



# Memory Mapped IO used for GPIO

Lecture 2



# Accessing Peripherals

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



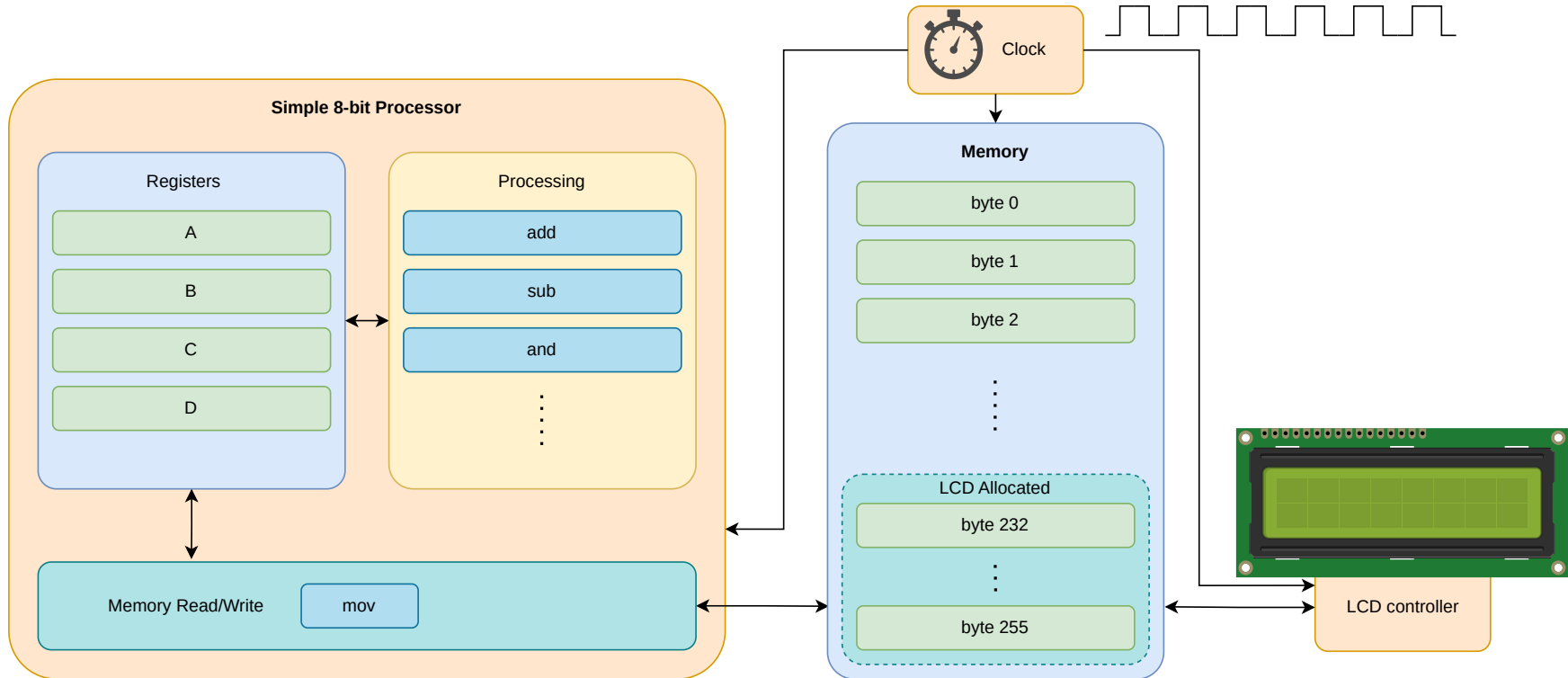
# MMIO

Memory Mapped Input Output



# 8 bit processor

a simple 8 bit processor with a text display

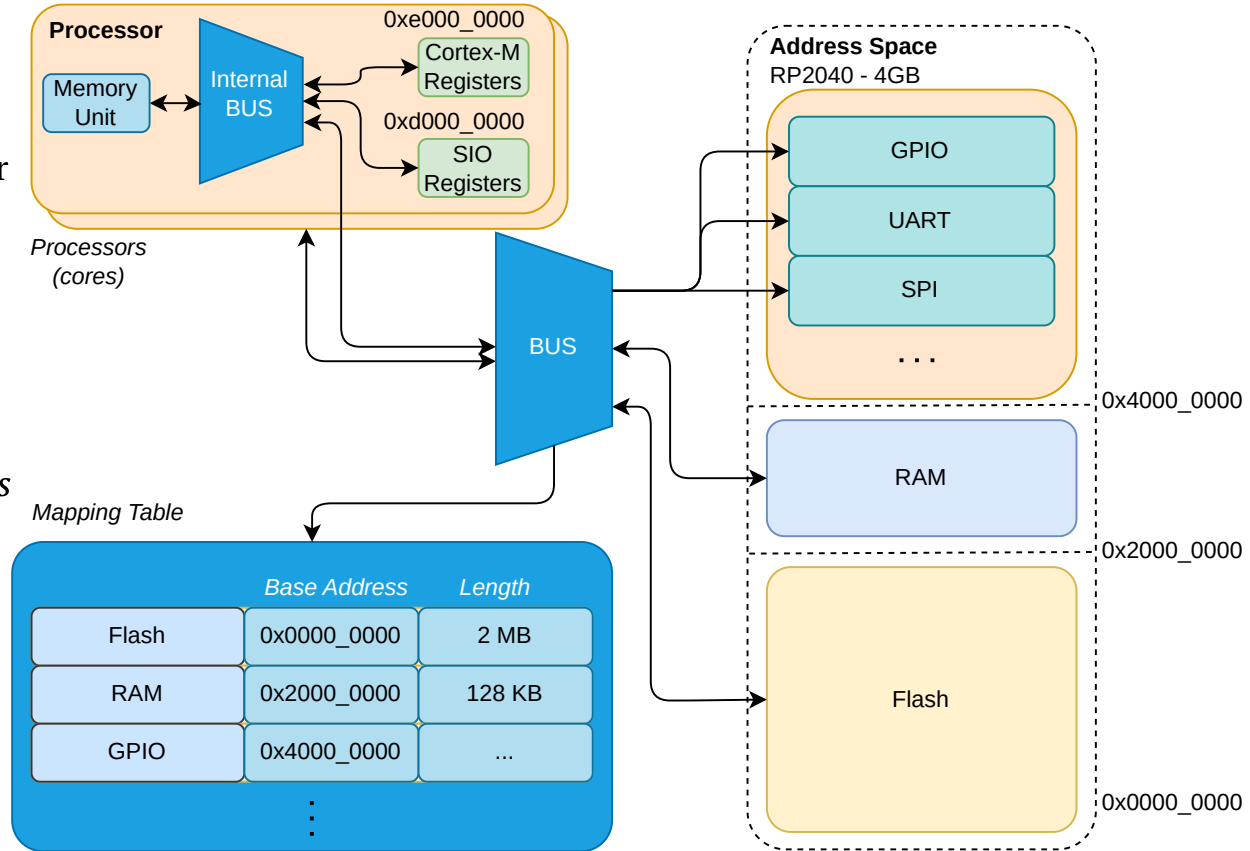


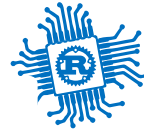


# The Bus

example for RP2

1. **Memory Controller** asks for data transfer
2. **Internal Bus Routes** the request
