C Programming

Lecture 08

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Outline

- C refresher
  - Common idioms to set/clear bits
  - Pointers and arrays
  - Structures
- Writing a simple device driver: GPIO
  - Finding information in documentation
  - Writing code to properly configure the peripheral

Learning Objectives

By the end of this lecture you should be able to…

- Recall basic C programming idioms and concepts (e.g., pointers, arrays, structures).
- Write a simple device driver to control the peripherals in your MCU using memory-mapped I/O.

C Programming Review

Important Concepts in C

- C is libertarian by nature. You can stomp on any memory address you want!
- There is no memory management built in. You must manually allocate (and deallocate!) any memory you need.

Primitive Data Types in C

Table eC.2 **Primitive data types and sizes**

Type	Size (bits)	Minimum	Maximum
`char`	8	$-2^{-7} = -128$	$2^7 - 1 = 127$
`unsigned char`	8	0	$2^8 - 1 = 255$
`short`	16	$-2^{15} = -32,768$	$2^{15} - 1 = 32,767$
`unsigned short`	16	0	$2^{16} - 1 = 65,535$
`long`	32	$-2^{31} = -2,147,483,648$	$2^{31} - 1 = 2,147,483,647$
`unsigned long`	32	0	$2^{32} - 1 = 4,294,967,295$
`long long`	64	-2^{63}	$2^{63} - 1$
`unsigned long`	64	0	$2^{64} - 1$
`int`	machine-dependent		
`unsigned int`	machine-dependent		
`float`	32	$\pm 2^{-126}$	$\pm 2^{127}$
`double`	64	$\pm 2^{-1023}$	$\pm 2^{1022}$

Primitive Data Types in `stdint.h`

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`unsigned char`	8	0	$2^8 - 1 = 255$
`int`	machine-dependent		
`unsigned int`	machine-dependent		
`int16_t`	16	$-2^{15} = -32{,}768$	$2^{15} - 1 = 32{,}767$
`uint16_t`	16	0	$2^{16} - 1 = 65{,}535$
`int32_t`	32	$-2^{31} = -2{,}147{,}483{,}648$	$2^{31} - 1 = 2{,}147{,}483{,}647$
`uint32_t`	32	0	$2^{32} - 1 = 4{,}294{,}967{,}295$
`int64_t`	64	-2^{63}	$2^{63} - 1$
`uint64_t`	64	0	$2^{64} - 1$
`float`	32	$\pm 2^{-126}$	$\pm 2^{127}$
`double`	64	$\pm 2^{-1023}$	$\pm 2^{1022}$

Operators and Operator Precedence

Table eC.3 Operators listed by decreasing precedence

Category	Operator	Description	Example
Unary	++	post-increment	a++; // a = a+1
	−−	post-decrement	x--; // x = x−1
	&	memory address of a variable	x = &y; // x = the memory // address of y
	~	bitwise NOT	z = ~a;
	!	Boolean NOT	!x
	−	negation	y = -a;
	++	pre-increment	++a; // a = a+1
	−−	pre-decrement	--x; // x = x−1
	(type)	casts a variable to (type)	x = (int)c; // cast c to an // int and assign it to x
	sizeof()	size of a variable or type in bytes	long int y; x = sizeof(y); // x = 4
Multiplicative	*	multiplication	y = x * 12;
	/	division	z = 9 / 3; // z = 3
	%	modulo	z = 5 % 2; // z = 1
Additive	+	addition	y = a + 2;
	−	subtraction	y = a - 2;
Bitwise Shift	<<	bitshift left	z = 5 << 2; // z = 0b00010100
	>>	bitshift right	x = 9 >> 3; // x = 0b00000001
Relational	==	equals	y == 2
	!=	not equals	x != 7
	<	less than	y < 12
	>	greater than	val > max
	<=	less than or equal	z <= 2
	>=	greater than or equal	y >= 10

Table eC.3 Operators listed by decreasing precedence—Cont'd

Category	Operator	Description	Example
Bitwise	&	bitwise AND	y = a & 15;
	^	bitwise XOR	y = 2 ^ 3;
	|	bitwise OR	y = a | b;
Logical	&&	Boolean AND	x && y
	||	Boolean OR	x || y
Ternary	? :	ternary operator	y = x ? a : b; // if x is TRUE, // y=a, else y=b
Assignment	=	assignment	x = 22;
	+=	addition and assignment	y += 3; // y = y + 3
	−=	subtraction and assignment	z −= 10; // z = z - 10
	*=	multiplication and assignment	x *= 4; // x = x * 4
	/=	division and assignment	y /= 10; // y = y / 10
	%=	modulo and assignment	x %= 4; // x = x % 4
	>>=	bitwise right-shift and assignment	x >>= 5; // x = x>>5
	<<=	bitwise left-shift and assignment	x <<= 2; // x = x<<2
	&=	bitwise AND and assignment	y &= 15; // y = y & 15
	|=	bitwise OR and assignment	x |= y; // x = x | y
	^=	bitwise XOR and assignment	x ^= y; // x = x ^ y

Operator Precedence Tip!

