Introduction to the STM32 L432KC MCU & Refresher on C Programming

Lecture 06

Josh Brake
Harvey Mudd College

Outline

- Introduction to the STM32-L432KC
- Review of basic architecture
- C refresher
  - Common idioms to set/clear bits
  - Pointers and arrays
  - Structures

Learning Objectives

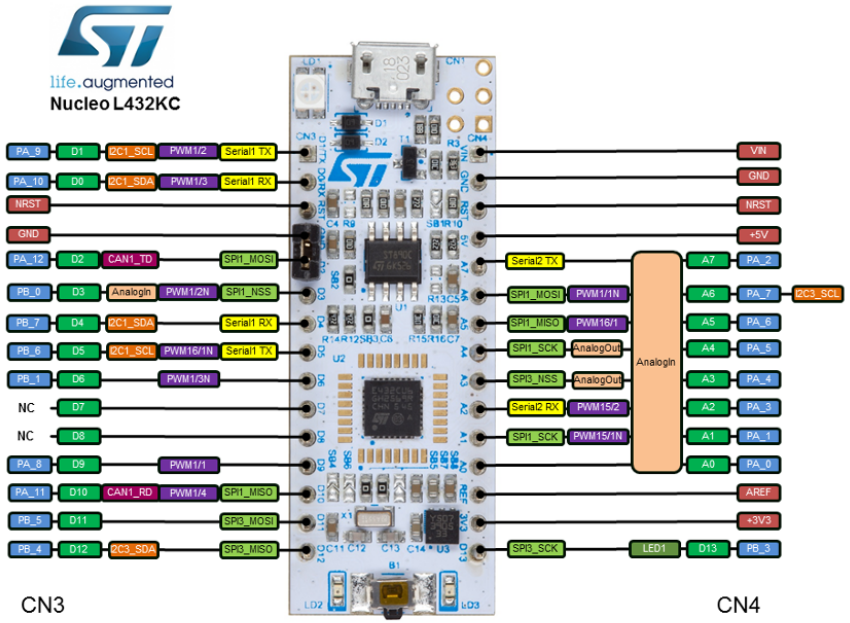
By the end of this lecture you should be able to…

- List the basic details of the architecture of the ARM Cortex-M4 CPU used in our STM32 MCU.
- Recall basic C programming idioms and concepts (e.g., pointers, arrays, structures).

STM32 Nucleo-32 board

Components

- MCU – STM32L432KC
- External flash memory
- 24 MHz crystal oscillator
- On-board ST-LINK debugger/programmer. Virtual COM port and debug port.
- 1 user LED and 1 reset push button
- Arduino Nano V3 form factor