  - to the *External Bus* or
  - to the *Internal Peripherals*
3. **External Bus Routes** the request based on the *Address Mapping Table*
  1. to **RAM**
  2. to **Flash**
  3. to an **External Peripheral**

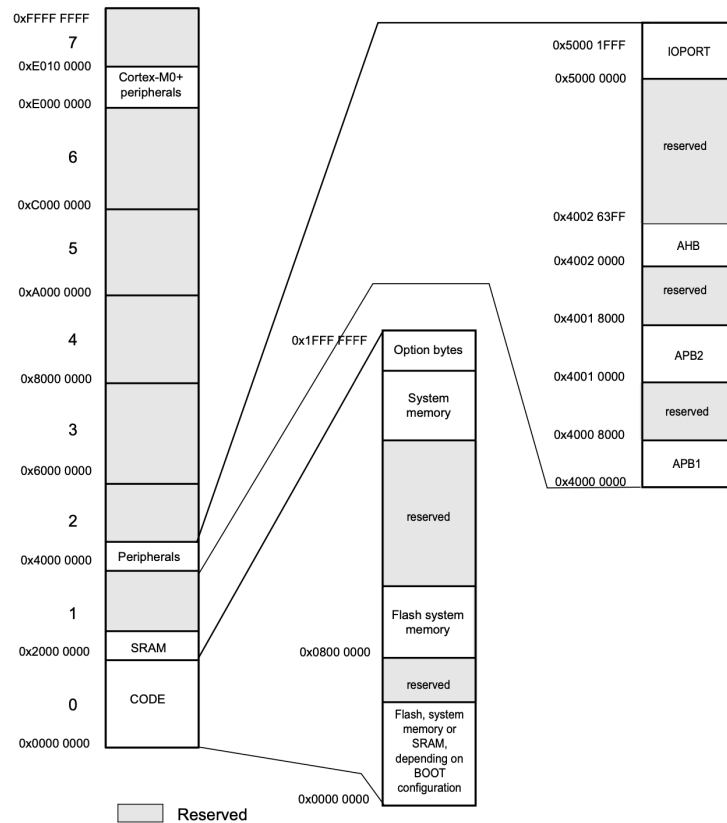




# STM32L0x2

A real MCU

Cortex-M0+ 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

Cortex-M0+<sup>[1]</sup> SCR Peripheral @0xe000\_0000

Compute the actual address

$$e000\_0000_{(16)} + register\_offset$$

Register Examples:

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

```
const SYS_CTRL_ADDR: usize = 0xe000_0000;
const CPUID_OFFSET: usize = 0xed00;

let cpuid_reg = (SYS_CTRL_ADDR+CPUID_OFFSET) as *const u32;
let cpuid_value = unsafe { *cpuid_reg };
// or
let cpuid_value = unsafe { cpuid_reg.read() };
```

⚠ 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_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

1. Cortex-M33 has some additional registers ↔



# Compiler Optimization

compilers optimize code

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

```
1  // we use mut as we need to write to it
2  const UART_TX: *mut u8 = 0x4003_4000 as *mut u8;
3  // b".." means ASCII string (Rust uses UTF-8 strings by default)
4  for character in b"Hello, World".iter() {
5      // character is &char, so we use *character to get the value
6      unsafe { UART_TX.write(*character); }
7  }
```

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: *mut u8 = 0x4003_4000;
2  unsafe { UART_TX.write(b'd'); }
```





# No Compiler Optimization

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

```
use core::ptr::read_volatile;

const SYS_CTRL_ADDR: usize = 0xe000_0000;
const CPUID_OFST: usize = 0xed00;

let cpuid_reg = (SYS_CTRL_ADDR + CPUID_OFST) as *const u32;
unsafe {
    // avoid compiler optimization
    read_volatile(cpuid_reg)
}
```

`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



# No Compiler Optimization

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

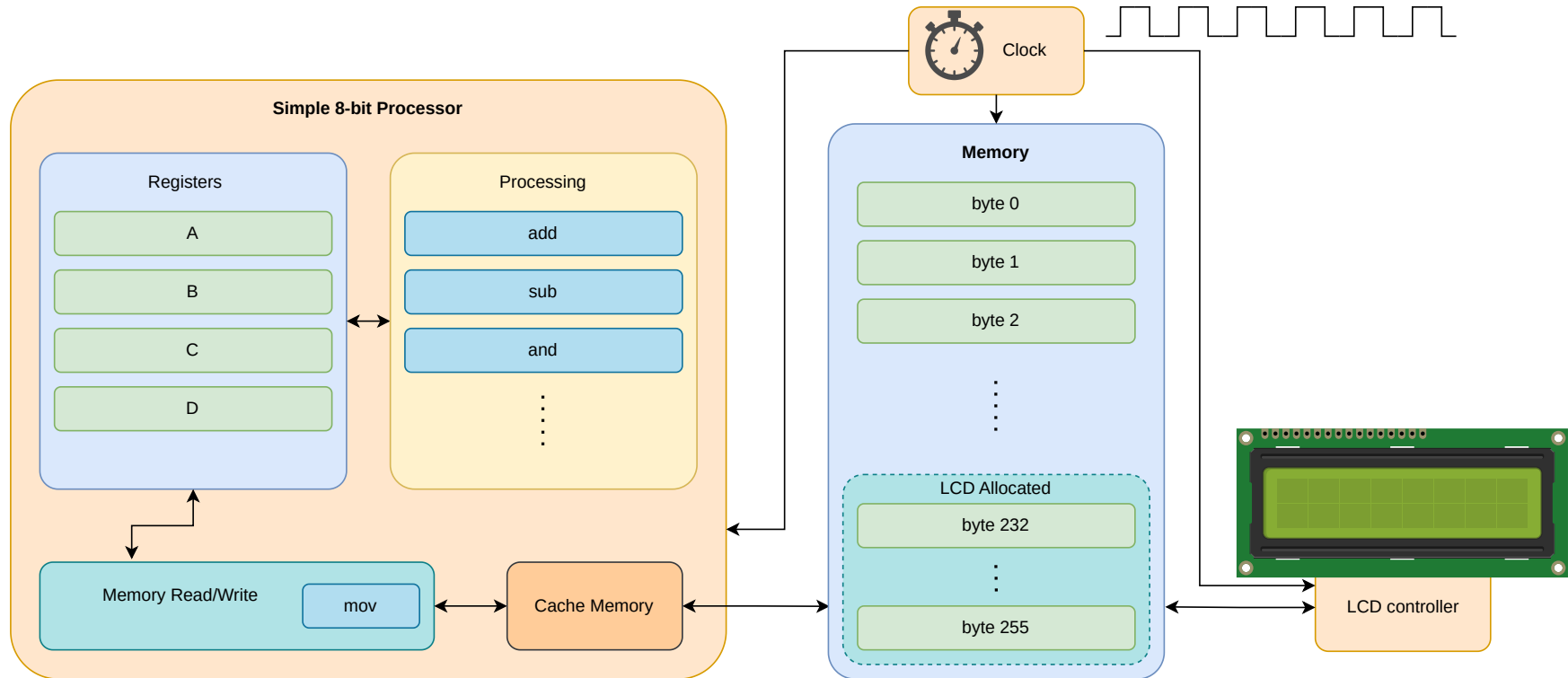
```
1  use core::ptr::write_volatile;
2
3  // we use mut as we need to write to it
4  const UART_TX: *mut u8 = 0x4003_4000 as *mut u8;
5  // b".." means ASCII string (Rust uses UTF-8 strings by default)
6  for character in b"Hello, World".iter() {
7      // character is &char, so we use *character to get the value
8      unsafe { write_volatile(UART_TX, *character); }
9  }
```

The compiler **knows** that `UART_TX` **must be written** every time.



# 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

