Software Libraries: CMSIS and mbed SDK

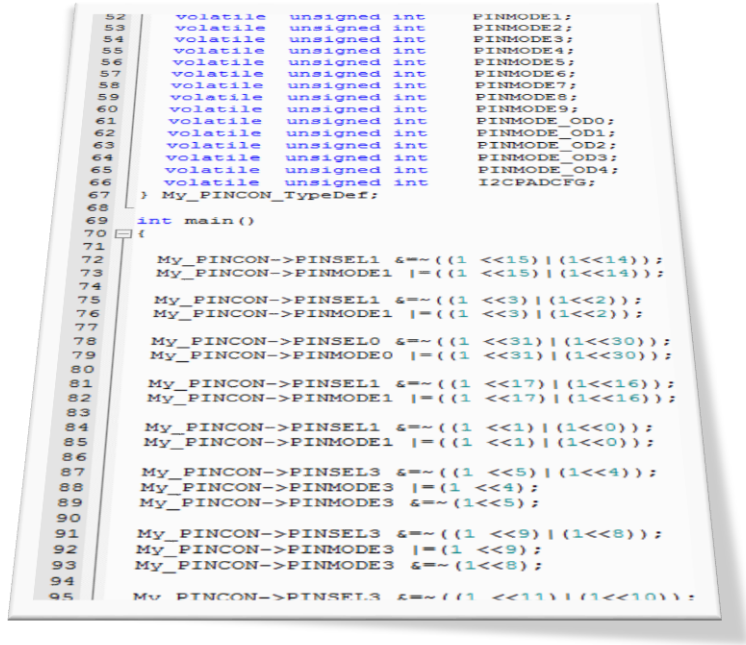
Module Syllabus

- Overview of Software Libraries
- Cortex Microcontroller Software Interface Standard (CMSIS)
  - What is CMSIS
  - What is Standardized in CMSIS
  - Benefits of CMSIS
  - CMSIS Functions
- mbed Software Development Kit (SDK)
  - What is mbed SDK
  - Features of mbed SDK
  - mbed SDK Library Structure
  - Example of mbed SDK Library Layers

Overview of Software Libraries

- In the previous modules, we have learned how to control a GPIO peripheral (connected to digital IOs such as LEDs) at a low-level. However, there are a number of disadvantages when programing in low-level, such as:

  - Low productivity
  - Less portable from one device to another device
  - Resulting code is more difficult for others to read, reuse, and maintain
  - Can result in inefficient code as high level optimization are missed (low code density)



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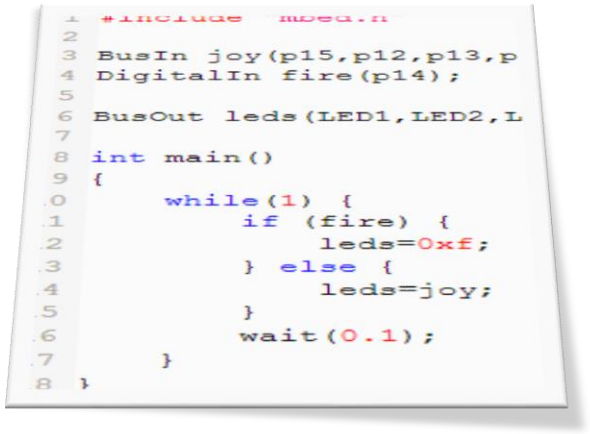
Overview of Software Libraries

- With support from software libraries or Application Programming Interfaces (APIs), we could ease our application development in a variety of ways to achieve :
  - Higher productivity (less development time)
  - Portability across devices
  - Resulting code is easier code to read, reuse and maintain by others
  - More efficient code (code density and performance)



