



# Exceptions and Interrupts

Lecture 3



# Exceptions and Interrupts

used by RP2040

- Exceptions
- Interrupts
- Boot



# Exceptions

for the ARM Cortex-M processor



# Bibliography

for this section

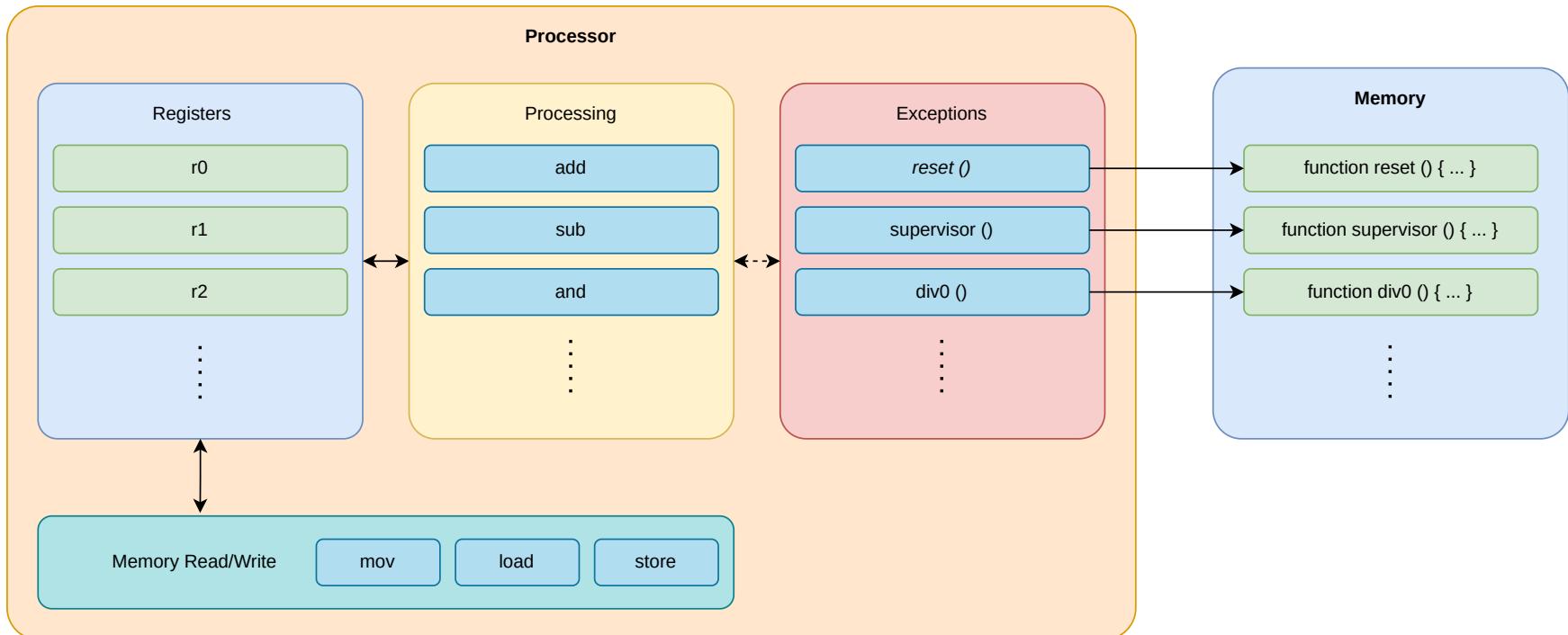
**Joseph Yiu, *The Definitive Guide to ARM® Cortex®-M23 and Cortex-M33 Processors***

- Chapter 4 - *Architecture*
  - Section 4.5 - *Exceptions and Interrupts*
    - Subsection 4.4.1 - *What are exceptions*
- Chapter 8 - *Exceptions and Interrupts*
  - Section 8.1 - *What are Exceptions and Interrupts*
  - Section 8.2 - *Exception types*<sup>+</sup>



