Fundamentals of Embedded and Real Time Systems

MODULE 07

TAMER AWAD

Review Module 06

Module 07

C Types

- stdint.h
- Mixing types
- typedef

Structures in C

- Syntax
- Access to struct members
- Layout
- Nested structures
- Pointers and structures
- Access in assembly

Cortex-M Software Interface Standard (CMSIS)

- What is CMSIS?
- CMSIS Standardization
- Organization of CMSIS
- How to use CMSIS?
- GPIO_TypeDef structure
- Demo: Blinking LED using CMSIS

Assignment

- Assignment 06

C Types

- stdint.h
- #include with quotes vs brackets
- Mixing types
- typedef

<stdint.h>

- The C standard does not define the size of the basic data types.
  - *For example:* “int” can occupy 32-bit on one machine and 16-bit or 8-bit on another.
- The C standard specifies that the size of “short” must not be bigger than “int” and “int” must be not bigger than “long”.
- It is often important to know exactly the size and sign of the variables so that the code runs the same way regardless of the target processor architecture.
- The C99 standard specifies the header <**stdint.h**> which declares sets of integer types with standard names, specified widths and defines corresponding sets of macros (see <u>section 7.18 in the C99</u> standard for details)
- Compiler vendors are responsible for providing the appropriate typedefs inside that standard library header file.
- The IAR compiler supports the C99 standard (in the project options settings).
- <u>**Note:**</u> If you switch your project to C89, you will get a compiler error including stdint.h

Fatal Error[Pe035]: #error directive: "Header is not supported in the C89 language mode"
Error while running C/C++ Compiler

typedef

- Each **typedef** statement defines a new type.
- Hint: Typedef definitions should be read from right to left (similar to pointers)
- EX> **typedef int uint32_t:**
  - Reads: “uint32_t” is typedef name for an int data type
- int* b;
  - Reads: “b” is a pointer to an “int” variable type.
- typedef vs #define:
  - https://www.geeksforgeeks.org/typedef-versus-define-c/

<stdint.h>

- The file uses typedefs to define the following fixed-width integer types (among other things):
  - **int8_t**: for signed 8-bit integer
  - **uint8_t**: for unsigned 8-bit integer
  - **int16_t**: for signed 16-bit integer
  - **uint16_t**: for unsigned 16-bit integer
  - **int32_t**: for signed 32-bit integer
  - **uint32_t**: for unsigned 32-bit integer
- The value of the **stdint** header file is in standardizing the type names and the fact that it is the responsibility of the compiler vendor to provide the right definitions for the CPU.
- It's done by means of macros, such as __INT32_T_TYPE__, which in turn are defined in terms of the built-in types.

Size & Range of Data Types in ARM

Table 2.2 Size and Range of Data Types in ARM Architecture Including Cortex-M Processors

C and C99 (stdint.h) Data Type	Number of Bits	Range (Signed)	Range (Unsigned)
char, int8_t, uint8_t	8	–128 to 127	0 to 255
short int16_t, uint16_t	16	–32768 to 32767	0 to 65535
int, int32_t, uint32_t	32	–2147483648 to 2147483647	0 to 4294967295
Long	32	–2147483648 to 2147483647	0 to 4294967295
long long, int64_t, uint64_t	64	–(2^63) to (2^63 - 1)	0 to (2^64 - 1)
Float	32	$-3.4028234 \times 10^{38}$ to 3.4028234×10^{38}	
Double	64	$-1.7976931348623157 \times 10^{308}$ to $1.7976931348623157 \times 10^{308}$	
long double	64	$-1.7976931348623157 \times 10^{308}$ to $1.7976931348623157 \times 10^{308}$	
Pointers	32	0x0 to 0xFFFFFFFF	
Enum	8 / 16/ 32	Smallest possible data type, except when overridden by compiler option	
bool (C++ only), _Bool (C only)	8	True or false	
wchar_t	16	0 to 65535	

Table 2.3 Data Size Definition in ARM Processor

Terms	Size
Byte	8-bit
Half word	16-bit
Word	32-bit
Double word	64-bit

#include with "quotes" vs <brackets>

- C99 Spec section 6.10.2:
  - A preprocessing directive of the form **# include <***h-char-sequence***>**
    - Searches a sequence of implementation-defined places for a header identified uniquely by the specified sequence between the **<** and **>** delimiters, and causes the replacement of that directive by the entire contents of the header. How the places are specified or the header identified is implementation-defined.
  - A preprocessing directive of the form **# include "***q-char-sequence***"**
    - Causes the replacement of that directive by the entire contents of the source file identified by the specified sequence between the **"** delimiters. The named source file is searched for in an implementation-defined manner. If this search is not supported, or if the search fails, the directive is reprocessed as if it read **# include <***h-char-sequence***>** *new-line*

- In summary: It's compiler dependent, but in general:
  - Using *"quotes"* prioritizes headers in the current working directory over system headers.
  - Using *<brackets>* is often used for system headers

Assignment of different types

```
uint8_t u8a, u8b;
uint16_t u16c, u16d;
uint32_t u32e, u32f;

u8a = 0xa1u;
u16c = 0xc1c2u;
u32e = 0xe0e1e2e3;

u8b = u8a;
u16d = u16c;
u32f = u32e;
```

```
 u8b = u8a;
0x800'0062: 0x7800      LDRB     R0, [R0]
0x800'0064: 0x4b15      LDR.N    R3, [PC, #0x54]   ...
0x800'0066: 0x7018      STRB     R0, [R3]
 u16d = u16c;
0x800'0068: 0x8808      LDRH     R0, [R1]
0x800'006a: 0x4915      LDR.N    R1, [PC, #0x54]   ...
0x800'006c: 0x8008      STRH     R0, [R1]
 u32f = u32e;
0x800'006e: 0x6810      LDR      R0, [R2]
0x800'0070: 0x4914      LDR.N    R1, [PC, #0x50]   ...
0x800'0072: 0x6008      STR      R0, [R1]
```

Mixing types and implicit conversion

- ***C always automatically promotes smaller-size integers to the built-in 'int' or 'unsigned int' type before performing computations.***
- The precision in which the computation is performed does not depend on the left-hand side of the assignment.
- Enforce promotion at least of one of the operands.
- The computation is performed at the largest precision of the involved operands.
- When mixing signed and unsigned operands, both are promoted to 'unsigned int' and the result is 'unsigned int'.

