Embedded Swift Workshop

ARCtic Conference 2025

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Introduction

- Subset of the Swift language
  - Small runtime
  - No runtime reflection
  - Restrictions on existential types
  - Dynamic heap allocations can be disabled
- Work in progress

Supported Architectures

- RISC-V (ESP32)
- STM32
- ARM32 (nRF52840, Raspberry Pi Pico)
- ARM64 (Raspberry Pi 4b/5)
- PowerPC (Freescale)

The ESP32 Family

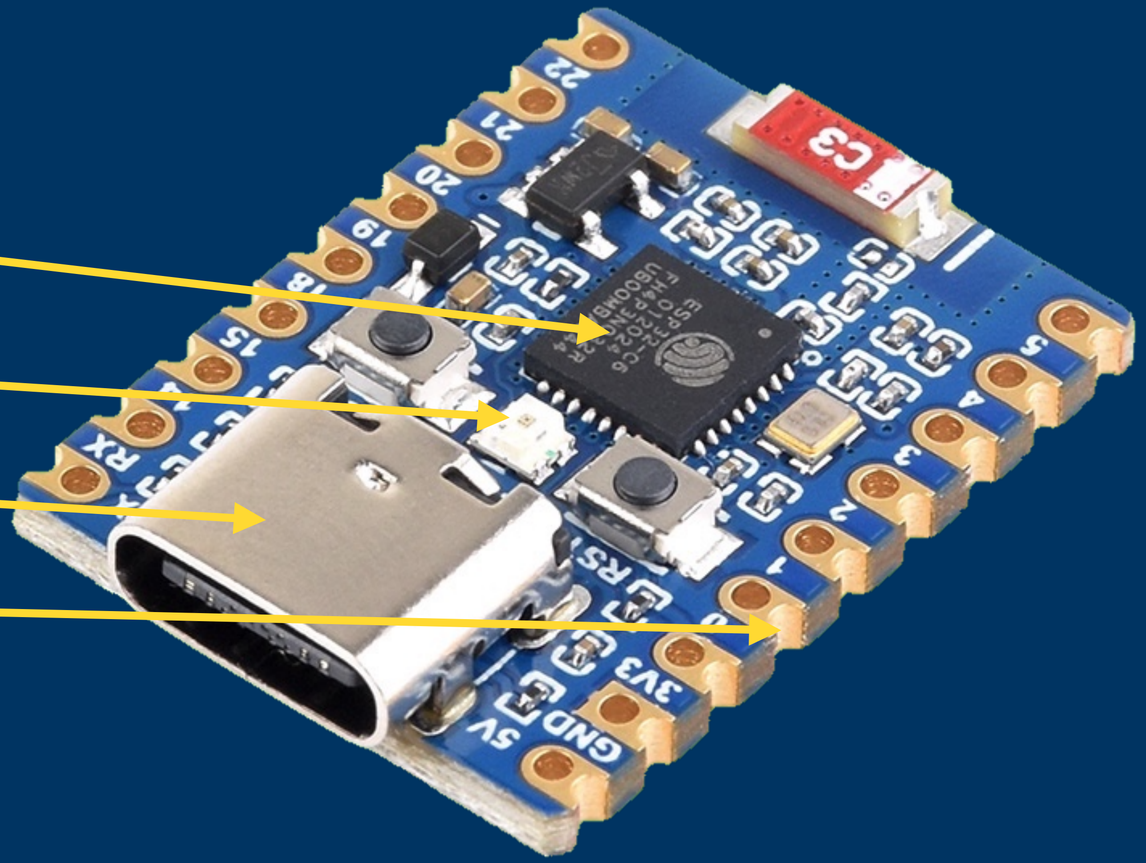
Series	Architecture	Wi-Fi	Bluetooth	Ethernet
ESP32-S	Xtensa (single core)	✔	✔ (ESP32-S3)	
ESP32-D	Xtensa (dual core)	✔		
ESP32-C	RISC-V (single core)	✔	✔	
ESP32-H	RISC-V (single core)		✔	
ESP32-P	RISC-V (dual core)			✔

ESP32-C6

- Single-Core 160 MHz RISC-V CPU (+ low-power core)
- 512KB RAM
- Up to 16MB Flash
- Wi-Fi 6 (2.4 GHz)
- Bluetooth LE 5.3
- Threads, Zigbee

