Welcome!

Install the Rust toolchain, so you can follow along with the workshop:

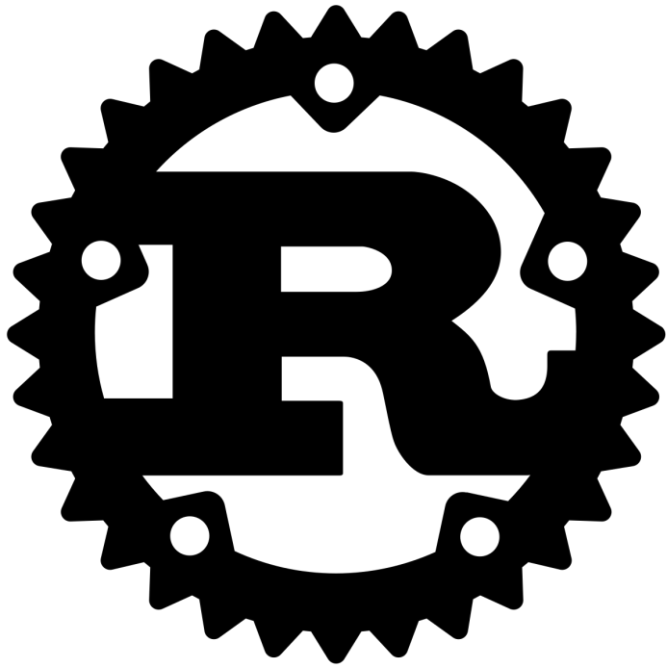
https://www.rust-lang.org/learn/get-started

Download some example code, and these slides:

https://github.com/neon64/rust_workshop_materials

Please feel free to type in the chat / unmute your mic to ask questions at any time!

- this workshop is meant to be interactive if you so prefer! ☺



Introduction to Rust

CHRIS CHAMBERLAIN – CISSA 2021

Overview

Why learn Rust?

- Broaden your horizon of what is possible in a language
  - A compiler that helps you write correct and efficient code
- Beginning to be adopted widely across industry:
  - Dropbox (new sync engine),
  - Cloudflare (core edge logic)
  - npm Inc.
  - Microsoft
  - Google (Fuschia, likely other projects)
  - Xero,
  - Atlassian (service analyzing source code)
  - Have seem some AWS job listings mention it

- Not prolific as e.g.: Node.js or React,
  - [elitist view] Rust really shines to write *difficult* software, rather than churning out generic web apps

History of Rust

- First emerged in 2010, created originally by Graydon Hoare from Mozilla Research
  - Some influences: Cyclone, SML/OCaml, C++, Haskell
- Two big projects driving language evolution: Rust compiler, Servo browser engine
  - Many components (WebRender, Stylo) – now in Firefox
- 1.0 release in 2015
- Previously: many developers employed by Mozilla, with relatively autonomous governance
- In 2021, Rust Foundation was announced, taking ownership of the project.
  - Founding Partners: AWS, Huawei, Google, Microsoft, and Mozilla

Key Characteristics

Defining features

abstractions without overhead

memory safety without garbage collection

concurrency without data races

Rust compared to other languages

Low-level, can run on bare metal without any runtime, *like C*

Strong static typing, lots of rich type system features, *like Haskell*

Zero-cost abstractions, a relatively complex language, *like C++*

Memory-safe by default, protects against segfaults/null pointers, *like Java/Python/JavaScript/[any other managed language],* but **also** against data races.

```rust
fn parse_value(&mut self) -> Value {
    match self.next_char() {
        '0'...'9' => self.parse_length(),
        '#' => self.parse_color(),
        _ => Value::Keyword(self.parse_identifier())
    }
}

fn parse_length(&mut self) -> Value {
    Value::Length(self.parse_float(), self.parse_unit())
}

fn parse_float(&mut self) -> f32 {
    let s = self.consume_while(|c| match c {
        '0'...'9' | '.' => true,
        _ => false
    });
    s.parse().unwrap()
}
```

Some example Rust code out in the wild.
https://github.com/mbrubeck/robinson/blob/master/src/css.rs

Rust “as a better C”