Demo: stdint.h & Mixing Types

- Include “stdint.h”
- Failure to compile with C89
- Open stdint.h and show location as “system” file.
- Look inside stdint.h
- sizeof(<stdint_types>)
- Mixing types issues

Mixing types: Example 1 - Issue

```
uint32_t u32e, u32f;
uint64_t u64z;

u32e = 4000000000u;
u32f = 3000000000u;

u64z = u32e + u32f;
```

- On a 64-bit machine, the promotion will be to 64-bit, because this is the size of 'int' on that machine.
- However, on 32-bit machine, no promotion happens, because the type 'int' is only 32-bit wide.
  - 4000,000,000 + 7000,000,000 will overflow
  - The result of the computation is eventually assigned to a 64-bit wide number, which has enough range to represent 7000,000,000.
- This example shows that *the precision in which the computation is performed does not depend on the left-hand side of the assignment*.

How do you fix this?

Mixing types: Example 1 - Solution

```
uint32_t u32e, u32f;

uint64_t u64z;


u32e = 4000000000u;

u32f = 3000000000u;


u64z = u32e + u32f;                          //Not Portable

u64z = (uint64_t)u32e + u32f;                // Portable

u64z = (uint64_t)u32e + (uint64_t)u32f;      // Portable
```

- Enforce promotion to a 64-bit precision of at least one of the operands.
- According to the implicit conversion rule of the C language: ***The computation is performed at the largest precision of the involved operands*.**
- If one of the operands is 64-bit wide, the other will be promoted to 64-bits and the whole computation will be performed at 64-bit.

Mixing types: Example 2 - Issue

```
uint32_t u32e = 1000;
if (u32e > -1)
{
    u8a = 1u;
}
else
{
    u8a = 0u;
}
```

Remember that in a mixed sign operation, the C standard will promote the signed operand to unsigned int.

How do you fix this?

Mixing types: Example 2 - Solution

```
uint32_t u32e = 1000;
if ((int32_t)u32e > -1)
{
    u8a = 1u;
}
else
{
    u8a = 0u;
}
```

Mixing types: Example 3 - Issue

```c
uint8_t u8a;
uint32_t u32f;
u8a = 0xffu;
if (~u8a == 0x00u)
{
    u8b = 1u;
}
u32f = ~u8a;
```

What’s the problem?

u8a will be promoted to int (32-bit), so the most significant bytes will be all 0, and the inversion will make them all ones.

Watch 1

Expression	Value	Location	Type
u8a	0xFF	0x20000010	uint8_t
u32f	0xFFFFFF00	0x20000004	uint32_t
<click to add>			

Mixing types: Example 3 - Solution

```
uint8_t u8a;
uint32_t u32f;
u8a = 0xffu;
if ((uint8_t)(~u8a) == 0x00u)
{
    u8b = 1u;
}
u32f = ~u8a;
```

BREAK 1

C - Structures

- Syntax
- Access to struct members
- Layout
- Nested structures
- Pointers and structures
- Access in assembly

Structures in C

- Structures in C offer a way to group together variables, possibly of different types.
- The benefit of structures is that they permit a group of related variables to be treated as a unit instead of separate entities.
- In embedded systems, structures also permit you to access hardware in an elegant and intuitive way (CMSIS)
- <u>According to C99 standard:</u>

  A structure type describes a sequentially allocated nonempty set of member objects

  each of which has an optionally specified name and possibly distinct type.

Syntax 1: struct definition & declaration with tags

```
struct <optional_tag> {
    type1 member_1;
    type2 member_2;
 } <optional_declaration>;
```

```
struct  Point {
    uint16_t x;
    uint8_t y;
 } p1, p2;
```

Syntax 2: struct definition & declaration without tags

```
struct <optional_tag> {
    type1 member_1;
    type2 member_2;
} <optional_declaration>;
```

```
struct {
    uint16_t x;
    uint8_t y;
} p1, p2;
```

Syntax 3: struct declaration after definition

```
struct <optional_tag> {
    type1 member_1;
    type2 member_2;
 } <optional_declaration>;
```

```
struct Point {
    uint16_t x;
    uint8_t y;
 };

struct  Point p1, p2;
```

NOTE:
Must repeat the “struct” keyword in front of the tag. Unlike C++ where “struct” and “class” are not needed before each declaration.

Syntax 4: typedef after struct definition

```
struct <optional_tag> {
    type1 member_1;
    type2 member_2;
 } <optional_declaration>;
```

```
struct  Point {
   uint16_t x;
   uint8_t y;
 };
 typedef struct Point Point;

 Point p1, p2;
```

Tag Name

Typedef Name

Note:
Tag names in C occupy a different namespace than typedef names, variable names, and function names; hence, can have Tag “Point” followed by variable name “Point” as shown above.

