Rust embedded at Espressif

Scott Mabin

What I'll cover today

- What is an embedded system?
- Why Rust for embedded systems?
- `async` + embedded Rust
- Espressif's offerings

What is an embedded system?

- A system created with a specific purpose
- Usually has some real-time computing and resource constraints

What do we mean by real-time?

- Reacting to system events with as little latency as possible
- Usually with hard deadlines for response times
- Typically measured in the order of a few milliseconds

Resource constraints

- Kilobytes of RAM, instead of Gigabytes found on modern computers
- 10's of Megahertz CPU frequencies, instead of the Gigahertz frequencies and multiple cores on modern computers

Executing & Debugging programs

- Program(s) are stored in flash memory
- They need to be flashed from a host machine
- Debugging happens remotely

Why Rust for embedded?

- Memory safety is even more important, most embedded systems do not have an MMU
- Ownership: Model physical hardware peripherals as singletons

Why Rust for embedded - Tooling

- cargo, no more Makefiles!
- Package management
  - Interface trait crates like `embedded-hal`
  - Non-allocating data structure crates like `heapless`
- probe-rs, a debugging toolkit for embedded devices
- Wokwi - Simulating embedded systems in the browser

Why Rust for embedded - `async`

- Works without alloc
- Provides single-threaded concurrency (multitasking)
    - Can run on a single stack, great for resource-constrained microcontrollers
- Write asynchronous code that has similar ergonomics and readability as synchronous code

How does `async` work?

You can only `await` something that implements the `Future` trait.

The `Future` trait has one required method, `poll` which returns either `Poll::Ready(_)` if the asynchronous operation is complete, or `Poll::Pending` if it needs to be polled again later.

`async`'s relationship with `Future`

- `async` functions are compiled down to state machines that implement the `Future` trait. This is handled completely by the Rust compiler

When to poll?

You *could* just `poll` the future in a hot loop, but this is not very efficient and will block other `async` operations from running.

```
while let Poll::Pending = some_fut.poll() {
    // 100% CPU used here waiting for `Poll::Ready(_)`
}
```

We'd like to do other things until the `async` operation is ready. This is where the `Waker` concept is introduced.

The `Waker`

A `Waker` is something that can be used to signal that a future should be polled again.

`wake`ing a `Waker` can happen from anywhere, some examples being a call-back function from a completed operation, just another function or in many embedded cases, an interrupt handler.

How to run futures - Executors

Where do `Poll::Pending` futures yield to? They yield back to the *executor*.

The executor is the mechanism to run futures, it handles the response to a `wake` event and then `poll`'s that future again.

The embassy-executor

A popular executor for embedded is the embassy projects executor.

In Embassy, tasks are statically allocated to avoid the need for an allocator. The `#[embassy_executor::task]` macro takes care of this for us.

```rust
#[embassy_executor::task]
async fn task() {
    loop {
        Timer::after(Duration::from_millis(100)).await;
    }
}
```

Blocking vs Async

Read the state of a button connected to a pin. Depending on whether the button is pressed, turn on or off an LED connected to another pin.

Blocking

```
#[esp_riscv_rt::entry]
fn main() {
    let io = IO::new(peripherals.GPIO, peripherals.IO_MUX);
    let mut led = io.pins.gpio7.into_push_pull_output();
    let button = io.pins.gpio9.into_pull_down_input();

    loop {
        if button.is_high() {
            led.set_high();
        } else {
            led.set_low();
        }
    }
}
```

Blocking

- Repeatedly checks for a condition to be true before proceeding
- Simple program flow
- Easy to write yet highly inefficient, causing 100% utilization of the CPU.

Async

```rust
#[embassy_executor::main(entry = "esp_riscv_rt::entry")]
async fn main(spawner: embassy_executor::Spawner) {
    let io = IO::new(peripherals.GPIO, peripherals.IO_MUX);
    let mut led = io.pins.gpio7.into_push_pull_output();
    let button = io.pins.gpio9.into_pull_down_input();

    loop {
        button.wait_for_any_edge().await;
        if button.is_high() {
            led.set_high();
        } else {
            led.set_low();
        }
    }
}
```

Async

- Structurally, it's similar to a `busy loop` but with `async`, each `.await` point allows the CPU to do something else, or even sleep to save power.
- Uses interrupts behind the scenes but the user doesn't have to worry about setting them up.