```
use core::ptr::read_volatile;

const SYS_CTRL_ADDR: usize = 0xe000_0000;
const CPUID_OFST: usize = 0xed00;

let cpuid_reg = (SYS_CTRL_ADDR+CPUID_OFST) as *const u32;
let cpuid_value = unsafe {
    read_volatile(cpuid_reg)
};

// shift right 24 bits and keep only the last 8 bits
let variant = (cpuid_value >> 24) & 0b1111_1111;

// shift right 16 bits and keep only the last 4 bits
let architecture = (cpuid_value >> 16) & 0b1111;

// shift right 4 bits and keep only the last 12 bits
let part_no = (cpuid_value >> 4) & 0b1111_1111_1111;

// shift right 0 bits and keep only the last 4 bits
let revision = (cpuid_value >> 0) & 0b1111;
```

## CPUID Register

Offset: 0xed00

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

```
use core::ptr::read_volatile;
use core::ptr::write_volatile;

const SYS_CTRL_ADDR: usize = 0xe000_0000;
const AIRCR_OFST: usize = 0xed0c;

const VECTKEY_POS: u32 = 16;
const SYSRESETREQ_POS: u32 = 2;

let aircr_register = (SYS_CTRL + AIRCR) as *mut u32;
let mut aircr_value = unsafe {
    read_volatile(aircr_register)
};

aircr_value = aircr_value & !(0xffff << VECTKEY_POS);
aircr_value = aircr_value | (0x05fa << VECTKEY_POS);
aircr_value = aircr_value | (1 << SYSRESETREQ_POS);

unsafe {
    write_volatile(aircr_register, aircr_value);
}
```

# AIRCR Register

Offset: 0xed0c

Bits	Name	Description	Type	Reset
31:16	VECTKEY	Register key: Reads as Unknown On writes, write 0x05FA to VECTKEY, otherwise the write is ignored.	RW	0x0000
15	ENDIANESS	Data endianness implemented: 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: Reads as Unknown On writes, write 0x05FA to VECTKEY, otherwise the write is ignored.	RW	0x0000
15	ENDIANESS	Data endianness implemented: 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>
```





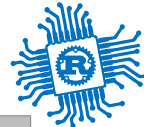
# tock-registers

## define registers format

```
1  use tock_registers::register_bitfields;
2  register_bitfields! {u32,
3      CPUID [
4          IMPLEMENTER OFFSET(24) NUMBITS(8) [],
5          VARIANT OFFSET(20) NUMBITS(4) [],
6          ARCHITECTURE OFFSET(16) NUMBITS(4) [
7              ARM_V6_M = 0xc,
8              ARM_V8_M = 0xa
9          ],
10         PARTNO OFFSET(4) NUMBITS(12) [
11             CORTEX_M0P = 0xc60,
12             CORTEX_M33 = 0xd21
13         ],
14         REVISION OFFSET(0) NUMBITS(2) []
15     ],
16     AIRCR [
17         VECTKEY OFFSET(16) NUMBITS(8) [KEY = 0x05fa],
18         ENDIANESS OFFSET(15) NUMBITS(1) [],
19         SYSRESETREQ OFFSET(2) NUMBITS(1) [],
20         VECTCLRACTIVE OFFSET(1) NUMBITS(1) []
21     ]
22 }
```

Bits	Name	Description	Type	Reset
31:24	IMPLEMENTER	Implementor code: 0x41 = ARM	RO	0x41
23:20	VARIANT	Major revision number n in the mpm revision status: 0x0 = Revision 0.	RO	0x0
19:16	ARCHITECTURE	Constant that defines the architecture of the processor: 0xC = ARMv6-M architecture.	RO	0xc
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3:0	REVISION	Minor revision number m in the mpm revision status: 0x1 = Patch 1.	RO	0x1