Syntax 5: typedef before struct definition

```
struct <optional_tag> {
   type1 member_1;
   type2 member_2;
 } <optional_declaration>;
```

```
typedef struct Point Point;

struct Point {
   uint16_t x;
   uint8_t y;
 };


 Point p1, p2;
```

Note:
Can place the typedef before the struct.

Syntax 6: Untagged struct inside typedef

```
typedef struct {
    type1 member_1;
    type2 member_2;
 } TypeDefName;
```

```
typedef struct {
    uint16_t x;
    uint8_t y;
 } Point;

 Point p1, p2;
```

Note:
Struct tag names are almost never needed. The exception being the self-referential structures, such as nodes of linked lists or trees.

Member Access

```
typedef struct {
    uint16_t x;
    uint8_t y;
} Point;
```

```
Point p1, p2;

p1.x = sizeof(Point);

P1.y = 42;
```

Question:

What is the value of p1.x?

Demo - Structures

1. Definition and declaration.
2. Show memory layout, addressing, and assembly:
   1. typedef struct {uint16_t x; uint8_t y;} Point;
   2. typedef struct {uint8_t y; uint16_t x;} Point;
3. Use __packed extended-keyword
4. Switch to Cortex-M0 and show layout, addressing, and assembly.

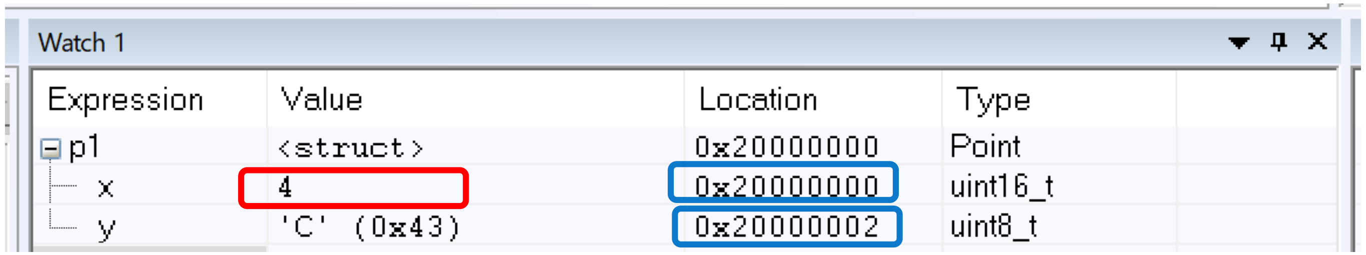
Layout: Size & Padding

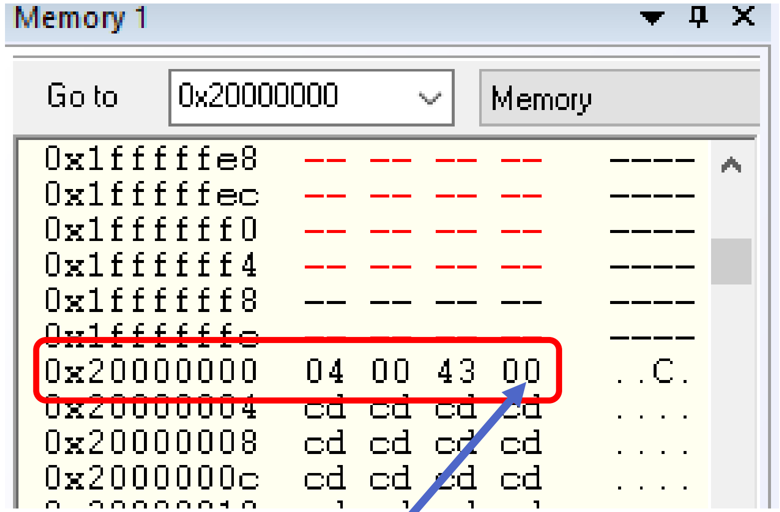
```
typedef struct {
   uint16_t x;
   uint8_t y;
 } Point;


Point p1, p2;
p1.x = sizeof(Point);
P1.y = ‘C’;
```

```
void main(void)
{
main:
    0x800'0040: 0xb538        PUSH     {R3-R5, LR}
     p1.x = sizeof(Point);
    0x800'0042: 0x4810        LDR.N    R0, [PC, #0x40]      ...
    0x800'0044: 0x2103        MOVS     R1, #3
    0x800'0046: 0x8001        STRH     R1, [R0]
     p1.y = 'C';
    0x800'0048: 0x2143        MOVS     R1, #67              ...
    0x800'004a: 0x7081        STRB     R1, [R0, #0x2]
```

Layout: Size & Padding





The compiler padded the structure by one byte to avoid “odd” addresses

Layout: Changing order of struct members

```
typedef struct {
   uint8_t y;
  uint16_t x;
 } Point;
```

