Ariel OS — The Embedded Rust Software Stack for Microcontroller-based Internet of Things

About us

Kaspar Schleiser *Koen Zandberg*

… part of Ariel OS contributors:

Ariel OS: A library operating system for secure, memory-safe, low-power Internet of Things, written in Rust

Outline

1. Context
2. Rust embedded and the Ecosystem
3. Ariel OS
4. Getting started: From Hello World to Networking
5. Wrapping up

Context: Microcontroller hardware

Restrictions

- Limited processing power
- Low memory
- Single memory: no user- vs kernel-space, no MMU, but probably an MPU

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Firmware

- **Baremetal**: no underlying OS with threads, networking, heap allocation…
- **No alloc**: deterministic behaviour, avoid panic and memory fragmentation

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Rust: Language

Memory safety!

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But we know that by now.

Rust: Language

Crates:

Shared code on crates.io, integrated in the Cargo build system.

Traits:

Interfaces that allow for interoperability between crates.

`no_std`:

No use of the standard library and dynamic memory allocations

Async

Provide asynchronous cooperative multitasking implementations with minimal memory usage

Fosters collaboration across projects

Rust Embedded: Ecosystem

What the ecosystem provides:

`embedded-hal` traits

Provide good generic interfaces for common peripherals across architectures

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Sensor and peripheral drivers as separate crate, make use of the `embedded-hal` traits

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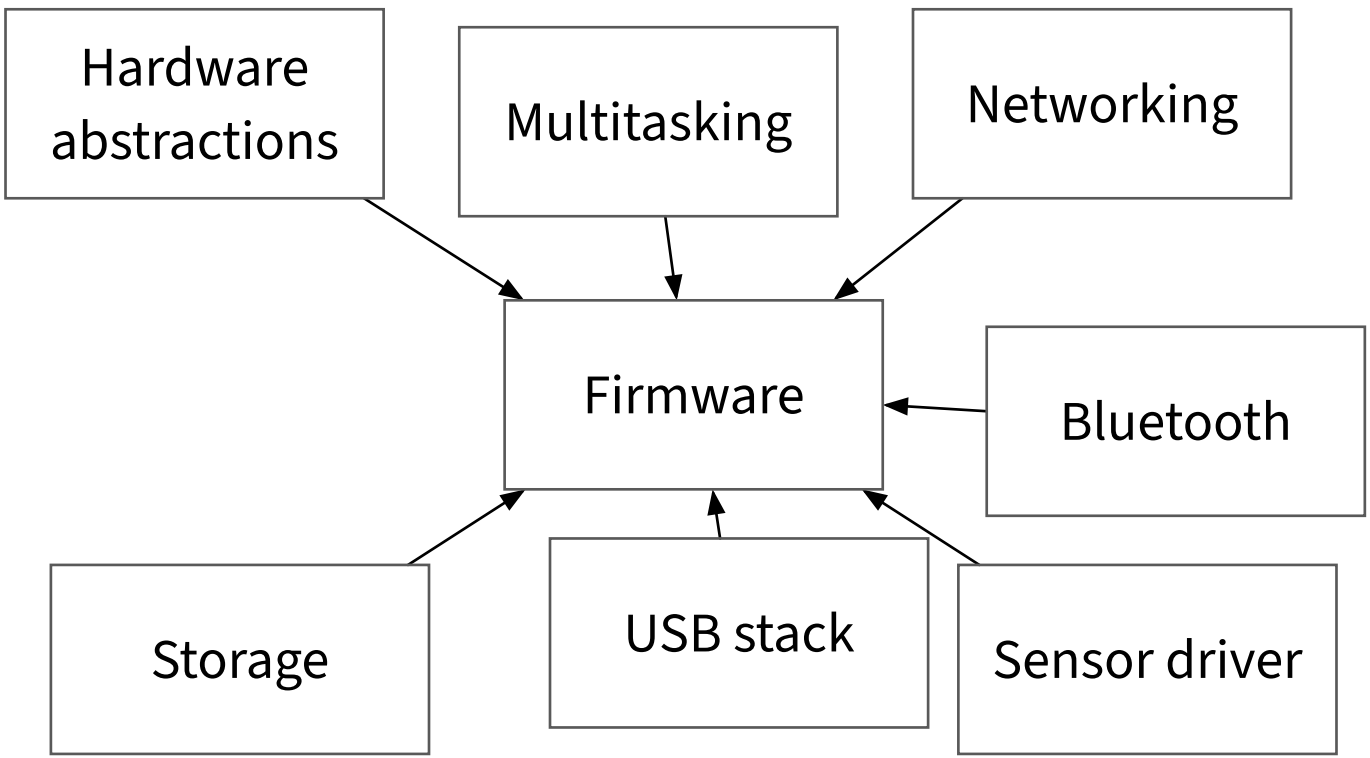
Async framework: Embassy

- Implements hardware abstractions for STM32, nRF and Pi Pico
- Provides a low memory async scheduler

The ecosystem of crates around embedded Rust is huge and growing fast!

