Safe Programming With Rust

Slide credit today: Michael Hicks

Why Rust in a Software Engineering Course

- I've been telling you about the security implications of using unsafe languages
- But that advice is only actionable if you have a practical alternative!
- Enter: Rust.

What choice do programmers have today?

C/C++

- Low level
- More control
- Performance over safety
- Memory managed manually
- No periodic garbage collection
- …

Java, OCaml, Go, Ruby…

- High level
- Secure
- Less control
- Restrict direct access to memory
- Run-time management of memory via periodic garbage collection
- No explicit malloc and free
- Unpredictable behavior due to GC
- …

Rust: Type- and Thread-safe, and Fast

- Begun in 2006 by Graydon Hoare
- Sponsored as full-scale project and announced by Mozilla in 2010
  - Changed a lot since then; source of frustration
  - But now: most loved programming language in Stack Overflow annual surveys every year from 2016 through 2020
- Takes ideas from functional and OO languages, and recent research
- Key properties: Type safety, and no data races, despite use of concurrency and manual memory management

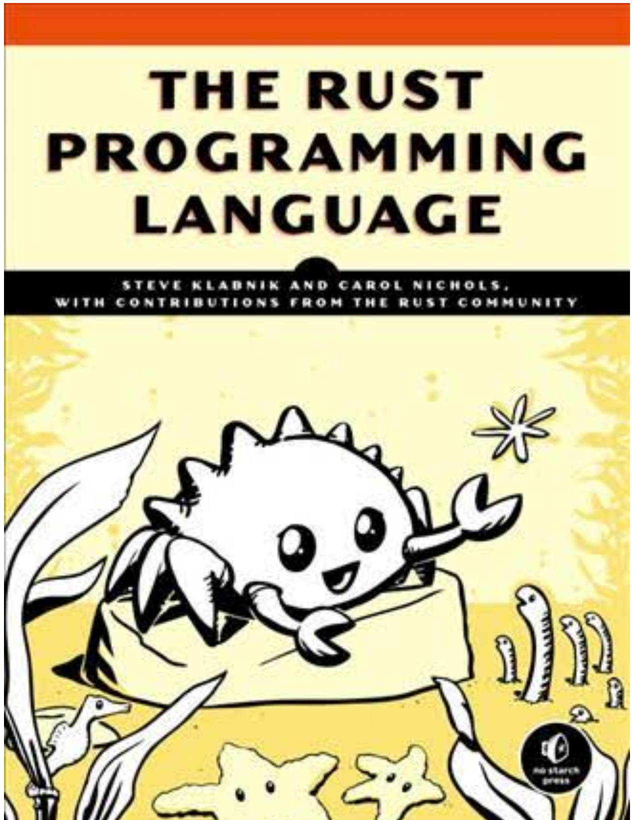
Features of Rust

- Lifetimes and Ownership
  - Key feature for ensuring safety
- Traits as core of object(-like) system
- Variable default is immutability
- Data types and pattern matching
- Type inference
  - No need to write types for local variables
- Generics (aka parametric polymorphism)
- First-class functions
- Efficient C bindings

Rust in the real world

- Firefox Quantum and Servo components
  - https://servo.org
- REmacs port of Emacs to Rust
  - https://github.com/Wilfred/remacs
- Amethyst game engine
  - https://www.amethyst.rs/
- Magic Pocket filesystem from Dropbox
  - https://www.wired.com/2016/03/epic-story-dropboxs-exodus-amazon-cloud-empire/
- OpenDNS malware detection components
- https://www.rust-lang.org/en-US/friends.html

Information on Rust



- Rust book free online
  - https://doc.rust-lang.org/book/
  - **We will follow it in these lectures**
- More references via Rust site
  - https://www.rust-lang.org/en-US/documentation.html
- Rust Playground (REPL)
  - https://play.rust-lang.org/

Installing Rust

- Instructions, and stable installers, here:

  https://www.rust-lang.org/en-US/install.html

- On a Mac or Linux (VM), open a terminal and run

  ```
  curl https://sh.rustup.rs -sSf | sh
  ```