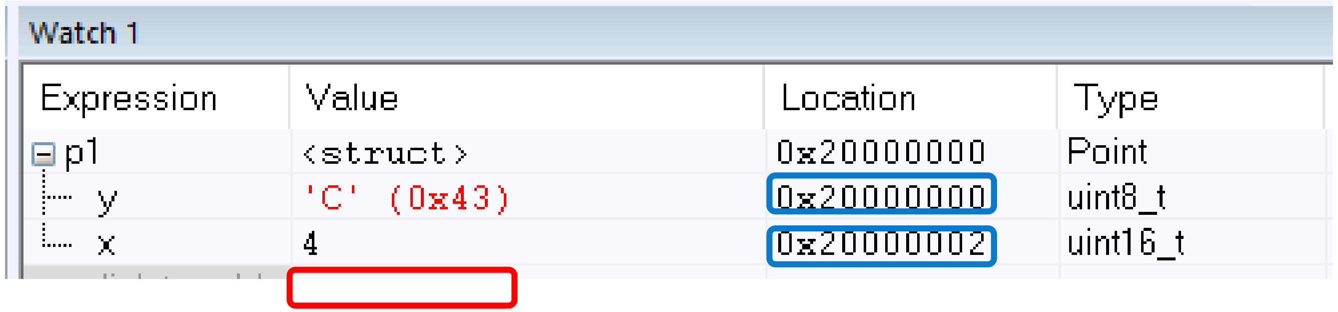
```
  p1.x = sizeof(Point);
0x800'004a: 0x4810        LDR.N     R0, [PC, #0x40]   ...
0x800'004c: 0x2104        MOVS      R1, #4
0x800'004e: 0x8041        STRH      R1, [R0, #0x2]
  p1.y = 'C';
0x800'0050: 0x2143        MOVS      R1, #67           ...
0x800'0052: 0x7001        STRB      R1, [R0]
```

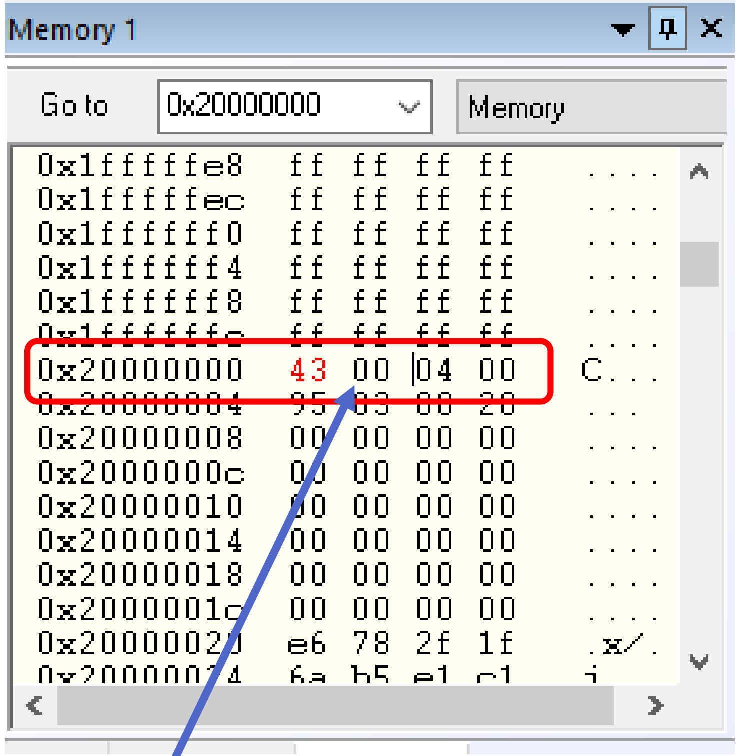
```
Point p1, p2;
p1.x = sizeof(Point);
P1.y = 'C';
```

Watch 1

Expression	Value	Location	Type
p1	<struct>	0x20000000	Point
y	'C' (0x43)	0x20000000	uint8_t
x	4	0x20000002	uint16_t

Layout: Changing order of struct members





The compiler padded the structure by one byte

Layout: Using "__*packed*"

```
typedef __packed struct {
    uint16_t x;
    uint8_t y;
 } Point;

 Point p1, p2;
 p1.x = sizeof(Point);
 P1.y = 42;
```

- **Not in C standard**
- **Most embedded compilers provide some non-standard extension to pack the structure members.**
- **The IAR compiler provides the keyword "__packed", which is placed in front of the struct keyword.**
- **Question:**
  - **So what is the value of p1.x?**

Layout: Odd addressing

```
typedef __packed struct {
    uint8_t y;
    uint16_t x;
} Point;
```

```
    p1.x = sizeof(Point);
        0x4a: 0x4811        LDR.N    R0, [PC, #0x44]   ...
        0x4c: 0x2103        MOVS     R1, #3
        0x4e: 0xf8a0 0x1001 STRH.W   R1, [R0, #0x1]
    p1.y = 'C';
        0x52: 0x2143        MOVS     R1, #67            ...
        0x54: 0x7001        STRB     R1, [R0]
```

```
Point p1, p2;
p1.x = sizeof(Point);
P1.y = 0x43;
```

Watch 1

Expression	Value	Location	Type
p1	<struct>	0x20000000	Point
y	'C' (0x43)	0x20000000	uint8_t
x	3	0x20000001	uint16_t

Layout: Misalignment- Cortex M4 vs M0

CORTEX M4

```
p1.x = sizeof(Point);
    0x4a: 0x4811          LDR.N     R0, [PC, #0x44]    ...
    0x4c: 0x2103          MOVS      R1, #3
    0x4e: 0xf8a0 0x1001   STRH.W    R1, [R0, #0x1]
p1.y = 'C';
    0x52: 0x2143          MOVS      R1, #67             ...
    0x54: 0x7001          STRB      R1, [R0]
```

CORTEX M0

```
p1.x = sizeof(Point);
    0x4a: 0x4812          LDR.N     R0, [PC, #0x48]    ...
    0x4c: 0x2103          MOVS      R1, #3
    0x4e: 0x7041          STRB      R1, [R0, #0x1]
    0x50: 0x0a09          LSRS      R1, R1, #8
    0x52: 0x7081          STRB      R1, [R0, #0x2]
p1.y = 'C';
    0x54: 0x2143          MOVS      R1, #67             ...
    0x56: 0x7001          STRB      R1, [R0]
```

Why Padding?