# Processor Exceptions

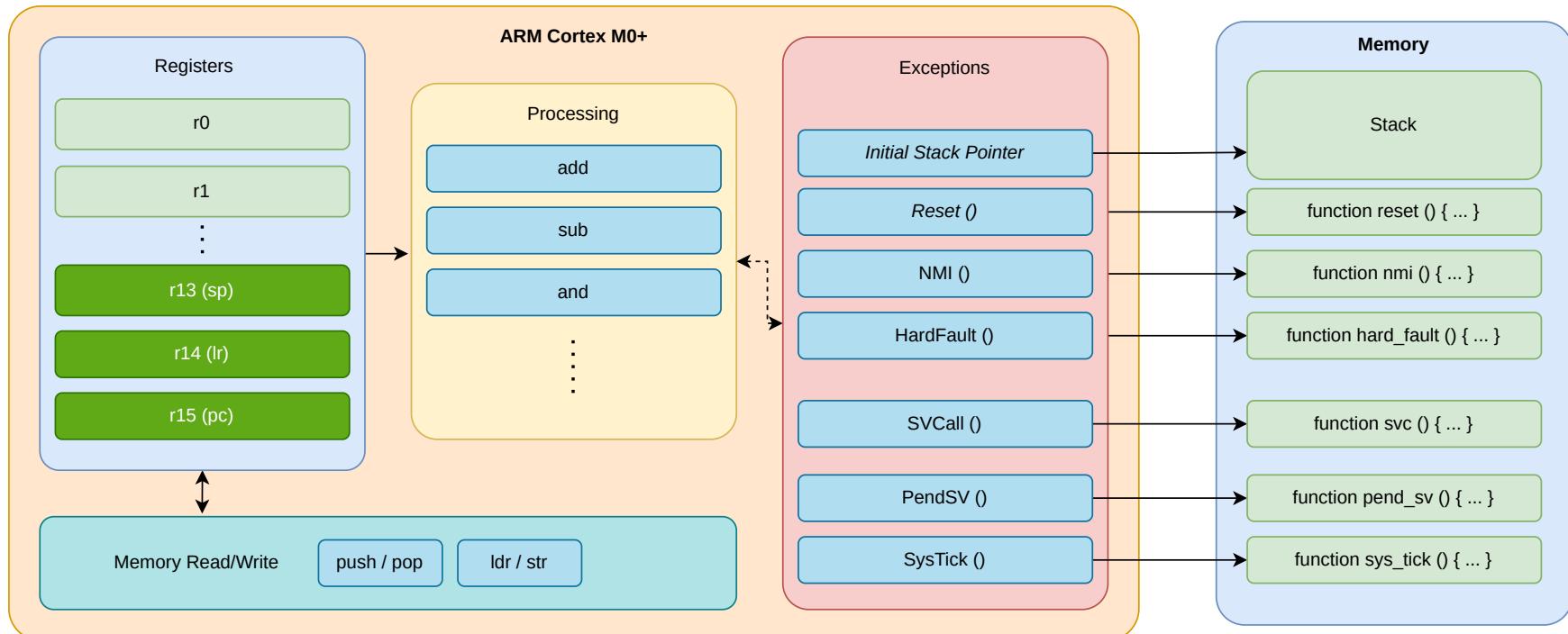
what happens if something does not work as required





