Part 2

Embedded Rust Workshop

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Recap

- Rust's embedded ecosystem
  - HALs, PACs, embedded-hal
- Portable drivers in Rust
  - Traits
  - Generics

Questions on reading material?

Our day

- **Ask questions anytime!**
- Interrupt me when needed
- Help each other out

We'll see how far we get

Our day

- The RTIC runtime
- Exercise 2A: RTIC basics

Bonus material:

- Rust in IoT
- Exercise 2B: Device-host communication

Part 2A

RTIC

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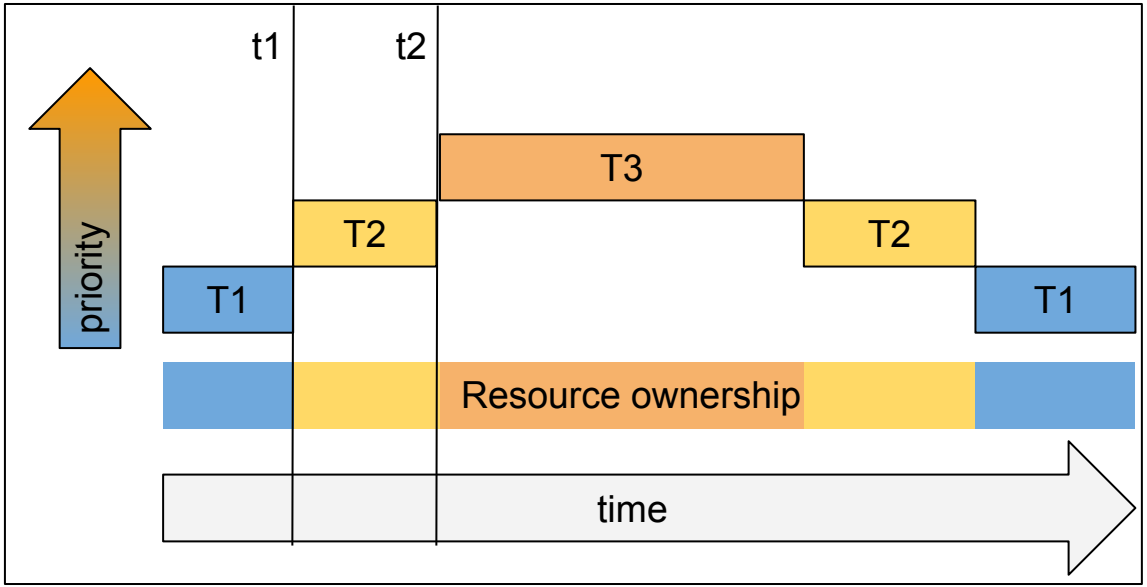
Contents

- **The concurrency problem**
- RTIC introduction
- App structure
- Task scheduling
- Resource locking
- Exercise 2A

Sharing data between tasks

- Multiple tasks
- Shared resource
- Task preemption
- Data corruption

Bad things happen!



Sharing data

- Rust is pedantic about sharing globals
- Dereferencing mutable globals is `unsafe`

How to safely share mutable data between app code and interrupts?

Global state declaration

```
use cortex_m::interrupt::Mutex;
// Flags for events
static BUTTON_1_PRESSED: AtomicBool = AtomicBool::new(false);
static BUTTON_1_RELEASED: AtomicBool = AtomicBool::new(true);
static TIMER0_FIRED: AtomicBool = AtomicBool::new(false);

// Handle to the GPIOTE peripheral. Uninitialized on reset.
// Must be initialized before use
static GPIOTE_HANDLE: Mutex<RefCell<Option<Gpiote>>> = Mutex::new(RefCell::new(None));

// Handle to the TIMER0 peripheral. Uninitialized on reset.
// Must be initialized before use
static TIMER0_HANDLE: Mutex<RefCell<Option<Timer<pac::TIMER0, Periodic>>>> =
    Mutex::new(RefCell::new(None));
```