What is an MCU

- MCU = MicroController Unit
- Processor core + peripherals

Figure 1. System architecture

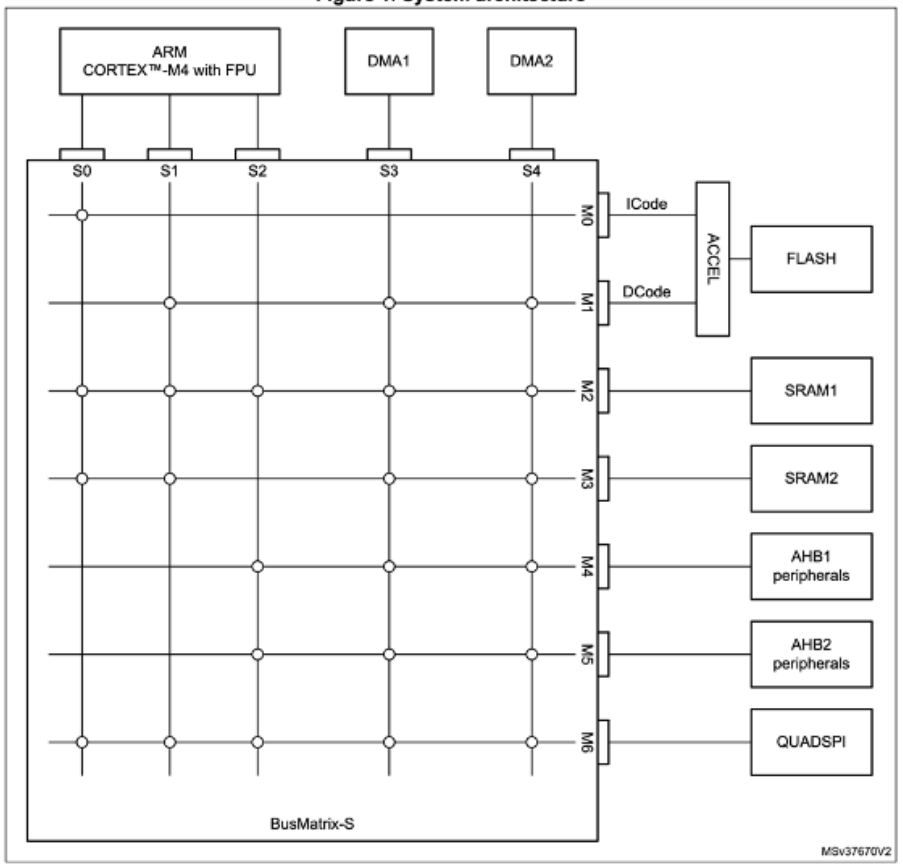
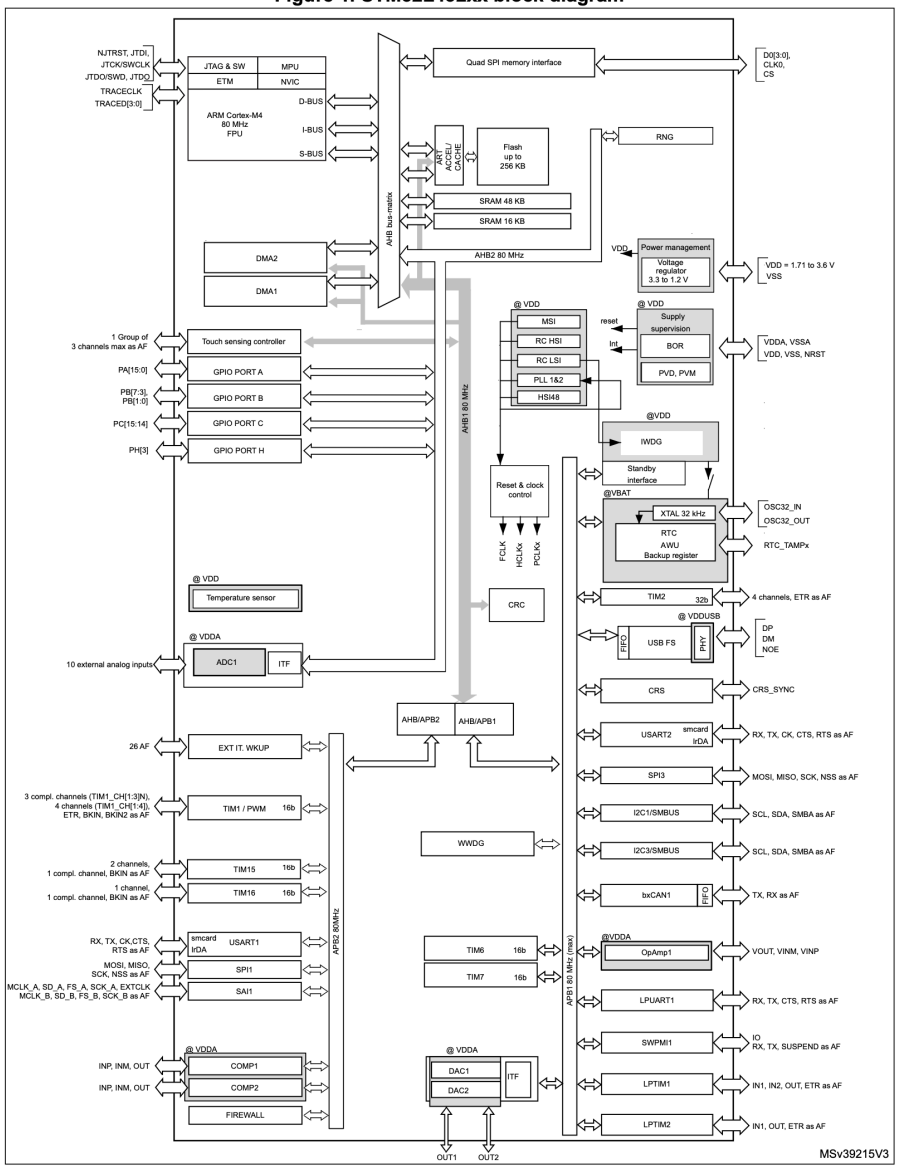


Figure 1. STM32L432xx block diagram



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

Documentation

Reference Manual: Information about all peripherals and their control registers

Datasheet: System block diagram, Pin functions, electrical characteristics, timing specs

Programmer's Manual: Information about the architecture (e.g., Cortex-M4), supported assembly instructions, registers, memory map, etc.