# ARM Cortex-M Exceptions

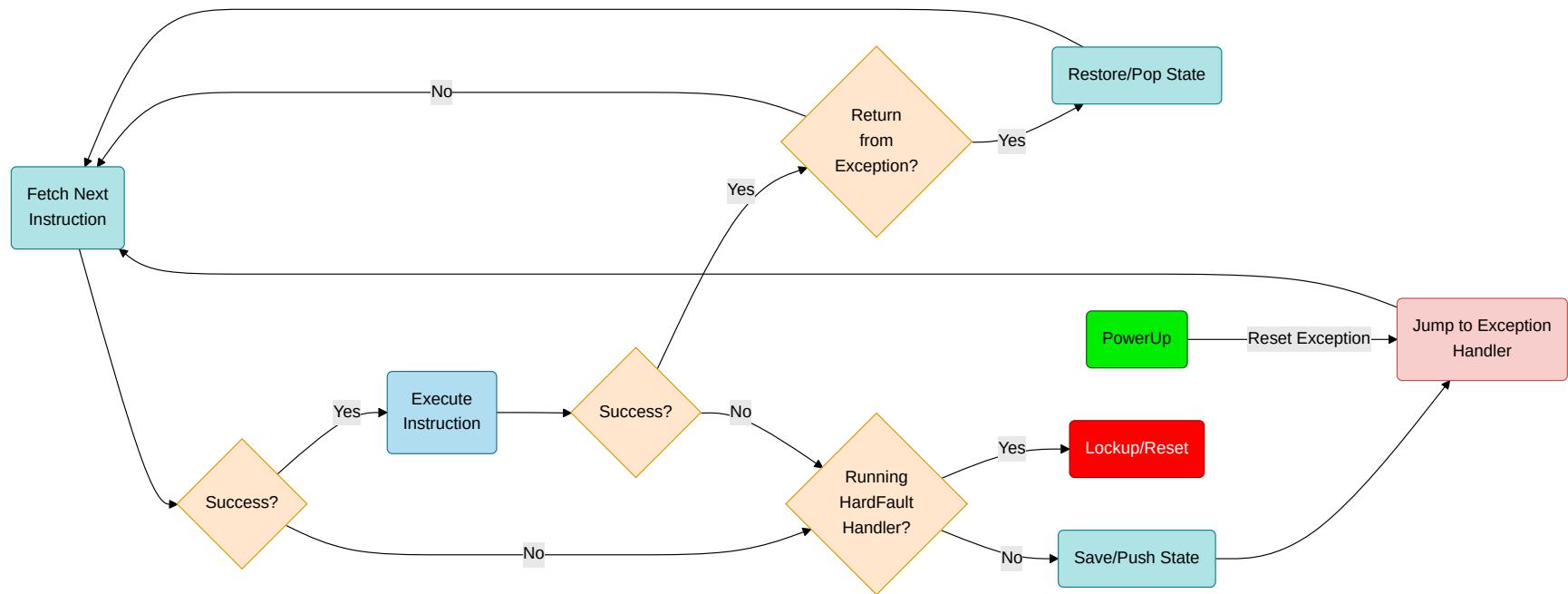
what happens if something does not work as required





# Exception (HardFault) Handling

ARM Cortex-M has one **actual exception**, *HardFault*



- the exception table of RP2040 at address 0x1000\_0100, RP2350 at address 0x1000\_0000
- the processor generates a *Reset* exception when it starts



