Programming Project (3)

Yesterday, we looked at:

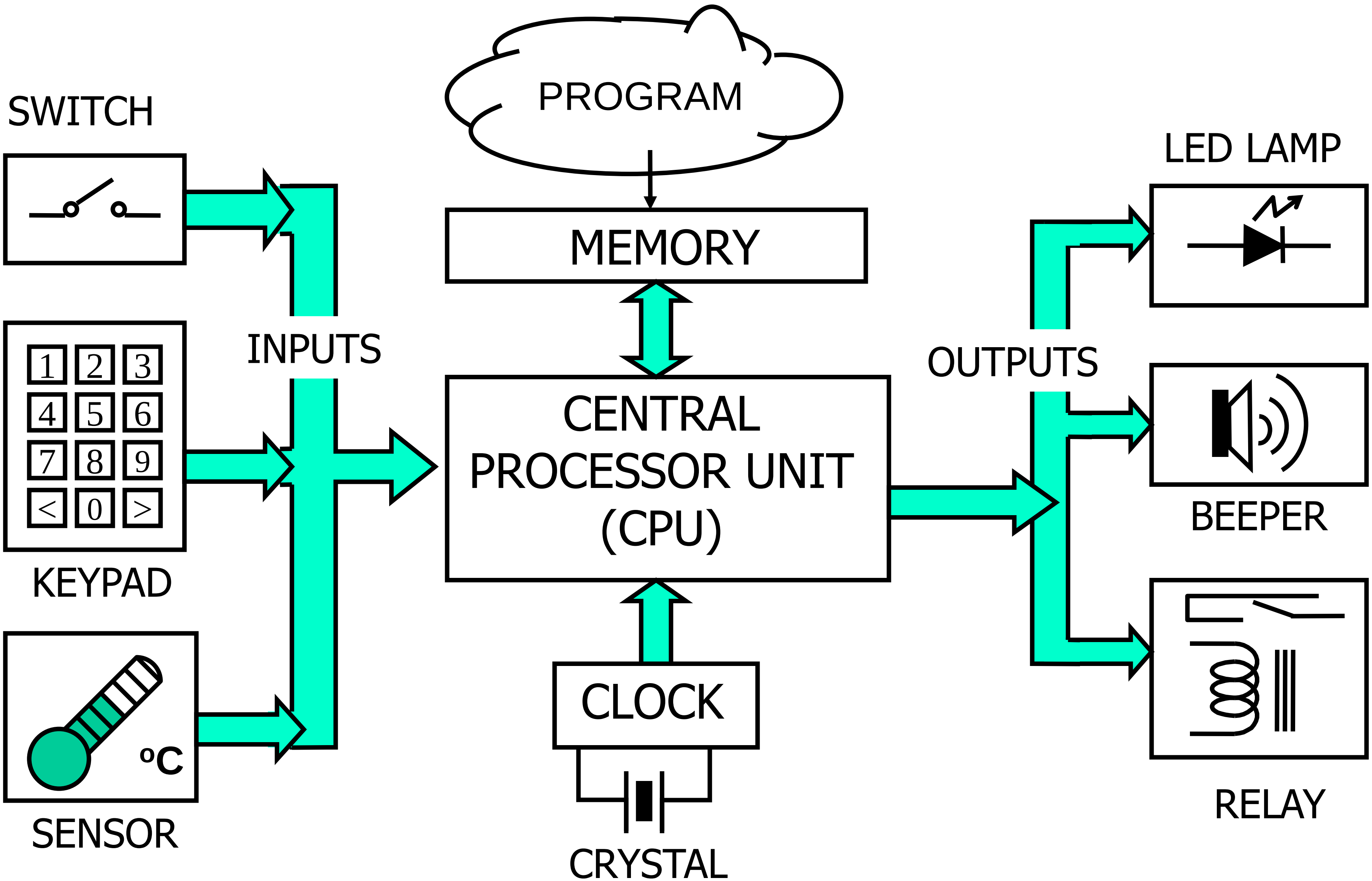
- Control Flow (cont.): if, switch, while, do, for, break & continue, goto
- Range & precedence of operators
- Program structure in C
- SW Architecture & Documentation
- Project Schedule & Block Diagram
- Tables & Arrays. Arrays & Pointers
- Pointers and Function Arguments
- Structures
- Typical errors in C
- Exercise 3: Fixed Point Arithmetic
- Ex. 4: Ball bouncing between walls
- Bit Manipulation Exercise

Today, we will look at:

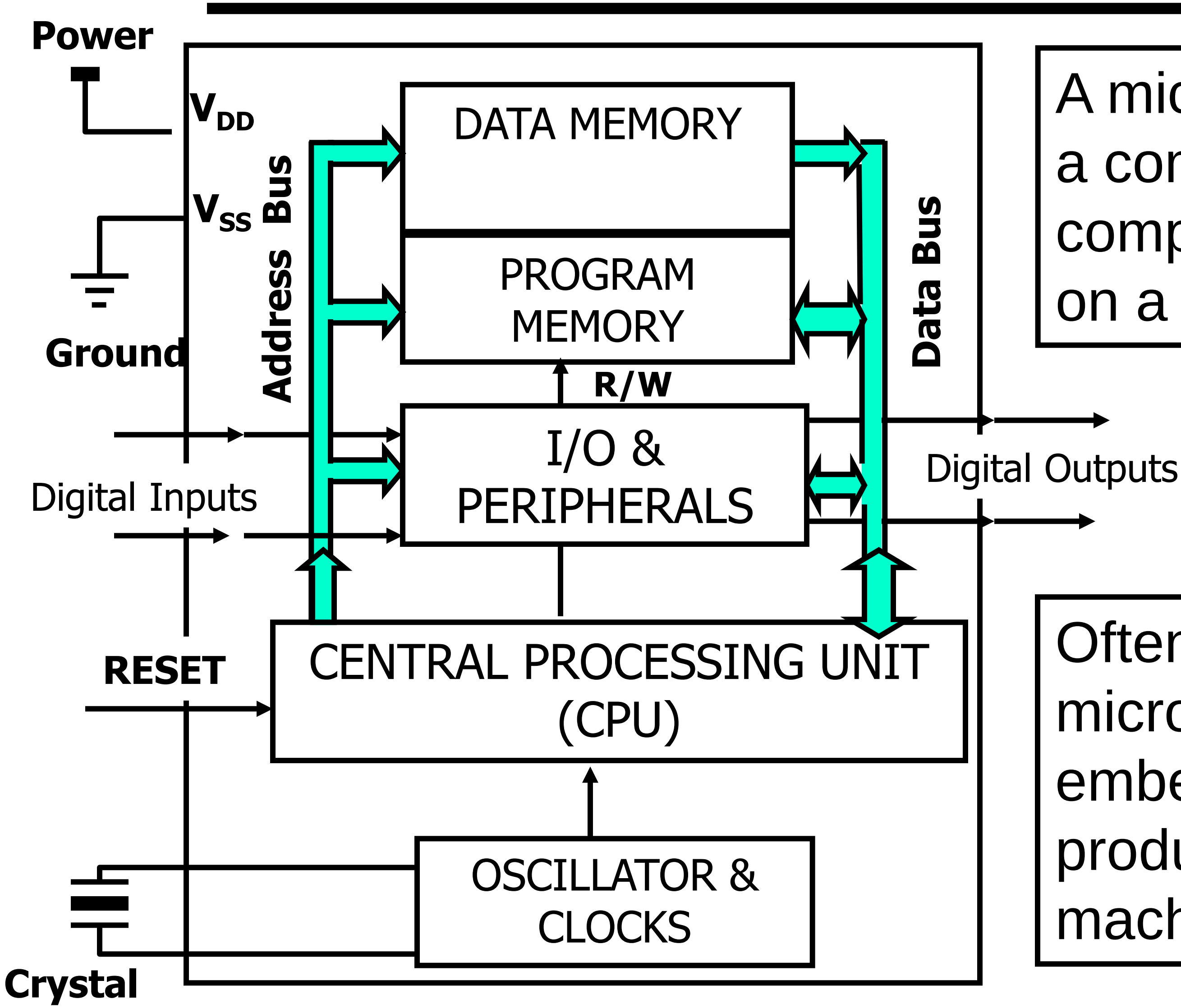
- Computer Systems and MCU
- Central Processor Unit (CPU)
- Memory in a computer
- Computer Number Interpretation
- Conversion: Binary-Hex-Decimal
- ARM Cortex MCU: Block Diagram and General-Purpose I/O (GPIO)
- Relation between Register & Ports
- Configuration of GPIOs

- Exercise 5: Read & Write from I/Os
- Exercise 6: Stop watch using Timer

Computer Systems



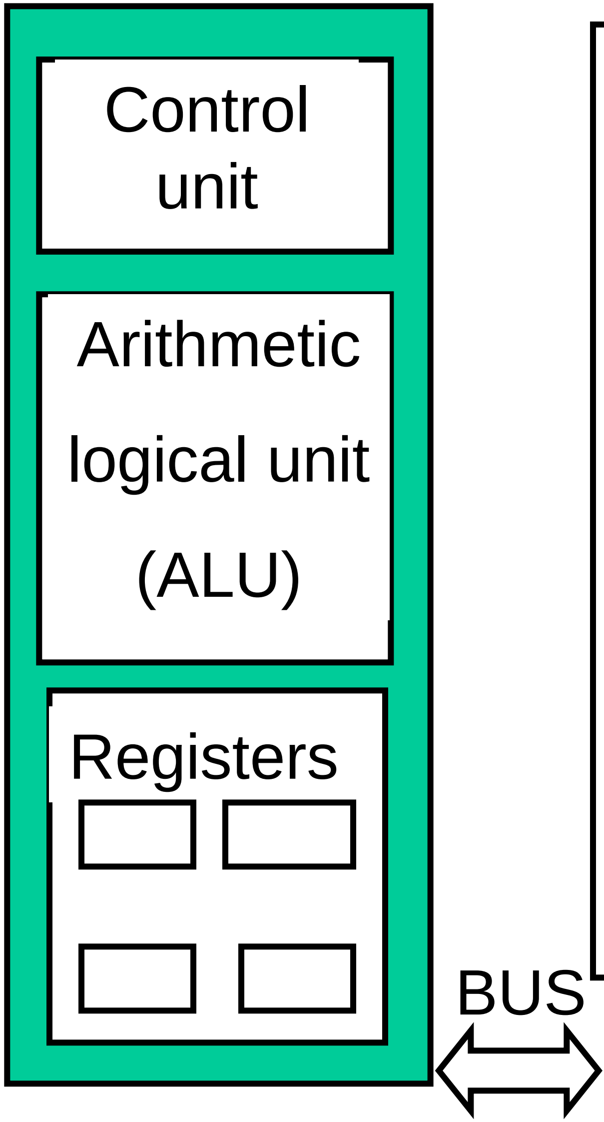
Microcontroller unit (MCU)



A microcontroller is a complete computer system on a chip.