Rust is a *systems programming language*, in the sense of C, C++

- Control over memory allocations, no garbage collector, minimal runtime

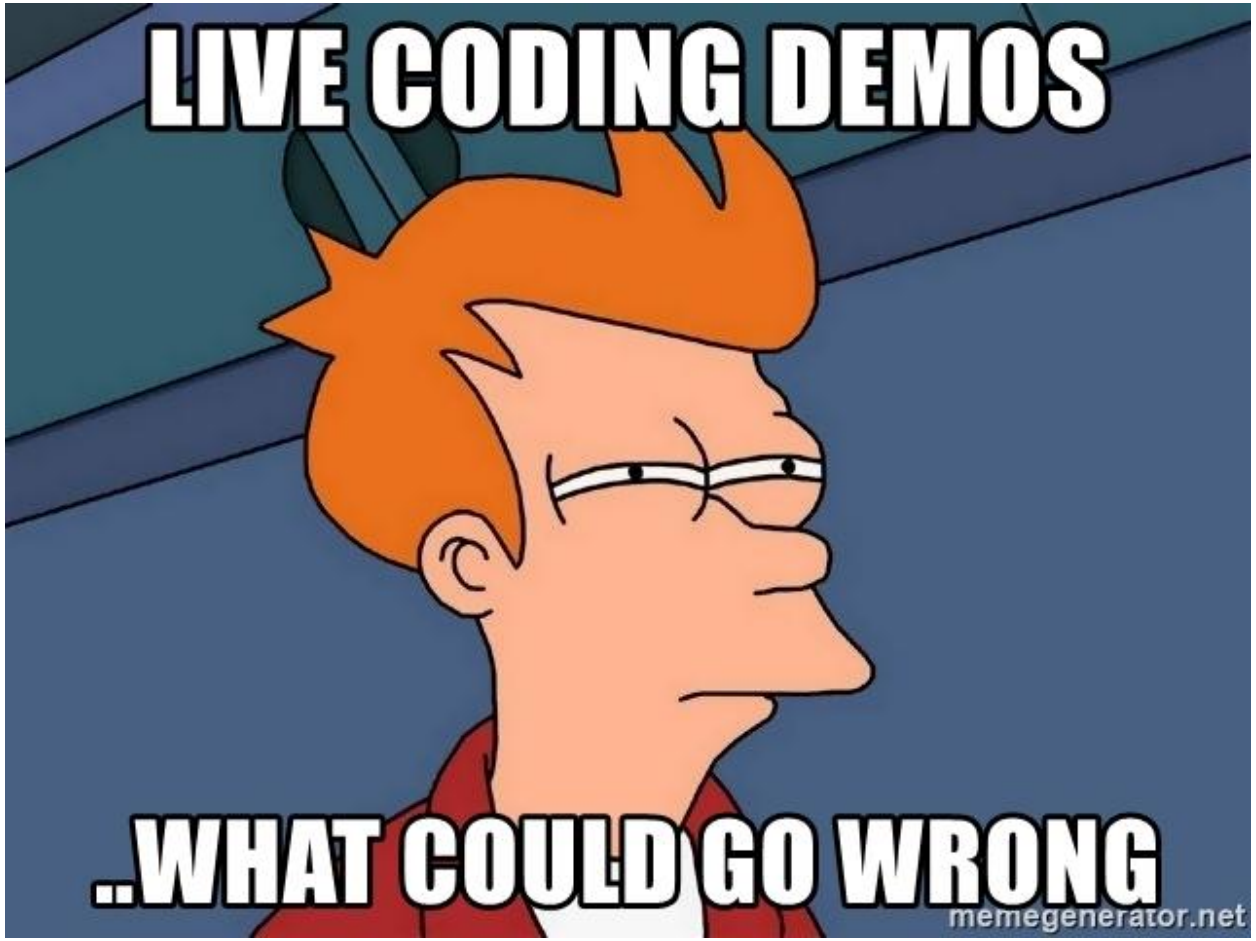
Rust is very fast

- Compiles through the LLVM compiler backend (same as clang),
  - performance more or less equal to C/C++,
  - in some cases, stronger ownership guarantees allow optimizer to beat C/C++
  - in the real world, fearless concurrency can lead to faster code on multithreaded systems

Demo time!

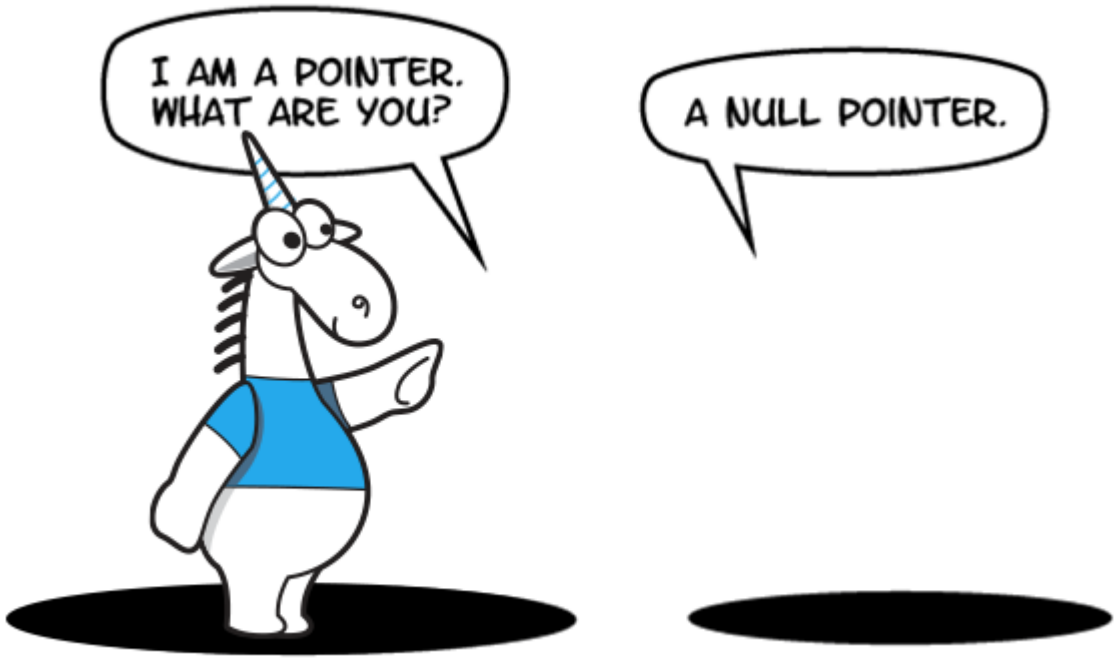
Goals:

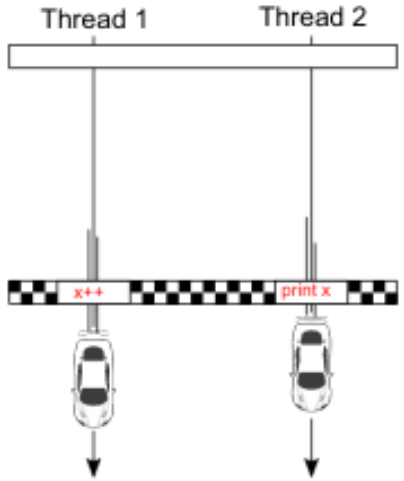
- Download/install Rust, Rust Analyzer
- Hello-world application, variables/functions/structs etc…



What is Rust trying to protect against?