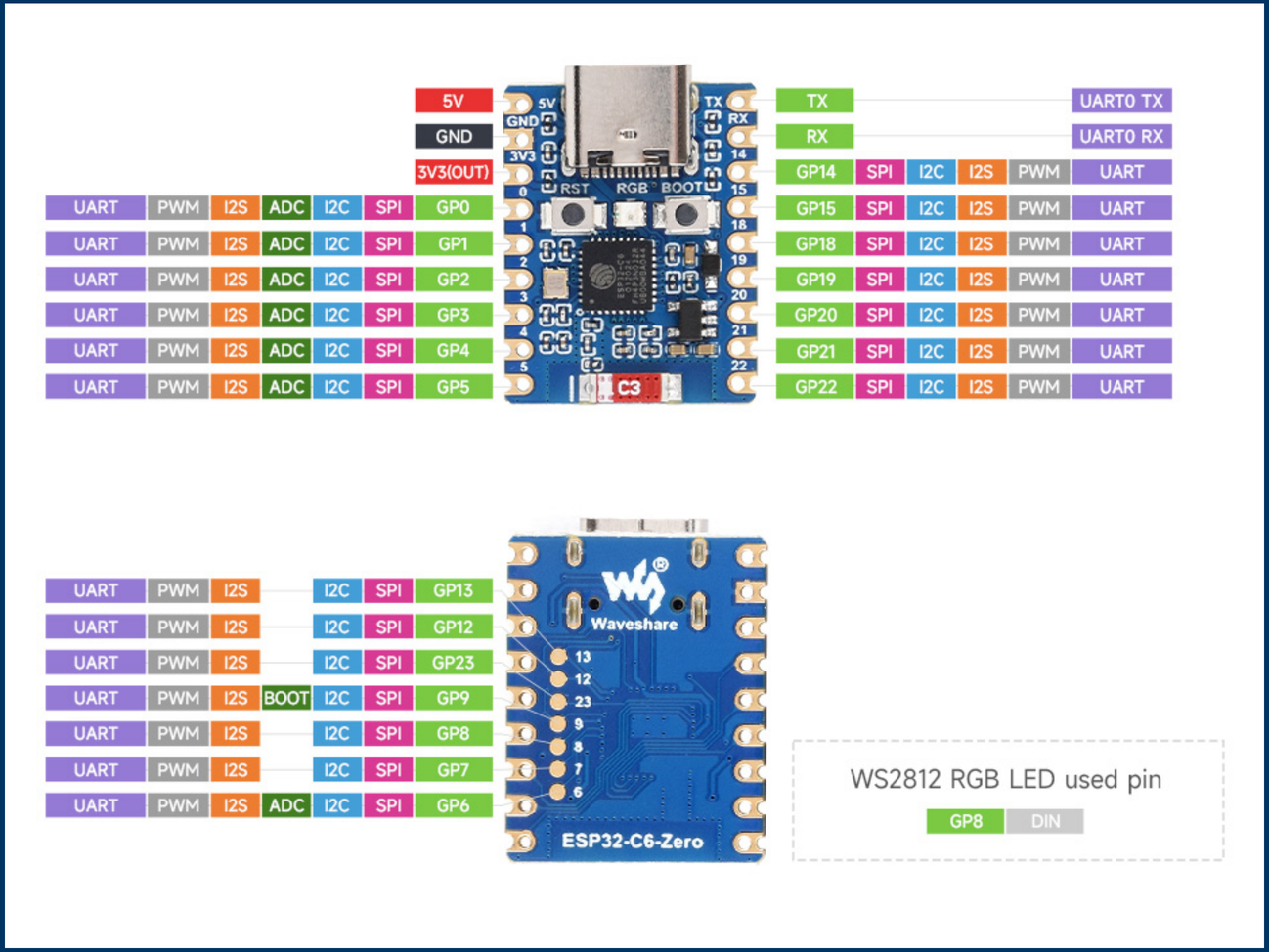
Waveshare ESP32-C6 development board

- ESP32-C6 (4MB Flash)
- RGB LED
- USB-C power+data
- 20 programmable IO pins



Development Board I/O

Flexible configuration



Tools & Resources

- Swift Toolchain: development snapshot
- Visual Studio Code
- ESP-IDF
- CMake, Ninja

Hands-on

Setup

- Download and install
  - Swift Toolchain
  - Visual Studio Code
  - ESP-IDF plugin for VS Code
  - Swift plugin for VS Code
- Build and run “blink” project

Blinking LED

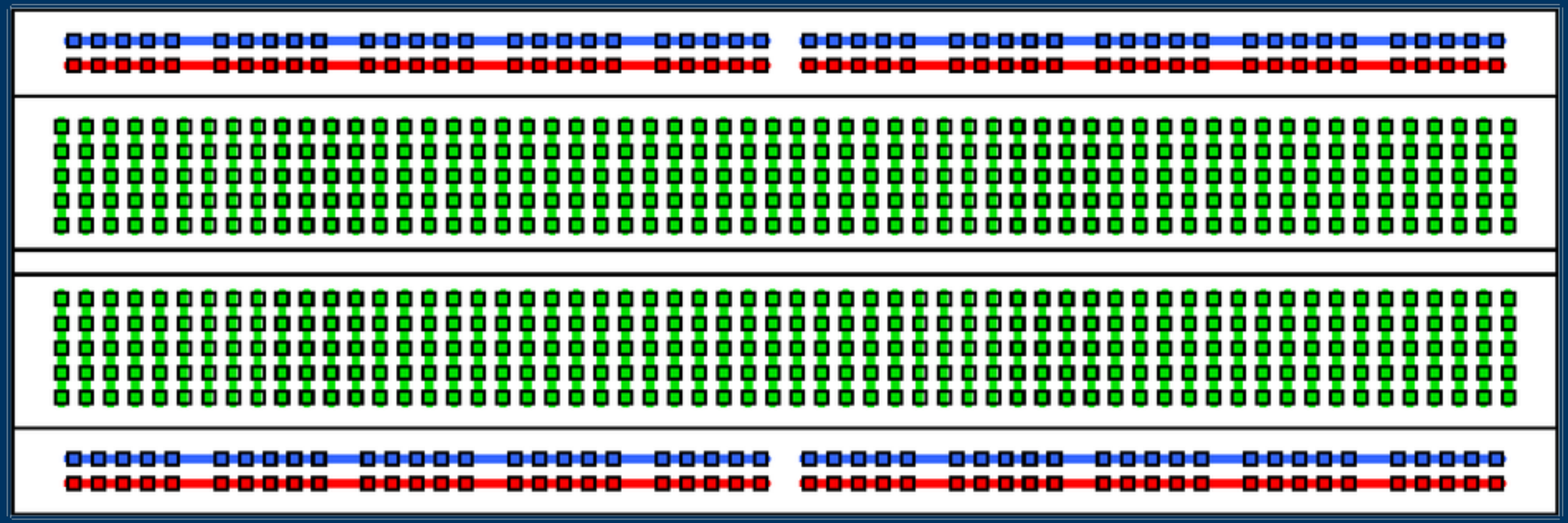
Basic GPIO

- GPIO pin configuration by software
- Output mode
  - 0V, 3.3V
  - 20 mA max (200 mA total)