Often the microcontrollers are embedded in a product (e.g. washing machine)

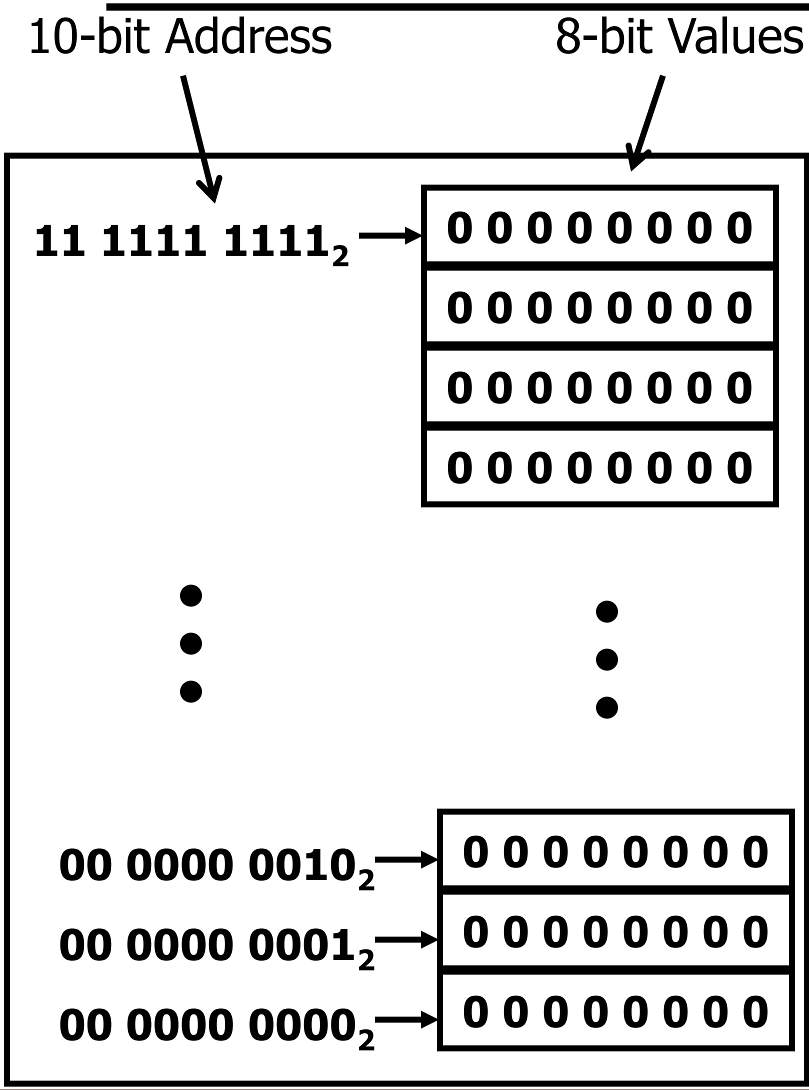
Central Processor Unit (CPU)



CPU executes programs that are stored on the memory.

- **Control unit** is responsible for fetching instructions from memory and interpreting them.
- **ALU** makes operations like addition, subtraction and boolean algebra.
- **Registers** are high speed memory cells which are used to stored temporarily data og control information.

How does a Computer see Memory



- A 8-bit computer with 10 address lines see memory a continuous row of 1024 8-bit values.
- In hexadecimal notation go these address from `$0000` to `$03FF`.

In an 8-bit computer is a good idea to use `char` variables intead of `int`! Type int is either 16 or 32 bit

How a number is interpreted on a computer

Text string: ’3~ÛÛÿ¿B<‘ is a man!!?

Ascii	Decimal	Hexadecimal	Binary	Graphical representation							
’3’	51	0x33	00110011	0	0	1	1	0	0	1	1
’~’	126	0x7E	01111110	0	1	1	1	1	1	1	0
’Û’	219	0xDB	11011011	1	1	0	1	1	0	1	1
’Û’	219	0xDB	11011011	1	1	0	1	1	0	1	1
‘ÿ’	255	0xFF	11111111	1	1	1	1	1	1	1	1
‘¿’	191	0xBF	10111111	1	0	1	1	1	1	1	1
‘B’	66	0x42	01000010	0	1	0	0	0	0	1	0
‘<‘	60	0x3C	00111100	0	0	1	1	1	1	0	0

One number in a computer is what the user interprets it as

Conversion between number systems

Binary to Hexadecimal (8 bit)

```
10010001    Split the number in 2x4 bits
 8    4  2 1
1001  ~ 1x8+0x4+0x2+1x1 = 9
1101  ~ 1x8+1x4+0x2+1x1 = 13 ~ D

~ 0x9D hexadecimal
```

Decimal to Hexadecimal

```
09 ~ 0x09
10 ~ 0x0A
15 ~ 0x0F
16 ~ 0x10
31 ~ 0x1F
32 ~ 0x20
```