The motivation for ownership/borrowing.





Pitfalls of C/C++

- Null pointers / uninitialized values
- Dangling pointers / use-after-frees / double-frees
- Buffer overflows
- Data races

Consequences of undefined behaviour

- Program crashes (SIGSEGV)

- Bad data, corruption

- The compiler is allowed to assume anything about your program now…


```
Program received signal SIGSEGV, Segmentation fault.
[Switching to Thread 0x7ffff6dcb700 (LWP 25830)]
_int_malloc (av=0x7ffff0000020, bytes=41) at malloc.c:3351
3351    malloc.c: No such file or directory.
(gdb) backtrace
#0  _int_malloc (av=0x7ffff0000020, bytes=41) at malloc.c:3351
#1  0x00007ffff71547b0 in __GI___libc_malloc (bytes=41) at malloc.c:2891
#2  0x00007ffff7929dad in operator new(unsigned long) () from /usr/lib/x86_64-linux-gnu/libs
#3  0x00007ffff7985249 in std::string::_Rep::_S_create(unsigned long, unsigned long, std::al
#4  0x00007ffff7986971 in char* std::string::_S_construct<char const*>(char const*, char con
   from /usr/lib/x86_64-linux-gnu/libstdc++.so.6
#5  0x00007ffff7986d88 in std::basic_string<char, std::char_traits<char>, std::allocator<cha
   from /usr/lib/x86_64-linux-gnu/libstdc++.so.6
#6  0x0000000000402107 in GameServer::start (this=0x7fffffffe570) at gameserver.cpp:89
#7  0x0000000000403611 in runServer (server=0x7fffffffe570) at main.cpp:9
#8  0x0000000000404d68 in std::_Bind_simple<void (*(GameServer*))(GameServer*)>::_M_invoke<0
#9  0x0000000000404c73 in std::_Bind_simple<void (*(GameServer*))(GameServer*)>::operator()()
#10 0x0000000000404c0c in std::thread::_Impl<std::_Bind_simple<void (*(GameServer*))(GameSer
#11 0x00007ffff797ca60 in ?? () from /usr/lib/x86_64-linux-gnu/libstdc++.so.6
#12 0x00007ffff749f182 in start_thread (arg=0x7ffff6dcb700) at pthread_create.c:312
#13 0x00007ffff71cc47d in clone () at ../sysdeps/unix/sysv/linux/x86_64/clone.S:111
(gdb) frame 6
#6  0x0000000000402107 in GameServer::start (this=0x7fffffffe570) at gameserver.cpp:89
89                                      std::stringstream split((const char *)event.packet->
(gdb)
```

Consequences of undefined behaviour

The compiler is allowed to assume anything about your program now…

Here are some references of unexpected results after optimisations are applied, if you are curious:

- https://en.cppreference.com/w/cpp/language/ub
- http://blog.llvm.org/2011/05/what-every-c-programmer-should-know_14.html

Dangling pointer access in C

```c
typedef struct {
    int x;
    int y;
} useful_data_t;

int main() {
    useful_data_t* data = malloc(sizeof(useful_data_t));
    data->x = 3;
    data->y = 5;

    int *dangling = &data->x;

    // In the real world, this call to `free` could be
    //  hidden away in some other function.
    free(data);

    printf("should print zero: %d\n", *dangling);

    return 0;
}
```