You should only have to remember multiplication/division before addition/subtraction.
For everything else, use parentheses!

Important Keywords in C

- ______________ – prevents the compiler from using a cached value (forces load)
- ___________ – “read-only”. Prevents you from assigning a value to the variable.
- ____________
  - Inside a function: retains its values between calls.
  - Applied to a function: visible only in this file
- ____________
  - Applied to a function definition: has global scope (redundant)
  - Applied to a variable: defined elsewhere
- __________
  - As return type of function: doesn’t return a value
  - In a pointer declaration, the type of a generic pointer
  - In a parameter list: takes no parameters

Important Libraries

- ________________ – standard fixed-width types (e.g., uint32_t)
- _______________ - standard input and output. Contains functions like printf or fprintf.
- ________________ – standard library: random number generation (rand and srand), allocating or freeing memory (malloc and free).
- ______________ – math library: standard math functions like sin, cos, sqrt, log, exp, floor, ceil.
- ________________ – string library: functions to compare, copy, concatenate, and determine the length of a string.

Setting and Clearing Bits

C Idioms for Setting and Clearing Bits

```
#define GPIOA_BASE 0x48000000
#define GPIOA_MODER (*((volatile unsigned long *) (GPIOA_BASE + 0x00)))

// Set bit 3 of the GPIOA_MODER to 1.

                                                                          ①
// Clear bit 7 of the GPIOA_MODER (i.e., set to 0)

                                                                          ②
```

① ____

② ____

Pointers and Arrays

Pointers and Arrays in C: Arrays

```
int * p = (int*) 0x20000000;

int a = *p;                                  ①

int b = *(p+3);                              ②

*(p+5) = b;                                  ③
```

① Equivalent to a= ____________

② Equivalent to b= ____________, address ______________________

③ Equivalent to p[5]= ________, address ______________________

Pointers and Arrays in C: Strings

```
char * str = (char *) 0x20001000;

str[13] = 'A';  ①
```

① Address ______________________

Dereferencing

```

int * p = (int*) 0x20000000;

int a = *p;                      ①
int * aptr = &a;                 ②

*aptr = 3;                       ③

int * ptr = &p[0];               ④

ptr = &p[5]                      ⑤

*ptr = 42;                       ⑥
```

① Equivalent to a = __________

② `aptr` stores address of ______

③ same as `a=3`

④ `ptr=` ___________________

⑤ `ptr=` __________________

⑥ `p[5]=` _______

Structures

```
struct optional_tag {
    type_1 identifier_1;
    type_2 identifier_2;
    ...
    type_N identifier_N;
} optional_variable_definitions ;
```

Structures

```
struct contact {
    char name[30];
    unsigned long long phone;
    float height;
};

struct contact jbrake; // example variable definition
```

How many bytes does this structure occupy in memory?

Using structures as part of a new type

Can also wrap in a typedef to avoid needing to use the `struct` keyword.

```
typedef struct my_tag {int i;} my_type; // Declaration of new type

// Creating variable with struct keyword

                                                          ①

// Creating variable using new type

                                                          ②
```

① ____________________

② ____________________

Arrow Operator

Use a structure to access a chunk of memory in a specific location.