- The code for the assignment of p1.x is bigger on Cortex M0 than Cortex M4.
- The compiled code for Cortex-M0 consists of two STRB instructions plus a logical-shift-right instruction; whereas Cortex-M4 achieved the same effect with just one STRH instruction.
- While Cortex-M0 has the STRH instruction; unlike on Cortex-M4, it cannot access a half-word allocated at an odd address.
- **The compiler prefers to keep the data aligned instead of wasting the CPU cycles to access the mis-aligned data.**
- <u>Note:</u> Packed structures might not be always be as efficient to access as an un-packed structures.

Nested structures

```
typedef struct {
    uint16_t x;
    uint8_t y;
} Point;

typedef struct {
    Point bottom_left;
    Point top_right;
} Rectangle;

typedef struct {
    Point corners[3];
} Triangle;
```

```
Rectangle s1, s2;
Triangle t1, t2;

s1.bottom_left.x = 1;
s1.bottom_left.y = 1;
s1.top_right.x = 5;
s1.top_right.y = 5;

t1.corners[0].x = 1;
t1.corners[0].y = 1;

t1.corners[1].x = 3;
t1.corners[1].y = 4;

t1.corners[2].x = 5;
t1.corners[2].y = 1;
```

Pointers to structures

Complex structures can occupy considerable memory.

So structure assignment can mean copying a large size of memory from one variable to another.

It is more efficient to use “pointers” to structures and avoid copying structures where ever possible.

```
typedef struct {
    uint16_t x;
    uint8_t y;
 } Point;

Point p1;
p1.x = sizeof(Point);
P1.y = 42;

Point *p3;
p3 = &p1;
(*p3).y = 42;
p3->x = p1.x;
```

Access in assembly

The compiler accesses the structure by using the offset addressing from the beginning of the structure.

```
 p1.x = sizeof(Point);
0x800'004a: 0x4814        LDR.N     R0, [PC, #0x50]    ...
0x800'004c: 0x2104        MOVS      R1, #4
0x800'004e: 0x8041        STRH      R1, [R0, #0x2]
 p1.y = 'C';
0x800'0050: 0x2143        MOVS      R1, #67             ...
0x800'0052: 0x7001        STRB      R1, [R0]
```

Demo - Structures

1. Nested Structures.
2. Pointers to Structures.
3. View data member access in disassembly.

BREAK 2

CMSIS

- What is CMSIS
- CMSIS Standardization
- Organization of CMSIS-Core
- How to use CMSIS?
- GPIO_TypeDef structure
- Demo: Blinking LED using CMSIS

Cortex Microcontroller Software Interface Standard (CMSIS)

- With a significant amount of hardware components being identical, a large portion of the Hardware Abstraction Layer (HAL) can also be identical.
- However, reality has shown that lacking a common standard we find a variety of HAL/driver libraries for different devices that do the same thing.
- ARM has recognized that there is a need to create a standard to access these hardware components and put effort into a standard.
- The result of that effort is CMSIS.

Cortex Microcontroller Software Interface Standard (CMSIS)

- The CMSIS is a vendor-independent hardware abstraction layer for microcontrollers that are based on Arm Cortex processors.
- CMSIS is a framework that is implemented by vendors.
  - It provides a common API (Application Programming Interface) for core specific components.
  - And defines convention on how the device specific portions should be implemented.
- In general, most microcontroller vendors provide C header files and driver libraries for their microcontrollers.
- In most cases, these files are developed with the Cortex Microcontroller Software Interface Standard (CMSIS).
- ***CMSIS enables the use of structures to access hardware in Cortex-M microcontrollers.***

Benefits of CMSIS

- Portability between Cortex-M microcontroller-based devices.
  - Peripheral setup and access code will need to be modified, but processor core access functions are based on the same CMSIS source code and do not require changes.
- Reduces the learning curve for microcontroller developers
- Improves time to market.
- Tested by many silicon vendors and software developers

CMSIS Standardization

The CMSIS-Core standardizes a number of areas:

- Standard definitions for the processor’s peripherals.
- Standard functions for accessing special instructions easily.
- Standard function names for system exception handlers
- Standard functions for system initialization
- Standard software variables for clock speed information

Organization of CMSIS

- The CMSIS files are integrated into device-driver library packages from microcontroller vendors.
- Some are prepared by ARM and are common to various microcontroller vendors (ex: core_cm4.h)
- Other files are vendor/device specific (“stm32f401xe.h” & “system_stm32f4xx.h”)
- The aim of CMSIS is to provide a common starting point, and the microcontroller vendors can add additional functions if they prefer.
- Software using these added functions will need porting if the software design is to be reused on another microcontroller product.

