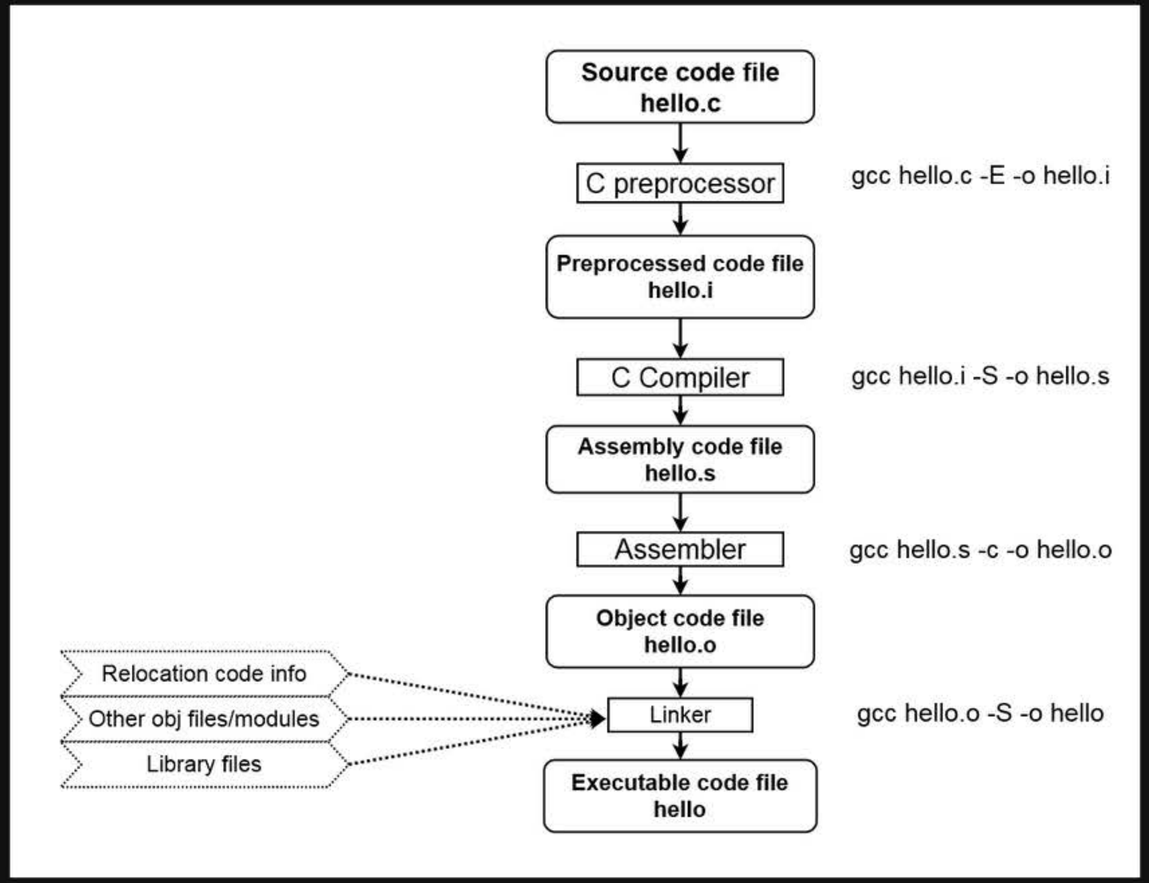
Getting Started

1. How to install rust.

   https://www.rust-lang.org/learn/get-started

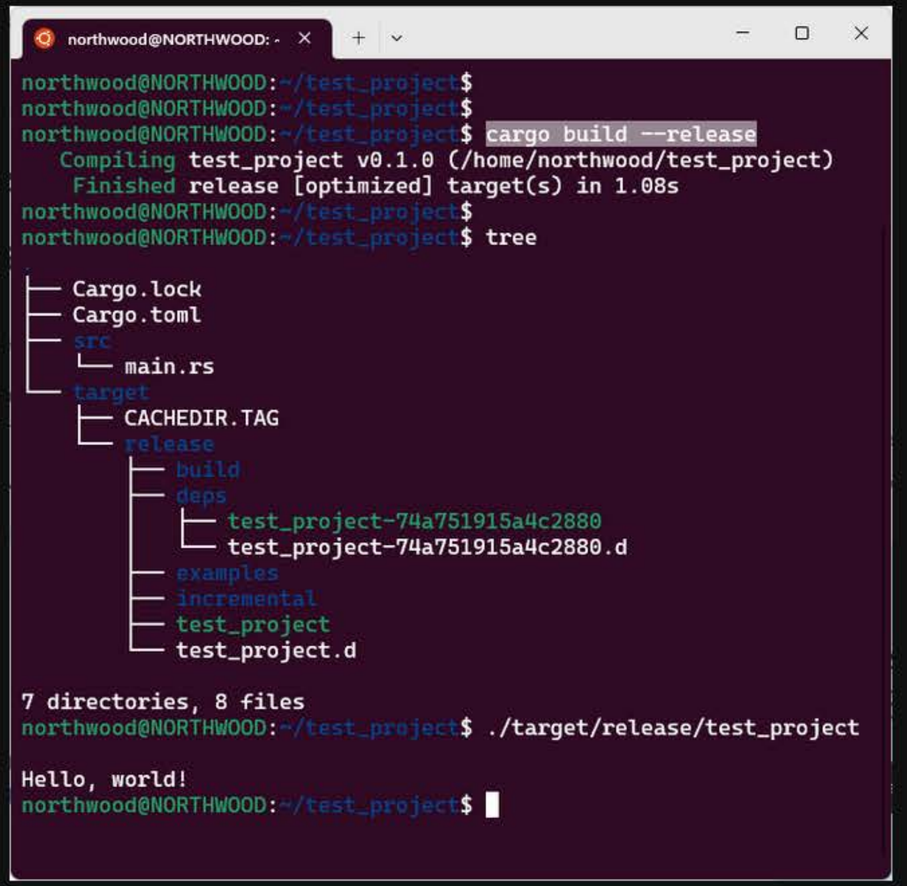
2. Rust tools.
   - rustup
   - cargo
   - rustc
   - crates.io
3. Rust Project Structure

Compilation Process in C/C++



Makefile

Compilation Process in Rust



TOML file

Data Types

Variables and Mutability

Variables are immutable by default

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

Variables and Mutability

Error message displayed:

```
$ 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
For more information about this error, try `rustc --explain E0384`.
error: could not compile `variables` due to previous error
```


Mutability

To fix the error add `mut` keyword before variable name.

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

Output:

```
1 $ cargo run
2 Compiling variables v0.1.0 (file:///projects/variables)
3  Finished dev [unoptimized + debuginfo] target(s) in 0.30s
4   Running `target/debug/variables`
5 The value of x is: 5
6 The value of x is: 6
```

Constants

- Constants are values that are bound to a name and are not allowed to change
- **`const`** keyword is used to declare constants instead of the `let` keyword, and the type of the value must be annotated
- **`mut`** is not used with **`const`**

Constants

- Constants can be declared in any scope, including the global scope
- Constants may be set only to a constant expression, not the result of a value that could only be computed at runtime

```rust
struct Circle {
  radius: f64,
}

impl Circle {
  const PI: f64 = 3.14159;

  fn new(radius: f64) -> Circle {
    Circle { radius }
  }
  fn calculate_area(&self) -> f64 {
    Circle::PI * self.radius * self.radius
  }
}
```

Shadowing

- You can declare a new variable with the same name as a previous variable
- The first variable is shadowed by the second

```
1  fn main() {
2    let x = 5;
3    let x = x + 1;
4
5    {
6      let x = x * 2;
7      println!("The value of x in the inner scope is: {x}");
8    }
9
10   println!("The value of x is: {x}");
11 }
```

Data Types

- Data type subsets: *scalar* and *compound*
- Rust is a statically typed language, which means that it must know the types of all variables at compile time
- Data Structures in Rust

Scalar Types

A scalar type represents a single value

- Integers
- Floating-point numbers
- Booleans
- Characters

Integer Types

An integer is a number without a fractional component

Number literals	Example
Decimal	98_222
Hex	0xff
Octal	0o77
Binary	0b1111_0000
Byte (u8 only)	b'A'

Floating-Point Types

- Numbers with decimal points
- Rust's floating-point types are f32 and f64

```
1 fn main() {
2   let x = 2.0;          // f64 (default)
3   let y: f32 = 3.0;     // f32
4 }
```

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
    let remainder = 43 % 5;
}
```

The Boolean Type

- Rust has two possible values: true and false
- Booleans are one byte in size
- It is specified using `bool`

```
1 fn main() {
2
3   let t = true;
4
5   let f: bool = false; // with explicit type annotation
6 }
```

The Character Type

- Rust's **`char`** type is the language's most primitive alphabetic type
- Specify `char` literals with single quotes `''`
- Rust's `char` type is four bytes in size and represents a unicode Scalar Value, which means it can represent a lot more than just ASCII

```
1 fn main() {
2   let c = 'z';
3   let z: char = 'ℤ';          // with explicit type annotation
4   let heart_eyed_cat = '😻'; //emoji
5 }
```

Compound Types

- Compound types can group multiple values into one type
- Rust has two primitive compound types: **tuples** and **arrays**

The Tuple Type

- A tuple is a general way of grouping together a different types into one compound type
  - Fixed length
  - Known at Compile time
  - Heterogeneous

```
1  fn main() {
2    // creating tuple
3    let tup: (i32, f64, u8) = (500, 6.4, 1);
4    let gfg: (&str, &str, &str) = ("Apple", "For", "Bananas");
5
6    // accessing tuple data using positional argument
7    println!("{} {} {}", gfg.0, gfg.1, gfg.2);
8
9    // creating another tuple
10   let article = ("abc", "xyz", 14,12,2020);
11   let (a,b,c,d,e) = article;
12
13   // accessing tuple using variables
14   println!("This written by {} at {} on {}/{}/{}", b,a,c,d,e);
15 }
```

Destructuring Tuple

```
1 fn main() {
2
3   let tup = (500, 6.4, 1);
4
5   let (x, y, z) = tup;
6
7   println!("The value of y is: {y}");
8 }
```

The Array Type

- Collection of multiple values is with an array
- Every element of an array must have the same type
- Arrays in Rust have a fixed length

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

Accessing Array Elements

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

Compound Types

Exercise-1

(clue: all the array elements should be of same type)

```
1 fn main() {
2
3   // Fix the error
4   let _arr = [1, 2, '3'];
5
6   println!("Success!");
7 }
```


Compound Types

Exercise-2

(clue: indexing should start from 0)

```
1 fn main() {
2   let arr = ['a', 'b', 'c'];
3   let ele = arr[1]; // Only modify this line to make the code work!
4   assert!(ele == 'a');
5   println!("Success!");
6 }
```

Structure

- Structs hold multiple related values
- In a struct you'll name each piece of data so it's clear what the values mean
- Order of the data to specify or access the values of an instance need not be same

Defining a Struct

- The `struct` keyword is used to declare a structure followed by the name
- Inside curly brackets, we define the names and types of the pieces of data, which we call **'fields'**

```
1 struct User {
2   active: bool,
3   username: String,
4   email: String,
5   sign_in_count: u64,
6 }
7
8 fn main() {}
```

Instantiating a Struct

Create instance by stating the name of the `struct` and then add curly brackets {} containing **'key:value'** pairs

- keys are the names of the fields
- values are the data stored in those fields

```
1 fn main() {
2     let user1 = User {
3         active   : true,
4         username: String::from("someusername123"),
5         email    : String::from("someone@example.com"),
6         count    : 1,
7     };
8 }
```

Enums

- The `enum` keyword allows the creation of a type which may be one of a few different variants.
- Any variant which is valid as a struct is also valid as an enum

```
enum Work {
  Civilian,
  Soldier,
}
fn main() {
  use crate::Work::{Civilian, Soldier};
  // Equivalent to `Work::Civilian`.
  let work = Civilian;
  match work {
    // Note the lack of scoping because of the explicit `use` above
    Civilian => println!("Civilians work!"),
    Soldier  => println!("Soldiers fight!"),
  }
}
```

Functions

What we are covering

- Define a Function in Rust
- Calling a Function in Rust
- Function Parameters
- Function with Return Value
- Memory Management
- Generic Functions
- Associated Functions
- Method that Access Data
- Generic Types
- Closures

Define a Function in Rust

Function is a reusable block of code, in Rust `fn` keyword is used to define a function.