A_{dec} ~ $A_{dec}/16$ or $A_{dec}\%16$

$A_{dec}=212$ ~ $212/16$ $212\%16$ = 13 4 = 0xD4

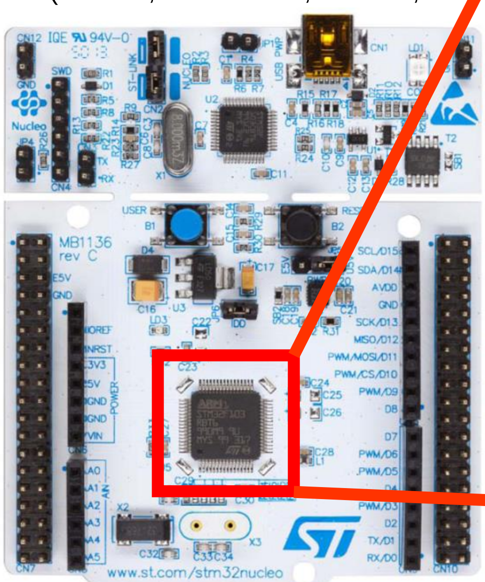
Integer division   Remainder

ASCII characters

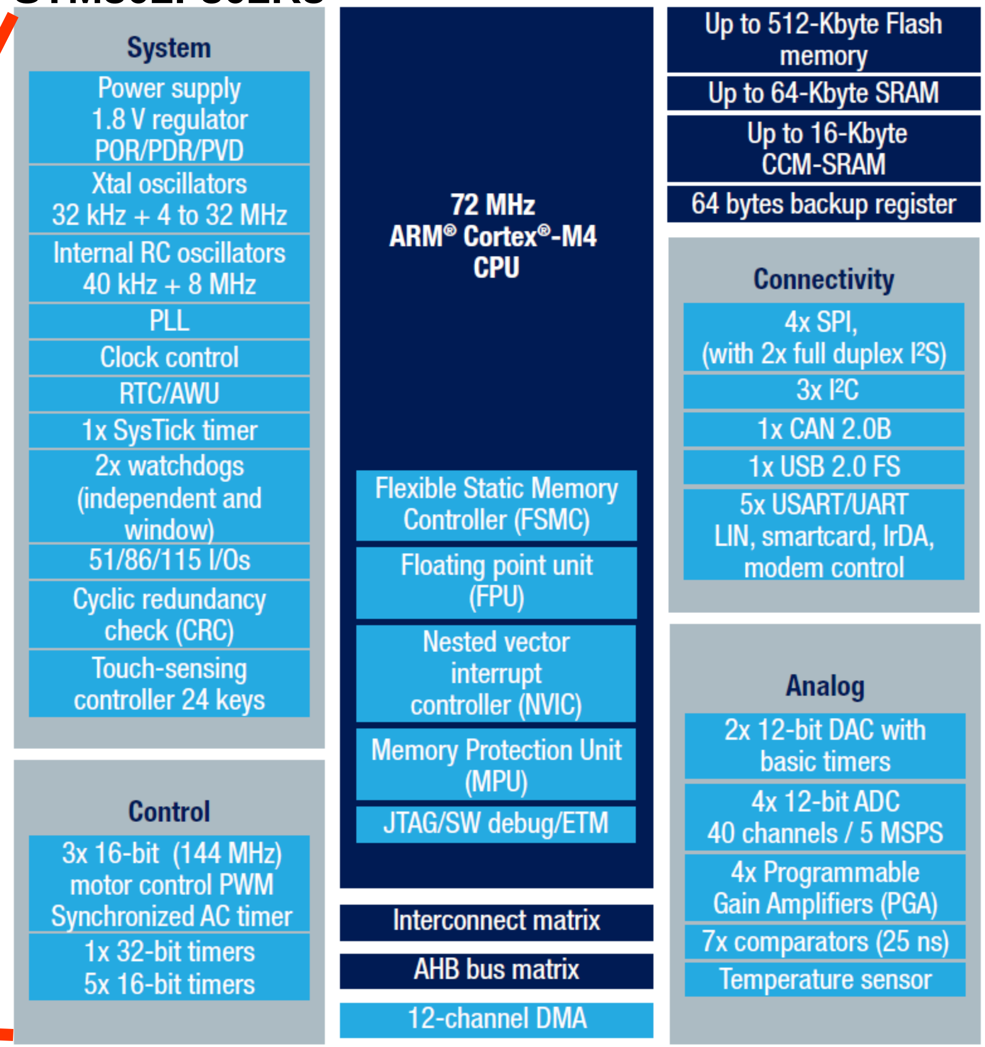
```
'A','B','C',...  ~ 0x41, 0x42, 0x43,...
'a','b','c',...  ~ 0x61, 0x62, 0x63,...
'1','2','3',...  ~ 0x31, 0x32, 0x33,...
```

ARM Cortex MCU Block Diagram

- Core: ARM® 32-bit Cortex®-M4 CPU with FPU (72 MHz max.)
- Memories: 32 to 64 Kb Flash, 16 Kb SRAM on data bus
- CRC calculation unit
- Clock management
- Up to 51 fast I/O ports
- Interconnect matrix
- 1 × ADC 0.20 µs (up to 15 channels)
- Temperature sensor
- 1 x 12-bit DAC channel
- Three fast rail-to-rail analog comparators
- 1 x operational amplifier
- Up to 18 capacitive sensing channels
- Up to 9 timers (PWM, Watchdog,...)
- Calendar RTC with alarm, periodic wakeup from Stop/Standby
- Comm. IF (3x I2Cs, <3 USARTs, <2 SPIs, USB 2.0, CAN, Infrared)