Collecting everything

Collecting everything



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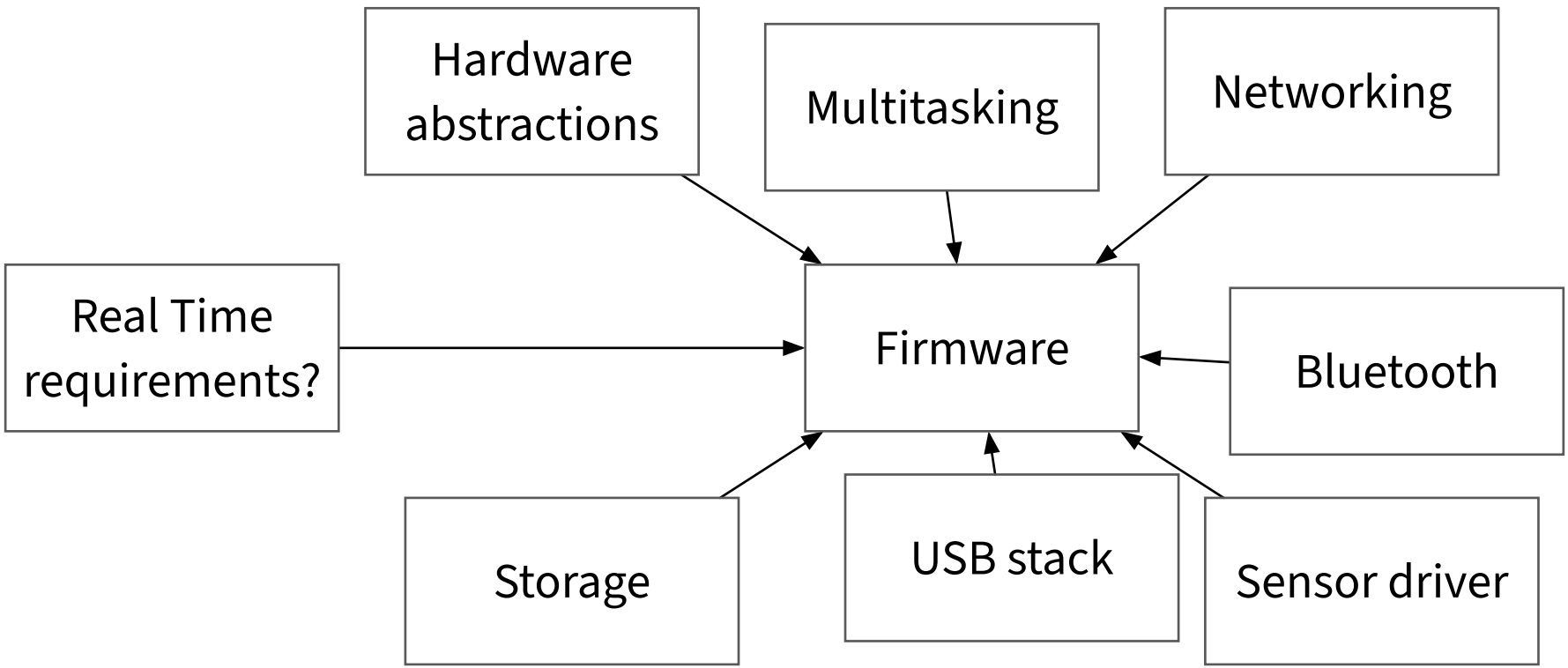