```
1 //define a function
2 fn function_name(arguments) -> return_val {
3   // code
4 }
```

Example:

```
1 // greet function
2 fn greet() {
3   println!("Hello world!");
4 }
5
6 // main function
7 fn main() {
8 }
```

Calling a Function in Rust

Function name followed by parentheses "()" is used to call a function

```
1 fn greet() {          <---------
2                                  |
3     println!("Hello world!");    | Execution flow is
4 }                                | tranferred to
5                                  | called function
6 fn main() {                      |
7     greet(); --------------------^
8 }
```

Function Parameters

```rust
fn multiply(num1: f64, num2: i64) {

  let result = num1 * num2 as f64;

  println!("Result: {}", result);
}
```

In this example function **multiply** accepts two parameters:

1. 'num1' - which has type f64 i.e. float 64
2. 'num2' - which has type i64 i.e. integer 64

Function with Return Value

- `->` syntax is used to specify the return type
- possible to return a without explicitly using the `return` keyword
- the last expression is returned as the result of function

```
1  fn return_nothing() {
2    // code
3  }
4
5  fn return_bool() -> bool {
6    //code
7    return true;
8  }
9
10 fn multiply(float: f64, integer: i64) -> f64 {
11   let result = float * integer as f64;
12   result
13 }
```

Generic Functions

Generic parameters allow a function, struct, or enum to work with multiple types, instead of just one specific type. You can specify generic parameters in a function signature by enclosing them in angle brackets (< >) after the function name.

Example using `PartialOrd` trait:

```
fn min< T:PartialOrd > (a: T, b: T) -> T {
  if a < b {
    a
  } else {
    b
  }
}

fn main(){
  let x = min(5, 10);                // integer
  let y = min(5.0, 10.0);            // float
  let z = min("hello", "world");     // string
  println!("x: {x}");
  println!("y: {y}");
  println!("z: {z}");
}
```

Associated Functions

- function that belongs to a struct or enum, rather than an instance of that struct or enum
- Associated functions are called using the name of the struct or enum, followed by the double colon (::) operator

Example of an associated function `new` that acts as a constructor

```
1  struct Point {
2    x: i32,
3    y: i32,
4  }
5
6  impl Point {
7    fn new(x: i32, y: i32) -> Point {
8      Point { x, y }
9    }
10 }
11 fn main(){
12   let p = Point::new(1, 2);
13 }
```

Methods that access data

- 'new': a constructor that creates a new instance of the Rectangle struct.
- 'area': a method that calculates the area of the Rectangle and uses **`&self`** to access the data

```
1  struct Rectangle {
2    width: i32,
3    height: i32,
4  }
5
6  impl Rectangle {
7    fn new(width: i32, height: i32) -> Rectangle {
8      Rectangle { width, height }
9    }
10   fn area(&self) -> i32 {
11     self.width * self.height
12   }
13 }
```

Closures

- Closure is an anonymous function that can capture values from the enclosing environment and defined using the `||` characters.
- Optional body delimination `{ }` for a single expression (mandatory otherwise).

```
let print_text = | |  println!("Hello, World!");
                 ~~~  ~~~~~~~~~~~~~~~~~~~~~~~~~~
                 ^                    ^
                 |                    |
        start of closure       Body of closure
```

Closures

Examples:

```rust
fn call_function< F: Fn(i32) -> i32>(f: F, x: i32) -> i32 {
  f(x)
}

fn return_function() -> Box < dyn Fn(i32) -> i32> {
  Box::new(|x: i32| -> i32 { x * x })
}

fn main(){
  // Closure
  let square = |x: i32| -> i32 { x * x };
  println!("The square of 2 is {}", square(2));

  // Closure can be passed as an argument to a function
  println!("The square of 2 is {}", call_function(square, 2));

  // Closure can be returned as a result from a function:
  let square = return_function();
}
```

Strings

Strings

There are two types of strings in Rust

- String
- &str

String

- Implemented as a smart pointer, specifically a Vec.
- Heap allocated, growable
- Can be mutated
- Always be a valid UTF-8, not null terminated sequence.

Deref and String

String implements Deref trait, which means that you can pass a &String to something expecting a &str, and it will Just Work:

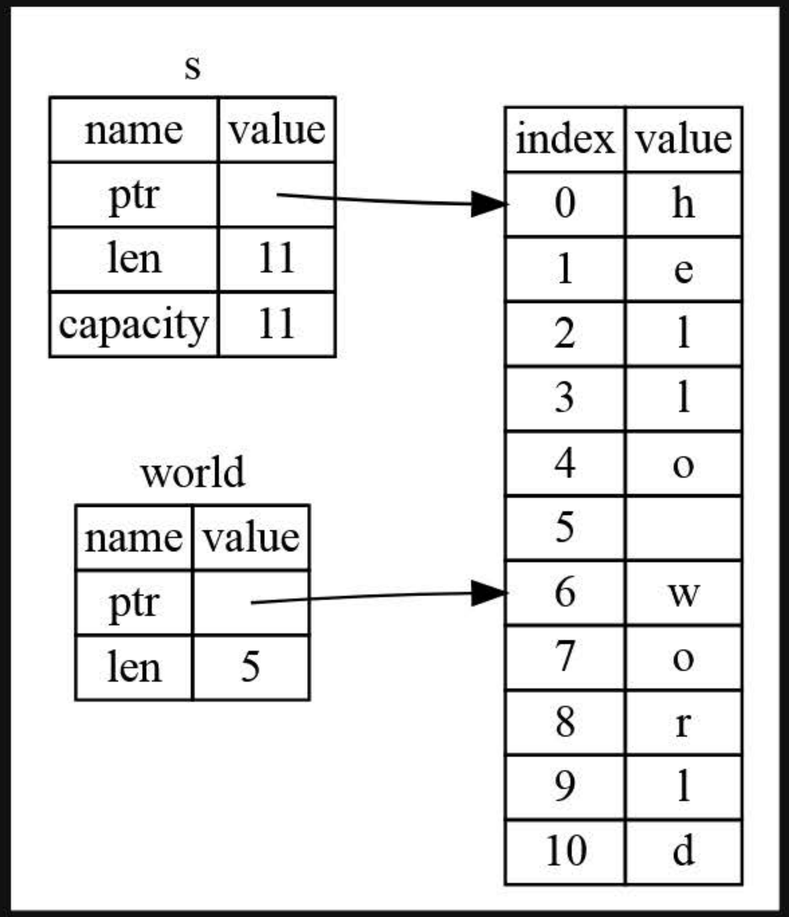
```
1 fn accepts_str(s: &str) {
2   // code ..
3 }
4
5 fn main(){
6   let s = String::from("hello");
7   accepts_str(&s);
8 }
```

&str

- An immutable reference to a valid UTF-8 sequence.
- May be anywhere, on the heap, stack, or in program memory.
- Only seen as a borrowed value.
- Has a fixed size, the value is known at run time

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

let world: &str = &s[6..11];
```



Initialization

String

```rust
// creating a String using the String::new
let s = String::new();
//creating a String using the String::from function
let s = String::from("hello");
//converting a `&str` to a `String` using the to_string method
let s = "hello".to_string();
```

Use `String` when you need to modify or own a string

&str

```rust
//creating an &str from a string literal
let s = "hello";
//creating an &str from a String:
let s = String::from("hello");
let str_slice = &s[0..2];
```

Use `&str` when you just want to borrow a reference to a string

Operations on Strings

concatenation | appending | slicing | splitting | replacing | iterating | checking starts prefix | checkin ends suffix

```rust
let s1 = String::from("hello world");
let mut s2 = String::from("rust is awesome");

let s3 = s1 + &s2;                  // Concat using the `+` operator
let s4 = format!("{}{}",s1,s2);// Concat using the format! macro
s2.push_str(", & memory safe");// Appending using the push_str
let slice = &s[0..2];               // Slicing using string indices

for c in "hello".chars() {      // Iterating over the string
  println!("{}", c);
}
println!("Length:{}", s.len());// Finding the length of a string
if(s1.starts_with("he")){}      // Check if starts with a prefix
if(s1.ends_with("ld")){}        // Check if ends with a suffix
```

Ownership & Borrowing

Ownership

- Every resource has a unique **owner**.
- The **owner** can change the owning value according to mutability.
- Ownership can be transferred to an other variable.
- Owner cannot free or mutate its resource while it is borrowed.
- Ownership model guarantees safety.

Ownership Rules

Each value in Rust has only **one owner**

```
1 fn main () {
2   let vector1 = vec![1, 2, 3];
3 }
```

here '*vector1*' is ***owner***

```
1 fn main () {
2     let vector1 = vec![1, 2, 3];
3                   ~~~~~~~~~~~~~  <---
4                                      |
5                              This memory
6                             gets `deallocated`
7 }   <------------------------ here `vector1` goes out of scope
```

Value is **dropped**,

when owner goes out of scope.

Ownership Rules

```
1 fn main () {
2
3   let vector1 = vec![1, 2, 3];  <--`vector1` is invalid variable
4   let vector2 = vector1;                        beacause
5       ~~~~~~~  <------------------ `vector2` is New Owner
6
7   println!("{:?}",vector1);
8 }
```

Error:

```
 1 error[E0382]: borrow of moved value: `vector1`
 2     --> src/main.rs:4:19
 3      |
 4 2    |   let vector1 = vec![1, 2, 3];
 5      |       ------- move occurs because `vector1` has
 6      |               type `Vec< i32>`, which does not implement
 7      |               the `Copy` trait
 8 3    |   let vector2 = vector1;
 9      |                 ------- value moved here
10 4    |   println!("{:?}",vector1);
11      |                   ^^^^^^^ value borrowed here after move
```

Borrowing

```
1 let vector2 = &vector1;
2               ^ ------------
3 someFunction(&vector1);      |---> Reference
4               ^ --------------
```

Borrowing Rules

All references are ***immutable***

by default.

```
1 fn main () {
2   let mut vector1 = vec![1, 2, 3];
3       ^^^  --------------------
4   let vector2 = &mut vector1;  |---> Explicitly mentioned
5                 ^^^ ----------      as `mutable`
6                                     using `mut` keyword
7 }
```

Borrowing Rules

Not **more than one**

'mutable reference' is allowed in *a scope*

```
1 fn main () {
2     let mut _vector1 = vec![1, 2, 3];
3     let _vector2 = &mut _vector1;
4     let _vector3 = &mut _vector1;
5     ^^^^^^^^^^^^^^^^^^^^^^^^^^^^ ---> NOT ALLOWED
6 }
```

'mutable' and 'immutable' reference **can not go hand in hand** *within a scope*

Traits

Traits

- ***'Traits'*** are the abstract mechanism for adding functionality to types or it tells *Rust compiler* about functionality a type **must** provide.
- ***'Traits'*** are a way to group methods to define a set of **behavior** necessary to accomplish some purpose.