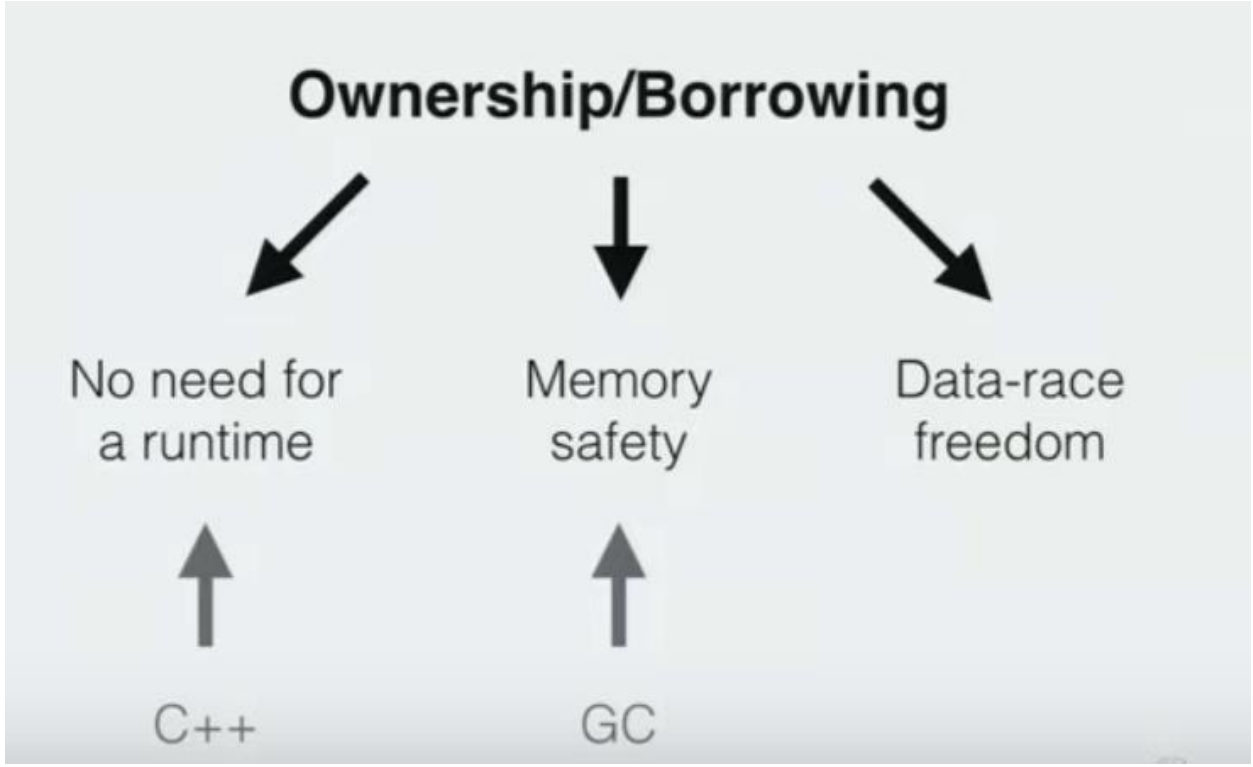
A quote from the Rust Book

“In languages with a garbage collector (GC), the GC keeps track and cleans up memory that isn’t being used anymore, and we don’t need to think about it. Without a GC, it’s our responsibility to identify when memory is no longer being used and call code to explicitly return it, just as we did to request it.

Doing this correctly has historically been a difficult programming problem. If we forget, we’ll waste memory. If we do it too early, we’ll have an invalid variable. If we do it twice, that’s a bug too. We need to pair exactly one allocate with exactly one free.”

Ownership

The claim is that ownership solves all three of these desirable properties.



Three rules of **ownership**

Three rules:

- **Every** value in Rust has a variable that's called its *owner*.
- There can only be **one** owner at a time.
- When the owner goes out of scope, the value will be dropped.

If you're familiar with modern C++, this is strikingly similar to C++'s
notion of *Resource Acquisition Is Initialization (RAII),*
except more strictly enforced.

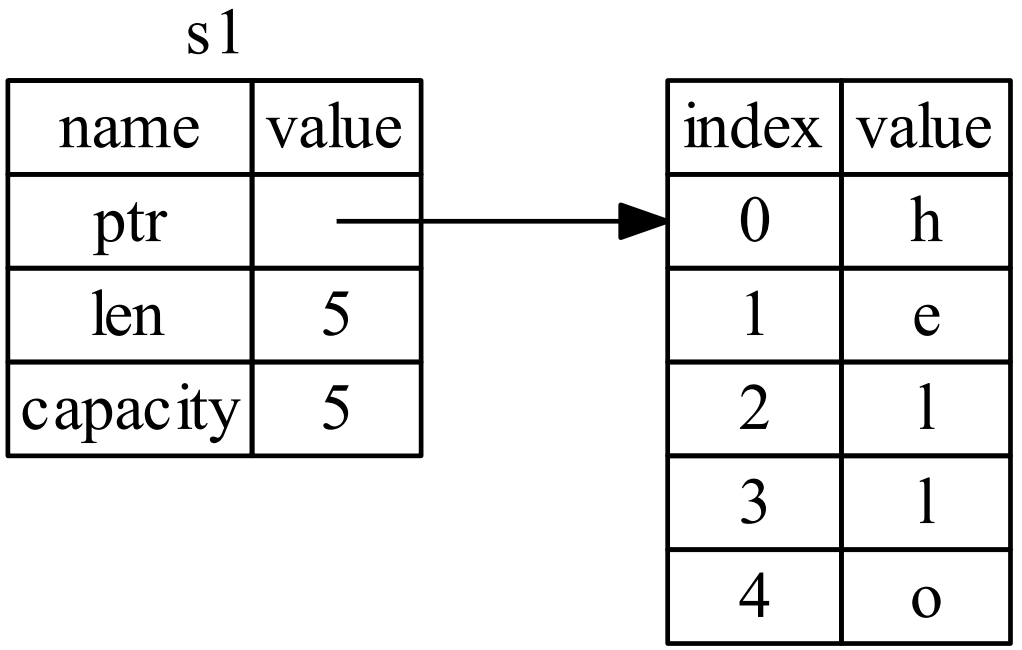
Demo time!

Goals:

- Demonstrate ownership.
- Motivate the need for something more flexible (borrowing)

