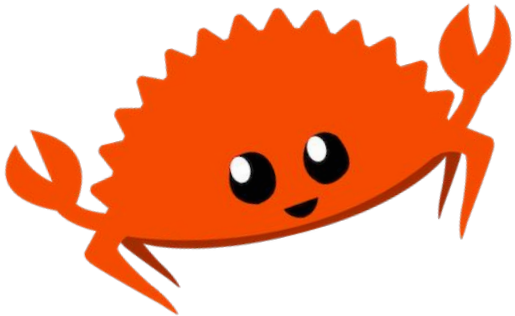
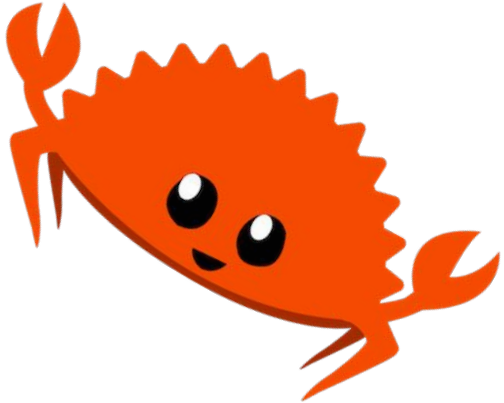




CIS1905

Welcome!

Who are we?

Course Staff

Including Penn emails and *ask me anything about...*

Paul Biberstein

Instructor

`paulbib`

Distance running and baking

Alexander Robertson

Instructor

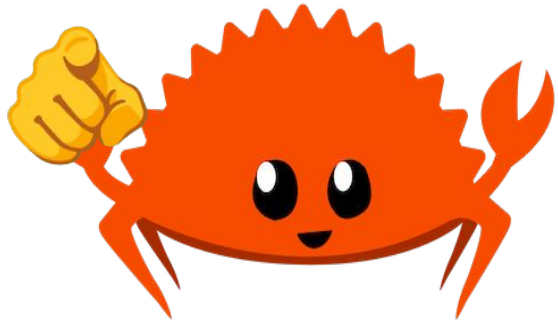
`xanrob`

Bitcoin and guitar

https://www.cis.upenn.edu/~cis1905/2025fall/#course-staff

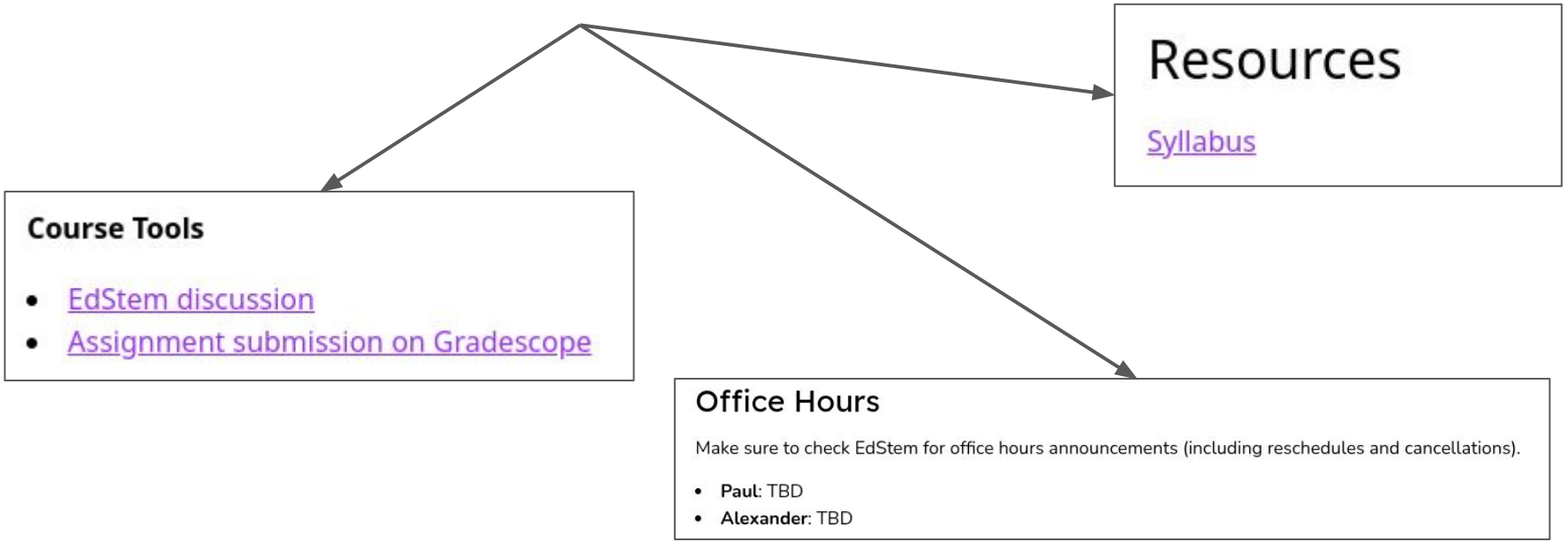
What about you?