LED

- Characteristic voltage: 1.8V (red/green), 2.5V (blue)
- 20 mA max
- Resistor: 330Ω

Solderless Breadboard



Hands-on

Blinking LED

- Connect LED & resistor
- Open 00-Start-Here project with VS Code
- Change settings
- Build and run

Troubleshooting

Troubleshooting

Build & Install

- $PATH
  - idf.py
- toolchain
  - swift -version
- connection
  - ls /dev/tty.*
  - echo $ESPPORT

Troubleshooting

Runtime

- print() debugging
  - string interpolation limitations
- LED debugging
- Core dump analysis
  - swift demangle
  - use the embedded toolchain

Swift-C Interoperability 101

Using C Types from Swift

Swift-C Interoperability

- BridgingHeader.h
- Simple types
- Simple functions
- #define macros

Memory Layout

- MemoryLayout<Type>.size
- MemoryLayout<Type>.stride
- MemoryLayout<Type>.alignment

Typed Pointers

- UnsafePointer<Type>
- UnsafeMutablePointer<Type>
- access to payload: pointee
- Heap allocation: allocate(capacity:), deallocate()
- Temporary use as pointer: withUnsafe[Mutable]Pointer { ptr in ... }
  - Valid only inside closure

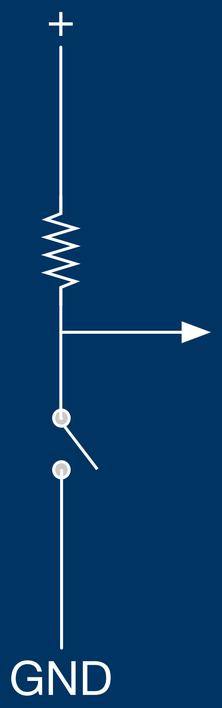
Opaque Pointers

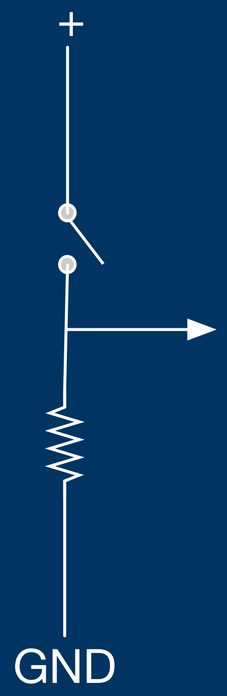
- C: void *
- Swift: UnsafeMutableRawPointer?
- Access to typed data
  - assumingMemoryBound(to: Type.self) -> UnsafeMutablePointer<Type>

Simple Input

GPIO Input Setup

- Switch: opened, closed
- Pull-up, pull-down





Hands-on

Simple input

- Connect the switch
- Create Input class
- Update main
- Test

Interrupts

Interrupts on ESP32

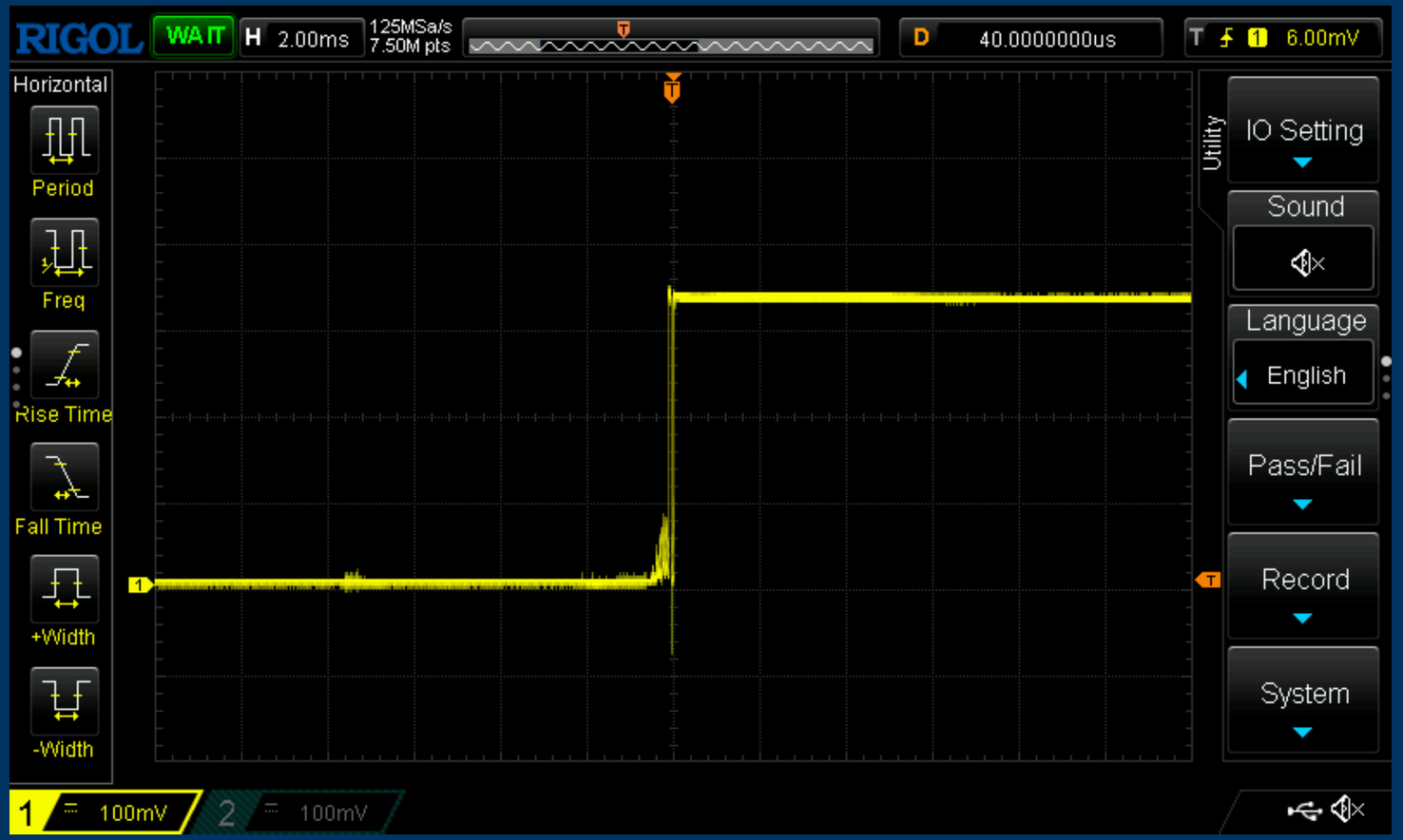
- 7 priority levels
  - level 1 = low priority
  - level 7 = NMI
- Interrupt handling
- ISR constraints

