



# Memory Mapped IO used for GPIO

Lecture 2



# GPIO for RP2040

- Memory Mapped I/O
  - GPIO Peripheral
- Embedded Rust Stack
- embassy-rs



# MMIO

Memory Mapped Input Output



# 8 bit processor

a simple 8 bit processor with a text display





# STM32L0x2

A real MCU

|                           |  |
|---------------------------|--|
| Cortex-M0+<br>Peripherals | MCU's <i>settings</i> and internal peripherals, available at the same address on all M0+ |
| Peripherals               | GPIO, USART, SPI, I2C, USB, etc  |
| Flash                     | The storage space  |
| SRAM                      | RAM memory   |
| @0x0000_0000              | Alias for SRAM or Flash  |





# System Control Registers

@0xe000\_0000

Compute the actual address

- $0xe000\_0000 + \text{Offset}$

Examples:

- SYST\_CSR: **0xe000\_e010** ( $0xe000\_0000 + 0xe010$ )
- CPUID: **0xe000\_ed00** ( $0xe000\_0000 + 0xed00$ )

```
1  const SYS_CTRL: usize = 0xe000_0000;  
2  const CPUID: usize = 0xed00;  
3  
4  let cpuid_reg = (SYS_CTRL + CPUID) as *const u32;  
5  let cpuid_value = unsafe { *cpuid_reg };
```

⚠ Compilers optimize code and processors use cache!

| Offset | Name                       | Info   |
|--------|----------------------------|--|
| 0xe010 | <a href="#">SYST_CSR</a>   | SysTick Control and Status Register              |
| 0xe014 | <a href="#">SYST_RVR</a>   | SysTick Reload Value Register                    |
| 0xe018 | <a href="#">SYST_CVR</a>   | SysTick Current Value Register                   |
| 0xe01c | <a href="#">SYST_CALIB</a> | SysTick Calibration Value Register               |
| 0xe100 | <a href="#">NVIC_ISER</a>  | Interrupt Set-Enable Register                    |
| 0xe180 | <a href="#">NVIC_ICER</a>  | Interrupt Clear-Enable Register                  |
| 0xe200 | <a href="#">NVIC_ISPR</a>  | Interrupt Set-Pending Register                   |
| 0xe280 | <a href="#">NVIC_ICPR</a>  | Interrupt Clear-Pending Register                 |
| 0xe400 | <a href="#">NVIC_IPR0</a>  | Interrupt Priority Register 0                    |
| 0xe404 | <a href="#">NVIC_IPR1</a>  | Interrupt Priority Register 1                    |
| 0xe408 | <a href="#">NVIC_IPR2</a>  | Interrupt Priority Register 2                    |
| 0xe40c | <a href="#">NVIC_IPR3</a>  | Interrupt Priority Register 3                    |
| 0xe410 | <a href="#">NVIC_IPR4</a>  | Interrupt Priority Register 4                    |
| 0xe414 | <a href="#">NVIC_IPR5</a>  | Interrupt Priority Register 5                    |
| 0xe418 | <a href="#">NVIC_IPR6</a>  | Interrupt Priority Register 6                    |
| 0xe41c | <a href="#">NVIC_IPR7</a>  | Interrupt Priority Register 7                    |
| 0xed00 | <a href="#">CPUID</a>      | CPUID Base Register                              |
| 0xed04 | <a href="#">ICSR</a>       | Interrupt Control and State Register             |
| 0xed08 | <a href="#">VTOR</a>       | Vector Table Offset Register                     |
| 0xed0c | <a href="#">AIRCR</a>      | Application Interrupt and Reset Control Register |
| 0xed10 | <a href="#">SCR</a>        | System Control Register                          |
| 0xed14 | <a href="#">CCR</a>        | Configuration and Control Register               |



# Compiler Optimization

compilers optimize code

Write bytes to the `UART` (serial port) data register

```
1  const UART_TX: *const u8 = 0x400_3400;
2  for b in b"Hello, World".iter() {
3      unsafe { UART_TX.write(*b); }
4  }
```

1. The compiler does not know that `UART_TX` is a register and uses it as a memory address.
2. Writing several values to the same memory address will result in having the last value stored at that address.
3. The compiler optimizes the code write the value

```
1  const UART_TX: *const u8 = 0x400_3400;
2  unsafe { UART_TX.write(b'd'); }
```

.



# No Compiler Optimization

CPUID: `0xe000_ed00` (`0xe000_0000 + 0xed00`)

```
1 use core::ptr::read_volatile;
2
3 const SYS_CTRL: usize = 0xe000_0000;
4 const CPUID: usize = 0xed00;
5
6 let cpuid_reg = (SYS_CTRL + CPUID) as *const u32;
7 unsafe {
8     read_volatile(cpuid_reg) // avoid cache
9 }
```