Trait Definition

- Traits are defined by the `trait` keyword followed by the name of the trait
- While defining any trait we have to provide method signatures (method declaration)

```
1 pub trait Calculator {
2   fn add(&self) -> i32;
3   fn sub(&self) -> i32;
4   fn div(&self) -> i32;
5   fn mul(&self) -> i32;
6 }
```

Trait implementation

- `impl` keyword used to implement a trait
- `for` is used when implementing traits as in impl Trait for Type

```
1 impl trait_name for type_name {
2
3   //method definitions
4 }
```

Example

```
struct Data {
  first_num: i32,
  second_num: i32
}
impl Calculator for Data {
  fn add(&self) -> i32 {
    self.first_num + self.second_num
  }
  fn sub(&self) -> i32 {
    self.first_num - self.second_num
  }
  fn div(&self) -> i32 {
    self.first_num / self.second_num
  }
  fn mul(&self) -> i32 {
    self.first_num * self.second_num
  }
}
fn main() {
  println!("Output of Add: {}", Data {first_num:2, second_num: 2}.add());
  println!("Output of Sub: {}", Data {first_num:4, second_num: 2}.sub());
  println!("Output of Div: {}", Data {first_num:10, second_num: 2}.div());
  println!("Output of Mul: {}", Data {first_num:2, second_num: 2}.mul());
}
```

Output:

```
Compiling playground v0.0.1 (/playground)
Finished dev [unoptimized + debuginfo] target(s) in 0.59s
  Running `target/debug/playground`

Output of Add: 4
Output of Sub: 2
Output of Div: 5
Output of Mul: 4
```

Default implementation of trait

- Rust allows you to provide a default implementation of the Trait's methods
- A Type can keep the implementation or can override also
- In the same Trait, default implementation can call another method also

Example

```rust
pub trait Calculator {
  fn add(&self) -> i32;
  fn sub(&self) -> i32;
  fn get_result(&self) {
    println!("The result of Addition is {}", self.add());
  }
}

struct Data {
  first_num: i32,
  second_num: i32
}

impl Calculator for Data {
  fn add(&self) -> i32 {
    self.first_num + self.second_num
  }

  fn sub(&self) -> i32 {
    self.first_num - self.second_num
  }
}

fn main() {
  Data {first_num:2, second_num: 2}.get_result();
  println!("Output of Sub: {}", Data {first_num:4, second_num: 2}.sub());
}
```

Implement traits for existing types

- Unlike *interfaces* in languages like Java, new traits can be implemented for existing types
- For example, we can implement **trait** for existing types like bool, f32, i32, etc.

```rust
trait PrintInfo {            //Define a trait called `PrintInfo`
  fn print_info(&self);
}

impl PrintInfo for i32 {     // Implement `PrintInfo` for the built-in type `i32`
  fn print_info(&self) {
    println!("This is an integer: {}", self);
  }
}

fn main() {
  let num: i32 = 42;
  num.print_info();          // Output: "This is an integer: 42"
}
```

Access Methods from the Same Trait

We can access other methods declared in the same trait using `self`

```
1 trait Calculator {
2   fn add(&self) -> u32;
3   // We can provide default method definitions.
4   fn get_result(&self) {
5     println!("Result of Add() is {}", self.add());
6   }
7 }
```

Passing Trait as a Function's Parameters

Passing *trait* into a function's parameter is a quite interesting concept in the traits environment so, with the help of this user can put the restriction into his functionality like only limit functions can able to use it.

```
1 pub fn calculate(item: impl Calculator) {
2   println!("Addition {}", item.add());
3 }
```

Trait Bound Concept

Trait Bound Concept is quite similar to the Passing Trait as a Function's Parameters but with some syntactical differences.

```
1 pub fn calculate< T: Calculator> (item: T) {
2   println!("Addition {}", item.add());
3 }
```

Lifetimes

- It represents scope in which a reference is valid.
- It ensures that references do not outlive the data they refer to.
- By analyzing the lifetimes, the compiler can enforce memory safety.
- Lifetimes are denoted by apostrophes ('), also known as "ticks."
- Often used in function signatures, struct definitions, and generic type parameters to specify the relationship between references.

```rust
fn longest_string<'a>(s1: &'a str, s2: &'a str) -> &'a str {
  if s1.len() > s2.len() {
    s1
  } else {
    s2
  }
}

fn main() {
  let s1 = "Hello";
  let s2 = "World";
  let result = longest_string(s1, s2);
  println!("Longest string: {}", result);
}
```

Visibility Modifiers

- It control the accessibility of structs, enums, functions, methods, and modules
- Rust provides three visibility modifiers:
  - `pub`: accessible from other modules or crates
  - `pub(crate)`: accessible only within the same crate
  - `pub(in path)`: accessible only within the specified module path and its submodules.

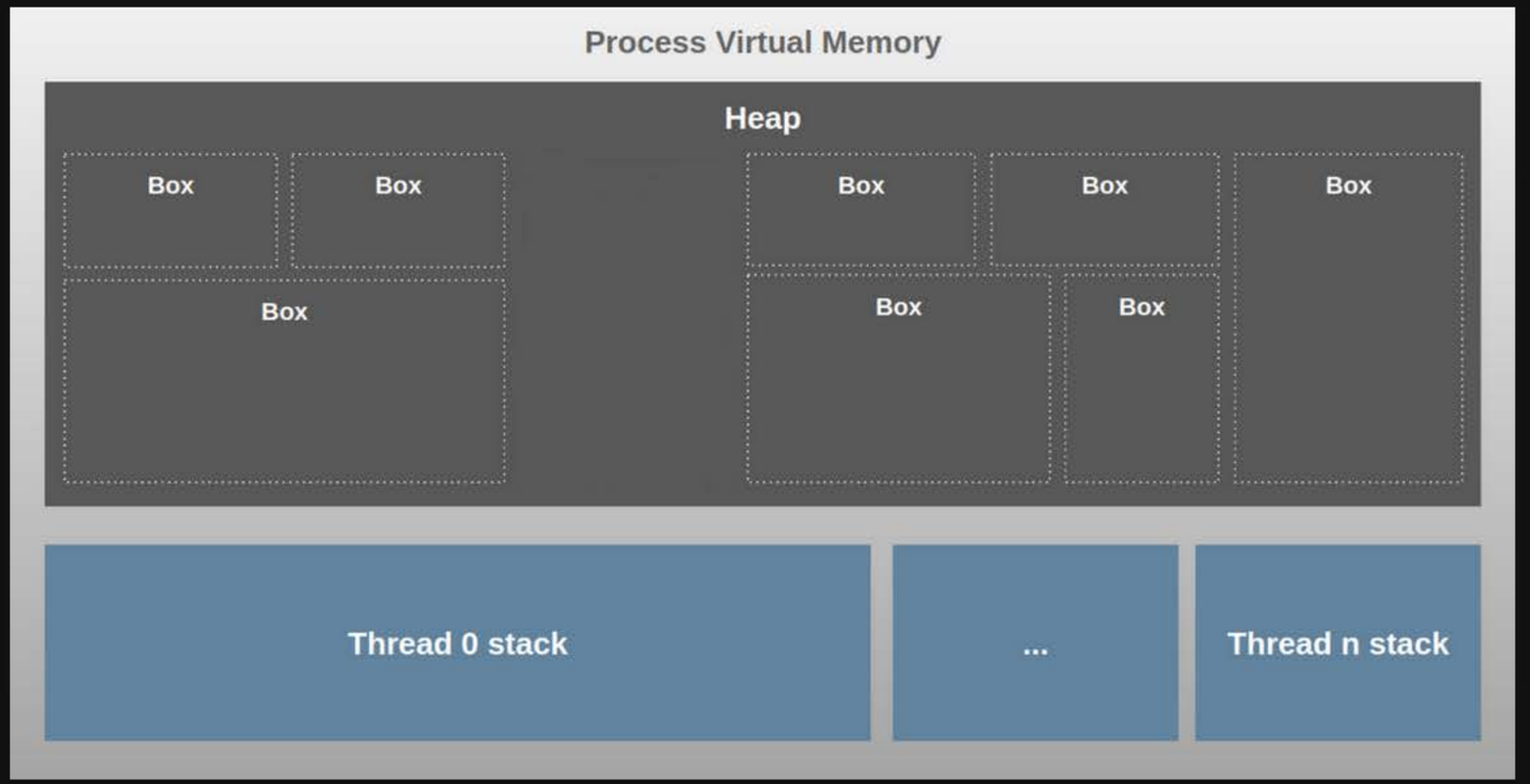
```rust
mod my_module {
  pub struct PublicStruct { }
  struct PrivateStruct { }
  pub fn public_function() { }
  fn private_function() { }
  pub(crate) fn crate_function() { }
  pub(in crate::my_module::nested) fn restricted_function() { }
}

fn main() {
  let public_struct = my_module::PublicStruct {};
  my_module::public_function();
  // let private_struct = my_module::PrivateStruct {}; // Error: not accessible here
  // my_module::private_function();                    // Error: not accessible here
}
```

Memory Management

Memory Management

Rust program process is allocated some virtual memory by the Operating System(OS), this is the total memory that the process has access.



Heap Memory

- This is where all dynamic data(any data for which size cannot be calculated at compile time) is stored.
- This is the biggest block of memory and the part managed by Rust's Ownership model.
- **Box:** The Box type is an abstraction for a heap-allocated value in Rust.
- Heap memory is allocated when Box::new is called.
- A Box < T > holds the smart-pointer to the heap memory, allocated for type T and the reference is saved on the Stack.

Stack Memory

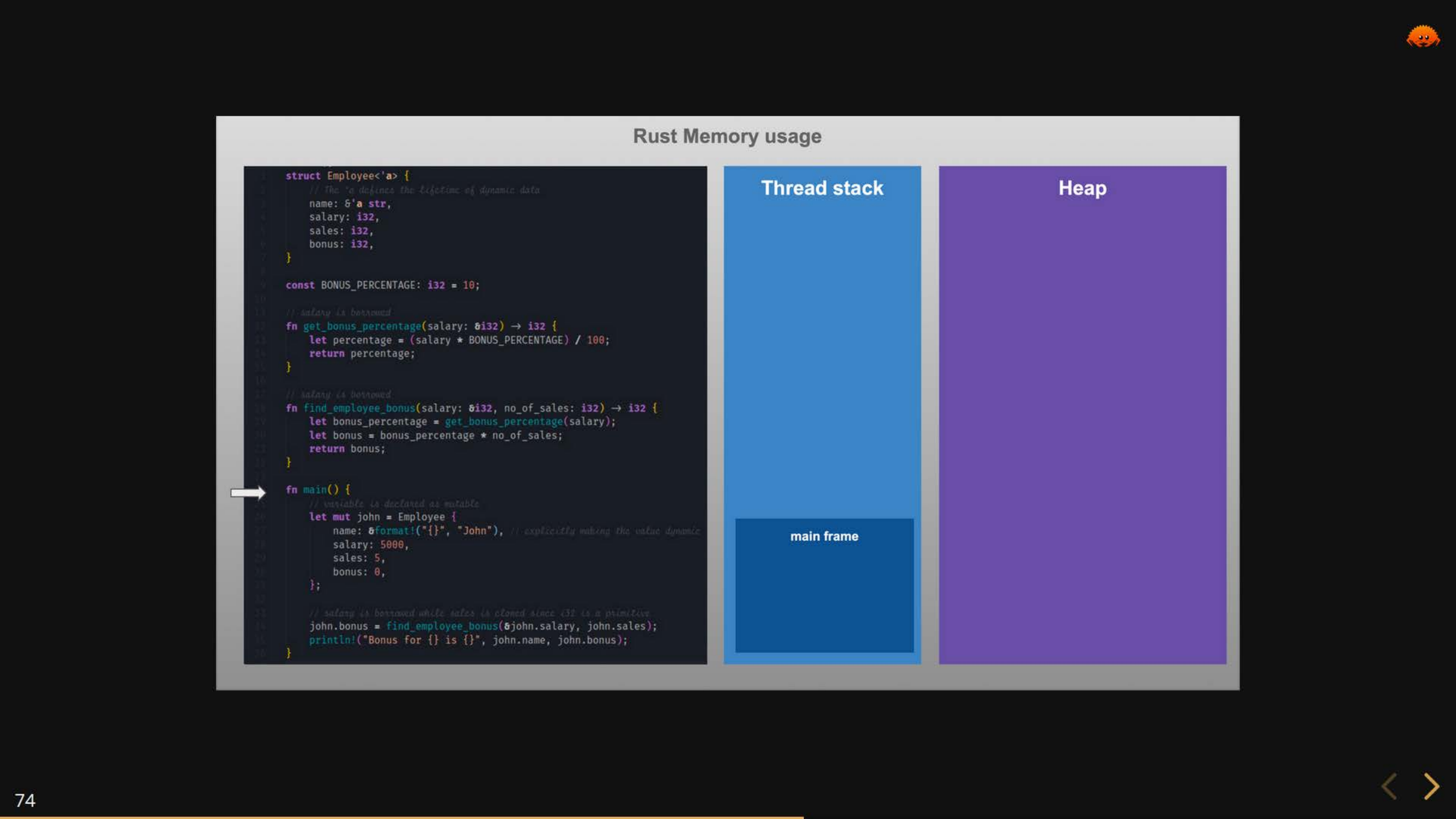
- This is the Stack memory area and there is one stack per thread.
- This is where static values are allocated by default.
- Static data(data size known at compile time) includes function frames, primitive values, structs and pointers to dynamic data in Heap

Memory Usage

All values in Rust are allocated on the Stack by default. There are two exceptions to this

1. When size of the value is dynamic like Strings/Vectors
2. When you manually create a Box < T > value which is allocated on heap

In both exception cases, the value will be allocated on Heap and its pointer will live on the Stack.