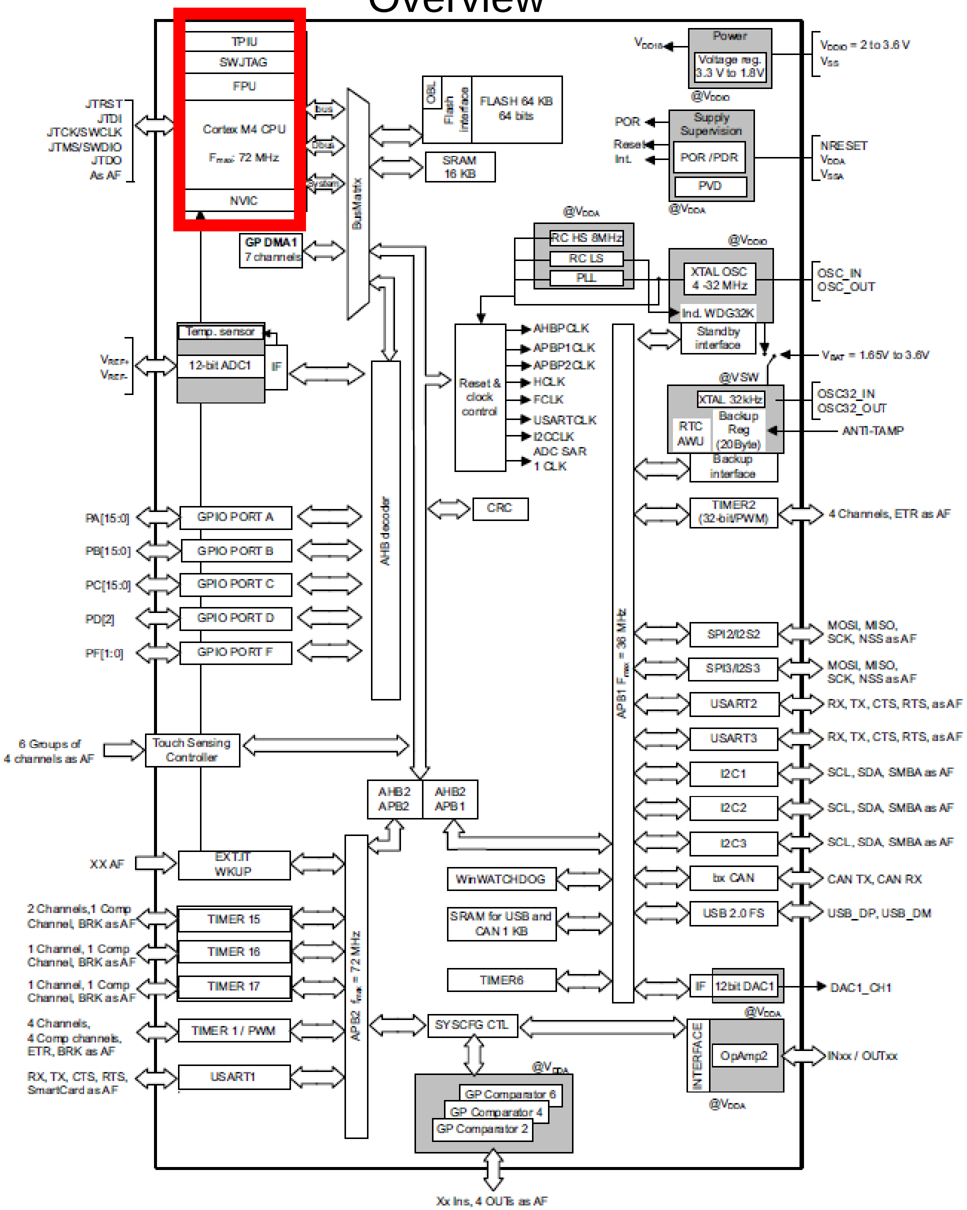


STM302F302R8

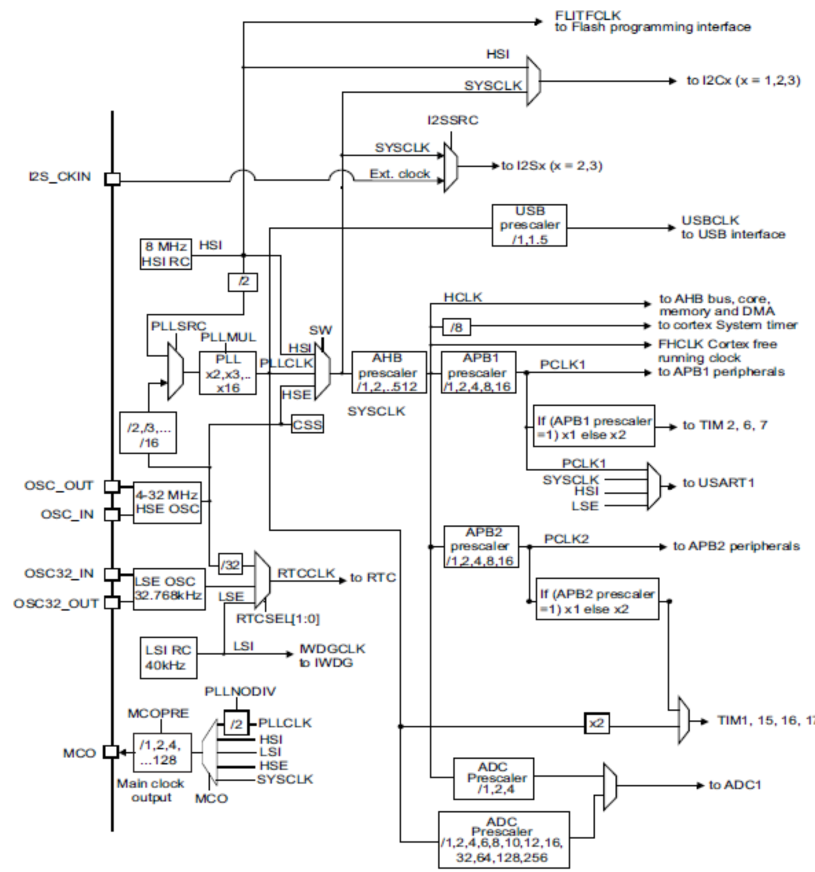


STM32F302R8

Overview



Timing Diagram

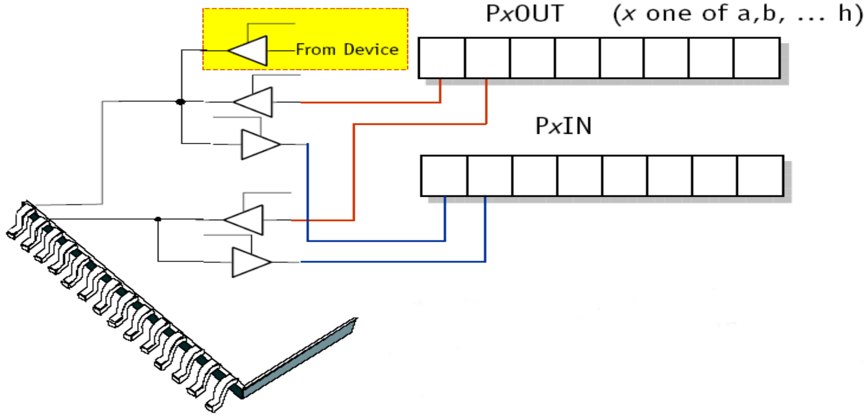


ARM Cortex General-Purpose I/O (GPIO)