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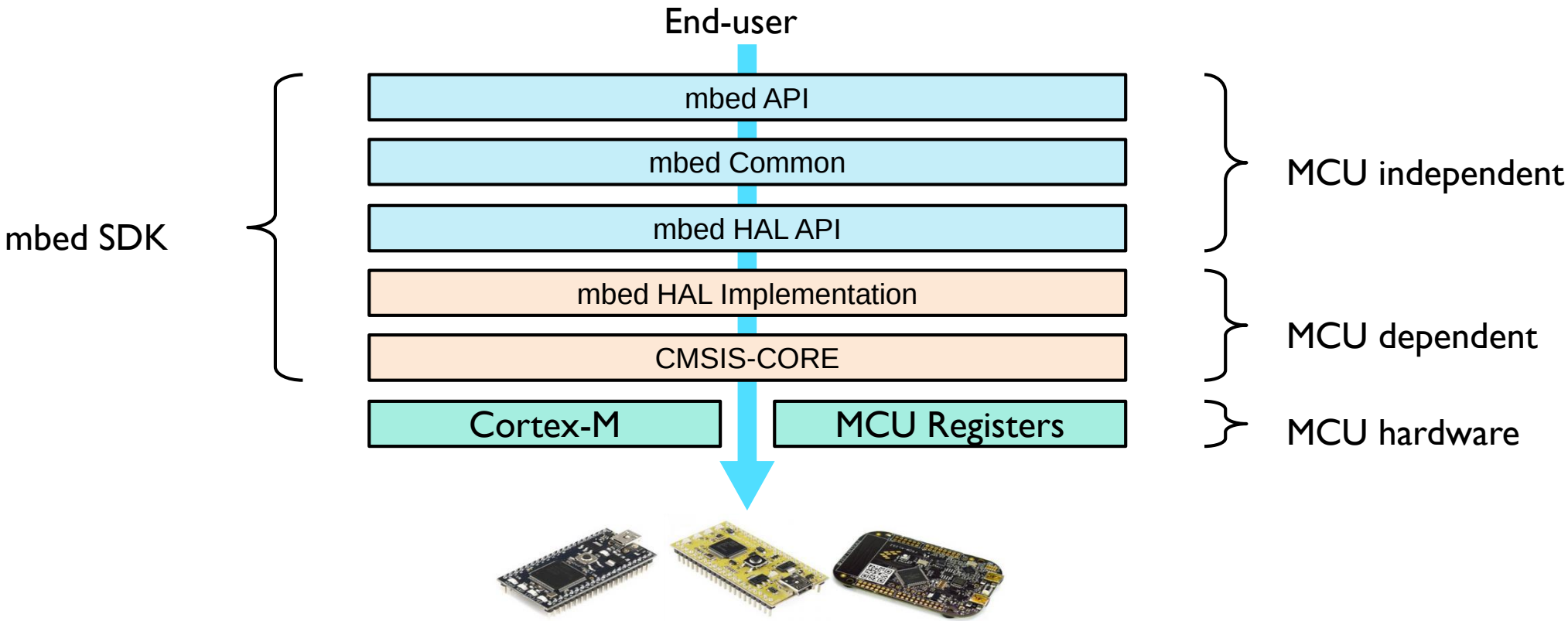
ARM CMSIS and mbed SDK

- In this module, we will introduce two libraries/APIs:
  - CMSIS-CORE – Cortex Microcontroller Software Interface Standard
  - mbed SDK – mbed Software Development Kit



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CMSIS – Cortex Microcontroller Software Interface Standard

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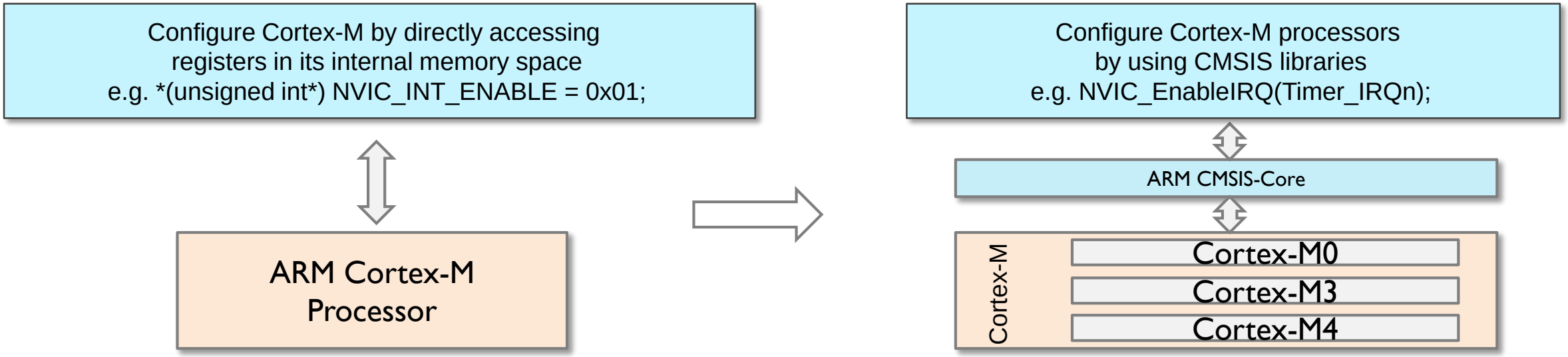
What is CMSIS