Rust Memory usage
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// The 'a defines the lifetime of dynamic data
name: &'a str,
salary: i32,
sales: i32,
bonus: i32,
}
const BONUS_PERCENTAGE: i32 = 10;
// salary is borrowed
fn get_bonus_percentage(salary: &i32) -> i32 {
let percentage = (salary * BONUS_PERCENTAGE) / 100;
return percentage;
}
// salary is borrowed
fn find_employee_bonus(salary: &i32, no_of_sales: i32) -> i32 {
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}
fn main() {
// variable is declared as mutable
let mut john = Employee {
name: &format!("{}", "John"), // explicitly making the value dynamic
salary: 5000,
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// salary is borrowed while sales is cloned since i32 is a primitive
john.bonus = find_employee_bonus(&john.salary, john.sales);
println!("Bonus for {} is {}", john.name, john.bonus);
}
Thread stack
main frame
Heap

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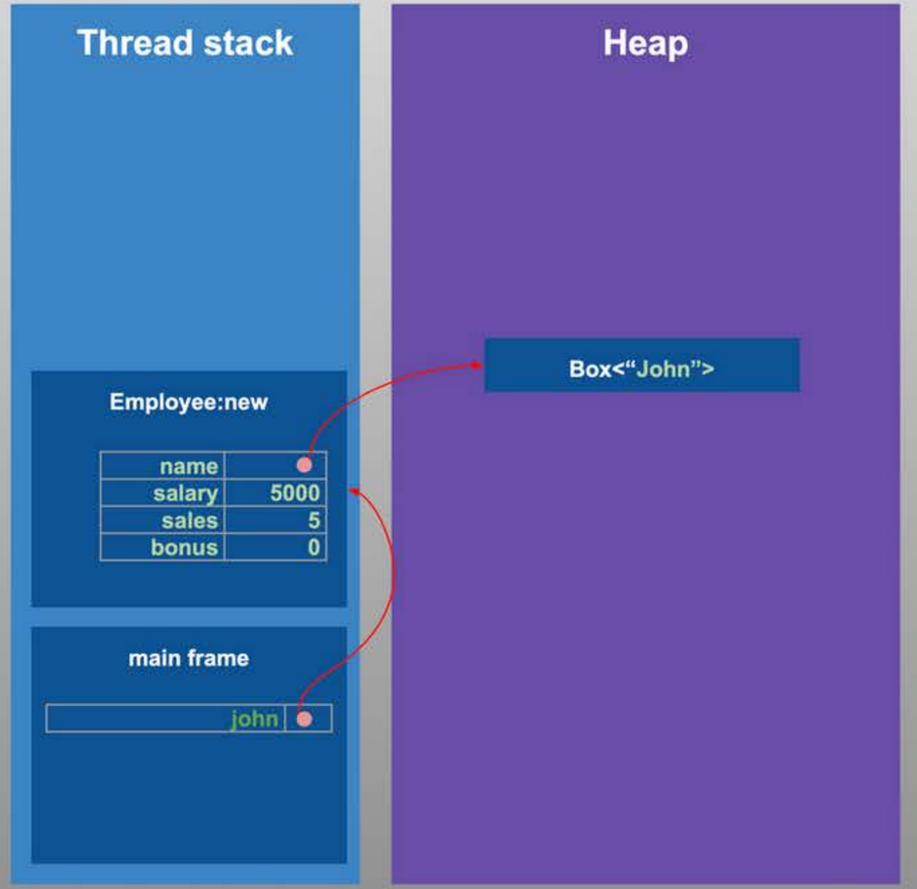

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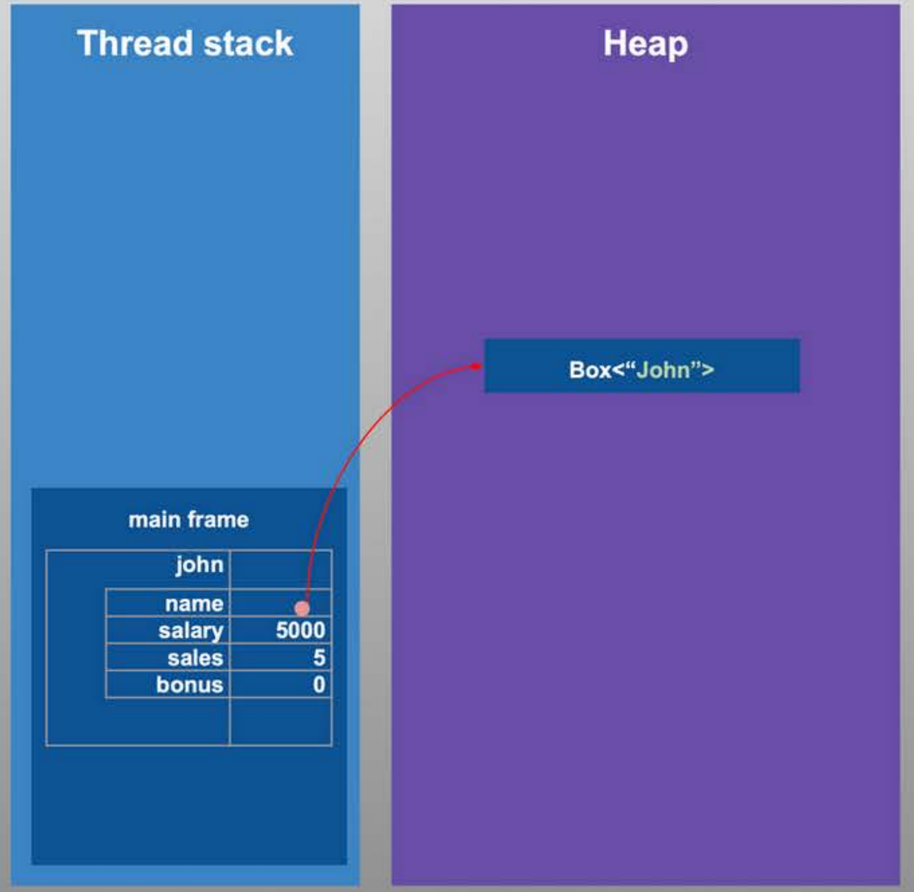

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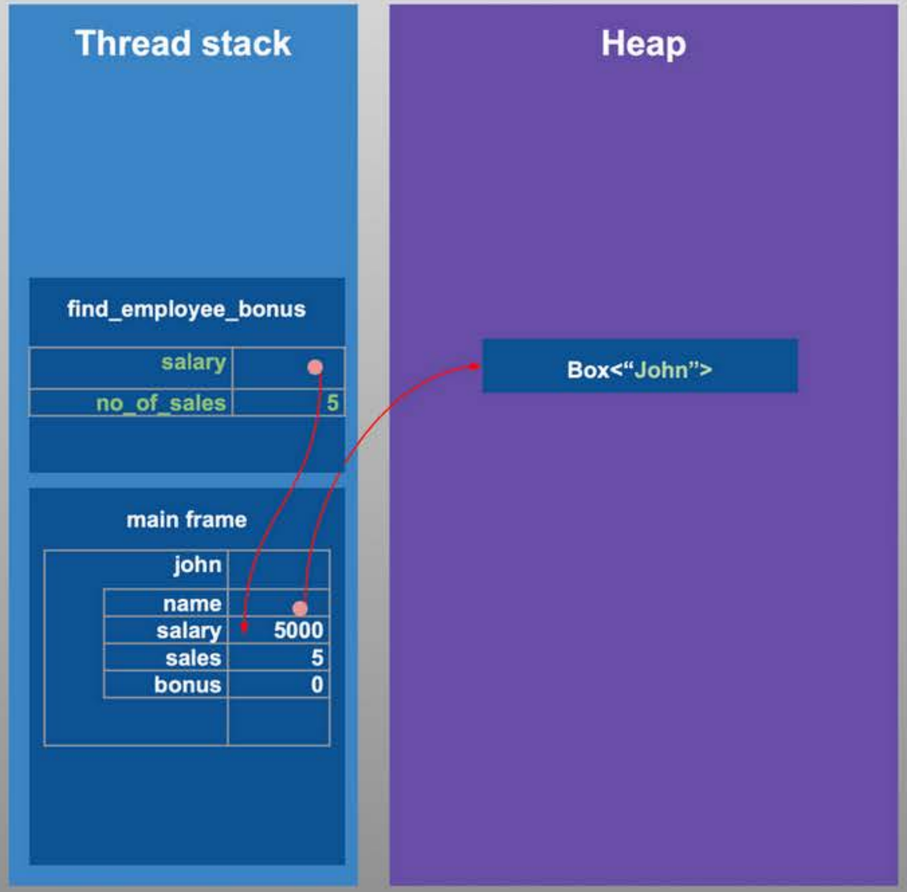

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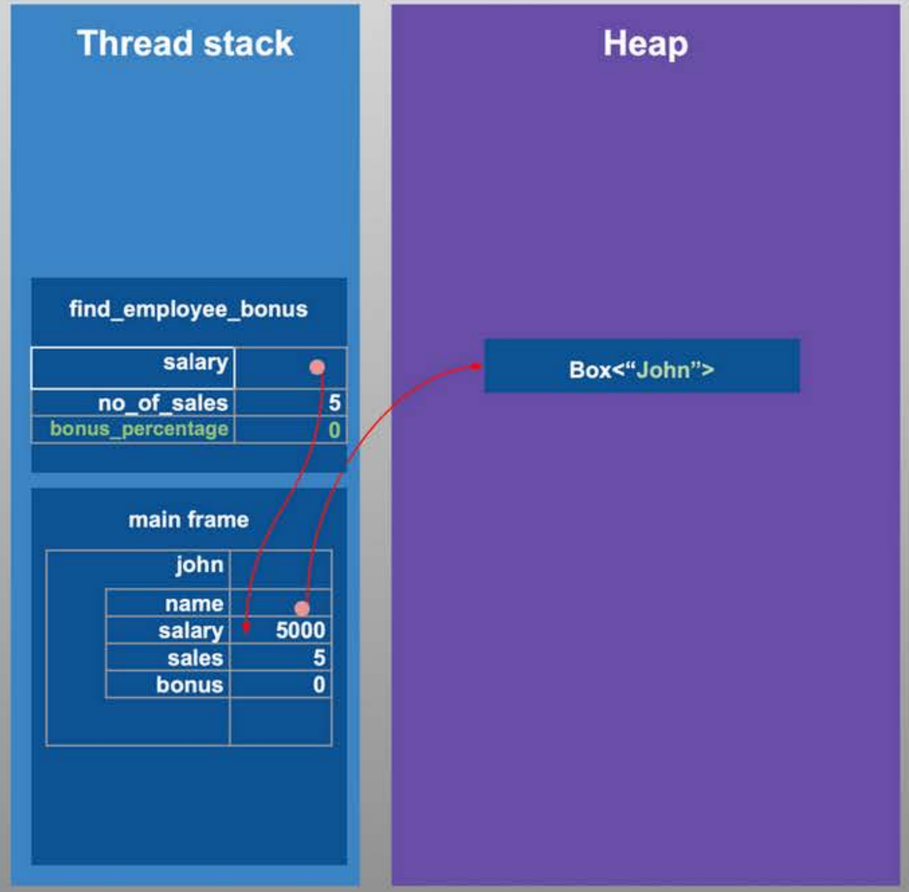