Questions for a new MCU

- What is the register set?
- What does the memory map look like?
- What addressing modes are used?
- What types of instructions exist?
- What I/O functions are available?

STM32 L432KC Architecture

- STM32 MCU has an ARM Cortex-M4.
- It runs the ARMv7E-M architecture. This is a 32-bit architecture.
- Also supports Thumb-2 execution. Thumb-2 is a set of compressed, 16-bit instructions.
- One special thing to watch with Thumb is conditional execution. With Thumb execution you can only use conditional execution within an “if-then” block which can hold up to four successive instructions.

Architecture Overview

- Instructions are 32-bit
- Sixteen 32-bit registers R0-R15
- Supports condition codes
- Most instructions operate on two registers and put result in a third.

Microarchitecture Flashback

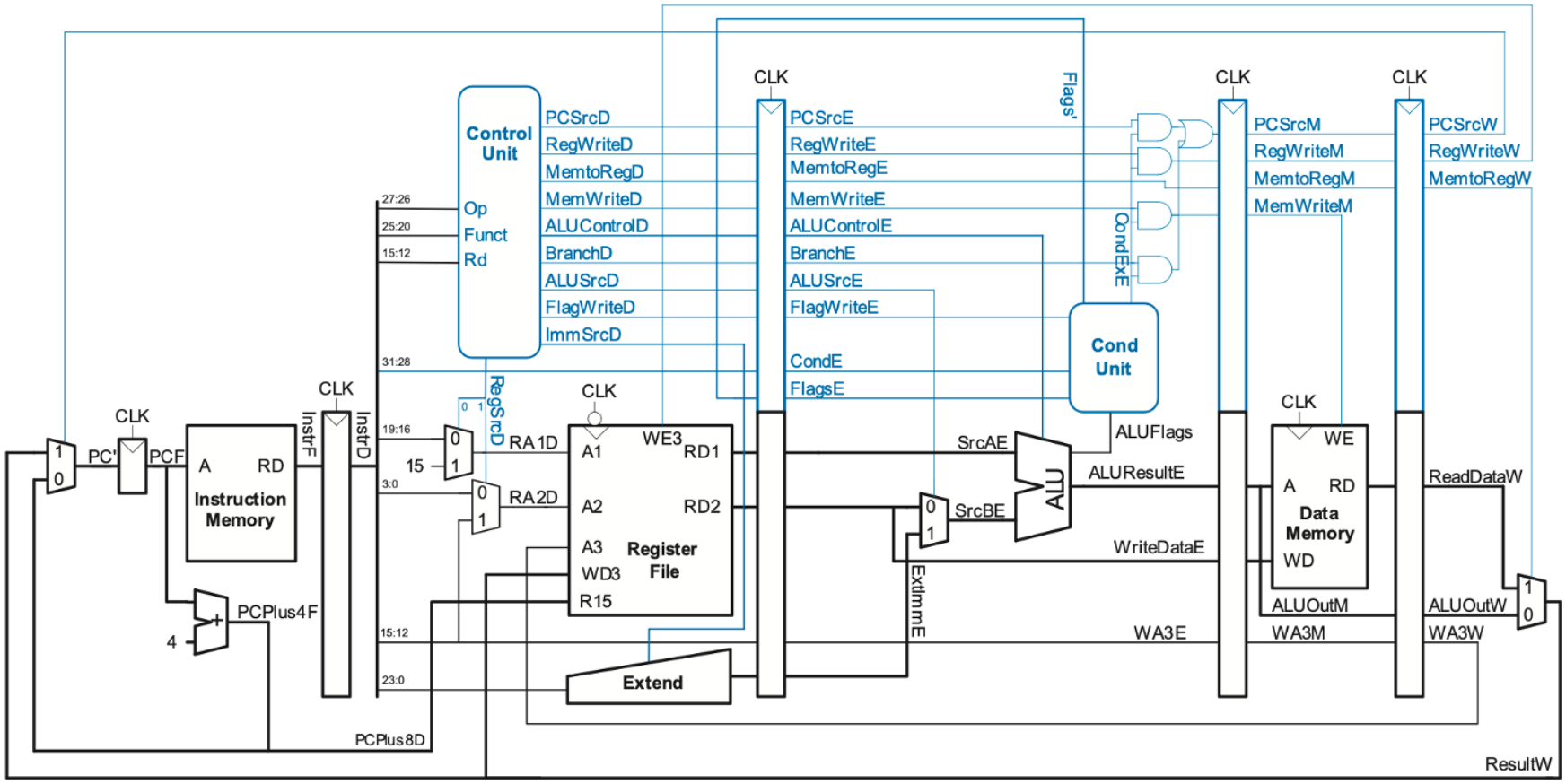


Figure 7.47 **Pipelined processor with control**

Harris and Harris, *Digital Design and Computer Architecture ARM Ed.*, p. 430

Register Set

- R15 is Program Counter (PC)
- R14 is Link Register (LR). Holds return addresses
- R13 by convention used as the stack pointer.
- Four condition codes in current program status register (CPSR)
  - N – negative
  - Z – zero
  - C – carry (unsigned overflow)
  - V – (signed) overflow

