Bridging the gap between Typestates and Rust in production code

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NOVA School of Science and Technology

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Hello everyone! My name is José Duarte and today I will be talking about using typestates in Rust. I'll present:

- A brief definition of typestates.
- Why they are useful.
- And finally I'll discuss their relationship with Rust and my proposal to integrate them in the ecosystem.

Outline

Introduction

State of the Art

Case Study

Plan

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Durante a apresentação irei introduzir o tema, rever sumáriamente o estado da arte, apresentar a proposta de trabalho e por fim rever o plano de trabalho da mesma.

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Context

Software plays a crucial role in our lives.

- From web browsers, to word processors and more!

As software becomes more important, bugs become more expensive.

- Losing work due to a bug in the save procedure is not nice.
- A bug in the firmware for a pacemaker may cost a life.

Context

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Problem

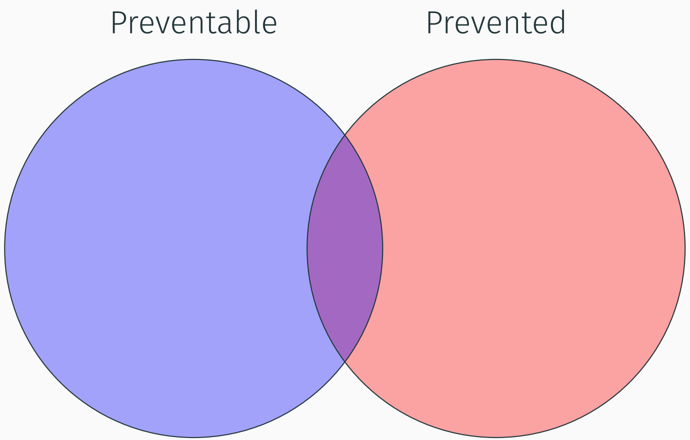
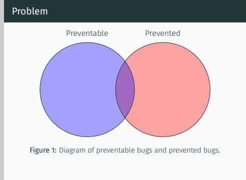


Figure 1: Diagram of preventable bugs and prevented bugs.



Problem - with Rust

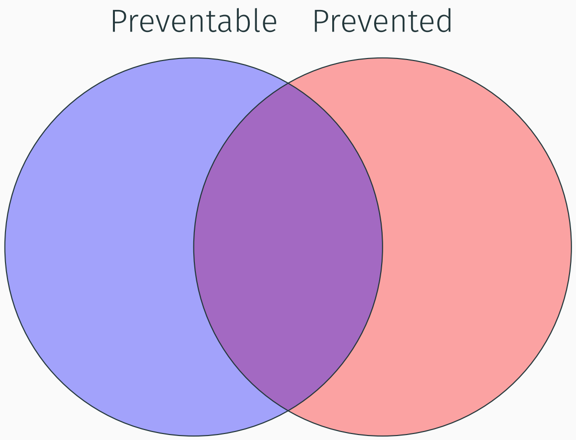
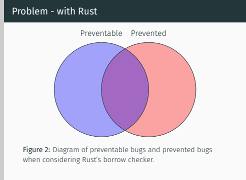


Figure 2: Diagram of preventable bugs and prevented bugs when considering Rust’s borrow checker.



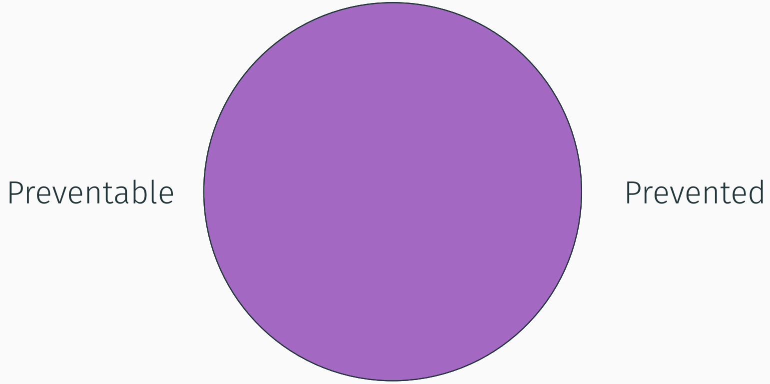


Figure 3: The ideal diagram of preventable bugs and prevented bugs, where all bugs are prevented.

Problem - Ideal
Preventable
Prevented
Figure 3: The ideal diagram of preventable bugs and prevented bugs, where all bugs are prevented.

Objectives

A library which brings *practical* typestates to Rust.

- Minimal learning overhead.
- Zero-cost abstraction.
- Scalable to large projects.

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Session Types

Session Types

Typestates

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└─Typestates

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Approach

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Problem

Error happens at runtime, possibly crashing the program.

```rust
fn main() {
    let protocol = Protocol::new();
    protocol.step1();
    protocol.step3(); // runtime error
    protocol.step2();
}
```

Our tools should work for us, not make us work for them.

Problem

Error happens at runtime, possibly crashing the program.

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Solution

Ideally, we want to catch the error at compile-time.

```
fn main() {
    let protocol = Protocol::new();
    protocol.step1();
    protocol.step3();
            ^^^^^^^
            | error: cannot call `step3`
    protocol.step2();
}
```


Solution

Ideally, we want to catch the error at compile-time.