Hands-on

Interrupt-driven callback

- Define InterruptHandlerContext
- Deal with opaque pointer in interrupt handler
- Update Input.init
- Update main
- Test

Bouncing


RIGOL
WAIT
H 2.00ms
125MSa/s
7.50M pts
D 40.0000000us
T 1 6.00mV
Horizontal
Period
Freq
Rise Time
Fall Time
+Width
-Width
Utility
IO Setting
Sound
Language
English
Pass/Fail
Record
System
1 100mV
2 100mV

Bouncing


RIGOL
WAIT
H 100us
125MSa/s
7.50M pts
D -58.0000000us
T 1 6.00mV
Horizontal
Period
Freq
Rise Time
Fall Time
+Width
-Width
Utility
IO Setting
Sound
Language
English
Pass/Fail
Record
System
1 100mV
2 100mV

Debouncing

Debouncing

- Start timer in input interrupt handler
- Ignore input state changes while timer is running
- Check input state when timer expires
- Typical timer duration: 2-20 ms

Hands-on

Debouncing

- Enable ESP Timer ISR dispatch
- Add Timer.swift and Errors.swift, update BridgingHeader.h
- Build
- Create DebouncedInput class
- Update main
- Test

Event Loop

Event Loop

- Event Queue
- Posting from ISR

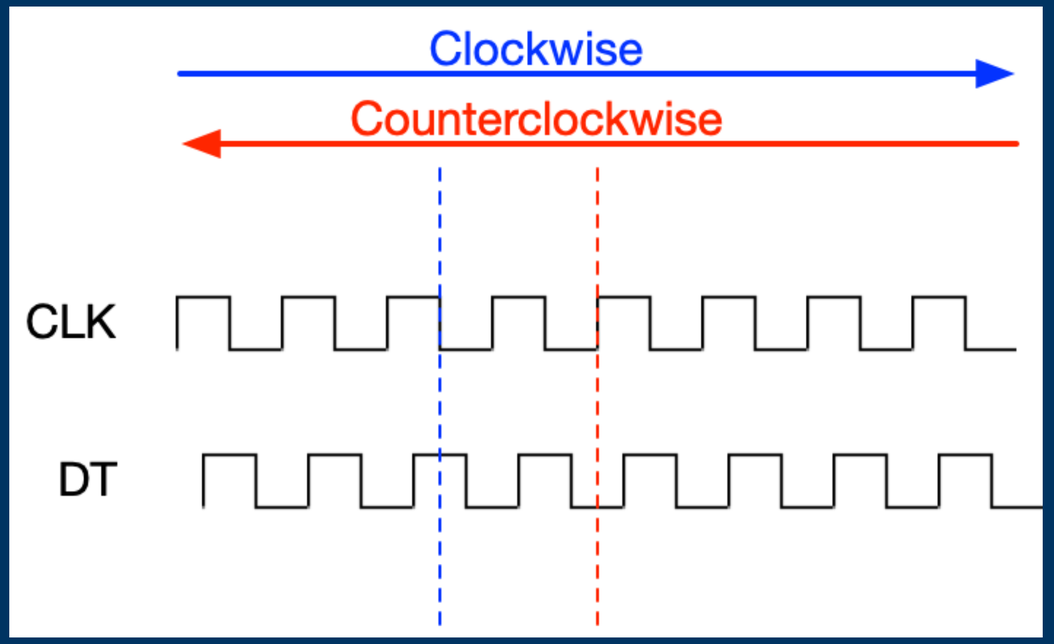
Hands-on

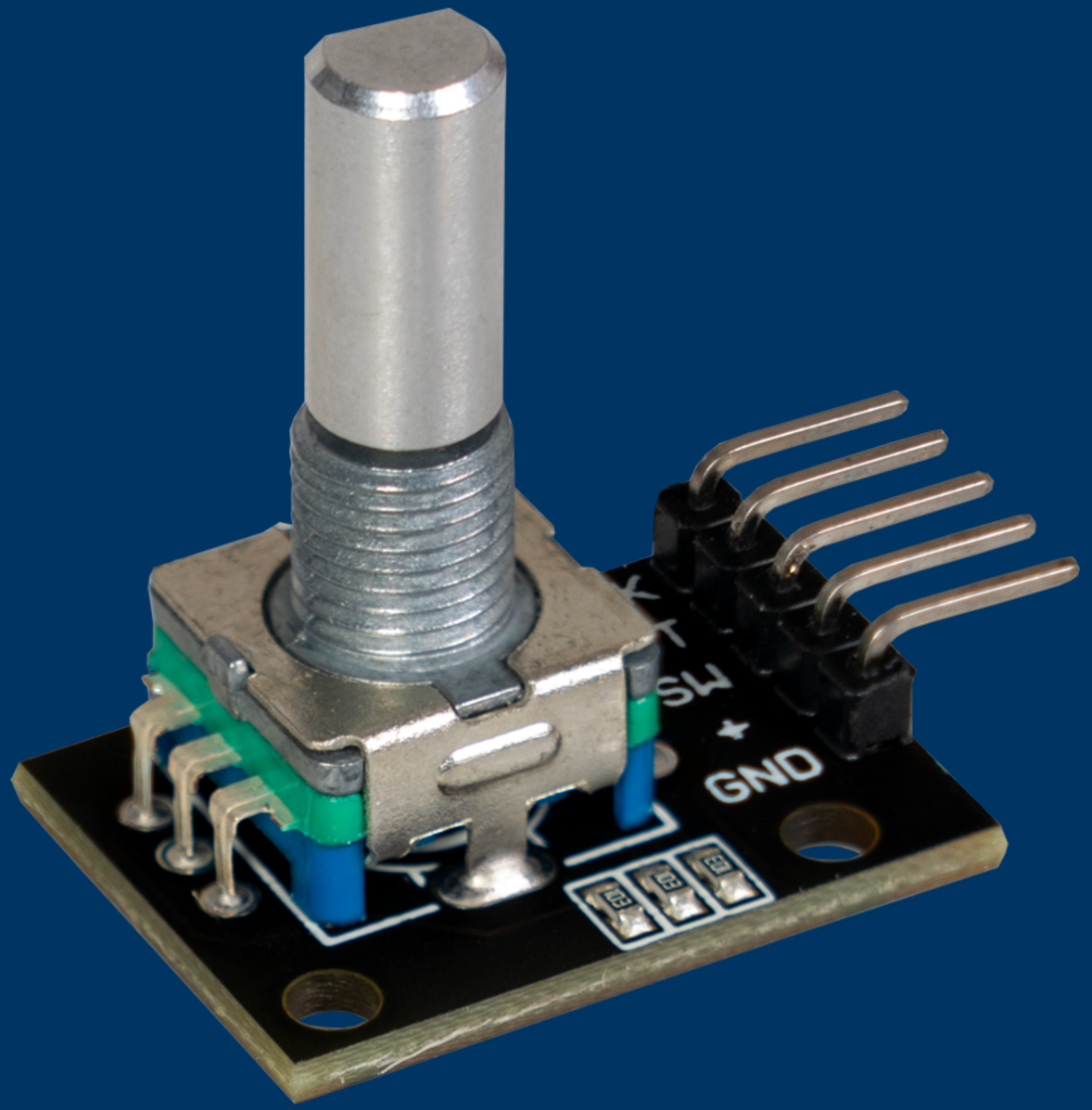
Event Loop

- Add Queue.swift and update BridgingHeader.h
- Create TimedEvent<Event> and EventLoop<Event>
- Update main
- Test