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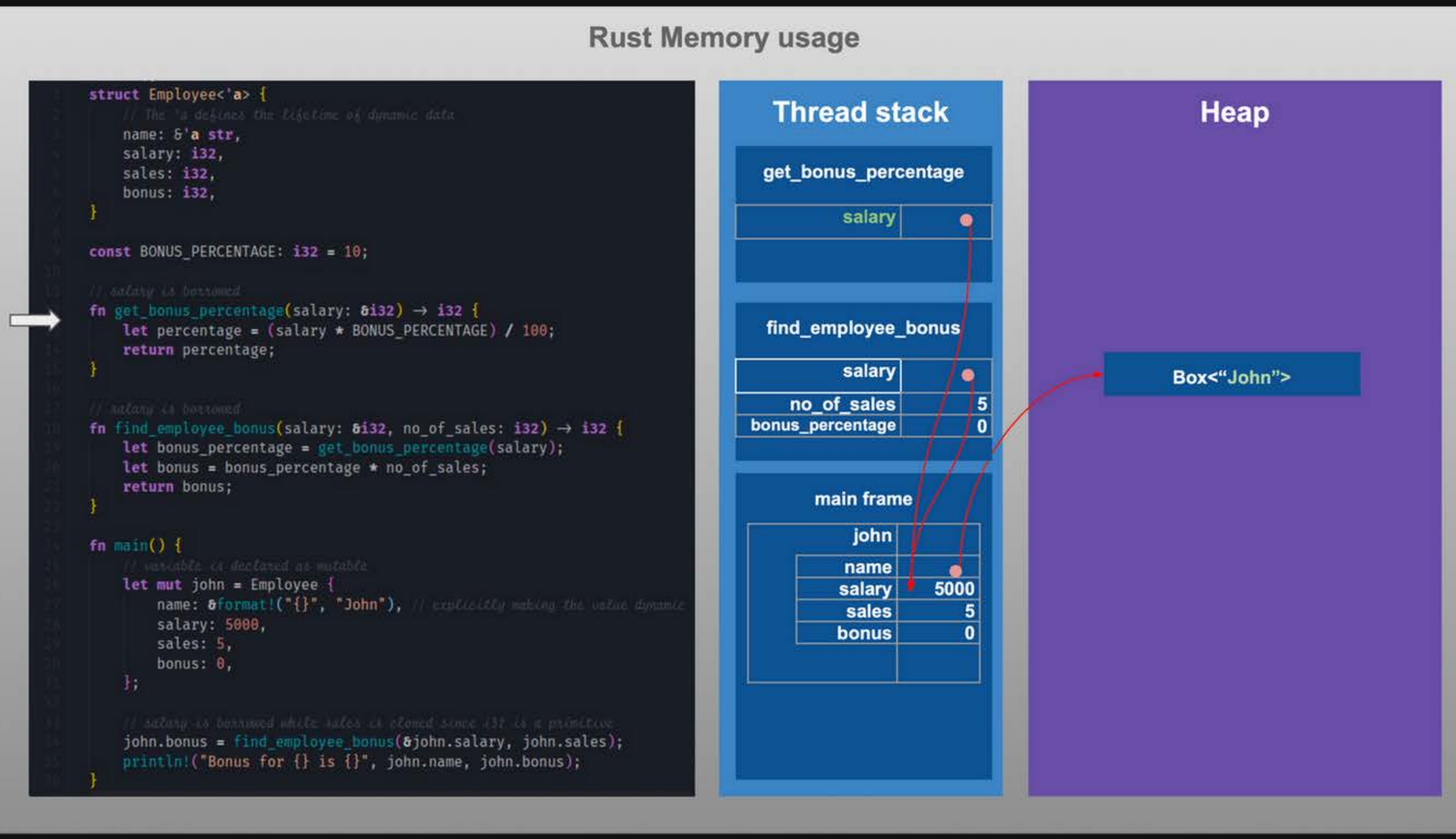

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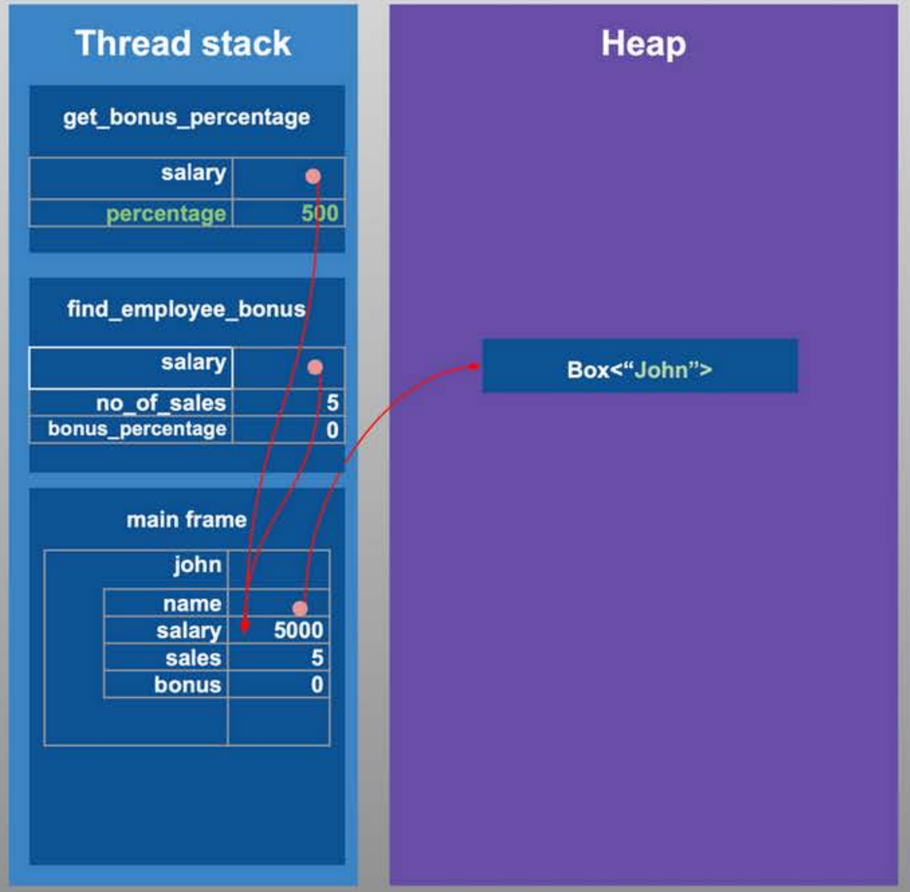

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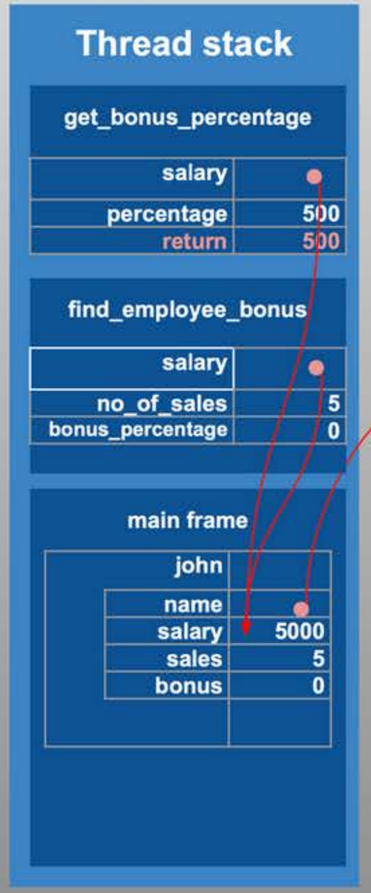

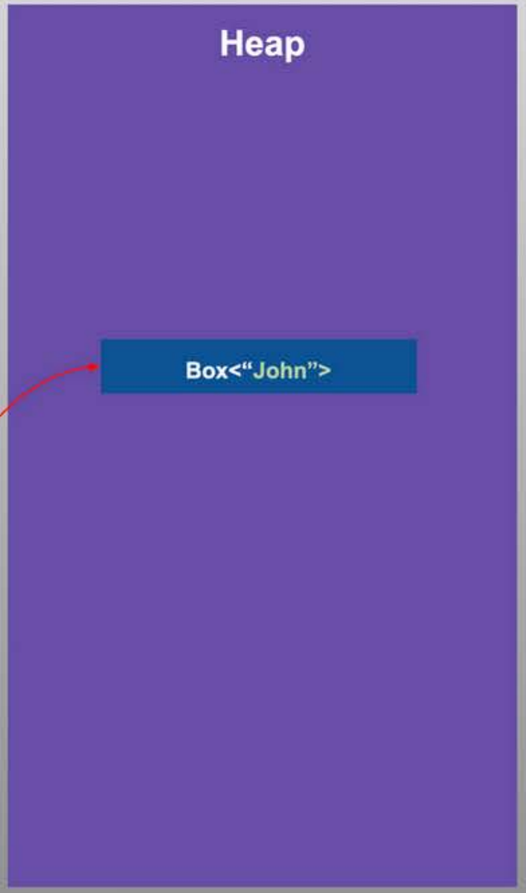

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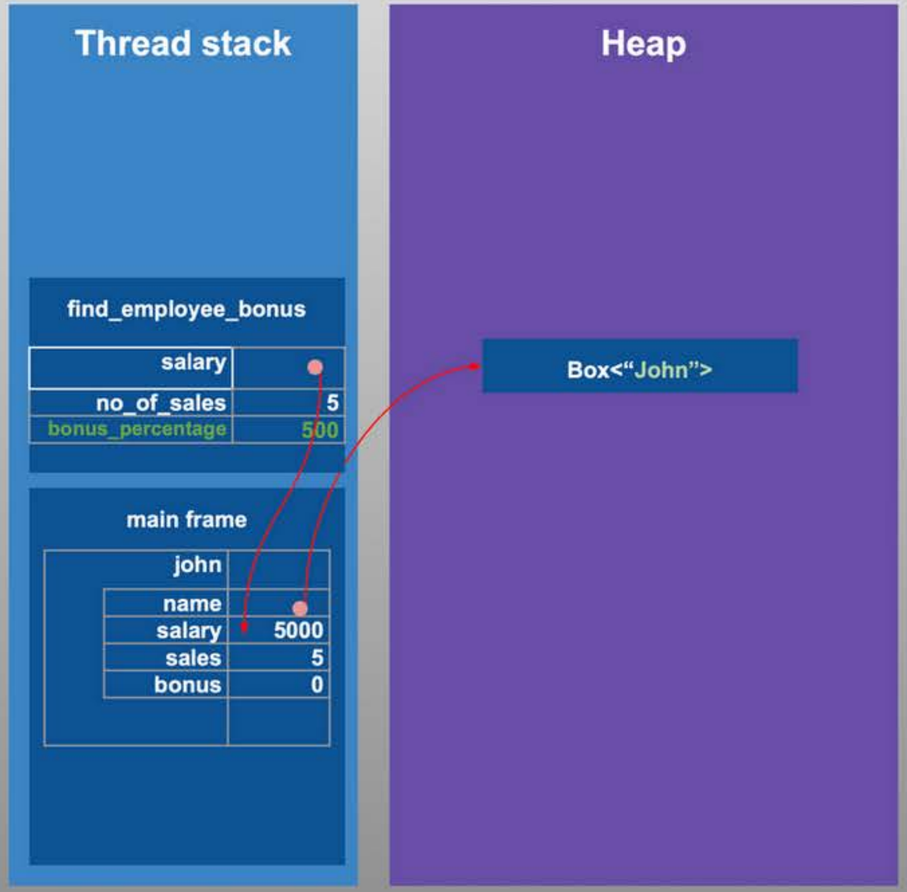

