Lifetimes, Function Types & More Ownership

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Outline

Recall: Ownership Rules

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- Some subsection of the duration we can use the owning variable
- Construct of Rust’s borrow checker, not checked at runtime!

Lifetimes Roughly Correspond To Scope

```rust
// Error: x isn't in scope
let x_ref1 = &x;

let x = String::from("hello");

let x_ref2 = &x;
take_ownership(x);

// Error: x was moved
let x_ref3 = &x;
```

Recall: Returning An Invalid Reference

```rust
fn make_string() -> &String {
    let s = String::from("hello");
    &s
}
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- Compiler knows lifetime of `make_string` will end once it returns, so reference won't be valid
- (but first we'd run into an issue about what lifetime the returned reference would have)

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[1] and the compiler will *automatically* determine if it's faster to pass pointer to output struct or pass via registers

Denoting Lifetimes

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&'a mut Ty
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- Not super common to need to denote explicitly, but sometimes necessary for:
  - Structs/Enums with references inside them
  - Functions taking in those structs/enums
  - Other, more funky functions

Explicit Lifetimes In Structs

```
struct Vertex<'a> {
    edges: Vec<&'a Edge<'a>>,
}
struct Edge<'a> {
    info: EdgeInfo,
    vertex: &'a Vertex<'a>,
}
```

Explicit Lifetimes In Function Signatures

```
fn bfs<'a>(
    start_vertex: &'a Vertex<'a>,
    max_depth: usize,
) -> Vec<&'a Vertex<'a>> {
    ...
}
```

Returning An Invalid Reference Revisited

```
fn make_string<'a>() -> &'a String {
    let s = String::from("hello");
    &s
}
```

The same underlying issue as before, made more obvious by the lifetime annotation.

Rules For Lifetimes In Function Signatures

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- Any reference *must* have an annotated lifetime
- Any reference being returned *must* have the same lifetime as an input, or be `'static`

```
fn f1<'a, 'b>(x: &'a i32, y: &'b i32) -> &'a i32 {
    // what goes here?
}
```

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```
fn f1<'a, 'b>(x: &'a i32, y: &'b i32) -> &'a i32 {
    // what goes here?
}
```

```
fn f2<'a, 'b>(x: &'a i32) -> &'b i32 {
    // what goes here?
}
```

Lifetime Elison

Certain patterns in Rust are very common:

```
// One input lifetime, return value is reference
fn f3<'a>(x: &'a i32) -> &'a i32 { ... }
// Multiple input lifetimes, return value is not reference
fn f4<'a, 'b, 'c>(x: &'a i32, y: &'b i32, z: &'c i32) -> i32 { ... }
```

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// One input lifetime, return value is reference
fn f3<'a>(x: &'a i32) -> &'a i32 { ... }
// Multiple input lifetimes, return value is not reference
fn f4<'a, 'b, 'c>(x: &'a i32, y: &'b i32, z: &'c i32) -> i32 { ... }
```

So if a function signature falls into one of these patterns, you don't have to explicitly write lifetimes for it!

```rust
fn g3(x: &i32) -> &i32 { ... }
fn g4(x: &i32, y: &i32, z: &i32) -> i32 { ... }
```

Lifetime Elison Example

```
fn make_string(allocator: &mut Vec<String>) -> &String {
    allocator.push(String::from("hello"));
    &allocator[allocator.len() - 1]
}
```

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- Input and output lifetimes elided to be the same

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    allocator.push(String::from("hello"));
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}
```

- Input and output lifetimes elided to be the same
- Valid reference returned via reference to original data

Sidenote: Loop Labels

```
'outer: for y in 0..5 {
    'inner: for x in 0..5 {
        if arr1[y][x] { break 'outer; }
        if arr2[x][y] { break 'inner; }
    }
}
```

Loop labels are not lifetimes—same syntax as lifetimes, and same sort of scope idea, but you can't actually make references with these names and have it make sense

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  - Structs, Enums
  - Types, Traits
  - Constants, Static members,
  - Other modules!
- Defines a namespace

Modules Within a File

```
fn f() { ... }
mod foo {
    fn f() { ... }
}
```

Directory Structure *Is* Module Structure

```
src/
├── lib.rs
└── bar/
    ├── mod.rs (bar)
    ├── baz.rs (bar::baz)
    └── qux.rs (bar::qux)
```

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Alternatively,

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Declaring File Modules

```rust
// In src/lib.rs:
mod bar;
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// In src/lib.rs:
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```rust
// In the `bar` module:
mod baz;
mod qux;
```

Visibility

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We need to explicitly declare items as public using the `pub` keyword:

```
pub struct Foo {
    x: usize,
    pub y: usize,
}
pub enum Bar {
    Bar1,
    Bar2,
}
pub fn calculate(f: Foo) -> Bar { ... }

pub mod baz;
mod qux;
```

Using Modules

```
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    fn f() { ... }
}
fn main() {
    foo::f();
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use foo::f;
fn main() {
    f();
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Using Multiple Things At Once

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```

Useful for re-exports, collecting all useful includes into one “prelude”:

```rust
pub use crate::{
    bar::{g, baz::h},
    qux::*,
};
```

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- Functions are values! (sorry 15-122 stans)
- Allows us to pass in functions as arguments to other functions, which many other good languages do in some capacity

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Value of the function pointer type is either:

- A "function item" (named function in the code), or
- A closure that doesn't capture (which is effectively the same)

Example: Using A Function Pointer

