Experiment 1: Development Platform

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1. Objectives

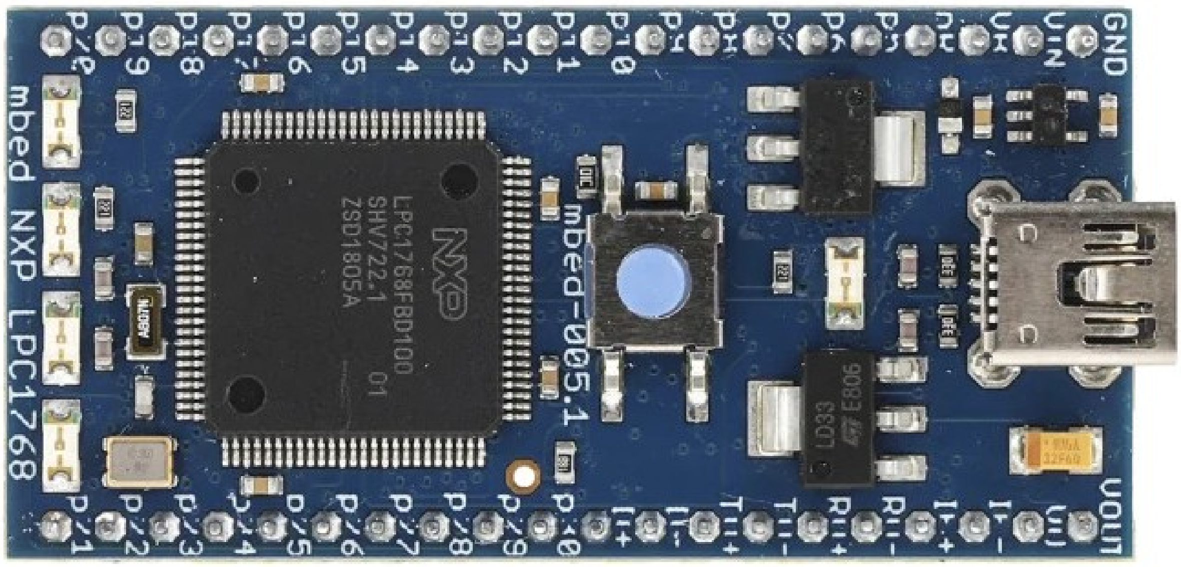
- Get familiar with the development platform:

Hardware	microcontroller, development board, peripherals
Software	IDE, compiler, debugging, programming

- General-purpose input/output (GPIO): digital output
- Introduce CMSIS: Cortex Microcontroller Software Interface Standard

2. Parts List

- LPC1768 mbed board



- USB A-Type to Mini-B cable

3. Background

3.1. Microcontroller

LPC1768 is a microcontroller manufactured by NXP. LPC1768 is only one member of a big family of microcontolles. NXP was founded by Philips as Philips Semiconductors, and renamed NXP in 2006. A major difference between a microcontroller and a microprocessor is that the former has some additional built-in devices, such as memory, I/O peripherals, and timers.

The LPC1768 microcontroller is an ARM 32-bit Cortex-M3 microcontroller. Some of its features include: CPU clock up to 120MHz, 512kB on-chip Flash ROM, 64kB RAM, Ethernet 10/100 MAC, USB 2.0 full-speed Device controller and Host controller, four UARTs, general purpose I/O pins, 12-bit ADC, 10-bit DAC, four 32-bit timers, Real Time Clock, System Tick Timer.

The product data sheet for the LPC1768 microcontroller [lpc1768-data-sheet] and the more detailed user munual [lpc1768-manual] are essential resources for any developer.

3.2. Development Board

The LPC1768 microcontroller chip is used to build the *LPC1768 mbed board*, which we will be using in this LAB.

The LPCXpresso board consists of two parts:

1. LPCXpresso target board, which hosts the LPC1768 microcontroller
2. LPC-Link: a debug probe for debugging and the target microcontroller.

3.3. Compilation Methods

There are two main ways to compile C/C++ code for LPC1768:

1. Using mbed online compiler where you only need a web browser to compile the source code and download the binary. Then, you need to copy the binary file to the mbed drive. In order to use mbed online compiler, you need to create an account at mbed online compiler.
2. Using MCUXpresso IDE which allows a wide range of advanced debugging features. The MCUXpresso IDE will build/compile the project and transfer the compiled binary to the development board. Then, it will start execution of the `main` function.