- Name
- Year
- Why you’re taking the course
- If you were a sea creature, which sea creature would you be?



Logistics

https://www.cis.upenn.edu/~cis1905/2025fall/



Assignments

3.5 coding assignments

Post lecture quizzes (¾ credit for completion, ¼ for correctness)

Open ended final project (done in groups)

No exams

Final Project

Native GUI applications

- Chat app
- Music player
- Code editor
- Video game

Challenging projects from other domains:

- Graphics: pathtracer, FEM simulation
- Networks: TCP/UDP/IP stack,
- PL: garbage collector, compiler
- DBs: relational database
- OS: filesystem, device driver
- Distributed systems: load balancer, consensus algorithm

Open source contributions

- Contribute a crate to the Rust ecosystem
- Make Rust bindings to a C/C++ library
- Make a fast scientfic computing library with...
  - Python bindings
  - or WebAssembly bindings
- Rewrite a CLI application

Anything else!

- (just check first)

A Brief Rusty History

Early history (2009-2012): personal project by Mozilla employee Graydon Hoare. Sponsored by Mozilla

Pre-release (2012-2015): larger open source community formed, underwent many feature changes trying to find a niche

May 15 2015: Rust 1.0 release, commitment stability

Adoption (2015-2020): Firefox code migrated to Rust, adoption elsewhere in industry

Modern era (2020-present):

- Mozilla lay offs include core Rust contributors
- Rust Foundation started by AWS, Huawei, Google, Microsoft, and Mozilla

Who’s using Rust Now?

Developers: StackOverflow’s most loved language eight years running

CLI tools: `grep` -> `ripgrep` (~5x faster), `make` -> `just`

Full rewrites: Dropbox core syncing code fully rewritten in Rust

Partial migrations: Firefox (20% of core codebase), Android (20% as of 2022)

https://github.blog/developer-skills/programming-languages-and-frameworks/why-rust-is-the-most-admired-language-among-developers/

https://github.com/BurntSushi/ripgrep

https://dropbox.tech/infrastructure/rewriting-the-heart-of-our-sync-engine

https://4e6.github.io/firefox-lang-stats/

Rust is a *Systems Programming* Language

One definition: applications that require control of **memory layout** and access to **machine primitives**

Better definition: applications that have strong **correctness** and **performance** requirements.

- OS Kernels
- Databases
- Networking code

But also...

- Scientific computing
- Embedded systems
- Web programming

Why Rust?