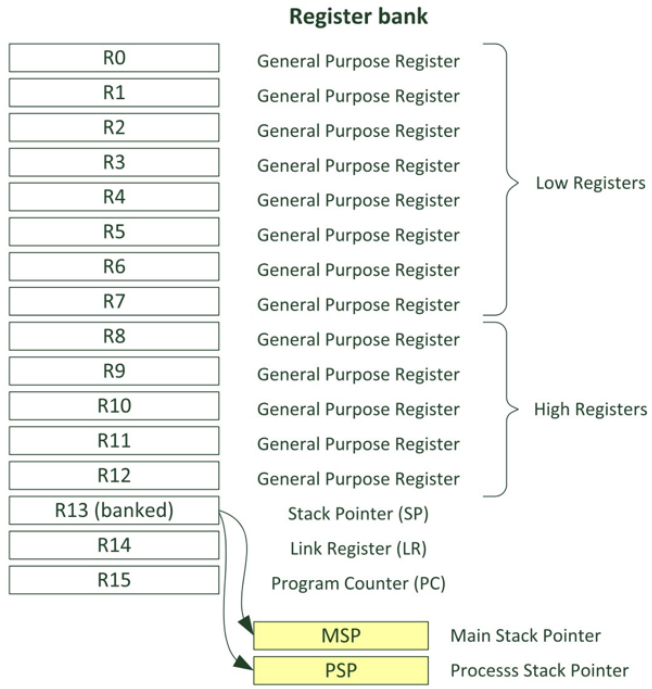


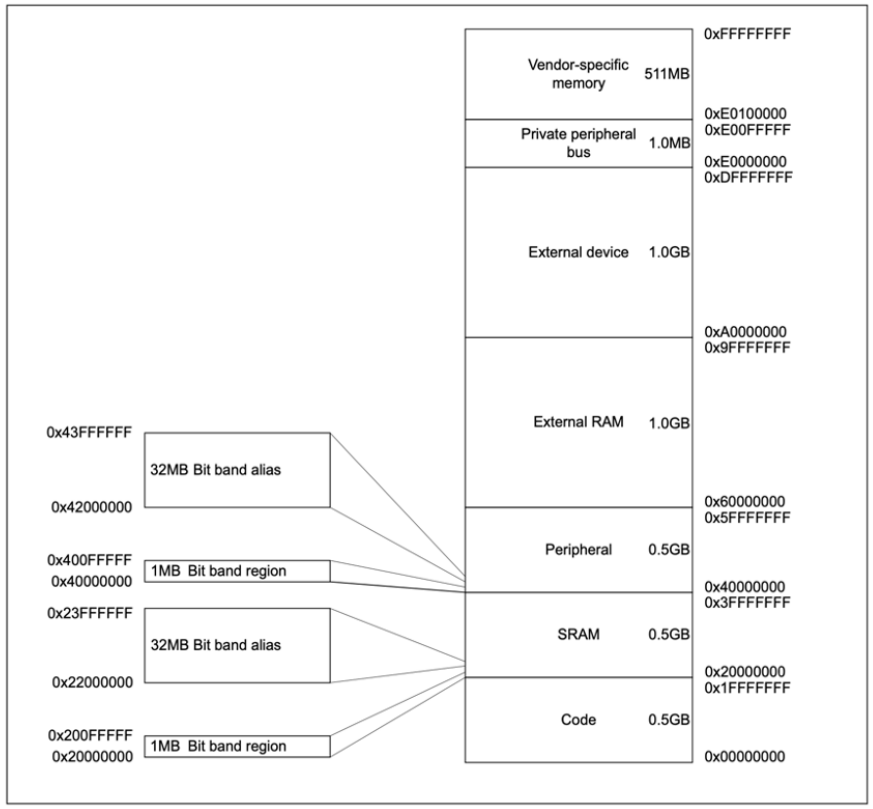
FIGURE 4.3

Registers in the register bank

Memory Map

- Flat 32-bit instruction set
- Addressed in bytes.
- 2^{32} bytes of memory accessible (4 Gigabytes)
- Instructions are always aligned on word (4-byte) in standard ARM and halfword (2-byte) boundaries in Thumb mode.