`read_volatile`,  
`write_volatile`

**no compiler  
optimization**

`read`, `write`, `*p`

**use compiler  
optimization**

| Offset | Name                       | Info   |
|--------|----------------------------|--|
| 0xe010 | <a href="#">SYST_CSR</a>   | SysTick Control and Status Register              |
| 0xe014 | <a href="#">SYST_RVR</a>   | SysTick Reload Value Register                    |
| 0xe018 | <a href="#">SYST_CVR</a>   | SysTick Current Value Register                   |
| 0xe01c | <a href="#">SYST_CALIB</a> | SysTick Calibration Value Register               |
| 0xe100 | <a href="#">NVIC_IJSER</a> | Interrupt Set-Enable Register                    |
| 0xe180 | <a href="#">NVIC_ICER</a>  | Interrupt Clear-Enable Register                  |
| 0xe200 | <a href="#">NVIC_ISPR</a>  | Interrupt Set-Pending Register                   |
| 0xe280 | <a href="#">NVIC_ICPR</a>  | Interrupt Clear-Pending Register                 |
| 0xe400 | <a href="#">NVIC_IPR0</a>  | Interrupt Priority Register 0                    |
| 0xe404 | <a href="#">NVIC_IPR1</a>  | Interrupt Priority Register 1                    |
| 0xe408 | <a href="#">NVIC_IPR2</a>  | Interrupt Priority Register 2                    |
| 0xe40c | <a href="#">NVIC_IPR3</a>  | Interrupt Priority Register 3                    |
| 0xe410 | <a href="#">NVIC_IPR4</a>  | Interrupt Priority Register 4                    |
| 0xe414 | <a href="#">NVIC_IPR5</a>  | Interrupt Priority Register 5                    |
| 0xe418 | <a href="#">NVIC_IPR6</a>  | Interrupt Priority Register 6                    |
| 0xe41c | <a href="#">NVIC_IPR7</a>  | Interrupt Priority Register 7                    |
| 0xed00 | <a href="#">CPUID</a>      | CPUID Base Register                              |
| 0xed04 | <a href="#">ICSR</a>       | Interrupt Control and State Register             |
| 0xed08 | <a href="#">VTOR</a>       | Vector Table Offset Register                     |
| 0xed0c | <a href="#">AIRCR</a>      | Application Interrupt and Reset Control Register |
| 0xed10 | <a href="#">SCR</a>        | System Control Register                          |
| 0xed14 | <a href="#">CCR</a>        | Configuration and Control Register               |





# 8 bit processor

with cache





# No Cache or Flush Cache

- Cache types:
  - *write-through* - data is written to the cache and to the main memory (bus)
  - *write-back* - data is written to the cache and later to the main memory (bus)
- few Cortex-M MCUs have cache
- the Memory Mapped I/O region is set as *nocache*
- for chips that use cache
  - *nocache* regions have to be set manually (if MCU knows)
  - or, the cache has to be flushed before a `volatile_read` and after a `volatile_write`
  - beware DMA controllers that can't see the cache contents



# Read the CPUID

About the MCU

```
1  use core::ptr::read_volatile;
2
3  const SYS_CTRL: usize = 0xe000_0000;
4  const CPUID: usize = 0xed00;
5
6  let cpuid_reg = (SYS_CTRL + CPUID) as *const u32;
7  let cpuid_value = unsafe {
8      read_volatile(cpuid_reg)
9  };
10
11 // shift right 24 bits and keep only the last 8 bits
12 let variant = (cpuid_value >> 24) & 0b1111_1111;
13
14 // shift right 16 bits and keep only the last 4 bits
15 let architecture = (cpuid_value >> 16) & 0b1111;
16
17 // shift right 4 bits and keep only the last 12 bits
18 let part_no = (cpuid_value >> 4) & 0b11_1111_1111;
19
20 // shift right 0 bits and keep only the last 4 bits
21 let revision = (cpuid_value >> 0) & 0b1111;
```

## CPUID Register

Offset: 0xed04

| Bits  | Name         | Description  | Type | Reset |
|-------|--------------|--|------|-------|
| 31:24 | IMPLEMENTER  | Implementor code: 0x41 = ARM   | RO   | 0x41  |
| 23:20 | VARIANT      | Major revision number n in the rnpn revision status: 0x0 = Revision 0.               | RO   | 0x0   |
| 19:16 | ARCHITECTURE | Constant that defines the architecture of the processor: 0xC = ARMv6-M architecture. | RO   | 0xc   |
| 15:4  | PARTNO       | Number of processor within family: 0xC60 = Cortex-M0+                                | RO   | 0xc60 |
| 3:0   | REVISION     | Minor revision number m in the rnpn revision status: 0x1 = Patch 1.                  | RO   | 0x1   |



# AIRCR

Application Interrupt and Reset Control Register

```
1 use core::ptr::read_volatile;
2 use core::ptr::write_volatile;
3
4 const SYS_CTRL: usize = 0xe000_0000;
5 const AIRCR: usize = 0xed0c;
6
7 const VECTKEY: u32 = 16;
8 const SYSRESETREQ: u32 = 2;
9
10 let aircr_register = (SYS_CTRL + AIRCR) as *mut u32;
11 let mut aircr_value = unsafe {
12     read_volatile(aircr_register)
13 };
14
15 aircr_value = aircr_value & ~(0x1111 << VECTKEY);
16 aircr_value = aircr_value | (0x05fa << VECTKEY);
17 aircr_value = aircr_value | (1 << SYSRESETREQ);
18
19 unsafe {
20     write_volatile(aircr_register, aircr_value);
21 }
```

# AIRCR Register

Offset: 0xed0c

| Bits  | Name      | Description  | Type | Reset  |
|-------|-----------|--|------|--------|
| 31:16 | VECTKEY   | Register key:<br>Reads as Unknown<br>On writes, write 0x05FA to VECTKEY, otherwise the write is ignored. | RW   | 0x0000 |
| 15    | ENDIANESS | Data endianness implemented:<br>0 = Little-endian.   | RO   | 0x0    |
| 14:3  | Reserved. | -  | -    | -      |

| Bits | Name          | Description   | Type | Reset |
|------|---------------|---|------|-------|
| 2    | SYSRESETREQ   | Writing 1 to this bit causes the SYSRESETREQ signal to the outer system to be asserted to request a reset. The intention is to force a large system reset of all major components except for debug. The C_HALT bit in the DHCSR is cleared as a result of the system reset requested. The debugger does not lose contact with the device. | RW   | 0x0   |
| 1    | VECTCLRACTIVE | Clears all active state information for fixed and configurable exceptions. This bit: is self-clearing, can only be set by the DAP when the core is halted. When set: clears all active exception status of the processor, forces a return to Thread mode, forces an IPSR of 0. A debugger must re-initialize the stack.                   | RW   | 0x0   |
| 0    | Reserved.     | -   | -    | -     |