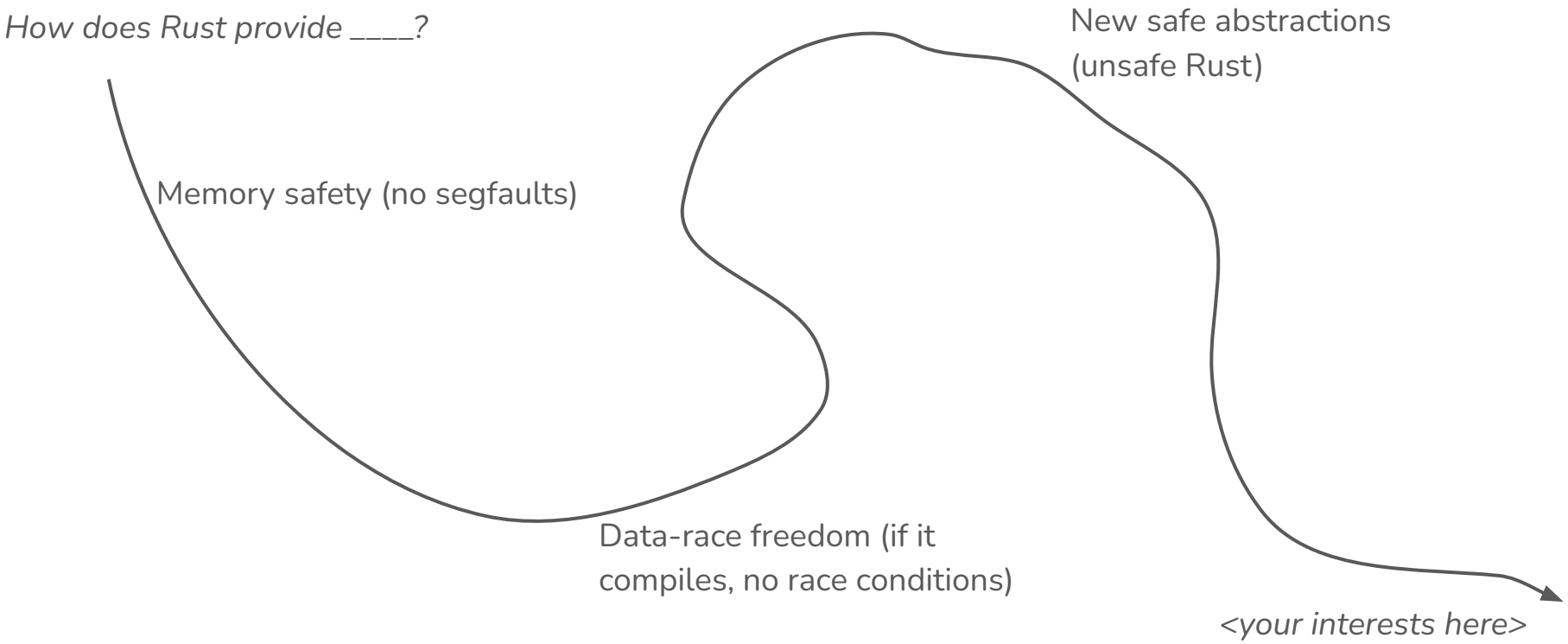
We'll primarily be comparing to C/C++, languages that give more control than nearly anything else out there.

Unfortunately, with great power comes great danger:

- read past buffer
- use-after-free
- double free
- memory leaks
- race conditions

Key question: can you keep the control of C/C++ while not having the dangers?

Course roadmap



Course roadmap

How does Rust provide ?