Figure 8. Memory map

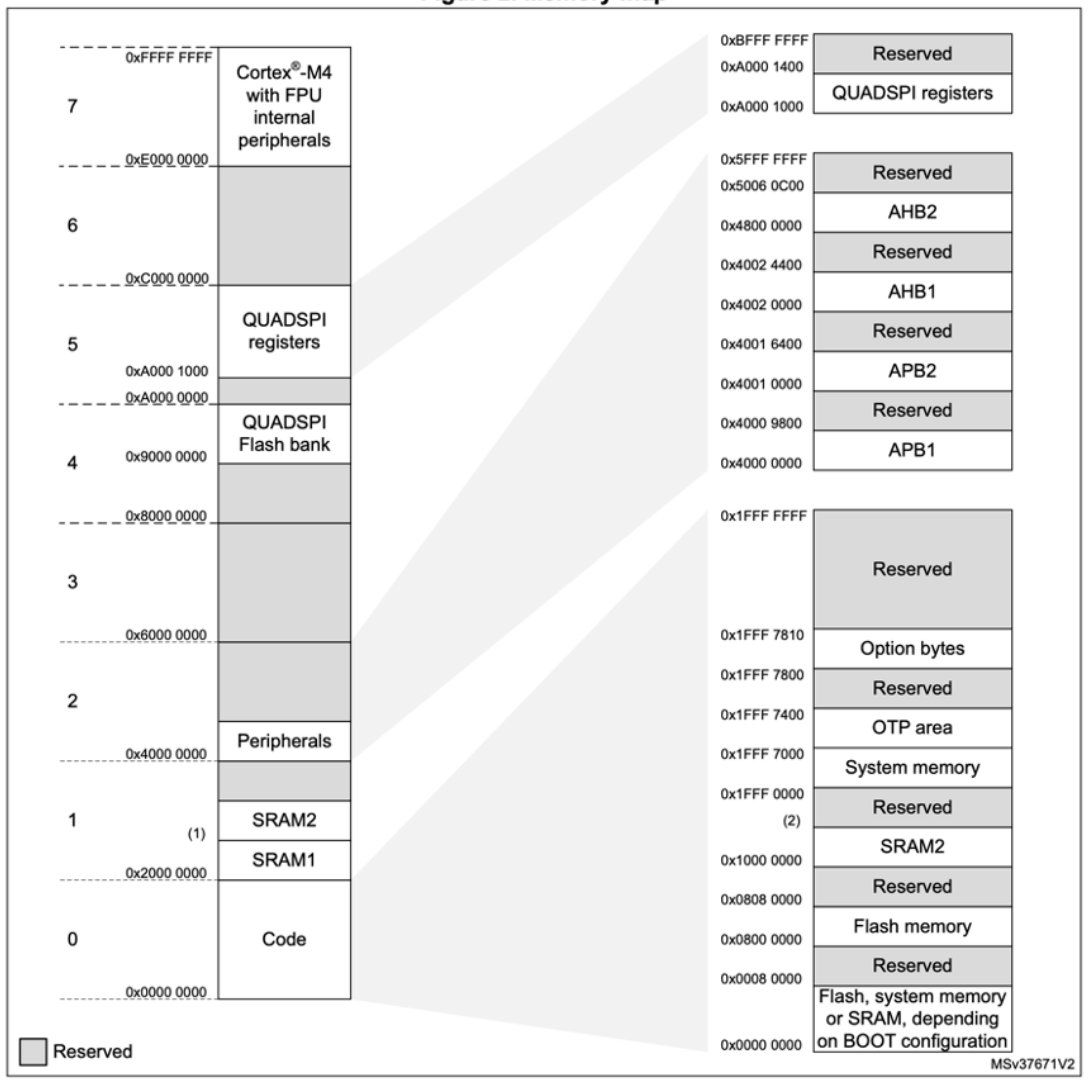


PM0214 Cortex-M4 Programmers Manual

Memory Map - STM32L432KC

RM0394 p. 67

Figure 2. Memory map



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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`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

- `volatile` – prevents the compiler from using a cached value (forces load)
- `const` – “read-only”. Prevents you from assigning a value to the variable.
- `static`
  - Inside a function: retains its values between calls.
  - Applied to a function: visible only in this file
- `extern`
  - Applied to a function definition: has global scope (redundant)
  - Applied to a variable: defined elsewhere
- `void`
  - 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

- `stdint.h` – standard fixed-width types (e.g., uint32_t)
- `stdio.h` - standard input and output. Contains functions like printf or fprintf.
- `stdlib.h` – standard library: random number generation (rand and srand), allocating or freeing memory (malloc and free).
- `math.h` – math library: standard math functions like sin, cos, sqrt, log, exp, floor, ceil.
- `string.h` – 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

```
1  #define GPIOA_BASE 0x48000000
2  #define GPIOA_MODER (*((volatile unsigned long *) (GPIOA_BASE + 0x00)))
3
4  // Set bit 3 of the GPIOA_MODER to 1.
5
6                                                                          ①
7  // Clear bit 7 of the GPIOA_MODER (i.e., set to 0)
8
9                                                                          ②
10
```

① `GPIOA_MODER |= (1 << 3);`

② `GPIOA_MODER &= ~(1 << 7);`

Pointers and Arrays

Pointers and Arrays in C: Arrays

```
1  int * p = (int*) 0x20000000;
2
3  int a = *p;                                                    ①
4
5  int b = *(p+3);                                                ②
6