# Read and Write

they do stuff

- Read
  - reads the value of a register
  - might ask the peripheral to do something
- Write
  - writes the value to a register
  - might ask the peripheral to do something
    - SYSRESETREQ

## AIRCR Register

Offset: 0xed0c

| Bits  | Name      | Description  | Type | Reset  |
|-------|-----------|--|------|--------|
| 31:16 | VECTKEY   | Register key:<br>Reads as Unknown<br>On writes, write 0x05FA to VECTKEY, otherwise the write is ignored. | RW   | 0x0000 |
| 15    | ENDIANESS | Data endianness implemented:<br>0 = Little-endian.   | RO   | 0x0    |
| 14:3  | Reserved. | -  | -    | -      |

| Bits | Name          | Description   | Type | Reset |
|------|---------------|---|------|-------|
| 2    | SYSRESETREQ   | Writing 1 to this bit causes the SYSRESETREQ signal to the outer system to be asserted to request a reset. The intention is to force a large system reset of all major components except for debug. The C_HALT bit in the DHCSR is cleared as a result of the system reset requested. The debugger does not lose contact with the device. | RW   | 0x0   |
| 1    | VECTCLRACTIVE | Clears all active state information for fixed and configurable exceptions. This bit: is self-clearing, can only be set by the DAP when the core is halted. When set: clears all active exception status of the processor, forces a return to Thread mode, forces an IPSR of 0. A debugger must re-initialize the stack.                   | RW   | 0x0   |
| 0    | Reserved.     | -   | -    | -     |



# SVD XML File

## System View Description

```
1  <device schemaVersion="1.1"
2    xmlns:xs="http://www.w3.org/2001/XMLSchema-instance" xs:noNamespaceSchemaLocation="CMSIS-SVD.xsd">
3    <name>RP2040</name>
4    <peripherals>
5      <name>PPB</name>
6      <baseAddress>0xe0000000</baseAddress>
7      <register>
8        <name>CPUID</name>
9        <addressOffset>0xed00</addressOffset>
10       <resetValue>0x410cc601</resetValue>
11       <fields>
12         <field>
13           <name>IMPLEMENTER</name>
14           <description>Implementor code: 0x41 = ARM</description>
15           <bitRange>[31:24]</bitRange>
16           <access>read-only</access>
17         </field>
18         <!-- rest of the fields of the register -->
19       </fields>
20     </register>
21   </peripherals>
22 </device>
```



# Bitwise Ops

How to set and clear bits



# Set bit

set the 1 on position bit of register

```
1 fn set_bit(register: usize, bit: u8) -> usize {
2     // assume register is 0b1000, bit is 2
3     // 1 << 2 is 0b0100
4     // 0b1000 | 0b0100 is 0b1100
5     register | 1 << bit
6 }
```

## Set multiple bits

```
1 fn set_bits(register: usize, bits: usize) -> usize {
2     // assume register is 0b1000, bits is 0b0111
3     // 0b1000 | 0b0111 is 0b1111
4     register | bits
5 }
```





# Clear bit

set the 0 on position bit of register

```
1 fn clear_bit(register: usize, bit: u8) -> usize {
2     // assume register is 0b1100, bit is 2
3     // 1 << 2 is 0b0100
4     // !(1 << 3) is 0b1011
5     // 0b1100 & 0b1011 is 0b1000
6     register & !(1 << bit)
7 }
```

## Clear multiple bits

```
1 fn clear_bits(register: usize, bits: usize) -> usize {
2     // assume register is 0b1111, bits is 0b0111
3     // !bits = 0b1000
4     // 0b1111 & 0b1000 is 0b1000
5     register & !bits
6 }
```



# Flip bit

flip the bit on position `bit` of `register`

```
1  fn flip_bit(register: usize, bit: u8) -> usize {
2      // assume register is 0b1000, bit is 2
3      // 1 << 2 is 0b0100
4      // 0b1100 ^ 0b0100 is 0b1000
5      register ^ 1 << bit
6  }
```

## Flip multiple bits

```
1  fn flip_bits(register: usize, bits: usize) -> usize {
2      // assume register is 0b1000, bits is 0b0111
3      // 0b1000 ^ 0b0111 is 0b1111
4      register ^ bits
5  }
```



# GPIO

General Purpose Input Output for RP2040



# Bibliography

for this section

## **Raspberry Pi Ltd, *RP2040 Datasheet***

- Chapter 2 - *System Description*
  - Section 2.3 - *Processor subsystem*
    - Subsection 2.3.1 - *SIO*
      - Subsection 2.3.1.2 - *GPIO Control*
  - Section 2.4 - *Cortex-M0+* (except NVIC and MPU)
  - Section 2.19 - *GPIO* (except Interrupts)