In order to use MCUXpresso IDE with LPC1768, the LPC1768 must have firemware version equal to or greater than `141212`. The firmware version is stored in the `MBED.htm` file in the LPC1768, use a text editor to open the `MBED.htm` file. Please refere to LPC1768_Firmware to download and upgrade the firmware of the LPC1768.

MCUXpresso IDE will be used for the lab manual, but feel free to use mbed online compiler.

3.4. MCUXpresso IDE

The MCUXpresso IDE is an Eclipse-based software development environment for NXP's LPC microcontrollers.

The MCUXpresso IDE uses the GNU toolchain (compiler and linker), and offers the choice of two C libraries:

- Redlib (default): a proprietary ISO C90 standard C library, with some C99 extensions. Often results in smaller binary size.
- Newlib: an open source complete C99 and C++ library.

3.4.1. Installation

To install your copy of the MCUXpresso IDE:

1. Using a web browser, navigate to the MCUXpresso Integrated Development Environment (IDE) page.
2. Use the *Download* button to go to the download page, then use the download link that matches your operating system.

   You may need to create an account to access the download page.

3. Run the downloaded installer.

3.5. Input/Output Ports

The LPC1768 microcontroller has five input/output (I/O) ports. Each port is 32 bits. However, not all of them are available for the developer. For example, pins 12, 13, 14, and 31 of port 0 are not available.

Each of the I/O pins can be referred to using the port number and the pin number. For example, `P0.17` or `P0[17]` is pin 17 in port 0, and `P1.22` or `P1[22]` is pin 22 in port 1.

Most of the I/O pins have multiple functions. For example: `P0.10` can perform one of these jobs:

P0[10]	General purpose digital input/output pin.
TXD2	Transmitter output for UART2.
SDA2	I2C2 data input/output.
MAT3[0]	Match output for Timer 3, channel 0.

Don't worry if you don't understand these functions, you will learn about them throughout the course.

A command is needed to choose which function is to be used in a specific pin. The only exception is the first function (GPIO) because it is the default function.

Relying on a default value may be acceptable in simple programs. However, a good programming style when you have many functions and interrupts is not to assume any default value as they may have been changed somewhere in your program. Instead, you should explicitly specify any desired values.

3.5.1. Pin Layout

The pin layout of the LPC1768 mbed board is shown in the LPC1768 pin layout figure below.

