In this module

Advanced Rust syntax

In this module

- Structured data, enums, matching
- Error handling
- Memory management, references, slices

Ownership

We previously talked about ownership

- In Rust there is always a single owner for each stack value
- Once the owner goes out of scope any associated values should be cleaned up
- Copy types creates copies, all other types are *moved*

Moving out of a function

We have previously seen this example

```rust
fn main() {
    let s1 = String::from("hello");
    let len = calculate_length(s1);
    println!("The length of '{s1}' is {len}.");
}

fn calculate_length(s: String) -> usize {
    s.len()
}
```

- `main` loses ownership of `s1`: it is moved into `calculate_length`
- We can use `Clone` to create an explicit copy
- We can give ownership back by returning the value
- What about other options?

Borrowing

To temporary hold a value, but "give back" the borrow.

- If a value is borrowed, it is not moved and the ownership stays with the original owner
- To borrow in Rust, we create a *reference*

```rust
fn main() {
    let x = String::from("hello");
    let len = calculate_length(&x);
    println!("{x}: {len}");
}

fn calculate_length(arg: &String) -> usize {
    arg.len()
}
```

References (immutable)

References are either *immutable* (default) or *mutable*.

```rust
fn main() {
    let s = String::from("hello");
    change(&s);
    println!("{s}");
}

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

```
   Compiling playground v0.0.1 (/playground)
error[E0596]: cannot borrow `*some_string` as mutable, as it is behind a `&` reference
 --> src/main.rs:8:5
  |
7 | fn change(some_string: &String) {
  |                        ------- help: consider changing this to be a mutable reference: `&mut String`
8 |     some_string.push_str(", world");
  |     ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^ `some_string` is a `&` reference, so the data it refers to cannot be borrowed as mutable

For more information about this error, try `rustc --explain E0596`.
error: could not compile `playground` due to previous error
```

References (mutable)

References are either *immutable* (default) or *mutable*.

```rust
fn main() {
    let mut s = String::from("hello");
    change(&mut s);
    println!("{s}");
}

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

```
   Compiling playground v0.0.1 (/playground)
    Finished dev [unoptimized + debuginfo] target(s) in 2.55s
     Running `target/debug/playground`
hello, world
```

- A mutable reference can even fully replace the original value
- To do this, you can use the dereference operator (`*`) to modify the value:

```rust
*some_string = String::from("Goodbye");
```

Rules for borrowing and references

These rules are enforced by the Rust compiler.

- One mutable reference at the same time
- Any number of immutable references at the same time as long as there is no mutable reference
- References cannot *live* longer than their owners
- A reference will always point to a valid value

These rules are enforced by the Rust compiler.

Borrowing and memory safety

The borrowing rules and ownership model make Rust safe.

- Rust is memory safe without runtime overhead like a garbage collector
- Rust performs like a language with manual memory management

Reference example

```rust
fn main() {
    let mut s = String::from("hello");
    let s1 = &s;
    let s2 = &s;
    let s3 = &mut s;
    println!("{s1} - {s2} - {s3}");
}
```

```
   Compiling playground v0.0.1 (/playground)
error[E0502]: cannot borrow `s` as mutable because it is also borrowed as immutable
 --> src/main.rs:5:14
  |
3 |     let s1 = &s;
  |              -- immutable borrow occurs here
4 |     let s2 = &s;
5 |     let s3 = &mut s;
  |              ^^^^^^ mutable borrow occurs here
6 |     println!("{s1} - {s2} - {s3}");
  |                ‐‐ immutable borrow later used here

For more information about this error, try `rustc --explain E0502`.
error: could not compile `playground` due to previous error
```

Returning references

You can return references, but the value borrowed from must exist at least as long

```rust
fn give_me_a_ref() -> &String {
    let s = String::from("Hello, world!");
    &s
}
```

```
   Compiling playground v0.0.1 (/playground)
error[E0106]: missing lifetime specifier
 --> src/lib.rs:1:23
  |
1 | fn give_me_a_ref() -> &String {
  |                       ^ expected named lifetime parameter
  |
  = help: this function's return type contains a borrowed value, but there is no value for it to be borrowed from
help: consider using the `'static` lifetime
  |
1 | fn give_me_a_ref() -> &'static String {
  |                       ~~~~~~~~

For more information about this error, try `rustc --explain E0106`.
error: could not compile `playground` due to previous error
```

