Rust Workshop - ADSAI

Plan for today:

- 1 hour presentation to **motivate** and **explain** Rust
- Coffee break
- 2 hours hands-on working on Rust mini-project

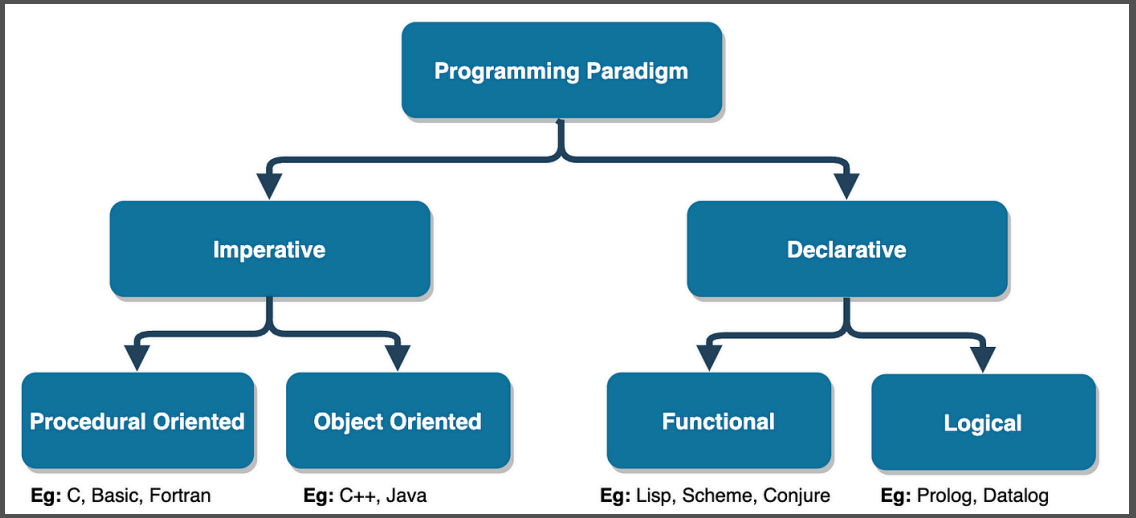
What is Rust?

Rust is a programming language focusing on:

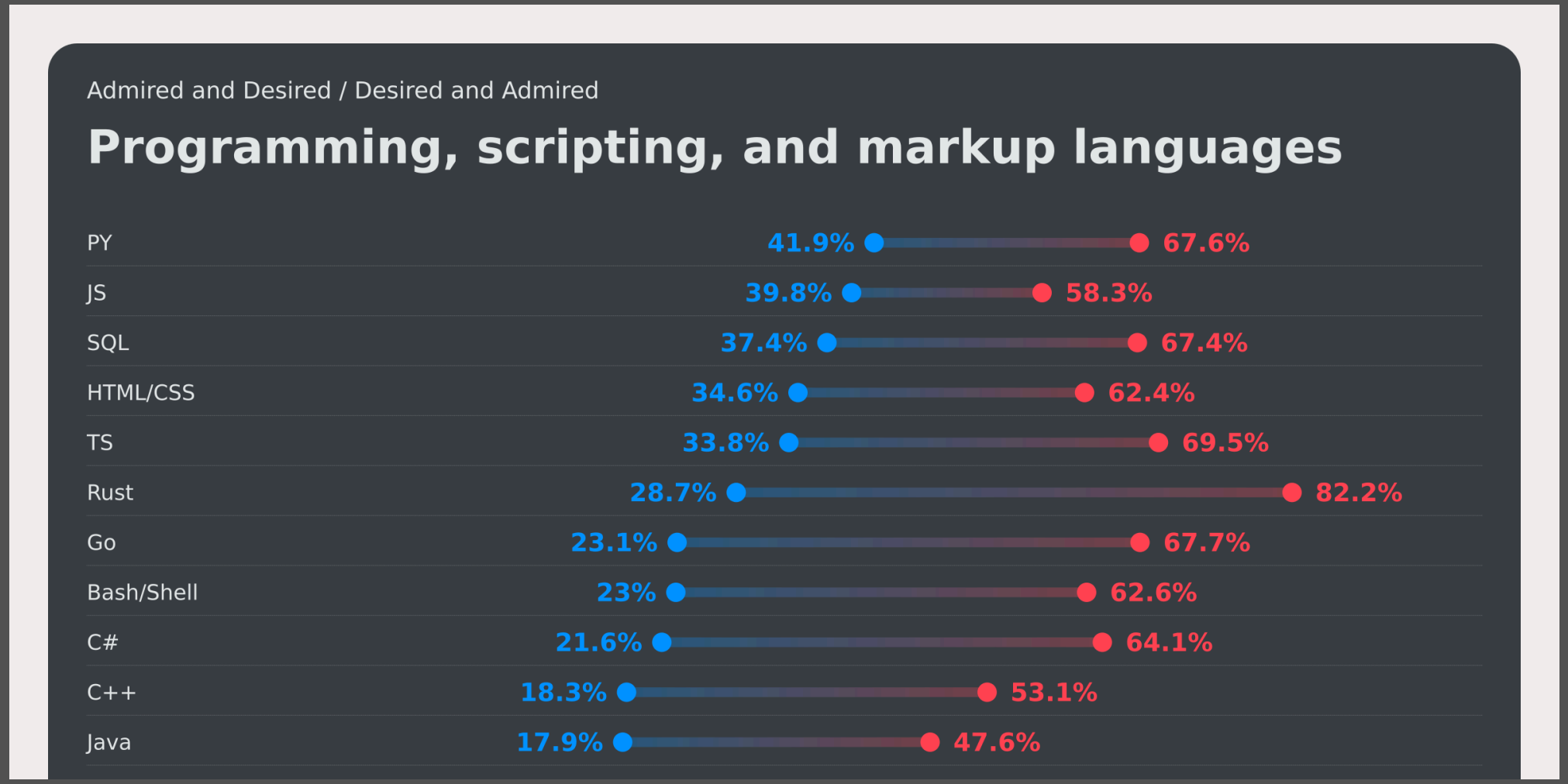
- **Speed**
- **Memory safety**
- **Concurrency**