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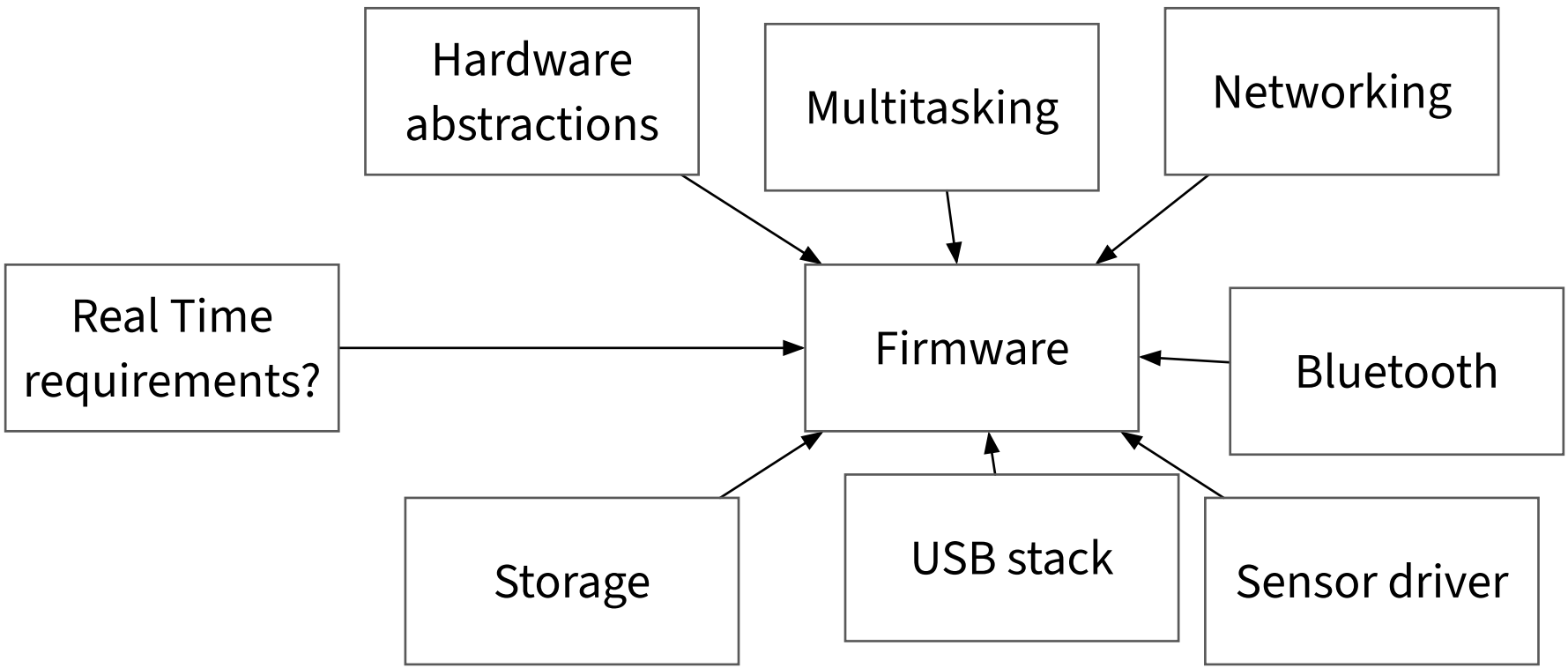

Curating and integrating crates for everything is time consuming

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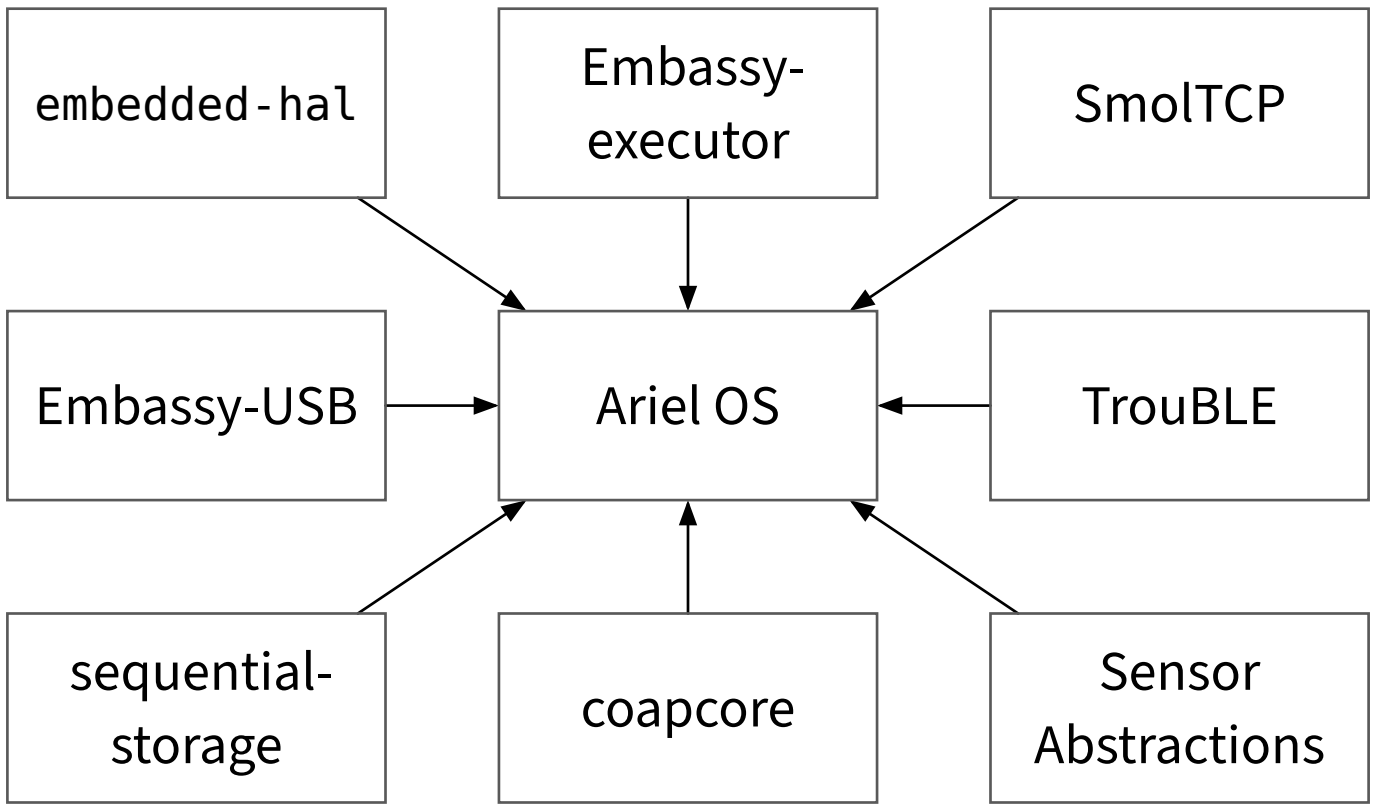
Ariel OS