# GPIO

## Peripherals



**SIO** Single Cycle Input/Output, is able to control the GPIO pins

**GPIO** Multiplexes the functions of the GPIO pins

|      | Function |           |          |        |     |      |      |    |               |
|------|----------|-----------|----------|--------|-----|------|------|----|---------------|
| GPIO | F1       | F2        | F3       | F4     | F5  | F6   | F7   | F8 | F9            |
| 0    | SPI0 RX  | UART0 TX  | I2C0 SDA | PWM0 A | SIO | PIO0 | PIO1 |    | USB OVCCR DET |
| 1    | SPI0 CSn | UART0 RX  | I2C0 SCL | PWM0 B | SIO | PIO0 | PIO1 |    | USB VBUS DET  |
| 2    | SPI0 SCK | UART0 CTS | I2C1 SDA | PWM1 A | SIO | PIO0 | PIO1 |    | USB VBUS EN   |
| 3    | SPI0 TX  | UART0 RTS | I2C1 SCL | PWM1 B | SIO | PIO0 | PIO1 |    | USB OVCCR DET |
| 4    | SPI0 RX  | UART1 TX  | I2C0 SDA | PWM2 A | SIO | PIO0 | PIO1 |    | USB VBUS DET  |
| 5    | SPI0 CSn | UART1 RX  | I2C0 SCL | PWM2 B | SIO | PIO0 | PIO1 |    | USB VBUS EN   |
| 6    | SPI0 SCK | UART1 CTS | I2C1 SDA | PWM3 A | SIO | PIO0 | PIO1 |    | USB OVCCR DET |
| 7    | SPI0 TX  | UART1 RTS | I2C1 SCL | PWM3 B | SIO | PIO0 | PIO1 |    | USB VBUS DET  |
| 8    | SPI1 RX  | UART1 TX  | I2C0 SDA | PWM4 A | SIO | PIO0 | PIO1 |    | USB VBUS EN   |
| 9    | SPI1 CSn | UART1 RX  | I2C0 SCL | PWM4 B | SIO | PIO0 | PIO1 |    | USB OVCCR DET |
| 10   | SPI1 SCK | UART1 CTS | I2C1 SDA | PWM5 A | SIO | PIO0 | PIO1 |    | USB VBUS DET  |
| 11   | SPI1 TX  | UART1 RTS | I2C1 SCL | PWM5 B | SIO | PIO0 | PIO1 |    | USB VBUS EN   |
| 12   | SPI1 RX  | UART0 TX  | I2C0 SDA | PWM6 A | SIO | PIO0 | PIO1 |    | USB OVCCR DET |
| 13   | SPI1 CSn | UART0 RX  | I2C0 SCL | PWM6 B | SIO | PIO0 | PIO1 |    | USB VBUS DET  |
| 14   | SPI1 SCK | UART0 CTS | I2C1 SDA | PWM7 A | SIO | PIO0 | PIO1 |    | USB VBUS EN   |

**IO Bank (GPIO):** Use the correct MUX function (F5)

**SIO:** Set the pin as Input or Output



# SIO Registers

The SIO registers start at a base address of `0xd0000000` (defined as `SIO_BASE` in SDK).

| Offset | Name                         | Info                      |
|--------|------------------------------|---------------------------|
| 0x000  | <a href="#">CPUID</a>        | Processor core identifier |
| 0x004  | <a href="#">GPIO_IN</a>      | Input value for GPIO pins |
| 0x008  | <a href="#">GPIO_HI_IN</a>   | Input value for QSPI pins |
| 0x010  | <a href="#">GPIO_OUT</a>     | GPIO output value         |
| 0x014  | <a href="#">GPIO_OUT_SET</a> | GPIO output value set     |
| 0x018  | <a href="#">GPIO_OUT_CLR</a> | GPIO output value clear   |
| 0x01c  | <a href="#">GPIO_OUT_XOR</a> | GPIO output value XOR     |
| 0x020  | <a href="#">GPIO_OE</a>      | GPIO output enable        |
| 0x024  | <a href="#">GPIO_OE_SET</a>  | GPIO output enable set    |
| 0x028  | <a href="#">GPIO_OE_CLR</a>  | GPIO output enable clear  |

- Input
  - set `GPIO_OE` bit x to 0
  - read `GPIO_IN` bit x
- Output
  - set `GPIO_OE` bit x to 1
  - write `GPIO_OUT` bit x

## GPIO\_OE

| Bits  | Description  | Type | Reset      |
|-------|--|------|------------|
| 31:30 | Reserved.  | -    | -          |
| 29:0  | Set output enable (1/0 → output/input) for GPIO0...29.<br>Reading back gives the last value written.<br>If core 0 and core 1 both write to <code>GPIO_OE</code> simultaneously (or to a <code>SET/CLR/XOR</code> alias), the result is as though the write from core 0 took place first, and the write from core 1 was then applied to that intermediate result. | RW   | 0x00000000 |

## GPIO\_IN

| Bits  | Description                | Type | Reset      |
|-------|----------------------------|------|------------|
| 31:30 | Reserved.                  | -    | -          |
| 29:0  | Input value for GPIO0...29 | RO   | 0x00000000 |

## GPIO\_OUT

| Bits  | Description   | Type | Reset      |
|-------|---|------|------------|
| 31:30 | Reserved.   | -    | -          |
| 29:0  | Set output level (1/0 → high/low) for GPIO0...29.<br>Reading back gives the last value written, NOT the input value from the pins.<br>If core 0 and core 1 both write to <code>GPIO_OUT</code> simultaneously (or to a <code>SET/CLR/XOR</code> alias), the result is as though the write from core 0 took place first, and the write from core 1 was then applied to that intermediate result. | RW   | 0x00000000 |



# SIO Input

The SIO registers start at a base address of `0xd0000000` (defined as `SIO_BASE` in SDK).

| Offset | Name                         | Info                      |
|--------|------------------------------|---------------------------|
| 0x000  | <a href="#">CPUID</a>        | Processor core identifier |
| 0x004  | <a href="#">GPIO_IN</a>      | Input value for GPIO pins |
| 0x008  | <a href="#">GPIO_HI_IN</a>   | Input value for QSPI pins |
| 0x010  | <a href="#">GPIO_OUT</a>     | GPIO output value         |
| 0x014  | <a href="#">GPIO_OUT_SET</a> | GPIO output value set     |
| 0x018  | <a href="#">GPIO_OUT_CLR</a> | GPIO output value clear   |
| 0x01c  | <a href="#">GPIO_OUT_XOR</a> | GPIO output value XOR     |
| 0x020  | <a href="#">GPIO_OE</a>      | GPIO output enable        |
| 0x024  | <a href="#">GPIO_OE_SET</a>  | GPIO output enable set    |
| 0x028  | <a href="#">GPIO_OE_CLR</a>  | GPIO output enable clear  |

