

Exceptions and Interrupts

Lecture 3

Exceptions and Interrupts

used by RP2040

- Exceptions
- Interrupts
- Boot





Exceptions

for the ARM Cortex-M0+ processor

Bibliography



for this section

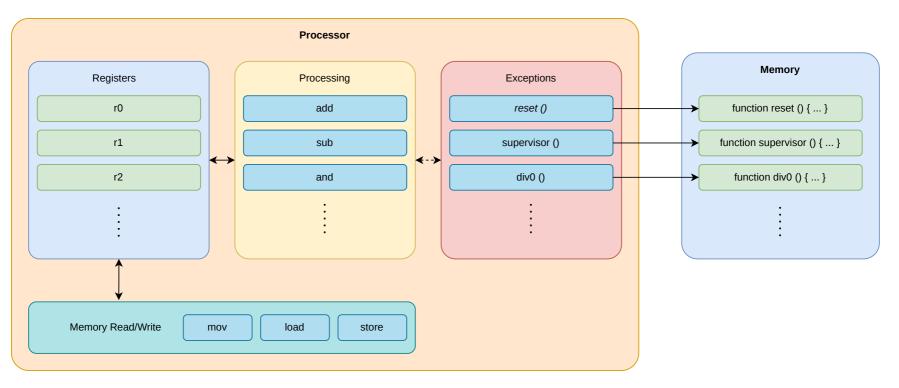
Joseph Yiu, The Definitive Guide to ARM® Cortex®-M0 and Cortex-M0+ Processors, 2nd Edition

- Chapter 4 Architecture
 - Section 4.4 Stack Memory Operations
 - Section 4.5 Exceptions and Interrupts
- Chapter 8 *Exceptions and Interrupts*
 - Section 8.1 What are Exceptions and Interrupts
 - Section 8.2 Exception types on Cortex-M0 and Cortex-M0+



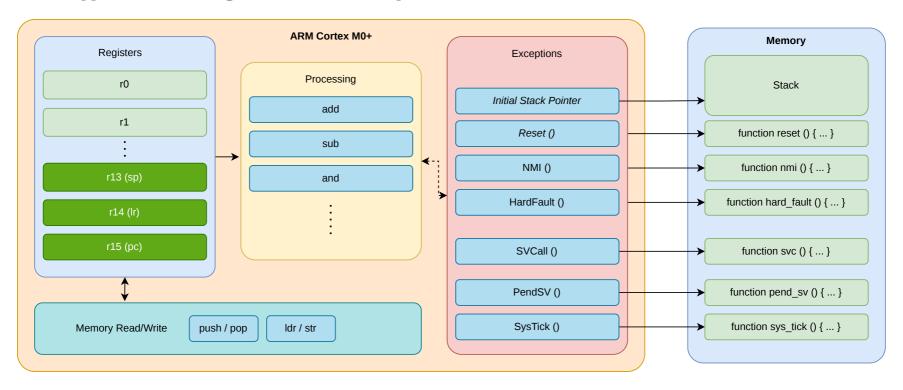


what happens if something does not work as required



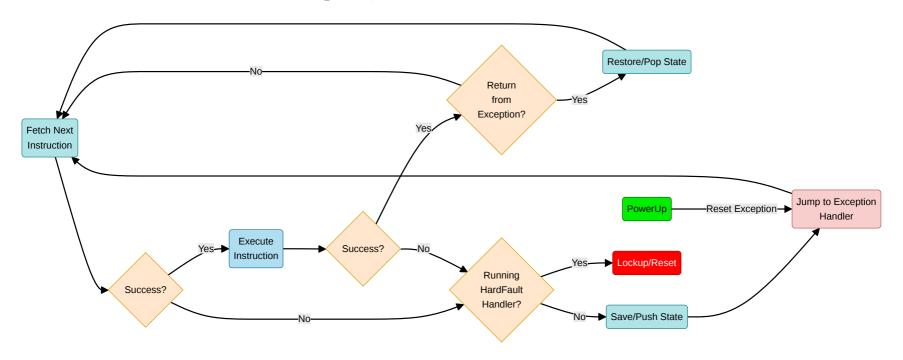


what happens if something does not work as required



Exception (HardFault) Handling

ARM Cortex-M0+ has one actual exception, *HardFault*



- the exception table of RP2040 at address 0x1000_0100 (start of the boot area + 4 bytes)
- the processor generates a Reset exception when it starts