New safe abstractions

70% of vulnerabilities in Microsoft's codebases are memory safety

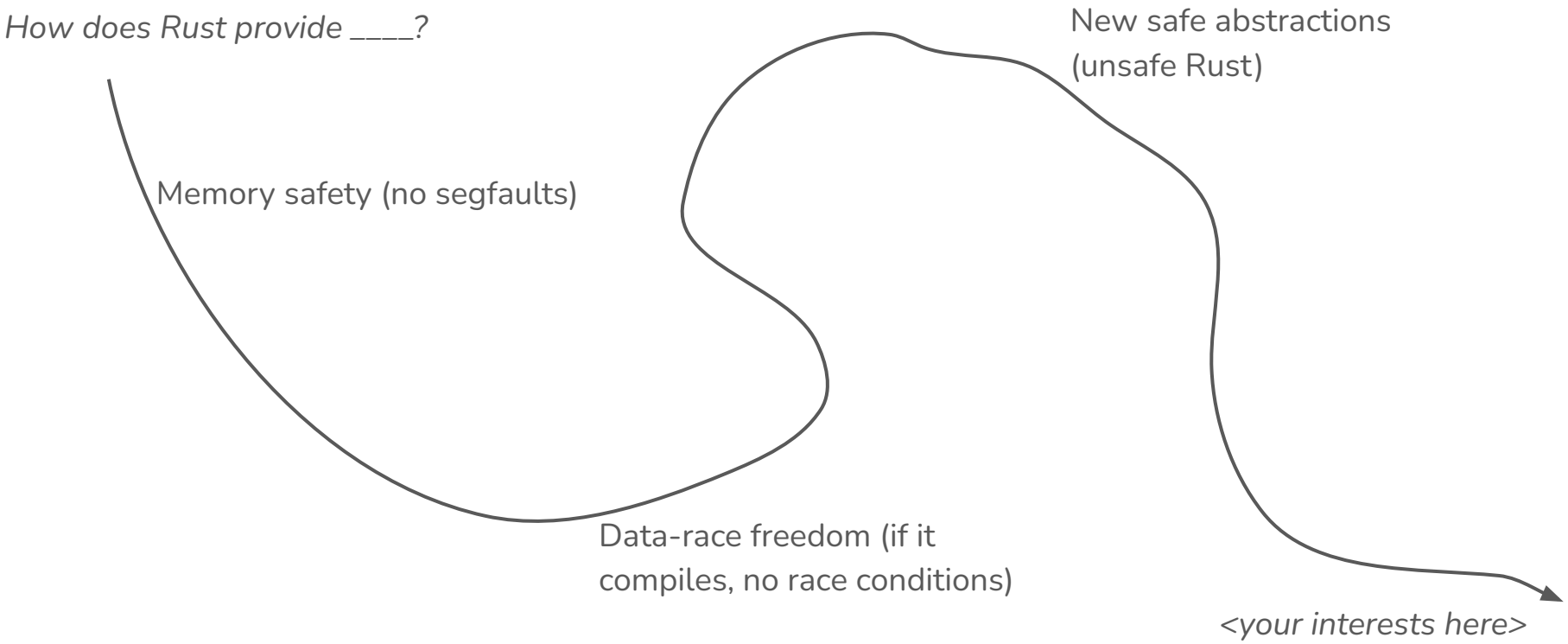
Chrome, Firefox have similar numbers

The source? U.S. Homeland Security: *The Urgent Need for Memory Safety in Software Products*

- How can languages address memory safety?

https://www.cisa.gov/news-events/news/urgent-need-memory-safety-software-products

Course roadmap



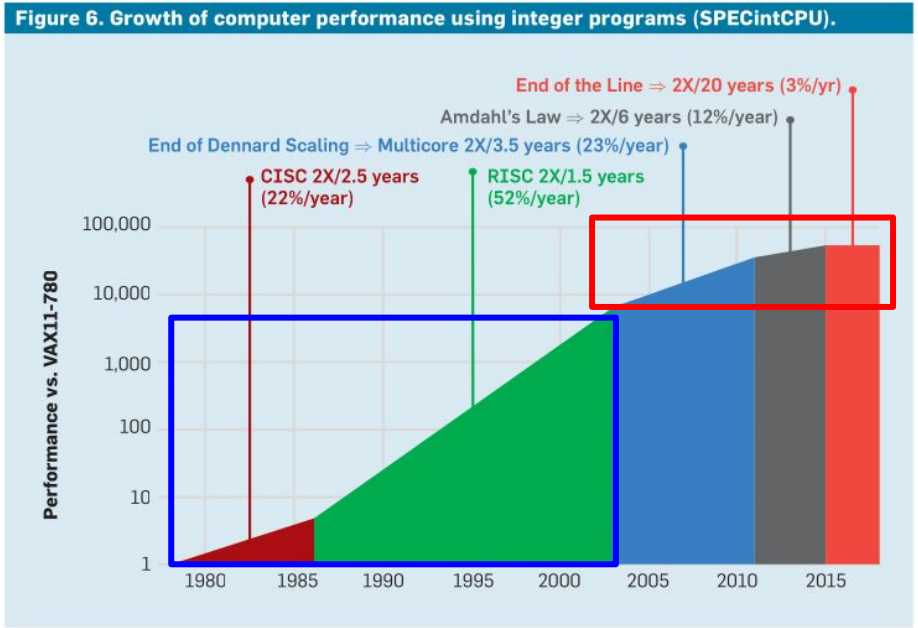
Course roadmap

How does Rust provide ... ?