Core Structure

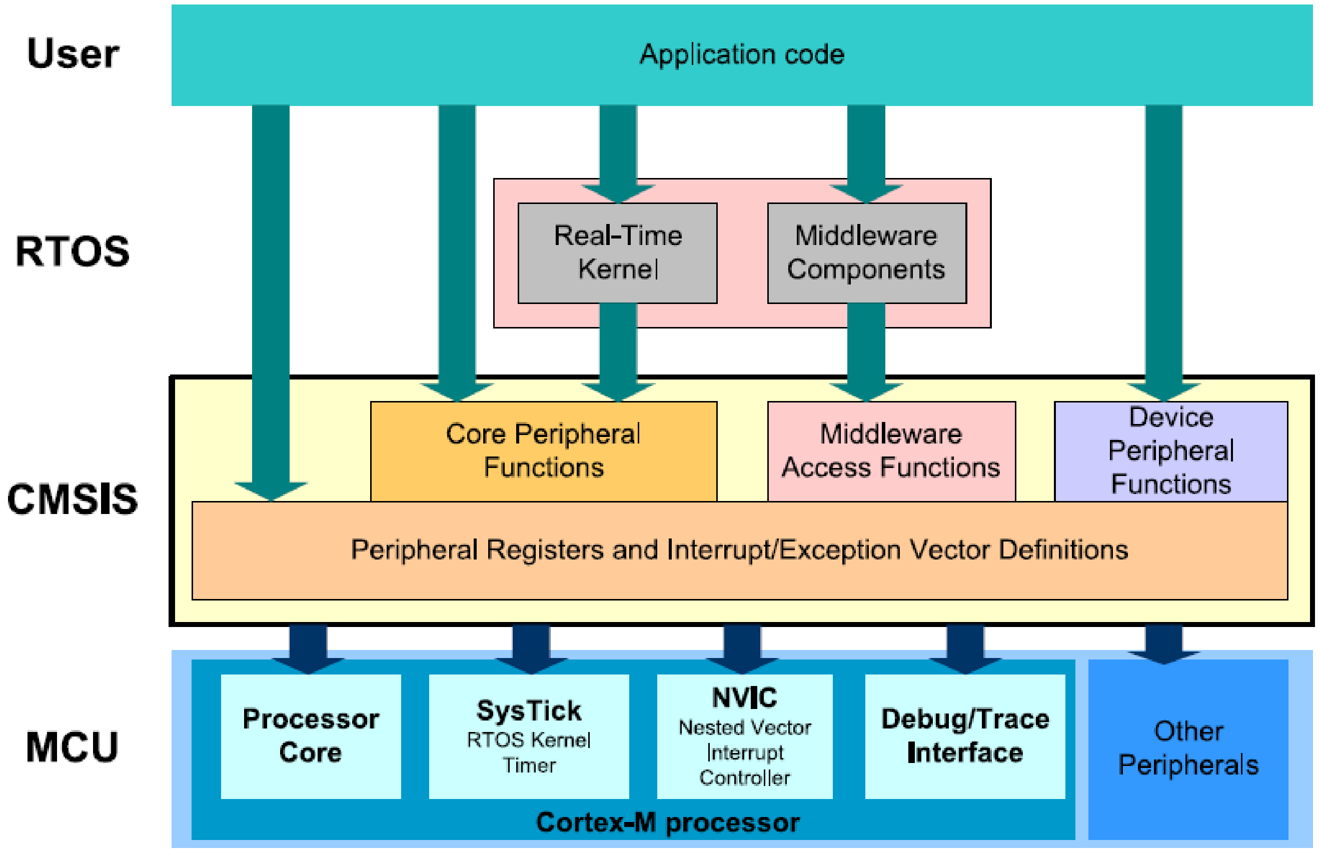


FIGURE 2.13

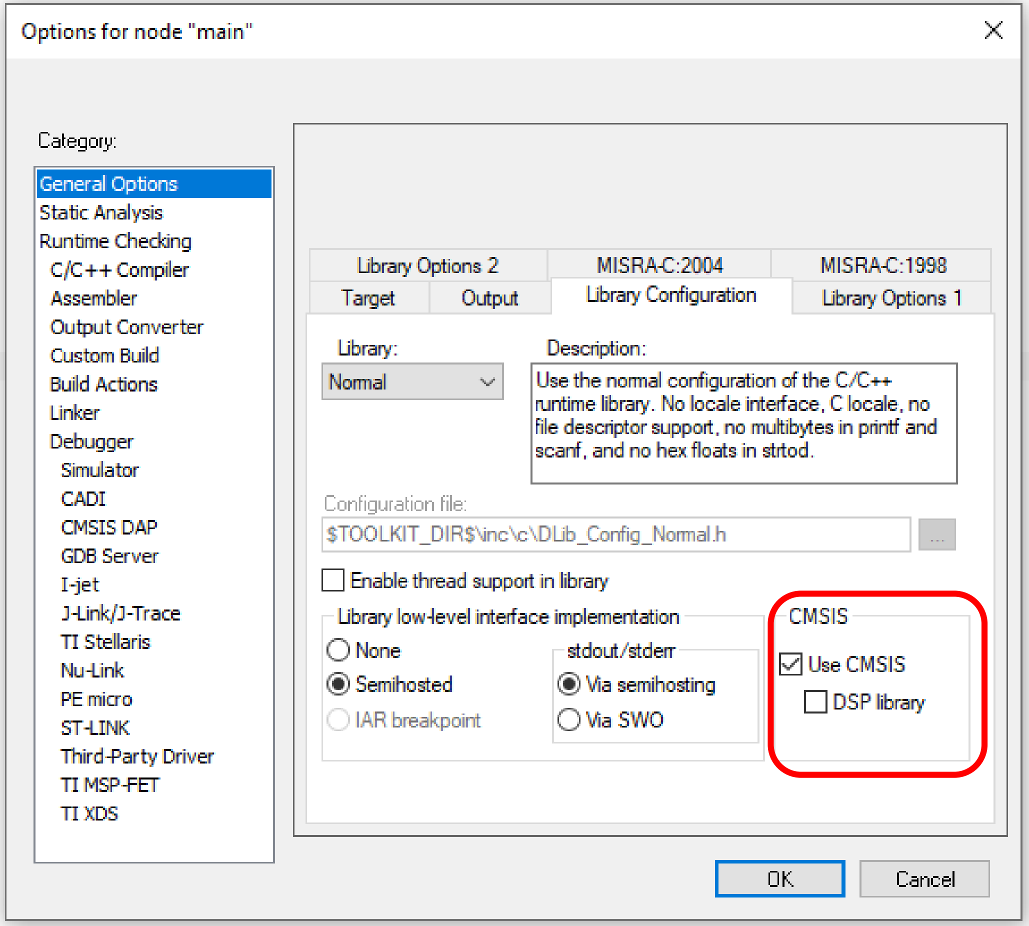
CMSIS-Core structure

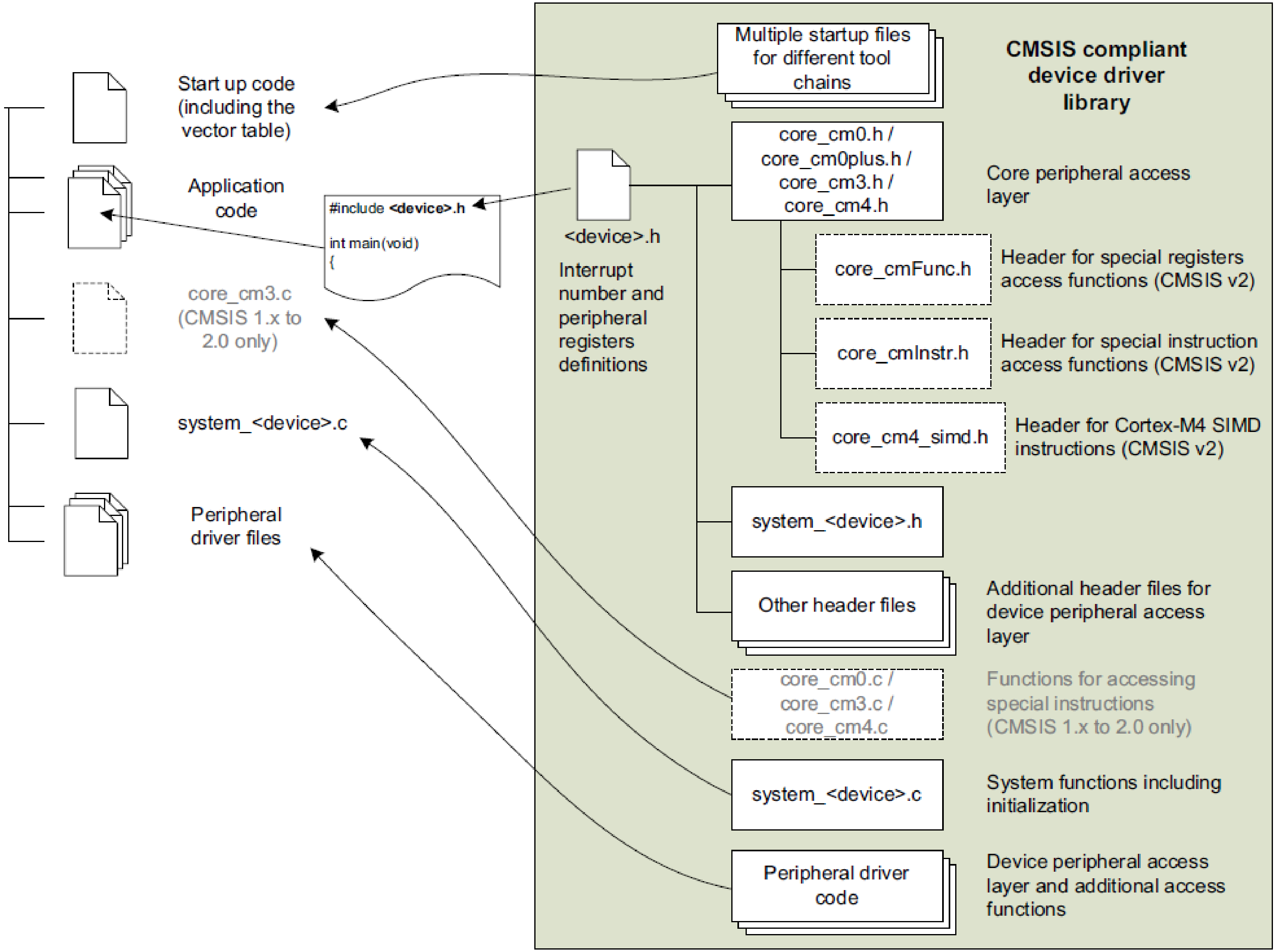
<u>Source:</u> "The Definitive guide to ARM Cortex-M3 & M4 Processors", by Joseph Yiu

How to use CMSIS - Setup

- Get the <device.h> header file for your board **"stm32f401xe.h"**
  - Contains peripheral registers definitions and interrupt assignment definitions.
- Get the “system_<device>.h” header file for your board **"system_stm32f4xx.h"**
  - Contains functions in device initialization code
- Include the device-specific header file in your application code, which will automatically include additional header files
- Therefore, you will need to set up the project search path for the header files in order to compile the project correctly.
- IAR provides the ability to do that with one click which provides a pointer to the path of the CMSIS header files that came with the IDE.
- One of those files is the **core_cm4.h** header file
  - This is part of the CMSIS industry standard and is a generic file for all microcontroller vendors.
  - IAR distributes it as an integral part of the toolset.