Demo

Espressif's chip offerings

- RISC-V based ESP32-Cx, ESP32-Hx & ESP32-Px series
- Xtensa based ESP32, ESP32-Sx series
- WiFi
- Bluetooth
- IEEE 802.15.4
- Single-core and dual-core options available

Espressif's Rust offerings

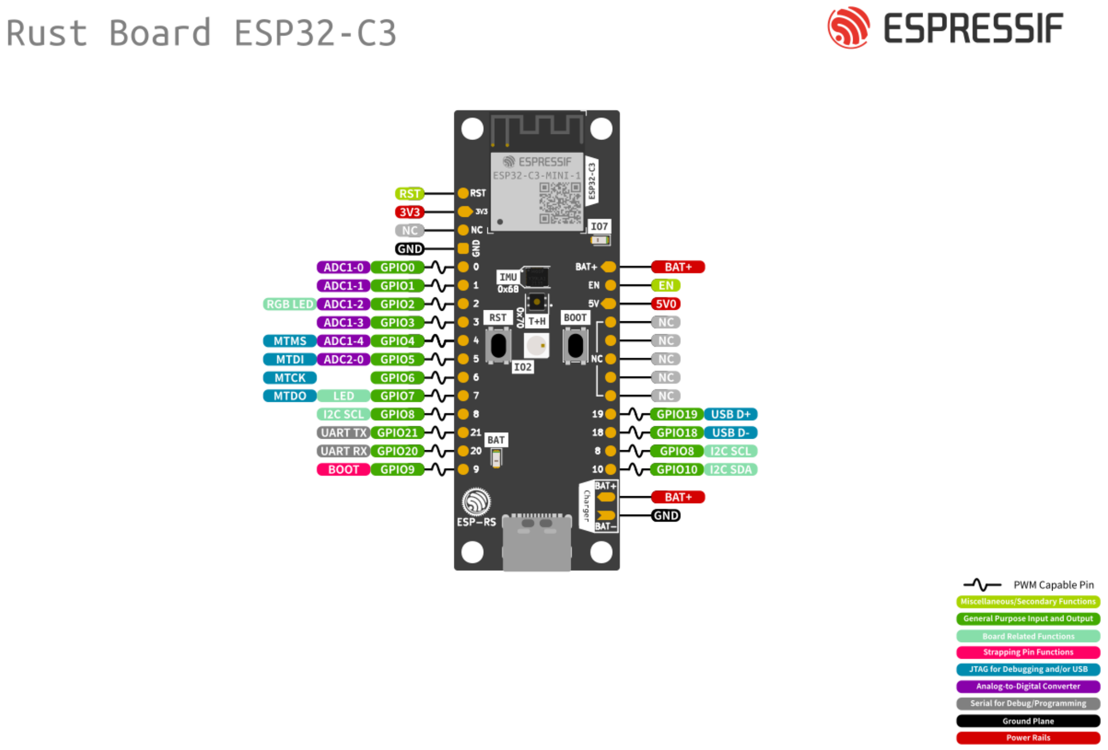
- esp-rs/esp-hal - `no_std` peripheral drivers, UART, I2C, SPI etc
- esp-rs/esp-wifi - `no_std` WiFi and Bluetooth drivers
- esp-rs/esp-ieee802154 - `no_std` ieee802154 radio driver

Bonus - STD support

- It's possible to use the Rust standard library with Espressif chips, we have a port upstream called `espidf`.
- It's based on esp-idf, the C SDK which exposes a newlib environment which the Rust standard library can be built on top of.

A Rust development kit

- The esp-rs/esp-rust-board



Books, resources and trainings

- Our own mdbook for getting started with Rust on Espressif chips esp-rs/book
- We have a training pack created by Ferrous Systems available for free using this board esp-rs/std-training.
- We also have a no_std variant using the same training materials, if the no_std option is more appealing esp-rs/no_std-training
- The Rust embedded book from the Rust embedded working group