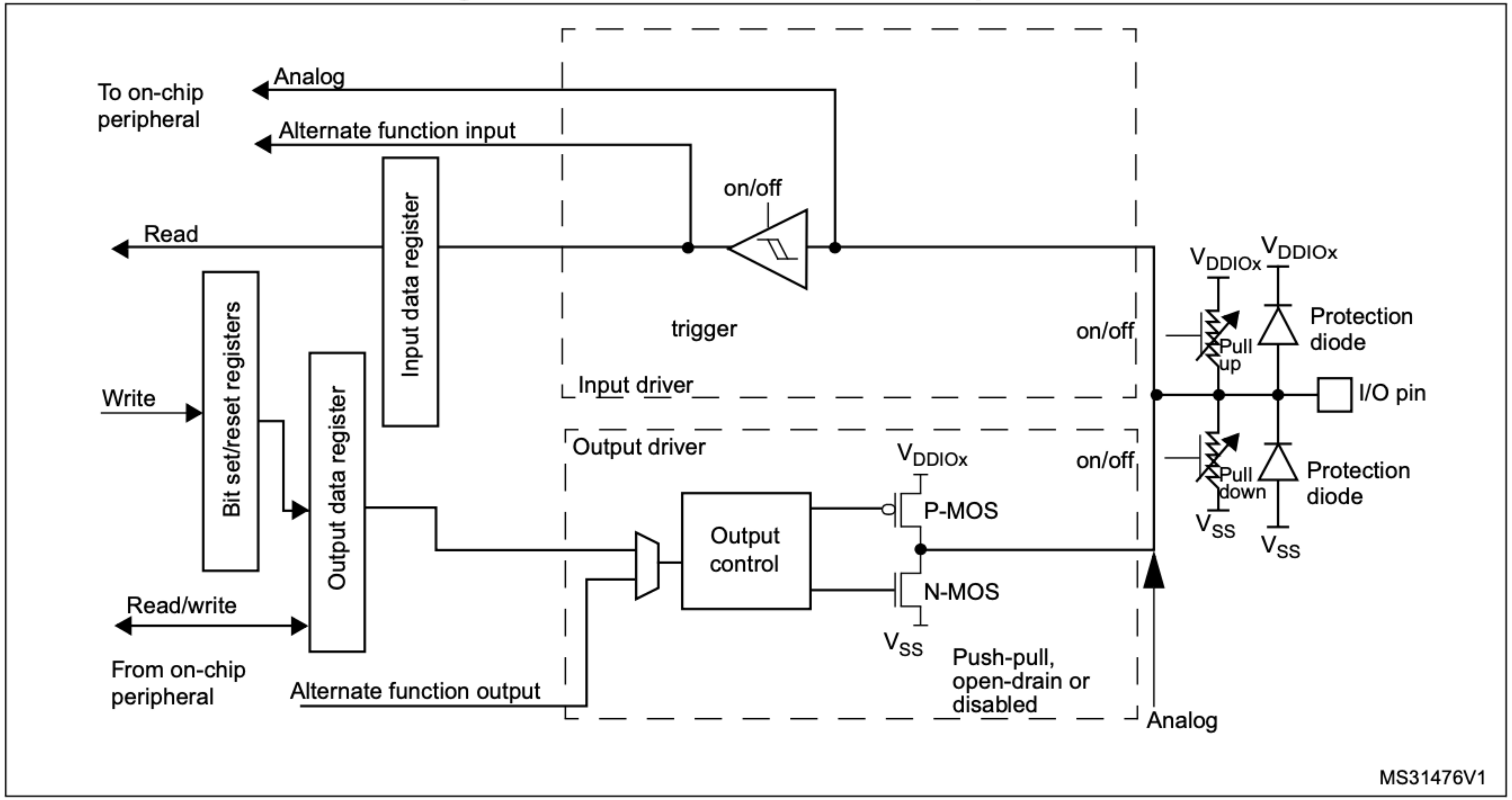
```c
typedef struct {
  char first_name[30];
  unsigned long long phone;
  float height;
} contact_type;

contact_type jbrake;
strcpy(jbrake.first_name, "Josh Brake");
jbrake.phone = (unsigned long long) 9096218553;
contact_type * contact_type_ptr = &jbrake;
unsigned long long phone_num = contact_type_ptr->phone;
```