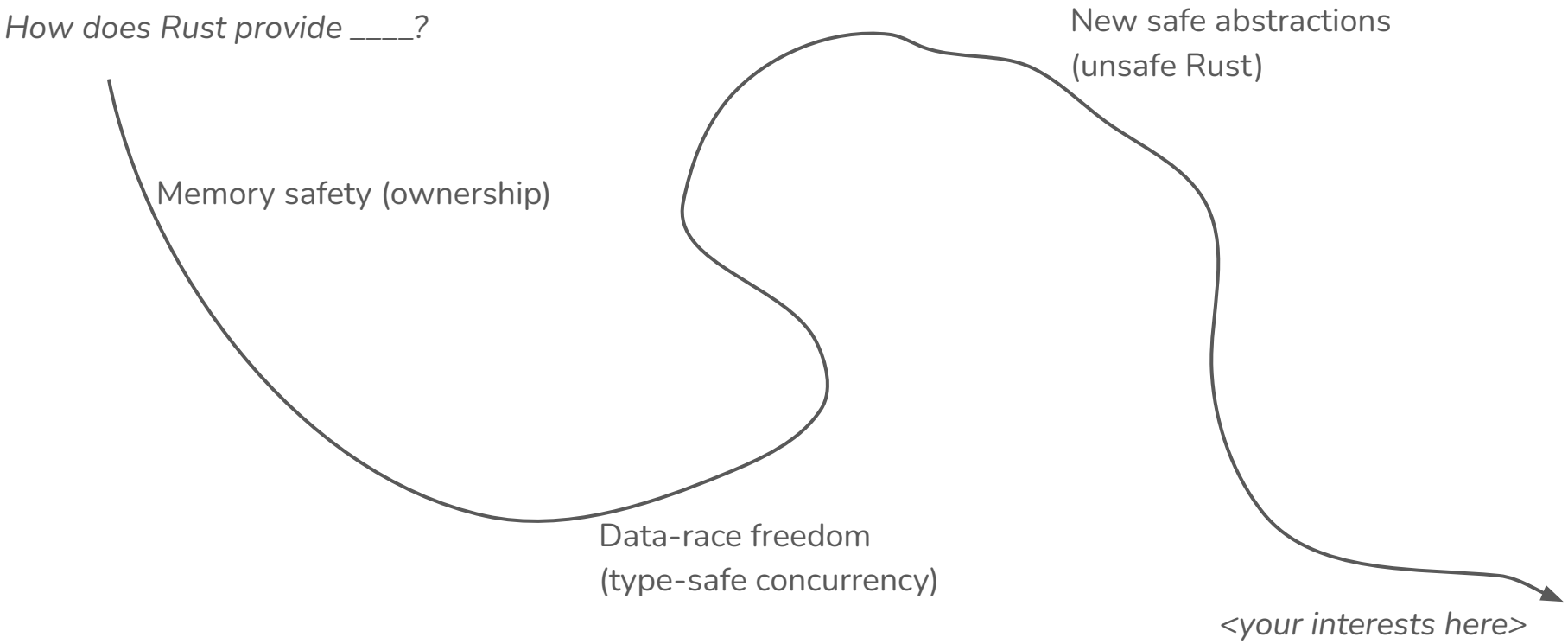
New safe abstractions

Parallel Programming is inevitable
multi-core is what separates CPUs from 2005 and today

Unfortunately, parallel programming is hard. Can it be easier?



Course roadmap



Anatomy of a Rust Program

```rust
fn main() {
    println!("fib(6) = {}", fib(6));
}

fn fib(n: u64) -> u64 {
    match n {
        0 | 1 => n,
        _ => fib(n - 1) + fib(n - 2)
    }
}
```

Anatomy of a Rust Program

```rust
fn main() {
    println!("fib(6) = {}", fib(6));
}

fn fib(n: u64) -> u64 {
    match n {
        0 | 1 => n,
        _ => fib(n - 1) + fib(n - 2)
    }
}
```

`println!(...)`

Like C-style printf formatting but...

