

# Lecture 2: Traits

Methods, traits, functional programming and standard library

Willem Vanhulle

**DevLab Rust 2025**

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[github.com/wvhulle/rust-course-ghent](https://github.com/wvhulle/rust-course-ghent)

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## 1.1. Disclaimer

- These are difficult questions. Just try your best!
- Will not be graded.

## 1. Quiz about last lecture

## 1.2. Loop

### 1.2.1. Question

```
1 struct S;  
2  
3 fn main() {  
4     let [x, y] = &mut [S, S];  
5  
6     let eq = x as *mut S == y as *mut S;  
7     print!("{}", eq as u8);  
8 }
```

*(playground link)*

What does this program print?

## 1.2. Loop

### 1.2.1. Question

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What does this program print?

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## 1.2. Loop

### 1.2.2. Explanation

What are zero-sized types?

1. Quiz about last lecture

## 1.2. Loop

### 1.2.2. Explanation

What are zero-sized types?

Types that occupy no space at runtime.

```
1 struct S;  
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[\(playground link\)](#)

# 1.2. Loop

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[\(playground link\)](#)

Desugaring  
pattern match

```
1 fn main() {  
2     let tmp: [S; 2] = [S, S];  
3     let x = &mut tmp[0];  
4     let y = &mut tmp[1];  
5     let eq = x as *mut S == y as *mut S;  
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[\(playground link\)](#)



# 1.2. Loop

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6     print!("{}", eq as u8);  
7 }
```

(playground link)

Operator precedence

```
1 fn main() {  
2     let tmp: [S; 2] = [S, S];  
3     let x = &mut tmp[0];  
4     let y = &mut tmp[1];  
5     let eq = (x as *mut S) == (y as *mut S);  
6     print!("{}", eq as u8);  
7 }
```

(playground link)

# 1.2. Loop

## 1.2.2. Explanation

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```
1 struct S;
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[\(playground link\)](#)

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[\(playground link\)](#)

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6     print!("{}", eq as u8);
7 }
```

[\(playground link\)](#)

Explicit casts

```
1 fn main() {
2     let tmp: [S; 2] = [S, S];
3     let x = &mut tmp[0];
4     let y = &mut tmp[1];
5     let x_ptr: *mut S = x;
6     let y_ptr: *mut S = y;
7     let eq = x_ptr == y_ptr;
8     print!("{}", eq as u8);
9 }
```

[\(playground link\)](#)

Are x\_ptr and y\_ptr equal?

# 1.2. Loop

## 1.2.2. Explanation

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Types that occupy no space at runtime.

```
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Operator precedence

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(playground link)

Explicit casts

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1 fn main() {
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5     let x_ptr: *mut S = x;
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7     let eq = x_ptr == y_ptr;
8     print!("{}", eq as u8);
9 }
```

(playground link)

Are x\_ptr and y\_ptr equal?

Yes, since the compiler can see that S is a zero-sized type.

## 1.3. Patterns

### 1.3.1. Question

Last session I mentioned that variable assignments are actually patterns.

```
1 fn main() {  
2     let (_, x, y) = (0, 1, ..);  
3     print!("{}", b"066"[y][x]);  
4 }
```

*(playground link)*

What does this program print?

## 1.3. Patterns

### 1.3.1. Question

Last session I mentioned that variable assignments are actually patterns.

```
1 fn main() {  
2     let (_, x, y) = (0, 1, ..);  
3     print!("{}", b"066"[y][x]);  
4 }
```

*(playground link)*

What does this program print?

...

## 1.3. Patterns

1. Quiz about last lecture

### 1.3.2. Explanation

```
1 fn main() {  
2     let (_, x, y) = (0,  
3     1, ..);  
4     print!("{}", b"066"[y][x]);  
5 }
```

*(playground link)*

## 1.3. Patterns

### 1.3.2. Explanation

```
1 fn main() {  
2     let (.., x, y) = (0,  
3         1, ..);  
4     print!("{}", b"066"[y][x]);  
                                     (playground link)
```

Desugaring  
→

```
1 fn main() {  
2     let x = 1;  
3     let y: RangeFull = ..;  
4     print!("{}", b"066"[y][x]);  
5 }  
                                     (playground link)
```

## 1.3. Patterns

### 1.3.2. Explanation

```
1 fn main() {  
2     let (_, x, y) = (0,  
3         1, ..);  
4     print!("{}", b"066"[y][x]);  
                                     (playground link)
```

Desugaring  
→

```
1 fn main() {  
2     let x = 1;  
3     let y: RangeFull = ..;  
4     print!("{}", b"066"[y][x]);  
5 }  
                                     (playground link)
```

Type inference  
↙

```
1 fn main() {  
2     let x = 1;  
3     let y = ..;  
4     let bytes: &'static [u8; 3] =  
5         b"066";  
6     print!("{}", bytes[..][x]);  
                                     (playground link)
```



# 1.3. Patterns

## 1.3.2. Explanation

```
1 fn main() {  
2     let (_, x, y) = (0,  
3         1, ..);  
4     print!("{}", b"066"[y][x]);  
5 }  
                                     (playground link)
```

Desugaring  
→

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1 fn main() {  
2     let x = 1;  
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5 }  
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Type inference  
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1 fn main() {  
2     let x = 1;  
3     let y = ..;  
4     let bytes: &'static [u8; 3] =  
5         b"066";  
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7 }  
                                     (playground link)
```

Slice  
indexing  
→

```
1 fn main() {  
2     let x = 1;  
3     let bytes = b"066";  
4     print!("{}", bytes[x]);  
5 }  
                                     (playground link)
```

What is the decimal representation of the ASCII character ‘6’?

# 1.3. Patterns

## 1.3.2. Explanation

```
1 fn main() {  
2     let (_, x, y) = (0,  
3         1, ..);  
4     print!("{}", b"066"[y][x]);  
5 }  
                                     (playground link)
```

Desugaring  
→

```
1 fn main() {  
2     let x = 1;  
3     let y: RangeFull = ..;  
4     print!("{}", b"066"[y][x]);  
5 }  
                                     (playground link)
```

Type inference  
↙

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1 fn main() {  
2     let x = 1;  
3     let y = ..;  
4     let bytes: &'static [u8; 3] =  
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                                     (playground link)
```

Slice  
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1 fn main() {  
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5 }  
                                     (playground link)
```

What is the decimal representation of the ASCII character ‘6’?

54

## 1.4. Bool

### 1.4.1. Question

```
1  fn check(x: i32) -> bool {
2      print!("{}", x);
3      false
4  }
5
6  fn main() {
7      match (1, 2) {
8          (x, _) | (_, x) if check(x) => {
9              print!("3")
10             }
11          _ => print!("4"),
12      }
13 }
```

*(playground link)*

What does this program print?

## 1.4. Bool

### 1.4.1. Question

```
1  fn check(x: i32) -> bool {  
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11             _ => print!("4"),  
12         }  
13 }
```

*(playground link)*

What does this program print?

...

## 1.4. Bool

### 1.4.2. Explanation

1. Quiz about last lecture

```
1 fn check(x: i32) -> bool {  
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## 1.4. Bool

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```
1 fn main() {  
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```

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```
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# 1.4. Bool

## 1.4.2. Explanation

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(playground link)

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(playground link)

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(playground link)

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(playground link)

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(playground link)

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(playground link)

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(playground link)

What is going on here?

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(playground link)

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(playground link)

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(playground link)

What is going on here?

the guard is being run multiple times, once per |-separated alternative in the match-arm.

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## 2.1. Irrefutable patterns

### Info

An **irrefutable pattern** is a pattern that always matches.

```
1  fn takes_tuple(tuple: (char, i32, bool)) {  
2      let a = tuple.0;  
3      let b = tuple.1;  
4      let c = tuple.2;  
5  
6      // This does the same thing as above.  
7      let (a, b, c) = tuple;  
8  
9      // Ignore the first element, only bind the  
10     second and third.  
11  
12     // Ignore everything but the last element.  
13     let (_, c) = tuple;  
14 }
```

*(playground link)*

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13     // Ignore everything but the last element.  
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                                     (playground link)
```

What happens when adding or removing an element to the tuple and look at the resulting compiler errors

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*(playground link)*

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The destructuring pattern must match the structure of the value exactly.

## 2.1. Irrefutable patterns

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14 }
```

*(playground link)*

What happens when adding or removing an element to the tuple and look at the resulting compiler errors

The destructuring pattern must match the structure of the value exactly.

### Info

A variable binding is actually a pattern itself!

The `_` pattern matches anything.



## 2.1. Irrefutable patterns

### 2.1.1. Advanced usage of ..

Ignoring middle element:

```
1 fn takes_tuple(tuple: (char, i32, bool, u8)) {  
2     let (first, .., last) = tuple;  
3 }
```

*([playground link](#))*

## 2.1. Irrefutable patterns

### 2.1.1. Advanced usage of ..

Ignoring middle element:

```
1 fn takes_tuple(tuple: (char, i32, bool, u8)) {  
2     let (first, .., last) = tuple;  
3 }
```

*(playground link)*

Works with arrays as well:

```
1 fn takes_array(array: [u8; 5]) {  
2     let [first, .., last] = array;  
3 }
```

*(playground link)*

## 2.1. Irrefutable patterns

### 2.1.1. Advanced usage of ..

Ignoring middle element:

```
1 fn takes_tuple(tuple: (char, i32, bool, u8)) {  
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*(playground link)*

Works with arrays as well:

```
1 fn takes_array(array: [u8; 5]) {  
2     let [first, .., last] = array;  
3 }
```

*(playground link)*

#### Warning

Pattern matching works on all data types in Rust!

## 2.2. Matching values

Patterns can also be simple values like characters:

```
1  #[rustfmt::skip]
2  fn main() {
3      let input = 'x';
4      match input {
5          'q'                => println!("Quitting"),
6          'a' | 's' | 'w' | 'd' => println!("Moving around"),
7          '0'..'9'           => println!("Number input"),
8          key if key.is_lowercase() => println!("Lowercase: {key}"),
9          _                  => println!("Something else"),
10     }
11 }
```

*(playground link)*

A variable in the pattern (key in this example) will create a binding that can be used within the match arm.

## 2.2. Matching values

A **match guard**:

- causes the arm to match only if the condition is true.
- If the condition is false the match will continue checking later cases.

```
1  #[rustfmt::skip]
2  fn main() {
3      let input = 'a';
4      match input {
5          key if key.is_uppercase() => println!("Uppercase"),
6          key => if input == 'q' { println!("Quitting") },
7          _   => println!("Lowercase"),
8      }
9  }
```

*(playground link)*

What is the bug in this program?

## 2.2. Matching values

A **match guard**:

- causes the arm to match only if the condition is true.
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```
1  #[rustfmt::skip]
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5          key if key.is_uppercase() => println!("Uppercase"),
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7          _   => println!("Lowercase"),
8      }
9  }
```

*(playground link)*

What is the bug in this program?

The second arm will always match, so the third arm is unreachable. Write match guard in front of the second arm: `key if key == 'q' => ...`

### Warning

**Can't use an existing variable** as the condition in a match arm, as it will instead be interpreted as a variable name pattern, which creates a new variable that will shadow the existing one.

```
1 let expected = 5;
2 match 123 {
3     expected => println!("Expected value is 5, actual is {expected}"),
4     _ => println!("Value was something else"),
5 }
```

[\(playground link\)](#)

What is the output of this program?

### Warning

**Can't use an existing variable** as the condition in a match arm, as it will instead be interpreted as a variable name pattern, which creates a new variable that will shadow the existing one.

```
1 let expected = 5;
2 match 123 {
3     expected => println!("Expected value is 5, actual is {expected}"),
4     _ => println!("Value was something else"),
5 }
```

[\(playground link\)](#)

What is the output of this program?

Will always print “Expected value is 5, actual is 123”.



## 2.2. Matching values

Use @ to bind to a value while also testing it:

```
1 let expected = 5;
2 match 123 {
3     val @ 1..=10 => println!("Value {val} is between 1 and 10"),
4     val @ 11..=20 => println!("Value {val} is between 11 and 20"),
5     val => println!("Value {val} is something else"),
6 }
```

*([playground link](#))*

Like tuples, structs can also be deconstructed by matching:

```
1  struct Foo {  
2      x: (u32, u32),  
3      y: u32,  
4  }  
5  
6  #[rustfmt::skip]  
7  fn main() {  
8      let foo = Foo { x: (1, 2), y: 3 };  
9      match foo {  
10         Foo { y: 2, x: i }    => println!("y = 2, x = {i:?}"),  
11         Foo { x: (1, b), y } => println!("x.0 = 1, b = {b}, y = {y}"),  
12         Foo { y, .. }        => println!("y = {y}, other fields were ignored"),  
13     }  
14 }
```

*(playground link)*

Add or remove fields to Foo and see what happens!

## 2.3. Structs

### 2.3.1. Reference patterns

When matching on a reference, Rust **automatically dereferences** it for you:

```
1 fn main() {  
2     let foo = Foo { x: (1, 2), y: 3 };  
3     match &foo { // `foo` is turned into a reference  
4         Foo { y: 2, x: i } => println!("y = 2, x = {i:?}"),  
5         Foo { x: (1, b), y } => println!("x.0 = 1, b = {b}, y = {y}"),  
6         Foo { y, .. }      => println!("y = {y}, other fields were ignored"),  
7     }  
8 }
```

*(playground link)*

#### Info

The pattern `Foo { ... }` works on `&foo` because Rust automatically dereferences. You could also write `&Foo { ... }` explicitly, but it's not required.