- On Windows, download+run rustup-init.exe

  https://static.rust-lang.org/rustup/dist/i686-pc-windows-gnu/rustup-init.exe

Rust compiler, build system

- Rust programs can be compiled using rustc
  - Source files end in suffix .rs
  - Compilation, by default, produces an executable
    - No –c option
- Preferred: Use the cargo package manager
  - Will invoke rustc as needed to build files
  - Will download and build dependencies
  - Based on a .toml file and .lock file
    - You won’t have to mess with these for this class
  - Like ocamlbuild or dune

Using rustc

- Compiling and running a program

main.rs:

```
fn main() {
    println!("Hello, world!”)
}
```

```
% rustc main.rs
% ./main
Hello, world!
%
```

Using cargo

- Make a project, build it, run it

```
% cargo new hello_cargo --bin
% cd hello_cargo
% ls
Cargo.toml   src/
% ls src
main.rs
% cargo build
 Compiling hello_cargo v0.1.0 (file:///…)
 Finished dev [unoptimized + debuginfo] …
% ./target/debug/hello_cargo
Hello, world!
```

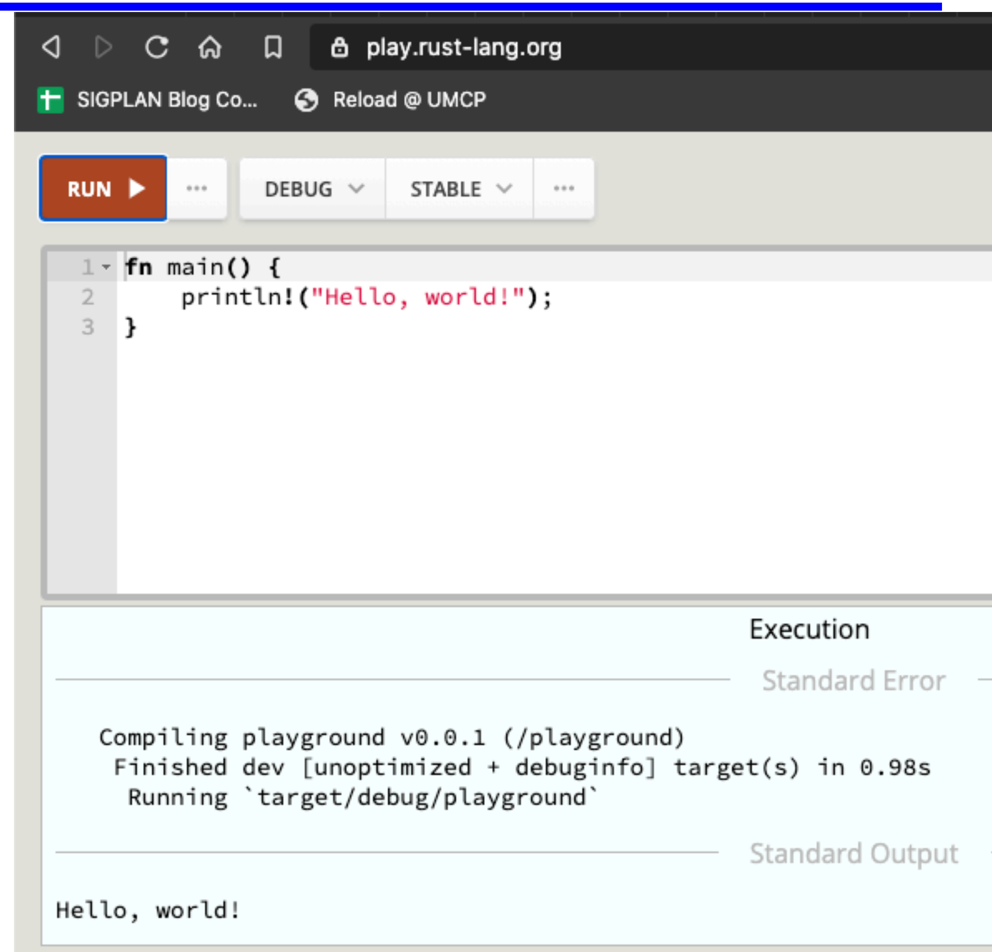
```
fn main() {
    println!("Hello, world!”)
}
```

Use `cargo` to run tests, too; will discuss later

More at https://doc.rust-lang.org/stable/cargo/getting-started/first-steps.html

Rust, interactively

- Rust has no top-level *a la* OCaml or Ruby
- There is an in-browser execution environment
  - https://play.rust-lang.org/



Rust Documentation

- Rust documentation is a good reference, and way to learn
  - https://doc.rust-lang.org/stable/

- This contains links to
  - the Rust Book (on which most of our slides are based),
  - the reference manual, and
  - short manuals on the compiler, cargo, and more

Rust Basics

Functions

```
// comment
fn main() {
    println!("Hello, world!");
}
```

Hello, world!