- CMSIS – Cortex Microcontroller Software Interface Standard
  - CMSIS is a vendor-independent hardware abstraction layer for the Cortex-M processor series
  - CMSIS provides a standardized software interface, such as library functions which help you control the processor more easily, e.g. configuring the Nested Vectored Interrupt Controller (NVIC)
  - Main reason is to improve software portability across different Cortex-M processors and Cortex-M based microcontrollers



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What is Standardized in CMSIS

- Standardized functions to access NVIC, System Control Block (SCB), and System Tick timer (SysTick), for example:
  - Enables an interrupt or exception: NVIC_EnableIRQ (IRQn_Type IRQn)
  - Sets pending status of interrupt: void NVIC_SetPendingIRQ (IRQn_Type IRQn)
- Standardized access of special registers, for example:
  - Read PRIMASK register: uint32_t __get_PRIMASK (void)
  - Set CONTROL register: void __set_CONTROL (uint32_t value)
- Standardized functions to access special instructions, e.g.
  - REV: uint32_t __REV(uint32_t int value)
  - NOP: void __NOP(void)
- Standardized names of system initialization functions, e.g.
  - System initialization: void SystemInit(void)

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Benefits of CMSIS

- Easier to port application code from one Cortex-M based microcontroller to another Cortex-M based microcontroller
- Less effort to reuse the same code between different Cortex-M based microcontrollers

- Better compatibility when integrating third-party software components, since all the third-party components such as applications, embedded OS, middleware etc., can share the same standard CMSIS interface
- Better code density and smaller memory footprint, since the codes in CMSIS have been optimised and tested

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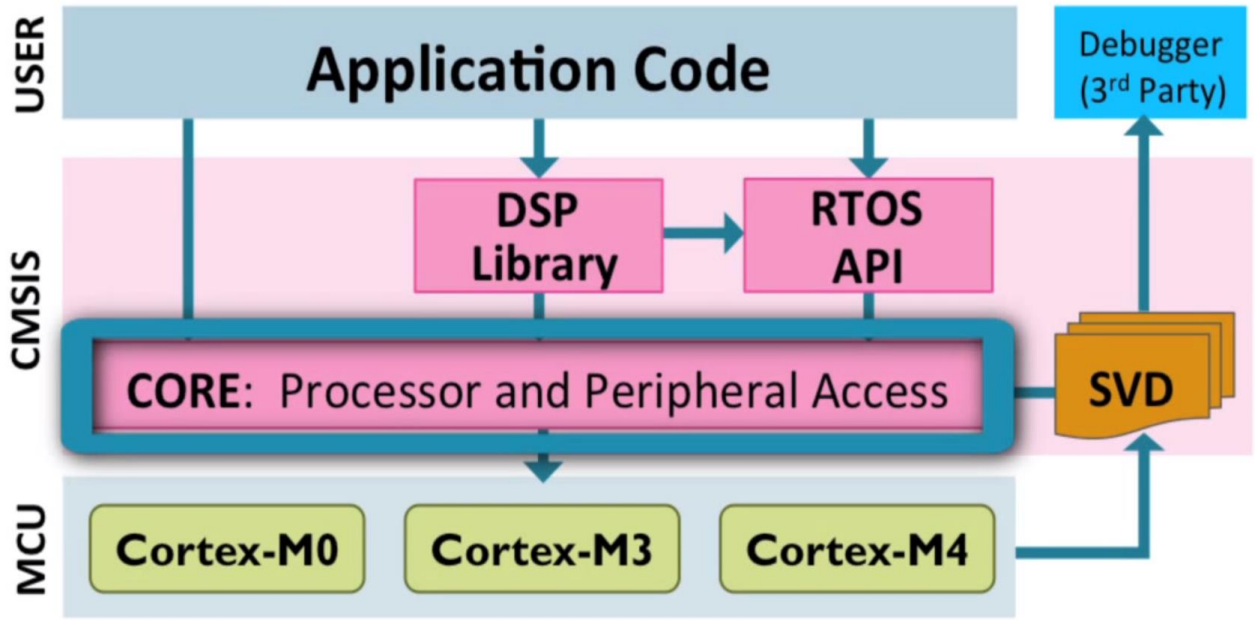
CMSIS Components