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



# tock-registers

define a structure for the peripheral

```
use tock_registers::register_structs;
use tock_registers::registers::{ReadOnly, ReadWrite};

// generates a C-style SysCtrl struct
register_structs! {
SysCtrl {
    // we registers up to 0xed00
    (0x0000 => _reserved1),
    // we define the CPUID register
    (0xed00 => cpuid: ReadOnly<u32, CPUID::Register>),
    // we registers up to 0xed
    (0xed04 => _reserved2),
    // we define the AIRCR register
    (0xed0c => aircr: ReadWrite<u32, AIRCR::Register>),
    // we ignore the rest of the registers
    (0xed10 => @END),
}
}
```

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



# Reset the processor

using tock-registers

```
1  const SYS_CTRL_ADDR: usize = 0xe000_0000;
2
3  register_bitfields! {u32,
4      // ...
5      AIRCR [
6          VECTKEY OFFSET(16) NUMBITS(8) [KEY = 0x05fa],
7          ENDIANESS OFFSET(15) NUMBITS(1) [],
8          SYSRESETREQ OFFSET(2) NUMBITS(1) [],
9          VECTCLRACTIVE OFFSET(1) NUMBITS(1) []
10     ]
11 }
12
13 register_structs! {
14     SysCtrl {
15         (0xed0c => aircr: ReadWrite<u32, AIRCR::Register>),
16     }
17 }
18
19 let sys_ctrl = unsafe { &*(SYS_CTRL_ADDR as *const SysCtrl) }; // C: struct SysCtrl *sys_ctrl = SYS_CTRL_ADDR;
20
21 sys_ctrl.aircr
22     .modify(AIRCR::VECTKEY::KEY + AIRCR::SYSRESETREQ::SET);
```



# Read the CPUID

using tock-registers

```
1  const SYS_CTRL_ADDR: usize = 0xe000_0000;
2  register_bitfields! {u32,
3      CPUID [
4          IMPLEMENTER OFFSET(24) NUMBITS(8) [],
5          VARIANT OFFSET(20) NUMBITS(4) [],
6          ARCHITECTURE OFFSET(16) NUMBITS(4) [ARMv6M = 0xc, ARMv8M0 = 0xa],
7          PARTNO OFFSET(4) NUMBITS(12) [CORTEX_M0P = 0xc60, CORTEX_M33 = 0xd21],
8          REVISION OFFSET(0) NUMBITS(2) []
9      ],
10     // ...
11 }
12 let sys_ctrl = unsafe { &*(SYS_CTRL_ADDR as *const SysCtrl) };
13
14 let variant = sys_ctrl.cpuid.read(CPUID::VARIANT);
15 let revision = sys_ctrl.cpuid.read(CPUID::REVISION);
16 let architecture = sys_ctrl.cpuid.read(CPUID::ARCHITECTURE);
17 let part_no = sys_ctrl.cpuid.read(CPUID::PARTNO);
18
19 if part_no == CPUID::PARTNO::Value::CORTEX_M0P as u32 {
20     // this is a Cortex-M0+
21 } else if part_no == CPUID::PARTNO::Value::CORTEX_M33 as u32 {
```



# GPIO

General Purpose Input Output for RP2040



# Bibliography

for this section

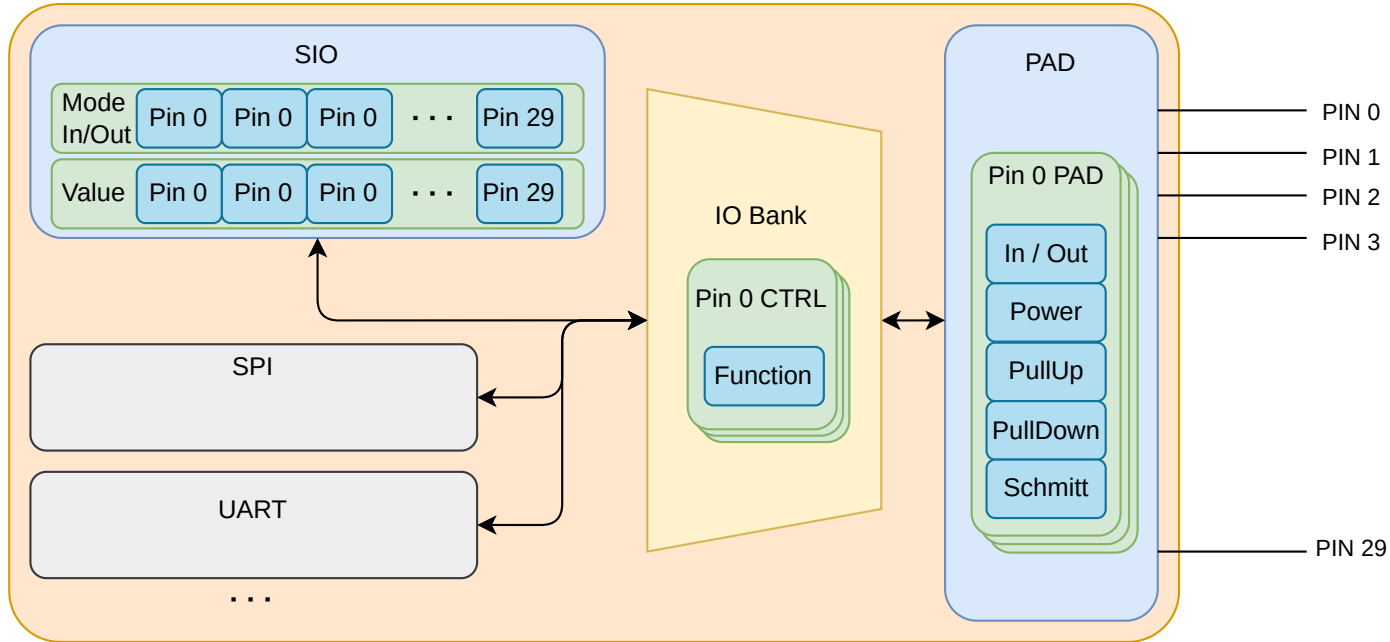
## **Raspberry Pi Ltd, *RP2040 Datasheet***