Multi-paradigm styles

- Pure-functional
- Imperative-procedural
- Object-oriented



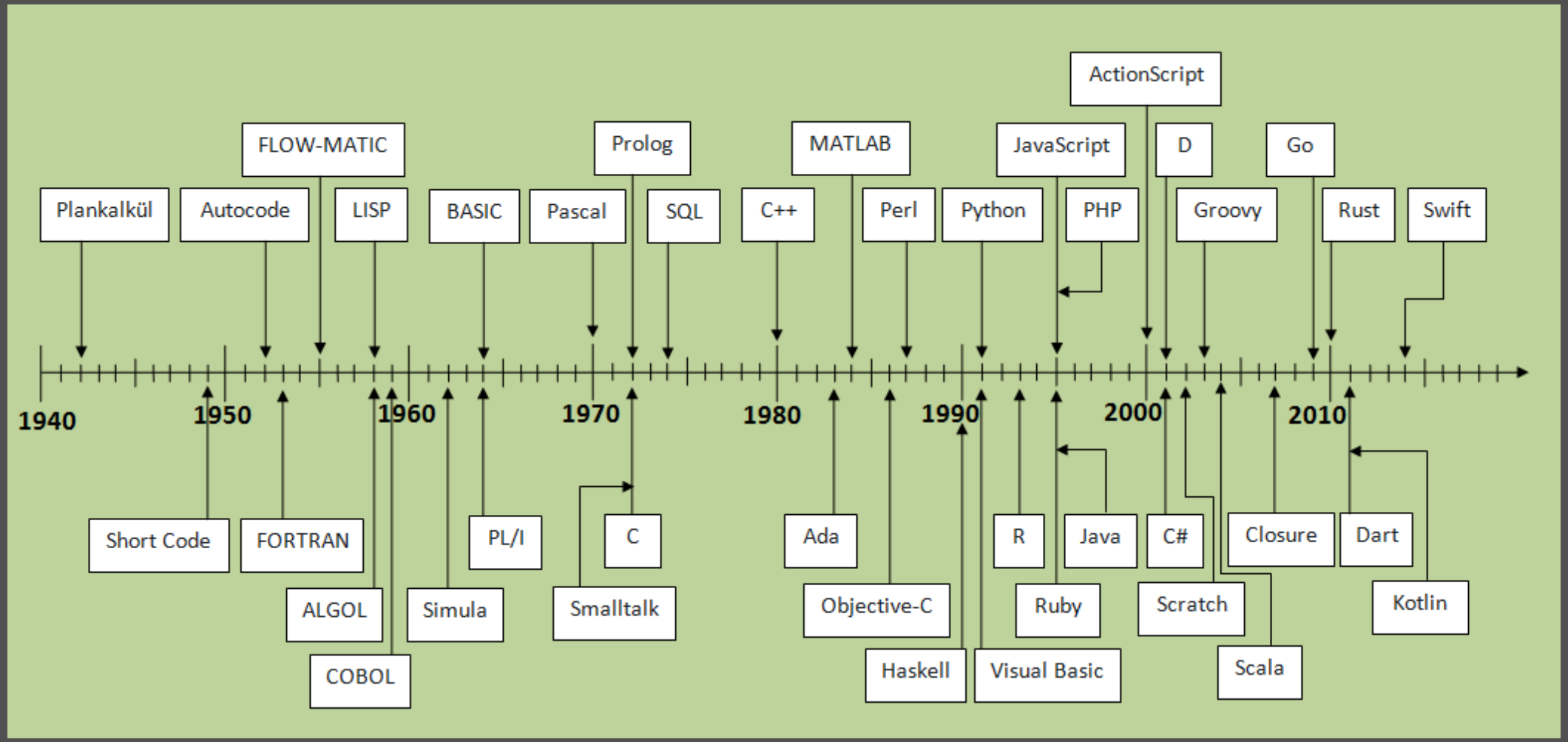
StackOverflow developer survey 2024