## GPIO\_OE

| Bits  | Description  | Type | Reset      |
|-------|--|------|------------|
| 31:30 | Reserved.  | -    | -          |
| 29:0  | Set output enable (1/0 → output/input) for GPIO0...29.<br>Reading back gives the last value written.<br>If core 0 and core 1 both write to GPIO_OE simultaneously (or to a SET/CLR/XOR alias), the result is as though the write from core 0 took place first, and the write from core 1 was then applied to that intermediate result. | RW   | 0x00000000 |

## GPIO\_IN

| Bits  | Description                | Type | Reset      |
|-------|----------------------------|------|------------|
| 31:30 | Reserved.                  | -    | -          |
| 29:0  | Input value for GPIO0...29 | RO   | 0x00000000 |

```
1 use core::ptr::read_volatile;
2 use core::ptr::write_volatile;
3
4 const GPIO_OE: *mut u32 = 0xd000_0020 as *mut u32;
5 const GPIO_IN: *const u32 = 0xd000_0004 as *const u32;
6
7 let value = unsafe {
8     // write_volatile(GPIO_OE, !(1 << pin));
9     let gpio_oe = read_volatile(GPIO_OE);
10    // set bin `pin` of `gpio_oe` to 0 (input)
11    gpio_oe = gpio_oe & !(1 << pin);
12    write_volatile(GPIO_OE, gpio_oe);
13    read_volatile(GPIO_IN) >> pin & 0b1
14 };
```



# SIO Input

The SIO registers start at a base address of `0xd0000000` (defined as `SIO_BASE` in SDK).

| Offset | Name                      | Info                      |
|--------|---------------------------|---------------------------|
| 0x000  | <code>CPUID</code>        | Processor core identifier |
| 0x004  | <code>GPIO_IN</code>      | Input value for GPIO pins |
| 0x008  | <code>GPIO_HI_IN</code>   | Input value for QSPI pins |
| 0x010  | <code>GPIO_OUT</code>     | GPIO output value         |
| 0x014  | <code>GPIO_OUT_SET</code> | GPIO output value set     |
| 0x018  | <code>GPIO_OUT_CLR</code> | GPIO output value clear   |
| 0x01c  | <code>GPIO_OUT_XOR</code> | GPIO output value XOR     |
| 0x020  | <code>GPIO_OE</code>      | GPIO output enable        |
| 0x024  | <code>GPIO_OE_SET</code>  | GPIO output enable set    |
| 0x028  | <code>GPIO_OE_CLR</code>  | GPIO output enable clear  |

## GPIO\_OE\_SET

| Bits  | Description   | Type | Reset      |
|-------|---|------|------------|
| 31:30 | Reserved.   | -    | -          |
| 29:0  | Perform an atomic bit-clear on GPIO_OE, i.e. <code>GPIO_OE &amp;= ~wdata</code> | WO   | 0x00000000 |

## GPIO\_IN

| Bits  | Description                | Type | Reset      |
|-------|----------------------------|------|------------|
| 31:30 | Reserved.                  | -    | -          |
| 29:0  | Input value for GPIO0...29 | RO   | 0x00000000 |

```
1 use core::ptr::read_volatile;
2 use core::ptr::write_volatile;
3
4 const GPIO_OE_CLR: *mut u32 = 0xd000_0028 as *mut u32;
5 const GPIO_IN: *const u32 = 0xd000_0004 as *const u32;
6
7 let value = unsafe {
8     // set bit `pin` of `GPIO_OE` to 0 (input)
9     write_volatile(GPIO_OE_CLR, 1 << pin);
10    read_volatile(GPIO_IN) >> pin & 0b1
11 };
```





# SIO Output

The SIO registers start at a base address of `0xd0000000` (defined as `SIO_BASE` in SDK).

| Offset | Name                         | Info                      |
|--------|------------------------------|---------------------------|
| 0x000  | <a href="#">CPUID</a>        | Processor core identifier |
| 0x004  | <a href="#">GPIO_IN</a>      | Input value for GPIO pins |
| 0x008  | <a href="#">GPIO_HI_IN</a>   | Input value for QSPI pins |
| 0x010  | <a href="#">GPIO_OUT</a>     | GPIO output value         |
| 0x014  | <a href="#">GPIO_OUT_SET</a> | GPIO output value set     |
| 0x018  | <a href="#">GPIO_OUT_CLR</a> | GPIO output value clear   |
| 0x01c  | <a href="#">GPIO_OUT_XOR</a> | GPIO output value XOR     |
| 0x020  | <a href="#">GPIO_OE</a>      | GPIO output enable        |
| 0x024  | <a href="#">GPIO_OE_SET</a>  | GPIO output enable set    |
| 0x028  | <a href="#">GPIO_OE_CLR</a>  | GPIO output enable clear  |

## GPIO\_OE\_CLR

| Bits  | Description   | Type | Reset      |
|-------|---|------|------------|
| 31:30 | Reserved.   | -    | -          |
| 29:0  | Perform an atomic bit-clear on GPIO_OE, i.e. <code>GPIO_OE &amp;= ~wdata</code> | WO   | 0x00000000 |

## GPIO\_OUT

| Bits  | Description   | Type | Reset      |
|-------|---|------|------------|
| 31:30 | Reserved.   | -    | -          |
| 29:0  | Set output level (1/0 → high/low) for GPIO0...29.<br>Reading back gives the last value written, NOT the input value from the pins.<br>If core 0 and core 1 both write to GPIO_OUT simultaneously (or to a SET/CLR/XOR alias),<br>the result is as though the write from core 0 took place first,<br>and the write from core 1 was then applied to that intermediate result. | RW   | 0x00000000 |

```
1 use core::ptr::read_volatile;
2 use core::ptr::write_volatile;
3
4 const GPIO_OE_SET: *mut u32 = 0xd000_0024 as *mut u32;
5 const GPIO_OUT: *mut u32 = 0xd000_0010 as *mut u32;
6
7 unsafe {
8     // set bit `pin` of GPIO_OE to 1 (output)
9     write_volatile(GPIO_OE_SET, 1 << pin);
10    // write_volatile(GPIO_OUT, (value & 0b1) << pin);
11    let gpio_out = read_volatile(GPIO_OUT);
12    gpio_out = gpio_out | (value & 0b1) << pin;
13    write_volatile(GPIO_OUT, gpio_out);
14 }
```