- 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)



# RP2040 GPIO Pins

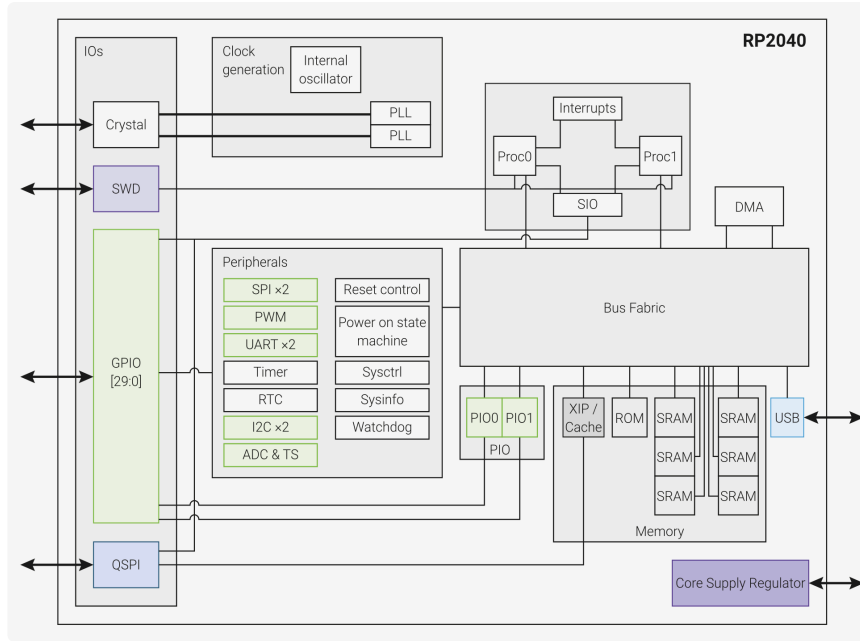
GPIO pins are connected to the processor pins through three peripherals





# GPIO

## Peripherals



SIO

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

GPIO

Multiplexes the functions of the GPIO pins



*SIO*: Set the pin as Input or Output

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

*PAD*: Set the pin input and output parameters





# 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

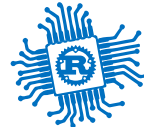
Bits	Description	Type	Reset
31:30	Reserved.	-	-
29:0	Set output enable (1/0 → output/input) for GPIO0...29. Reading back gives the last value written. If core 0 and core 1 both write to <code>GPIO_OE</code> simultaneously (or to a <code>SET/CLR/XOR</code> alias), the result is as though the write from 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. Reading back gives the last value written, NOT the input value from the pins. 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).

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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