Returning references

You can return references, but the value borrowed from must exist at least as long

```rust
fn give_me_a_ref(input: &(String, i32)) -> &String {
    &input.0
}
```

```rust
fn give_me_a_value() -> String {
    let s = String::from("Hello, world!");
    s
}
```

Structured data types

Types redux

We have seen some basic types

- Primitives (integers, floats, booleans, characters)
- Compounds (tuples, arrays)
- Most types were `` `Copy` ``
- Borrowing becomes more interesting with more complex data types

Structuring data

Rust has two important ways to structure data

- structs
- enums
- ~~unions~~

Structs

A struct is similar to a tuple, but this time the combined type gets its own name

```rust
struct ControlPoint(f64, f64, bool);
```

This is an example of a *tuple struct*. You can access the fields in the struct the same way as with tuples:

```rust
fn main() {
  let cp = ControlPoint(10.5, 12.3, true);
  println!("{}", cp.0); // prints 10.5
}
```

Structs

Much more common though are structs with named fields

```rust
struct ControlPoint {
  x: f64,
  y: f64,
  enabled: bool,
}
```

- We can add a little more purpose to each field
- No need to keep our indexing up to date when we add or remove a field

```rust
fn main() {
  let cp = ControlPoint {
    x: 10.5,
    y: 12.3,
    enabled: true,
  };
  println!("{}", cp.x); // prints 10.5
}
```

Enumerations

One of the more powerful kinds of types in Rust are enumerations

```rust
enum IpAddressType {
  Ipv4,
  Ipv6,
}
```

- An enumeration (listing) of different *variants*
- Each variant is an alternative value of the enum, you pick a single variant to create an instance

```rust
fn main() {
  let ip_type = IpAddressType::Ipv4;
}
```

Enumerations

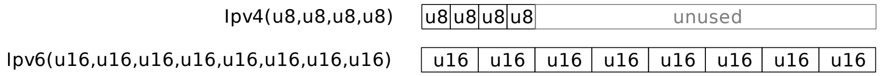
Enums get more powerful, because each variant can have associated data with it

```rust
enum IpAddress {
  Ipv4(u8, u8, u8, u8),
  Ipv6(u16, u16, u16, u16, u16, u16, u16, u16),
}
```

- This way, the associated data and the variant are bound together
- Impossible to create an IPv6 address while only giving a 32-bit integer

```rust
fn main() {
  let ipv4_home = IpAddress::Ipv4(127, 0, 0, 1);
  let ipv6_home = IpAddress::Ipv6(0, 0, 0, 0, 0, 0, 0, 1);
}
```

- Note: an enum always is as large as the largest variant



Pattern matching

To extract data from enums we can use pattern matching using the `if let [pattern] = [value]` statement

```rust
fn accept_ipv4(ip: IpAddress) {
  if let IpAddress::Ipv4(a, b, _, _) = ip {
    println!("Accepted, first octet is {a} and second is {b}");
  }
}
```

- `a` and `b` introduce local variables within the body of the if that contain the values of those fields
- The underscore (`_`) can be used to accept any value

Match

Pattern matching is very powerful if combined with the match statement

```rust
fn accept_home(ip: IpAddress) {
  match ip {
    IpAddress::Ipv4(127, 0, 0, 1) => {
      println!("You are home!");
    },
    IpAddress::Ipv6(0, 0, 0, 0, 0, 0, 0, 1) => {
      println!("You are in your new home!");
    },
    _ => {
      println!("You are not home");
    },
  }
}
```

- Every part of the match is called an arm
- A match is exhaustive, which means that all variants must be handled by one of the match arms
- You can use a catch-all `` `_` `` arm to catch any remaining cases if there are any left

Match as an expression

The match statement can even be used as an expression

```rust
fn get_first_byte(ip: IpAddress) {
  let first_byte = match ip {
    IpAddress::Ipv4(a, _, _, _) => a,
    IpAddress::Ipv6(a, _, _, _, _, _, _, _) => a / 256 as u8,
  };
  println!("The first byte was: {first_byte}");
}
```

- The match arms can return a value, but their types have to match
- Note how here we do not need a catch all `` `_` `` arm because all cases have already been handled by the two arms

Generics

Data types become even more powerful if we introduce generics

```rust
struct PointFloat(f64, f64);
struct PointInt(i64, i64);
```

We are repeating ourselves here, what if we could write a data structure for both of these cases?

```rust
struct Point<T>(T, T);

fn main() {
  let float_point: Point<f64> = Point(10.0, 10.0);
  let int_point: Point<i64> = Point(10, 10);
}
```

Generics are much more powerful, but this is all we need for now

Option

A quick look into the basic enums available in the standard library

- Rust does not have null, but you can still define variables that optionally do not have a value
- For this you can use the `` `Option<T>` `` enum

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

fn main() {
  let some_int = Option::Some(42);
  let no_string: Option<String> = Option::None;
}
```

Option

A quick look into the basic enums available in the standard library

- Rust does not have null, but you can still define variables that optionally do not have a value
- For this you can use the `Option<T>` enum

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

fn main() {
  let some_int = Some(42);
  let no_string: Option<String> = None;
}
```

`Some` and `None` are in scope by default.