# SIO Output

efficient

The SIO registers start at a base address of `0xd0000000` (defined as `SIO_BASE` in SDK).

| Offset | Name                         | Info                      |
|--------|------------------------------|---------------------------|
| 0x000  | <a href="#">CPUID</a>        | Processor core identifier |
| 0x004  | <a href="#">GPIO_IN</a>      | Input value for GPIO pins |
| 0x008  | <a href="#">GPIO_HI_IN</a>   | Input value for QSPI pins |
| 0x010  | <a href="#">GPIO_OUT</a>     | GPIO output value         |
| 0x014  | <a href="#">GPIO_OUT_SET</a> | GPIO output value set     |
| 0x018  | <a href="#">GPIO_OUT_CLR</a> | GPIO output value clear   |
| 0x01c  | <a href="#">GPIO_OUT_XOR</a> | GPIO output value XOR     |
| 0x020  | <a href="#">GPIO_OE</a>      | GPIO output enable        |
| 0x024  | <a href="#">GPIO_OE_SET</a>  | GPIO output enable set    |
| 0x028  | <a href="#">GPIO_OE_CLR</a>  | GPIO output enable clear  |

## GPIO\_OUT\_SET

| Bits  | Description  | Type | Reset      |
|-------|--|------|------------|
| 31:30 | Reserved.  | -    | -          |
| 29:0  | Perform an atomic bit-set on GPIO_OUT, i.e. <code>GPIO_OUT  = wdata</code> | WO   | 0x00000000 |

## GPIO\_OUT\_CLR

| Bits  | Description   | Type | Reset      |
|-------|---|------|------------|
| 31:30 | Reserved.   | -    | -          |
| 29:0  | Perform an atomic bit-clear on GPIO_OUT, i.e. <code>GPIO_OUT &amp;= ~wdata</code> | WO   | 0x00000000 |

```
1 use core::ptr::read_volatile;
2 use core::ptr::write_volatile;
3
4 const GPIO_OE_SET: *mut u32 = 0xd000_0024 as *mut u32;
5 const GPIO_OUT_SET: *mut u32 = 0xd000_0014 as *mut u32;
6 const GPIO_OUT_CLR: *mut u32 = 0xd000_0018 as *mut u32;
7
8 unsafe {
9     write_volatile(GPIO_OE_SET, 1 << pin);
10    let reg = match value {
11        0 => GPIO_OUT_CLR,
12        _ => GPIO_OUT_SET
13    };
14    write_volatile(reg, 1 << pin);
15 }
```



# IO Bank



The User Bank IO registers start at a base address of `0x40014000` (defined as `IO_BANK0_BASE` in SDK).

| Offset | Name                         | Info  |
|--------|------------------------------|---|
| 0x000  | <a href="#">GPIO0_STATUS</a> | GPIO status   |
| 0x004  | <a href="#">GPIO0_CTRL</a>   | GPIO control including function select and overrides. |

- set **FUNCSEL** to **5** (*SIO*)

## GPIOx\_CTRL

Offset: 0x004, 0x00c, ... 0x0ec ( $0x4 + 8 * x$ )

| Bits  | Name      | Description  | Type | Reset |
|-------|-----------|--|------|-------|
| 31:30 | Reserved. | -  | -    | -     |
| 29:28 | IRQOVER   | 0x0 → don't invert the interrupt<br>0x1 → invert the interrupt<br>0x2 → drive interrupt low<br>0x3 → drive interrupt high  | RW   | 0x0   |
| 27:18 | Reserved. | -  | -    | -     |
| 17:16 | INOVER    | 0x0 → don't invert the peri input<br>0x1 → invert the peri input<br>0x2 → drive peri input low<br>0x3 → drive peri input high  | RW   | 0x0   |
| 15:14 | Reserved. | -  | -    | -     |
| 13:12 | OEOVER    | 0x0 → drive output enable from peripheral signal selected by funcsel<br>0x1 → drive output enable from inverse of peripheral signal selected by funcsel<br>0x2 → disable output<br>0x3 → enable output | RW   | 0x0   |
| 11:10 | Reserved. | -  | -    | -     |
| 9:8   | OUTOVER   | 0x0 → drive output from peripheral signal selected by funcsel<br>0x1 → drive output from inverse of peripheral signal selected by funcsel<br>0x2 → drive output low<br>0x3 → drive output high         | RW   | 0x0   |
| 7:5   | Reserved. | -  | -    | -     |
| 4:0   | FUNCSEL   | Function select. 31 == NULL. See GPIO function table for available functions.  | RW   | 0x1f  |



# IO Bank Input

The User Bank IO registers start at a base address of `0x40014000` (defined as `IO_BANK0_BASE` in SDK).

| Offset | Name                         | Info  |
|--------|------------------------------|---|
| 0x000  | <a href="#">GPIO0_STATUS</a> | GPIO status   |
| 0x004  | <a href="#">GPIO0_CTRL</a>   | GPIO control including function select and overrides. |

```
1 use core::ptr::read_volatile;
2 use core::ptr::write_volatile;
3
4 const GPIOX_CTRL: u32 = 0x4001_4004;
5 const GPIO_OE_CLR: *mut u32 = 0xd000_0028 as *mut u32;
6 const GPIO_IN: *const u32 = 0xd000_0004 as *const u32;
7
8 let gpio_ctrl = (GPIOX_CTRL + 8 * pin) as *mut u32;
9
10 let value = unsafe {
11     write_volatile(gpio_ctrl, 5);
12     write_volatile(GPIO_OE_CLR, 1 << pin);
13     read_volatile(GPIO_IN) >> pin & 0b1
14 };
```