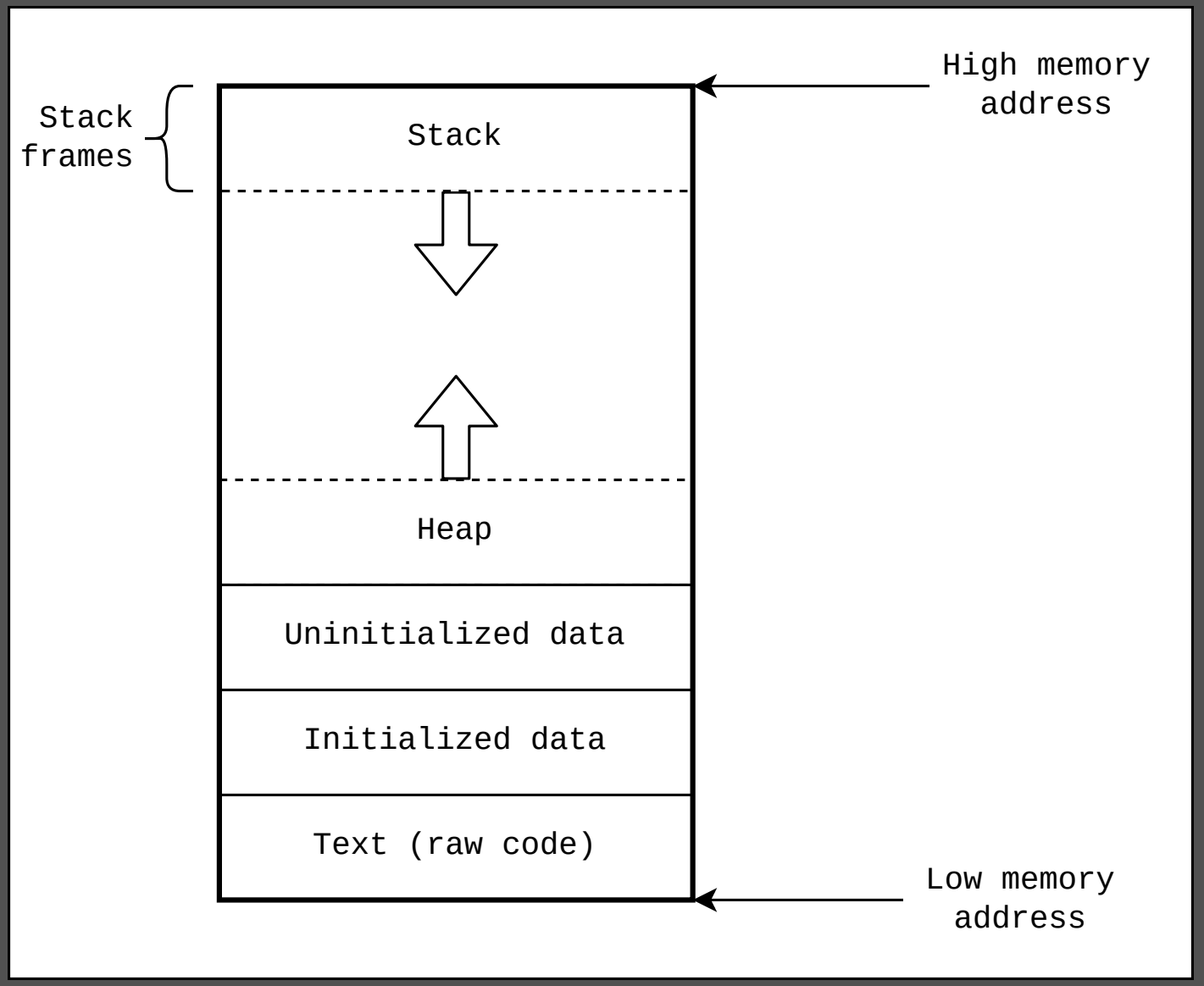
A little more motivation is needed

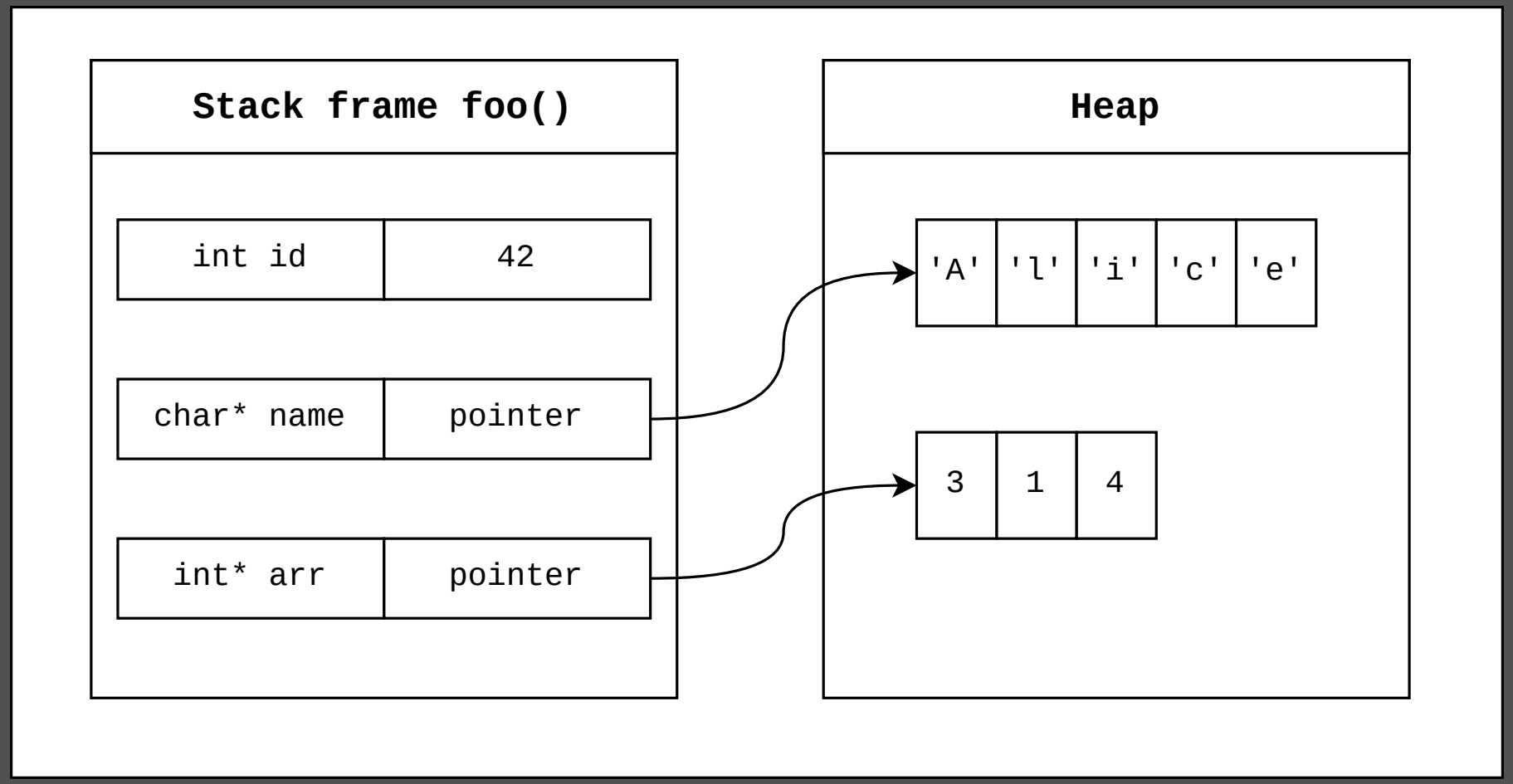
- What do we mean by memory safety?
- Let's go back in time...

