

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

Kernel, 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 μ A average power draw
- ▶ 10s of kB of RAM
- ▶ Moderate clock speeds

Microcontrollers

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

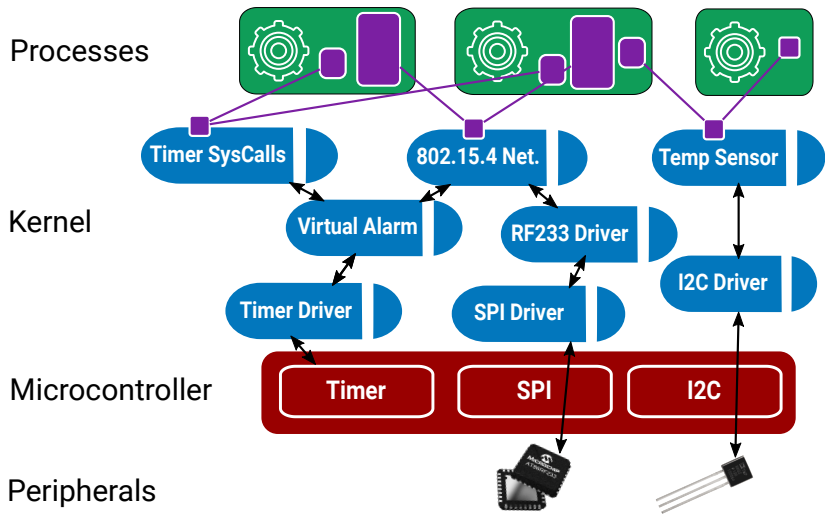
Typically:

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

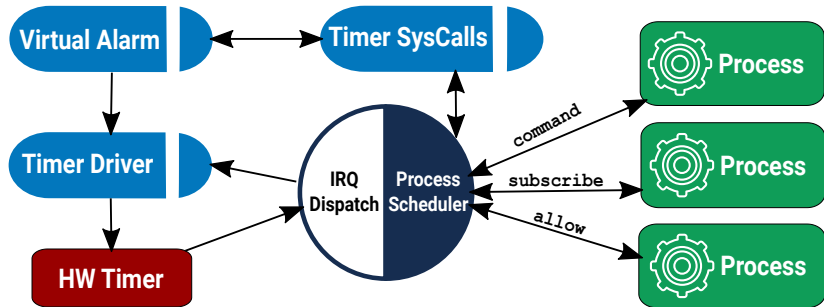
Maybe...

- ▶ 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

Accelerometer

MCU

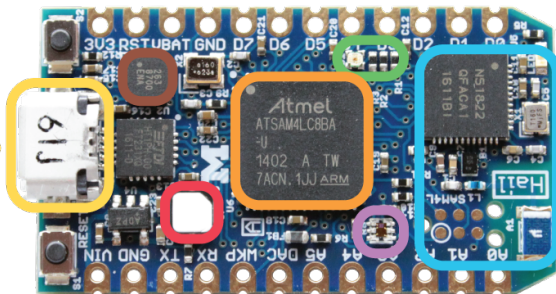
RGB LED

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 Format¹:

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

Restart the board and connect to the debug console:

```
$ tockloader listen
```

¹TBFs 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 infinite 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
- ▶ Core Tock primitives

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(),  
            ...  
        }  
    }  
}
```

Event-driven execution model

```
impl Ast {
    pub fn handle_interrupt(&self) {
        self.clear_alarm();
        self.callback.get().map(|cb| { cb.fired(); });
    }
}

impl time::Client for MuxAlarm {
    fn fired(&self) {
        for cur in self.virtual_alarms.iter() {
            if cur.should_fire() {
                cur.armed.set(false);
                self.enabled.set(self.enabled.get() - 1);
                cur.fired();
            }
        }
    }
}
```

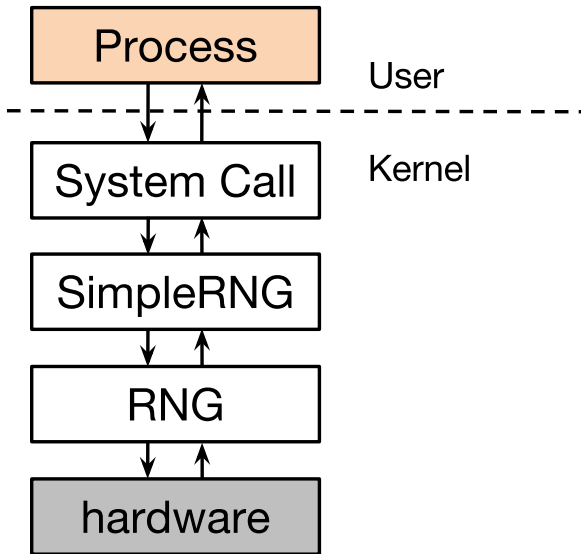



Figure: Capsules reference each other directly, assisting inlining

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	✗	✓	✓	✗