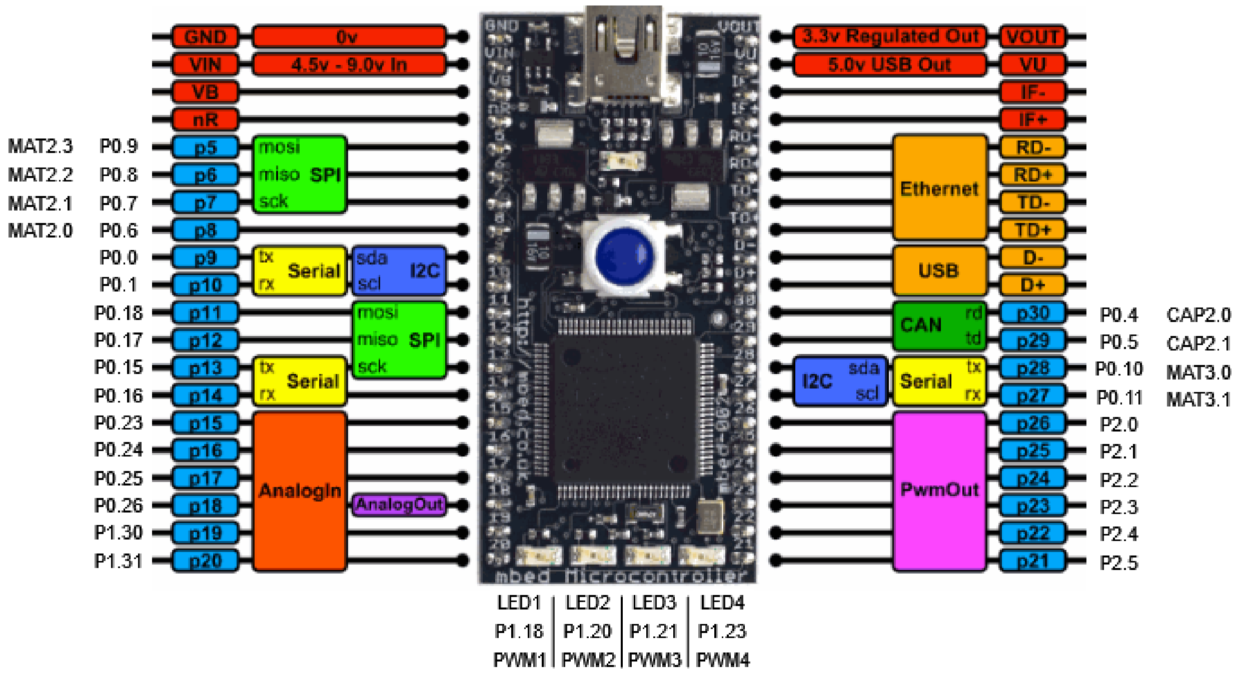


Figure 1. LPC1768 pin layout

3.5.2. Memory-Mapped I/O

ARM uses memory-mapped I/O. When using memory-mapped I/O, the same address space is shared by memory and I/O devices. Some addresses represent memory locations, while others represent registers in I/O devices. No separate I/O instructions are needed in a CPU that uses memory-mapped I/O. Instead, we can use any instruction that can reference memory to move values to or from memory-mapped device registers.

3.5.3. General-Purpose Input/Output (GPIO)

GPIO is available in most I/O pins. A GPIO pin is a pin that can be used for digital input or digital output. You need to choose the direction of the pin (whether it is used for input or output). In the first example of this experiment, we will set the direction to be output. To use a digital output pin, you need to be able to to *set* the output to HIGH (1), and to *clear* it to LOW (0).

In summery, we need to learn about 3 registers for our first experiment:

1. The register that controls the *direction* of GPIO pins
2. How to *set* a pin to HIGH.
3. How to *clear* a pin to LOW.

3.5.4. Accessing Registers

Each I/O register has an address. For example:

1. The address of the register that controls the direction of port 0 pins is: `0x2009c000`.
2. The address of the register that *sets* port 0 pins to HIGH is: `0x2009c018`.
3. The address of the register that *clears* port 0 pins to LOW is: `0x2009c01c`.

To access a register more easily, you can give it a name. One way to give a register a name in the C programming language is to use *pointers*, *pointer dereferencing*, and the `define` directive.

For more details about these features (and more) of the *C programming language*, it is strongly recommended to consult the document Data Structures in C.

Example 1. Giving Registers Names

Here are examples showing how to assign names to registers:

```
// GPIO Port 0
#define DIR_P0  (*((volatile unsigned long *) 0x2009c000))
#define SET_P0  (*((volatile unsigned long *) 0x2009c018))
#define CLR_P0  (*((volatile unsigned long *) 0x2009c01c))
// GPIO Port 1
#define DIR_P1  (*((volatile unsigned long *) 0x2009c020))
#define SET_P1  (*((volatile unsigned long *) 0x2009c038))
#define CLR_P1  (*((volatile unsigned long *) 0x2009c03c))
```

Example 2. Setting Pin Direction

To set the direction for pins 1, 2, 3 and 4 of port 0 as output, while setting the direction of the remaining pins as input:

```
DIR_P0 = 0x0000001E;
// OR
DIR_P0 = 30;

// Make sure that you understand that these statements are equivalent!
```

The first task is to blink an LED using the above registers!

In the first experiment, you can avoid making any external connections by using the one of on board LEDs, which is connected to `P1.18`.

3.6. CMSIS

> The *Cortex Microcontroller Software Interface Standard* (CMSIS) is a vendor-independent hardware abstraction layer for the Cortex-M processor series […]. The CMSIS enables consistent device support and simple software interfaces to the processor and the peripherals, simplifying software re-use […].
>
> — ARM Ltd., CMSIS: Introduction

The CMSIS components are: CMSIS-CORE, CMSIS-Driver, CMSIS-DSP, CMSIS-RTOS API, CMSIS-Pack, CMSIS-SVD, CMSIS-DAP, CMSIS-DAP/

The most relevant component to us is CMSIS-CORE.