# Interrupts

for ARM Cortex-M0+



# Bibliography

for this section

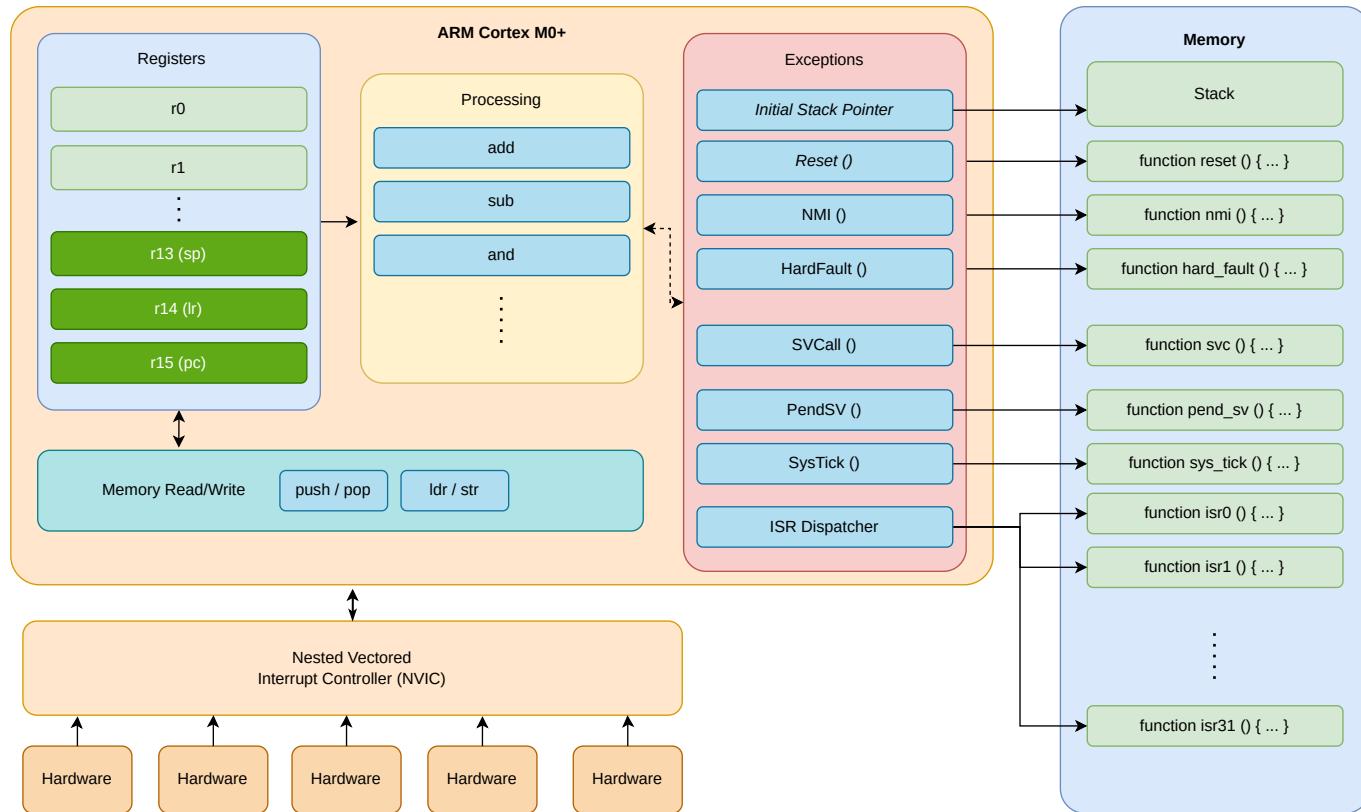
**Joseph Yiu**, *The Definitive Guide to ARM® Cortex®-M0 and Cortex-M0+ Processors, 2nd Edition*

- Chapter 8 - *Exceptions and Interrupts*
  - Section 8.1 - *What are Exceptions and Interrupts*
  - Section 8.3 - *Brief Overview of the NVIC*
  - Section 8.4 - *Definition of Exception Priority Levels*
  - Section 8.5 - *Vector Table*
  - Section 8.6 - *Exception Sequence Overview*
- Chapter 11 - *Fault Handling*
  - Section 11.1 - *Fault Exception Overview*
  - Section 11.2 - *What Can Cause a Fault*
  - Section 11.7 - *Lockup*