Age old problem of memory safety



Refresher on the Stack and Heap


High memory address
Stack frames
Stack
Heap
Uninitialized data
Initialized data
Text (raw code)
Low memory address


Stack frame foo()
int id
42
char* name
pointer
int* arr
pointer
Heap
'A'
'l'
'i'
'c'
'e'
3
1
4

Example in C

```c
void foo(){
  ...
  int id = 42;  // stack allocation

  char* name = malloc(sizeof(char) * 5); // heap allocation
  memcpy(name, "Alice", 5);

  int* arr = malloc(sizeof(int) * 3); // heap allocation
  arr[0] = 3;
  arr[1] = 1;
  arr[2] = 4;
  ...
}
```

Example in C

```c
void foo(){
  ...
  int id = 42;  // stack allocation

  char* name = malloc(sizeof(char) * 5); // heap allocation
  memcpy(name, "Alice", 5);

  int* arr = malloc(sizeof(int) * 3); // heap allocation
  arr[0] = 3;
  arr[1] = 1;
  arr[2] = 4;
  ...
  free(name); free(arr); // solution
}
```

Examples of memory safety errors:

Use-after-free

```
void foo(){
  ...
  char* name = malloc(sizeof(char) * 5); // heap allocation
  memcpy(name, "Alice", 5);
  ...
  free(name); // free name pointer
  ...
  register_in_database(name); // use after free error
}
```

Examples of memory safety errors:

Buffer overflow

```c
void foo(){
  ...
  int* arr = malloc(sizeof(int) * 3); // heap allocation
  arr[0] = 3;
  arr[1] = 1;
  arr[2] = 4;
  arr[3] = 2; // out-of-bound writes may corrupt adjacent memory
  ...
  free(arr); // free arr pointer
}
```

Examples of memory safety errors:

Uninitialized variables

```
void foo(){
  ...
  char* name = malloc(sizeof(char) * 5); // heap allocation
  register_in_database(name); // forgot to initialize name
  ...
  free(name); // free name pointer
  ...
}
```

Examples of memory safety errors:

Null pointer dereference

```
void foo(){
  ...
  char* name = malloc(sizeof(char) * 5); // heap allocation
  ...
  name = NULL; // name points to unvalid data
  ...
  char first_letter = *name // NULL pointer dereference
  ...
}
```

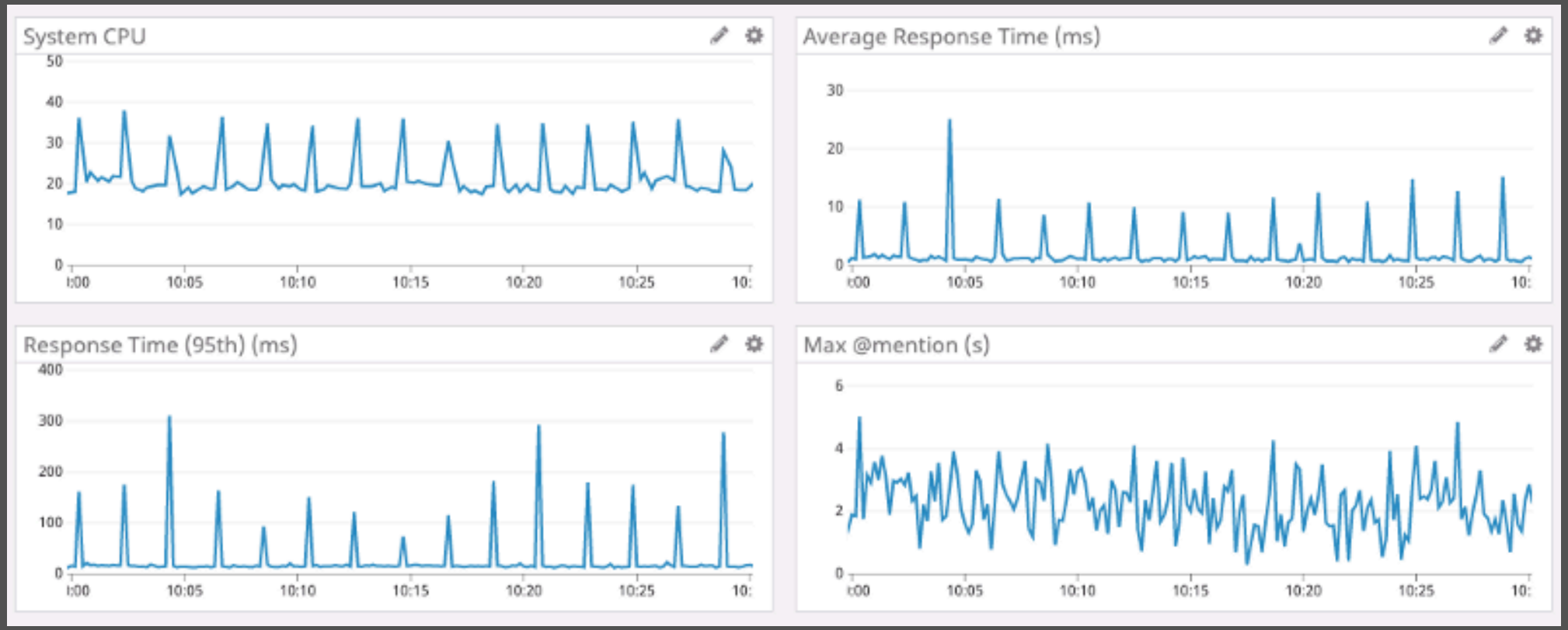
How do other languages deal with memory safety?