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fn main() {
    let protocol = Protocol::new();
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Approach - Overview

We can exploit the Rust typesystem to emulate typestates, however this approach requires boilerplate.

Use macros!

- Integral part of the language, requiring no new experience.
- Able to throw errors during compile-time.
- Rewrite the annotated code, generating boilerplate for the user.

Approach - Overview
We can exploit the Rust typesystem to emulate typestates, however this approach requires boilerplate.
Use macros!
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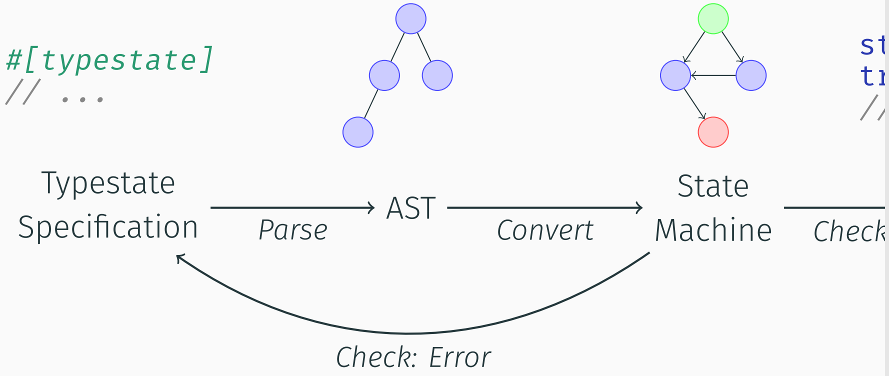
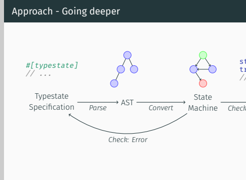
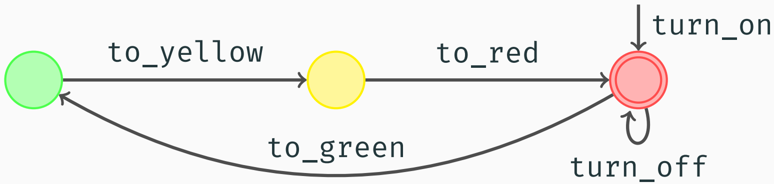
Approach - Going deeper

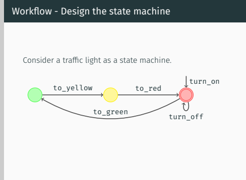




Workflow - Design the state machine

Consider a traffic light as a state machine.





Workflow - Declaring state in Rust

Using the DSL we first declare the module, main automata and the states:

```rust
#[typestate] mod traffic_light {
    #[automata] struct TrafficLight;
    #[state] struct Green;
    #[state] struct Yellow;
    #[state] struct Red;
    // ...
```

We still need transitions!

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```

We still need transitions!

Workflow - Declaring transitions in Rust

All transition functions take ownership of the current state and return the new state.

```rust
    // code from the previous slide ...
    fn to_yellow(self: Green) -> Yellow;
    fn to_red(self: Yellow) -> Red;
    fn to_green(self: Red) -> Green;
    // ...
```

Finally, we need *start* and *end* states.

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Workflow - Declaring *start* and *end* states in Rust

Functions that do not use **self** and *return* a valid state are inferred as the *start* state.

Functions that take **self** and do *not return* a valid state are inferred as the *end* state.

```
    // code from the previous slides ...
    fn turn_on() -> Red;
    fn turn_off(self: Red);
}
```

Our traffic light is ready!

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Our traffic light is ready!

Workflow - The other features

There are still other important features left. For maintenance purposed, consider that our traffic light is now required to count every **GYR** cycle.

The `TrafficLight` structure is now declared as follows:

```
#[automata] struct TrafficLight { cycles:u64 }
```


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Workflow - The other features

How can we check if the light requires maintenance?

We add a **pure** function:

```
fn requires_maintenance(
    &self: TrafficLight
) -> bool;
```

This function is not able to perform mutations due to the immutable reference (&).

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Workflow - The other features

After maintenance, how can we reset the counter?

We add an **`impure`** function:

```rust
fn reset_counter(self: &mut TrafficLight);
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The function is able to perform mutations, due to usage of a mutable reference (`&mut`), but it is unable to transition between states.

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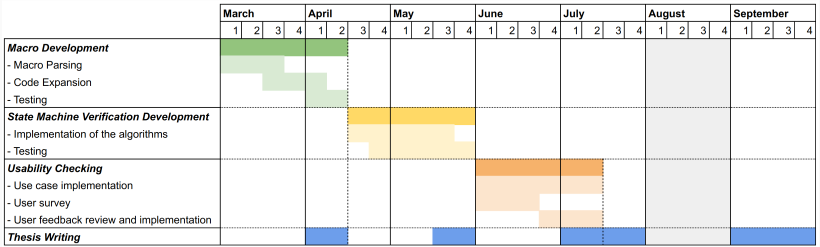

Figure 4: Work plan Gantt chart