# ARM Cortex-M Interrupts

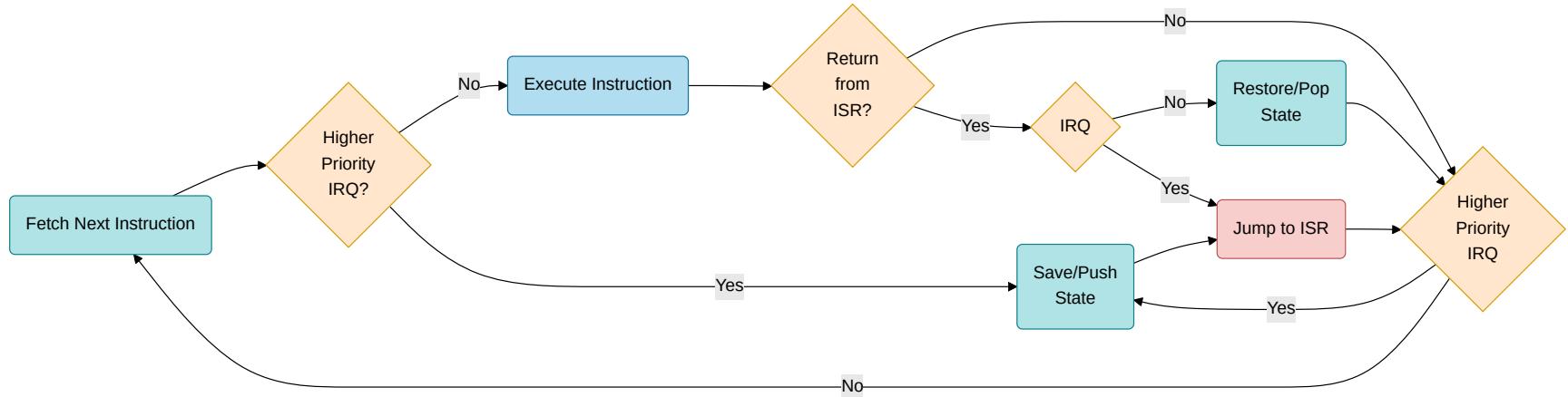
some hardware device notifies the MCU





# Interrupt Handling

ARM Cortex-M



*IRQ*      Interrupt Request

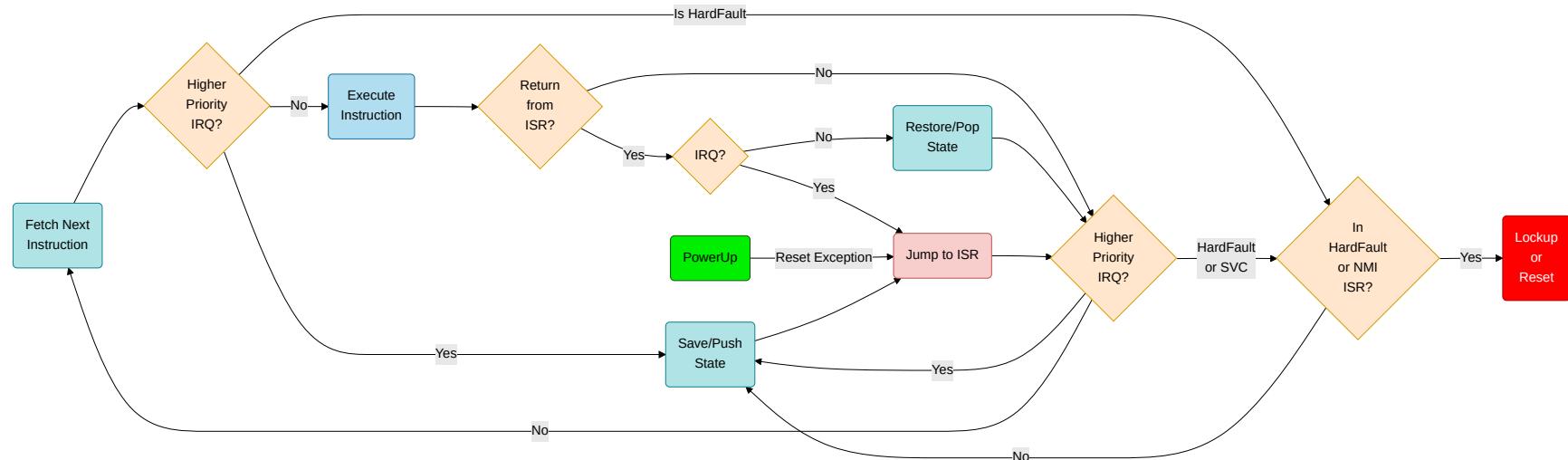
*ISR*      Interrupt Service Routine

- the interrupt vector (table) of RP2350 starts at address 0x1000\_0040 (after the exceptions table with 15 interrupts)
- ARM Cortex-M0+ has a maximum of 32 IRQs
- ARM Cortex-M33 has a maximum of 480 IRQs



# Exceptions are Software Interrupt Requests

with a negative IRQ number and a higher priority





# Boot

of the RP2040 and RP2350



# Bibliography

for this section

## Raspberry Pi Ltd, RP2040 Datasheet

- Chapter 2 - *System Description*
  - Section 2.7 - *Boot sequence*
  - Section 2.8 - *Bootrom*
    - Subsection 2.8.1 - *Processor Controlled Boot Sequence*