Garbage Collector

- Second process runs alongside your program
- During runtime, collect and free unused memory
- Difficult to predict when memory will be cleaned
- Comes at the expense of performance overhead
- e.g., Java, Go, JavaScript, Python, Ruby

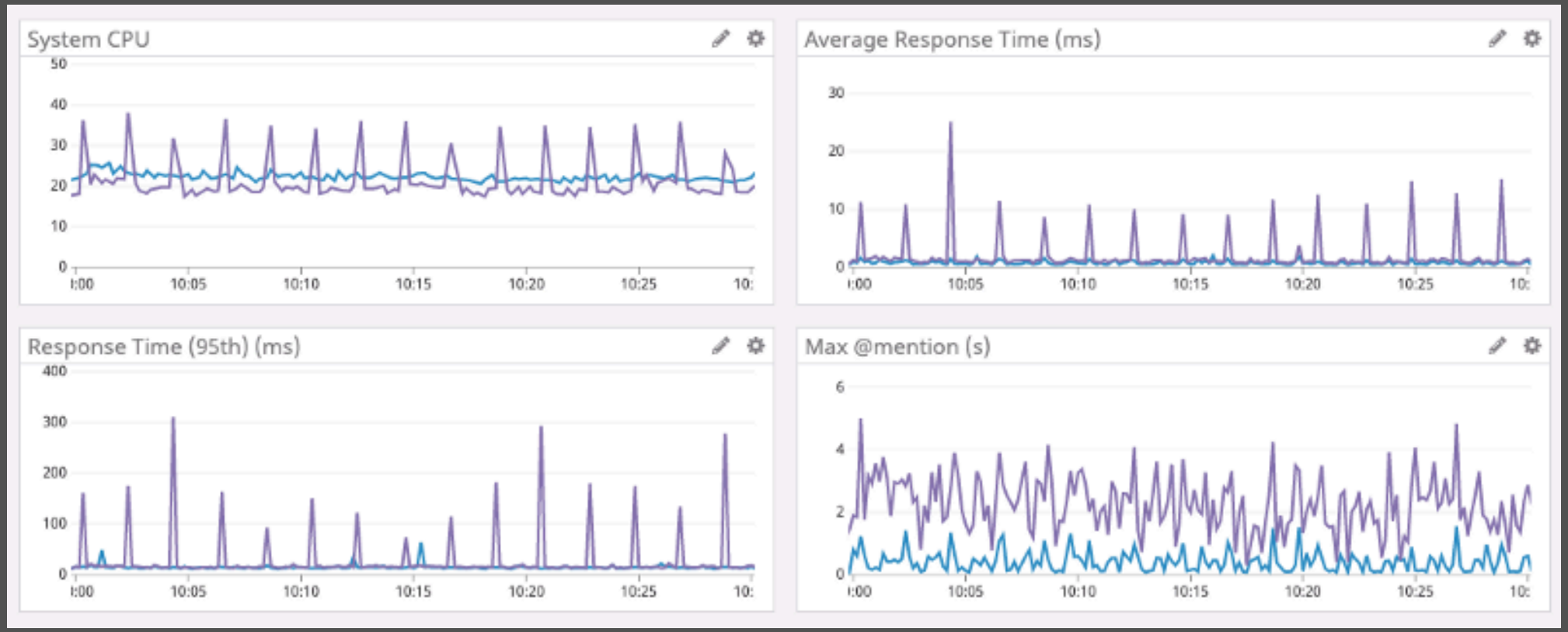
Example: Why Discord switched from Go to Rust

- CPU spikes roughly every 2 minutes
- Go forces Gargabe Collector to run at a minimum every 2 minutes



Example: Why Discord switched from Go to Rust

- Go team switched to Rust (no Garbage Collector)
- (Rust in blue, Go in purple)



Enforce immutable state

- Do not let users manipulate state/memory
- Functional programming paradigm
- Only pure functions $f : A \to B$
- No side effects (memory or I/O)
- e.g., Haskell, Lisp, Erlang, F#

Enforce object-orientation

- Encapsulate state in objects
- Constructor/destructor to allocate/free memory
- e.g., Java, C++

Indirect solution to the problem at hand

Rust's solution: the borrow checker

Ownership rules

- Each value in Rust has an owner
- There can only be one owner at a time
- When the owner goes out of scope, the value will be dropped

The String type in Rust

Two string types in Rust

- `&str` is a hardcoded string literal in the text of the program

```
let s_lit = "hello"; // string literal stored on the stack
```

- `String` is an owned growable data type stored on the heap

```
let s = String::from("hello"); // owned String type
s.push_str(", world!"); // push_str() appends a literal to a String
```

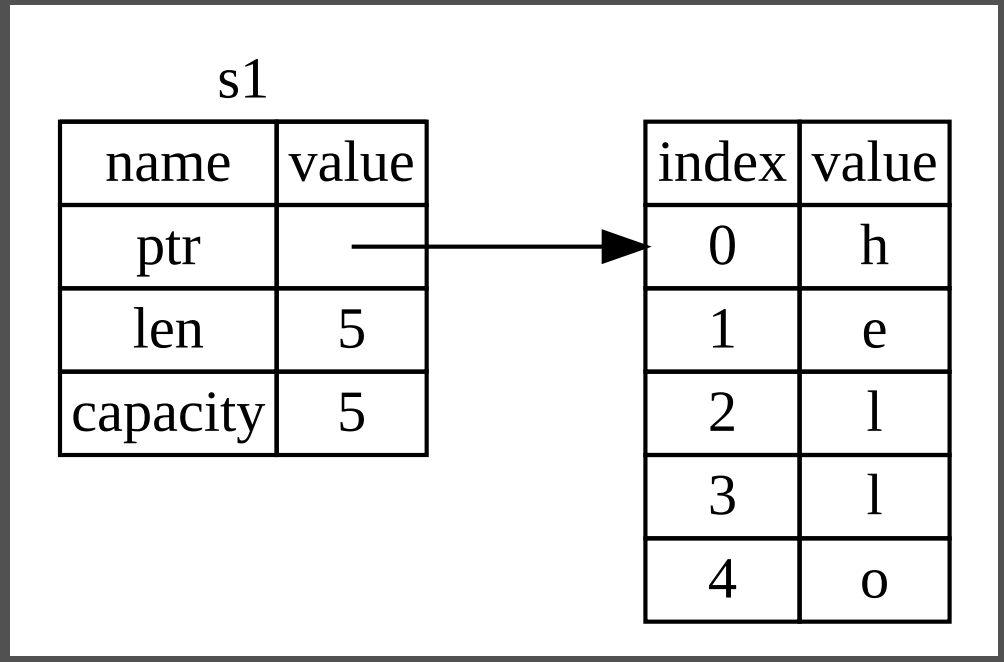
Variable scope in Rust

```
{                       // s is not valid here, it’s not yet declared
    let s = String::from("hello");   // s is valid from this point forward

    // do stuff with s
}                       // this scope is now over, and s is no longer valid
```