> CMSIS-CORE implements the basic run-time system for a Cortex-M device and gives the user access to the processor core and the device peripherals. In detail it defines:
>
> - **Hardware Abstraction Layer (HAL)** for Cortex-M processor registers with standardized definitions for the SysTick, NVIC, System Control Block registers, MPU registers, FPU registers, and core access functions.
> - **System exception names** to interface to system exceptions without having compatibility issues.
> - **Methods to organize header files** that makes it easy to learn new Cortex-M microcontroller products and improve software portability. This includes naming conventions for device-specific interrupts.
> - **Methods for system initialization** to be used by each MCU vendor. For example, the standardized `SystemInit()` function is essential for configuring the clock system of the device.
> - **Intrinsic functions** used to generate CPU instructions that are not supported by standard C functions.
> - A variable to determine the **system clock frequency** which simplifies the setup the SysTick timer.
>
> — ARM Ltd., CMSIS-CORE: Overview

CMSIS provides abstraction at the chip level only. Other libraries provide more extensive APIs for additional peripherals and board features, but are usually less generic and more vendor-specific.

3.7. Accessing Registers Using CMSIS

When using CMSIS, you don’t need to know register addresses, which implies that you don’t need to use the `#define` directive to name the registers. Instead, you use the `#include` directive to include the `lpc17xx.h` header file, which contains all the register address definitions for the LPC17xx family of microcontrollers. When you use the LPCXpresso IDE to create a CMSIS project, the IDE generates a basic source file which already includes this header file.

In the lpc17xx.h header file, the names are not given using the #define directive only. They are given using #define (for the base address) then using structures to group similar (and adjecent) registers.

3.7.1. Structures and Pointers

The CMSIS header file, lpc17xx.h, organizes the registers into logical groups based on their functions, using C structures. First, a structure is defined by listing its fields. Then, a pointer is defined for each needed instance of that structure, pointing to the starting address of the instance, as documented in the microcontroller manual.

For example, the names of the pointers to the structure instances for the five GPIO ports are:

LPC_GPIO0	for port 0
LPC_GPIO1	for port 1
LPC_GPIO2	for port 2
LPC_GPIO3	for port 3
LPC_GPIO4	for port 4

These pointers are defined in the lpc17xx.h file as follows:

```
#define LPC_GPIO0  ((LPC_GPIO_TypeDef *)  LPC_GPIO0_BASE)
#define LPC_GPIO1  ((LPC_GPIO_TypeDef *)  LPC_GPIO1_BASE)
#define LPC_GPIO2  ((LPC_GPIO_TypeDef *)  LPC_GPIO2_BASE)
#define LPC_GPIO3  ((LPC_GPIO_TypeDef *)  LPC_GPIO3_BASE)
#define LPC_GPIO4  ((LPC_GPIO_TypeDef *)  LPC_GPIO4_BASE)
```

where LPC_GPIO_TypeDef is the name of the structure, which is defined earlier in the file to describe the registers related to GPIO ports, and LPC_GPIO0_BASE through LPC_GPIO4_BASE are fixed addresses, also defined earlier in the header file, at which the registers for each port start. Other structures are also defined for registers related to functions other than GPIO.

3.7.2. Fields are Registers

For each instance of a structure, such as LPC_GPIO0, you can access a register by accessing the corresponding field in that structure instance. For example, the three registers used in Experiment 1 are defined in the aforementioned LPC_GPIO_TypeDef structure as the following fields:

1. FIODIR
2. FIOSET
3. FIOCLR

Each of these registers is accessible within the structure instance of each port.

Therefore, when using CMSIS, you need to know two names to access a register:

1. The name of the pointer to the structure instance.
2. The name of the field within the structure, corresponding to the desired register.

Example 3. Setting Pin Directions and Values

- To set the direction of pins 3,4, 5, and 6 in port 2 as output (and set the remaining pins as input):

```
LPC_GPIO2->FIODIR = 0x00000078;
```

- To set pins 3 and 7 in port 1 while keeping the rest of the pins unchanged, use:

```
LPC_GPIO1->FIOSET = 0x00000088;
```

Again, to learn more about structures and pointers in the *C programming language*, refer to the Data Structures in C document.

3.8. LEDs

- What is an LED?
- How does an LED work?
- What is the maximum voltage that an LED can tolerate?
- If the output voltage is higher than the LED maximum voltage, what should you do?

An LED should be connected to an output GPIO pin.

GPIO, Revisited

The GPIO mode is available in all I/O pins. A GPIO pin is one that can be used as a digital input or digital output. Obviously, you need to choose the direction of the pin to determine whether it is going to be used as input or output. In this experiment, we will choose the direction to make the required pin work as GPO (General-Purpose Output). In this case (GPO), you need a command to set this output pin to HIGH (1), and a command to Clear it to LOW (0).