Ariel OS integrates crates into a coherent operating system

Ariel OS: Concurrency

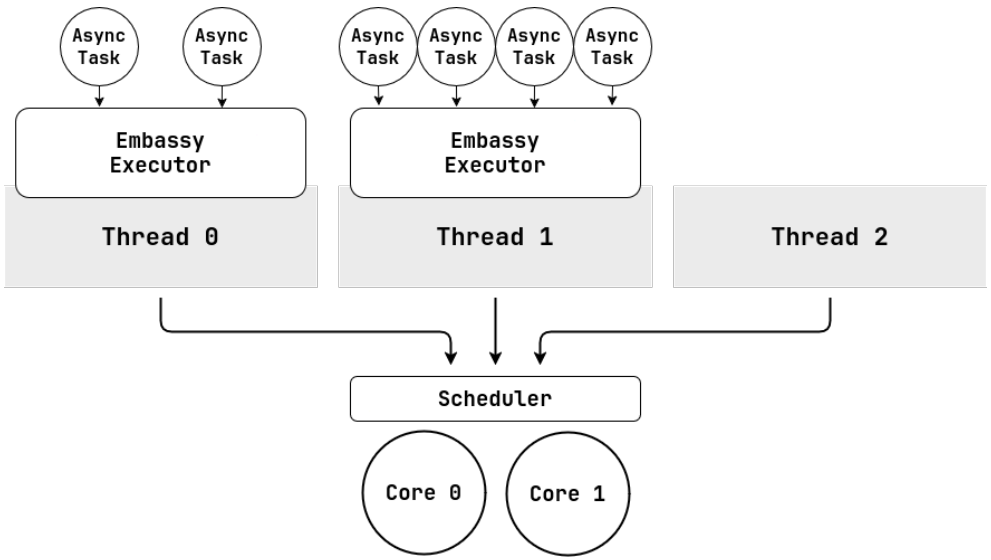
Threading

- Preemptive scheduler
- Priority-based scheduling
- Separate stacks

Async

- Based on the Embassy executor
- Can run inside a thread

Support both preemptive scheduling and low memory async scheduling



Ariel OS: To the Ecosystem

Provide high level functionality

Sensor abstractions

- Enumerate available sensors on a board
- Read out available sensors
- Provides a generic interface to sensors and measurements.

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Structured Board Descriptions

Provide machine-readable descriptions of boards

- Microcontroller information
- Peripherals
- Supported features

Ariel OS: Build system

The configuration space is huge

- Enable features
- Features can conflict
- Catch issues *before* compilation

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Laze

yaml-based declarative build configuration.

- Select required modules
- Abstract away board specifics
- Steers cargo builds
- Runs tasks to flash and inspect builds

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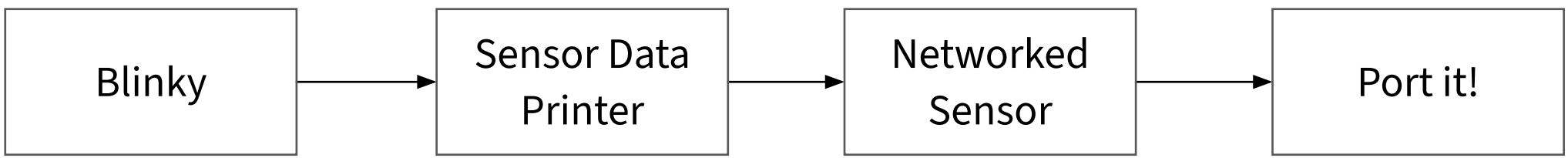
Goal