Bits	Description	Type	Reset
31:30	Reserved.	-	-
29:0	Set output enable (1/0 → output/input) for GPIO0...29. Reading back gives the last value written. 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 mut 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	<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\_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. Reading back gives the last value written, NOT the input value from the pins. If core 0 and core 1 both write to GPIO_OUT 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

```
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 mut 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

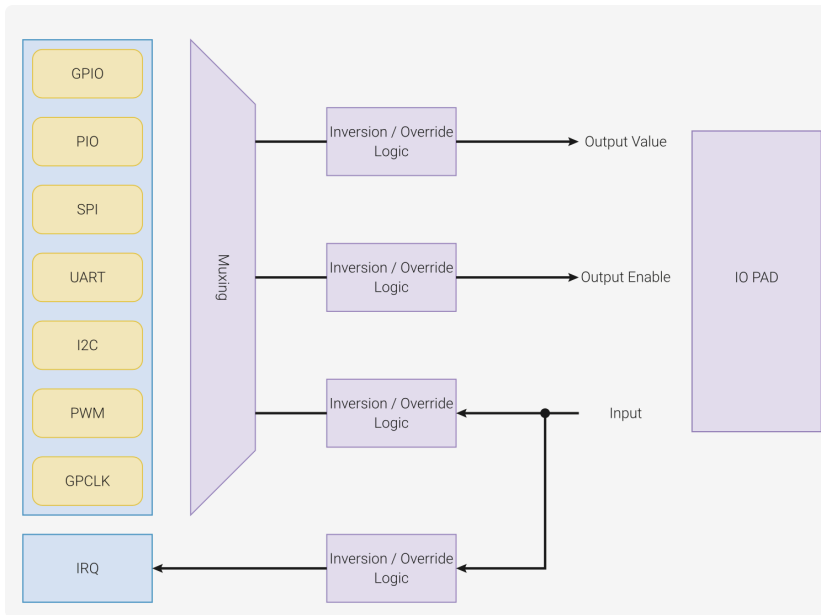
## GPIO\_OUT\_CLR

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 ( $0x4 + 8 \times x$ )

Bits	Name	Description	Type	Reset
31:30	Reserved.	-	-	-
29:28	IRQOVER	0x0 → don't invert the interrupt 0x1 → invert the interrupt 0x2 → drive interrupt low 0x3 → drive interrupt high	RW	0x0
27:18	Reserved.	-	-	-
17:16	INOVER	0x0 → don't invert the peri input 0x1 → invert the peri input 0x2 → drive peri input low 0x3 → drive peri input high	RW	0x0
15:14	Reserved.	-	-	-
13:12	OEOVER	0x0 → drive output enable from peripheral signal selected by funcsel 0x1 → drive output enable from inverse of peripheral signal selected by funcsel 0x2 → disable output 0x3 → enable output	RW	0x0
11:10	Reserved.	-	-	-
9:8	OUTOVER	0x0 → drive output from peripheral signal selected by funcsel 0x1 → drive output from inverse of peripheral signal selected by funcsel 0x2 → drive output low 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: usize = 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 ( $0x4 + 8 \cdot x$ )

Bits	Name	Description	Type	Reset
31:30	Reserved.	-	-	-
29:28	IRQOVER	0x0 → don't invert the interrupt 0x1 → invert the interrupt 0x2 → drive interrupt low 0x3 → drive interrupt high	RW	0x0
27:18	Reserved.	-	-	-
17:16	INOVER	0x0 → don't invert the peri input 0x1 → invert the peri input 0x2 → drive peri input low 0x3 → drive peri input high	RW	0x0
15:14	Reserved.	-	-	-
13:12	OEOVER	0x0 → drive output enable from peripheral signal selected by funcsel 0x1 → drive output enable from inverse of peripheral signal selected by funcsel 0x2 → disable output 0x3 → enable output	RW	0x0
11:10	Reserved.	-	-	-
9:8	OUTOVER	0x0 → drive output from peripheral signal selected by funcsel 0x1 → drive output from inverse of peripheral signal selected by funcsel 0x2 → drive output low 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 ( $0x4 + 8 \times x$ )

Bits	Name	Description	Type	Reset
31:30	Reserved.	-	-	-
29:28	IRQOVER	0x0 → don't invert the interrupt 0x1 → invert the interrupt 0x2 → drive interrupt low 0x3 → drive interrupt high	RW	0x0
27:18	Reserved.	-	-	-