Error handling

What would we do when there is an error?

```rust
fn divide(x: i64, y: i64) -> i64 {
  if y == 0 {
    // what to do now?
  } else {
    x / y
  }
}
```

Error handling

What would we do when there is an error?

```rust
fn divide(x: i64, y: i64) -> i64 {
  if y == 0 {
    panic!("Cannot divide by zero");
  } else {
    x / y
  }
}
```

- A **panic** is the most basic way to handle errors; and
- is an *all or nothing* kind of error
- *immediately stops* running the current thread using one of two methods:
  - Unwinding: going up through the stack and making sure that each value is cleaned up
  - Aborting: ignore everything and immediately exit the thread/program
- should only be used if normal error handling would also exit the program
- should be avoided in library code

Error handling

What would we do when there is an error? We could try and use the option enum instead of panicking

```rust
fn divide(x: i64, y: i64) -> Option<i64> {
  if y == 0 {
    None
  } else {
    Some(x / y)
  }
}
```

Result

Another really powerful enum is the result, which is even more useful if we think about error handling

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

enum DivideError {
  DivisionByZero,
  CannotDivideOne,
}

fn divide(x: i64, y: i64) -> Result<i64, DivideError> {
  if x == 1 {
    Err(DivideError::CannotDivideOne)
  } else if y == 0 {
    Err(DivideError::DivisionByZero)
  } else {
    Ok(x / y)
  }
}
```

Handling results

The caller may decide how to handle a possible error.

```rust
fn div_zero_fails() {
  match divide(10, 0) {
    Ok(div) => println!("{div}"),
    Err(e) => panic!("Could not divide by zero"),
  }
}
```

- The `divide` function's signature is explicit in how it can fail
- The function's caller can decide what to do, even if it is panicking
- Note: just as with `Option`: `Ok` and `Err` are available globally

Handling results

Sometimes, you want to postpone writing error handling code later. For both `Option` and `Result`:

```rust
fn div_zero_fails() {
  let div = divide(10, 0).unwrap();
  println!("{div}");
}
```

- `unwrap` checks for the "happy path", or it panics with an error message
- Having unwraps all over the place is considered a bad practice
- Sometimes you can ensure that an error won’t occur, in such cases `unwrap` can be a good solution

Handling results

Sometimes, you want to postpone writing error handling code later. For both `` `Option` `` and `` `Result` ``:

```rust
fn div_zero_fails() {
  let div = divide(10, 0).unwrap_or(-1);
  println!("{div}");
}
```

Besides unwrap, there are some other useful utility functions:

- `` `unwrap_or(val)` ``: Recovers with a specified `` `val` ``
- `` `unwrap_or_default()` ``: Recovers with a default value for the type
- `` `expect(msg)` ``: Same as unwrap, but instead panic with a custom error message
- `` `unwrap_or_else(fn)` ``: Recovers lazily with the result of a specified function

Result and the `?` operator

Results are so common, they have a special operator: the `?` operator

```rust
fn can_fail() -> Result<i64, Error> {
  let intermediate_result = match divide(10, 0) {
    Ok(ir) => ir,
    Err(e) => return Err(e);
  };

  match divide(intermediate_result, 0) {
    Ok(sec) => Ok(sec * 2),
    Err(e) => Err(e),
  }
}
```

Look how this function changes if we use the `?` operator

```rust
fn can_fail() -> Result<i64, Error> {
  let intermediate_result = divide(10, 0)?;
  Ok(divide(intermediate_result, 0)? * 2)
}
```

Result and the `?` operator

```rust
fn can_fail() -> Result<i64, Error> {
  let intermediate_result = divide(10, 0)?;
  Ok(divide(intermediate_result, 0)? * 2)
}
```

- The `?` operator does an implicit match, if there is an error, that error is then immediately returned and the function returns early
- If the result is `Ok()` then the value is extracted and we can continue right away

Intermission: Impl blocks

In the past few slides we saw a syntax which wasn’t explained before:

```rust
fn main() {
  let x = Some(42);
  let unwrapped = x.unwrap();
  println!("{unwrapped}");
}
```

- The syntax `` `x.y()` `` looks similar to how we accessed a field in a struct
- We can define functions on our types using impl blocks
- Impl blocks can be defined on any type, not just structs (with some limitations)

Intermission: Impl blocks

```rust
enum IpAddress {
  Ipv4(u8, u8, u8, u8),
  Ipv6(u16, u16, u16, u16, u16, u16, u16, u16),
}

impl IpAddress {
  fn as_u32(&self) -> Option<u32> {
    match self {
      IpAddress::Ipv4(a, b, c, d) => a << 24 + b << 16 + c << 8 + d
      _ => None,
    }
  }
}

fn main() {
  let addr = IpAddress::Ipv4(127, 0, 0, 1);
  println!("{:?}", addr.as_u32());
}
```

Intermission: Impl blocks, self and Self

- The `` `self` `` parameter defines how the method can be used.
- Absence of a `` `self` `` parameter defines an *associated function*

```rust
struct Foo(i32);

impl Foo {
  fn consume(self) -> Self {
    Self(self.0 + 1)
  }

  fn borrow(&self) -> &i32 {
    &self.0
  }

  fn borrow_mut(&mut self) -> &mut i32 {
    &mut self.0
  }

  fn new() -> Self {
    Self(0)
  }
}
```

Intermission: Impl blocks, the self parameter

- Associated functions are called via `` `Type::method()` ``
- Methods are called via `` `instance.method()` ``

```rust
fn main () {
  let mut f = Foo::new();
  println!("{}", f.borrow());
  *f.borrow_mut() = 10;
  let g = f.consume();
  println!("{}", g.borrow());
}
```

Intermission: Impl blocks, self and Self

The `self` parameter is called the *receiver*.

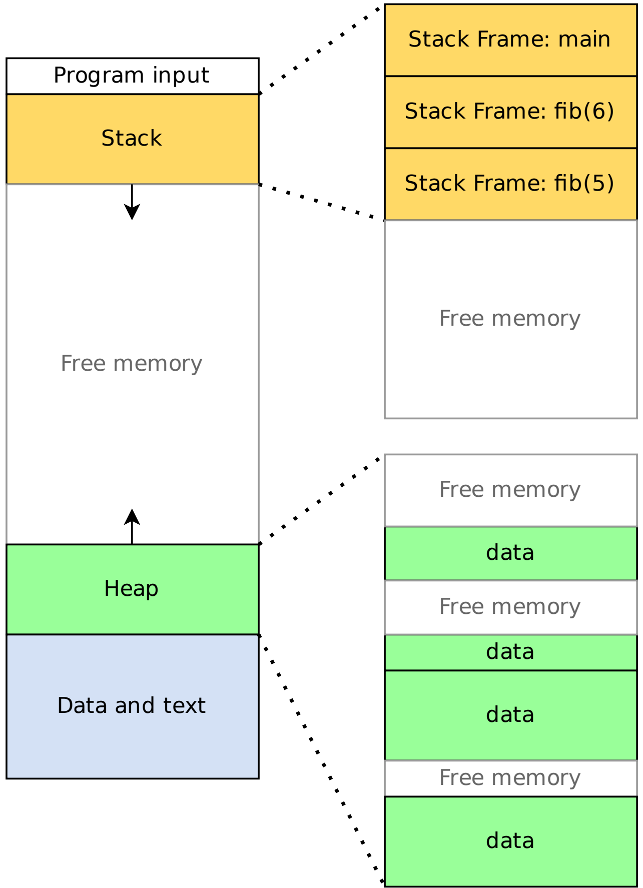
- The `self` parameter is always first
- We don't have to specify the type of the `self` parameter
- We can optionally prepend `&` or `&mut `
- The `Self` type is a shorthand for the type on which the current implementation is specified.