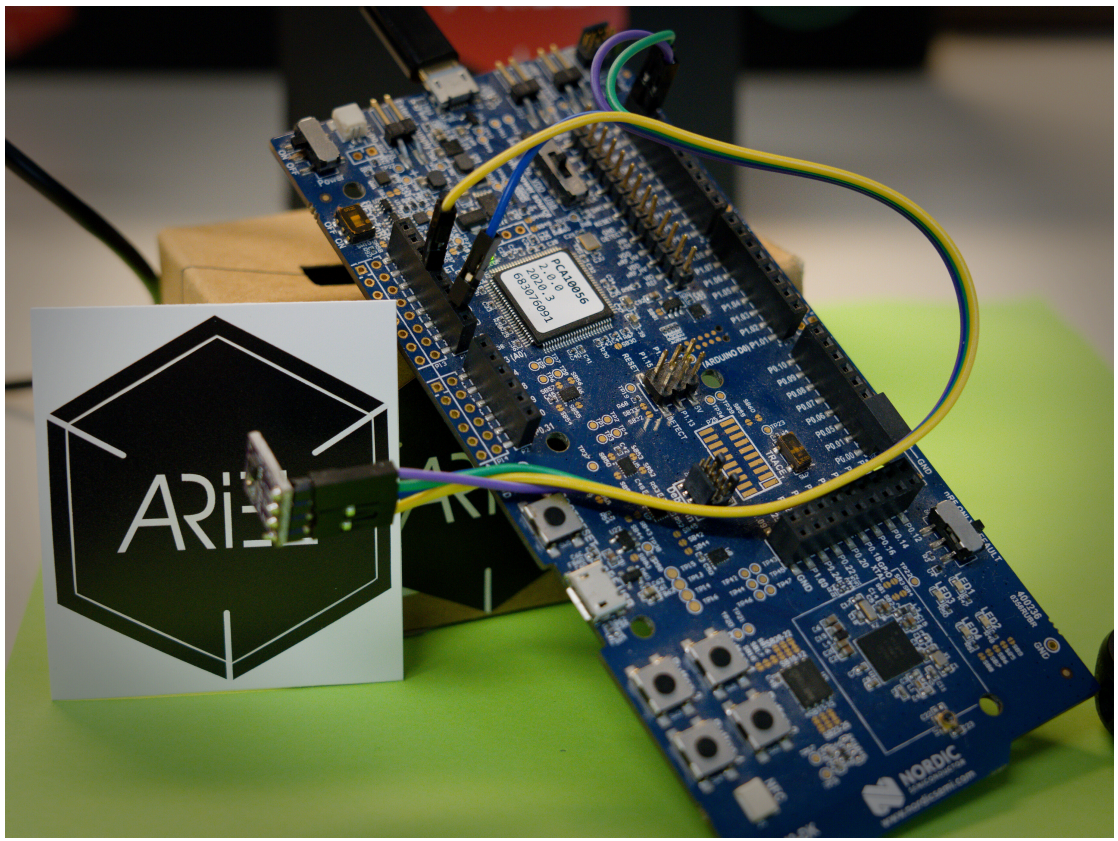
Minimal setup with blinking LED

Connect a sensor

Connect the sensor to the internet

Port the example to another board

Hello World: Hardware



Hello World: Steps

Goal

Show a basic blinking LED

Hardware:

Nordic nRF52840 development kit

Steps

1. Generate the basic project from the template
2. Define LED (GPIO) pin
3. Toggle the led pin in a loop

Hello World: Steps

```Shell
$ cargo generate --git https://github.com/ariel-os/ariel-os-template --name hello-fosdem
```

Project content

```
├─ Cargo.toml
├─ laze-project.yml
└─ src/
   └─ main.rs
```

Hello World: Code

Rust

```rust
#![no_main]
#![no_std]

use ariel_os::debug::
  {ExitCode, exit, log::*};

#[ariel_os::task(autostart)]
async fn main() {
    info!("Hello World!");

    exit(ExitCode::SUCCESS);
}
```

Boilerplate

YAML

```yaml
# laze-project.yml
apps:
  - name: hello-fosdem
```

TOML

```toml
# Cargo.toml
[package]
name = "hello-fosdem"
version = "0.1.0"
edition = "2024"
[dependencies]
ariel-os = { path = "..." }
ariel-os-boards = { path = "..." }
```

Hello World: Running

```
1 $ laze build -b nrf52840dk run                                    Shell
2 [...] (compiling & flashing)
3 [INFO ] Hello World! (hello_fosdem hello-fosdem/src/main.rs:8)    } Printed by hardware
4 Firmware exited successfully
```