Enable CMSIS usage in Project Options





CMSIS use in a project

Key files:

- <device>.h

- system_<device>.h

- core_cm4.h

<u>Source:</u> "The Definitive guide to ARM Cortex-M3 & M4 Processors", by Joseph Yiu

GPIO_TypeDef structure

STM32F401 – REFERENCE MANUAL

- 8.4 GPIO registers
  - 8.4.1 GPIO port mode register (GPIOx_MODER) (x = A..E and H)
  - 8.4.2 GPIO port output type register (GPIOx_OTYPER) (x = A..E and H)
  - 8.4.3 GPIO port output speed register (GPIOx_OSPEEDR) (x = A..E and H)
  - 8.4.4 GPIO port pull-up/pull-down register (GPIOx_PUPDR) (x = A..E and H)
  - 8.4.5 GPIO port input data register (GPIOx_IDR) (x = A..E and H)
  - 8.4.6 GPIO port output data register (GPIOx_ODR) (x = A..E and H)
  - 8.4.7 GPIO port bit set/reset register (GPIOx_BSRR) (x = A..E and H)
  - 8.4.8 GPIO port configuration lock register (GPIOx_LCKR) (x = A..E and H)
  - 8.4.9 GPIO alternate function low register (GPIOx_AFRL) (x = A..E and H)
  - 8.4.10 GPIO alternate function high register (GPIOx_AFRH) (x = A..E and H)

STM32F401XE.H (<DEVICE.H> CMSIS FILE)

stm32f401xe.h

```c
/**
  * @brief General Purpose I/O
  */

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: 0x0C      */
  __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: 0x1C      */
  __IO uint32_t AFR[2];   /*!< GPIO alternate function registers,     Address offset: 0x20-0x24 */
} GPIO_TypeDef;
```

GPIO_TypeDef *is a C structure designed in such a way that its data members correspond to all the registers within a given hardware block, such as the GPIO Registers.*

GPIO_TypeDef structure

```
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: 0x0C      */
  __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: 0x1C      */
  __IO uint32_t AFR[2];   /*!< GPIO alternate function registers,     Address offset: 0x20-0x24 */
} GPIO_TypeDef;
```

- Since all registers are 32-bit wide, the struct uses uint32_t datatype for its members.
- The __IO, __I, and __O identifiers are preprocessor macros defined in the Cortex Microcontroller Software Interface Standard (CMSIS), which the “core_cm4.h” header file is part of.
- __IO == Read/Write
- __I == Read-Only
- __O == Write-Only

GPIO_TypeDef structure

- Need to make sure that the GPIO structure is at the right base address.
- We have only created instances of Point, Rectangle, and Triangle structures, where the compiler controlled their placement in memory.
- Similar to type casting the GPIO addresses to pointers, we can use pointers to structures initialized to the hard-coded base address for that GPIO.
- This is what is done in the “stm32f401xe.h” header:
    - **#define GPIOA ((GPIO_TypeDef *) GPIOA_BASE)**
- The GPIOA macro defines a pointer to the GPIO_TypeDef structure, which is hard-coded to the GPIO_BASE address.

Replace registers with structures

1. Replace every register access using the structure pointer form.
2. For example, to replace the first register access:
    1. Take the RCC pointer and append the member access operator.
    2. IAR will help with intelli-sense displaying all the members of this structure.
    3. Choose the appropriate register from the list.
3. The same for the other registers (Assignment).

Demo – Blinking LED using CMSIS

1. Create a new project
2. Bring in the files “stm32f401xe.h” & “system_stm32f4xx.h”
3. Show compiler failures
4. Enable use of CMSIS in project
5. Add code for Blinking LED using GPIO addresses type-casted to pointers (as shown here)
6. Convert usage of type-casted addresses to CMSIS structures

```
void delay(unsigned int iteration);

void delay(unsigned int iteration)
{
   while (iteration > 0)
   {
      iteration--;
   }
}

// RCC Base Address: 0x40023800
// RCC AHB1 peripheral clock enable register (RCC_AHB1ENR)
// Address offset: 0x30
// Set bit[0] to 1
// 1. Enable clock to Peripheral
*((unsigned int*)(0x40023800+0x30)) |= 0x1;

// GPIOA Base Address: 0x40020000
// GPIO port mode register (GPIOx_MODER) (x = A..E and H)
// Address offset: 0x00
// Set bit[11:10] to 0x01  so --> 0x400 // To enable Port5 as output
*((unsigned int*)(0x40020000+0x00)) |= 0x400;

 // GPIOA Base Address: 0x40020000
 // GPIO port output data register (GPIOx_ODR) (x = A..E and H)
 // Address offset: 0x14
 // Set bit[5] to 1 --> 0x20; // Turn LED ON
 // Set bit[5] to 0 --> 0x00; // Turn LED OFF

 while(1)
   {
      delay(1000000);
      *((unsigned int*)(0x40020000+0x14)) |= (1<<5);

      delay(1000000);
      *((unsigned int*)(0x40020000+0x14)) &= ~(1<<5);
   }
```


To learn more about CMSIS

- https://developer.arm.com/tools-and-software/embedded/cmsis
- https://github.com/ARM-software/CMSIS_5
- https://www.st.com/en/embedded-software/stm32-standard-peripheral-libraries.html

Assignment 06

Suggested Reading

- ***"The Cortex-M4 Device Generic User Guide"***
  - 2.6: Data types in C programming
  - 2.9: The Cortex microcontroller software interface standard
- ***"The Definitive Guide to ARM Cortex M3 & M4" by Joseph Yiu (Third Edition)***
  - Chapter 2.9: The Cortex microcontroller software interface standard (CMSIS)
- ***"An Embedded Software Primer" by David E. Simon***
  - Chapter 5: Survey of Software Architecture
  - Chapter 6.1: Tasks & Task State
  - Chapter 6.2: Tasks & Data