Rotary Encoder

KY-040



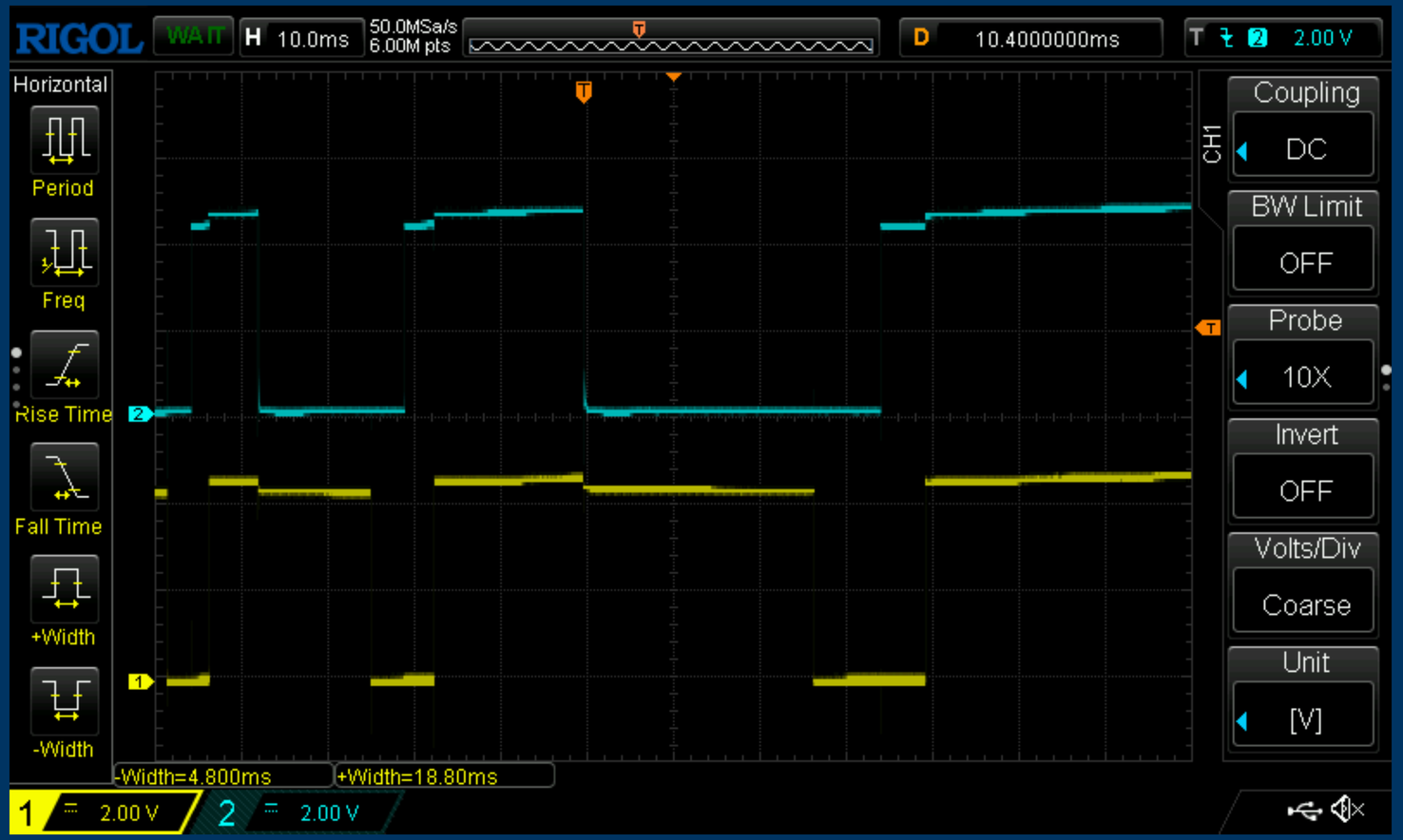


KY-040

Clockwise

CLK

DT

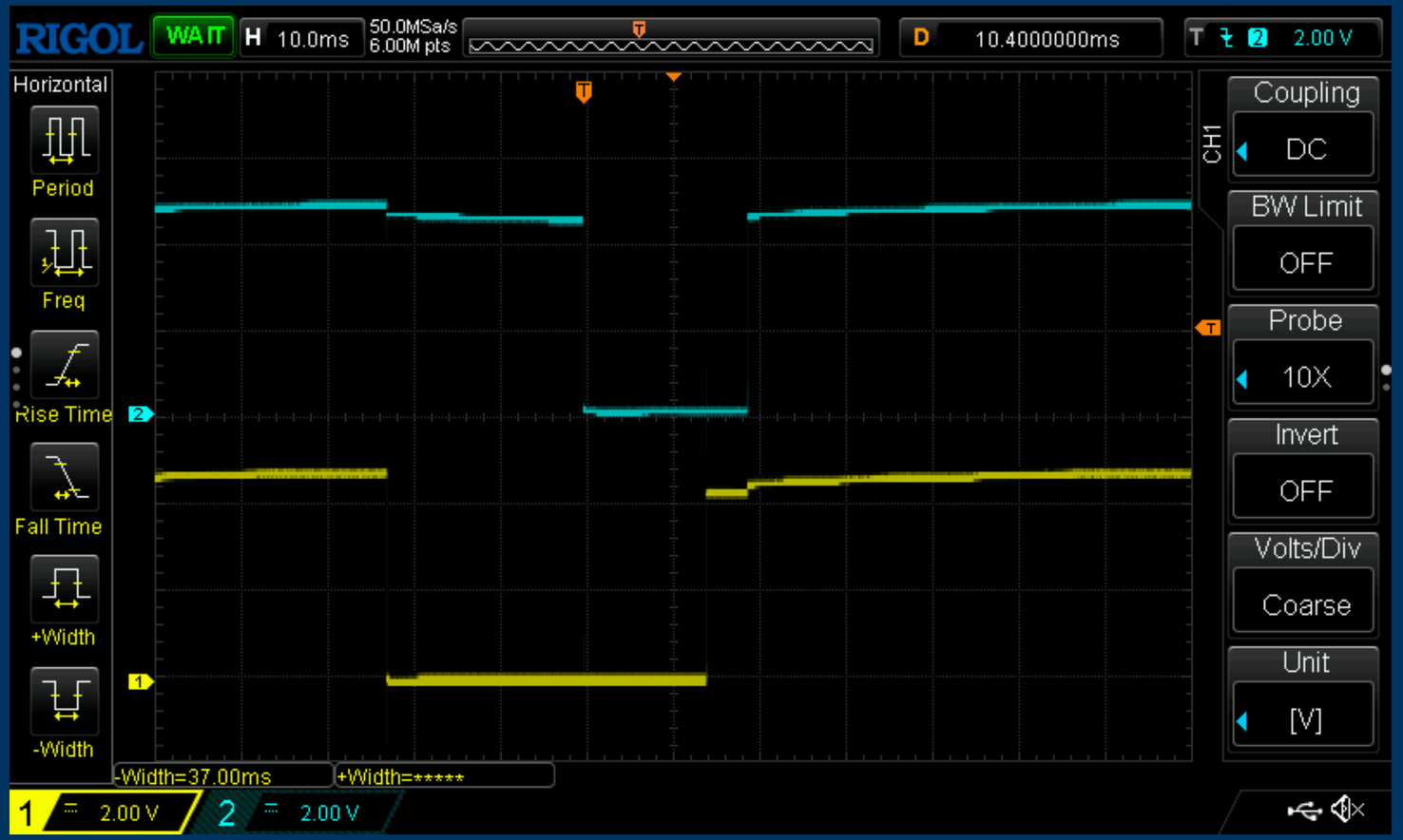


KY-040

Counterclockwise

CLK

DT



Hands-on

Rotary Encoder

- Connect CLK and DT
- Create Direction enum
- Create RotaryController class
- Update main
- Test