Two equivalent ways to match on a reference:

```
1 match &foo {  
2     Foo { y, .. } => println!("y = {y}"), // Implicit dereference  
3 }  
4  
5 match &foo {  
6     &Foo { y, .. } => println!("y = {y}"), // Explicit dereference pattern  
7 }                                     (playground link)
```

Pick the one you like best!

### Warning

In the implicit version, bound variables like `y` will be references. In the explicit version with `&Foo`, `y` will be a value (copied from the struct).

## 2.3. Structs

### 2.3.2. Mutable reference patterns

When matching on `&mut`, bound variables are mutable references:

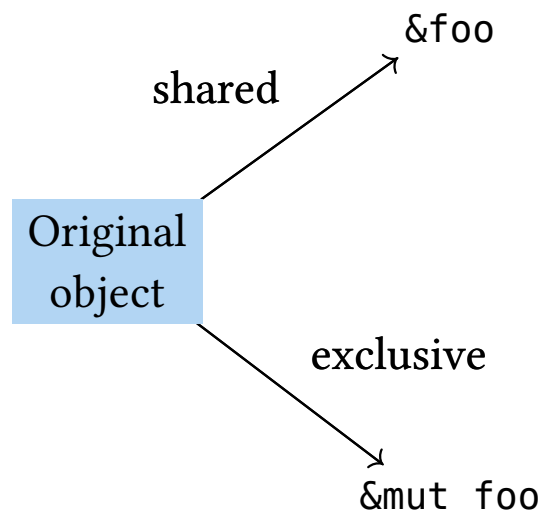
```
1  struct Foo {  
2      x: (u32, u32),  
3      y: u32,  
4  }  
5  fn main() {  
6      let mut foo = Foo { x: (1, 2), y: 3 };  
7      match &mut foo {  
8          Foo { x: (1, 2), y } => *y = 4, // y is &mut u32, need * to assign  
9          Foo { y, .. }      => println!("y = {y}"),  
10     }  
11 }
```

*(playground link)*

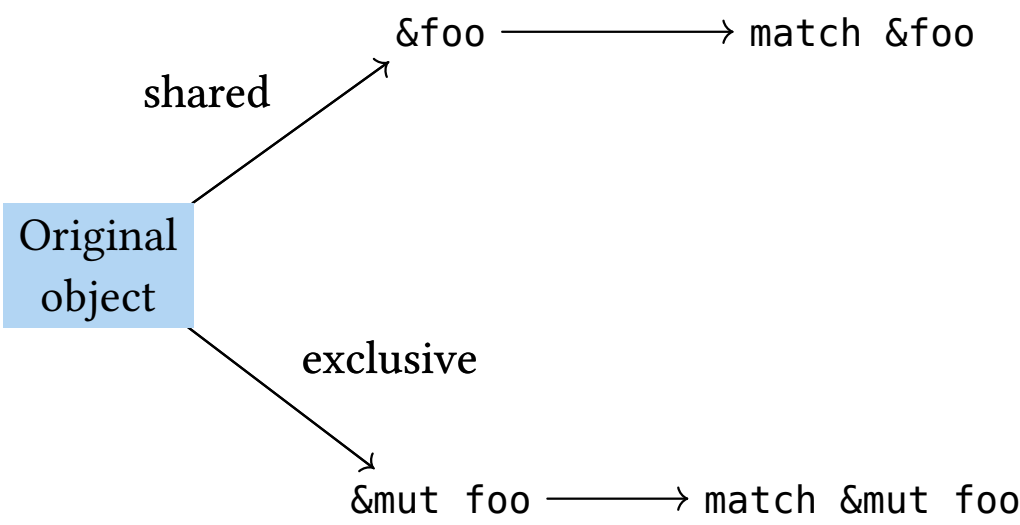
#### Warning

Bound variables like `y` are `&mut u32`, not `u32`. You must dereference with `*` to assign values.

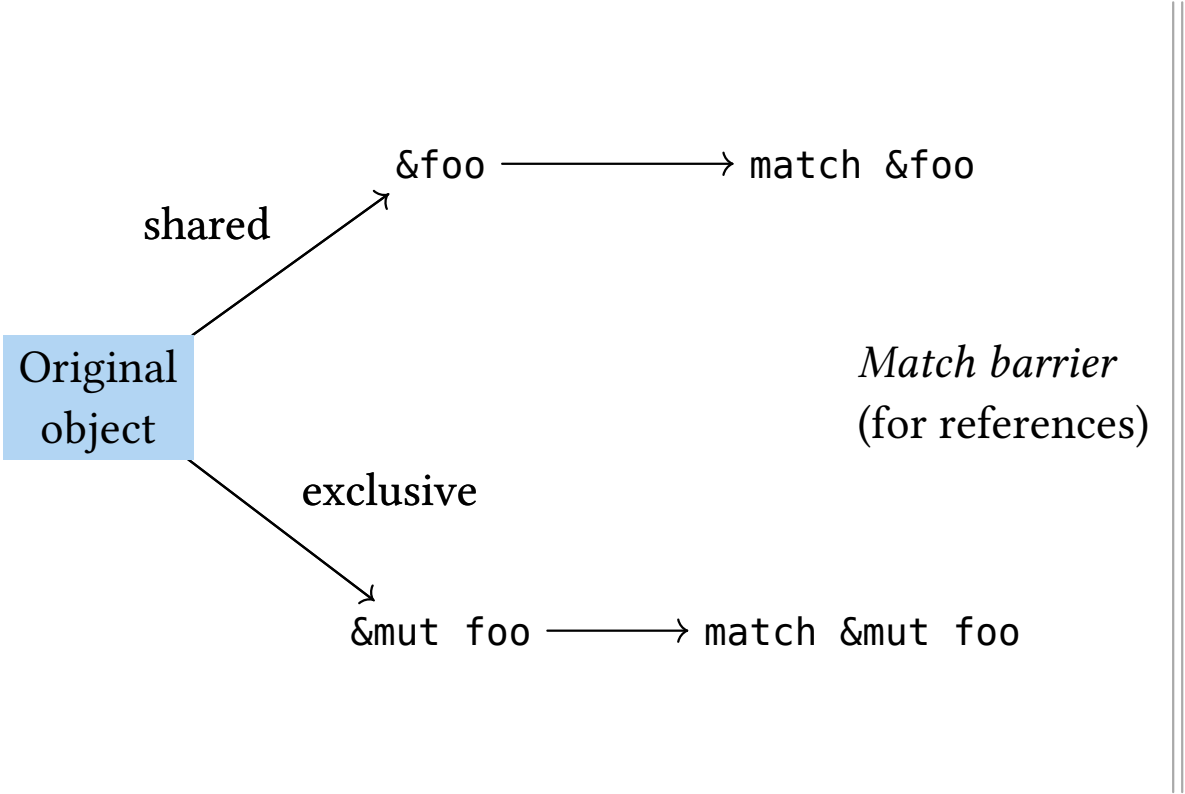
### 2.3.3. Intuition



2.3.3. Intuition

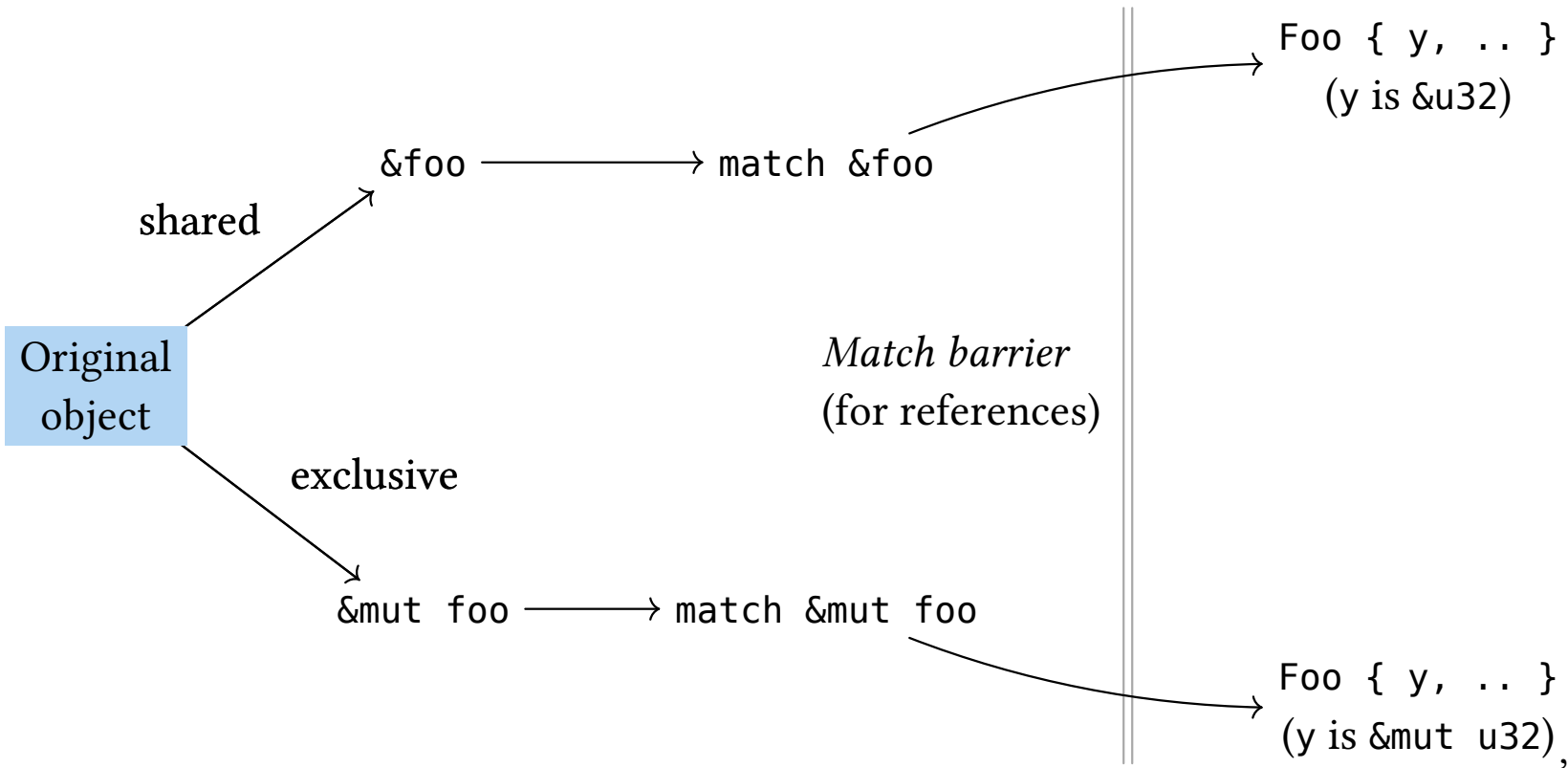


2.3.3. Intuition





2.3.3. Intuition



## 2.4. Enums

Like tuples, enums can also be deconstructed by matching:

```
1  enum Result {  
2      Ok(i32),  
3      Err(String),  
4  }  
5  
6  fn divide_in_two(n: i32) -> Result {  
7      if n % 2 == 0 {  
8          Result::Ok(n / 2)  
9      } else {  
10         Result::Err(format!("cannot divide {n} into two equal parts"))  
11     }  
12 }
```

*(playground link)*

## 2.4. Enums

Like tuples, enums can also be deconstructed by matching:

```
1  enum Result {
2      Ok(i32),
3      Err(String),
4  }
5
6  fn divide_in_two(n: i32) -> Result {
7      if n % 2 == 0 {
8          Result::Ok(n / 2)
9      } else {
10         Result::Err(format!("cannot divide {n} into two equal parts"))
11     }
12 }
```

[\(playground link\)](#)

```
1  fn main() {
2      let n = 100;
3      match divide_in_two(n) {
4          Result::Ok(half) => println!("{n} divided in two is {half}"),
5          Result::Err(msg) => println!("sorry, an error happened: {msg}"),
6      }
7  }
```

[\(playground link\)](#)

### Warning

Rust does not allow non-exhaustive matches

## 2.5. Let control flow

```
1 use std::time::Duration;
2
3 fn sleep_for(secs: f32) {
4     let result = Duration::try_from_secs_f32(secs);
5
6     if let Ok(duration) = result {
7         std::thread::sleep(duration);
8         println!("slept for {duration:?}");
9     }
10 }
11
12 fn main() {
13     sleep_for(-10.0);
14     sleep_for(0.8);
15 }
```

*(playground link)*

When to use if let over match?

## 2.5. Let control flow

```
1 use std::time::Duration;
2
3 fn sleep_for(secs: f32) {
4     let result = Duration::try_from_secs_f32(secs);
5
6     if let Ok(duration) = result {
7         std::thread::sleep(duration);
8         println!("slept for {duration:?}");
9     }
10 }
11
12 fn main() {
13     sleep_for(-10.0);
14     sleep_for(0.8);
15 }
```

*(playground link)*

When to use if let over match?

Use if let when you only care about one specific pattern and want to ignore all others.

## 2.6. Exercise: Expression evaluation

Let's write a simple recursive evaluator for arithmetic expressions.