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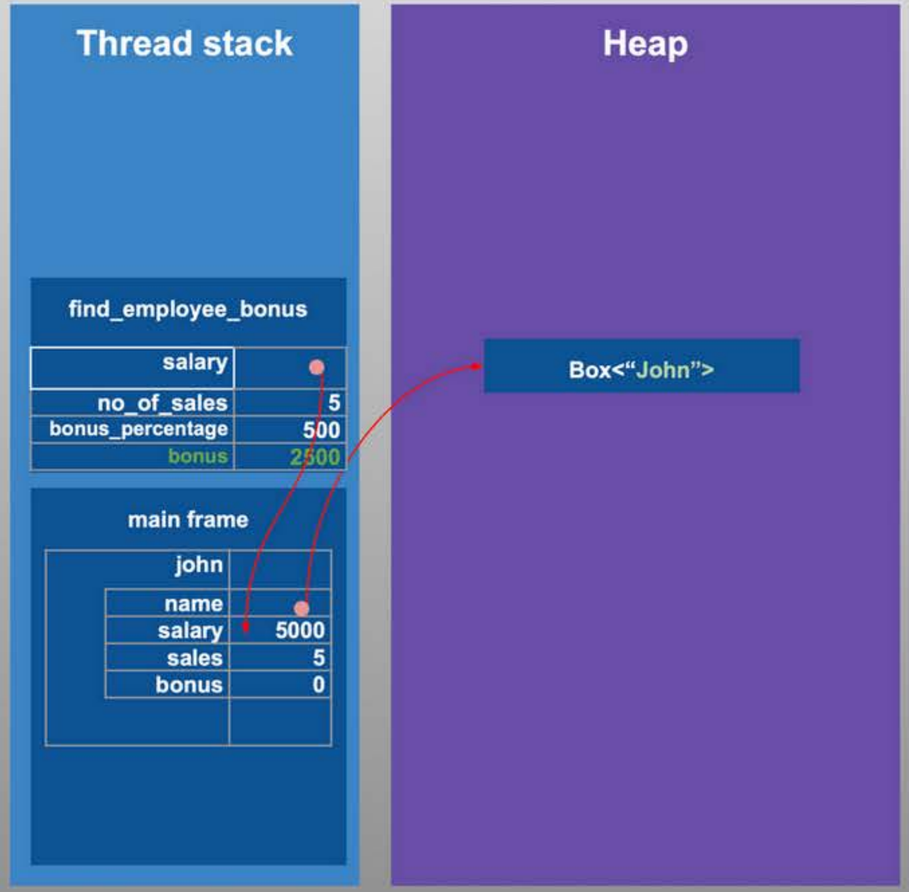

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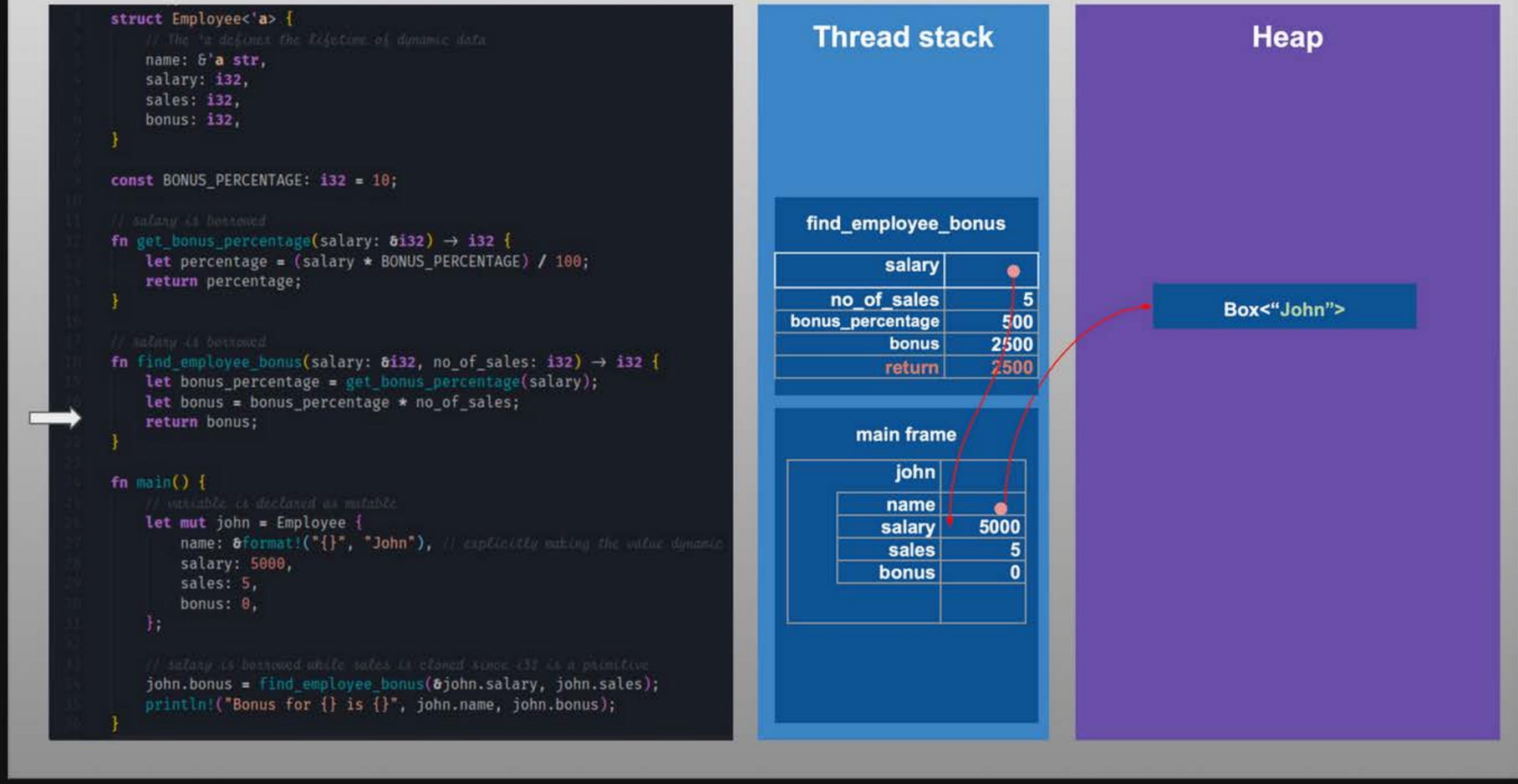

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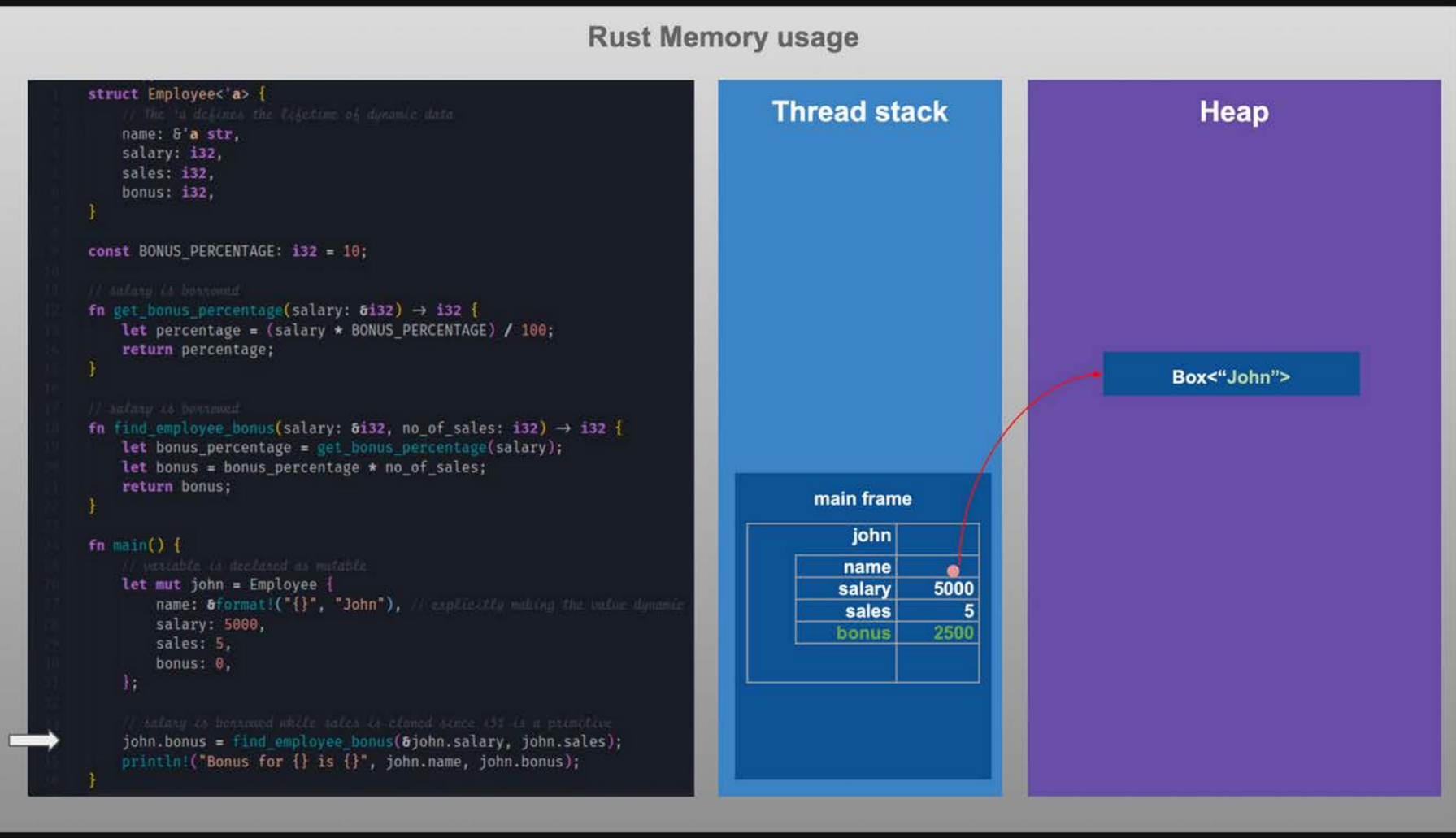

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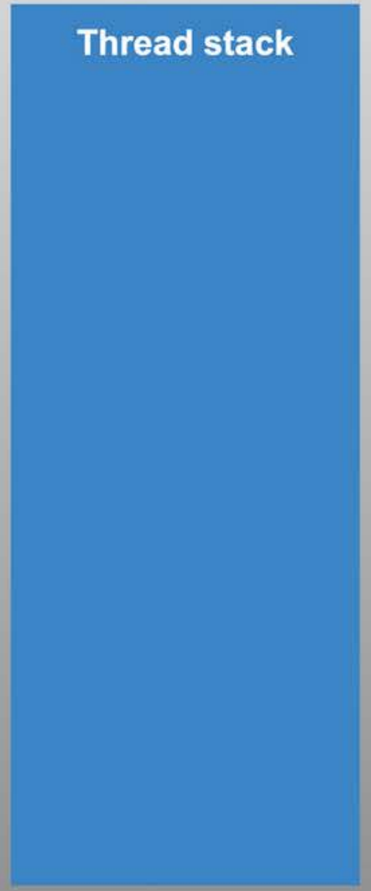
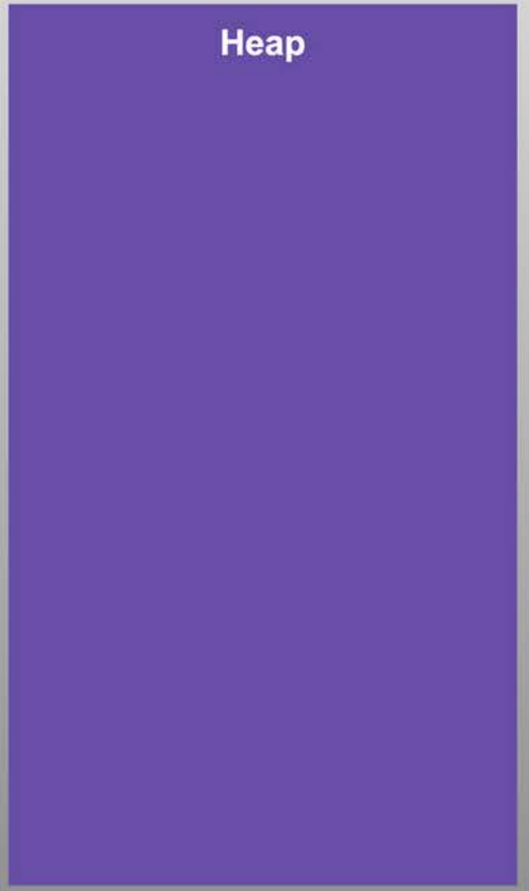




Smart Pointers

- A pointer is a general concept for a variable that contains an address in memory.
- Smart pointers implement the `Deref` and `Drop` traits.
  - The Deref trait allows an instance of the smart pointer struct to behave like a reference so you can write your code to work with either references or smart pointers.
  - The Drop trait allows you to customize the code that's run when an instance of the smart pointer goes out of scope.