Hello World: Add the LED

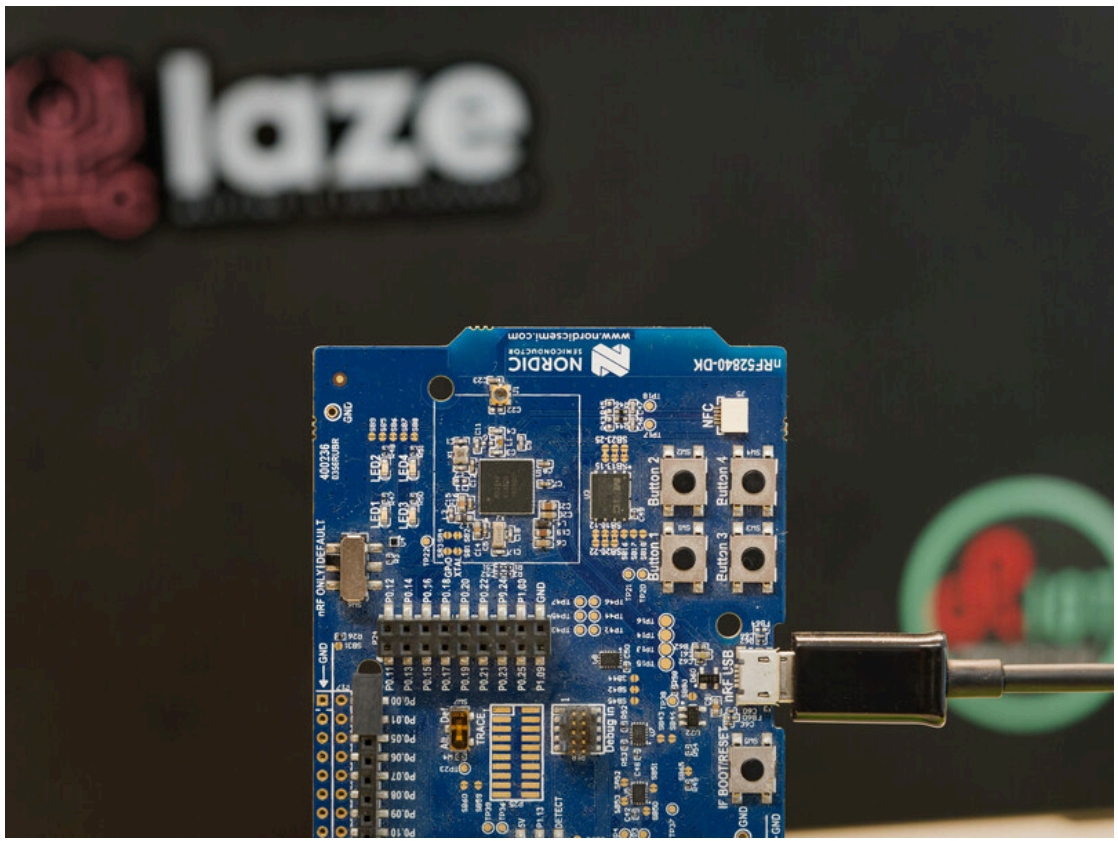
Rust

```rust
define_peripherals!(Peripherals { led0: P0_13 });

#[ariel_os::task(autostart, peripherals)]
async fn main(peripherals: Peripherals) {
    let mut led0 = Output::new(peripherals.led0, Level::Low);

    loop {
        Timer::after_millis(1000).await;
        led0.toggle();
    }
}
```

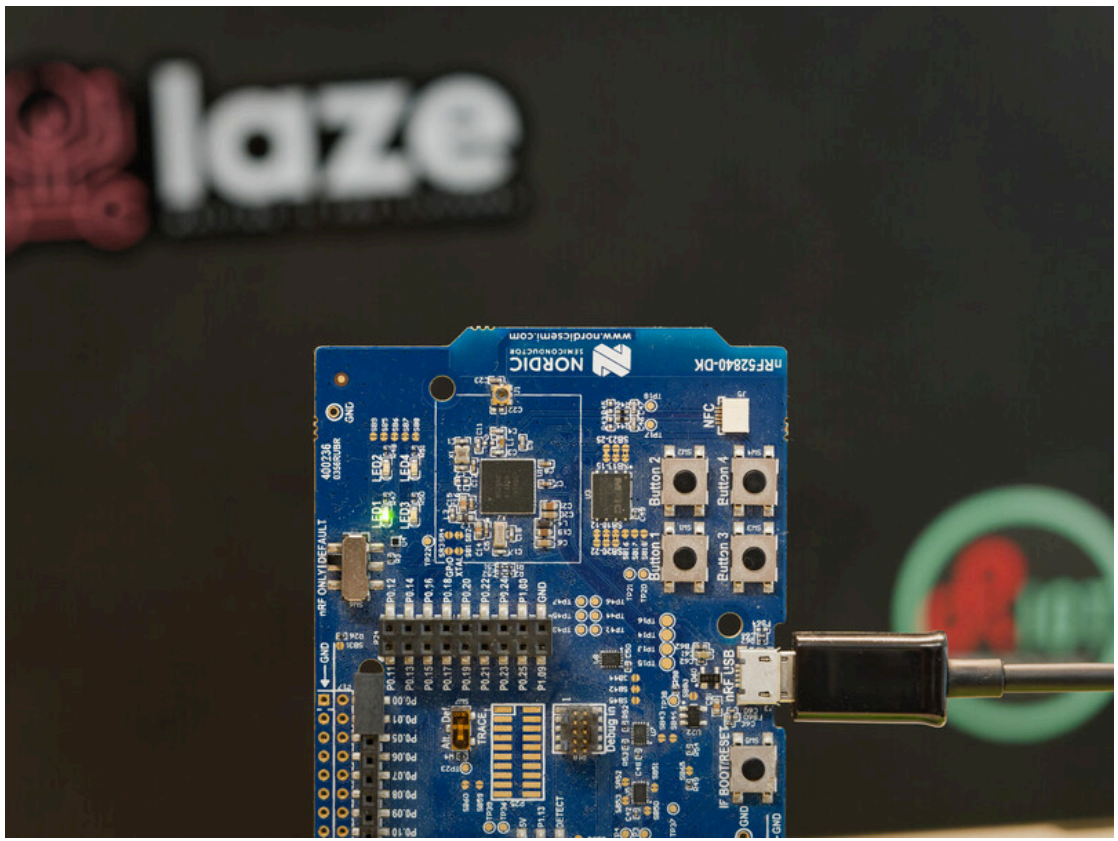
Hello World: Add the LED

```toml
[dependencies]
# add "time" feature
ariel-os = { path = "...", features = ["time"] }
```