```
fn double(n: i32) -> i32 { 2 * n }
fn giveme_fnptr(f: fn(i32) -> i32) -> i32 {
    f(42)
}
fn test_fnptr() {
    assert_eq!(giveme_fnptr(double), 84);
}
```

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Closure Syntax

From https://doc.rust-lang.org/book/ch13-01-closures.html

```
fn  add_one_v1   (x: i32) -> i32 { x + 1 }
let add_one_v2 = |x: i32| -> i32 { x + 1 };
let add_one_v3 = |x|             { x + 1 };
let add_one_v4 = |x|               x + 1  ;
```

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```

This can't be done with functions! Will fail to compile:

```
fn f(x: i32) -> bool { z == x }
```

Consuming State With Closures

Sometimes, we *do* want to move a value into a closure:

```
let message = String::from("hello");
thread::spawn(move || {
    println!("{}", message);
});
```

Consuming State With Closures

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let message = String::from("hello");
thread::spawn(move || {
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```

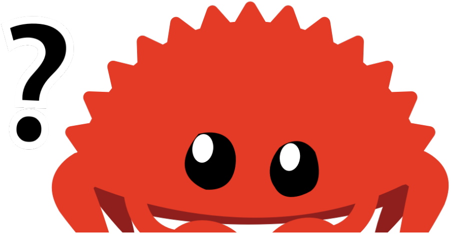
`move` keyword: anything that would be captured by reference is now captured by value (moved)

Things Closures Can't Be

- Recursive
- Generic
- In most cases, function pointers
  - If a closure doesn't capture anything from its environment, it can be coerced to a function pointer:

```
let x: fn(i32, i32) -> i32 = |x, y| x + y;
```

Type Of A Closure



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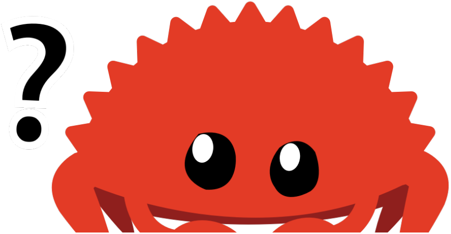

Type Of A Closure

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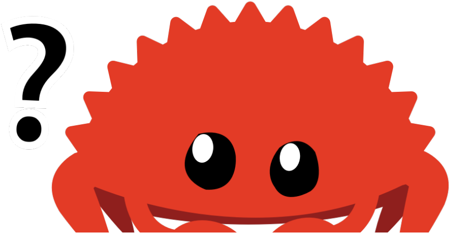
- Wait, so how can we take them as arguments??



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- Traits: describe what a type can do

Fn Trait

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let fn_closure = |x| 2 * x;
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- We say: `fn_closure` implements `Fn(i32) -> i32`
- Can be called by shared reference
- Closure must:
  - Not mutate any captured state
  - Not move any captured state out
- All (safe) function pointers also implement `Fn`

Example: Using `Fn`

```
fn giveme_fn1(f: impl Fn(i32) -> i32) -> i32 {
    f(42)
}
// Or, verbosely:
fn giveme_fn2<T: Fn(i32) -> i32>(f: T) -> i32 {
    f(42)
}
// Or, even more verbosely:
fn giveme_fn3<T>(f: T) -> i32
    where T: Fn(i32) -> i32
{
    f(42)
}
```

Example: Using Fn

```rust
fn giveme_fn1(f: impl Fn(i32) -> i32) -> i32 {
    f(42)
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// Or, verbosely:
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FnMut Trait

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let mut state = 0;
let fnmut_closure = |x| {
    state += x;
    state
};
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```

- Can be called by mutable reference
- Closure must not move any captured state out

Example: Using FnMut

```
fn giveme_fnmut(mut f: impl FnMut(i32) -> i32) -> i32 {
    let x = f(42);
    f(x)
}
assert_eq!(giveme_fnmut(fnmut_closure), 84);
```

Example: Using FnMut

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fn giveme_fnmut(mut f: impl FnMut(i32) -> i32) -> i32 {
    let x = f(42);
    f(x)
}
assert_eq!(giveme_fnmut(fnmut_closure), 84);
```

FnOnce Trait

```
let state = Box::new(42);
let fnonce_closure = move |x| {
    let y = x + *state;
    drop(state);
    y
};
```

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let fnonce_closure = move |x| {
    let y = x + *state;
    drop(state);
    y
};
```

- Can be called by taking ownership of the closure
- All closures implement this

Example: Using `FnOnce`

```
fn giveme_fnonce(f: impl FnOnce(i32) -> i32) -> i32 {
    let x = f(42);
    // let y = f(9 * 6); // Does not compile
    x
}
```

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  - `FnOnce`: "This can only be called 0 or 1 times because it may drop local state when called."

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- Need to distinguish between all the different ways we can capture state, interact with borrow/ownership system!
  - `Fn`: "This acts like a function pointer, doesn't modify any local state"
  - `FnMut`: "This may modify local state, but doesn't result in any local state being dropped when called"
  - `FnOnce`: "This can only be called 0 or 1 times because it may drop local state when called."
- Anything higher on the list can be used as anything lower on the list

Manually Implementing Function Traits?

Unfortunately, only on nightly, a.k.a. “unstable” Rust. Only closures will implement these traits for now.

Next Time

- Livecoding!!

Homework: What We Meant To Give You Last Time

Tarball: https://rust-stuco.github.io/handouts/TODO-handout.tgz
Handout PDF: https://rust-stuco.github.io/handouts/TODO-writeup.pdf