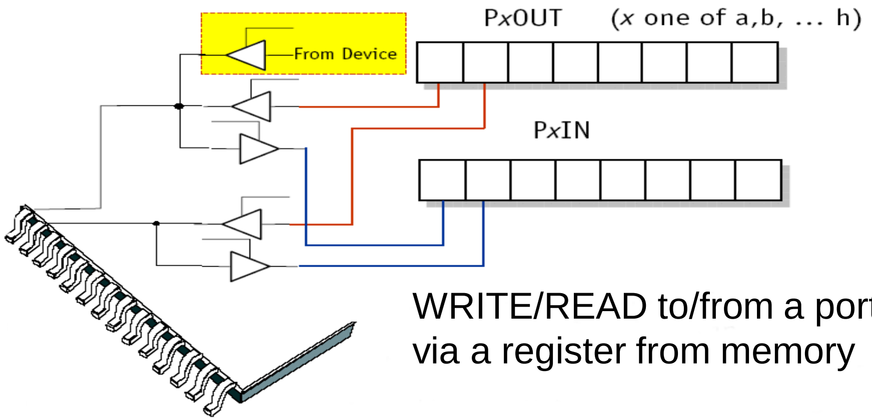
There are 5 ports, each with up to 16 bits available on the MCU (PA[16], PB[16], PC[16], PD[1], PF[2]). On the chip it is possible to get access to the bits on the ports.

Each pin on the port can:

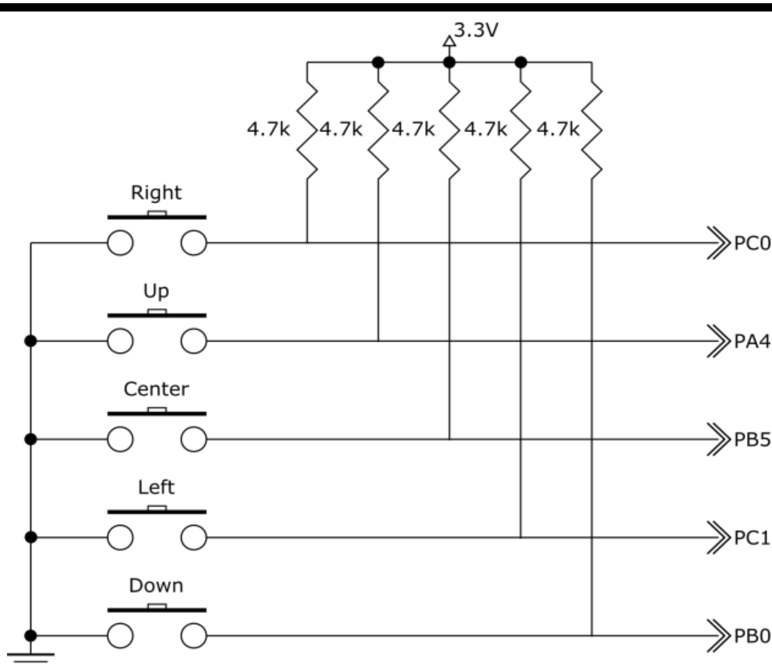
1. Be connected to a register (in the memory) to
   - WRITE to an external unit, or
   - READ from an external unit
2. Be connected to alternative function unit on the chip:
   - Timer
   - A/D converter
   - Communication module
   - Etc.



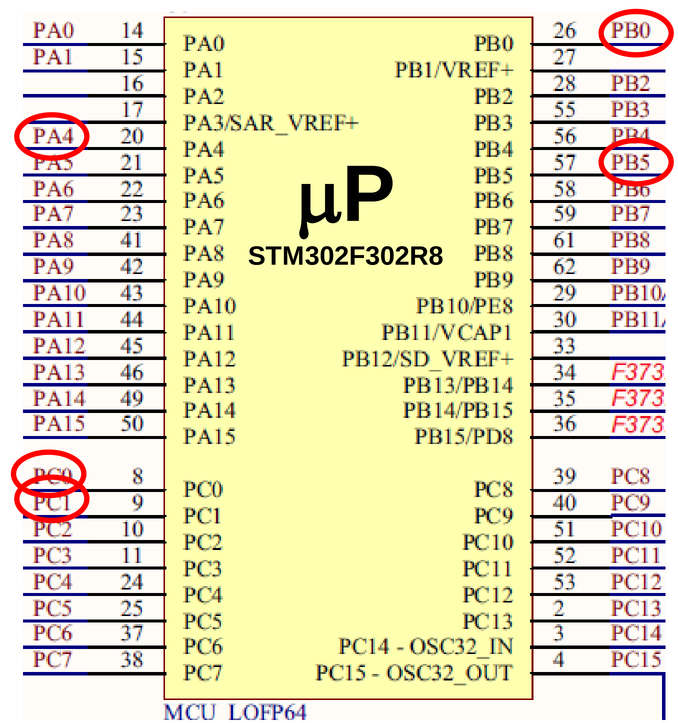
Relation between register & port



WRITE/READ to/from a port
via a register from memory



Schematics of ARM Cortex with GPIOs



General Purpose In/Out (GPIO)