```rust
struct Foo(i32);

impl Foo {
  fn borrow_mut(&mut self) -> &mut i32 {
    &mut self.0
  }

  fn new() -> Self {
    Self(0)
  }
}
```

Memory management

Memory management

- Most of what we have seen so far is stack-based and small in size
- All these primitive types are `` `Copy` ``: create a copy on the stack every time we need them somewhere else
- We don’t want to pass a copy all the time
- Large data that we do not want to copy
- Modifying original data
- What about data structures with a variable size?

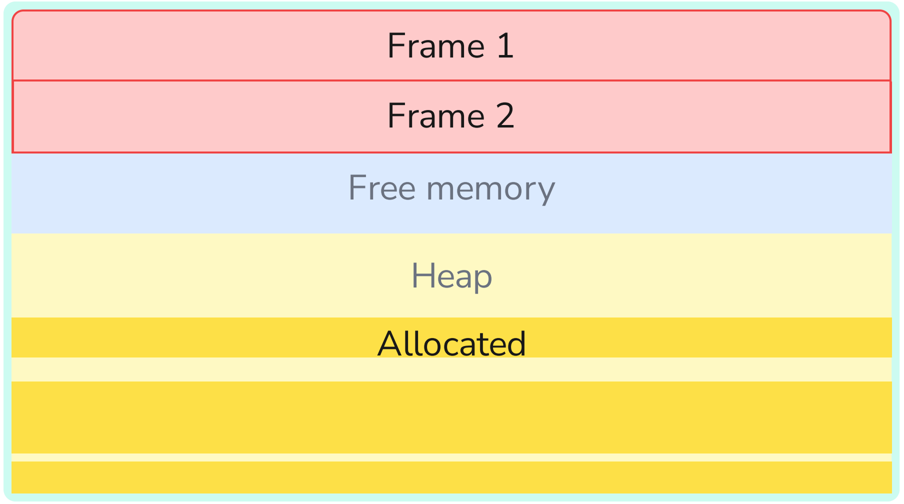


Memory

- A computer program consists of a set of instructions
- Those instructions manipulate some memory
- How does a program know what memory can be used?

Fundamentals

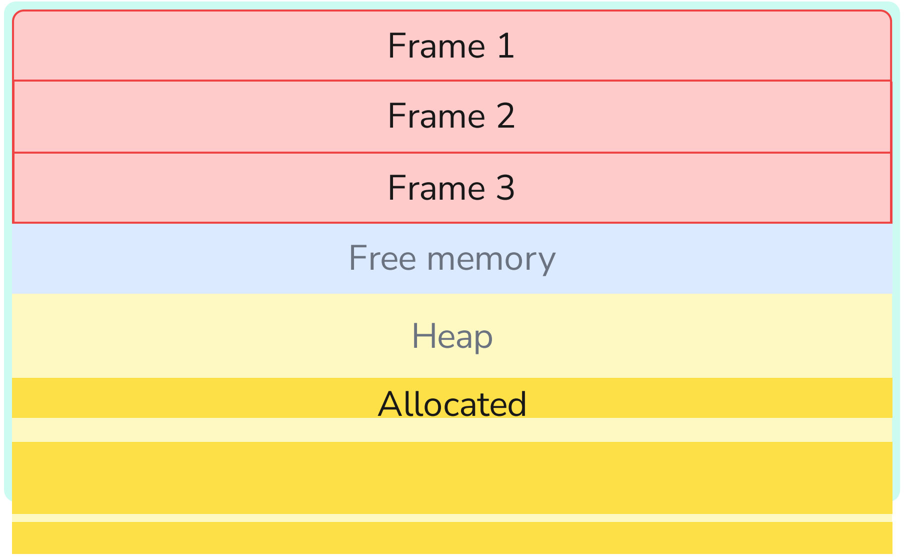
There are two mechanisms at play here, generally known as the stack and the heap



 Stack pointer

Fundamentals

There are two mechanisms at play here, generally known as the stack and the heap

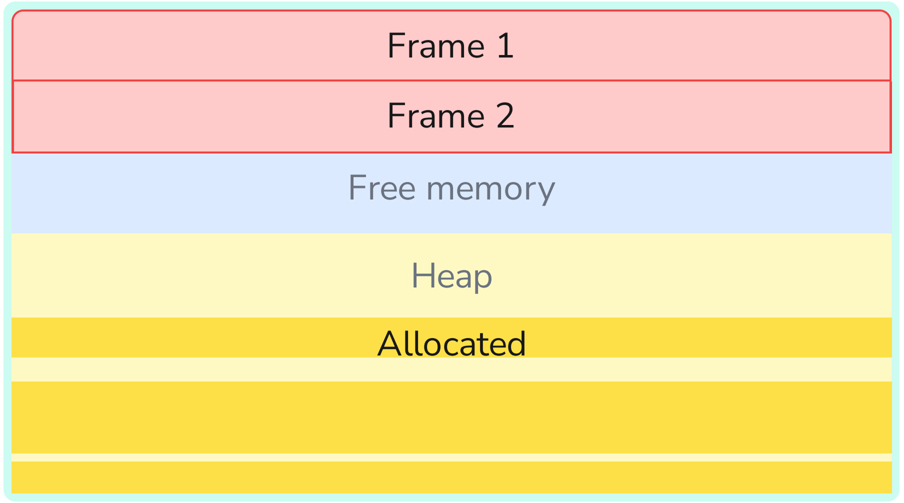


 Stack pointer

A stack frame is allocated for every function call. It contains exactly enough space for all local variables, arguments and stores where the previous stack frame starts.

Fundamentals

There are two mechanisms at play here, generally known as the stack and the heap



 Stack pointer

Once a function call ends we just move back up, and everything below is available as free memory once more.

Stack limitations

The stack has limitations: it only grows as a result of a function call.

- Size of items on stack frame must be known at compile time
- If I don’t know the size of a variable up front: What size should my stack frame be?
- How can I handle arbitrary user input efficiently?

The Heap

If the lifetime of some value needs to outlive its scope, it cannot be placed on the stack. We need the heap!

It’s all in the name, the heap is just one big pile of memory for you to store stuff in. But what part of the heap is in use? What part is available?

- Data comes in all shapes and sizes
- When a new piece of data comes in we need to find a place in the heap that still has a large enough chunk of data available
- When is a piece of heap memory no longer needed?
- Where does it start? Where does it end?
- When can we start using it?

Vec: storing more of the same

The vector is an array that can grow

- Compare this to the array we previously saw, which has a fixed size