Moving ownership

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



Moving ownership

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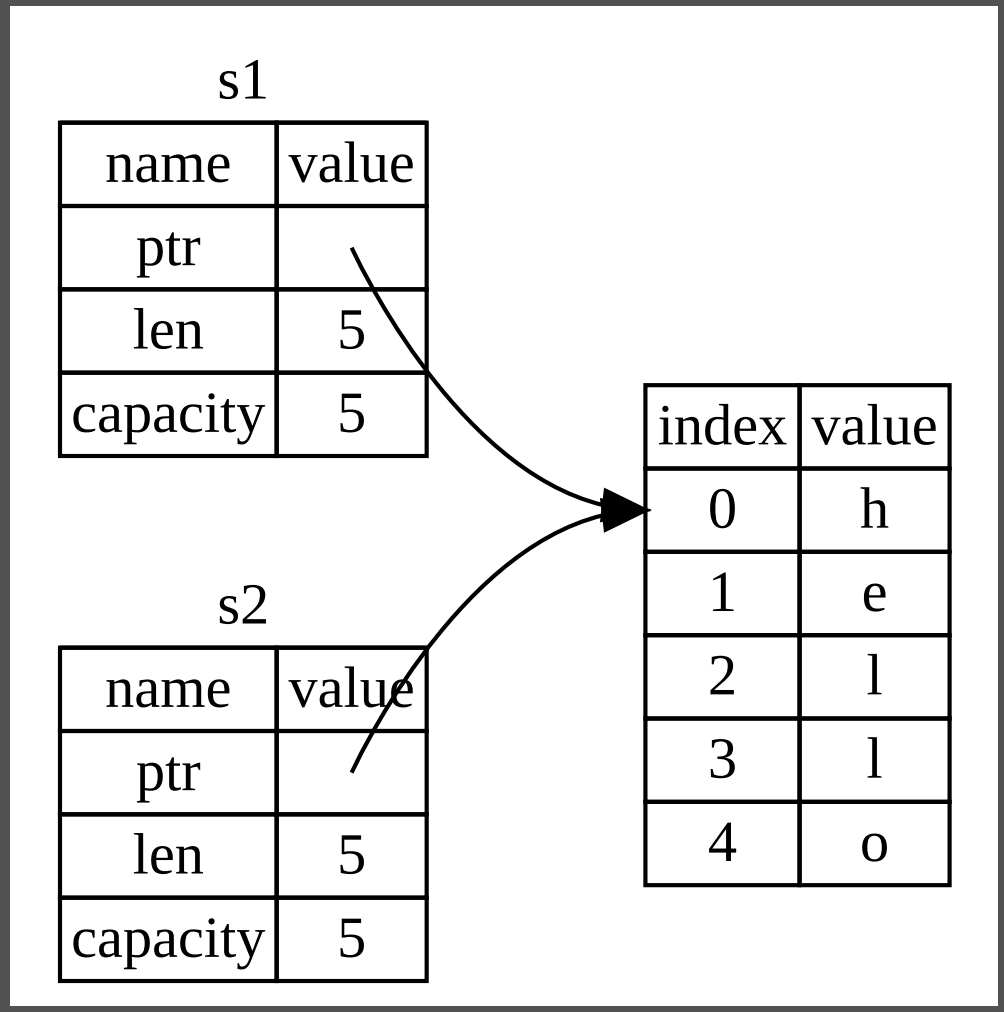
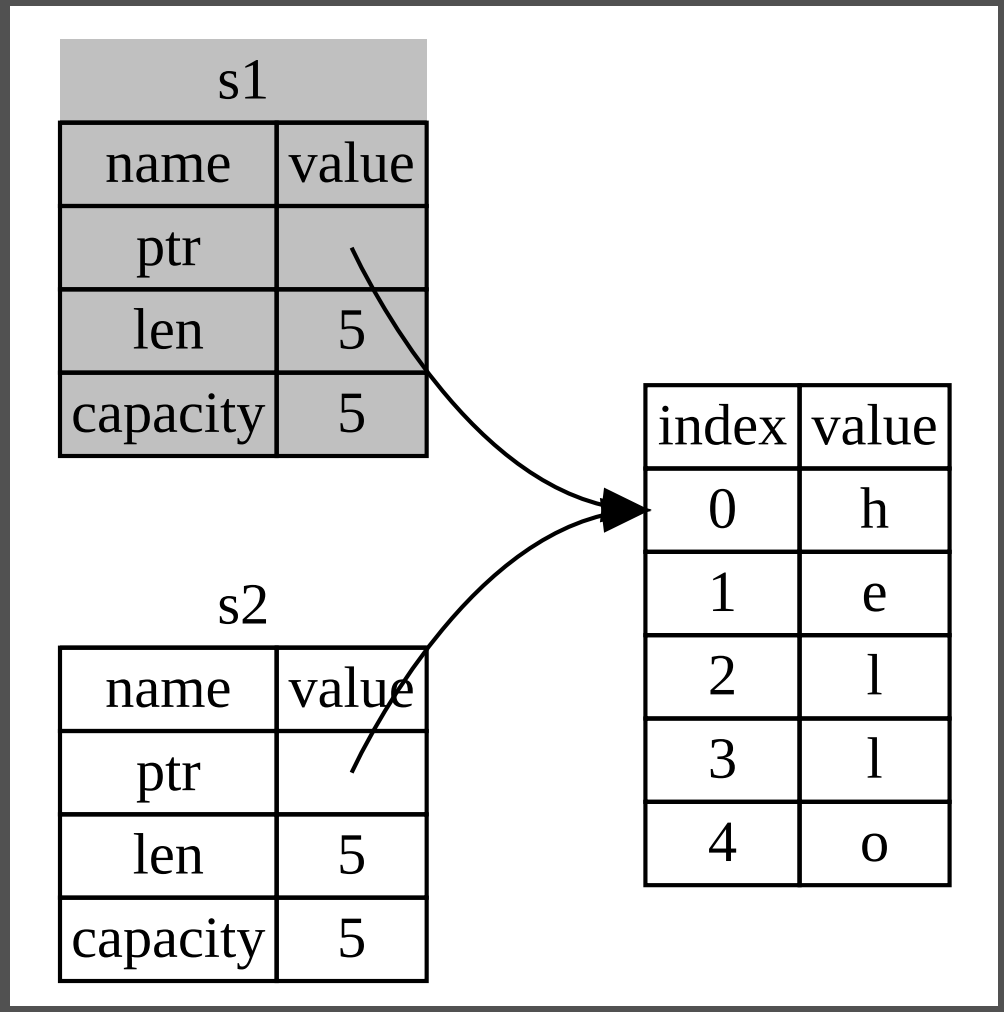