Hello World: it blinks



Hello World: it blinks



Sensor Data Printer: Steps

Goal

Add an I2C temperature and humidity sensor

Hardware

SHT31 Temperature & Humidity sensor

Steps

1. Add SHT3x sensor driver crate
2. Define I2C bus in `pins.rs`
3. Read & print out sensor data

Sensor Data Printer: add sensor driver crate

```toml
[dependencies]
# …
embedded-sht3x = { git = "https://gitlab.com/ghislainmary/embedded-sht3x",
                   features = [
                     "async"
                   ]
                 }
```

Sensor Data Printer: define I2C bus/pins

Rust

```rust
mod board {
    use ariel_os::hal::{peripherals, define_peripherals};

    pub type SensorI2c = ariel_os::hal::i2c::controller::TWISPI0;

    define_peripherals!(Peripherals {
        led0: P0_13,
        i2c_sda: P0_26,
        i2c_scl: P0_27,
    });
}
```

Sensor Data Printer: initialize I2C bus

Rust

```rust
#[ariel_os::task(autostart, peripherals)]
async fn main(peripherals: board::Peripherals) {
    let mut led0 = Output::new(peripherals.led0, Level::Low);

    let mut i2c_config = Config::default();
    i2c_config.frequency = const
      { highest_freq_in(Kilohertz::kHz(100)..=Kilohertz::kHz(400)) };

    let i2c_bus = board::SensorI2c::new(peripherals.i2c_sda,
                                        peripherals.i2c_scl,
                                        i2c_config)
```

I2C setup

Sensor Data Printer: perform measurement

Rust

```rust
    // set up sht3x driver
    let mut sensor = Sht3x::new(i2c_bus, DEFAULT_I2C_ADDRESS, Delay);

    loop {
        // Perform a temperature and humidity measurement
        let measurement = sensor.single_measurement().await.unwrap();
        let temp = measurement.temperature.celcius();
        let hum = measurement.relative_humidity;

        info!("temp: {} °C, rel. hum.: {} %\n", temp, hum);

        Timer::after_millis(1000).await;
    }
```

Retrieve Measurement

Sensor Data Printer: that's it

```
$ laze build -b nrf52840dk run
[...] (compiling)
     Running `probe-rs run --protocol=swd --chip nrf52840_xxAA --preverify build/bin/nrf52840dk/cargo/thumbv7em-none-eabihf/release/hello-fosdem`
    Verifying ✔ 100% [####################]  20.00 KiB @  30.90 KiB/s (took 1s)
     Finished in 0.65s
[INFO ] temp: 19.165329 °C, rel. hum.: 39.252308 %
 (hello_fosdem hello-fosdem-2026/src/main.rs:49)
[INFO ] temp: 19.17868 °C, rel. hum.: 39.33318 %
 (hello_fosdem hello-fosdem-2026/src/main.rs:49)
[INFO ] temp: 19.151978 °C, rel. hum.: 39.261463 %
 (hello_fosdem hello-fosdem-2026/src/main.rs:49)
[INFO ] temp: 19.151978 °C, rel. hum.: 39.223316 %
 (hello_fosdem hello-fosdem-2026/src/main.rs:49)
```

Networked Sensor: Steps

Goal

Provide the sensor measurements over a TCP socket

Steps

1. Add TCP send function
2. Call from our main loop
3. Add dependencies
4. Select networking in `laze.yml`

Networked Sensor: TCP send

Rust

```rust
async fn report(s: &str) -> Result<(), &'static str> {
    let host_addr = Ipv4Address::from_str("192.168.1.131").unwrap();
    let stack = net::network_stack().await.unwrap();
    let mut rx_buffer = [0; 256];
    let mut tx_buffer = [0; 256];
    stack.wait_config_up().await;
    let mut socket = TcpSocket::new(stack, &mut rx_buffer, &mut
    tx_buffer);
    socket.connect((host_addr, 4242)).await.map_err(|_| "connect")?;
    socket.write_all(s.as_bytes()).await.map_err(|_| "write_all")?;
    socket.flush().await.map_err(|_| "flush")?;
    Ok(())
}
```

Boilerplate

Create Socket, connect, send

Networked Sensor: Add to the loop

Rust

```rust
loop {
    // ...
    let mut s: String<64> = String::new();
    write!(s, "temp: {temp:.1} °C, rel. hum.: {hum:.1} %\n").unwrap();

    if let Err(e) = report(s.as_str()).await {
        info!("reporting failed: {}", e);
    }
}
```