```rust
fn main() {
  let arr = [1, 2];
  println!("{:?}", arr);

  let mut nums = Vec::new();
  nums.push(1);
  nums.push(2);
  println!("{:?}", nums);
}
```

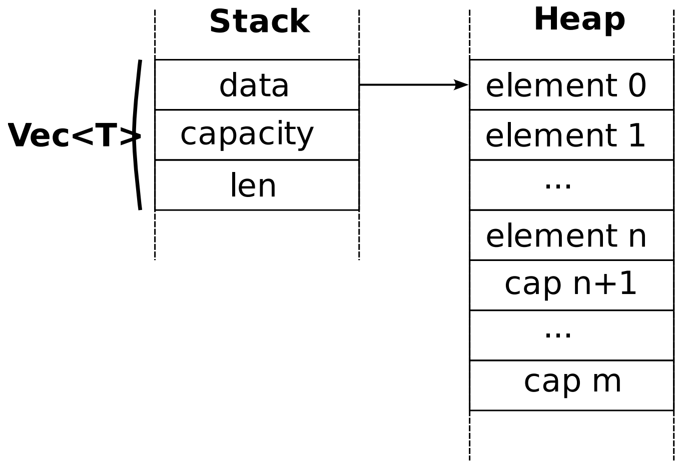
Vec

Vec is such a common type that there is an easy way to initialize it with values that looks similar to arrays

```rust
fn main() {
  let mut nums = vec![1, 2];
  nums.push(3);
  println!("{:?}", nums);
}
```

Vec: memory layout

How can a vector grow? Things on the stack need to be of a fixed size

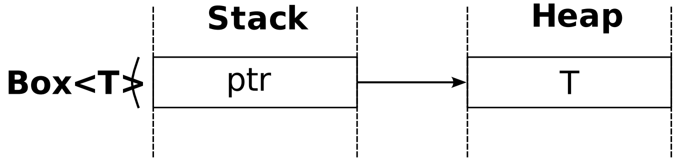


Put it in a `Box`

That pointer from the stack to the heap, how do we create such a thing?

- Boxing something is the way to store a value on the heap
- A `Box` uniquely owns that value, there is no one else that also owns that same value
- Even if the type inside the box is `Copy`, the box itself is not, move semantics apply to a box.