Ownership: an example

```
let s1 = String::from("hello");
let s2 = s1;
```



Ownership

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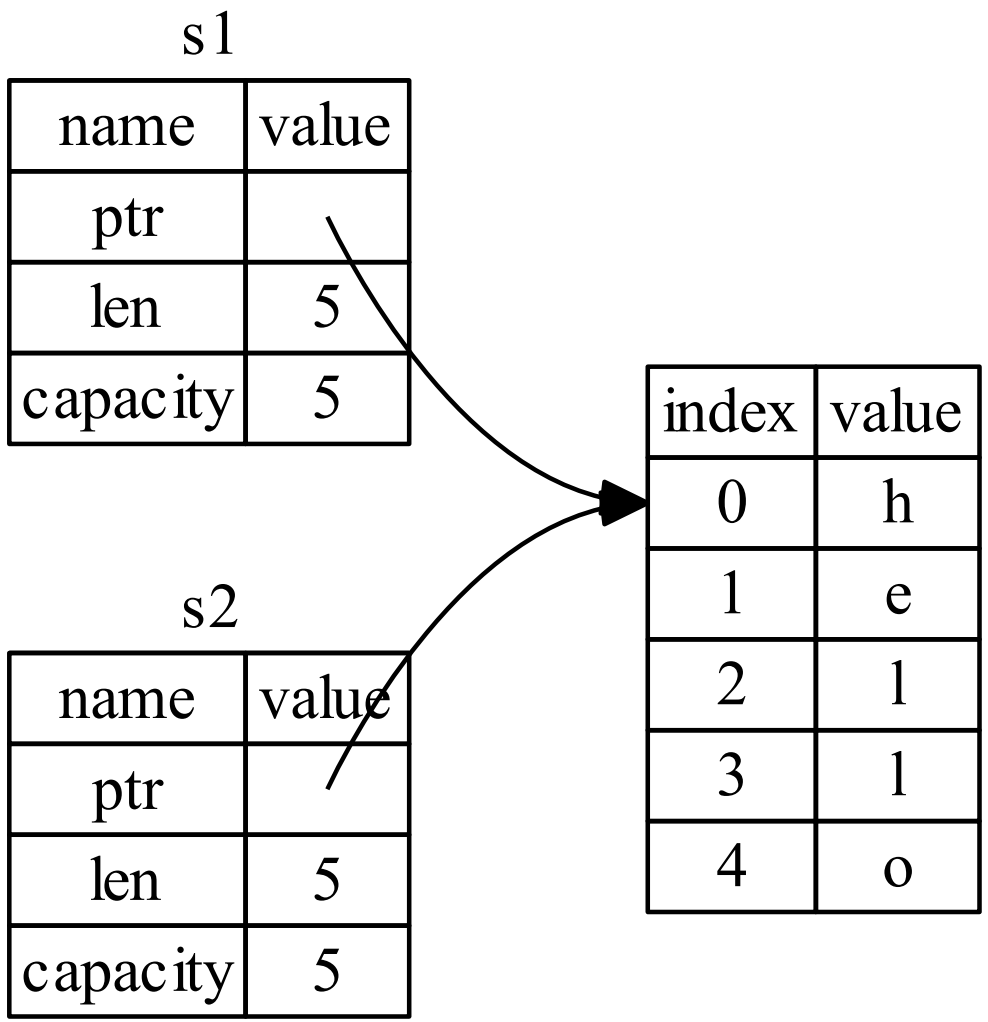

Ownership

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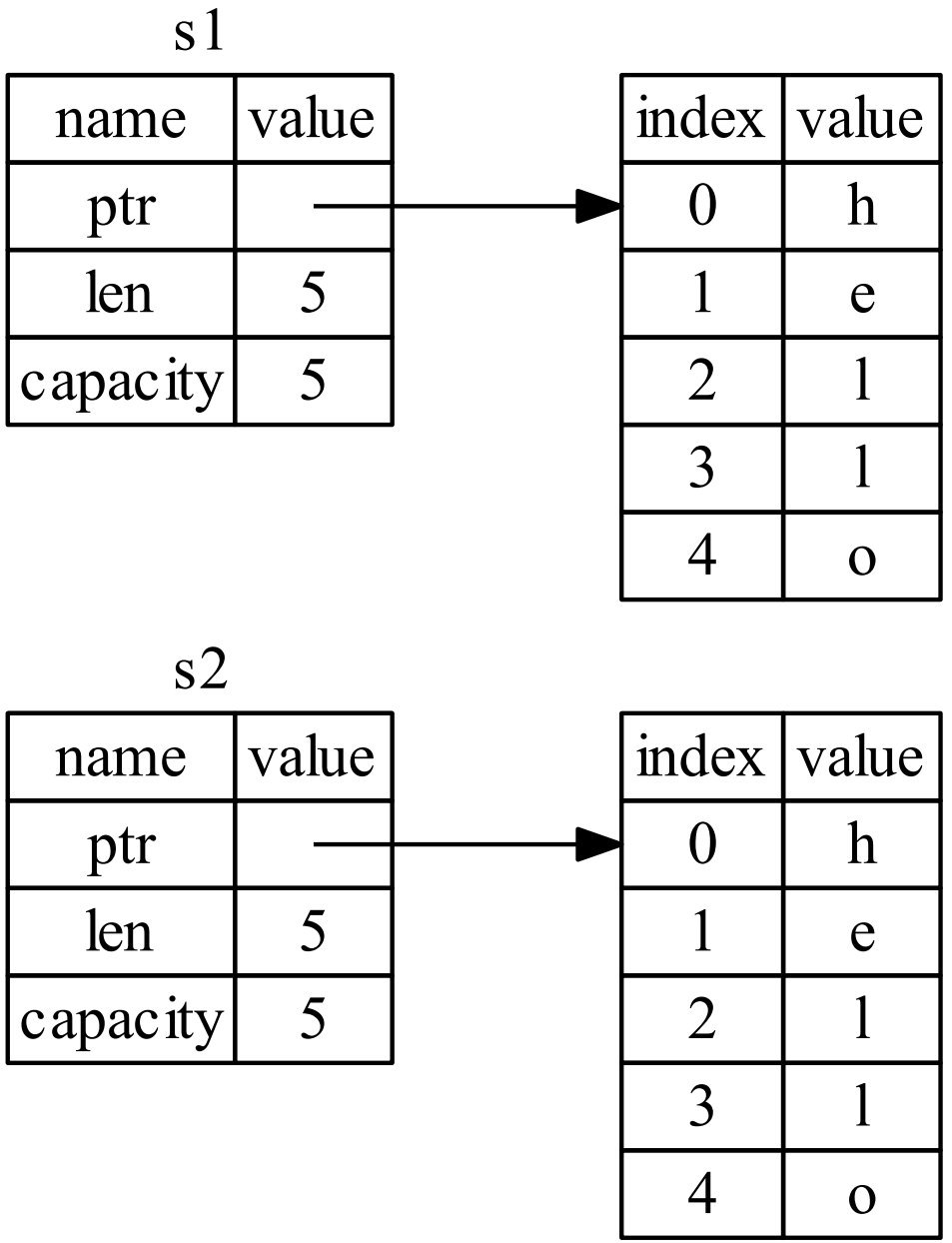