Complete the `eval` function in the file `session-2/tests/s2e2-evaluation.rs`.

Run tests with `cargo test --test s2e2-evaluation`.

1.	Quiz about last lecture .....	1
2.	Pattern matching .....	9
<b>3.</b>	<b>Tooling intermezzo .....</b>	<b>24</b>
3.1.	Debugger .....	24
3.2.	Clippy .....	25
3.3.	Summary .....	27
4.	Methods and traits .....	28
5.	Generics .....	42
6.	Closures .....	62
7.	Standard library types .....	74
8.	Conclusion .....	75

mod.rs - nu-lint - Visual Studio Code

RUN AND DEBUG | Debug unit tests | ignore\_good.rs .../error\_make\_metadata | x.rs .../error\_make\_metadata | mod.rs .../error\_make\_metadata

src > rules > error\_make\_metadata > mod.rs > check

```
194 fn check_error_make_call(call: &Call, context: &LintContext) {
195     call.is_call_to_command(command_name: "error_make", context)
196     .then_some(()) Option<()>
197     .and_then(|()| call.get_first_positional_arg()) Option<&Expression>
198     .and_then(extract_record_from_expr) Option<&Vec<RecordItem>>
199     .and_then(|record: &Vec<RecordItem>| check_error_make_metadata(record, context,
200     call.span()))
201 }
202
203 1 reference
204 fn check(context: &LintContext) -> Vec<RuleViolation> {
205     context.collect_rule_violations(collector: |expr: &Expression, ctx: &
206     LintContext<'>| match &expr.expr {
207         Expr::Call(call: &Box<Call>) => check_error_make_call(call, context: ctx).
208         into_iter().collect(),
209         _ => vec![],
210     })
211 }
```

7: tid=741466 "rules:... PAUSED ON BREAKPOINT

nu\_lint::rules::error\_make\_metadata  
nu\_lint::rule::Rule::assert\_detect  
nu\_lint::context::LintContext::tes  
nu\_lint::rule::Rule::assert\_detect

BREAKPOINTS  
[x] Rust: on panic  
[x] mod.rs src/rules/error\_make\_met... 203

MODULES  
EXCLUDED CALLERS

PROBLEMS 4 | OUTPUT | DEBUG CONSOLE | TERMINAL | PORTS | Filter | Debug

nu-lint | organise-rules\* | 4 0 | Debug unit tests in library 'nu\_lint' (nu-lint) | Live Share | rust-analyzer | Format: auto | Disasm: auto | Deref: on | Console: cmd | nu-lint | Rust | Prettier





Clippy Lints Total number: 795

Lint levels 4 ▾

Lint groups 2 ▾

Version 0 ▾

Filter:  Clear

Applicability 4 ▾

All

Default

None

☐ Cargo

☒ Complexity

☒ Correctness

☐ Nursery

☐ Pedantic

☐ Perf

☐ Restriction

☐ Style

☐ Suspicious

☐ Deprecated

## 3.2. Clippy

Place clippy rules in your `Cargo.toml` like this:

```
1 [lints.clippy]
2 complexity = { level = "deny", priority = -1 }
3 pedantic = { level = "deny", priority = -1 }
4 style = { level = "deny", priority = -1 }
5
6 absolute_paths = "deny"
7 allow_attributes_without_reason = "deny"
8 ...
```

*(playground link)*

Find more lint rules at [rust-lang.github.io/rust-clippy](https://rust-lang.github.io/rust-clippy).

### 3.3. Summary

Typical development workflow in Rust:

1. Debug with GDB / LLDB or VS Code
2. Format with `cargo fmt`
3. Lint with `cargo clippy`
4. Test with `cargo test`
5. Build with `cargo build` or `cargo build --release`

1. Quiz about last lecture .....	1
2. Pattern matching .....	9
3. Tooling intermezzo .....	24
<b>4. Methods and traits .....</b>	<b>28</b>
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4.2. Receivers .....	32
4.3. Traits .....	33
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4.5. Contracts .....	35
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5. Generics .....	42
6. Closures .....	62
7. Standard library types .....	74
8. Conclusion .....	75

## 4.1. Methods

In Rust, methods are separated from fields:

```
1  #[derive(Debug)]
2  struct CarRace {
3      name: String,
4      laps: Vec<i32>,
5  }
6
7  impl CarRace {
8      // No receiver, a static method
9      fn new(name: &str) -> Self {
10         Self { name: String::from(name), laps: Vec::new() }
11     }
12     // Exclusive borrowed read-write access to self
13     fn add_lap(&mut self, lap: i32) {
14         self.laps.push(lap);
15     }
16 }
17
18 fn main() {
19     let mut race = CarRace::new("Monaco Grand Prix");
20     race.add_lap(70);
21 }
```

([playground link](#))

## 4.1. Methods

Like in other languages, methods group functionality around *acting* data types, types that *do* related things.

How are methods in Rust different from methods in other languages?

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How are methods in Rust different from methods in other languages?

Methods cannot be overridden.

```
1 impl CarRace {  
2     fn add_lap(&mut self, lap: i32) {  
3         self.laps.push(lap);  
4     }  
5 }
```

(playground link)

What is the `&mut self` parameter syntax sugar for?

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```
1 impl CarRace {  
2     fn add_lap(&mut self, lap: i32) {  
3         self.laps.push(lap);  
4     }  
5 }
```

[\(playground link\)](#)

What is the `&mut self` parameter syntax sugar for?

For `self: &mut Self`.

```
1 impl CarRace {  
2     fn add_lap(self: &mut Self, lap: i32) {  
3         self.laps.push(lap);  
4     }  
5 }
```

[\(playground link\)](#)



Methods can **consume** self:

```
1  #[derive(Debug)]
2  struct CarRace {
3      name: String,
4      laps: Vec<i32>,
5  }
6
7  impl CarRace {
8      // Exclusive ownership of self (covered later)
9      fn finish(self) {
10         let total: i32 = self.laps.iter().sum();
11         println!("Race {} is finished, total lap time:
12         {}", self.name, total);
13     }
14 }
15 fn main() {
16     let mut race = CarRace::new("Monaco Grand Prix");
17     race.add_lap(70);
18     race.finish();
19     // race.add_lap(42);
20 }
```

*(playground link)*

## 4.1. Methods

Methods can **consume** self:

```
1  #[derive(Debug)]
2  struct CarRace {
3      name: String,
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5  }
6
7  impl CarRace {
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11         println!("Race {} is finished, total lap time:
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```

(playground link)

What is the name given to the `self` parameter in methods?

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17     race.add_lap(70);
18     race.finish();
19     // race.add_lap(42);
20 }
```

(playground link)

What is the name given to the self parameter in methods?

self is called the **receiver**.

After calling a method with `object.finish(self)`, you can no longer use `object`. It has been *consumed*.

### Warning

Use the self receiver to define destructors or functionality that should happen only once at the end.

## 4.2. Receivers

Rust allows receivers to be one of the following:

- `self`, consuming `self`
- any kind of reference to `self`: `&self`, `&mut self`
- exceptions (covered later)

Name a few reference types in Rust.

## 4.2. Receivers

Rust allows receivers to be one of the following:

- `self`, consuming `self`
- any kind of reference to `self`: `&self`, `&mut self`
- exceptions (covered later)

Name a few reference types in Rust.

`&T`, `&mut T`, `Box<T>`, `Rc<T>`, `Arc<T>`, ...

### Info

Reference types are also called **wrappers** and some are **smart pointers**.

Rust lets you abstract over types with traits. Similar to interfaces:

```
1 trait Pet {  
2     /// Return a sentence from this pet.  
3     fn talk(&self) -> String;  
4  
5     /// Print a string to the terminal greeting this pet.  
6     fn greet(&self);  
7 }
```

*(playground link)*

Properties of traits:

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```

*(playground link)*

Properties of traits:

- A trait is a list of methods that a type **must implement**

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*(playground link)*

Properties of traits:

- A trait is a list of methods that a type **must implement**
- The **signatures** of the type's methods **must be identical** to the trait's method signatures



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```

*(playground link)*

Properties of traits:

- A trait is a list of methods that a type **must implement**
- The **signatures** of the type's methods **must be identical** to the trait's method signatures

### Info

**Default implementations** can be provided

```
1  trait Pet {
2      fn talk(&self) -> String;
3
4      fn greet(&self) {
5          println!("Oh you're a cutie!
6              What's your name? {}",
7              self.talk());
8      }
9  }
10
11 struct Dog {
12     name: String,
13     age: i8,
14 }
```

*(playground link)*

## 4.4. Implementing traits

```
1  trait Pet {
2      fn talk(&self) -> String;
3
4      fn greet(&self) {
5          println!("Oh you're a cutie!
6              What's your name? {}",
7              self.talk());
8      }
9  }
10
11 struct Dog {
12     name: String,
13     age: i8,
14 }
```

*(playground link)*

```
1  impl Pet for Dog {
2      fn talk(&self) -> String {
3          format!("Woof, my name is {}", self.name)
4      }
5  }
6
7  fn main() {
8      let fido = Dog { name: String::from("Fido"),
9          age: 5 };
10     dbg!(fido.talk());
11     fido.greet();
12 }
```

*(playground link)*

## 4.4. Implementing traits

```
1  trait Pet {
2      fn talk(&self) -> String;
3
4      fn greet(&self) {
5          println!("Oh you're a cutie!
6              What's your name? {}",
7              self.talk());
8      }
9  }
10
11 struct Dog {
12     name: String,
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14 }
```

*(playground link)*

```
1  impl Pet for Dog {
2      fn talk(&self) -> String {
3          format!("Woof, my name is {}", self.name)
4      }
5  }
6
7  fn main() {
8      let fido = Dog { name: String::from("Fido"),
9          age: 5 };
10     dbg!(fido.talk());
11     fido.greet();
12 }
```

*(playground link)*

### Warning

a Cat type with a talk() method would not automatically satisfy Pet unless it is in an impl Pet block

## 4.4. Implementing traits

You can:

- split trait implementation blocks
- override default method implementations

```
1  impl Pet for Dog {  
2      fn talk(&self) -> String {  
3          format!("Woof, my name is {}!", self.name)  
4      }  
5  }  
6  
7  impl Pet for Dog {  
8      fn greet(&self) -> String {  
9          format!("Woof, my name is {}!", self.name)  
10     }  
11 }
```

*(playground link)*

vec  
write  
writeln

## Keywords

SelfTy  
as  
async  
await  
become  
break  
const  
continue  
crate  
dyn  
else  
enum  
extern  
false  
fn

level of pointer indirection each time a new object is added to the mix (and, practically, a heap allocation).

Although there were other reasons as well, this issue of expensive composition is the key thing that drove Rust towards adopting a different model. It is particularly a problem when one considers, for example, the implications of composing together the `Future`s which will eventually make up an asynchronous task (including address-sensitive `async fn` state machines). It is plausible that there could be many layers of `Futures` composed together, including multiple layers of `async fns` handling different parts of a task. It was deemed unacceptable to force indirection and allocation for each layer of composition in this case.

`Pin<Ptr>` is an implementation of the third option. It allows us to solve the issues discussed with the second option by building a *shared contractual language* around the guarantees of “pinning” data.

## Using `Pin<Ptr>` to pin values

In order to pin a value, we wrap a *pointer to that value* (of some type `Ptr`) in a `Pin<Ptr>`. `Pin<Ptr>` can wrap any pointer type, forming a promise that the **pointee** will not be *moved* or *otherwise invalidated*.

We call such a `Pin`-wrapped pointer a **pinning pointer**, (or pinning reference, or pinning `Box`, etc.) because its existence is the thing that is conceptually pinning the underlying pointee in place: it is the metaphorical “pin” securing the data in place on the pinboard (in memory).

Notice that the thing wrapped by `Pin` is not the value which we want to pin itself, but rather a pointer to that value! A `Pin<Ptr>` does not pin the `Ptr`; instead, it pins the pointer’s *pointee value*.

## Pinning as a library contract

Pinning does not require nor make use of any compiler “magic”<sup>2</sup>, only a specific contract between the `unsafe` parts of a library API and its users.

It is important to stress this point as a user of the `unsafe` parts of the `Pin` API. Practically, this means that performing the

Rust, being a systems programming language, focuses on safety.

## 4.5. Contracts

Rust, being a systems programming language, focuses on safety.

In Rust documentation, you will often encounter the word **contract**.

### Info

A contract is an agreement between two parties. There are mainly two kinds of contracts in Rust:

- Contracts between **two pieces of code**
- Contracts between **the programmer and the compiler**



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- Contracts between **the programmer and the compiler**

Contracts between two pieces of code are generally safe (can be enforced automatically).

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### Info

A contract is an agreement between two parties. There are mainly two kinds of contracts in Rust:

- Contracts between **two pieces of code**
- Contracts between **the programmer and the compiler**

Contracts between two pieces of code are generally safe (can be enforced automatically).

### Warning

... but contracts between the programmer and the compiler can be unsafe or **may have to be checked by the programmer**.

Examples of such contracts: Pin, Send, Sync traits (advanced topic).

## 4.6. Super-traits