Writing Device Drivers: GPIO Example

GPIO Block Diagram

Figure 19. Basic structure of an I/O port bit



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GPIO Register Map

Table 37. GPIO register map and reset values

Offset	Register name	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	**GPIOA_MODER**	MODE15[1:0]		MODE14[1:0]		MODE13[1:0]		MODE12[1:0]		MODE11[1:0]		MODE10[1:0]		MODE9[1:0]		MODE8[1:0]		MODE7[1:0]		MODE6[1:0]		MODE5[1:0]		MODE4[1:0]		MODE3[1:0]		MODE2[1:0]		MODE1[1:0]		MODE0[1:0]	
	Reset value	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x00	**GPIOB_MODER**	MODE15[1:0]		MODE14[1:0]		MODE13[1:0]		MODE12[1:0]		MODE11[1:0]		MODE10[1:0]		MODE9[1:0]		MODE8[1:0]		MODE7[1:0]		MODE6[1:0]		MODE5[1:0]		MODE4[1:0]		MODE3[1:0]		MODE2[1:0]		MODE1[1:0]		MODE0[1:0]	
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1
0x00	**GPIOx_MODER** (where x = **C..E,H**)	MODE15[1:0]		MODE14[1:0]		MODE13[1:0]		MODE12[1:0]		MODE11[1:0]		MODE10[1:0]		MODE9[1:0]		MODE8[1:0]		MODE7[1:0]		MODE6[1:0]		MODE5[1:0]		MODE4[1:0]		MODE3[1:0]		MODE2[1:0]		MODE1[1:0]		MODE0[1:0]	
	Reset value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0x04	**GPIOx_OTYPER** (where x = **A..E,H**)	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	OT15	OT14	OT13	OT12	OT11	OT10	OT9	OT8	OT7	OT6	OT5	OT4	OT3	OT2	OT1	OT0
	Reset value																	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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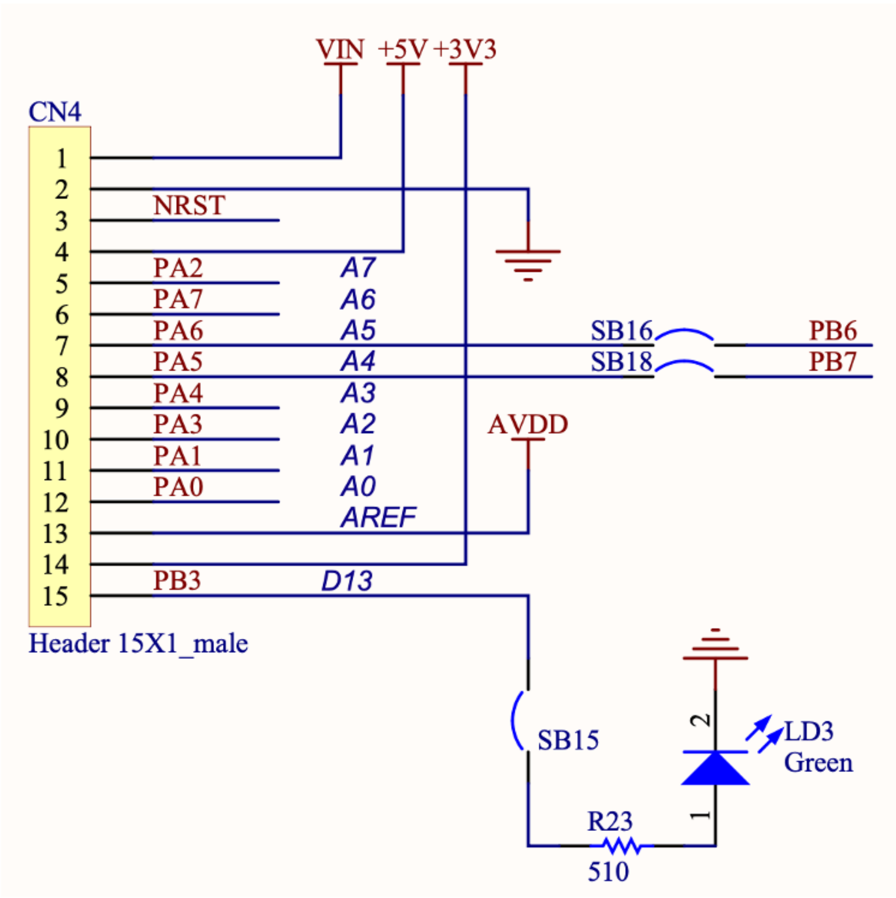
Steps for writing a device driver for a new peripheral

1. Look at block diagram
2. Note what elements in the diagram need to be configured
3. Find relevant registers and bits
4. Write code
    1. Base address for peripheral
    2. Create structure to define registers

Blink LED

On-board LED connected to pin PB3.



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Enabling peripheral clock

6.2.18 Peripheral clock enable register (RCC_AHBxENR, RCC_APBxENRy)

Each peripheral clock can be enabled by the xxxxEN bit of the RCC_AHBxENR, RCC_APBxENRy registers.

When the peripheral clock is not active, the peripheral registers read or write accesses are not supported.