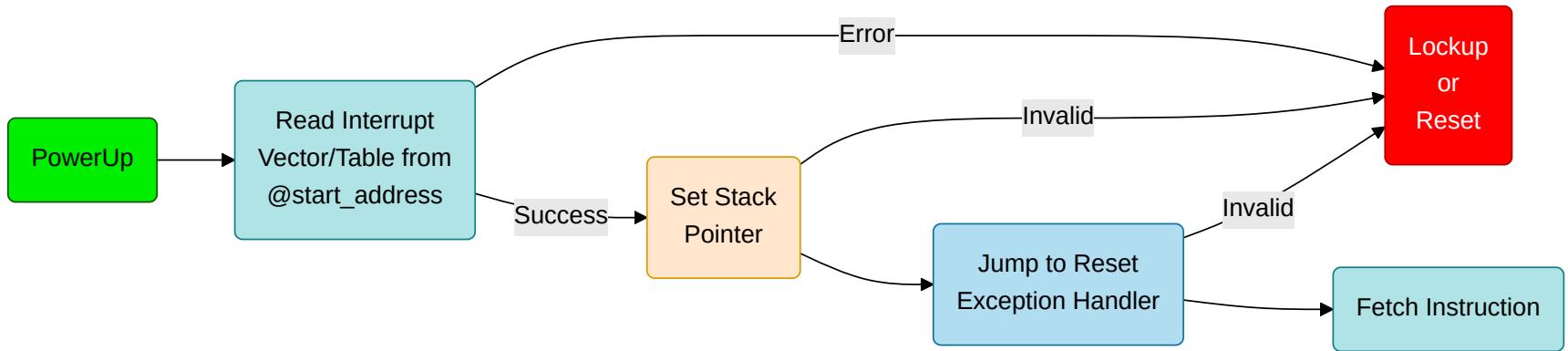
## Raspberry Pi Ltd, RP2350 Datasheet

- Chapter 5 - *Bootrom*
  - Section 5.1 - *Bootrom concepts*



# Boot

how the ARM Cortex-M starts

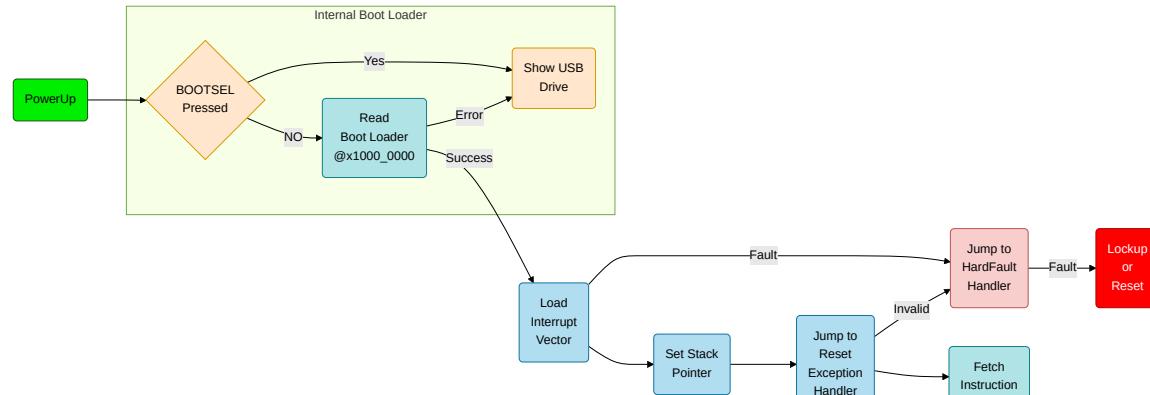


- the *start\_address* for RP2040 is 0x1000\_0100
- the *start\_address* for RP2350 depends on the *Start Block* items
- RP2040 & RP2350 have another boot loader that it loads from 0x0000\_0000