A `0` in a *SET* or a *CLR* register has no effect on the port pins!

A basic way to add *delay* is to use a `for` loop, e.g.: `for(i=0;i<500000;i++);`. You will learn about more sophisticated and accurate ways in later experiments.

4. Tasks

4.1. Create a Non-CMSIS Project

1. Click *Quickstart Panel* > *New project…*.
2. Choose *LPC13 / LPC15 / LPC17 / LPC18* > *LPC175x_6x* > *C Project*.
3. Choose a project name, e.g. `blinky`.

4. In the *Target selection* dialog, choose *LPC1700* > *LPC1768*.
5. In the *CMSIS Library Project Selection* dialog, set *CMSIS Core library to link project to* to `None`.
6. In the *CMSIS DSP Library Project Selection* dialog, set *CMSIS DSP Library to link project to* to `None`.
7. Uncheck *Enable linker support for CRP*, then click *Finish*.
8. Open the main source file named after the project, and write your `main` function.

4.2. Blink an LED without CMSIS

1. Figure out which pin is connected to the LED.

   Refer to the LPC1768 board documentation.

2. Give the required registers some friendly names using the `#define` directive.
3. In an infinite loop inside the `main` function:
   a. Set the pin to act as output by setting the correct bit in the direction register to `1`.
   b. Set the output pin to `1`.
   c. Clear the output pin (set to `0`).
   d. Insert a delay loop after both set and clear, to be able to see the LED blink.
4. Which value of the pin turns the LED on, and which value turns it off? and why?

4.3. Import the CMSIS Libraries

1. Click *Quickstart Panel* > *Import project(s)*
2. In the *Project archive (zip)* dialog, click *Browse* next to the *Archive* field, and choose:

```
C:\nxp\MCUXpressoIDE_<version>\ide\plugins\com.nxp.mcuxpresso.tools.wizards_<version>\Examples\L
egacy\CMSIS_CORE\CMSIS_CORE_Latest.zip
```

3. Keep only these two projects selected: `CMSIS_CORE_LPC17xx` and `CMSIS_DSPLIB_CM3`, and click *Finish*.

4.4. Create a CMSIS Project

To create a project that uses CMSIS, follow the same instructions for creating a non-CMSIS project up to the *CMSIS Library Project Selection* dialog. Instead of `None`, select `CMSIS_CORE_LPC17xx`.

4.5. Blink an LED Using CMSIS

Using a CMSIS project, rewrite your LED blinking program to use CMSIS facilities.

4.6. Debug Your Project

1. Click *Quickstart Panel* > *Build 'cmsis_blinky' [Debug]* to build the project.
2. Connect the LPC1768 board to the PC using the USB cable.
3. Click *Quickstart Panel* > *Debug 'cmsis_blinky' [Debug]* to debug the project interactively on the target board.

Running the Debugger

You can run the debugger using any of the following three ways:

1. In the *Quickstart Panel* at the lower left corner, click *Debug '<project-name>' [Debug]*.
2. In the main menu, choose *Run* > *Debug As* > *C/C++ (NXP Semiconductors) MCU Application*.
3. In the toolbar, click on the debug button .

You may need to download and install mbedWinSerial application if you cannot find the target board.

1. Once the debugger starts, it will pause execution at the first statement in the progrm. Resume execution by hitting the `F8` key, or using the resume button in the toolbar .

5. Grading Sheet

Task	Points
Blink an LED without CMSIS	4
Blink an LED using CMSIS	4
Debug your project	2

Resources

- [lpc1768-data-sheet]

  NXP Semiconductors. *LPC1769/68/67/66/65/64/63 — Product data sheet*. Rev. 9.10. 8 September 2020. https://www.nxp.com/docs/en/data-sheet/LPC1769_68_67_66_65_64_63.pdf

- [lpc1768-manual]

  NXP Semiconductors. *UM10360 — LPC176x/5x User Manual*. Rev. 3.1. 4 April 2014. https://www.waveshare.com/w/upload/0/07/LPC176x5x_User_manual_EN.pdf

- [lpc1768-schematic]

  Embedded Artists AB. _Board Schematics for current LPC1768 board — LPCXpresso LPC1768 25 July 2011. https://os.mbed.com/media/uploads/chris/lpc1768-refdesign-schematic.pdf

- [c-data-structures]

  Data Structures in C. http://www.ccse.kfupm.edu.sa/~salehs/courses/212-coe306/html/data-structures-in-c.html