- Atomics for flags
- `Mutex<RefCell<Option<T>>>` for safe synchronization

Global state initialization

```
// Initialize the TIMER0 and GPIOTE handles, passing the initialized
// peripherals.
use cortex_m::interrupt::{free as interrupt_free, CriticalSection};
interrupt_free(|cs: &CriticalSection| {
    // Interrupts are disabled globally in this block
    TIMER0_HANDLE.borrow(cs).replace(Some(timer0));
    GPIOTE_HANDLE.borrow(cs).replace(Some(gpiote));
});
```

- `cortex_m::interrupt::free` needed to mutate data in CS
- Disables **all** interrupts

Global state in ISR

```
#[interrupt]
// TIMER0 interrupt service routine
fn TIMER0() {
    use cortex_m::interrupt::{free as interrupt_free, CriticalSection};
    interrupt_free(|cs: &CriticalSection| {
        if let Some(ref timer0) = TIMER0_HANDLE.borrow(&cs).borrow().deref() {
            // Check whether capture/compare register 0 was reached
            if timer0.event_compare_cc0().read().bits() != 0x00u32 {
                // Raise flag that timer has fired
                TIMER0_FIRED.store(true, Relaxed);
                // Reset cc0, so as to prevent looping forever
                timer0.event_compare_cc0().write(|w| unsafe { w.bits(0) })
            }
        };
    });
}
```

Questions so far?

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Real-Time Interrupt-driven Concurrency (Née RTFM)

- Divide application into tasks
- Heavily uses interrupts to schedule tasks
- Handles passing global resources

Lock only when pre-emption might cause trouble

RTIC features

- Message passing
- Task scheduling
- Deadlock-free execution
- Works on all cortex-m devices
- (multi-core support)
- Lots of control

RTIC trade offs

Heavy on the macros

- Rust analyzer doesn’t like macros
- Vague compiler errors involving locks
- Compiler still helpful though

RTIC internals

- All tasks are interrupts
- Interrupt priority managed by NVIC
- Priority ceiling

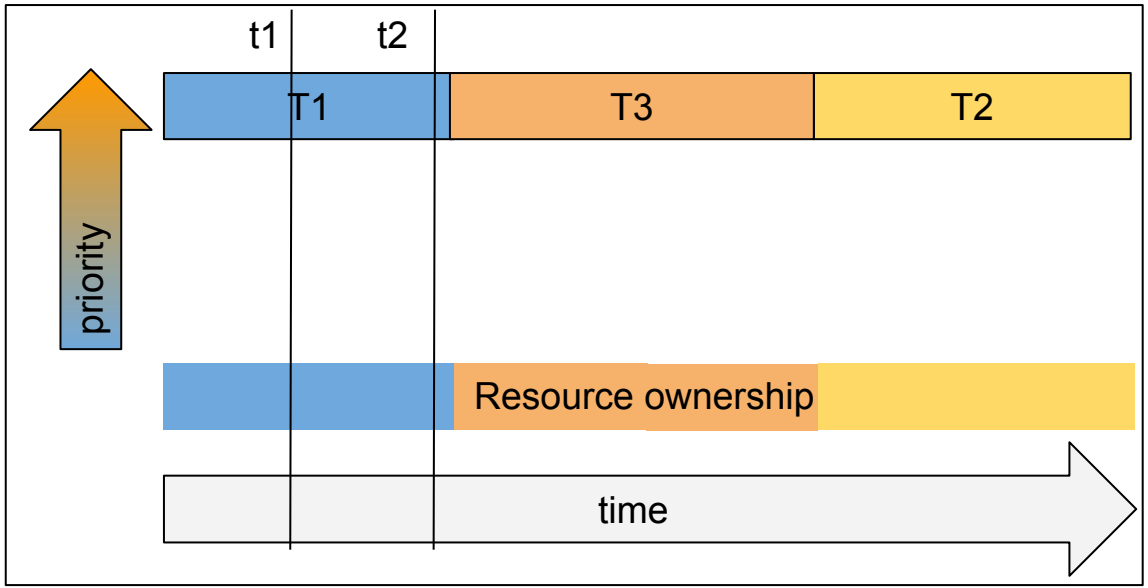
When locking a shared resource, temporarily increase current tasks priority s.t. no task that uses the resource can preempt the current task.