- Type-inferred
- Type-safe
- No run-time cost

Implemented via macros (we'll see more later)

Anatomy of a Rust Program

```rust
fn main() {
    println!("fib(6) = {}", fib(6));
}

fn fib(n: u64) -> u64 {
    match n {
        0 | 1 => n,
        _ => fib(n - 1) + fib(n - 2)
    }
}
```

Function Declaration

- Argument types and return types must be annotated

Numeric types

	signedness	
size	i8	u8
	i16	u16
	i32	u32
	i64	u64

f32
f64

Anatomy of a Rust Program

```rust
fn main() {
    println!("fib(6) = {}", fib(6));
}

fn fib(n: u64) -> u64 {
    match n {
        0 | 1 => n,
        _ => fib(n - 1) + fib(n - 2)
    }
}
```

Pattern Matching

- Very similar to OCaml
- Very flexible, we'll see more in future lectures and homework

Anatomy of a Rust Program

```rust
fn main() {
    println!("fib(6) = {}", fib(6));
}

fn fib(n: u64) -> u64 {
    match n {
        0 | 1 => n,
        _ => fib(n - 1) + fib(n - 2)
    }
}
```

Anatomy of a Rust Program

```
fn main() {
    println!("fib(6) = {}", fib(6));
}

fn fib(n: u64) -> u64 {
    match n {
        0 | 1 => n,
        _ => fib(n - 1) + fib(n - 2)
    }
}
```

Hang on, where are the semicolons?
What about `return`??

Anatomy of a Rust Program

```rust
fn main() {
    println!("fib(6) = {}", fib(6));
}

fn fib(n: u64) -> u64 {
    match n {
        0 | 1 => n,
        _ => fib(n - 1) + fib(n - 2)
    }
}
```

```rust
fn fib_imperative(n: u64) -> u64 {
    if n <= 1 {
        return n;
    } else {
        let mut result = fib(n - 1);
        result += fib(n - 2);
        return result;
    }
}
```

Anatomy of a Rust Program

```rust
fn main() {
    println!("fib(6) = {}", fib(6));
}

fn fib(n: u64) -> u64 {
    match n {
        0 | 1 => n,
        _ => fib(n - 1) + fib(n - 2)
    }
}
```

```rust
fn fib_imperative(n: u64) -> u64 {
    if n <= 1 {
        return n;
    } else {
        let mut result = fib(n - 1);
        result += fib(n - 2);
        return result;
    }
}
```

Rust borrows ideas from declarative and imperative programming.
Allows you to balance reasoning about code and performance
(In this case, the left is preferable)

Anatomy of a Rust Program

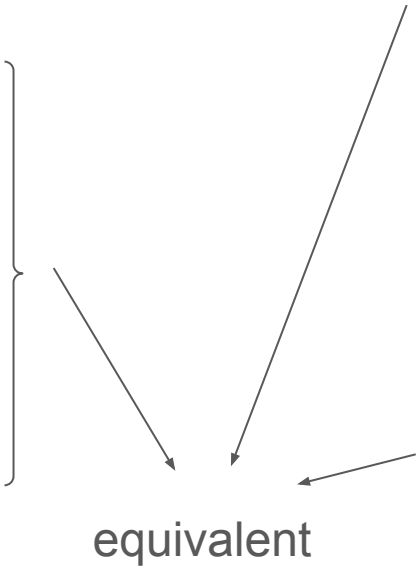
```
fn main() {
    println!("fib(6) = {}", fib(6));
}


fn fib_imperative(n: u64) -> u64 {
    if n <= 1 {
        return n;
    } else {
        let mut result = fib(n - 1);
        result += fib(n - 2);
        return result;
    }
}
```

Anatomy of a Rust Program

```rust
fn main() {
    println!("fib(6) = {}", fib(6));
}
```

```rust
fn fib_imperative(n: u64) -> u64 {
    if n <= 1 {
        return n;
    } else {
        let mut result = fib(n - 1);
        result += fib(n - 2);
        return result;
    }
}
```




```rust
fn fib_imperative(n: u64) -> u64 {
    if n <= 1 {
        n
    } else {
        let mut result = fib(n - 1);
        result += fib(n - 2);
        result
    }
}
```

```rust
fn fib_imperative(n: u64) -> u64 {
    return if n <= 1 {
        n
    } else {
        let mut result = fib(n - 1);
        result += fib(n - 2);
        result
    };
}
```