- The CMSIS consists of the following components:
  - CMSIS-CORE
  - CMSIS-DSP, CMSIS-RTOS API and CMSIS-SVD
  - In this module, we will focus on using CMSIS-CORE



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CMSIS Components

- CMSIS-CORE
  - Provides an interface to Cortex-M0, Cortex-M3, Cortex-M4, SecureCore™ SC000 and SC300 processors, and peripheral registers
- CMSIS-DSP
  - DSP library with over 60 functions in fixed-point (fractional q7, q15, q31) and single precision floating-point (32-bit) implementation
- CMSIS-RTOS API
  - Standardized programming interface for real-time operating systems, for thread control, resource, and time management
- CMSIS-SVD:
  - System View Description XML files that contain the programmer's view of a complete microcontroller system including peripherals

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CMSIS Functions: Access NVIC

CMSIS function	Description
void NVIC_EnableIRQ (IRQn_Type IRQn)	Enables an interrupt or exception.
void NVIC_DisableIRQ (IRQn_Type IRQn)	Disables an interrupt or exception.
void NVIC_SetPendingIRQ (IRQn_Type IRQn)	Sets the pending status of interrupt or exception to 1.
void NVIC_ClearPendingIRQ (IRQn_Type IRQn)	Clears the pending status of interrupt or exception to 0.
uint32_t NVIC_GetPendingIRQ (IRQn_Type IRQn)	Reads the pending status of interrupt or exception. This function returns non-zero value if the pending status is set to 1.
void NVIC_SetPriority (IRQn_Type IRQn, uint32_t priority)	Sets the priority of an interrupt or exception with configurable priority level to 1.
uint32_t NVIC_GetPriority (IRQn_Type IRQn)	Reads the priority of an interrupt or exception with configurable priority level. This function return the current priority level.

CMSIS Functions: Access Special Registers

Special register	Access	CMSIS function
PRIMASK	Read	*uint32_t __get_PRIMASK (void)*
	Write	*void __set_PRIMASK (uint32_t value)*
CONTROL	Read	*uint32_t __get_CONTROL (void)*
	Write	*void __set_CONTROL (uint32_t value)*
MSP	Read	*uint32_t __get_MSP (void)*
	Write	*void __set_MSP (uint32_t TopOfMainStack)*
PSP	Read	*uint32_t __get_PSP (void)*
	Write	*void __set_PSP (uint32_t TopOfProcStack)*

CMSIS Functions: Execute Special Instructions

Instruction	CMSIS intrinsic function
CPSIE i	*void __enable_irq(void)*
CPSID i	*void __disable_irq(void)*
ISB	*void __ISB(void)*
DSB	*void __DSB(void)*
DMB	*void __DMB(void)*
NOP	*void __NOP(void)*
REV	*uint32_t __REV(uint32_t int value)*
REV16	*uint32_t __REV16(uint32_t int value)*
REVSH	*uint32_t __REVSH(uint32_t int value)*
SEV	*void __SEV(void)*
WFE	*void __WFE(void)*
WFI	*void __WFI(void)*

CMSIS Functions: Access System

CMSIS function	Description
void NVIC_SystemReset(void)	Initiate a system reset request
uint32_t SysTick_Config(uint32_t ticks)	Initialize and start the SysTick counter and its interrupt
void SystemInit (void)	Initialize the system
void SystemCoreClockUpdate(void)	Update the SystemCoreClock variable

MBED SOFTWARE DEVELOPMENT KIT (SDK)

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What is mbed SDK

- mbed platform includes:
  - **A standards-based C/C++ Software Development Kit (SDK)**
  - A microcontroller Hardware Development Kit (HDK) and supported development boards
  - Integrated Development Environment (IDE), including an online compiler and online developer collaboration tools