Each GPIO port is associated with the following registers:

- 4 x 32-bit configuration registers:

  GPIOx_MODER -> input, output, AF, analog
  GPIOx_OTYPER -> push-pull or open-drain
  GPIOx_OSPEEDR -> speed
  GPIOx_PUPDR -> pull-up/pull-down whatever the I/O direction

- 2x 32-bit data registers:

  GPIOx_IDR -> stores the data to be input, it is a read-only register
  GPIOx_ODR -> stores the data to be output, it can be read/write

- 1x 32-bit set/reset register :

  GPIOx_BSRR

- 1x 32-bit locking register:

  GPIOx_LCKR

- 2x 32-bit alternate function selection registers:

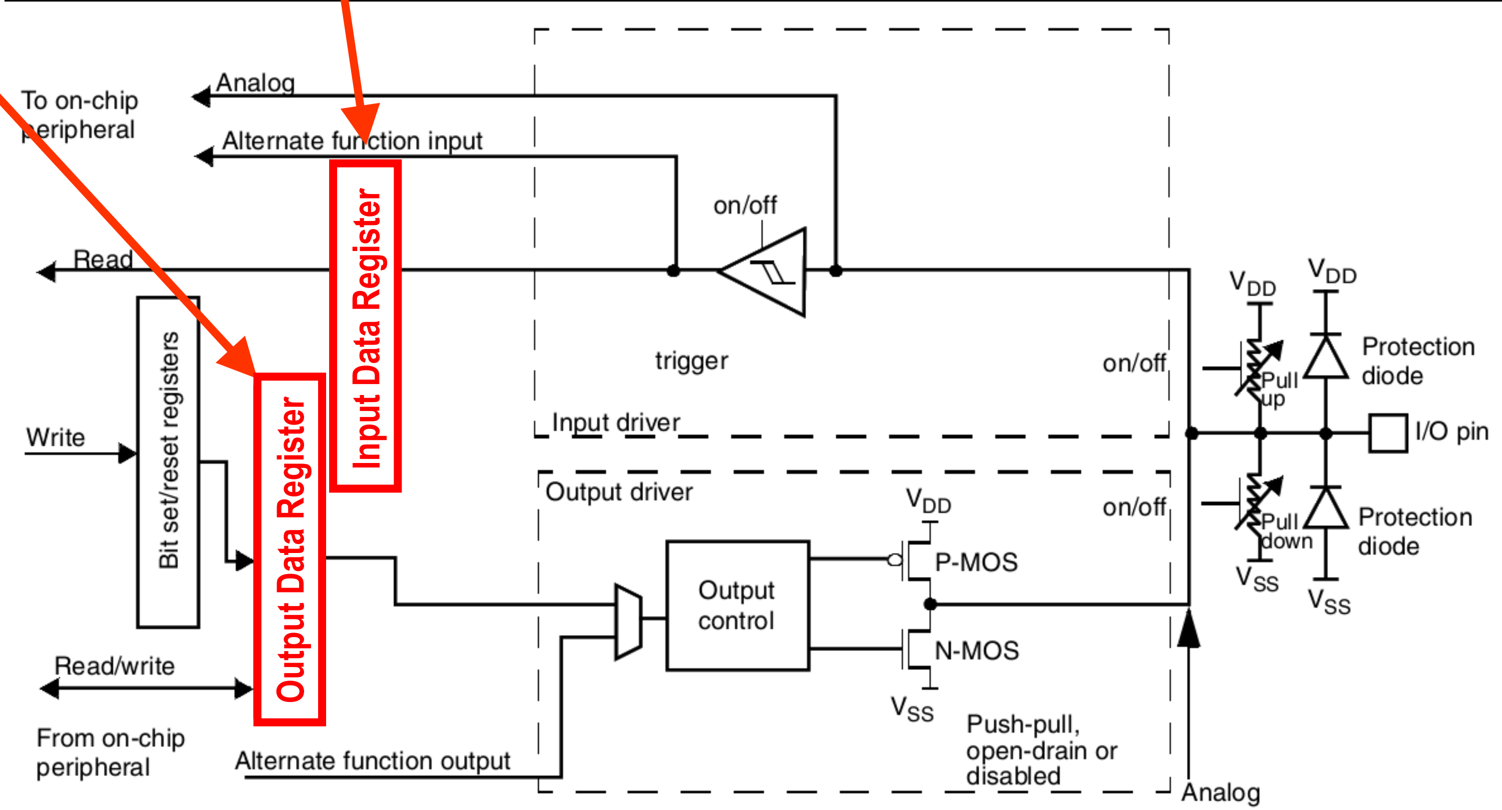
  GPIOx_AFRH
  GPIOx_AFRL

General Purpose In/Out - Data

GPIO registers for 32-bit data (only low 16 bit are valid) are called

- GPIOx_**I**DR (in)
- GPIOx_**O**DR (out)

Figure 17. Basic structure of an I/O port bit



General Purpose In/Out - Conf

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GPIOx_MODER (x =A..F)

Bits 2y+1:2y **MODERy[1:0]:** Port x configuration bits (y = 0..15)
These bits are written by software to configure the I/O mode.
00: Input mode (reset state)
01: General purpose output mode
10: Alternate function mode
11: Analog mode

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MODER15[1:0]		MODER14[1:0]		MODER13[1:0]		MODER12[1:0]		MODER11[1:0]		MODER10[1:0]		MODER9[1:0]		MODER8[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MODER7[1:0]		MODER6[1:0]		MODER5[1:0]		MODER4[1:0]		MODER3[1:0]		MODER2[1:0]		MODER1[1:0]		MODER0[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

GPIOx_OTYPER (x = A..F)

Bits 31:16 Reserved, must be kept at reset value.