Smart pointers in the standard library

- Box< T > for allocating values on the heap
- Rc< T >, a reference counting type that enables multiple ownership
- Ref< T > and RefMut< T >, accessed through RefCell< T >, a type that enforces the borrowing rules at runtime instead of compile time

Box< T >

- Boxes allow you to store data on the heap rather than the stack. What remains on the stack is the pointer to the heap data.
- Box< T > allows immutable or mutable borrows checked at compile time

```
1 fn main() {
2   let b = Box::new(5);
3   println!("b = {}", b);
4 }
```


Rc< T >

- To enable multiple ownership explicitly by using the Rust type Rc, which is an abbreviation for reference counting.
- The Rc type keeps track of the number of references to a value to determine whether or not the value is still in use
- If there are zero references to a value, the value can be cleaned up without any references becoming invalid.
- Rc allows only immutable borrows checked at compile time

RefCell< T >

- Rc< T >, the RefCell< T > type represents single ownership over the data it holds.
- At any given time, you can have either (but not both) one mutable reference or any number of immutable references.
- Rc< T > enables multiple owners of the same data; Box< T > and RefCell< T > have single owners.
- RefCell< T > allows immutable or mutable borrows checked at runtime.

Control Flow

if expression

- The most common way to introduce control flow and branch code.
- Provide a condition and then execute the block of code if the condition is met.

```
1 fn main() {
2   let price: i32 = 10;
3   if price > 0 {
4       println!(“true”);
5   }
6 }
```


if-else expression

- An else expression can be added optionally.
- If no else is provided the program will skip the if block if the condition is false.

```
1 fn main(){
2   let price: i32 = 10;
3   if price > 0 {
4     println!(“true”);
5   }
6   else {
7     println!(“false”);
8   }
9 }
```

else-if expression

- If you have more than two condition to check, if and else can be combined in else if expression.
- In the case all if and else if conditions evaluates to false, then the else block is executed.

```
1  fn main(){
2    let price: i32 = 10;
3    if price == 1 {
4      println!(“price is 1.”);
5      }
6    else if price = 2 {
7      println!(“price is 2.”);
8    }
9    else {
10     println!(“other price”);
11   }
12 }
```

match

- Rust provides pattern matching with the match keyword
- A scrutinee expression is provided to compare to the patterns.
- Arms are evaluated and compared with the scrutineer expression

```
1  fn main(){
2    let x = 1;
3    match x {
4      1 => println!(“one”),
5      2 => println!(“two”),
6      3 => println!(“three”),
7      4 => println!(“four”),
8      5 => println!(“five”),
9      _ => println!(“something else”),
10   }
11 }
```

match

- Here the scrutineer expression is 'x'
- Each arm has a pattern and some code. The `=>` operator separates the pattern and the code to run.
- The first arm with the matching pattern is chosen as the branch target of the match.

```
fn main(){
  let x = 1;
  match x {
    1 => println!(“one”),
    2 => println!(“two”),
    3 => println!(“three”),
    4 => println!(“four”),
    5 => println!(“five”),
    _ => println!(“something else”),
  }
}
```

loop

- Used to execute over block of code ***forever***, Or until it is stopped, or the program quits.
- Instead of having this **`loop`** infinitely the **`break`** keyword can be used.

```
1  fn main() {
2
3    let mut i = 0;
4
5    loop {
6      i += 1;
7
8      if i > 100 { break; }
9    }
10 }
```

while

- Conditional loops
- Run until the condition is met or become false

```
1  fn main(){
2
3    let mut num = 3;
4
5    while num !=0 {
6
7      println!(“{}”, num);
8      num -= 1;
9
10   }
11   println!(“LIFTOFF!!”);
12 }
```

for loop

- Iterate over a element in a collection.
- Every iteration of loop extracts values.

```
1  fn main(){
2
3    let a = [10, 20, 30, 40, 50];
4
5    for element in a.iter() {
6
7      println!(“the value is {}”, element);
8
9    }
10 }
```

iterators

- In Rust, iterators help us achieve the process of looping.
- Using the ***iter()*** function, we tell Rust that the given array can be used with a loop.

```
1 fn main(){
2   let a = [10, 20, 30, 40, 50];
3   for element in a.iter() {
4     println!("the value is {}", element);
5   }
6 }
```

iterator trait

- In Rust, all iterators implement a trait named 'iterator' that has a method called ***next()***
- Using the ***iter()*** function, we tell Rust that the given array can be used with a loop.

```
1 fn main(){
2   let a = [10, 20, 30, 40, 50];
3   for element in a.iter() {
4     println!(“the value is {}”, element);
5   }
6 }
```

Any data type which implements ***next()*** method can be iterator.

Difference in into_iter, iter, iter_mut

- ***into_iter:*** Consumes the collection, once the collection has been consumed, it is no longer available for reuse.
- ***iter:*** This borrows each element of the collection through each iteration, thus leaving the collection untouched and available for reuse after the loop
- ***iter_mut:*** This mutably borrows each element of the collection, allowing for the collection to be modified in place.

Creating our own iterator

Example:

```
1  struct Counter {
2    count: u32,
3  }
4  impl Counter {
5    fn new() -> Counter {
6      Counter { count: 0 }
7    }
8  }
9  impl Iterator for Counter {
10   type Item = u32;
11   fn next(&mut self) -> Option< Self::Item> {
12     if self.count < 5 {
13       self.count += 1;
14       Some(self.count)
15     } else {
16       None
17     }
18   }
19 }
20 fn main() {
21   let mut counter = Counter::new();
22   assert_eq!(counter.next(), Some(1));
23   assert_eq!(counter.next(), Some(2));
24   assert_eq!(counter.next(), Some(3));
25   assert_eq!(counter.next(), Some(4));
26   assert_eq!(counter.next(), Some(5));
27   assert_eq!(counter.next(), None);
28 }
```

Excercise:

```rust
struct Fibonacci {
  curr: u32,
  next: u32,
}

// Implement `Iterator` for `Fibonacci`.
// The `Iterator` trait only requires a method to be defined for the `next` element.
impl Iterator for Fibonacci {
  // We can refer to this type using Self::Item
  type Item = u32;

  /* Implement next method */
  fn next(&mut self)
}

// Returns a Fibonacci sequence generator
fn fibonacci() -> Fibonacci {
  Fibonacci { curr: 0, next: 1 }
}

fn main() {
  let mut fib = fibonacci();
  assert_eq!(fib.next(), Some(1));
  assert_eq!(fib.next(), Some(1));
  assert_eq!(fib.next(), Some(2));
  assert_eq!(fib.next(), Some(3));
  assert_eq!(fib.next(), Some(5));
}
```


+ Operator & where Clause

+ operator is used to add more trait bound.

```
pub fn calculate< T: Calculator + other_Trait> (item: T) -> u32 {
  /// function's stuff

}
```

`where` clause is used to simplify the concept of Trait Bound like

```
/// without where clause
pub fn calculate< T:Calculator, U:Display> (item: T, data: Display) -> u32 {
  /// function's stuff
}

///with where clause
pub fn calculate< T, U> (item: T, data: Display) -> u32
   where T: Calculator,
     U: Display
{
  /// function's stuff
}
```

Error Handling

Types of Error Handling

- Error handling is process of anticipating and working with the possibility of failure
- Learning how to handle errors in rust most effective and time saving
- There are two types of Errors in rust
  - Unrecoverable Errors
  - Recoverable Errors

Unrecoverable Errors

Unrecoverable errors are symptoms of bugs

panic! macro is a simplest way of handling errors

```
1 fn main() {
2   panic!("crash and burn");
3 }
```


What happens when panic is encountered

- Failure message is printed
- Program windups the stack
- Then it quits

When to use panic ?

- Panic only have to be used when a program comes to an unrecoverable state.

Recoverable Errors

Use of **Option** enum

Most errors aren't serious enough that require a program to stop entirely

Option < T > enum is useful to handle non-existing values

```
1 fn main(){
2   enum Option< T > {
3     None,
4     Some(T),
5   }
6 }
```

Recoverable Errors

Use of **Result** enum

Result type enum is used for most common errors, when a operation is expected to work but does not.

Result < T, E > enum is well suited when problems are expected.

```
1 fn main(){
2   enum Result< T, E>{
3     Ok(T),
4     Err(E),
5   }
6 }
```

Helper Functions of Result Type

`unwrap`

```
1 use std::fs::File;
2   fn main(){
3   let f = File::open("hello.txt").unwrap();
4 }
```

`expect`

```
1 use std::fs::File;
2   fn main(){
3   let f = File::open("hello.txt")
4                 .expect("Failed to open hello.txt");
5 }
```

The ? operator

This is similar to match statement

```
fn question() -> Result <(), Error> {
  // let x = ..
  match ultimate_answer(x) {
    Ok(_) => {},
    Err(err) => return Err(err.into()),
  };
  // code
}
```

The above code can be simplified using this ?

```
fn question() -> Result <(), Error> {
    // let x = // ...
    ultimate_answer(x)?; // if `ultimate_answer` returns an error,
                         //`question` stops here
                         //and returns the error.
}
```

Error Propagation

- Code must propagate error information back to caller function after detecting it.
- One of the benefits is that your code will look cleaner by simply propagating error information back to the caller that can handle the error.
- Other benefit is that your function doesn't need extra code to propagate both the successful and unsuccessful cases.

```
1 use std::fs::File;
2 fn main() {
3     let f = File::open("hello.txt");
4     let f = match f {
5         Ok(file) => file,
6         Err(error) => panic!("Can't open the file {:?}", error),
7     };
8 }
```

Concurrency

Fearless Concurrency

- Message-passing concurrency, where *'channels'* send messages between **threads**
- Shared-state concurrency, where multiple between **threads** have access to same piece of data
- The *Sync* and *Send* traits, which extend Rust's concurrency guarantees to user-defined types as well as types provided by the standard library
- To create threads to run multiple pieces of code at the same time

Creating a New Thread

To create a new thread, we call the **thread::spawn** function and pass it a **closure** containing the code we want to run in the new thread.

```
1  use std::thread;
2  use std::time::Duration;
3
4  fn main() {
5
6    thread::spawn(|| {
7      for i in 1..10 {
8        println!("hi number {} from the spawned thread!", i);
9        thread::sleep(Duration::from_millis(1));
10     }
11   });
12
13   for i in 1..5 {
14     println!("hi number {} from the main thread!", i);
15     thread::sleep(Duration::from_millis(1));
16   }
17 }
```

Creating a New Channel

- **Channel** has two haves: **transmitter** and **receiver**
- One thread uses transmitter to **send** data on the channel.
- Other thread uses receiver to **receive** data from the channel
- Channel is **closed** if either transmitter or receiver is **dropped**

```
1  use std::sync::mpsc;
2  use std::thread;
3
4  fn main() {
5
6    let (tx, rx) = mpsc::channel();
7
8    thread::spawn(move || {
9      let val = String::from("hi");
10     tx.send(val).unwrap();
11   });
12
13   let received = rx.recv().unwrap();
14   println!("Got: {}", received);
15 }
```

Shared-State Concurrency

- Shared memory concurrency is like multiple ownership.
- Multiple threads can access same data at the same time.
- `Mutex` ensures access to shared data to only thread at a time.

```
use std::sync::{Arc, Mutex};
use std::thread;

fn main() {
  let counter = Arc::new(Mutex::new(0));
  let mut handles = vec![];

  for _ in 0..10 {
    let counter = Arc::clone(&counter);
    let handle = thread::spawn(move || {
        let mut num = counter.lock().unwrap();
        *num += 1;
    });
    handles.push(handle);
  }
  for handle in handles {
    handle.join().unwrap();
  }
  println!("Result: {}", *counter.lock().unwrap());
}
```

Send and Sync Traits

- The **`Send` marker** trait indicates that ownership of values of the type can be transferred between threads.
- The **`Sync` marker** trait indicates that it is safe to be shared between threads.
- Any type **< T >** is **Sync** if **&T** is **Send**, meaning the immutable reference can be sent safely to another thread.
- Similar to Send, primitive types are Sync, and types composed entirely of types that are Sync are also Sync.