- mbed Software Development Kit (SDK) includes:
  - Software libraries
    - Official C/C++ software libraries
      - Start-up code, peripheral drivers, networking, RTOS and runtime environment
    - Customer-developed libraries and codes
      - Cookbook of hundreds of reusable peripheral and module libraries have been built on top of the SDK, which can be used to build your projects faster
  - Software tools, such as build tools, test and debug scripts

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Features of mbed SDK

- Legal – are you allowed to use mbed SDK?
  - mbed SDK is licensed under the permissive Apache 2.0 licence
  - All codes can be used in both commercial and personal projects with confidence
- Supported Toolchains and IDEs
  - GCC ARM: GNU Tools for ARM Embedded Processors
  - ARMCC (standard library and MicroLib): uVision
  - IAR: IAR Embedded Workbench
  - GCC code_red: Red Suite
  - GCC CodeSourcery: Sourcery CodeBench

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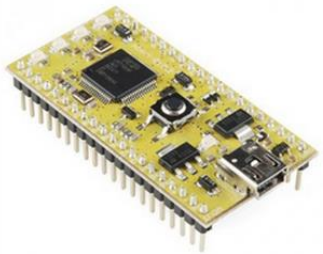
Features of mbed SDK

- Compatible with different hardware platforms
  - NXP series MCUs, including:
    - Cortex-M0: LPC11U24, LPC1114, LPC11C24, LPC4330
    - Cortex-M0+: LPC810, LPC812
    - Cortex-M3: LPC1768, LPC1347
    - Cortex-M4: LPC4088, LPC4330
    - ARM7TDMI-S: LPC2368
  - Freescale series MCUs including:
    - Cortex-M0+: KL25Z , KL05Z
  - STMicroelectronics series MCUs including:
    - Cortex-M4: STM32F407

mbed LPC1768



mbed LPC11U24

Freescale KL25Z

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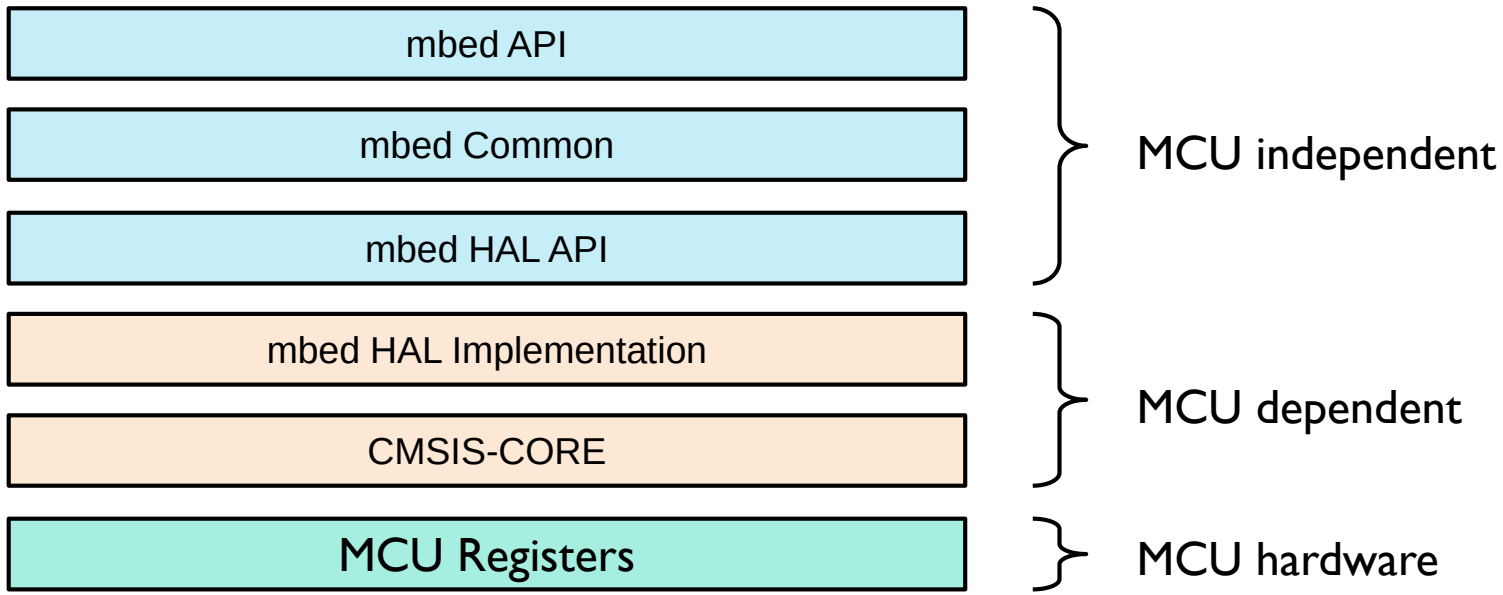
mbed SDK Library Structure