## GPIOx\_CTRL

Offset: 0x004, 0x00c, ... 0x0ec ( $0x4 + 8 * x$ )

| Bits  | Name      | Description  | Type | Reset |
|-------|-----------|--|------|-------|
| 31:30 | Reserved. | -  | -    | -     |
| 29:28 | IRQOVER   | 0x0 → don't invert the interrupt<br>0x1 → invert the interrupt<br>0x2 → drive interrupt low<br>0x3 → drive interrupt high  | RW   | 0x0   |
| 27:18 | Reserved. | -  | -    | -     |
| 17:16 | INOVER    | 0x0 → don't invert the peri input<br>0x1 → invert the peri input<br>0x2 → drive peri input low<br>0x3 → drive peri input high  | RW   | 0x0   |
| 15:14 | Reserved. | -  | -    | -     |
| 13:12 | OEOVER    | 0x0 → drive output enable from peripheral signal selected by funcsel<br>0x1 → drive output enable from inverse of peripheral signal selected by funcsel<br>0x2 → disable output<br>0x3 → enable output | RW   | 0x0   |
| 11:10 | Reserved. | -  | -    | -     |
| 9:8   | OUTOVER   | 0x0 → drive output from peripheral signal selected by funcsel<br>0x1 → drive output from inverse of peripheral signal selected by funcsel<br>0x2 → drive output low<br>0x3 → drive output high         | RW   | 0x0   |
| 7:5   | Reserved. | -  | -    | -     |
| 4:0   | FUNCSEL   | Function select. 31 == NULL. See GPIO function table for available functions.  | RW   | 0x1f  |



# IO Bank Output

The User Bank IO registers start at a base address of `0x40014000` (defined as `IO_BANK0_BASE` in SDK).

| Offset | Name                         | Info  |
|--------|------------------------------|---|
| 0x000  | <a href="#">GPIO0_STATUS</a> | GPIO status   |
| 0x004  | <a href="#">GPIO0_CTRL</a>   | GPIO control including function select and overrides. |

```
1 use core::ptr::read_volatile;
2 use core::ptr::write_volatile;
3
4 const GPIOX_CTRL: u32 = 0x4001_4004;
5 const GPIO_OE_SET: *mut u32 = 0xd000_0024 as *mut u32;
6 const GPIO_OUT_SET: *mut u32 = 0xd000_0014 as *mut u32;
7 const GPIO_OUT_CLR: *mut u32 = 0xd000_0018 as *mut u32;
8
9 let gpio_ctrl = (GPIOX_CTRL + 8 * pin) as *mut u32;
10 unsafe {
11     write_volatile(gpio_ctrl, 5);
12     write_volatile(GPIO_OE_SET, 1 << pin);
13     let reg = match value {
14         0 => GPIO_OUT_CLR,
15         _ => GPIO_OUT_SET
16     };
17     write_volatile(reg, 1 << pin);
18 };
```

## GPIOx\_CTRL

Offset: 0x004, 0x00c, ... 0x0ec ( $0x4 + 8 * x$ )

| Bits  | Name      | Description  | Type | Reset |
|-------|-----------|--|------|-------|
| 31:30 | Reserved. | -  | -    | -     |
| 29:28 | IRQOVER   | 0x0 → don't invert the interrupt<br>0x1 → invert the interrupt<br>0x2 → drive interrupt low<br>0x3 → drive interrupt high  | RW   | 0x0   |
| 27:18 | Reserved. | -  | -    | -     |
| 17:16 | INOVER    | 0x0 → don't invert the peri input<br>0x1 → invert the peri input<br>0x2 → drive peri input low<br>0x3 → drive peri input high  | RW   | 0x0   |
| 15:14 | Reserved. | -  | -    | -     |
| 13:12 | OEOVER    | 0x0 → drive output enable from peripheral signal selected by funcsel<br>0x1 → drive output enable from inverse of peripheral signal selected by funcsel<br>0x2 → disable output<br>0x3 → enable output | RW   | 0x0   |
| 11:10 | Reserved. | -  | -    | -     |
| 9:8   | OUTOVER   | 0x0 → drive output from peripheral signal selected by funcsel<br>0x1 → drive output from inverse of peripheral signal selected by funcsel<br>0x2 → drive output low<br>0x3 → drive output high         | RW   | 0x0   |
| 7:5   | Reserved. | -  | -    | -     |
| 4:0   | FUNCSEL   | Function select. 31 == NULL. See GPIO function table for available functions.  | RW   | 0x1f  |



# Pad Control

## GPIOx Register

Offset: 0x004, 0x008, ... 0x078 (0x4 + 4\*x)



The User Bank Pad Control registers start at a base address of 0x4001c000 (defined as PADS\_BANK0\_BASE in SDK).

| Offset | Name           | Info                             |
|--------|----------------|----------------------------------|
| 0x00   | VOLTAGE_SELECT | Voltage select. Per bank control |
| 0x04   | GPIO0          | Pad control register             |
| 0x08   | GPIO1          | Pad control register             |
| 0x0c   | GPIO2          | Pad control register             |
| 0x10   | GPIO3          | Pad control register             |
| 0x14   | GPIO4          | Pad control register             |
| 0x18   | GPIO5          | Pad control register             |

| Bits | Name      | Description  | Type | Reset |
|------|-----------|--|------|-------|
| 31:8 | Reserved. | -  | -    | -     |
| 7    | OD        | Output disable. Has priority over output enable from peripherals     | RW   | 0x0   |
| 6    | IE        | Input enable   | RW   | 0x1   |
| 5:4  | DRIVE     | Drive strength.<br>0x0 → 2mA<br>0x1 → 4mA<br>0x2 → 8mA<br>0x3 → 12mA | RW   | 0x1   |
| 3    | PUE       | Pull up enable   | RW   | 0x0   |
| 2    | PDE       | Pull down enable   | RW   | 0x1   |
| 1    | SCHMITT   | Enable schmitt trigger   | RW   | 0x1   |
| 0    | SLEWFAST  | Slew rate control. 1 = Fast, 0 = Slow                                | RW   | 0x0   |