```rust
fn main() {
  // put an integer on the heap
  let boxed_int = Box::new(10);
}
```



Boxing

There are several reasons to box a variable on the heap

- When something is too large to move around
- We need something that is sized dynamically
- For writing recursive data structures

```rust
struct Node {
  data: Vec<u8>,
  parent: Node,
}
```

Boxing

There are several reasons to box a variable on the heap

- When something is too large to move around
- We need something that is sized dynamically
- For writing recursive data structures

```rust
struct Node {
  data: Vec<u8>,
  parent: Box<Node>,
}
```

Vectors and arrays

What if we wanted to write a sum function, we could define one for arrays of a specific size:

```rust
fn sum(data: &[i64; 10]) -> i64 {
  let mut total = 0;
  for val in data {
    total += val;
  }
  total
}
```

Vectors and arrays

Or one for just vectors:

```rust
fn sum(data: &Vec<i64>) -> i64 {
  let mut total = 0;
  for val in data {
    total += val;
  }
  total
}
```

Slices

What if we want something to work on arrays of any size? Or what if we want to support summing up only parts of a vector?

- A slice is a dynamically sized view into a contiguous sequence
- Contiguous: elements are layed out in memory such that they are evenly spaced
- Dynamically sized: the size of the slice is not stored in the type, but is determined at runtime
- View: a slice is never an owned data structure
- Slices are typed as `` `[T]` ``, where `` `T` `` is the type of the elements in the slice

Slices

```rust
fn sum(data: [i64]) -> i64 {
  let mut total = 0;
  for val in data {
    total += val;
  }
  total
}

fn main() {
  let data = vec![10, 11, 12, 13, 14];
  println!("{}", sum(data));
}
```

```
   Compiling playground v0.0.1 (/playground)
error[E0277]: the size for values of type `[i64]` cannot be known at compilation time
 --> src/main.rs:1:8
  |
1 | fn sum(data: [i64]) -> i64 {
  |        ^^^^ doesn't have a size known at compile-time
  |
  = help: the trait `Sized` is not implemented for `[i64]`
help: function arguments must have a statically known size, borrowed types always have a known size
```

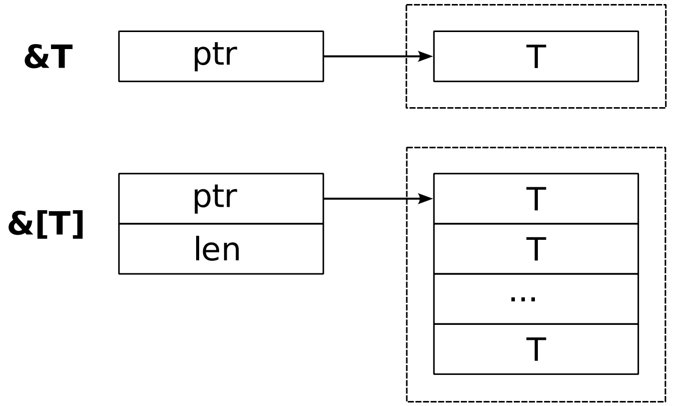
Slices

```rust
fn sum(data: &[i64]) -> i64 {
  let mut total = 0;
  for val in data {
    total += val;
  }
  total
}

fn main() {
  let data = vec![10, 11, 12, 13, 14];
  println!("{}", sum(&data));
}
```

```
   Compiling playground v0.0.1 (/playground)
    Finished dev [unoptimized + debuginfo] target(s) in 0.89s
     Running `target/debug/playground`
60
```

Slices

- `[T]` is an incomplete type: we need to know how many `T` there are
- Types that have a known compile time size implement the `Sized` trait, raw slices do **not** implement it
- Slices must always be behind a reference type, i.e. `&[T]` and `&mut [T]` (but also `Box<[T]>` etc)
- The length of the slice is always stored together with the reference



Creating slices

Because we cannot create slices out of thin air, they have to be located somewhere. There are three possible ways to create slices:

- Using a borrow
  - We can borrow from arrays and vectors to create a slice of their entire contents
- Using ranges
  - We can use ranges to create a slice from parts of a vector or array
- Using a literal (for immutable slices only)
  - We can have memory statically available from our compiled binary

Creating slices

Using a borrow

```rust
fn sum(data: &[i32]) -> i32 { /* ... */ }

fn main() {
  let v = vec![1, 2, 3, 4, 5, 6];
  let total = sum(&v);
  println!("{total}");
}
```

Creating slices

Using ranges

```rust
fn sum(data: &[i32]) -> i32 { /* ... */ }

fn main() {
  let v = vec![0, 1, 2, 3, 4, 5, 6];
  let all = sum(&v[..]);
  let except_first = sum(&v[1..]);
  let except_last = sum(&v[..5]);
  let except_ends = sum(&v[1..5]);
}
```

- The range `start..end` contains all values `x` with `start <= x < end`.
- Note: you can also use ranges on their own, for example in a for loop:

```rust
fn main() {
  for i in 0..10 {
    println!("{i}");
  }
}
```

Creating slices

From a literal