- The mbed SDK library provides abstractions for:
  - MCU independent layer – mbed API, mbed common, and mbed HAL API
  - MCU dependent layer – mbed HAL Implementation and CMSIS-CORE
  - MCU hardware – MCU Registers



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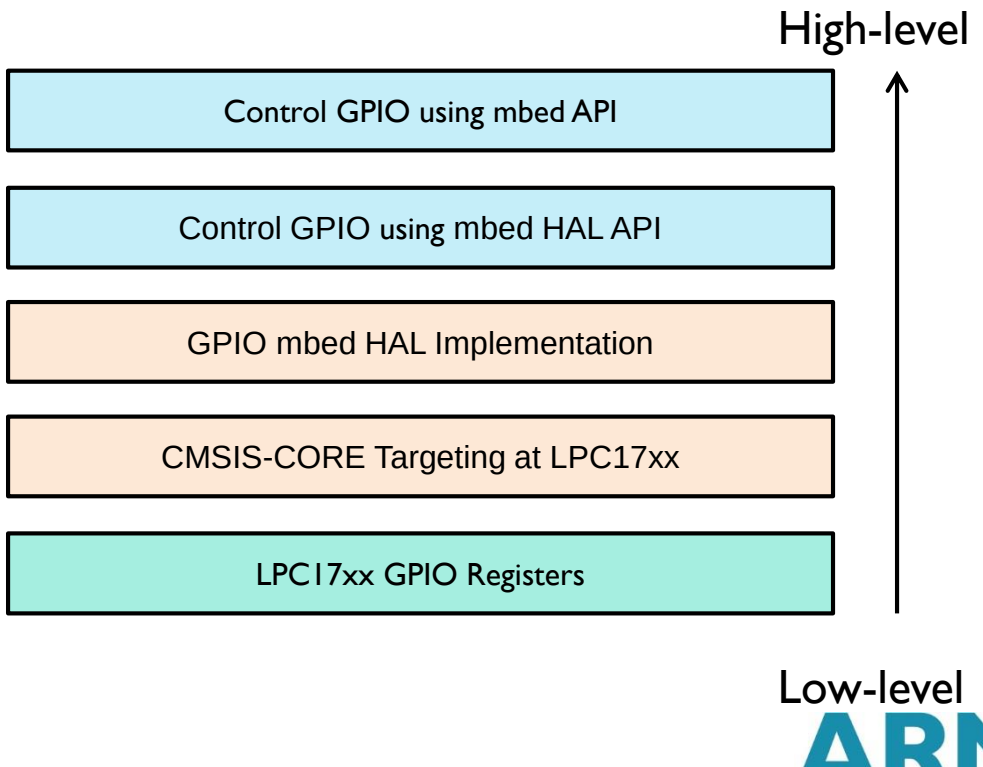
Example of mbed SDK Library Layers

- To understand how the mbed SDK library is structured and layered, we will use the GPIO example that we have been familiar with in the previous modules

- We will explain it using a LED blinky example, which can be programmed at different levels, using libraries from the lowest layer to the highest layer:

  - MCU register layer
    - Blinky example by poking registers
  - CMSIS-CORE
    - Blinky example using CMSIS-CORE structures
  - mbed HAL API
    - Blinky example using mbed HAL API functions
  - mbed API
    - Blinky example using mbed API functions