```
1  trait Animal {
2      fn leg_count(&self) -> u32;
3  }
4
5  trait Pet: Animal {
6      fn name(&self) -> String;
7  }
8
9  struct Dog(String);
10
11 impl Animal for Dog {
12     fn leg_count(&self) -> u32 {
13         4
14     }
15 }
16
17 impl Pet for Dog {
18     fn name(&self) -> String {
19         self.0.clone()
20     }
21 }
```

*(playground link)*

**Super-traits** are an extra constraint on traits that say: “to implement this trait, you must also implement that other trait”.

## 4.6. Super-traits

```
1  trait Animal {
2      fn leg_count(&self) -> u32;
3  }
4
5  trait Pet: Animal {
6      fn name(&self) -> String;
7  }
8
9  struct Dog(String);
10
11 impl Animal for Dog {
12     fn leg_count(&self) -> u32 {
13         4
14     }
15 }
16
17 impl Pet for Dog {
18     fn name(&self) -> String {
19         self.0.clone()
20     }
21 }
```

*(playground link)*

**Super-traits** are an extra constraint on traits that say: “to implement this trait, you must also implement that other trait”.

### Warning

Super traits are the kind of language feature you should **avoid as long as you are stuck with the OOP mindset**.

Once you are willing to forget OOP, you can see super-traits are actually easy.

## 4.6. Super-traits

```
1  trait Animal {
2      fn leg_count(&self) -> u32;
3  }
4
5  trait Pet: Animal {
6      fn name(&self) -> String;
7  }
8
9  struct Dog(String);
10
11 impl Animal for Dog {
12     fn leg_count(&self) -> u32 {
13         4
14     }
15 }
16
17 impl Pet for Dog {
18     fn name(&self) -> String {
19         self.0.clone()
20     }
21 }
```

(playground link)

**Super-traits** are an extra constraint on traits that say: “to implement this trait, you must also implement that other trait”.

### Warning

Super traits are the kind of language feature you should **avoid as long as you are stuck with the OOP mindset**.

Once you are willing to forget OOP, you can see super-traits are actually easy.

### Advanced

... at least as long as you don't constrain **associated types** of super traits in subtraits

## 4.7. Associated Types

```
1  #[derive(Debug)]
2  struct Meters(i32);
3  #[derive(Debug)]
4  struct MetersSquared(i32);
5
6  trait Multiply {
7      type Output;
8      fn multiply(&self, other: &Self) -> Self::Output;
9  }
10
11 impl Multiply for Meters {
12     type Output = MetersSquared;
13     fn multiply(&self, other: &Self) -> Self::Output {
14         MetersSquared(self.0 * other.0)
15     }
16 }
17
18 fn main() {
19     println!("{:?}", Meters(10).multiply(&Meters(20)));
20 }
```

*(playground link)*

Associated types are **placeholder types** that are supplied by the trait implementation.

## 4.7. Associated Types

```
1  #[derive(Debug)]
2  struct Meters(i32);
3  #[derive(Debug)]
4  struct MetersSquared(i32);
5
6  trait Multiply {
7      type Output;
8      fn multiply(&self, other: &Self) -> Self::Output;
9  }
10
11 impl Multiply for Meters {
12     type Output = MetersSquared;
13     fn multiply(&self, other: &Self) -> Self::Output {
14         MetersSquared(self.0 * other.0)
15     }
16 }
17
18 fn main() {
19     println!("{:?}", Meters(10).multiply(&Meters(20)));
20 }
```

*(playground link)*

Associated types are **placeholder types** that are supplied by the trait implementation.

Why are associated types are sometimes also called “output types”

## 4.7. Associated Types

```
1  #[derive(Debug)]
2  struct Meters(i32);
3  #[derive(Debug)]
4  struct MetersSquared(i32);
5
6  trait Multiply {
7      type Output;
8      fn multiply(&self, other: &Self) -> Self::Output;
9  }
10
11 impl Multiply for Meters {
12     type Output = MetersSquared;
13     fn multiply(&self, other: &Self) -> Self::Output {
14         MetersSquared(self.0 * other.0)
15     }
16 }
17
18 fn main() {
19     println!("{:?}", Meters(10).multiply(&Meters(20)));
20 }
```

(playground link)

Associated types are **placeholder types** that are supplied by the trait implementation.

Why are associated types sometimes also called “output types”

The implementer, not the caller, chooses the concrete associated type. (Compare with generics.)



## 4.7. Associated Types

```

1  #[derive(Debug)]
2  struct Meters(i32);
3  #[derive(Debug)]
4  struct MetersSquared(i32);
5
6  trait Multiply {
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9  }
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11 impl Multiply for Meters {
12     type Output = MetersSquared;
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15     }
16 }
17
18 fn main() {
19     println!("{}", Meters(10).multiply(&Meters(20)));
20 }

```

*(playground link)*

Associated types are **placeholder types** that are supplied by the trait implementation.

Why are associated types are sometimes also called “output types”

The implementer, not the caller, chooses the concrete associated type. (Compare with generics.)

Iterators from the standard library have an associated type `Item`:

```

1  pub trait Iterator {
2      type Item;
3      fn next(&mut self) ->
4          Option<Self::Item>;

```

*(playground link)*

## 4.8. Deriving

Supported traits can be automatically implemented for your custom types, as follows:

```
1  #[derive(Debug, Clone, Default)]
2  struct Player {
3      name: String,
4      strength: u8,
5      hit_points: u8,
6  }
7
8  fn main() {
9      let p1 = Player::default(); // Default trait adds `default` constructor.
10     let mut p2 = p1.clone(); // Clone trait adds `clone` method.
11     p2.name = String::from("EldurScrollz");
12     // Debug trait adds support for printing with `{:?}`.
13     println!("{p1:?} vs. {p2:?}");
14 }
```

*(playground link)*

How is the derive functionality implemented in Rust?

## 4.8. Deriving

Supported traits can be automatically implemented for your custom types, as follows:

```
1  #[derive(Debug, Clone, Default)]
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8  fn main() {
9      let p1 = Player::default(); // Default trait adds `default` constructor.
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11     p2.name = String::from("EldurScrollz");
12     // Debug trait adds support for printing with `{:?}`.
13     println!("{p1:?} vs. {p2:?}");
14 }
```

*(playground link)*

How is the derive functionality implemented in Rust?

With **procedural macros**, and many crates provide useful derive macros to add useful functionality.

## 4.8. Deriving

Supported traits can be automatically implemented for your custom types, as follows:

```
1  #[derive(Debug, Clone, Default)]
2  struct Player {
3      name: String,
4      strength: u8,
5      hit_points: u8,
6  }
7
8  fn main() {
9      let p1 = Player::default(); // Default trait adds `default` constructor.
10     let mut p2 = p1.clone(); // Clone trait adds `clone` method.
11     p2.name = String::from("EldurScrollz");
12     // Debug trait adds support for printing with `{:?}`.
13     println!("{p1:?} vs. {p2:?}");
14 }
```

*(playground link)*

How is the derive functionality implemented in Rust?

With **procedural macros**, and many crates provide useful derive macros to add useful functionality.

For example, `serde` can derive serialization support for a struct using `#[derive(Serialize)]`.

## 4.8. Deriving

### 4.8.1. Why is deriving useful?

A manual implementation of the Clone trait for the Player struct would look like this:

```
1 impl Clone for Player {  
2     fn clone(&self) -> Self {  
3         Player {  
4             name: self.name.clone(),  
5             strength: self.strength.clone(),  
6             hit_points: self.hit_points.clone(),  
7         }  
8     }  
9 }
```

*(playground link)*

It is easier to just write `#[derive(Clone)]`

#### Info

The derive attribute is similar to deriving in Haskell.

## 4.9. Exercise: Logger trait

Complete the test code in `session-2/examples/s2e3-logger.rs`.

Run code with `cargo run --example s2e3-logger`.

1. Quiz about last lecture .....	1
2. Pattern matching .....	9
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```
1 fn pick<T>(cond: bool, left: T, right: T) -> T {  
2     if cond { left } else { right }  
3 }  
4  
5 fn main() {  
6     println!("picked a number: {:?}", pick(true, 222, 333));  
7     println!("picked a string: {:?}", pick(false, 'L', 'R'));  
8 }
```

*(playground link)*

Bodies of generic functions need to be well-defined for all possible types T.

## 5.2. Monomorphisation

The compiler **generates concrete versions** of generic functions for each used type.

```
1 fn pick_i32(cond: bool, left: i32, right: i32) -> i32 {  
2     if cond { left } else { right }  
3 }  
4  
5 fn pick_char(cond: bool, left: char, right: char) -> char {  
6     if cond { left } else { right }  
7 }
```

*(playground link)*

Generics are a zero-cost abstraction.

## 5.3. Trait bounds

Require the types to implement some trait, so that you can call this trait's methods

```
1  fn duplicate<T: Clone>(a: T) -> (T, T) {  
2      (a.clone(), a.clone())  
3  }  
4  
5  struct NotCloneable;  
6  
7  fn main() {  
8      let foo = String::from("foo");  
9      let pair = duplicate(foo);  
10     println!("{pair:?}");  
11 }
```

*(playground link)*

What happens if we pass NotCloneable to duplicate? (Try in playground!)

## 5.3. Trait bounds

Require the types to implement some trait, so that you can call this trait's methods

```
1  fn duplicate<T: Clone>(a: T) -> (T, T) {  
2      (a.clone(), a.clone())  
3  }  
4  
5  struct NotCloneable;  
6  
7  fn main() {  
8      let foo = String::from("foo");  
9      let pair = duplicate(foo);  
10     println!("{pair:?}");  
11 }
```

*(playground link)*

What happens if we pass NotCloneable to duplicate? (Try in playground!)

A compile-time error, because NotCloneable does not implement the Clone trait.

## 5.4. Combining traits

When multiple traits are necessary, use + to join them.

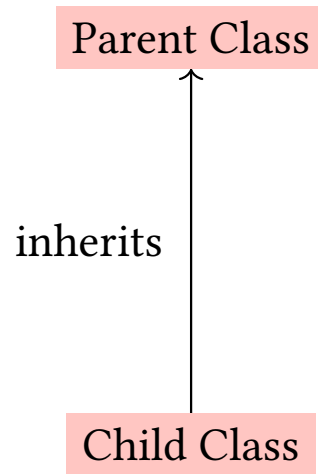
```
1 fn compare_and_print<T: PartialOrd + Display>(a: T, b: T) {  
2     if a < b {  
3         println!("{}", a, b);  
4     } else {  
5         println!("{}", a, b);  
6     }  
7 }
```

*(playground link)*

## 5.5. Composition over inheritance

Rust forbids object inheritance completely.

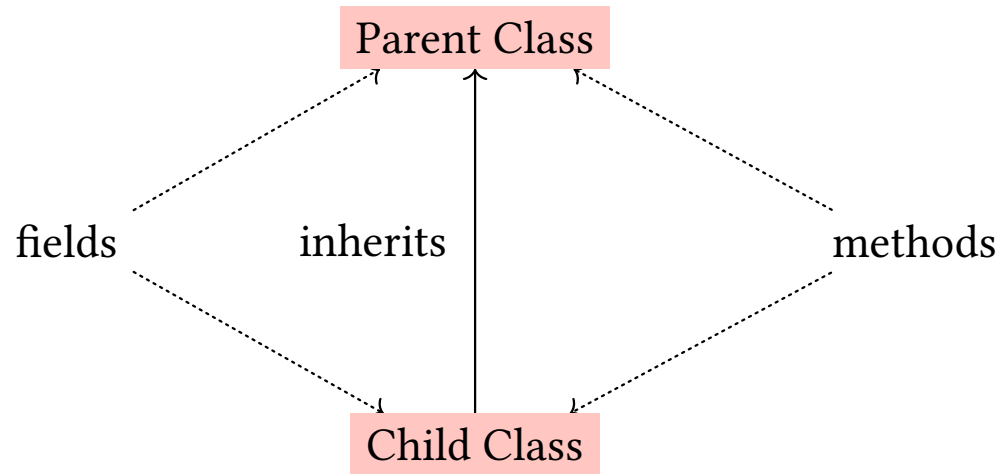
### Class inheritance



## 5.5. Composition over inheritance

Rust forbids object inheritance completely.