Format String

Call report

Networked Sensor: Add dependencies

TOML

```toml
[dependencies]
ariel-os = { path = "...",
features = [
  "i2c",
  "tcp",
  "time",
] }
// ...
embedded-io-async = "0.6.1"
heapless = "0.9.2"
```

YAML

```yaml
apps:
  - name: hello-fosdem
    selects:
      - network
```

Networked Sensor: output

```Shell
$ socat -u TCP-LISTEN:4242,fork STDOUT
temp: 20.1 °C, rel. hum.: 45.3 %
temp: 20.1 °C, rel. hum.: 45.2 %
temp: 20.1 °C, rel. hum.: 45.3 %
```

Port it: Steps

Goal

Run the networked sensor on different hardware

Steps

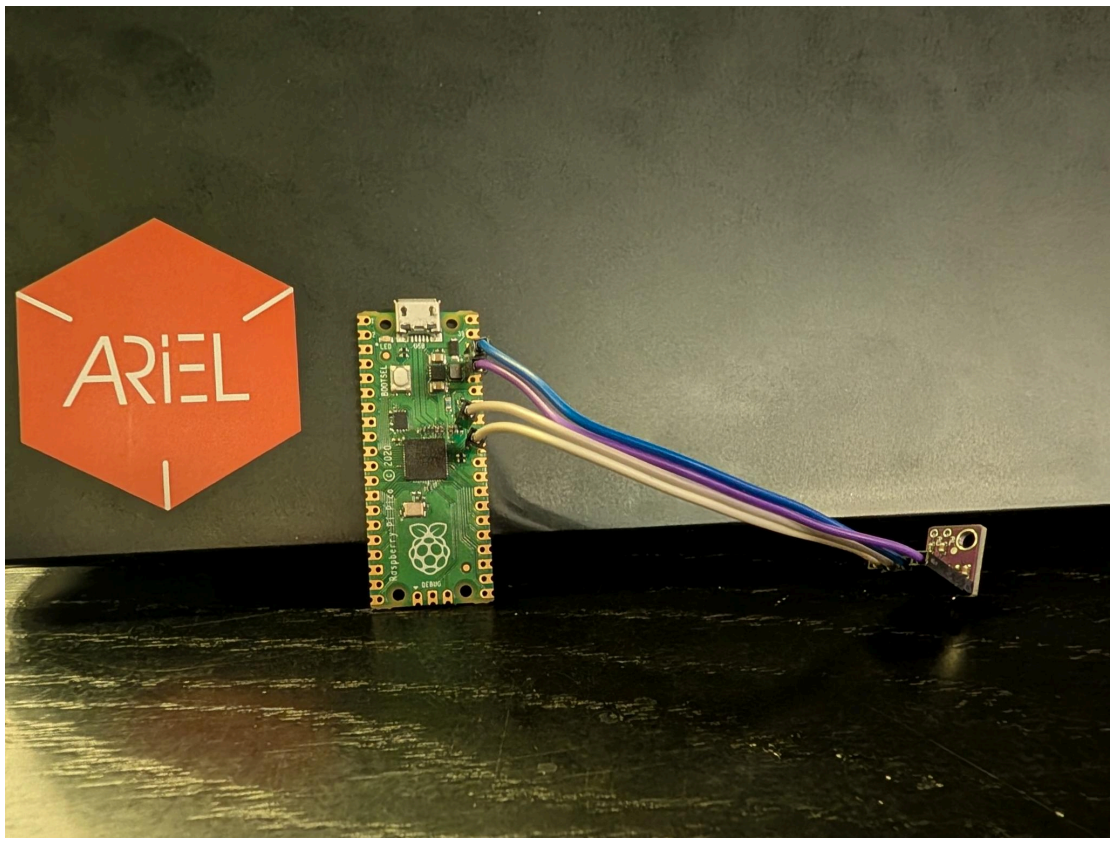
1. define I2C and LED pins for the next board

Port it: defining I2C and LED pins

Rust

```rust
#[cfg(context = "nrf52840dk")]
mod board { /* ... previous version ... */ }

#[cfg(context = "rpi-pico")]
mod board {
    pub type SensorI2c = ariel_os::hal::i2c::controller::I2C0;
    define_peripherals!(Peripherals {
        led0: PIN_25,
        i2c_sda: PIN_12,
        i2c_scl: PIN_13,
    });
}
```

Port it: that’s it



What’s up next

release 0.3.0 landing next week

Adding Bluetooth Low Energy, native “board”, Structured Board Descriptions, …

release after that

secure software updates, better power management, …

Wrapping up

- Ariel OS curates and integrates the embedded Rust ecosystem
- Embedded Rust has never been that easy

You’re now thinking:

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- “Why did they use IPv4 in 2026?”

Wrapping up

- Ariel OS curates and integrates the embedded Rust ecosystem
- Embedded Rust has never been that easy

You’re now thinking:

- “Why did they use IPv4 in 2026?”
- “This looks so approachable, I’ll try it!”

Thanks!

Join the action:

https://ariel-os.org