Ownership

```
let s1 = String::from("hello");
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```
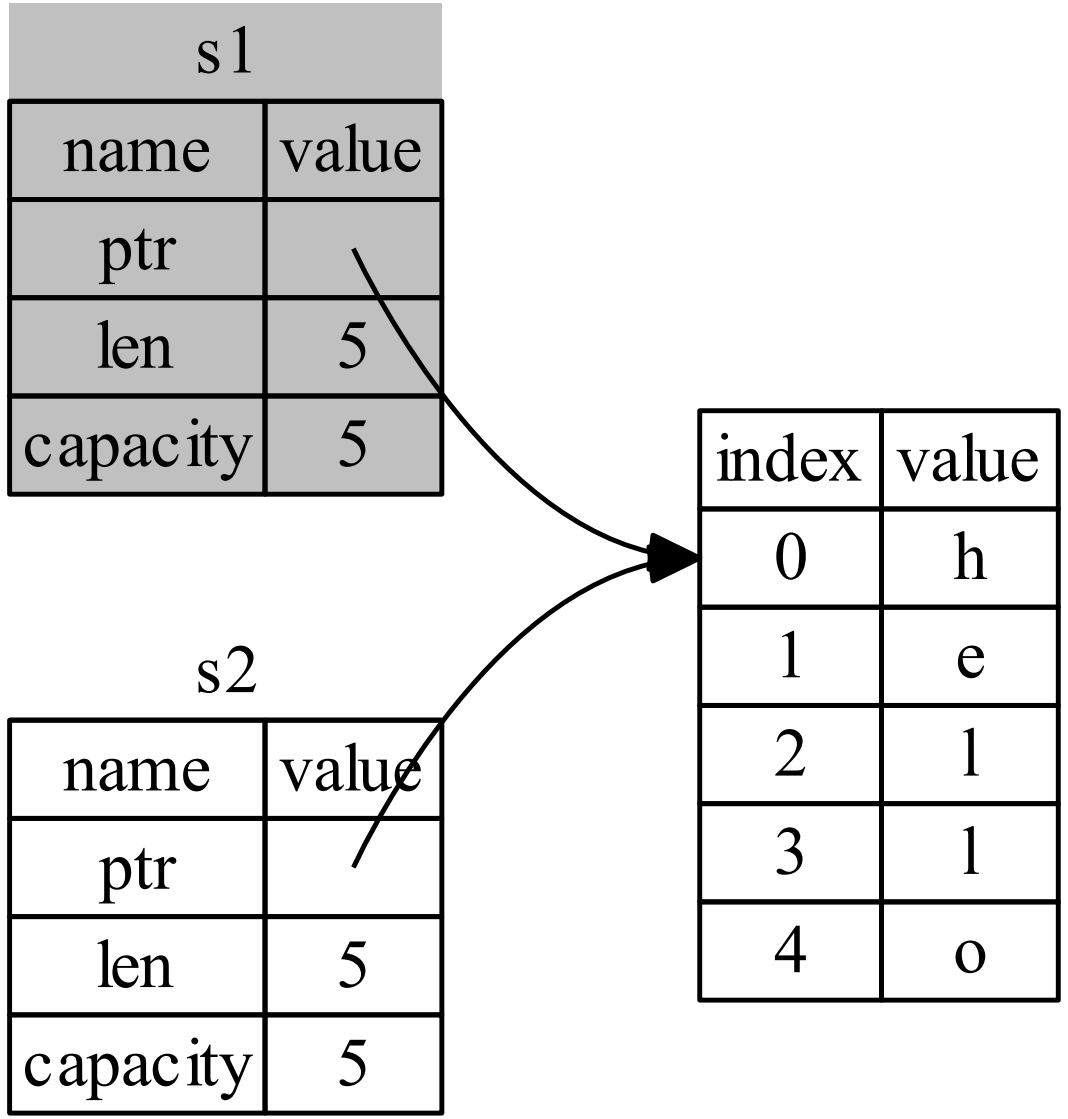



But isn’t that overly restrictive?

YES!

References and borrowing

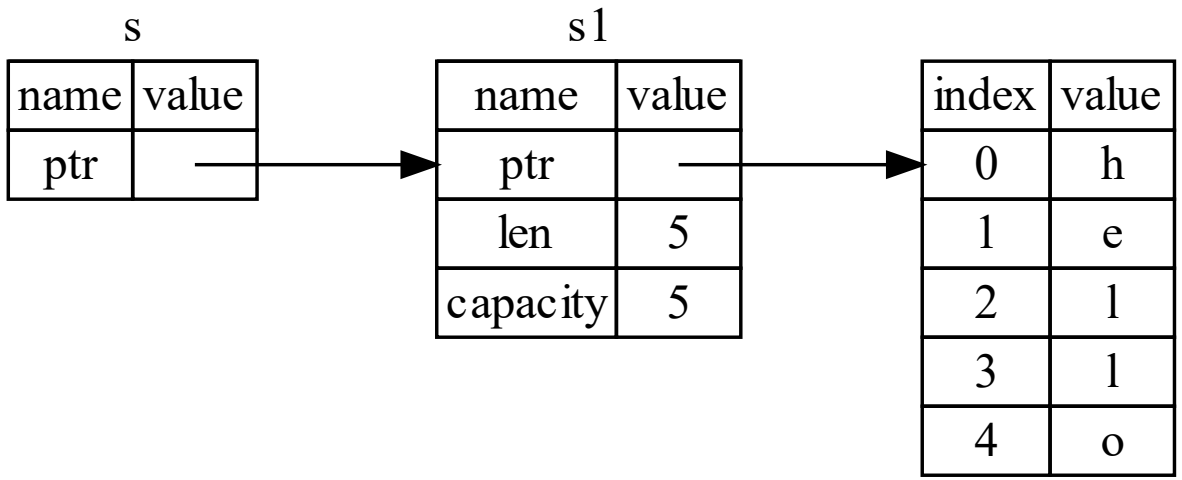
```rust
fn main() {
    let s1 = String::from("hello");