Moving ownership

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



Name example

```
let name = String::from("alice"); // 'name' owns data
let capitalized_name = capitalize(name); // ownership moved

println!(capitalized_name); // Ok
println!(name); // error: 'name' moved
```

Library example

```
let frankenstein = Book {};

loan_to_alice(&frankenstein); // borrow
loan_to_bob(&frankenstein); // borrow

// Still owner of 'frankenstein'

withdraw_book(frankenstein); // give up ownership to function

// Not allowed to use 'frankenstein' anymore

loan_to_charlie(&frankenstein); // error: 'frankenstein' moved
```

Author example

```
let frankenstein = Manuscript {};

let penguin_books = Editor {};
let alice = Editor {};

edit(&mut frankenstein, penguin_books); // mutable borrow
edit(&mut frankenstein, alice); // error: only one mut borrow

// Still owner of 'frankenstein'

sell_book(frankenstein); // pass ownership

// Not allowed to use 'frankenstein' anymore

loan_to_bob(&frankenstein); // error: 'frankenstein' moved
```

Rust compiler

- **Deep understanding** of your program's *memory*
  $\rightarrow$ **deep understanding** of your program's *code*
- **Learning curve**:
  - Fight with borrow checker at first
  - Compiler is your best friend!
- What you get in return:
  - Memory safety guarantees
  - Blazing Performance

> **In rust, you tell the compiler how the world works. It will hold you and everyone who contributes to your code accountable to the contract you have written.**

No Error

JavaScript:

```
let spam = ['cat', 'dog', 'mouse']
console.log(spam[6])
```

- No output
- No error's
- Just an `undefined`

Bad Error

Python:

```
spam = ['cat', 'dog', 'mouse']
print(spam[6])
```

Python ~~error~~ traceback

```
Traceback (most recent call last):
  File "segfaults.py", line 2, in <module>
    print(spam[6])
IndexError: list index out of range
```

Good Error

Rust:

```
let spam = ["cat", "dog", "mouse"];
println!("{}", spam[6])
```

Rust error ~~traceback~~

```
error: this operation will panic at runtime
 --> no_segfaults.rs:2:15
  |
2 |     println!("{}", spam[6]);
  |                     ^^^^^^^ index out of bounds:
        the length is 3 but the index is 6
```

```rust
fn main() {
    let text = "Hello World";
    println!(text);
}
```

```
 --> src/main.rs:4:14
  |
4 |     println!(text);
  |              ^^^^
  |
help: you might be missing a string literal to format with
  |
4 |     println!("{}", text);
  |              +++++
```

```rust
fn main() {
    let text = "Hello World";
    modify_text(text);
    println!("{}", text);
}
fn modify_text(v: &str) {
    v = "Heya";
}
```

```
error[E0384]: cannot assign to immutable argument `v`
 --> src/main.rs:8:5
  |
8 |     v = "Heya";
  |     ^^^^^^^^^^ cannot assign to immutable argument
  |
help: consider making this binding mutable
  |
7 | fn modify_text(mut v: &str) {
  |                +++
```

```rust
fn main() {
    let mut text: String = "Hello World".to_string();
    modify_text(text);
    println!("{}", text);
}

fn modify_text(mut v: String) {
    v = "Heya".to_string();
}
```

```
error[E0382]: borrow of moved value: `text`
 --> src/main.rs:4:20
  |
2 |     let mut text: String = "Hello World".to_string();
  |         -------- move occurs because `text` has type `String`,
                     which does not implement the `Copy` trait
3 |     modify_text(text);
  |                 ---- value moved here
4 |     println!("{}", text);
  |                    ^^^^ value borrowed here after move
  |
note: consider changing this parameter type in function `modify_text` to
borrow instead if owning the value isn't necessary
 --> src/main.rs:7:23
  |
7 | fn modify_text(mut v: String) {
  |    -----------        ^^^^^^ this parameter takes ownership of the value
  |    |
  |    in this function
  = note: this error originates in the macro `$crate::format_args_nl` which
    comes from the expansion of the macro `println`
help: consider cloning the value if the performance cost is acceptable
  |
3 |     modify_text(text.clone());
  |                     ++++++++
```