Bits 15:0 **OTy:** Port x configuration bits (y = 0..15)
These bits are written by software to configure the I/O output type.
0: Output push-pull (reset state)
1: Output open-drain

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OT15	OT14	OT13	OT12	OT11	OT10	OT9	OT8	OT7	OT6	OT5	OT4	OT3	OT2	OT1	OT0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

General Purpose In/Out – Conf(2)

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GPIOx_OSPEEDR (x =A..F)

Bits 2y+1:2y **OSPEEDRy[1:0]**: Port x configuration bits (y = 0..15)

These bits are written by software to configure the I/O output speed.

x0: Low speed
01: Medium speed
11: High speed

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
OSPEEDR15 [1:0]		OSPEEDR14 [1:0]		OSPEEDR13 [1:0]		OSPEEDR12 [1:0]		OSPEEDR11 [1:0]		OSPEEDR10 [1:0]		OSPEEDR9 [1:0]		OSPEEDR8 [1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OSPEEDR7 [1:0]		OSPEEDR6 [1:0]		OSPEEDR5 [1:0]		OSPEEDR4 [1:0]		OSPEEDR3 [1:0]		OSPEEDR2 [1:0]		OSPEEDR1 [1:0]		OSPEEDR0 [1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

GPIOx_PUPDR (x = A..F)

Bits 2y+1:2y **PUPDRy[1:0]:** Port x configuration bits (y = 0..15)

These bits are written by software to configure the I/O pull-up or pull-down

00: No pull-up, pull-down
01: Pull-up
10: Pull-down
11: Reserved

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
PUPDR15[1:0]		PUPDR14[1:0]		PUPDR13[1:0]		PUPDR12[1:0]		PUPDR11[1:0]		PUPDR10[1:0]		PUPDR9[1:0]		PUPDR8[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PUPDR7[1:0]		PUPDR6[1:0]		PUPDR5[1:0]		PUPDR4[1:0]		PUPDR3[1:0]		PUPDR2[1:0]		PUPDR1[1:0]		PUPDR0[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Configuration example

```
/*****************************************************************/
// set pin PA0 as input //
/*****************************************************************/

GPIOA->MODER &= ~(0x00000003 << (0 * 2)); // Clear mode register

GPIOA->MODER |=  (0x00000000 << (0 * 2)); // Set mode register
(0x00 - Input, 0x01 - Output, 0x02 - Alternate, 0x03 - Analog)

GPIOA->PUPDR &= ~(0x00000003 << (0 * 2)); // Clear push/pull reg.

GPIOA->PUPDR |=  (0x00000002 << (0 * 2)); // Set push/pull reg.
(0x00 - No pull, 0x01 - Pull-up, 0x02 - Pull-down)

uint16_t val = GPIOA->IDR & (0x0001 << 0); // Read from PA0
```

Configuration example (2)

```
/*****************************************************************/
// Set pin PA1 to output //
/*****************************************************************/

GPIOA->OSPEEDR &= ~(0x00000003 << (1 * 2)); // Clear speed register
GPIOA->OSPEEDR |=  (0x00000002 << (1 * 2)); // set speed register
(0x01 - 10 MHz, 0x02 - 2 MHz, 0x03 - 50 MHz)

GPIOA->OTYPER &= ~(0x0001 << (1)); // Clear output type register
GPIOA->OTYPER |=  (0x0000 << (1)); // Set output type register
                              (0x00 - Push pull, 0x01 - Open drain)

GPIOA->MODER &= ~(0x00000003 << (1 * 2)); // Clear mode register
GPIOA->MODER |=  (0x00000001 << (1 * 2)); // Set mode register
(0x00 - In, 0x01 - Out, 0x02 - Alternate, 0x03 - Analog in/out)

GPIOA->ODR |= (0x0001 << 1); //Set pin PA1 to high
```

Comments/Feedback to Exercise 3-4 (Friday)

- **Just in case … re-check which COMx is installed!**
- **Periodicity in sinus and cosinus**
  - **LUT: 0 degree is x0000, 360 degrees is x0200**
  - **236 degrees is in binary 0001.0100.1111 (x014F)**
  - **236+360 degrees is in binary 0011.0100.1111 (x034F)**
  - **236+2x360 degrees is in binary 0101.0100.1111 (x054F)**
- **`signed short sin(int a) {return SIN[a & 0x1FF];}`**
- **Use of Pointers when calling a function**

```
void swap (int *px, int *py)
     {int temp; temp=*px; *px=*py; *py=temp;}
```

- **Structure and function to Rotate**

```
void RotVector (struct vector_t *v, int angle) {
// call with RotVector (&vec,angle)//
// variable declarations://  long temp;
    (*v).x = // v->x = // Udtryk //;
    (*v).y = // v->y = // Udtryk //;}
```

Exercise 5

- **Learn how to use the General Purpose In/Out (GPIO) of the μP**
- **By detecting that a button has been pressed, a message is written**
- **Parts of the "STM32F302x" literature containing the chapters "General-Purpose I/O", "Interrupt Controller", and "Timers" should be used as reference.**
- **You control each I/O register (A to H) through a number of configuration registers:**

  – GPIOx_MODER -> input, output, AF, analog
  – GPIOx_OTYPER -> push-pull or open-drain
  – GPIOx_OSPEEDR -> speed
  – GPIOx_PUPDR -> pull-up/pull-down whatever the I/O direction

- **Display a color on the RGB LED**
- **Note:** The scope of a variable is the function where it was created. Variables declared outside of functions can not be accessed from other functions unless they're declared to be `static`. Variables declared in functions can preserve their value between calls if they are defined as `static`, otherwise they're automaticly getting recreated for each function call.