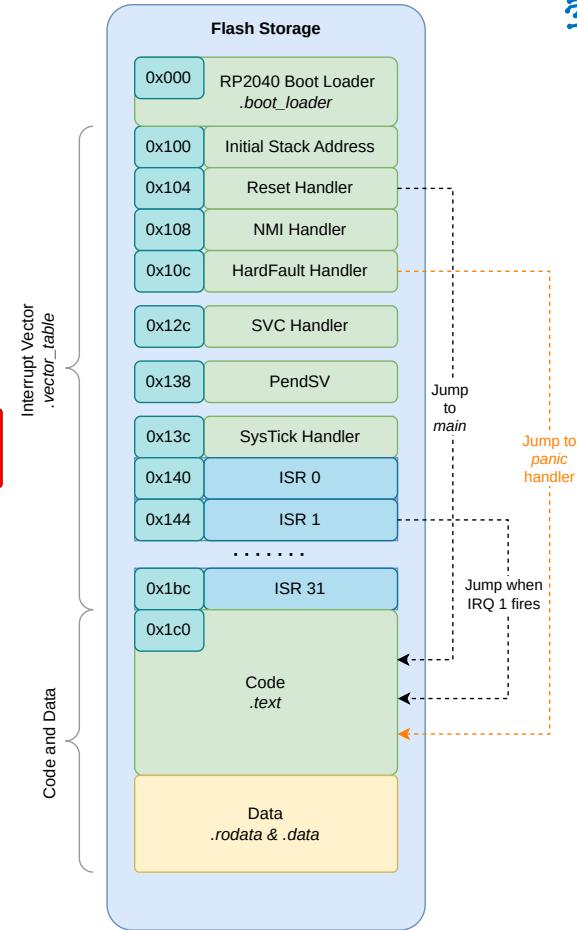


# Boot

The RP2040 boot process



The internal boot loader cannot be overwritten and assures that bricking the device is difficult.

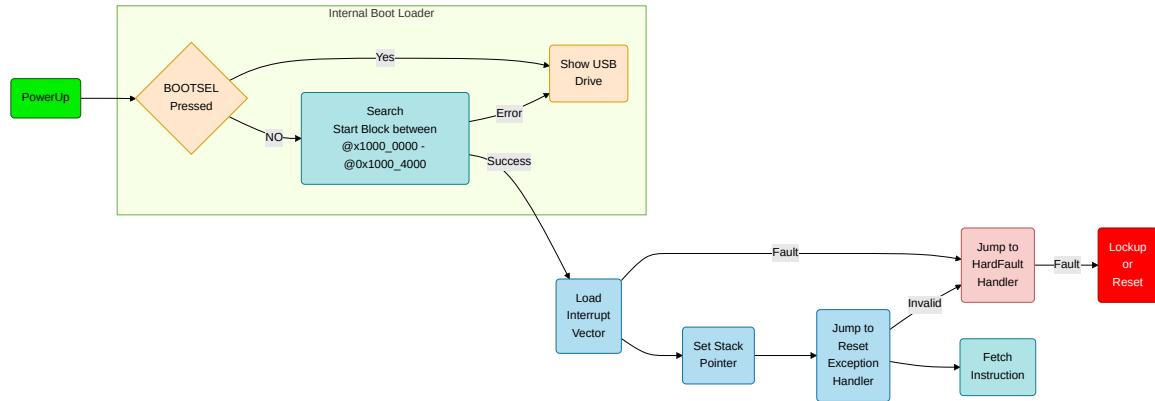


\* drawing is not at scale, code and data are significantly greater than the interrupt vector

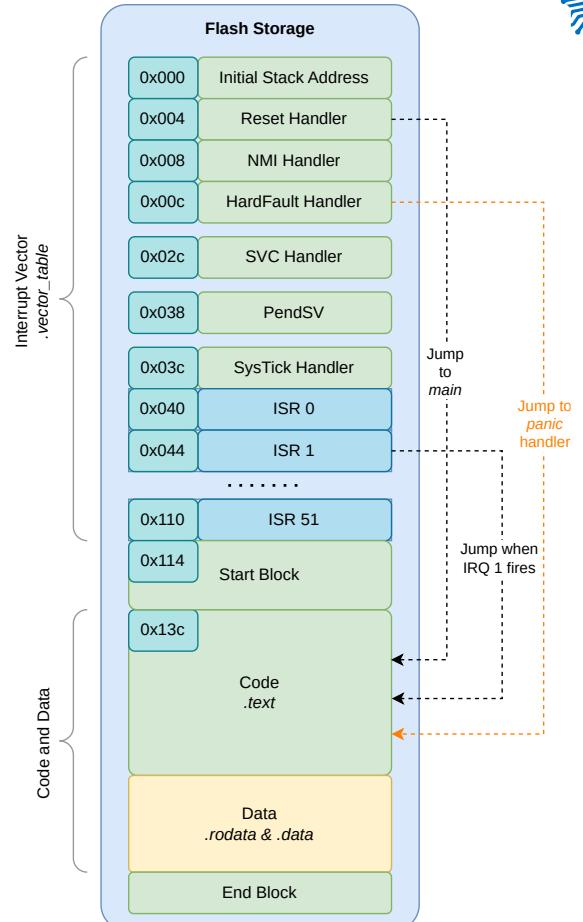


# Boot

The RP2350 boot process



The internal boot loader cannot be overwritten and assures that bricking the device is difficult.