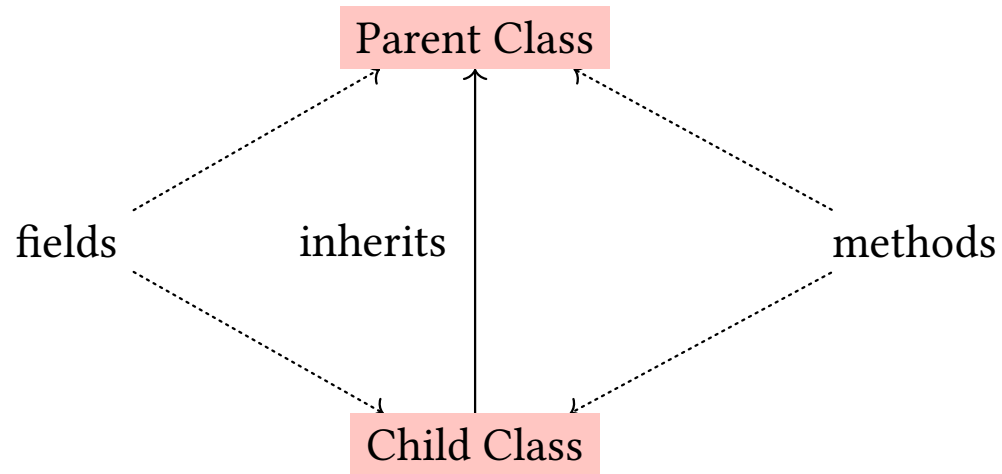
### Class inheritance



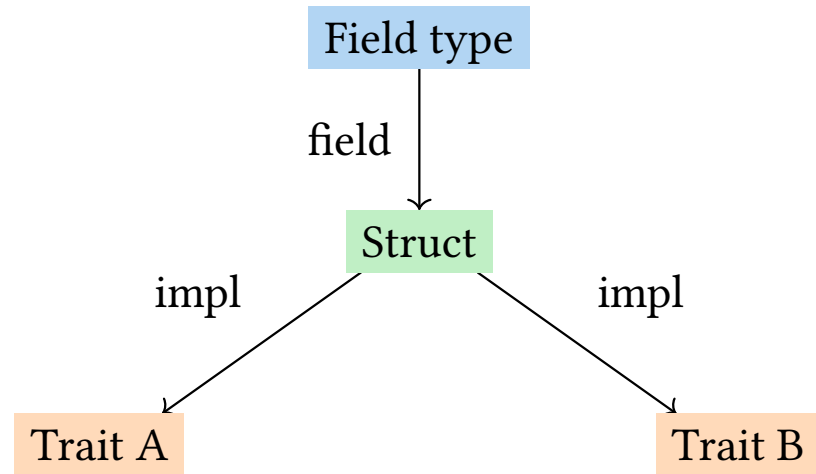
## 5.5. Composition over inheritance

Rust forbids object inheritance completely.

### Class inheritance



### Composition with traits

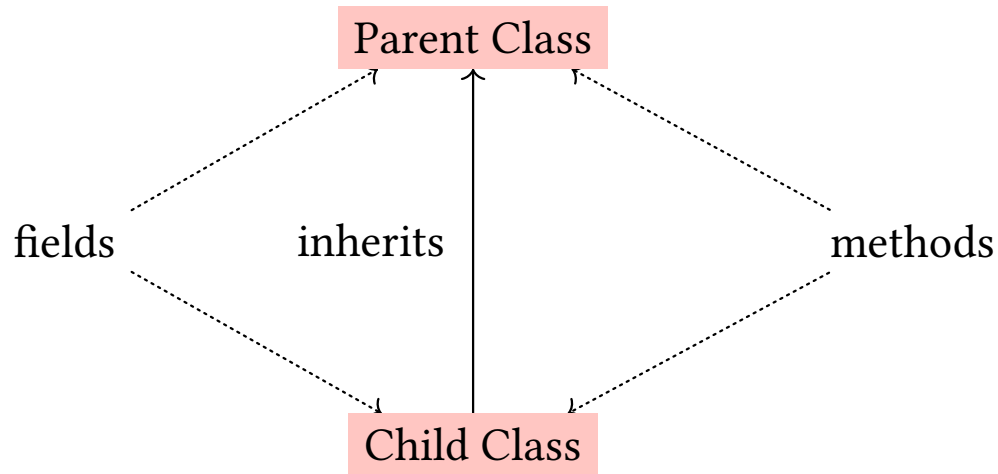




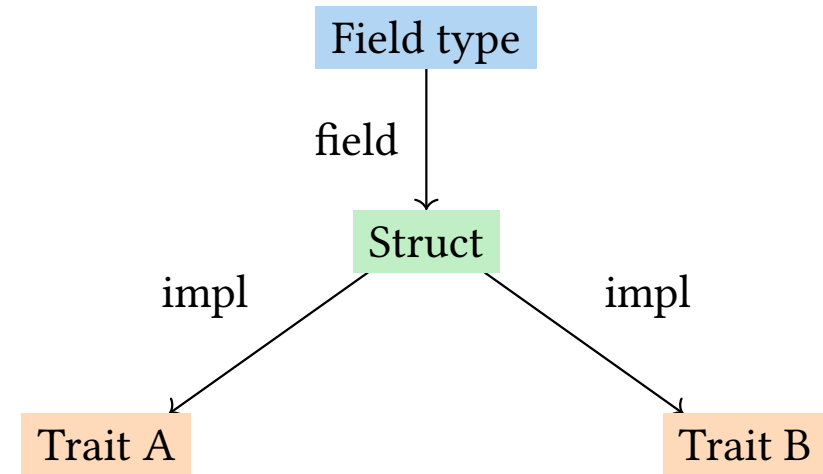
## 5.5. Composition over inheritance

Rust forbids object inheritance completely.

### Class inheritance



### Composition with traits



**Rust approach:** Embed types as fields + implement multiple traits

#### Info

Types and traits are completely separate. No data inheritance.

## 5.6. where clauses

Declutters the function signature if you have many parameters

```
1 fn duplicate<T>(a: T) -> (T, T)
2 where
3     T: Clone,
4 {
5     (a.clone(), a.clone())
6 }
```

*([playground link](#))*

## 5.7. Feature of where clauses

```
1  fn duplicate_option<T>(a: Option<T>) -> (Option<T>, Option<T>)
2  where
3      Option<T>: Clone,
4  {
5      (a.clone(), a.clone())
6  }
7
8  fn main() {
9      let s = Some(String::from("hello"));
10     let pair = duplicate_option(s);
11     println!("{pair:?}");
12 }
```

*(playground link)*

## 5.8. Generic datatypes

```

1  pub trait Logger {
2      /// Log a message at the given verbosity
   level.
3      fn log(&self, verbosity: u8, message: &str);
4  }
5
6  struct StderrLogger;
7
8  impl Logger for StderrLogger {
9      fn log(&self, verbosity: u8, message: &str) {
10         eprintln!("verbosity={verbosity}:
11             {message}");
12     }
13
14     /// Only log messages up to the given verbosity
   level.
15     struct VerbosityFilter<L> {
16         max_verbosity: u8,
17         inner: L,
18     }

```

*(playground link)*

```

1  impl<L: Logger> Logger for VerbosityFilter<L> {
2      fn log(&self, verbosity: u8, message: &str) {
3          if verbosity <= self.max_verbosity {
4              self.inner.log(verbosity, message);
5          }
6      }
7  }
8
9  fn main() {
10     let logger = VerbosityFilter { max_verbosity:
11         3, inner: StderrLogger };
12     logger.log(5, "FYI");
13     logger.log(2, "Uhoh");

```

*(playground link)*

Use generics to abstract over the concrete field type.

## 5.9. If X impl, then Y impl

### 5.9.1. Generic impl block

```
1 struct VerbosityFilter<L> {  
2     max_verbosity: u8,  
3     inner: L,  
4 }  
5  
6 impl<L: Logger> Logger for VerbosityFilter<L> {  
7     fn log(&self, verbosity: u8, message: &str) {  
8         if verbosity <= self.max_verbosity {  
9             self.inner.log(verbosity, message);  
10        }  
11    }  
12 }
```

[\(playground link\)](#)

Why is L specified twice in `impl<L: Logger> .. VerbosityFilter<L>`? Isn't that redundant?

## 5.9. If X impl, then Y impl

### 5.9.1. Generic impl block

```
1 struct VerbosityFilter<L> {  
2     max_verbosity: u8,  
3     inner: L,  
4 }  
5  
6 impl<L: Logger> Logger for VerbosityFilter<L> {  
7     fn log(&self, verbosity: u8, message: &str) {  
8         if verbosity <= self.max_verbosity {  
9             self.inner.log(verbosity, message);  
10        }  
11    }  
12 }
```

*(playground link)*

Why is L specified twice in `impl<L: Logger> .. VerbosityFilter<L>`? Isn't that redundant?

`impl` parameters are separate and usually carries trait bounds (not the datatype).

What happens if you would just use a concrete type as in `impl VerbosityFilter<StderrLogger> { .. }`

## 5.9. If X impl, then Y impl

### 5.9.1. Generic impl block

```
1 struct VerbosityFilter<L> {  
2     max_verbosity: u8,  
3     inner: L,  
4 }  
5  
6 impl<L: Logger> Logger for VerbosityFilter<L> {  
7     fn log(&self, verbosity: u8, message: &str) {  
8         if verbosity <= self.max_verbosity {  
9             self.inner.log(verbosity, message);  
10        }  
11    }  
12 }
```

*(playground link)*

Why is L specified twice in `impl<L: Logger> .. VerbosityFilter<L>`? Isn't that redundant?

`impl` parameters are separate and usually carries trait bounds (not the datatype).

What happens if you would just use a concrete type as in `impl VerbosityFilter<StderrLogger> { .. }`

Would only work with `StderrLogger` instances, not with any other type that implements `Logger`.

# 5.9. If X impl, then Y impl

## 5.9.2. Blanket impls

External  
library

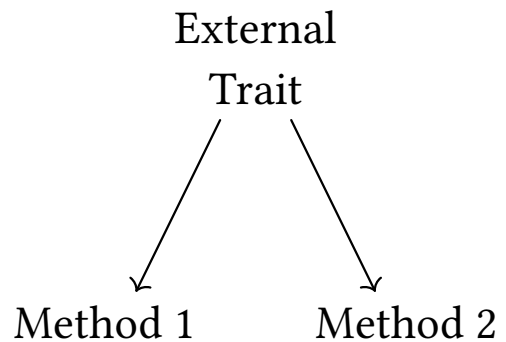
External  
Trait



## 5.9. If X impl, then Y impl

### 5.9.2. Blanket impls

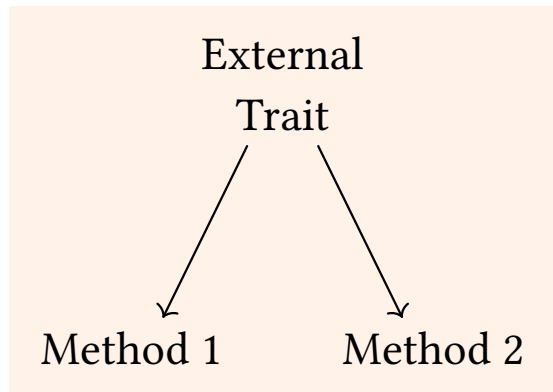
**External  
library**



## 5.9. If X impl, then Y impl

### 5.9.2. Blanket impls

External  
library



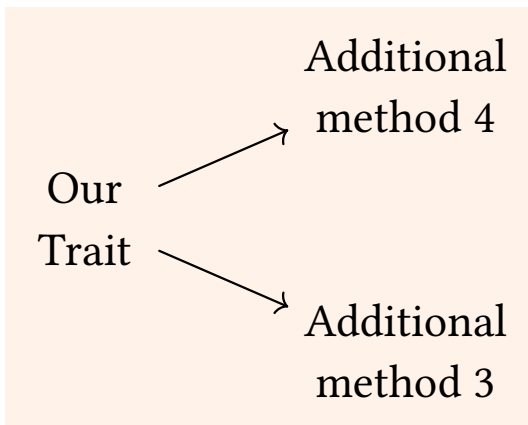
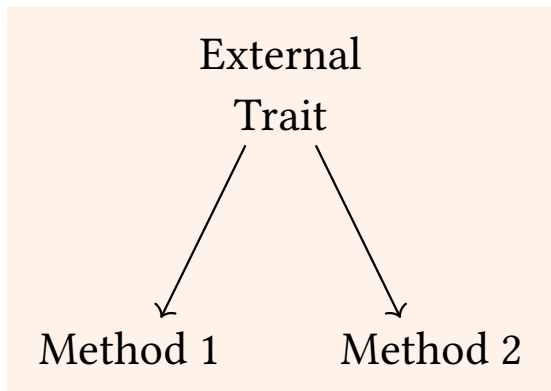
Our  
Trait