Anatomy of a Rust Program

Statements and expressions

Semicolon ➡️ sequence statements

```
fn baz() -> u32 {
    100
}
```

```
fn baz() -> u32 {
    let a = qux();
    let b = buzz();
    a + b
}
```

Braces ➡️ statements in expression context

```
let x = foo();
```

```
let x = { println!("Calling foo..."); foo() };
```

Anatomy of a Rust Program

```rust
fn main() {
    println!("fib(6) = {}", fib(6));
}

fn fib_imperative(n: u64) -> u64 {
    if n <= 1 {
        return n;
    } else {
        let mut result = fib(n - 1);
        result += fib(n - 2);
        return result;
    }
}
```

Anatomy of a Rust Program

```
fn main() {
    println!("fib(6) = {}", fib(6));
}

fn fib_imperative(n: u64) -> u64 {
    if n <= 1 {
        return n;
    } else {
        let mut result = fib(n - 1);
        result += fib(n - 2);
        return result;
    }
}
```

Type inference

- local variables are statically typed, but type inference allows omitting type annotations

Could write

```
let mut result: u64 = fib(n - 1);
```

Anatomy of a Rust Program

```rust
fn main() {
    println!("fib(6) = {}", fib(6));
}


fn fib_imperative(n: u64) -> u64 {
    if n <= 1 {
        return n;
    } else {
        let mut result = fib(n - 1);
        result += fib(n - 2);
        return result;
    }
}
```

```
error[E0384]: cannot assign twice to immutable variable `result`
 --> fib.rs:17:9
   |
16 |         let result = fib(n - 1);
   |             ------
   |             |
   |             first assignment to `result`
   |             help: consider making this binding mutable: `mut result`
17 |         result += fib(n - 2);
   |         ^^^^^^^^^^^^^^^^^^^^ cannot assign twice to immutable variable

error: aborting due to 1 previous error

For more information about this error, try `rustc --explain E0384`.
```

`mut` keyword

- bindings are immutable by default
- Reverse of C/C++ `const` keyword

Anatomy of a Rust Program

```rust
fn main() {
    println!("fib(6) = {}", fib(6));
}

fn fib_imperative(n: u64) -> u64 {
    if n <= 1 {
        return n;
    } else {
        let mut result = fib(n - 1);
        result += fib(n - 2);
        return result;
    }
}
```

Rapid fire time

Rapid fire time

```
fn main() {
    let s = "foobar"; // string literals

    let x = 1.0 + 2.0 / 3.0 * 4.0; // arithmetic

    let b = true || false; // bools

    let s: bool = 1 < 2; // explicit type annotations

    let c = '😻'; // unicode

    let tup = ('🦀', "Ferris"); // tuples

    while false {
        println!("Uh-oh");
    } // looping
}
```

But how do I run it?

Other languages have many build/package systems to choose from

- C/C++: `make`, `CMake`, `Bazel`, `Ninja`
- Python: `pip`, `poetry`, `setuptools`
- Javascript: `npm`, `yarn`, `webpack`

In Rust, we'll just use `cargo` :)

```
cargo init my-project
cd my-project
cargo add a-cool-dependency
cargo run # or cargo run --release
```

Philosophical Takeaways

Rust emphasizes ~safety~

- immutable by default

Rust emphasizes ~control~

- declarative code for pure functions,
  imperative code for procedural algorithms

Rust emphasizes ~productivity~

- type inference
- helpful error messages

Quiz time

Does it compile? Should it?

```
fn main() {
    x = 5;
    println!("{}", x + 1);
}
```

Does it compile? Should it?

```
fn main() {
    let x = 5;
    println!("{}", x + 1);
}
```

Does it compile? Should it?

```
fn main() {
    let mut x = 5;
    println!("{}", x + 1);
}
```

Does it compile? Should it?

```
fn main() {
    let x = 5;
    let x = 6;
    println!("{}", x + 1);
}
```

Does it compile? Should it?

```
fn main() {
    let mut x = 5;
    let x = 6;
    println!("{}", x + 1);
}
```

Does it compile? Should it?

```
fn main() {
    let mut x = 5;
    x = 6;
    println!("{}", x + 1);
}
```

Does it compile? Should it?