7  *(p+5) = b;                                                    ③
```

① Equivalent to `a= p[0]`

② Equivalent to `b= p[3]`, address `0x2000000C`

③ Equivalent to `p[5]= b`, address `0x20000014`

Pointers and Arrays in C: Strings

```
1  char * str = (char *) 0x20001000;
2
3  str[13] = 'A';                                                    ①
```

① Address `0x2000100D = 0x41`

Dereferencing

```
1
2  int * p = (int*) 0x20000000;
3
4  int a = *p;                                                    ①
5  int * aptr = &a;                                               ②
6
7  *aptr = 3;                                                     ③
8
9  int * ptr = &p[0];                                             ④
10
11 ptr = &p[5]                                                    ⑤
12
13 *ptr = 42;                                                     ⑥
```

① Equivalent to a = `p[0]`

② `aptr` stores address of `a`

③ same as `a=3`

④ `ptr= 0x200000000`

⑤ `ptr= 0x20000014`

⑥ `p[5]= 42`

Structures

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

Structures

```
1  struct contact {
2      char name[30];
3      unsigned long long phone;
4      float height;
5  };
6
7  struct contact jbrake; // example variable definition
```

How many bytes does this structure occupy in memory?

30*sizeof(char) + sizeof(unsigned long long) + sizeof(float)

= 30 B + 8 B + 4 B = 42 Bytes

Using structures as part of a new type

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

```
1 typedef struct my_tag {int i;} my_type; // Declaration of new type
2
3 // Creating variable with struct keyword
4
5
6
7 // Creating variable using new type
8
```

① `struct my_tag variable_1;`

② `my_type variable_2;`

Arrow Operator

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

```
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;
```

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.