Our concrete  
type

## 5.9. If X impl, then Y impl

### 5.9.2. Blanket impls

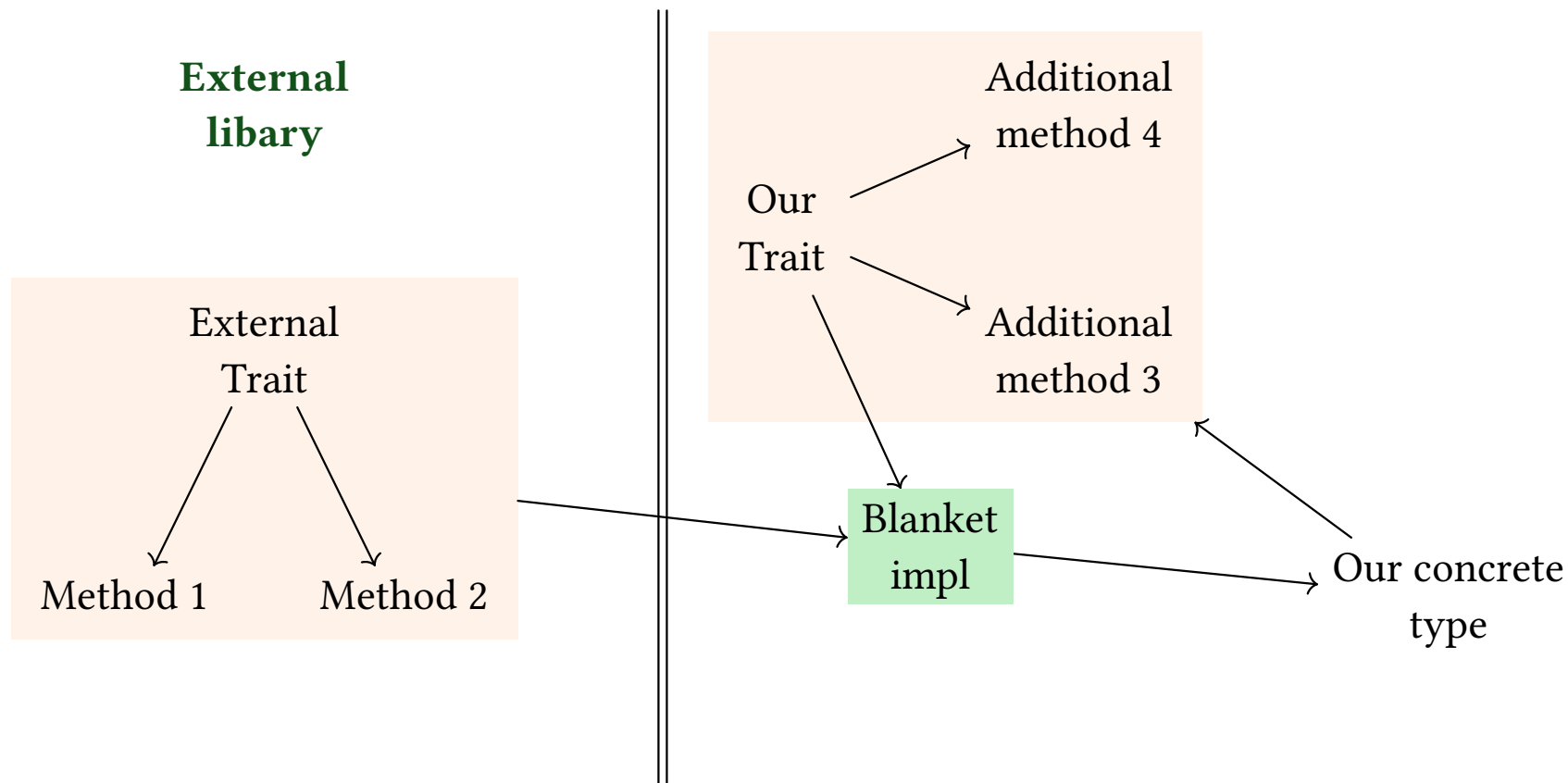
**External  
library**



Our concrete  
type

## 5.9. If X impl, then Y impl

### 5.9.2. Blanket impls



## 5.9. If X impl, then Y impl

### 5.9.3. Putting constraints on super-traits (advanced)

A subtrait can add constraints on the associated types of its supertrait.

```

1  trait Container {
2      type Item;
3      fn get(&self) -> &Self::Item;
4  }
5
6  trait PrintableContainer: Container
7  where
8      Self::Item: Display,
9  {
10     fn print_item(&self) {
11         println!("Item: {}", self.get());
12     }
13 }
14
15 struct Box<T> {
16     value: T,
17 }
```

*(playground link)*

```

1  impl<T> Container for Box<T> {
2      type Item = T;
3      fn get(&self) -> &Self::Item {
4          &self.value
5      }
6  }
7
8  impl<T: Display> PrintableContainer for Box<T> {}
9
10 fn main() {
11     let b = Box { value: 42 };
12     b.print_item();
13 }
```

*(playground link)*

Why does PrintableContainer require Self::Item: Display?

## 5.9. If X impl, then Y impl

### 5.9.3. Putting constraints on super-traits (advanced)

A subtrait can add constraints on the associated types of its supertrait.

```

1  trait Container {
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4  }
5
6  trait PrintableContainer: Container
7  where
8      Self::Item: Display,
9  {
10     fn print_item(&self) {
11         println!("Item: {}", self.get());
12     }
13 }
14
15 struct Box<T> {
16     value: T,
17 }
```

*(playground link)*

```

1  impl<T> Container for Box<T> {
2      type Item = T;
3      fn get(&self) -> &Self::Item {
4          &self.value
5      }
6  }
7
8  impl<T: Display> PrintableContainer for Box<T> {}
9
10 fn main() {
11     let b = Box { value: 42 };
12     b.print_item();
13 }
```

*(playground link)*

Why does PrintableContainer require Self::Item: Display?

It constrains the supertrait's associated type so that print\_item can use the Display trait.

## 5.10. Generic traits

The From trait is a standard library trait for type conversion.

```
1 pub trait From<T>: Sized {  
2     fn from(value: T) -> Self;  
3 }  
4  
5 #[derive(Debug)]  
6 struct Foo(String);
```

*(playground link)*

### Info

Common traits in the standard library will be covered later on.

## 5.10. Generic traits

### 5.10.1. Example From

```
1  impl From<u32> for Foo {
2      fn from(from: u32) -> Foo {
3          Foo(format!("Converted from integer: {from}"))
4      }
5  }
6
7  impl From<bool> for Foo {
8      fn from(from: bool) -> Foo {
9          Foo(format!("Converted from bool: {from}"))
10     }
11 }
12 fn main() {
13     dbg!(Foo::from(123));
14     dbg!(Foo::from(true));
15 }
```

[\(playground link\)](#)

#### Warning

Notice that a **generic trait can be implemented multiple times** for the same type!



## 5.11. Associated types vs. generic type parameters

It may not always be clear when to pick an associated type or a generic type.

### Associated types

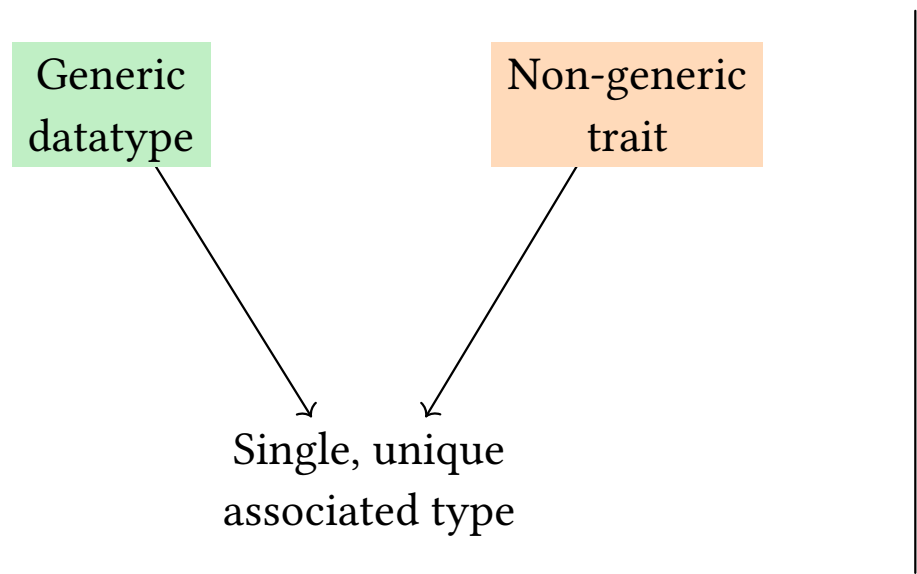
Generic  
datatype

Non-generic  
trait

## 5.11. Associated types vs. generic type parameters

It may not always be clear when to pick an associated type or a generic type.

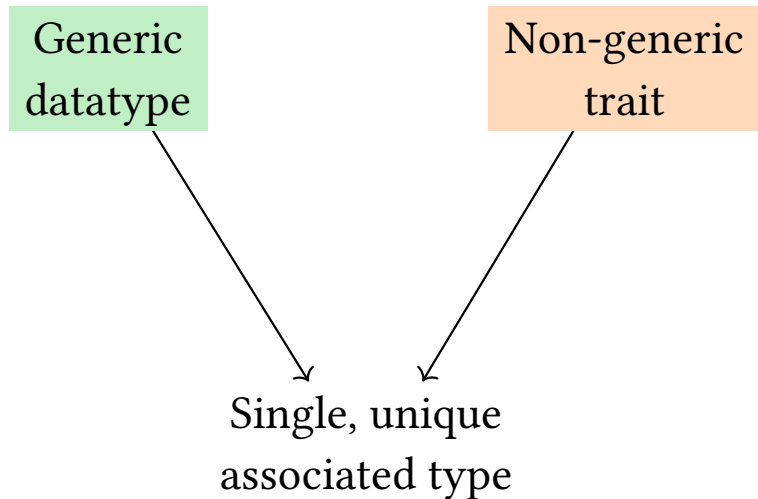
### Associated types



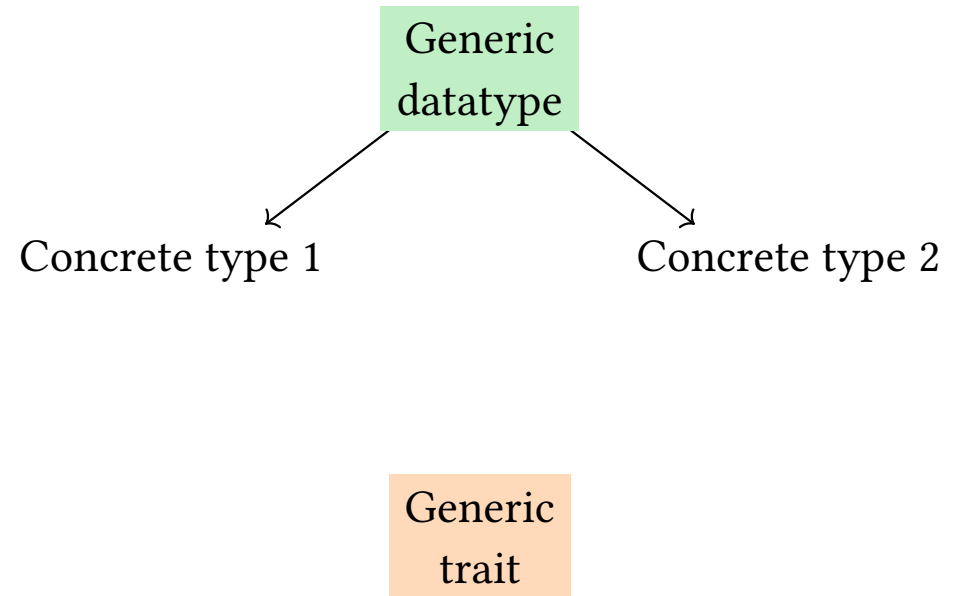
## 5.11. Associated types vs. generic type parameters

It may not always be clear when to pick an associated type or a generic type.

### Associated types



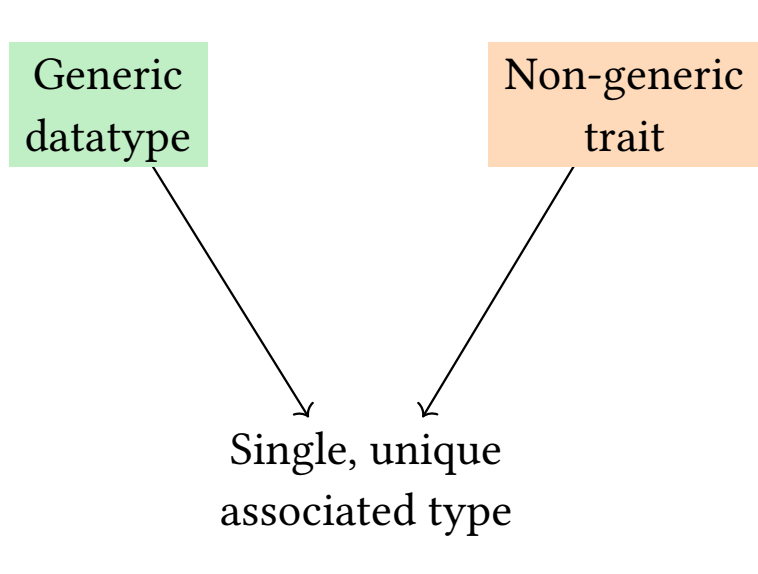
### Generic types parameters



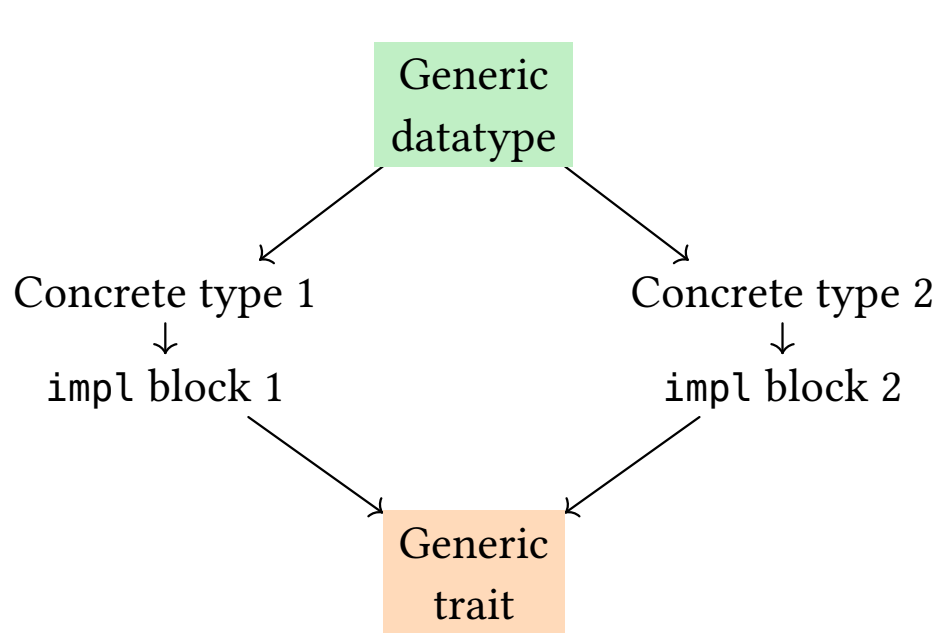
## 5.11. Associated types vs. generic type parameters

It may not always be clear when to pick an associated type or a generic type.