The enable bit has a synchronization mechanism to create a glitch free clock for the peripheral. After the enable bit is set, there is a 2 clock cycles delay before the clock be active.

Caution: Just after enabling the clock for a peripheral, software must wait for a delay before accessing the peripheral registers.

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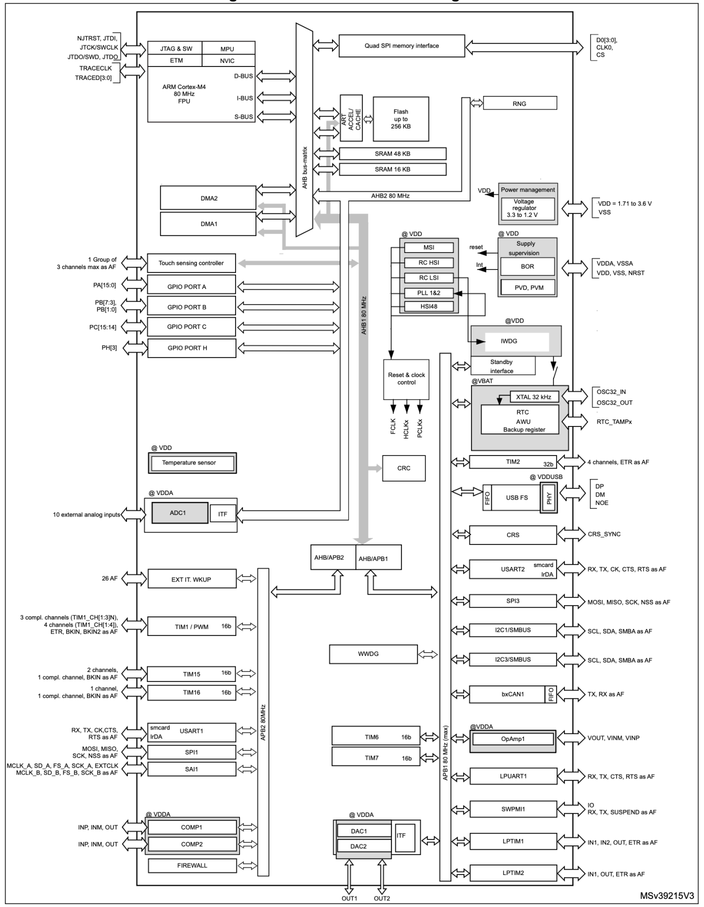
Figure 1. STM32L432xx block diagram



Note: AF: alternate function on I/O pins.

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Finding clock enable bit for GPIOB

6.4.16 AHB2 peripheral clock enable register (RCC_AHB2ENR)

Address offset: 0x4C

Reset value: 0x0000 0000

Access: no wait state, word, half-word and byte access

Note: *When the peripheral clock is not active, the peripheral registers read or write access is not supported.*

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.	RNG EN	res.	AESEN (1)
													rw		rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Res.	res.	ADCEN	res.	Res.	Res.	Res.	res.	GPIOH EN	res.	res.	GPIOE EN	GPIOD EN	GPIOC EN	GPIOB EN	GPIOA EN
		rw						rw			rw	rw	rw	rw	rw

1. Available on STM32L42xxx, STM32L44xxx and STM32L46xxx devices only.

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Where is that bit located?

1. Look in system and memory overview section
2. Look RCC register mapping to find register and bit offsets

AHB1	0x4002 4000 - 0x4002 43FF	1 KB	TSC	*Section 23.6.11: TSC register map*
	0x4002 3400 - 0x4002 3FFF	1 KB	Reserved	-
	0x4002 3000 - 0x4002 33FF	1 KB	CRC	*Section 14.4.6: CRC register map*
	0x4002 2400 - 0x4002 2FFF	3 KB	Reserved	-
	0x4002 2000 - 0x4002 23FF	1 KB	FLASH registers	*Section 3.7.13: FLASH register map*
	0x4002 1400 - 0x4002 1FFF	3 KB	Reserved	-
	0x4002 1000 - 0x4002 13FF	1 KB	RCC	*Section 6.4.32: RCC register map*
	0x4002 0800 - 0x4002 0FFF	2 KB	Reserved	-
	4002 07FF	1 KB	DMA2	*Section 11.6.8: DMA register map and reset values*
	4002 03FF	1 KB	DMA1	*Section 11.6.8: DMA register map and reset values*