Factorial in Rust (recursively)

```
fn fact(n:i32) -> i32
{
  if n == 0 { 1 }
  else {
    let x = fact(n-1);
    n * x
  }
}
```

```
fn main() {
  let res = fact(6);
  println!("fact(6) = {}",res);
}
```

```
fact(6) = 720
```

If *Expressions* (not Statements)

```
fn main() {
    let n = 5;
    if n < 0 {
        print!("{} is negative", n);
    } else if n > 0 {
        print!("{} is positive", n);
    } else {
        print!("{} is zero", n);
    }
}
```

5 is positive

Let Statements

- By default, Rust variables are immutable
  – Usage checked by the compiler
- **mut** is used to declare a resource as mutable.

```
fn main() {
  let a: i32 = 0;
  a = a + 1;
  println!("{}" , a);
}
```

```
fn main() {
  let mut a: i32 = 0;
  a = a + 1;
  println!("{}" , a);
}
```

Compile error

Let Statements

```
fn main() {
  let x = 5;

  let x: i32 = 5; //type annotation

  let mut x = 5; //mutable x: i32
  x = 10;
}
```

If *Expressions*

```
fn main() {
    let n = 5;
    let x =  if n < 0 {
         10
     } else {
         "a"
     };

     print!("{:?}|",x);
}
```

Type error

Let Statement Usage Examples

```
{
  let x = 37;
  let y = x + 5;
  y
}//42
```

```
{
  let x = 37;
  x = x + 5;//err
  x
}
```

```
{ //err:
  let x:u32 = -1;
  let y = x + 5;
  y
}
```

```
{
  let x = 37;
  let x = x + 5;
  x
}//42
```

```
{
  let mut x = 37;
  x = x + 5;
  x
}//42
```

```
{
  let x:i16 = -1;
  let y:i16 = x+5;
  y
}//4
```

Redefining a variable *shadows* it (like OCaml)

Assigning to a variable only allowed if **`mut`**

Type annotations must be consistent (may override defaults)

Quiz 1: What does this evaluate to?

```
{ let x = 6;
  let y = "hi";
  if x == 5 { y } else { 5 };
  7
}
```

A. 6

B. 7

C. 5

D. Error

Quiz 1: What does this evaluate to?

```
{ let x = 6;
  let y = "hi";
  if x == 5 { y } else { 5 };
  7
}
```

A. 6
B. 7
C. 5
D. Error – if and else have incompatible types

Quiz 2: What does this evaluate to?

```
{ let x = 6;
  let y = 4;
  let x = 8;
  x == 10-y
}
```

A. 6
B. true
C. false
D. error

Quiz 2: What does this evaluate to?

```
{ let x = 6;
  let y = 4;
  let x = 8;
  x == 10-y
}
```

A. 6

B. true

C. false

D. error

Quiz 3: What does this evaluate to?

```
let mut x = 1;
for i in 1..6 {
  let x = x + 1;
}
x
```

A. 1
B. 6
C. 0
D. error

Data: Scalar Types

- Integers
  - `i8`, `i16`, `i32`, `i64`, `isize`
  - `u8`, `u16`, `u32`, `u64`, `usize`
- Characters (unicode)
  - `char`
- Booleans
  - `bool` = { `true`, `false` }
- Floating point numbers
  - `f32`, `f64`

Machine word size

Defaults (from inference)

- Note: arithmetic operators (+, -, etc.) *overloaded*

Compound Data: Tuples

- Tuples
  - n-tuple type **(*t1*,…,*tn*)**
    - **unit ()** is just the 0-tuple
  - n-tuple expression **(*e1*,…,*en*)**
  - Accessed by pattern matching or like a record field

```
let tuple = ("hello", 5, 'c');
assert_eq!(tuple.0, "hello");
let(x,y,z) = tuple;
```