Other tasks may still preempt

Idea by T.P. Baker (1990)

RTIC priority ceiling

- T1 finishes first
- T2 has to wait
- No preemption



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RTIC app outline

- App attribute
- Init task
- Idle task
- Hardware tasks
- Software tasks

Example

RTIC app attribute

- Point RTIC to PAC
- Monotonic timer for task scheduling
- Procedural macro
- Analyzes task priorities

Code gets adapted at build!

```
#[rtic::app(
    device=firmware::hal::pac,
    peripherals=true,
    monotonic=rtic::cyccnt::CYCCNT
)]
const APP: () = {
```

RTIC resources

- Shared between tasks
- Some initialized by runtime
- Others lazily initialized in init

```
struct Resources {
    gpiote: Gpiote,
    timer0: Timer<TIMER0, Periodic>,
    led1: Pin<Output<PushPull>>,
}
```

RTIC init

- Initialize late resources
- Peripherals in `ctx.device`
- Use PAC and HAL
- Interrupts disabled

```
#[init]
fn init(ctx: init::Context) -> init::LateResources {
    let port0 = Parts::new(ctx.device.P0);

    // Init pins
    let led1 = port0.p0_13.into_push_pull_output(Level::High).degrade();
    let btn1 = port0.p0_11.into_pullup_input().degrade();

    // Configure GPIOTE
    let gpiote = Gpiote::new(ctx.device.GPIOTE);
    gpiote
        .channel0()
        .input_pin(&btn1)
        .hi_to_lo()
        .enable_interrupt();

    // Initialize TIMER0
    let mut timer0 = Timer::periodic(ctx.device.TIMER0);
    timer0.enable_interrupt();
    timer0.start(1_000_000u32); // 1000 ticks = 1 ms

    // Return the resources
    init::LateResources {
        led1,
        gpiote,
        timer0,
    }
}
```

RTIC idle task

- Default task
- Sleep, mostly (default)
- Pre-empted by other tasks

```
#[idle]
fn idle(_ctx: idle::Context) -> ! {
    loop {
        // Go to sleep, waiting for an interrupt
        cortex_m::asm::wfi();
    }
}
```

RTIC software task

- Capacity
- Priority
- Resources declared
- Message passing
- Task context

Resources are `&mut`!

```
#[task(
    capacity = 5,
    priority = 1, // Very low priority
    resources = [led1]
)]
fn set_led1_state(ctx: set_led1_state::Context, enabled: bool) {
    if enabled {
        ctx.resources.led1.set_low().unwrap();
    } else {
        ctx.resources.led1.set_high().unwrap();
    }
}
```

RTIC interrupt declaration

- Used to spawn software tasks
- Need as many as there are software tasks

```
extern "C" {
    // Software interrupt 0 / Event generator unit 0
    fn SWI0_EGU0();
    // Software interrupt 1 / Event generator unit 1
    fn SWI1_EGU1();
    // Software interrupt 2 / Event generator unit 2
    fn SWI2_EGU2();
}
```

RTIC hardware task

- Binds hardware interrupt
- High priority
- Resources
- Spawned SW tasks
- Task context

```
#[task(
    binds = TIMER0,
    priority = 99, // Very high priority
    resources = [timer0],
    spawn = [set_led1_state]
)]
fn on_timer0(ctx: on_timer0::Context) {
    let timer0 = ctx.resources.timer0;
    if timer0.event_compare_cc0().read().bits() != 0x00u32 {
        timer0.event_compare_cc0().write(|w| unsafe { w.bits(0) });
        // Try to spawn set_led1_state. If its queue is full, we do nothing.
        let _ = ctx.spawn.set_led1_state(false);
    }
}
```

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RTIC task scheduling (init)