0x40	RCC_ APB2RSTR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	DFSDM1RST	Res.	Res.	SAI1RST	Res.	Res.	Res.	TIM16RST	TIM15RST	Res.	USART1RST	Res.	SPI1RST	TIM1RST	SDMMC1RST	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	SYSCFGRST
	Reset value								0			0				0	0		0		0	0	0										0
0x48	RCC_AHB1 ENR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	TSCEN	Res.	Res.	Res.	CRCEN	Res.	Res.	Res.	FLASHEN	Res.	Res.	Res.	Res.	Res.	Res.	DMA2EN	DMA1EN
	Reset value																0				0				1							0	0
0x4C	RCC_AHB2 ENR	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	Res.	RNGEN	Res.	AESEN	Res.	Res.	ADCEN		Res.	Res.	Res.	Res.	GPIOHEN	Res.	Res.	GPIOEEN	GPIODEN	GPIOCEN	GPIOBEN	GPIOAEN
	Reset value														0		0			0						0			0	0	0	0	0

Configuration steps to enable basic GPIO: RCC

Turn on clock domain in Reset and Clock Control (RCC)

`RCC` base address: ____________________

`RCC_AHB2ENR` register offset: ___________

Bit for `GPIOB_EN`: _______

Configure pin as output in GPIO register block

Configure pin as an output (GPIO_MODER)

Base address of `GPIOB`: ____________________

Offset of MODER register: ___________

Bits in MODER to be set: ____________

Value for relevant bits to configure pin as output: ________

Blink Demo: Includes

```c
// Nucleo-L432KC Blink demo
// Josh Brake
// jbrake@hmc.edu
// 9/21/22
#include <stdint.h>
#define GPIOB_BASE_ADR (0x48000400UL)
#define RCC_BASE_ADR (0x40021000UL)
#define RCC_AHB2ENR ((uint32_t *) (RCC_BASE_ADR + 0x4C))
#define GPIOB_MODER ((uint32_t *) (GPIOB_BASE_ADR + 0x00))
#define GPIOB_ODR ((uint32_t *) (GPIOB_BASE_ADR + 0x14))
#define DUMMY_DELAY 100000

...
```

Blink Demo: `main`

```c
...

int main(void) {
  // Initialization code
  *RCC_AHB2ENR |= (1 << 1);
  // Set PB3 as output (MODER bit 7 to 0 and bit 6 to 1)
  *GPIOB_MODER &= ~(1 << 7);
  *GPIOB_MODER |= (1 << 6);
while(1) {
  for(volatile int i = 0; i < DUMMY_DELAY; i++);
  *GPIOB_ODR ^= (1 << 3);
}
```

Miscellanous Notes

Using MCU while connected to development board

- Make sure that you have the `MCU_+5V` header connected. This ensures the on-board voltage regulators work which makes sure the reset signal is held high. If not, you won't be able to connect to your MCU to program it (the reset pin will float and the MCU will always be in reset!)
- Remove jumper that came installed by default on the Nucleo board (connects reset to ground!)

Using structures to model memory-mapped I/O

```
// Base addresses for GPIO ports
#define GPIOA_BASE (0x48000000U)
typedef struct
{
__IO uint32_t MODER;    /*!< GPIO port mode register, Address offset: 0x00 */
__IO uint32_t OTYPER;   /*!< GPIO port output type register, Address offset: 0x04 *
__IO uint32_t OSPEEDR;  /*!< GPIO port output speed register, Address offset: 0x08
__IO uint32_t PUPDR;    /*!< GPIO port pull-up/pull-down register, Address offset:
__IO uint32_t IDR;  /*!< GPIO port input data register, Address offset: 0x10 */
__IO uint32_t ODR;  /*!< GPIO port output data register, Address offset: 0x14 */
__IO uint32_t BSRR;     /*!< GPIO port bit set/reset register, Address offset: 0x18
__IO uint32_t LCKR;     /*!< GPIO port configuration lock register, Address offset:
__IO uint32_t AFR[2];   /*!< GPIO alternate function registers, Address offset: 0x2
__IO uint32_t BRR;  /*!< GPIO Bit Reset register, Address offset: 0x28 */
} GPIO_TypeDef;
```

`__IO` is defined with a `#define` statement to one of the C keywords we discussed earlier. Which one?

Wrap Up

- C is libertarian – will allow you to do many things, not all of which are good for you.
- Understanding certain C data structures like pointers and structures will enable you to more easily and naturally write code to control your MCU.
- The MCU reference manual contains the information needed to write code to configure and manipulate the peripherals using memory-mapped I/O.