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MCU Register Example

- Similar as we did in the previous labs, the GPIO peripheral can be directly accessed by writing/ reading specific memory addresses
  - Assign a pointer to the address of each register
  - Registers can be read/ written to using the pointer

```
1  #include "mbed.h"
2
3  // Reuse initialization code from the mbed library
4  DigitalOut led1(LED1); // P1_18
5
6  int main() {
7      unsigned int mask_pin18 = 1 << 18;
8
9      volatile unsigned int *port1_set = (unsigned int *)0x2009C038;
10     volatile unsigned int *port1_clr = (unsigned int *)0x2009C03C;
11
12     while (true) {
13         *port1_set |= mask_pin18;
14         wait(0.5);
15
16         *port1_clr |= mask_pin18;
17         wait(0.5);
18     }
19 }
```

Directly access MCU registers

CMSIS-CORE Example

- Alternatively, we also have tried defining a structure for the peripheral and use the structure to ease our design
- Similar to what we did, the CMSIS-CORE library defines a structure for accessing the peripherals, for instance:

```
996 /** GPIO - Register Layout Typedef */
997 typedef struct {
998   __IO uint32_t PDOR;                              /**< Port Data Output Register, offset: 0x0 */
999   __O  uint32_t PSOR;                              /**< Port Set Output Register, offset: 0x4 */
1000  __O  uint32_t PCOR;                              /**< Port Clear Output Register, offset: 0x8 */
1001  __O  uint32_t PTOR;                              /**< Port Toggle Output Register, offset: 0xC */
1002  __I  uint32_t PDIR;                              /**< Port Data Input Register, offset: 0x10 */
1003  __IO uint32_t PDDR;                              /**< Port Data Direction Register, offset: 0x14 */
1004 } GPIO_Type;
1005
1006 /* ----------------------------------------------------------------------------
1007    -- GPIO Register Masks
1008    ---------------------------------------------------------------------------- */
1009
1010 /**
1011  * @addtogroup GPIO_Register_Masks GPIO Register Masks
1012  * @{
1013  */
1014
1015 /* PDOR Bit Fields */
1016 #define GPIO_PDOR_PDO_MASK                       0xFFFFFFFFu
1017 #define GPIO_PDOR_PDO_SHIFT                      0
1018 #define GPIO_PDOR_PDO(x)                         (((uint32_t)(((uint32_t)(x))<<GPIO_PDOR_PDO_SHIFT))&GPIO_PDOR_PDO_MAS
1019 /* PSOR Bit Fields */
1020 #define GPIO_PSOR_PTSO_MASK                      0xFFFFFFFFu
1021 #define GPIO_PSOR_PTSO_SHIFT                     0
1022 #define GPIO_PSOR_PTSO(x)                        (((uint32_t)(((uint32_t)(x))<<GPIO_PSOR_PTSO_SHIFT))&GPIO_PSOR_PTSO_M
1023 /* PCOR Bit Fields */
1024 #define GPIO_PCOR_PTCO_MASK                      0xFFFFFFFFu
1025 #define GPIO_PCOR_PTCO_SHIFT                     0
1026 #define GPIO_PCOR_PTCO(x)                        (((uint32_t)(((uint32_t)(x))<<GPIO_PCOR_PTCO_SHIFT))&GPIO_PCOR_PTCO_M
1027 /* PTOR Bit Fields */
```

Data structure provided by CMSIS-CORE

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CMSIS-CORE Example

- The mbed library also provides certain additions to the CMSIS-CORE layer, such as:
  - Startup file for each of the supported Toolchains
  - Linker file and support functions to define the Memory Map
  - Functions to set and get Interrupt Service Routines (ISR) addresses from the Nested Vectored Interrupt Controller (NVIC) and to program Vector Table Offset Register (VTOR)

```
1  #include "mbed.h"
2
3  // Reuse initialization code from the mbed library
4  DigitalOut led1(LED1); // P1_18
5
6  int main() {
7      unsigned int mask_pin18 = 1 << 18;
8
9      while (true) {
10         LPC_GPIO1->FIOSET |= mask_pin18;
11         wait(0.5);
12
13         LPC_GPIO1->FIOCLR |= mask_pin18;
14         wait(0.5);
15     }
16 }
```