```rust
fn sum(data: &[i32]) -> i32 { /* ... */ }

fn get_v_arr() -> &'static [i32] {
    &[0, 1, 2, 3, 4, 5, 6]
}

fn main() {
  let all = sum(get_v_arr());
  let v = vec![0, 1, 2, 3, 4, 5, 6];
  let all_vec = sum(&v as &[i32]);
  let all_vec = sum(&v);
}
```

- Interestingly `get_v_arr` works, even though the literal looks like it would only exist temporarily
- Literals actually exist during the entire lifetime of the program
- `&'static` here is used to indicate that this slice will exist the entire lifetime of the program

Strings

We have already seen the ``String`` type being used before, but let’s dive a little deeper

- Strings are used to represent text
- In Rust they are always valid UTF-8
- Their data is stored on the heap
- A String is almost the same as ``Vec<u8>`` with extra checks to prevent creating invalid text

Strings

Let’s take a look at some strings

```rust
fn main() {
  let s = String::from("Hello world\nSee you!");
  println!("{:?}", s.split_once(" "));
  println!("{}", s.len());
  println!("{:?}", s.starts_with("Hello"));
  println!("{}", s.to_uppercase());
  for line in s.lines() {
    println!("{line}");
  }
}
```

String literals

We have already seen string literals being used while constructing a string. The string literal is what arrays are to vectors

```rust
fn main() {
  let s1 = "Hello world";
  let s2 = String::from("Hello world");
}
```

String literals

We have already seen string literals being used while constructing a string. The string literal is what arrays are to vectors

```rust
fn main() {
  let s1: &'static str = "Hello world";
  let s2: String = String::from("Hello world");
}
```

- `s1` is actually a slice, a string slice

String literals

We have already seen string literals being used while constructing a string. The string literal is what arrays are to vectors

```rust
fn main() {
  let s1: &str = "Hello world";
  let s2: String = String::from("Hello world");
}
```

- `s1` is actually a slice, a string slice

str - the string slice

It should be possible to have a reference to part of a string. But what is it?

- Not `` `[u8]` ``: not every sequence of bytes is valid UTF-8
- Not `` `[char]` ``: we could not create a slice from a string since it is stored as UTF-8 encoded bytes
- We introduce a new special kind of slice: `` `str` ``
- For string slices we do not use brackets!

str, String, array, Vec

Static	Dynamic	Borrowed
`` `[T; N]` ``	`` `Vec<T>` ``	`` `&[T]` ``
-	`` `String` ``	`` `&str` ``

- There is no static variant of str
- This would only be useful if we wanted strings of an exact length
- But just like we had the static slice literals, we can use `` `&'static str` `` literals for that instead!

String or str

When do we use `` `String` `` and when do we use `` `str` ``?

```rust
fn string_len(data: &String) -> usize {
  data.len()
}
```

String or str

When do we use `String` and when do we use `str`?

```rust
fn string_len(data: &str) -> usize {
  data.len()
}
```

- Prefer `&str` over `String` whenever possible
- If you need to mutate a string you might try `&mut str`, but you cannot change a slice’s length
- Use `String` or `&mut String` if you need to fully mutate the string

Summary

- Rust uses ownership and borrowing to give memory safety without a garbage collector
- Rust has structs and enums to structure your data
- Use `` `panic!` ``, `` `Result` `` and `` `Option` `` for handling errors and missing values
- Define methods and associated functions with impl blocks
- Use `` `Vec<T>` `` for growable array storage
- Use `` `Box<T>` `` to put something on the heap
- Use slices whenever possible instead of owned `` `Vec<T>` `` and `` `String` `` types

Exercises

- We’ll be doing the A2 excercises, see https://101.rustiec.be, "A2 - Advanced Syntax, Ownership, references".
  - Use `` `rust101` `` and `` `Rust101!` `` as username and password.
- Don’t hesitate to ask when you get stuck!

Cheat sheet for A2

https://101.rustiec.be

Borrowing

```rust
let mut bar = 3; let foo = &mut bar; *foo = 1;
```

Error handling and propagation

```rust
enum MyError { OhNo, Almost, }
fn foo(..) -> Result<u32, MyError> { res?; Ok(1) }
```

Slices

```rust
let v = vec![0, 1, 2, 3, 4, 5, 6];
let all = sum(&v[..]);
let except_first = sum(&v[1..]);
let except_last = sum(&v[..5]);
let except_ends = sum(&v[1..5]);
```