### Associated types



### Generic types parameters



- Associated types behave like output (first choice).
- Generic type parameters behave like input.

```
1  struct Container<T> {  
2    value: T,  
3  }  
4  
5  impl<T> Container<T> {  
6    fn process(&self) -> &'static str { "generic implementation" }  
7  }  
8  
9  impl Container<i32> {  
10   fn process(&self) -> &'static str { "specialized implementation for i32" }  
11 }  
  
(playground link)
```

Will this code compile?

## 5.12. Multiple generic impl blocks

```
1  struct Container<T> {  
2    value: T,  
3  }  
4  
5  impl<T> Container<T> {  
6    fn process(&self) -> &'static str { "generic implementation" }  
7  }  
8  
9  impl Container<i32> {  
10   fn process(&self) -> &'static str { "specialized implementation for i32" }  
11 }  
  
(playground link)
```

Will this code compile?

No. Rust does not allow overlapping implementations.

## 5.13. impl Trait

### Info

`impl Into<i32>` is syntactic sugar for: `fn add_42_millions<T: Into<i32>>(x: T) -> i32.`  
T is an anonymous and **hidden generic type**.

```
1 fn add_42_millions(x: impl Into<i32>) -> i32 {  
2     x.into() + 42_000_000  
3 }  
4  
5 fn pair_of(x: u32) -> impl Debug {  
6     (x + 1, x - 1)  
7 }  
8  
9 fn main() {  
10     let many = add_42_millions(42_i8);  
11     dbg!(many);  
12     let many_more = add_42_millions(10_000_000);  
13     dbg!(many_more);  
14     let debuggable = pair_of(27);  
15     dbg!(debuggable);  
16 }
```

(playground link)

## 5.13. impl Trait

### 5.13.1. Inference for return type impl Trait

```
1  fn returns_impl_trait(x: i32) -> impl std::fmt::Display {  
2      if x > 0 {  
3          x  
4      } else {  
5          -x  
6      }  
7  }  
8  
9  fn main() {  
10     let result = returns_impl_trait(-5);  
11     println!("{}", result);  
12 }
```

*(playground link)*

What is the return type of `returns_impl_trait`?



## 5.13. impl Trait

### 5.13.1. Inference for return type impl Trait

```
1  fn returns_impl_trait(x: i32) -> impl std::fmt::Display {  
2      if x > 0 {  
3          x  
4      } else {  
5          -x  
6      }  
7  }  
8  
9  fn main() {  
10     let result = returns_impl_trait(-5);  
11     println!("{}", result);  
12 }
```

*(playground link)*

What is the return type of `returns_impl_trait`?

i32, because both branches return an i32.

## 5.14. Exercise

Please find the exercise in `./session-2/tests/s2e4-min.rs`.

Test using the command: `cargo test --test s2e4-min -- --nocapture`

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## 6.1. Syntax

### Info

Closures are anonymous functions that can capture variables from their surrounding scope.

```
1  fn main() {  
2    // Argument and return type can be inferred for lightweight syntax:  
3    let double_it = |n| n * 2;  
4    dbg!(double_it(50));  
5  
6    // Or we can specify types and bracket the body to be fully explicit:  
7    let add_1f32 = |x: f32| -> f32 { x + 1.0 };  
8    dbg!(add_1f32(50.));  
9  }
```

*(playground link)*

Properties:

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```

*(playground link)*

Properties:

- The body may be surrounded by { .. }
- Argument and return types are optional, and are inferred if not given.

## 6.2. Capturing

```
1  fn main() {  
2      let max_value = 5;  
3      let clamp = |v| {  
4          if v > max_value  
            { max_value } else { v }  
5      };  
6  
7      dbg!(clamp(1));  
8      dbg!(clamp(3));  
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12 }
```

*(playground link)*

By default, a closure captures values by reference. Here `max_value` is captured by `clamp`, but still available to `main` for printing.

Try making `max_value` mutable, changing it, and printing the clamped values again. Why doesn't this work?

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*(playground link)*

By default, a closure captures values by reference. Here `max_value` is captured by `clamp`, but still available to `main` for printing.

Try making `max_value` mutable, changing it, and printing the clamped values again. Why doesn't this work?

The closure captures by reference. No mutable borrow may coexist with an immutable borrow.



## 6.2. Capturing

### 6.2.1. Mutable capture

```
1  fn main() {  
2      let mut max_value = 5;  
3      let mut clamp = |v| {  
4          max_value += 1;  
5          if v > max_value  
            { max_value } else { v }  
6      };  
7  
8      dbg!(clamp(1));  
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If a closure mutates captured values, it captures them by mutable reference.

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Why does the closure need to be mut?

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The closure's internal state changes, so it must be declared mutable.

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Why does the closure need to be mut?

The closure's internal state changes, so it must be declared mutable.

What happens if you try to access `max_value` directly while the closure exists?

Compile error: the closure holds a mutable borrow, preventing other accesses.

## 6.3. Moving

### 6.3.1. Move closures

```
1  fn main() {  
2      let name =  
        String::from("Alice");  
3      let greet = move || {  
4          println!("Hello, {}", name);  
5      };  
6  
7      greet();  
8      greet();  
9  
10     // println!("{}", name); //  
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*(playground link)*

The `move` keyword forces a closure to take ownership of captured values.

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*(playground link)*

The `move` keyword forces a closure to take ownership of captured values.

What happens if you uncomment the last line?

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*(playground link)*

The move keyword forces a closure to take ownership of captured values.

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Compile error: name was moved into the closure and can no longer be used.



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The move keyword forces a closure to take ownership of captured values.

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Why can we call greet() multiple times?

The closure owns name, which implements Clone, so it can be called repeatedly.

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Compile error: name was moved into the closure and can no longer be used.

Why can we call greet() multiple times?

The closure owns name, which implements Clone, so it can be called repeatedly.

Common use case: passing closures to threads or async tasks that must outlive their parent scope.

## 6.4. Internal representation of closures

Closures are like structs with a function field:

1. Each captured variable is a reference field.
2. The closure body is a method that uses these fields.

For example, the closure `|x| x + offset` where `offset` is captured from the environment is represented as:

```
1 struct Closure {  
2     offset: &i32,  
3 }  
4  
5 impl Closure {  
6     fn call(&self, x: i32) -> i32 {  
7         x + *self.offset  
8     }  
9 }
```

*(playground link)*

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8     }  
9 }
```

[\(playground link\)](#)

### Warning

The thing that sets closures apart is the hidden signature of the `call` method (whether it takes `&self` or not).

Closures belong to the category of **anonymous types**. Each closure has a unique, unnamed type generated by the compiler.

## 6.5. Closure traits

Please open demo file `session-2/examples/s2e5-closure-traits.rs`.

## 6.5. Closure traits

Closures have anonymous types that implement one or more of these traits:

## 6.5. Closure traits

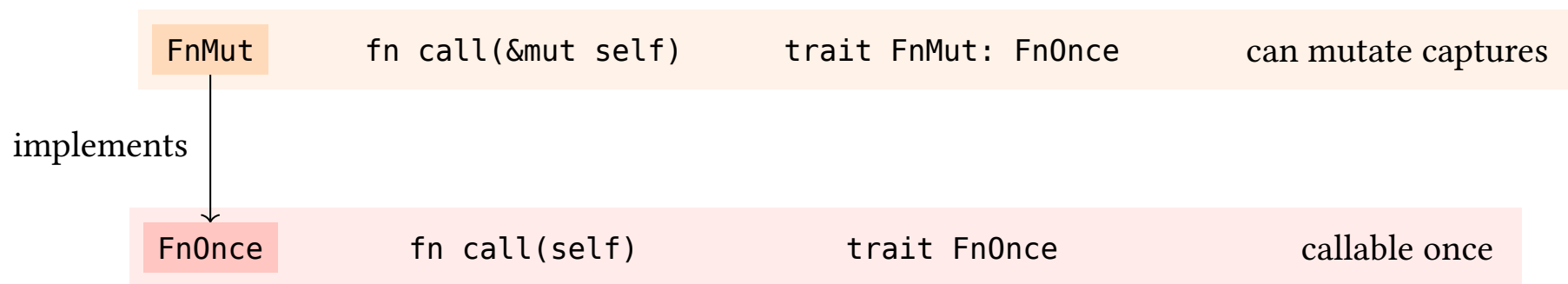
Closures have anonymous types that implement one or more of these traits:

`FnOnce``fn call(self)``trait FnOnce``callable once`



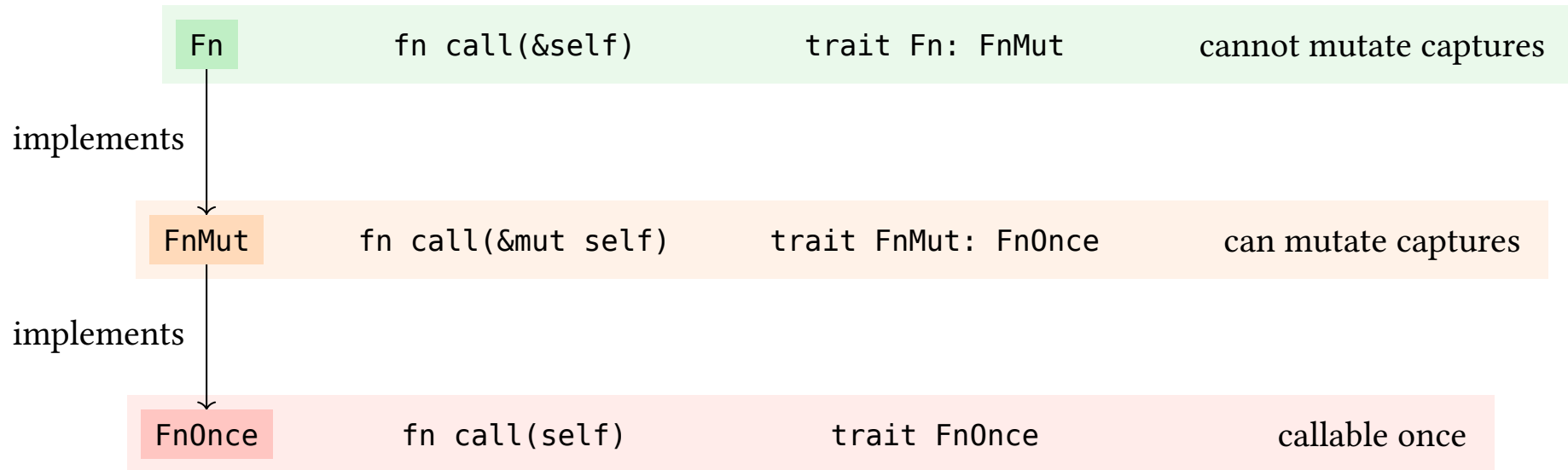
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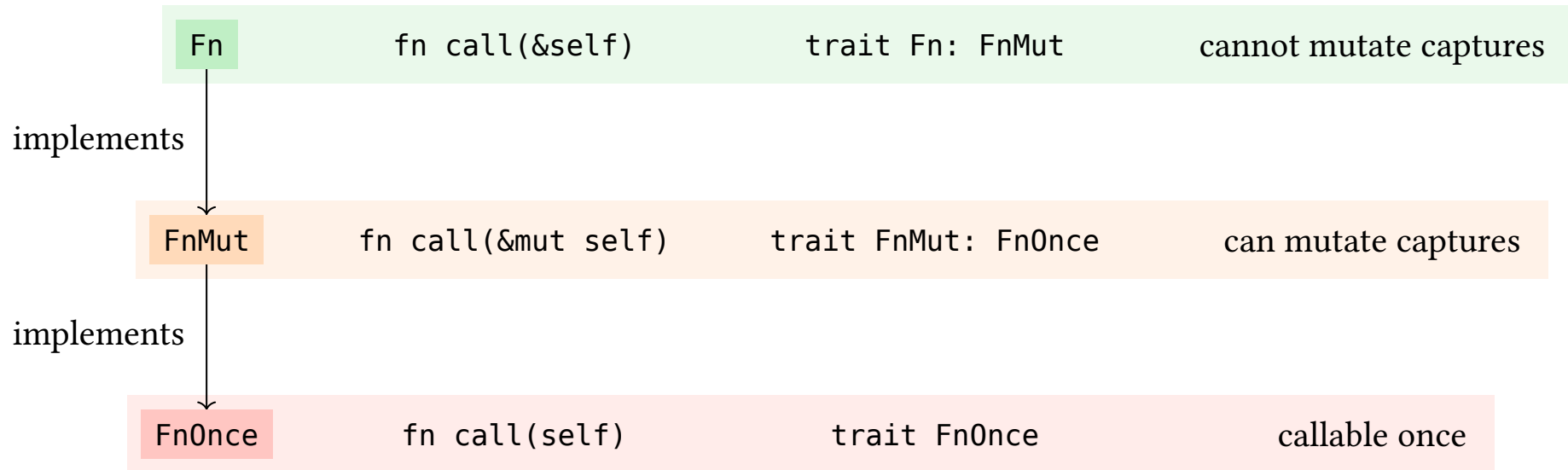
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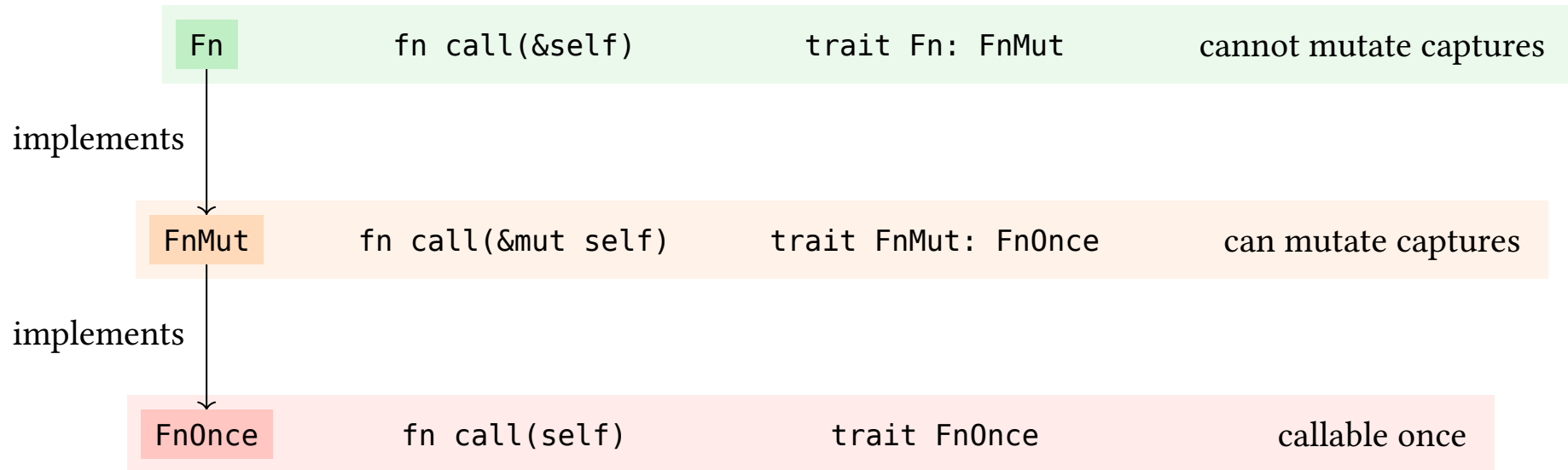


### Info

Trait hierarchy: `Fn` implements `FnMut`, `FnMut` implements `FnOnce`. A closure callable with `&self` can also be called with `&mut self` or `self`.

## 6.5. Closure traits

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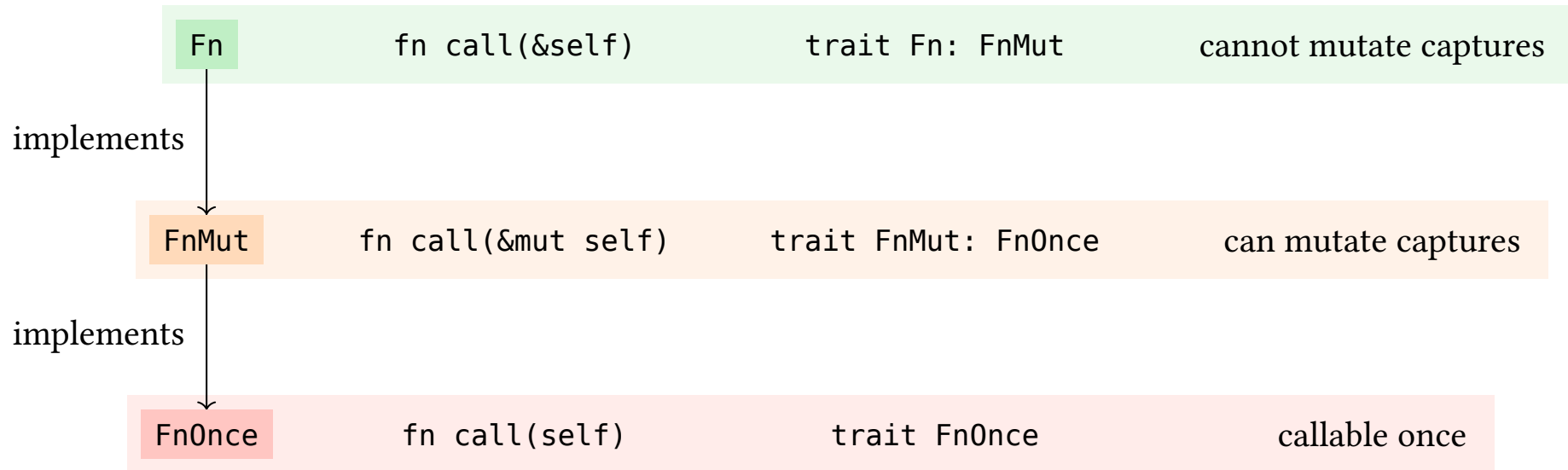
### Info

Trait hierarchy: `Fn` implements `FnMut`, `FnMut` implements `FnOnce`. A closure callable with `&self` can also be called with `&mut self` or `self`.

Can a closure implementing `Fn` be used where `FnOnce` is required?

## 6.5. Closure traits

Closures have anonymous types that implement one or more of these traits:



### Info

Trait hierarchy: Fn implements FnMut, FnMut implements FnOnce. A closure callable with `&self` can also be called with `&mut self` or `self`.

Can a closure implementing Fn be used where FnOnce is required?

Yes. Fn is a subtrait of FnMut, which is a subtrait of FnOnce.

## 6.6. Picking the right closure trait

You define a function accepting a closure (a higher-order function)

Which closure trait should use as a generic type trait bound?

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Prefer `FnOnce` (accepts any closure type).

Why?

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`Fn` and `FnMut` both implement `FnOnce`, so all closures can be passed. Most flexible for callers.



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Which closure trait should use as a generic type trait bound?

Prefer `FnOnce` (accepts any closure type).

Why?

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```
1 fn apply_once<F: FnOnce(i32) -> i32>(f: F, value: i32) -> i32 {  
2     f(value)  
3 }  
4  
5 fn main() {  
6     apply_once(|n| n + 1, 5);           // Fn works  
7     apply_once(move |n| n * 2, 5);     // FnOnce works  
8 }
```