# Input

read the value from pin  $x$

- set the FUNCSEL field of GPIOx\_CTRL to 5
- set the GPIO\_OE\_CLR bit  $x$  to 1
- read the GPIO\_IN bit  $x$
- *adjust the GPIOx fields to set the pull up/down resistor*



# Output

write a value to pin  $x$

- set the FUNCSEL field of GPIOx\_CTRL to 5
- set the GPIO\_OE\_SET bit  $x$  to 1
- if the value
  - is 0 ,set the GPIO\_OUT\_CLR bit  $x$  to 1
  - is 1 ,set the GPIO\_OUT\_SET bit  $x$  to 1
- *adjust the GPIOx fields to set the output current*





# Rust Embedded HAL

The Rust API for embedded systems





# The Rust Embedded Stack

|                           |  |
|---------------------------|--|
| Framework                 | Tasks, Memory Management, Network etc. <code>embassy-rs</code> , <code>rtic</code>                               |
| BSC                       | Board Support Crate <code>embassy-rp</code> , <code>rp-pico</code>   |
| <i>HAL Implementation</i> | Uses the PAC and exports a standard HAL towards the upper levels <code>embassy-rp</code>                         |
| PAC                       | Accesses registers, usually created automatically from SVD files - <code>rp2040_pac</code> , <code>rp-pac</code> |





# GPIO HAL

A set of standard traits

All devices should implement these traits for GPIO.

```
1 pub enum PinState {
2     Low,
3     High,
4 }
```

## Input

```
pub trait InputPin: ErrorType {
    // Required methods
    fn is_high(&mut self) -> Result<bool, Self::Error>;
    fn is_low(&mut self) -> Result<bool, Self::Error>;
}
```

## Output

```
pub trait OutputPin: ErrorType {
    // Required methods
    fn set_low(&mut self) -> Result<(), Self::Error>;
    fn set_high(&mut self) -> Result<(), Self::Error>;

    // Provided method
    fn set_state(&mut self, state: PinState) -> Result<(), Self::Error>;
}
```



# Bare metal

This is how a Rust application would look like

```
1  #![no_std]
2  #![no_main]
3
4  use cortex_m_rt::entry;
5
6  #[entry]
7  fn main() -> ! {
8      // your code goes here
9
10     loop { }
11 }
12
13 #[panic_handler]
14 pub fn panic(_info: &PanicInfo) -> ! {
15     loop { }
16 }
```

## Rules

1. never exit the `main` function
2. add a panic handler that does not exit



# Bare metal without PAC & HAL

This is how a Rust application would look like

```
1  #![no_std]
2  #![no_main]
3
4  use core::ptr::{read_volatile, write_volatile};
5  use cortex_m_rt::entry;
6
7  const GPIOX_CTRL: u32 = 0x4001_4004;
8  const GPIO_OE_SET: *mut u32 = 0xd000_0024 as *mut u32;
9  const GPIO_OUT_SET: *mut u32 = 0xd000_0014 as *mut u32;
10 const GPIO_OUT_CLR: *mut u32 = 0xd000_0018 as *mut u32;
11
12 #[panic_handler]
13 pub fn panic(_info: &PanicInfo) -> ! {
14     loop { }
15 }
```

```
18  #[entry]
19  fn main() -> ! {
20     let gpio_ctrl = GPIOX_CTRL + 8 * pin as *mut u32;
21     unsafe {
22         write_volatile(gpio_ctrl, 5);
23         write_volatile(GPIO_OE_SET, 1 << pin);
24         let reg = match value {
25             0 => GPIO_OUT_CLR,
26             _ => GPIO_OUT_SET
27         };
28         write_volatile(reg, 1 << pin);
29     };
30
31     loop { }
32 }
```



# embassy-rs

Embedded Asynchronous



# embassy-rs

- framework
- uses the rust-embedded-hal
- Features
  - Real-time
  - Low power
  - Networking
  - Bluetooth
  - USB
  - Bootloader and DFU



# GPIO Input

```
1  #![no_std]
2  #![no_main]
3
4  use embassy_executor::Spawner;
5  use embassy_rp::gpio;
6  use gpio::{Input, Pull};
7
8  #[embassy_executor::main]
9  async fn main(_spawner: Spawner) {
10     let p = embassy_rp::init(Default::default());
11     let pin = Input::new(p.PIN_3, Pull::Up);
12
13     if pin.is_high() {
14
15     } else {
16
17     }
18 }
```

The `main` function is called by the embassy-rs framework, so it can exit.



# GPIO Output

```
1  #![no_std]
2  #![no_main]
3
4  use embassy_executor::Spawner;
5  use embassy_rp::gpio;
6  use gpio::{Level, Output};
7
8  #[embassy_executor::main]
9  async fn main(_spawner: Spawner) {
10     let p = embassy_rp::init(Default::default());
11     let mut pin = Output::new(p.PIN_2, Level::Low);
12
13     pin.set_high();
14 }
```

The `main` function is called by the embassy-rs framework, so it can exit.





# Conclusion

we discussed about

- Memory Mapped IO
- RP2040 GPIO
  - Single Cycle IO
  - IO Bank
  - Pad
- The Rust embedded standard stack
- Bare metal Rust
- The embassy-rs framework