```

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

1. Read the Hail boot sequence in `boards/hail/src/main.rs`
2. Create a new capsule that prints “Hello World” to the debug console.
3. Create a new capsule that prints “Hello World” to the debug console every second.
4. Add your capsule to the boot sequence
5. Extend your capsule to sample the 9dof sensor

Part 3: User space

System calls

Call	Target	Description
command	Capsule	Invoke an operation on a capsule
allow	Capsule	Share memory with a capsule
subscribe	Capsule	Register an upcall
memop	Core	Modify memory break
yield	Core	Bloc until next upcall is ready

System calls: Rust

```
pub unsafe fn command(major: u32, minor: u32,
    arg: isize) -> isize;

pub unsafe fn allow(major: u32, minor: u32,
    slice: &[u8]) -> isize;

type ExternFn =
    extern fn (usize, usize, usize, *const usize);

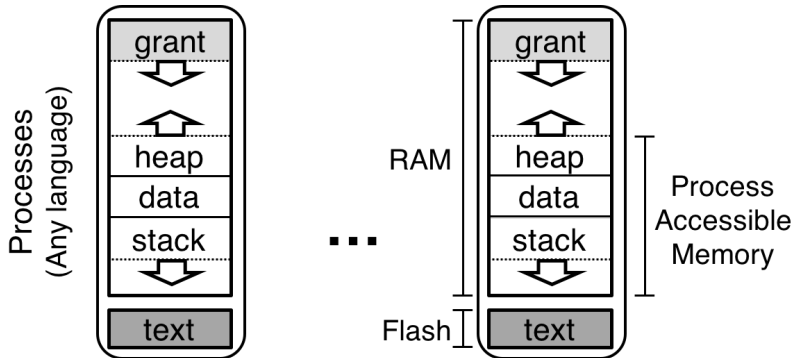
pub unsafe fn subscribe(major: u32, minor: u32,
    cb: ExternFn, ud: *const usize) -> isize {

pub fn yieldk();
pub fn yieldk_for<F: Fn() -> bool>(cond: F) {
    while !cond() { yieldk(); }
}
```

Example: printing to the debug console

```
pub fn write(string: Box<[u8]>) {  
    let done: Cell<bool> = Cell::new(false);  
    syscalls::allow(DRIVER_NUM, 1, string);  
    syscalls::subscribe(DRIVER_NUM, 1, callback,  
        &done as *const _ as usize);  
    syscalls::command(DRIVER_NUM, 1, string.len());  
    yieldk_for(|| done.get())  
}  
  
extern fn callback(_: usize, _: usize, _: usize,  
    ud: *const usize) {  
    let done: &Cell<bool> = unsafe {  
        mem::transmute(ud)  
    };  
    done.set(true);  
}
```

Process memory layout



Current Rust userland

Supported drivers

- ▶ Debug console
- ▶ Timer
- ▶ Sensors:
 - ▶ Accelerometer & magnetometer
 - ▶ Ambient light
 - ▶ Temperature

Caveats

- ▶ No global variables allowed!
 - ▶ Waiting on LLD 5.0 to be released this month
- ▶ Fixed code offset
- ▶ Blocking library calls only

Check your understanding

1. How does a process perform a blocking operation? Can you draw the flow of operations when a process calls `delay_ms(1000)`?
2. What is a Grant? How do processes interact with grants?
Hint: Think about memory exhaustion.

Hands-on: Write a BLE environment sensing application

1. Get a Rust application running on Hail
2. Periodically sample on-board sensors
3. Extend your app to report through the `ble-env-sense` service