    let len = calculate_length(&s1);

    println!("The length of '{}' is {}.", s1, len);
}

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

1. Use the `&` symbol before a type to denote an (immutable) reference.

2. Use the `&` operator to create a reference

References

implemented as pointers



References are immutable

(by default)

```
fn main() {
    let s = String::from("hello");

    change(&s);
}

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

This will not compile ^, since we cannot change the String through an **immutable** reference.

Mutable references

```
fn main() {
    let mut s = String::from("hello");

    change(&mut s);
}

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

Aliasing XOR mutability

Any reference in Rust can either

- Be **shared** with others.
- Be **mutable** (writable)

Not both at the same time!

Safety guarantees

Iterator invalidation

```rust
fn iterator_invalidation() {
    let mut xs = Vec::new();
    xs.push(1);
    xs.push(2);
    xs.push(3);

    for x in xs.iter() {
        println!("{}", x);
        xs.remove(index: 0);
    }
}
```

Problems Declaration Console

<terminated> Example [Java Application] C:\Program Files\Java\jre-10.0.2\bin\javaw.exe (12-Jul-2019, 5:00:57 PM)

```
List Value:1
List Value:2
Exception in thread "main" List Value:3
java.util.ConcurrentModificationException
        at java.base/java.util.ArrayList$Itr.checkForComodification(Unknown Source)
        at java.base/java.util.ArrayList$Itr.next(Unknown Source)
        at crux19aug.Crux19Aug2018.src.assignments.Example.main(Example.java:24)
```

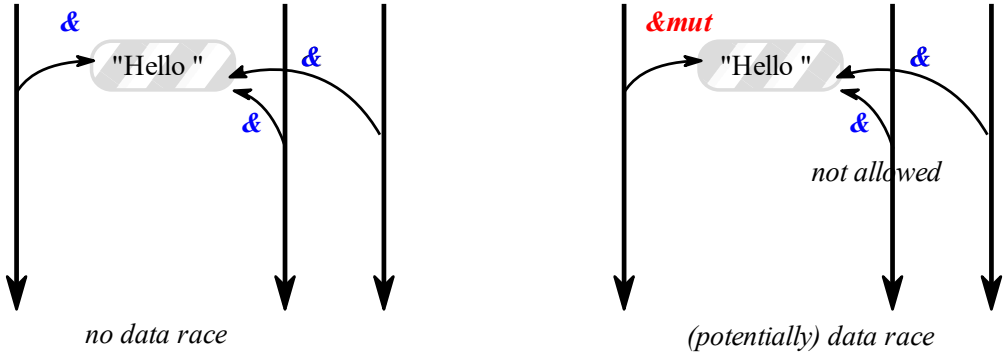
```
user@host:/tmp/segfault$ cat segfault.c
void main() {
  char *str = "Hello, world!";
  *str = 'A';
}
user@host:/tmp/segfault$ gcc segfault.c -o segfault
user@host:/tmp/segfault$ ./segfault
Segmentation fault
neil@snap:/tmp/segfault$
```

ComputerHope.com

“Fearless” concurrency

- Tools in the “concurrency” toolbox:
  - Shared state: *Atomics*, *Arc, Mutex*
  - Message passing: *Channels*, *Actors*

Rust stdlib (and crates) build on an “unsafe” foundation to give you efficient building blocks for **safe, data-race-free, highly-multithreaded** code.



‘*unsafe*’ code

You may have heard about *unsafe* code in Rust.

Essentially a special ‘lever’ which you can pull in order to:

- Dereference a raw pointer (`*T` or `*mut T`)
- Call an unsafe function or method
- Access a mutable static variable

Why does this exist?