Advanced I/O

Beyond binary I/O

Supported by ESP32

- Analog: ADC, PWM
- UART
- I2C, SPI, CAN
- I2S
- RMT

I2C

- Open-drain bus
- Bidirectional
- Master-slave
- SCL, SDA
- Selection: 7-bit identifier
- Typical throughput: 400 kbps

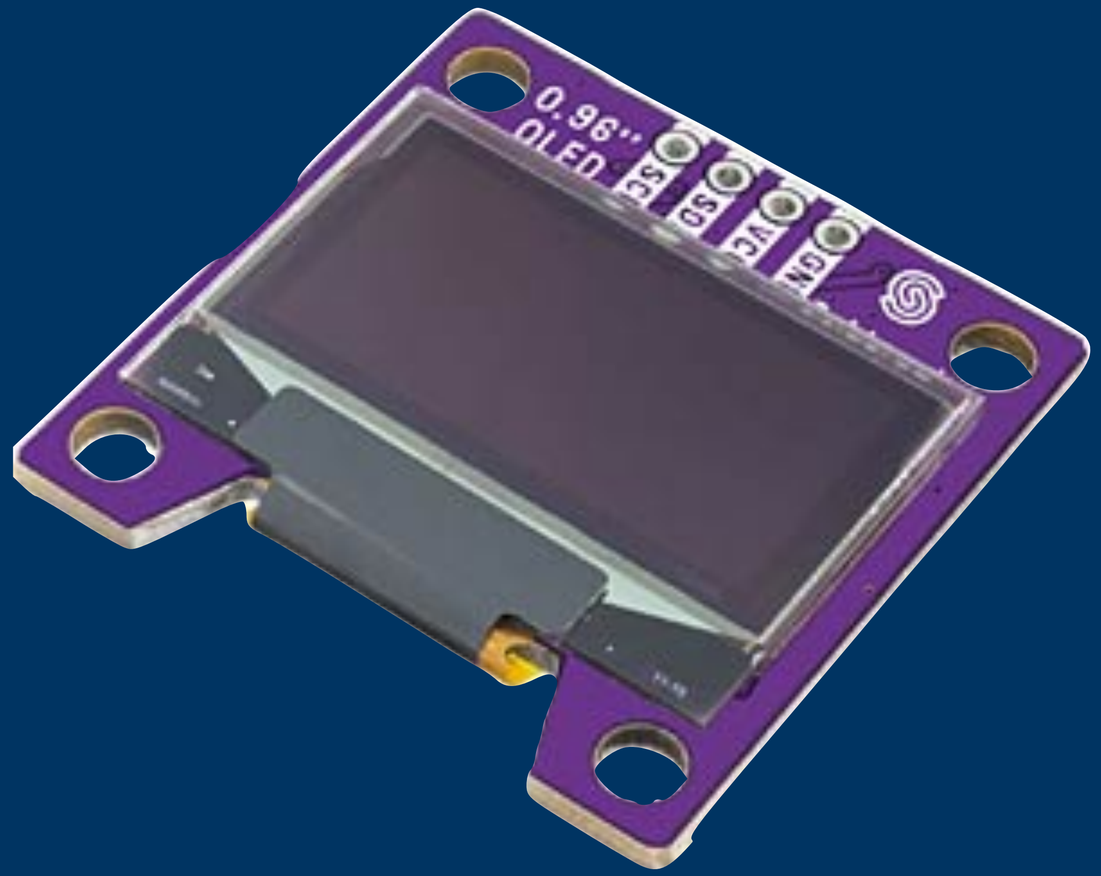
SPI

- Unidirectional
- Master-slave
- Signals: SCLK, MOSI, MISO
- Selection: SS (CS) wire
- Typical throughput > 1 Mbps

Display

SSD1306

- 128x64
- Monochrome OLED
- I2C connection
- 3.3V power



U8g2 Library

- Open source C library
- Lines, shapes
- Text, fonts
- 2 abstraction layers
  - display support: I2C, SPI
  - microcontroller support: requires driver (u8g2-hal-esp-idf)

Hands-on

Display

- Download and add u8g2 and u8g2-hal-esp-idf
- Apply patch to u8g2-hal-esp-idf
- Add Swift wrappers
- Display counter value
- Finish Display implementation
- Draw bargraph

Bluetooth LE

Generic Access Profile (GAP)

No connection (yet)