Interrupts

for ARM Cortex-M0+

Bibliography



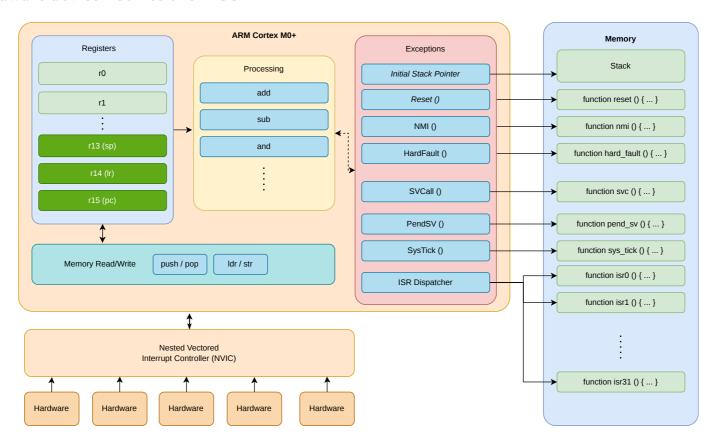
for this section

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

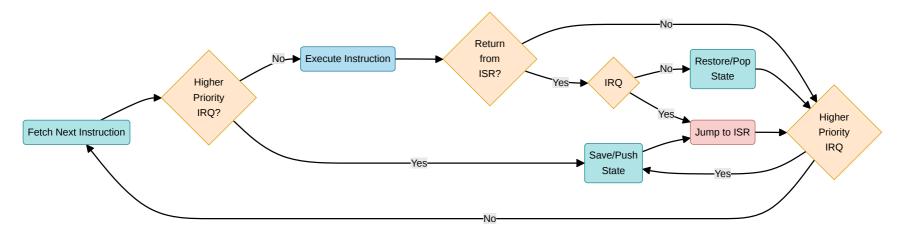
ARM Cortex-M0+ Interrupts

some hardware device notifies the MCU



Interrupt Handling

ARM Cortex-M0+

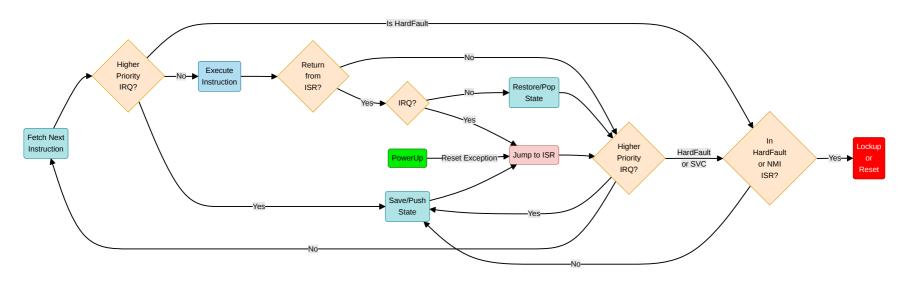


IRQ	Interrupt Request
ISR	Interrupt Service Routine

- the interrupt vector (table) of RP2040 starts at address 0x1000_0040 (after the exceptions table with 15 interrupts)
- ARM Cortex-M0+ has a maximum of 32 interrupt requests (IRQs)

Exceptions are Software Interrupt Requests

with a negative IRQ number and a higher priority



- Reset (-14)
- HardFault (-13)
- SVC (-5)
- PendSV (-2)
- SysTick (-1)

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		



Boot

of the RP2040

Bibliography

for this section

Raspberry Pi Ltd, RP2040 Datasheet

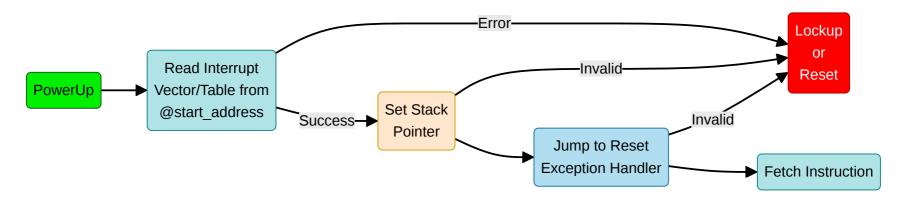
- Chapter 2 *System Description*
 - Section 2.7 *Boot sequence*
 - Section 2.8 *Bootrom*
 - Subsection 2.8.1 *Processor Controlled Boot Sequence*



Boot



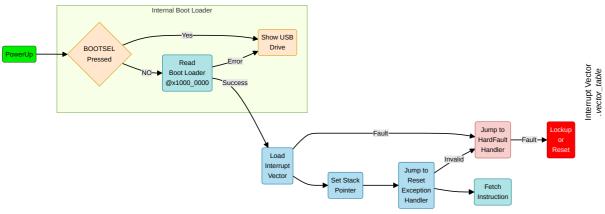
how the ARM Cortex-M0+ starts



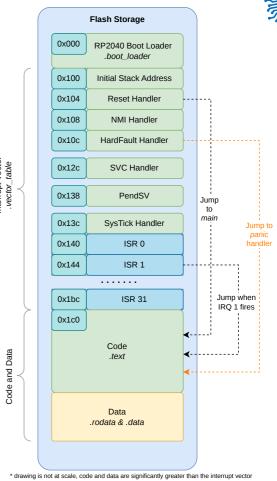
- the *start_address* for RP2040 is 0x1000_0100
- RP2040 has another boot loader that it loads from 0x1000_0000

Boot

The RP2040 boot process



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





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

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

Set SysTick Handler



bare metal, PAC or embassy-rs

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





bare metal, PAC

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		

```
#[interrupt]
unsafe fn IO_IRQ_BANK0 {
    // so some work when a pin interrupt triggers
}
```



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		

```
#[embassy executor::main]
     async fn main(_spawner: Spawner) {
         let p = embassy_rp::init(Default::default());
         let mut button = Input::new(p.PIN 20, Pull::None);
         loop {
             info!("Waiting for the button press");
             // waits for interrupt (sent by button)
             // IO IRQ BANKO
             button.wait for high().await;
11
13
             info!("Button was pressed");
14
```

Conclusion

we talked about

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