- Enable cycle counter in init
- SW Task: ctx.scheduled
- HW Task/init: ctx.start

```
#[init]
fn init(ctx: init::Context) -> init::LateResources {
    // Enable cycle counter
    ctx.core.DWT.enable_cycle_counter();

    // Init peripherals...

    let now = ctx.start;
    // Schedule toggle_led_2 task
    ctx.schedule.toggle_led_2(now, true).unwrap();

    init::LateResources {
        // The resources
    }
}
```

RTIC task scheduling (task)

- Enable cycle counter in init
- SW Task: ctx.scheduled
- HW Task/init: ctx.start

```
#[task(
    capacity = 5,
    priority = 2,
    resources = [led2],
    schedule = [toggle_led_2]
)]
fn toggle_led_2(ctx: toggle_led_2::Context, enabled: bool) {
    let led2 = ctx.resources.led2;
    if enabled {
        led2.set_high().unwrap(); // Disable
    } else {
        led2.set_low().unwrap(); // Enable
    }

    // Use ctx.start in HW task and init
    let task_scheduled_at = ctx.scheduled;
    ctx.schedule
        .toggle_led_2(task_scheduled_at + 10_000_000u32.cycles(), !enabled)
        .ok();
}
```

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RTIC resource locks

- Task preemption
- Lock needed for lower-prio task
- Temporarily increase task priority
- Only for common resources

Compiler error is pretty bad, beware!*

* Gets better in version 0.6

RTIC resource locks

Note: `led2` **is declared by** `toggle_led2` **task, prio 2**

```
#[task(capacity = 5, priority = 1, resources = [led2])]
fn low_prio_task(ctx: low_prio_task::Context) {
    let led2 = ctx.resources.led2;

    led2.set_high();
}
```

RTIC resource locks

```
error[E0599]: the method `set_high` exists for struct `led2<'_>`, but its trait bounds were not satisfied
   --> src/main.rs:172:14
    |
35  | / #[rtic::app(
36  | |     device=firmware::hal::pac,
37  | |     peripherals=true,
38  | |     monotonic=rtic::cyccnt::CYCCNT
39  | | )]
    | |  -
    | |  |
    | |  method `set_high` not found for this
    | |__doesn't satisfy `_: cortex_m::prelude::_embedded_hal_digital_OutputPin`
    |    doesn't satisfy `_: firmware::nrf52832_hal::prelude::OutputPin`
...
172 |           led2.set_high();
    |                ^^^^^^^^ method cannot be called on `led2<'_>` due to unsatisfied trait bounds
    |
    = note: the following trait bounds were not satisfied:
            `led2<'_>: cortex_m::prelude::_embedded_hal_digital_OutputPin`
            which is required by `led2<'_>: firmware::nrf52832_hal::prelude::OutputPin`
    = help: items from traits can only be used if the trait is implemented and in scope
    = note: the following trait defines an item `set_high`, perhaps you need to implement it:
            candidate #1: `cortex_m::prelude::_embedded_hal_digital_OutputPin`

For more information about this error, try `rustc --explain E0599`.
error: could not compile `firmware` due to previous error
```

RTIC resource locks

```
#[task(capacity = 5, priority = 1, resources = [led2])]
fn low_prio_task(ctx: low_prio_task::Context) {
    // Locking mutates
    let mut led2 = ctx.resources.led2;

    led2.lock(|led2_lock| {
        led2_lock.set_low().unwrap();
    });
}
```

Questions so far?

Exercise 2A

Instructions on **sodaq.workshop.tweede.golf**

Don’t forget to `git pull`!

Exercice 2A round up

- Show your code!
- Any questions?

Part 2B

Rust in IoT

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Contents

- **Project intro and demo**
- Exercise 2B

Demo: A bigger Project in Rust

- Intro
  - Device-host communication
  - Abstract over channel
- Project structure
  - Workspace with crates
  - Shared format crate
  - Firmware
  - Command-line application
- Serde and postcard
- CLI REPL

Questions so far?

Exercise 2B

Instructions on **sodaq.workshop.tweede.golf**

Exercice 2B round up

- Show your code!
- Any questions?

AMA

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