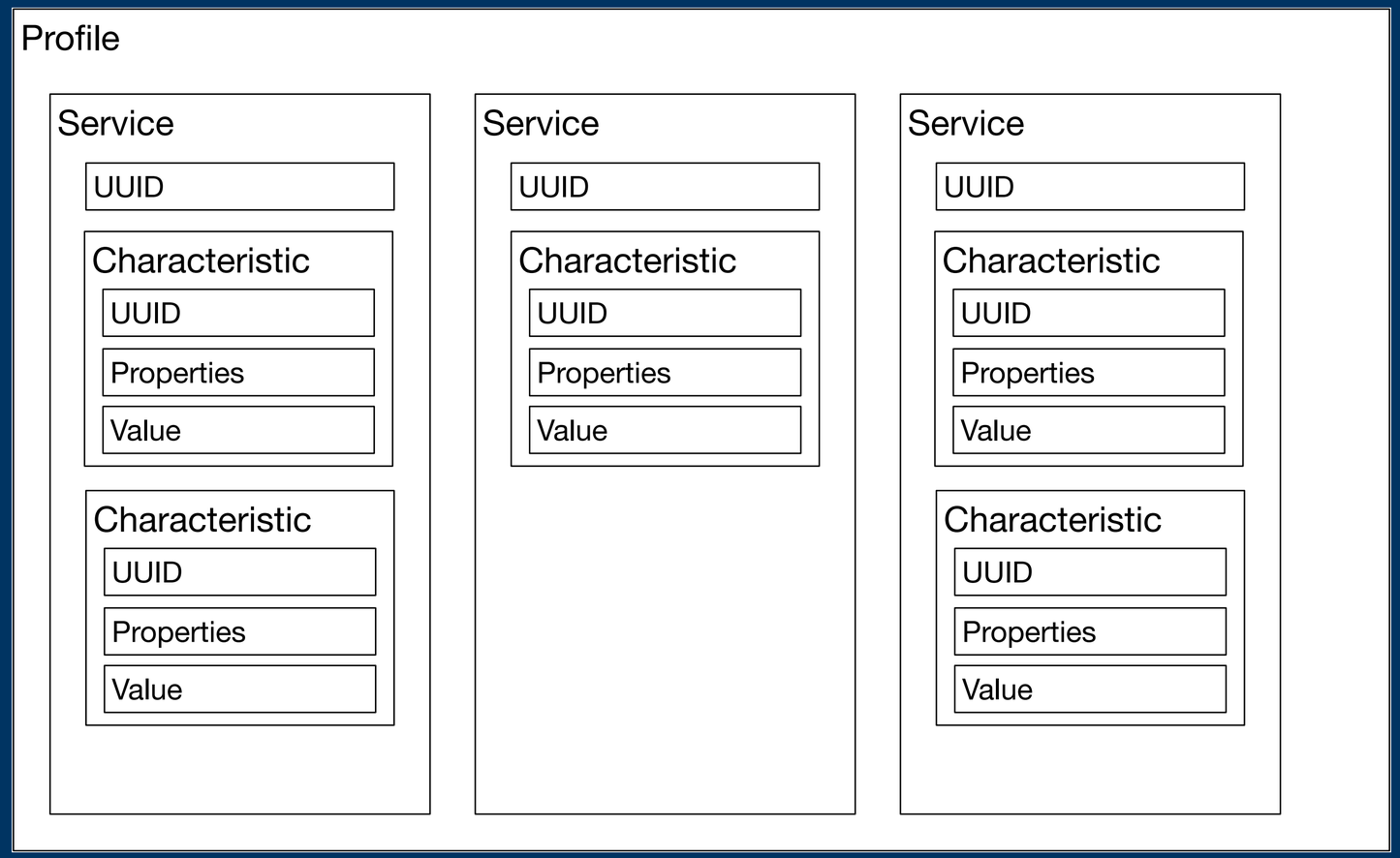
- Broadcasting Roles
  - Broadcaster
  - Observer
- Connecting Roles
  - Central
  - Peripheral

Generic Attribute Profile (GATT)

Connected state

- Device Roles
  - Client
  - Server
- Security
- Device Profile

Device Profile



BLE UUID

- Different lengths
  - 16-bit
  - 32-bit
  - 128-bit
- Well-known services and characteristics
- Central registry ("assigned numbers")

BLE with ESP-IDF

- Bluetooth Stacks
  - NimBLE
  - Bluedroid
- NimBLE Swift wrapper

String support

Advanced String support

- What is "advanced"?
  - Unicode grapheme clusters
  - count, compare (sort), Set/Dictionary, case, split…
- Embedded Swift constraints and workaround
  - libUnicodeDataTables.a
  - utf8 and unicodeScalars views

Hands-on

Bluetooth Peripheral

- Add wrappers
- Implement decoder for UUID128 strings
- Create service and characteristic
- Start advertising
- Test with LightBlue

Core Bluetooth

Core Bluetooth

- Delegate-based
- Main classes
  - CBCentralManager
  - CBPeripheral
  - CBService, CBCharacteristic
- Values: Data
- Permission in Info.plist

BluetoothConnectionManager

- Simple Core Bluetooth wrapper
- Single service, single characteristic
- Not production-ready
- Interface
  - Generic value
  - @Observable: state, readValue
  - write(value:)

Hands-on

iOS Application

- Create SwiftUI App
- Add BluetoothConnectionManager
- Handle state in ContentView
- Test
- Finish BluetoothConnectionManager implementation
- Update ContentView
- Test

AccessorySetupKit

AccessorySetupKit

- Discovery framework
- Bluetooth, Wi-Fi
- Better privacy
- Consistent UI
- Handles pairing process if needed
- Requires iOS 18

ASAccessorySession

Bluetooth Discovery

- activate with closure
  - activated event: list of known accessories
  - accessoryAdded, accessoryRemoved
  - pickerDidDismiss
- showPicker
  - ASPickerDisplayItem, ASDiscoveryDescriptor

Hands-on

AccessorySetupKit

- Update Info.plist
- Create DiscoveryService class
- Handle events
- Implement showPicker
- Update BluetoothServiceManager
- Test