*(playground link)*

## 6.6. Picking the right closure trait

You have to provide a closure for someone else's higher-order function

Which closure trait should your closure implement?

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You have to provide a closure for someone else's higher-order function

Which closure trait should your closure implement?

Aim for `Fn` if possible, fall back to `FnMut` or `FnOnce` if needed.

Why?

## 6.6. Picking the right closure trait

You have to provide a closure for someone else's higher-order function

Which closure trait should your closure implement?

Aim for Fn if possible, fall back to FnMut or FnOnce if needed.

Why?

Fn closures work wherever FnMut or FnOnce is required, giving maximum usability.  
Think of receiver types: `&self (Fn)` works where `&mut self (FnMut)` or `self (FnOnce)` is needed.

## 6.6. Picking the right closure trait

You have to provide a closure for someone else's higher-order function

Which closure trait should your closure implement?

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Why?

Fn closures work wherever FnMut or FnOnce is required, giving maximum usability.  
Think of receiver types: &self (Fn) works where &mut self (FnMut) or self (FnOnce) is needed.

```
1 fn process<F: Fn(i32) -> i32>(items: &[i32], f: F) {
2     for item in items {
3         println!("{}", f(*item)); // Requires Fn: called multiple times
4     }
5 }
6
7 fn main() {
8     process(&[1, 2, 3], |x| x * 2); // Fn: OK (no mutation)
9     // let mut c = 0;
10    // process(&[1, 2, 3], |x| { c += 1; x }); // FnMut: Error!
11 }
```

*(playground link)*

What are auto-traits?

## 6.7. Auto-traits of closures

What are auto-traits?

Traits that the compiler can automatically implement for types based on their structure.

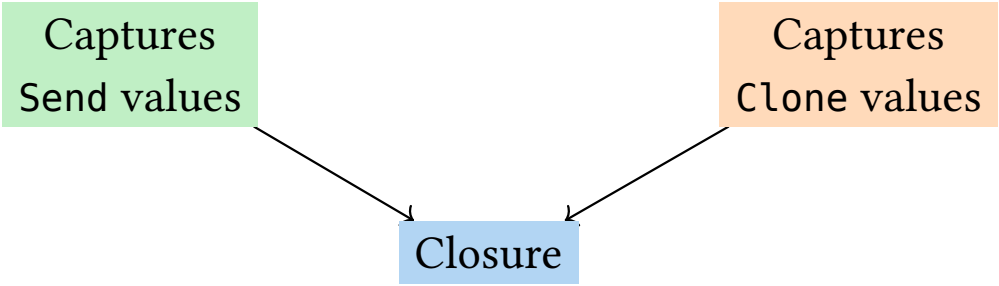
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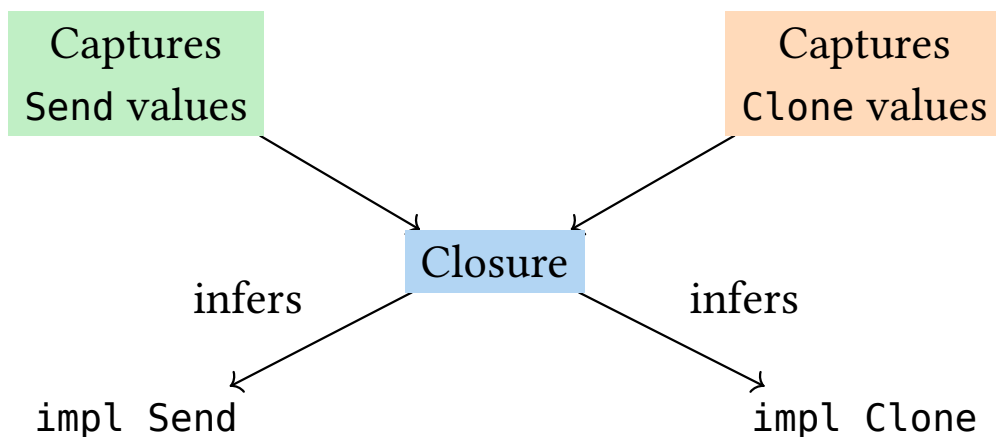


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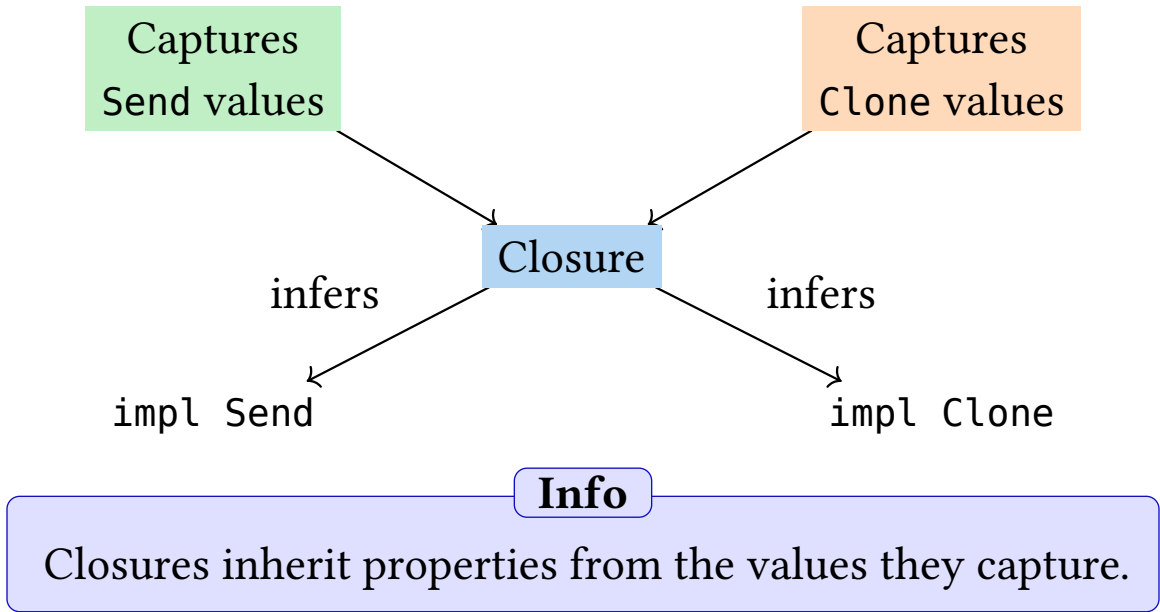


## 6.7. Auto-traits of closures

What are auto-traits?

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Closures automatically implement `Copy` and `Clone` based on captured values:



## 6.8. Exercise

Please find the statement of the exercise at `session-2/examples/s2d6-closures.rs` in this repo.

Run it with `cargo run --example s2d6-closures`.

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Homework: study standard library traits

Questions?

Feel free to contact me:

- Video meeting / email: [willemvanhulle@protonmail.com](mailto:willemvanhulle@protonmail.com)
- Phone: +32 479 080 252