Consuming

```
fn main() {
    let text: String = "Hello World".to_string();
    modify_text(text.clone());
    println!("{}", text);
}

fn modify_text(mut v: String) {
    v = "Heya".to_string();
}
```

Mutable reference

```
fn main() {
    let mut text: String = "Hello World".to_string();
    modify_text(&mut text);
    println!("{}", text);
}

fn modify_text(v: &mut String) {
    v.push_str("!!!!");
}
```

Returning

```
fn main() {
    let mut text: String = "Hello World".to_string();
    text = modify_text(text);
    println!("{}", text);
}

fn modify_text(v: String) -> String {
    v + "!!!!"
}
```

Is this funtion correct?

```
function add_one(n) {
    return n + 1;
}
```

...it depends

Is this funtion correct?

```
function add_one(n) {
    return n + 1;
}
```

...it depends, on:

- Is `n` always a number?
- How large is `n`?
- Could `n` be modified while we're reading its value?
- and so on...

Options Everywhere

You can't always get want you want

```
enum Option<T> { // T can contain any type of value
    Some(T),
    None,
}

let possibly_a_number = Some(1);
possibly_a_number.unwrap_or(0); // = 1

let another_number = None;
another_number.unwrap_or(0); // = 0
```

Results Everywhere

When things go south, you need another route

```
enum Result<T, E> {
    Ok(T), // T can contain any type of value
    Err(E), // E can contain any type of Error
}
```

Let's compair

python:

```
int(item["ViewCount"]["N"])
```

Rust:

```
i32::from_str_radix(
    item["ViewCount"].unwrap()
        .get("N").unwrap(),
    10
).unwrap()
```

A verbose rust solution

```
if let Some(view_count_attr) = item.get("ViewCount") {
    match view_count_attr.get("N") {
        Ok(view_count) => {
            match i32::from_str_radix(view_count, 10) {
                Ok(n) => n,
                Err(_) => {
                    // We couldn't parse the string as an i32
                }
            }
        }
        Err(_) => {} // There is no 'N' attribute
    }
} else {} // There is no 'ViewCount' attribute
```

An idiomatic rust solution

```
fn some_function() -> Result<i32> {
    let viewcount = item.get("ViewCount")?;
    let n_value = viewcount.get("N")?;
    let n = i32::from_str_radix(n_value, 10)?;
    n
}
```

Enums

```
enum Result {
    Ok(T),
    Err(E)
}

let success = Result::Ok(42);
```

- More powerful than C-style enums
- Can contain data
- Compiler ensures all cases handled

Structs

```
struct User {
    username: String,
    email: String,
    active: bool
}

let user = User {
    username: String::from("rust_fan"),
    email: String::from("rust@example.com"),
    active: true
};
```

```rust
struct FileMetas {
    pub files: Vec<(FileOperation, FileMeta)>,
}
enum FileOperation {
    Create,
    Modify,
    Remove,
    Indexed
}
struct FileMeta {
    pub path: String,
    pub file: bool,
    pub size: u64,
    pub premissions: u32,
    pub modified: u64,
    pub accessed: u64,
    pub created: u64,
    pub hash: Option<String>,
}
```

Struct functionality impl

```
struct Example {
    number: i32,
}

impl Example {
    fn boo() {
        println!("boo! Example::boo() was called!");
    }

    fn answer(&mut self) {
        self.number += 42;
    }

    fn get_number(&self) -> i32 {
        self.number
    }
}
```

Expressions Over Statements

```
let value = if condition {
    compute_something()
} else {
    compute_other()
};

// Even blocks are expressions
let result = {
    let x = 1;
    x + 1  // No semicolon = return value
};
```

Iterators: Zero-Cost Abstractions

```
let squares: Vec<i32> = (0..5)
    .map(|x| x * x)
    .filter(|x| x % 2 == 0)
    .collect();

// As efficient as hand-written loops
```

Pattern Matching

```
match value {
    0 => println!("Zero"),
    1 | 2 => println!("One or Two"),
    3..=9 => println!("Three to Nine"),
    _ => println!("Something else")
}

match optional_value {
    Some(x) => println!("Found: {}", x),
    None => (), // Do nothing
}
```

Traits: Interface Definitions

```
trait Display {
    fn fmt(&self, f: &mut Formatter) -> Result;
}

impl Display for User {
    fn fmt(&self, f: &mut Formatter) -> Result {
        write!(f, "{} ({})", self.username, self.email)
    }
}
```

Generics: Zero-Cost Abstraction

```
struct Queue<T> {
    items: Vec<T>
}

impl<T> Queue<T> {
    fn push(&mut self, item: T) {
        self.items.push(item)
    }
}

// Monomorphization: No runtime cost
```

Overflow

```
let mut test: u8 = 0;
loop {
    test += 1
    println!("{}", test);
}
```

Overflow

```
let mut test: u8 = 0;
loop {
    test = match test.checked_add(1) {
        Some(x) => x,
        None => break,
    };
    println!("{}", test);
}
println!("We almost had an overflow");
```

Rust compiler, won't let you crash

Cargo

```
cargo new hello_world
$ cd hello_world
$ tree .
.
├── Cargo.toml
└── src
    └── main.rs
$ cargo run
$ cargo run --release
```

Cargo

```
# Add a simple dependency
cargo add serde

# Add a specific version
cargo add tokio@1.28.0

# Add with version requirements
cargo add regex@^1.5
cargo add chrono@~4.0.0

# Add multiple crates at once
cargo add serde serde_json tokio

# Add with specific features enabled
cargo add tokio --features full
cargo add serde --features derive,rc
```