Blink an LED using the data structure provided by CMSIS-CORE

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HAL API Example

- The Hardware Abstraction Layer (HAL) Application Programming Interface (API) is a library layer that provides easy-to-use functions which are hardware platform independent
- For example, the GPIO HAL API defines the following functions:

```
typedef struct gpio_s gpio_t;

void gpio_init (gpio_t *obj, PinName pin, PinDirection direction);

void gpio_mode (gpio_t *obj, PinMode mode);
void gpio_dir  (gpio_t *obj, PinDirection direction);

void gpio_write(gpio_t *obj, int value);
int  gpio_read (gpio_t *obj);
```

GPIO functions defined in HAL API

- The HAL API is an internal interface
  - Used to help porting the mbed library to a new target and is subject to change
  - If you want to "future proof" your application avoid using this API and use the mbed API instead

mbed API Example

- The mbed API provides the actual user-friendly object-oriented API to the final user
  - More friendly functions/ APIs
  - Object oriented API (using C++)
  - Top-level API used by the majority of the programs developed on the mbed platform
  - Define basic operators to provide intuitive casting to primitive types and assignments
  - A digital IO class is defined as shown in the code clip

```
class DigitalInOut {

public:
    DigitalInOut(PinName pin) {
        gpio_init(&gpio, pin, PIN_INPUT);
    }

    void write(int value) {
        gpio_write(&gpio, value);
    }

    int read() {
        return gpio_read(&gpio);
    }

    void output() {
        gpio_dir(&gpio, PIN_OUTPUT);
    }

    void input() {
        gpio_dir(&gpio, PIN_INPUT);
    }

    void mode(PinMode pull) {
        gpio_mode(&gpio, pull);
    }

    DigitalInOut& operator= (int value) {
        write(value);
        return *this;
    }

    DigitalInOut& operator= (DigitalInOut& rhs) {
        write(rhs.read());
        return *this;
    }
```


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mbed API Example

- With the support of the mbed API, the same blinky example can be programed in a much simpler and ,ore intuitive way:

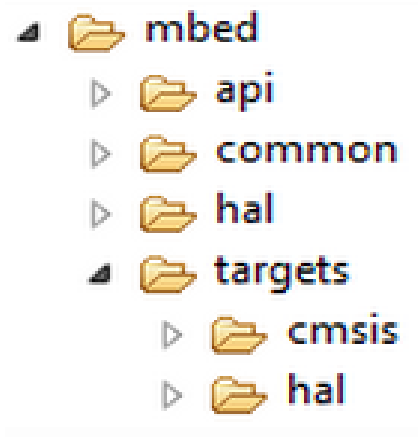
```
1  #include "mbed.h"
2
3  DigitalOut led1(LED1);
4
5  int main() {
6      while (true) {
7          led1 = 1;
8          wait(0.5);
9
10         led1 = 0;
11         wait(0.5);
12     }
13 }
```

- Note that the mbed API is programed using the object-oriented language C++, which originated from C language with object oriented features such as classes

- Deep knowledge of C++ is not necessary to use the mbed API. However, there is a large number of tutorials and books on C++ programming that you can avail of to learn C++

mbed SDK Library Directory Structure

- Three target independent directories:
  - `mbed/api`
  - The headers defining the actual mbed library API
  - `mbed/common`
  - mbed common sources
  - `mbed/hal`
  - The HAL API to be implemented for every target
- Two target dependent directories:
  - `mbed/targets/hal`
  - The HAL implementations
  - `mbed/targets/cmsis`
  - CMSIS-CORE sources



- The directory structure of the sources constituting the mbed library is published on the official mbed github repository at:
  - https://github.com/mbedmicro/mbed/tree/master/libraries

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Useful Resources

- CMSIS webpage
  - http://www.arm.com/products/processors/cortex-m/cortex-microcontroller-software-interface-standard.php
- Explore the mbed platform
  - http://mbed.org/explore/
- Official mbed github repository
  - https://github.com/mbedmicro/mbed/tree/master/libraries
- mbed SDK porting
  - http://mbed.org/handbook/mbed-SDK-porting
- mbed library internals
  - http://mbed.org/handbook/mbed-library-internals
- "The Definitive Guide to ARM Cortex-M3 and Cortex-M4 Processors" by Joseph Yiu, ISBN 13: 9780124080829 ISBN 10: 0124080820, 13 December 2013

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