1. Speed
2. Interacting with other languages (C, C++), and the hardware (e.g.: in an OS kernel)
    - Underlying computer hardware is inherently unsafe

Safe abstractions

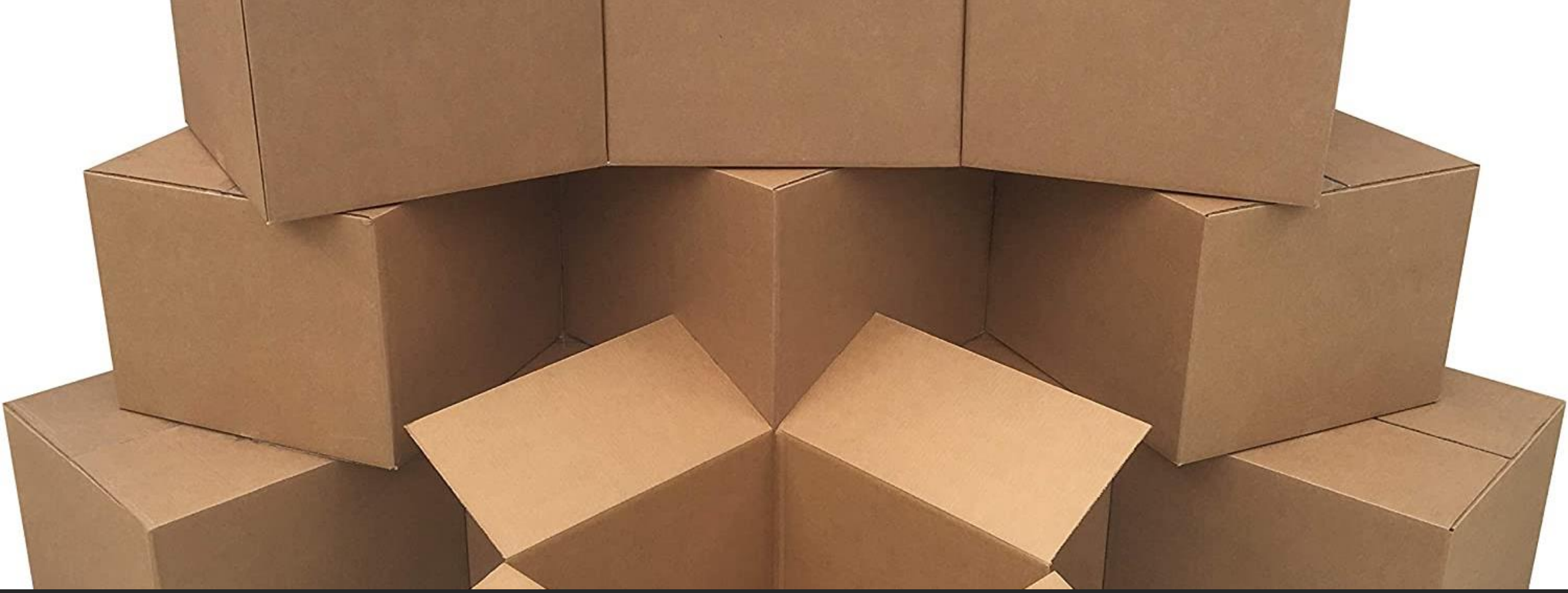
So if ‘unsafe’ Rust exists, aren’t we back to square one?

I believe not for two reasons:

1. Vast majority of application code in Rust can be written without *unsafe*
2. Rust allows to build safe abstractions on top of unsafe code
   - Crossbeam (concurrency primitives)
   - Rayon (data parallelism library)
   - Rust stdlib (e.g.: Vec, String implementation)
   - Tokio (high-performance async runtime

“Rust teaches you the rules that good C/C++ programmers have in their head anyway”

- SOMEONE ON THE RUST FORUM



Appendix: OOP in Rust

Is Rust object-oriented?

Sort of.

Rust does **not** have classes or data inheritance (only **structs**)

- Inheritance has recently fallen out of favor (see: composition over inheritance)
- Rust's enums can fill some of the void.

Rust **does** have data-hiding through *marking* structs/functions/fields **pub** or not

Traits and polymorphism

Traits ⇔ interfaces

Rust supports *polymorphism* by implementing **traits** for specific types.

Traits

We can build functions which work with any particular implementation of a trait (static dispatch)

```
pub fn notify<T: Summary>(item: &T) {
    println!("Breaking news! {}", item.summarize());
}
```

Traits

We can also build functions which use *virtual dispatch* to use support multiple implementations at runtime.

```
pub trait Draw {
    fn draw(&self);
}
```

```
pub struct Screen {
    pub components: Vec<Box<dyn Draw>>,
}
```

```
impl Screen {
    pub fn run(&self) {
        for component in self.components.iter() {
            component.draw();
        }
    }
}
```

This is very similar to *`virtual`* in C++

Or using *`void*`* for polymorphism in C.

Conclusion

Why not Rust?

Some very good points from “matklad” – a major contributor to Rust (main dev of Rust Analyzer)

https://matklad.github.io/2020/09/20/why-not-rust.html

I repeat some of them here:

1. Not all programming is systems programming
2. Complexity
3. Compile times
4. Maturity

Rust’s price for improved control is the curse of choice:

```
struct Foo     { bar: Bar         }
struct Foo<'a> { bar: &'a Bar     }
struct Foo<'a> { bar: &'a mut Bar }
struct Foo     { bar: Box<Bar>    }
struct Foo     { bar: Rc<Bar>     }
struct Foo     { bar: Arc<Bar>    }
```

How to learn more Rust

- I can highly recommend the official Rust book as a learning resource:
  - https://doc.rust-lang.org/stable/book/title-page.html
  - Many examples from my slides are unceremoniously copied from here!

- For a more advanced learner, I can recommend Jon Gjengset's "Crust of Rust" series
  - https://www.youtube.com/watch?v=rAl-9HwD858&list=PLqbS7AVVErFiWDOAVrPt7aYmnuuOLYvOa
  - I started watching some of these just a few months ago and found them very insightful, but he comes from quite an academic standpoint and assumes great familiarity with the language.

- Try and **build** something!
  - A console application, a game, a webapp, an operating system, you name it!

Thank you!

If you have further questions?