\* drawing is not at scale, code and data are significantly greater than the interrupt vector



# Set Fault Handler

bare metal, pac or embassy-rs

```
// defined by the cortex-m-rt crate
pub struct ExceptionFrame {
    r0: u32,
    r1: u32,
    r2: u32,
    r3: u32,
    r12: u32,
    lr: u32,
    pc: u32,
    xpsr: u32,
}
```

HardFault never returns

```
1 #[exception]
2 unsafe fn HardFault(_frame: &ExceptionFrame) -> ! {
3     panic!("HardFault {:?}", frame);
4 }
```



# Set SysTick Handler

bare metal, PAC or embassy-rs

```
1  #[exception]
2  unsafe fn SysTick() {
3      // execute at a fixed interval
4 }
```



# Set Interrupt Handlers

*embassy-rs already defined the interrupts as it needs them*

IRQ	Interrupt Source								
0	TIMER_IRQ_0	6	XIP_IRQ	12	DMA_IRQ_1	18	SPI0_IRQ	24	I2C1_IRQ
1	TIMER_IRQ_1	7	PIO0_IRQ_0	13	IO_IRQ_BANK0	19	SPI1_IRQ	25	RTC_IRQ
2	TIMER_IRQ_2	8	PIO0_IRQ_1	14	IO_IRQ_QSPI	20	UART0_IRQ		
3	TIMER_IRQ_3	9	PIO1_IRQ_0	15	SIO_IRQ_PROC0	21	UART1_IRQ		
4	PWM_IRQ_WRAP	10	PIO1_IRQ_1	16	SIO_IRQ_PROC1	22	ADC_IRQ_FIFO		
5	USBCTRL_IRQ	11	DMA_IRQ_0	17	CLOCKS_IRQ	23	I2C0_IRQ		

```
1 // The name of the function has to match the
2 // interrupt name defined by the
3 // *Peripheral Access Crate* (PAC)
4 unsafe fn IO_IRQ_BANK0() {
5     // so some work when a pin interrupt triggers
6 }
```



# Use interrupts in embassy-rs

embassy-rs registers interrupt handlers and exposes a high level API

IRQ	Interrupt Source								
0	TIMER_IRQ_0	6	XIP_IRQ	12	DMA IRQ_1	18	SPI0_IRQ	24	I2C1_IRQ
1	TIMER_IRQ_1	7	PIO0_IRQ_0	13	IO_IRQ_BANK0	19	SPI1_IRQ	25	RTC_IRQ
2	TIMER_IRQ_2	8	PIO0_IRQ_1	14	IO_IRQ_QSPI	20	UART0_IRQ		
3	TIMER_IRQ_3	9	PIO1_IRQ_0	15	SIO_IRQ_PROC0	21	UART1_IRQ		
4	PWM_IRQ_WRAP	10	PIO1_IRQ_1	16	SIO_IRQ_PROC1	22	ADC_IRQ_FIFO		
5	USBCTRL_IRQ	11	DMA_IRQ_0	17	CLOCKS_IRQ	23	I2C0_IRQ		

```
1 #[embassy_executor::main]
2 async fn main(_spawner: Spawner) {
3     let p = embassy_rp::init(Default::default());
4     let mut button = Input::new(p.PIN_20, Pull::None);
5
6     loop {
7         info!("Waiting for the button press");
8
9         // waits for interrupt (sent by button)
10        // IO_IRQ_BANK0
11        button.wait_for_high().await;
12
13        info!("Button was pressed");
14    }
15 }
```



# Conclusion

we talked about

- Exceptions
- Interrupts
- How the RP2040 boots and loads the software