Tock Embedded OS Training

RustConf 2017

Tock is a...

1. Secure
2. Embedded
3. Operating System
4. for Low Resource
5. Microcontrollers

Secure

~~*Secure*~~ Safe

Tock has isolation primitives that allow you to build secure systems.

Embedded

Definition A

Operating system, applications and hardware are tightly integrated.

Definition B

You'll likely be writing the kernel.

Operating System

Tock itself provides services to components in the system:

- Scheduling
- Communication
- Hardware multiplexing

Low Resource

- 10s uA average power draw
- 10s of kBs of RAM
- Moderate clock speeds

Microcontrollers

System-on-a-chip with integrated flash, SRAM, CPU and a bunch of hardware controllers.

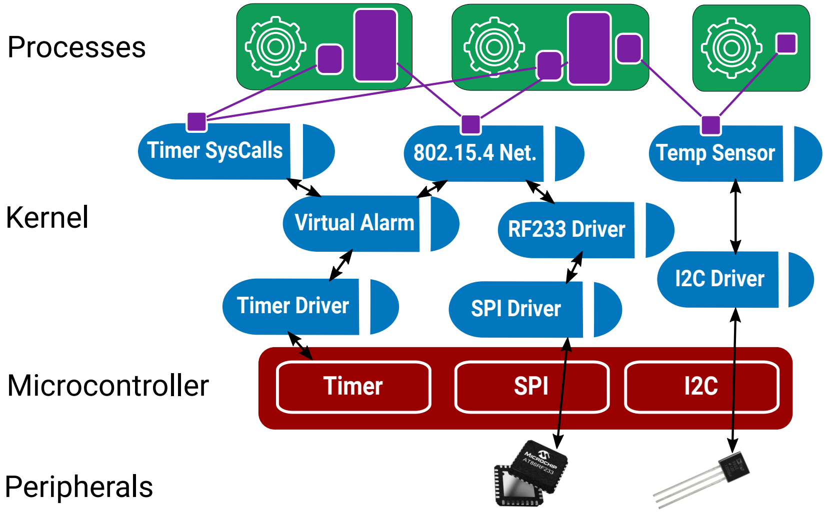
Typically:

- Communication: UART, SPI, I2C, USB, CAN...
- External I/O: GPIO, external interrupt, ADC, DAC
- Timers: RTC, countdown timers

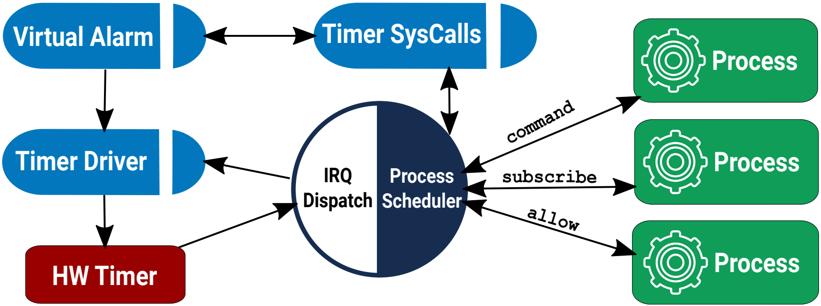
Maybe...

- Radio (Bluetooth, 15.4)
- Cryptographic accelerators
- Other specialized hardware...

Two types of components: capsules and processes

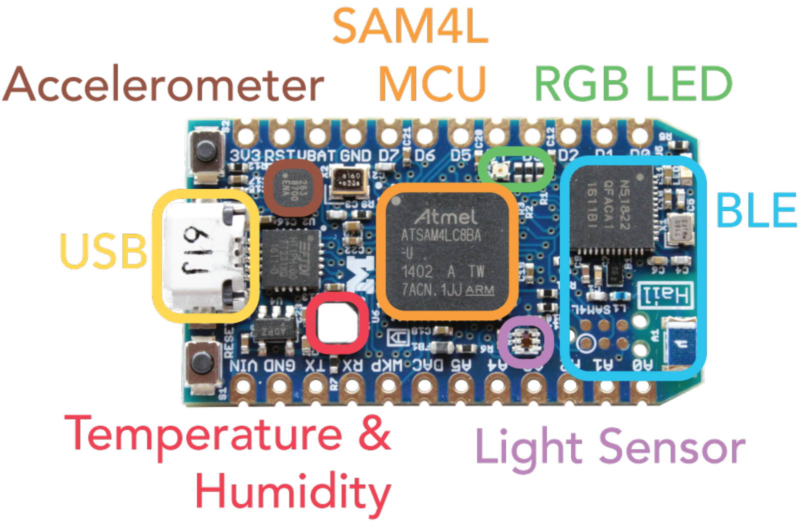


Two types of scheduling: cooperative and preemptive



Part 1: Hardware, tools and development environment

Hail


SAM4L
MCU
Accelerometer
RGB LED
USB
BLE
Temperature &
Humidity
Light Sensor

Binaries on-board

- Bootloader
- Kernel
- Processes

Tools

- `make`
- Rust nightly (`asm!`, compiling `core`)
- `xargo` to automate compiling base libraries
- `arm-none-eabi` GCC to link binaries
- `tockloader` to interact with Hail and the bootloader

Tools: tockloader

Write a binary to a particular address in flash

```
$ tockloader flash --address 0x1000 \
    target/thumbv7em-none-eabi/release/hail.bin
```

Program a process in Tock Binary Format[1]:

```
$ tockloader install myapp.tab
```

Restart the board and connect to the debug console:

```
$ tockloader listen
```

[1] TBFs are relocatable process binaries prefixed with headers like the package name. .tab is a tarball of TBFs for different architectures as well as a metadata file for tockloader.