17:16	INOVER	0x0 → don't invert the peri input 0x1 → invert the peri input 0x2 → drive peri input low 0x3 → drive peri input high	RW	0x0
15:14	Reserved.	-	-	-
13:12	OEOVER	0x0 → drive output enable from peripheral signal selected by funcsel 0x1 → drive output enable from inverse of peripheral signal selected by funcsel 0x2 → disable output 0x3 → enable output	RW	0x0
11:10	Reserved.	-	-	-
9:8	OUTOVER	0x0 → drive output from peripheral signal selected by funcsel 0x1 → drive output from inverse of peripheral signal selected by funcsel 0x2 → drive output low 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

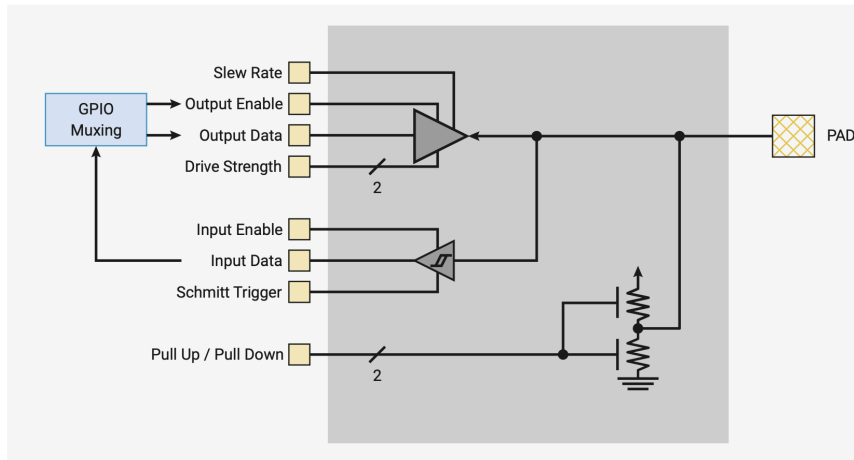




# Pad Control

## GPIOx Register

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



The User Bank Pad Control registers start at a base address of `0x4001c000` (defined as `PADS_BANK0_BASE` in SDK).

Offset	Name	Info
0x00	<a href="#">VOLTAGE_SELECT</a>	Voltage select. Per bank control
0x04	<a href="#">GPIO0</a>	Pad control register
0x08	<a href="#">GPIO1</a>	Pad control register
0x0c	<a href="#">GPIO2</a>	Pad control register
0x10	<a href="#">GPIO3</a>	Pad control register
0x14	<a href="#">GPIO4</a>	Pad control register
0x18	<a href="#">GPIO5</a>	Pad control register

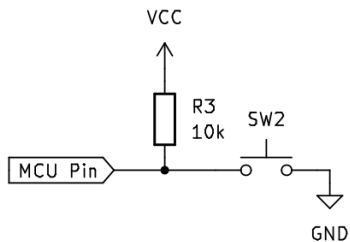
Bits	Name	Description	Type	Reset
31:8	Reserved.	-	-	-
7	OD	Output disable. Has priority over output enable from peripherals	RW	0x0
6	IE	Input enable	RW	0x1
5:4	DRIVE	Drive strength. 0x0 → 2mA 0x1 → 4mA 0x2 → 8mA 0x3 → 12mA	RW	0x1
3	PUE	Pull up enable	RW	0x0
2	PDE	Pull down enable	RW	0x1
1	SCHMITT	Enable 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 GPIO $x$ \_CTRL to 5
- set the GPIO\_OE\_CLR bit  $x$  to 1
- read the GPIO\_IN bit  $x$
- *adjust the GPIO $x$  fields to set the pull up/down resistor*



# Output

write a value to pin  $x$

- set the FUNCSEL field of GPIO $x$ \_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 GPIO $x$  fields to set the output current*



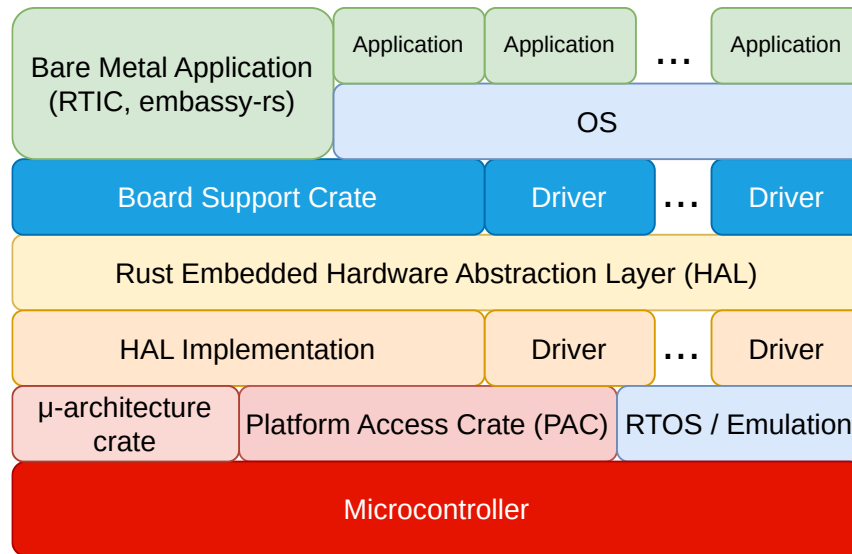
# Rust Embedded HAL

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  use core::panic::PanicInfo;
6
7  #[entry]
8  fn main() -> ! {
9      // your code goes here
10
11      loop { }
12  }
13
14  #[panic_handler]
15  pub fn panic(_info: &PanicInfo) -> ! {
16      loop { }
17  }
```

## 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  use core::panic::PanicInfo;
7
8  const GPIOX_CTRL: u32 = 0x4001_4004;
9  const GPIO_OE_SET: *mut u32 = 0xd000_0024 as *mut u32;
10 const GPIO_OUT_SET: *mut u32 = 0xd000_0014 as *mut u32;
11 const GPIO_OUT_CLR: *mut u32 = 0xd000_0018 as *mut u32;
12
13 #[panic_handler]
14 pub fn panic(_info: &PanicInfo) -> ! {
15     loop { }
16 }
```

```
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 talked about

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