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

Does it compile? Should it?

```
fn main() {
    x = 5;
    println!("{}", x + 1);
}
```

```
error[E0425]: cannot find value `x` in this scope
--> shadow.rs:2:5
  |
2 |     x = 5;
  |     ^
  |
help: you might have meant to introduce a new binding
  |
2 |     let x = 5;
  |     +++
```

Does it compile? Should it?

```
fn main() {
    let x = 5;
    println!("{}", x + 1);
}
```

Does it compile? Should it?

```
fn main() {
    let mut x = 5;
    println!("{}", x + 1);
}
```

```
warning: variable does not need to be mutable
 --> shadow.rs:13:9
   |
13 |     let mut x = 5;
   |         ----^
   |         |
   |         help: remove this `mut`
   |
  = note: `#[warn(unused_mut)]` on by default
```

Does it compile? Should it?

```
fn main() {
    let x = 5;
    let x = 6;
    println!("{}", x + 1);
}
```

✅

Does it compile? Should it?

```
fn main() {
    let mut x = 5;
    let x = 6;
    println!("{}", x + 1);
}
```

Does it compile? Should it?

```
fn main() {
    let mut x = 5;
    x = 6;
    println!("{}", x + 1);
}
```

Does it compile? Should it?

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

```
error[E0308]: mismatched types
 --> shadow.rs:37:9
   |
36 |     let mut x = 5;
   |                 - expected due to this value
37 |     x = "🦀🦀🦀";
   |         ^^^^^^^^ expected integer, found `&str`
```

Does it compile? Should it?

```
fn foo() -> u32 {
    let x = 5;
    x
}
```

Does it compile? Should it?

```
fn foo() -> u32 {
    if true {
        1
    } else {
        2
    }
}
```

Does it compile? Should it?

```rust
fn foo() -> u32 {
    if true {
        1
    } else {
        '🦀'
    }
}
```

```
error[E0308]: mismatched types
 --> func.rs:20:9
   |
16 | fn foo2() -> u32 {
   |              --- expected `u32` because of return type
...
20 |         '🦀'
   |         ^^^^ expected `u32`, found `char`
   |
help: you can cast a `char` to a `u32`, since a `char` always occupies 4 bytes
   |
20 |         '🦀' as u32
   |              ++++++
```

Does it compile? Should it?

```
fn foo() {
    let x = if true {
        1
    } else {
        '🦀'
    };
}
```

```
error[E0308]: `if` and `else` have incompatible types
 --> func.rs:37:9
   |
34 |       let x = if true {
   |  _____________-
35 | |         1
   | |         - expected because of this
36 | |     } else {
37 | |         '🦀'
   | |         ^^^^ expected integer, found `char`
38 | |     };
   | |_____- `if` and `else` have incompatible types
```

Does it compile? Should it?

```rust
fn foo(n: u32) -> u32 {
    match n {
        0 | 1 => 0,
        2 | 3 | 4 | 5 => 1
    }
}
```

```
error[E0004]: non-exhaustive patterns: `6_u32..=u32::MAX` not
covered
 --> func.rs:25:11
   |
25 |     match n {
   |           ^ pattern `6_u32..=u32::MAX` not covered
   |
  = note: the matched value is of type `u32`
help: ensure that all possible cases are being handled by adding a
match arm with a wildcard pattern or an explicit pattern as shown
   |
27 ~        2 | 3 | 4 | 5 => 1,
28 +         6_u32..=u32::MAX => todo!()
   |
```

Final notes

- Make sure you're on EdStem and Gradescope
- Bookmark course website
- Project 0 released soon: exercises to get you more familiar with Rust
- Complete post-lecture quiz

Slide Credits

Inspiration from:

https://www.cis.upenn.edu/~cis1905/2024spring/

https://github.com/trifectatechfoundation/teach-rs

https://www.cs.umd.edu/class/fall2021/cmsc388Z/