Send Trait

If a type implements Send, it is guaranteed to be safe to `move` between threads. It means that multiple threads can use a value of a type

```
1 use std::thread;
2
3 fn main(){
4
5   let data = vec![1, 2, 3];
6   thread::spawn(move || {
7     println!("{:?}", data);
8   });
9 }
```

Sync Trait

If a type implements Sync, it is guaranteed to be safe to share between threads and a value of a type can be accessed in multiple threads at the same time

```rust
use std::sync::Arc;
use std::thread;

fn main(){
  let data = Arc::new(vec![1, 2, 3]);
  let data_clone = data.clone();

  thread::spawn(move || {
    println!("{:?}", data_clone);
  });

  println!("{:?}", data);
}
```

Use `Arc` instead of a raw pointer, it provides thread-safety and prevent data race conditions.

Async / Await

What is async programming ?

A concurrent programming model

Multitasking

- One of the fundamental features of most operating systems is multitasking, which is the ability to execute multiple tasks concurrently.

  - Preemptive Multitasking

    Preemptive multitasking is that the operating system controls when to switch tasks.

  - Cooperative Multitasking

    Cooperative multitasking lets each task run until it voluntarily gives up control of the CPU.

Async / Await

- Built-in tool in rust programming for writing asynchronous functions.

  - async

    Transforms a block of code into a state machine that implements a trait called **'future'**.

  - await
    - Mechanism to run a future
    - It asynchronously waits for the future to complete.

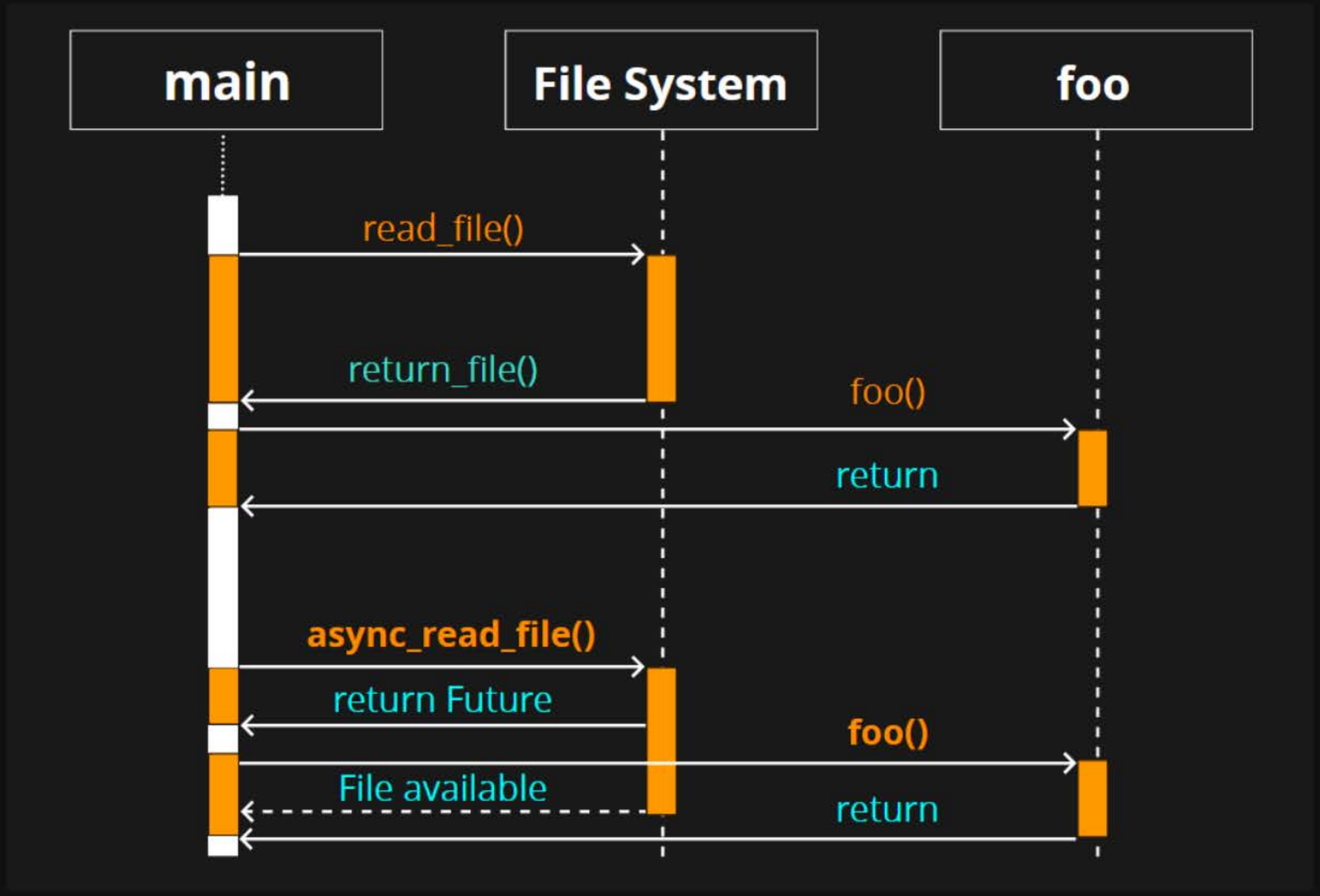
Futures

- A future represents a value that might not be available yet.
- Futures make it possible to continue execution until the value is available.

```
let future = async_read_file("foo.txt");

let file_content = loop {

  match future.poll(…) {

    Poll::Ready(value) => break value,
    Poll::Pending => {}, // do nothing

  }
}
```

```
pub enum Poll< T > {
  Ready(T),
  Pending,
}
```

Flow Diagram for `async`



The async/await Pattern

async/await pattern let the programmer write code that looks like normal synchronous code, but the compiler turns it into asynchronous at compile time.

```
1 async fn foo() -> u32 {
2     0
3 }
```

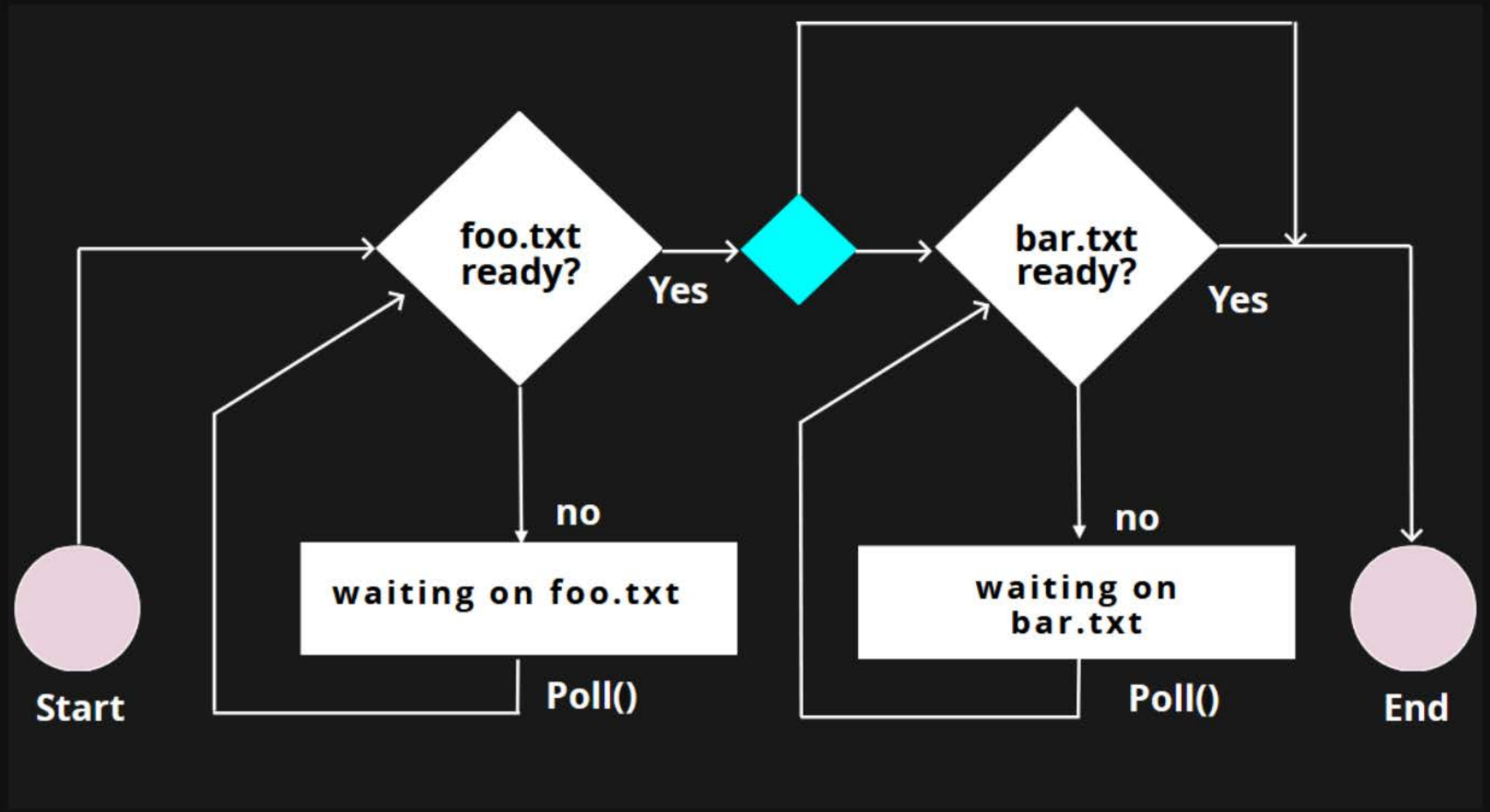
Above code is roughly translated by the compiler to:

```
1 fn foo() -> impl Future < Output = u32 > {
2     future::ready(0);
3 }
```

State Machine Transformation

```
async fn example(min_len: usize) -> String {
  let content = async_read_file("foo.txt").await;
  if content.len() < min_len {
    content + &async_read_file("bar.txt").await
  } else {
    content
  }
}
```

State Machine Transformation



Executors and Wakers

- Executors
  - Allow spawning futures as independent tasks, typically through some sort of 'spawn' method.
  - Responsible for polling all futures until they are completed.
  - Can Switch to a different future whenever a future returns 'Poll::Pending'.
- Wakers
  - Wakers are objects that are used to wake up a task that is blocked waiting for some event to occur.
  - Wakers are typically created by executors and passed to tasks, allowing tasks to be woken up when the relevant event occurs.

Thank You