Compound Data: Tuples

Distance between two points s:(x1,y1) e:(x2,y2)

```
fn dist(s:(f64,f64),e:(f64,f64)) -> f64 {
  let (sx,sy) = s;
  let ex = e.0;
  let ey = e.1;
  let dx = ex - sx;
  let dy = ey - sy;
  (dx*dx + dy*dy).sqrt()
}
```

Compound Data: Tuples

Can include patterns in parameters directly, too

```
fn dist2((sx,sy):(f64,f64),(ex,ey):(f64,f64)) -> f64 {
    let dx = ex - sx;
    let dy = ey - sy;
    (dx*dx + dy*dy).sqrt()
}
```

We'll see Rust `structs` later. They generalize tuples.

Arrays: Standard Operations

- Creating an array (can be mutable or not)
  - But must be of fixed length
- Indexing an array
- Assigning at an array index

```
let nums = [1,2,3];
let strs = ["Monday","Tuesday","Wednesday"];
let x = nums[0]; // 1
let s = strs[1]; // "Tuesday"
let mut xs = [1,2,3];
xs[0] = 1; // OK, since xs mutable
let i = 4;
let y = nums[i]; //fails (panics) at run-time
```

Arrays: Iteration

- Rust provides a way to iterate over a collection
  - Including arrays

```
let a = [10, 20, 30, 40, 50];
for element in a.iter() {
  println!("the value is: {}", element);
}
```

  - `a.iter()` produces an iterator, like a Java iterator
    - This is a method call, *a la* Java. More about these later
  - The special `for` syntax issues the `.next()` call until no elements are left
    - No possibility of running out of bounds

Quiz 4: Will this function type check?

```
fn f(n:[u32]) -> u32 {
  n[0]
}
```

A. Yes
B. No

Quiz 4: Will this function type check?

```
fn f(n:[u32]) -> u32 {
  n[0]
}
```

A. Yes

B. No – because array length not known

Testing

- In any language, there is the need to test code
- In most languages, testing requires extra libraries:
  - Minitest in Ruby
  - Ounit in Ocaml
  - Junit in Java
- Testing in Rust is a first-class citizen!
  - The testing framework is built into cargo

Unit Testing In Rust

```
#[cfg(test)]
mod tests {
        #[test]
        fn it_works() {
                assert_eq!(my_function(), 4);
        }
 }
```

Mark the *module* as containing tests

Mark this function as a test

Unit Testing In Rust

- Unit testing is for local or private functions
  - Put such tests in the same file as your code
- Use **`assert!`** to test that something is true
- Use **`assert_eq!`** to test that two things that implement the **`PartialEq`** trait are equal
  - E.g., integers, booleans, etc.

Integration Testing In Rust

- Integration testing is for APIs and whole programs
- Create a **`tests`** directory
- Create different files for testing major functionality
- Files don't need **`#[cfg(test)]`** or **`mod tests`**
  - But they do still need **`#[test]`** around each function
- Tests refer to code as if it were an external library
  - Declare it as an external library using **`extern crate`**
  - Include the functionality you want to test with **`use`**

Integration Testing In Rust

src/lib.rs

```
pub fn add(a: i32, b: i32) -> i32 {
  a + b
}
```

tests/test_add.rs

```
extern crate my-project-name;
use my-project-name::add;
#[test]
pub fn test_add() {
          assert_eq!(add(1,2), 3));
}
#[test]
pub fn test_negative_add() {
          assert_eq!(add(1,-2), -1));
}
```

Running Tests

- `cargo test` runs all of your tests
- `cargo test` ***s*** runs all tests that contain ***s*** in the name
- By default, console output is hidden
  - Use `cargo test -- --nocapture` to un-hide it

Fun Fact

- The original Rust compiler was written in OCaml
  - Betrays the sentiments of the language's designers!
- Now the Rust compiler is written in … Rust
  - How is this possible? Through a process called bootstrapping:
    - The first Rust compiler written in Rust is compiled by the Rust compiler written in OCaml
    - Now we can use the binary from the Rust compiler to compile itself
    - We discard the OCaml compiler and just keep updating the binary through self-compilation
    - So don't lose that binary! ☺