Check your understanding

1. What kinds of binaries exist on a Tock board? Hint: There are three, and only two can be programmed using `tockloader`.
2. What are the differences between capsules and processes? What performance and memory overhead does each entail? Why would you choose to write something as a process instead of a capsule and vice versa?
3. Is it acceptable for a process to enter an infinte loop? What about a capsule?

Hands-on: Set-up development environment

1. Compile and flash the kernel
2. Compile and program `ble-env-sense` service
3. (Optional) Add some other apps from the repo, like `blink` and `sensors`
4. (Optional) Familiarize yourself with `tockloader` commands
   - `uninstall`
   - `list`
   - `erase-apps`

Part 2: The kernel

Trusted Computing Base (`unsafe` allowed)

- Hardware Abstraction Layer
- Board configuration
- Event & Process scheduler
- Rust `core` library
- A few data structures

`kernel/`
`chips/`

Capsules (`unsafe` not allowed)

- Virtualization
- Peripheral drivers
- Communication protocols (IP, USB, etc)
- Application logic

`capsules/`

Constraints

Small isolation units

Breaking a monolithic component into smaller ones should have low/no cost

Avoid memory exhaustion in the kernel

No heap. Everything is allocated statically.

Low communication overhead

Communicating between components as cheap as an internal function call. Ideally inlined.

Event-driven execution model

```
pub fn main<P, C>(platform: &P, chip: &mut C,
                  processes: &mut [Process]) {
    loop {
        chip.service_pending_interrupts();
        for (i, p) in processes.iter_mut().enumerate() {
            sched::do_process(platform, chip, process;
        }

        if !chip.has_pending_interrupts() {
            chip.prepare_for_sleep();
            support::wfi();
        }
    }
}
```

Event-driven execution model

```
fn service_pending_interrupts(&mut self) {
    while let Some(interrupt) = get_interrupt() {
        match interrupt {
            ASTALARM => ast::AST.handle_interrupt(),
            USART0 => usart::USART0.handle_interrupt(),
            USART1 => usart::USART1.handle_interrupt(),
            USART2 => usart::USART2.handle_interrupt(),
            ...
        }
    }
}
```

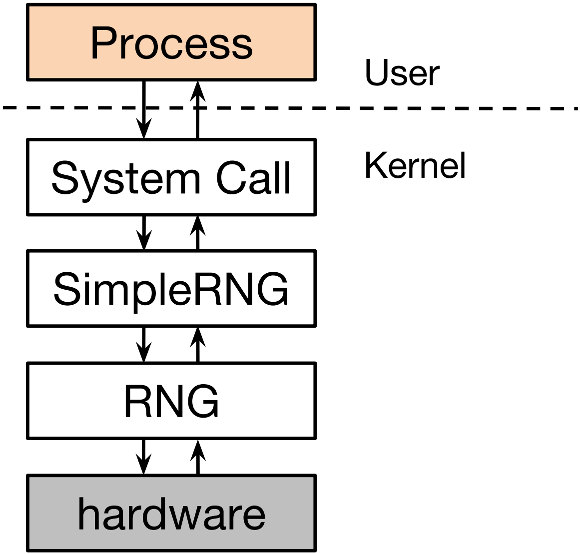


Figure: Capsules reference each other directly, assisting inlining

The mutable aliases problem

```
enum NumOrPointer {
  Num(u32),
  Pointer(&mut u32)
}

// n.b. will not compile
let external : &mut NumOrPointer;
match external {
  Pointer(internal) => {
    // This would violate safety and
    // write to memory at 0xdeadbeef
    *external = Num(0xdeadbeef);
    *internal = 12345;  // Kaboom
  },
  ...
}
```

Interior mutability to the rescue

Type	Copy-only	Mutual exclusion	Opt.	Mem Opt.
`Cell`	✓	✗	✓	✓
`VolatileCell`	✓	✗	✗	✓
`TakeCell`	✗	✓	✗	✓
`MapCell`	✗	✓	✓	✗

```rust
pub struct Fxos8700cq<'a> {
  i2c: &'a I2CDevice,
  state: Cell<State>,
  buffer: TakeCell<'static, [u8]>,
  callback:
    Cell<Option<&'a hil::ninedof::NineDofClient>>,
}

impl<'a> I2CClient for Fxos8700cq<'a> {
  fn cmd_complete(&self, buf: &'static mut [u8]) { ... }
}

impl<'a> hil::ninedof::NineDof for Fxos8700cq<'a> {
  fn read_accelerometer(&self) -> ReturnCode { ... }
}

pub trait NineDofClient {
  fn callback(&self, x: usize, y: usize, z: usize);
}
```

Check your understanding

1. What is a `VolatileCell`? Can you find some uses of `VolatileCell`, and do you understand why they are needed? Hint: look inside `chips/sam4l/src`.
2. What is a `TakeCell`? When is a `TakeCell` preferable to a standard `Cell`?

Hands-on: Write and add a capsule to the kernel

Part 3: User space

Hands-on: Write a BLE environment sensing app