Experiment 1
Development Platform

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1. Objectives

- Get familiar with the development platform:

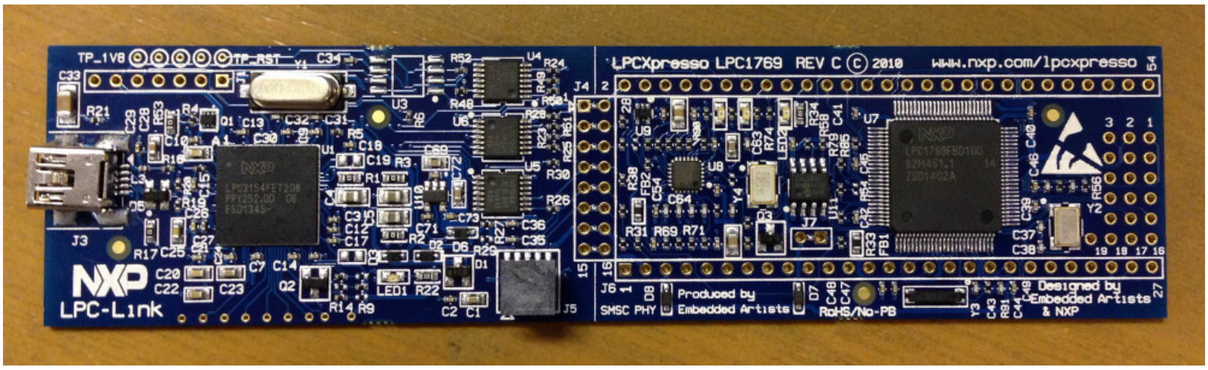
  Hardware
  : microcontroller, development board, peripherals

  Software
  : IDE, compiler, debugging, programming

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

2. Parts List

- LPC1769 LPCXpresso board



- USB A-Type to Mini-B cable

3. Background

3.1. Microcontroller

LPC1769 is a microcontroller manufactured by NXP. LPC1769 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 LPC1769 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 LPC1769 microcontroller [lpc1769-data-sheet] and the more detailed user munual [lpc1769-manual] are essential resources for any developer.

3.2. Development Board

The LPC1769 microcontroller chip is used to build the *LPC1769 LPCXpresso board*, which we will be using in this LAB.

The LPCXpresso board consists of two parts:

1. LPCXpresso target board, which hosts the LPC1769 microcontroller
2. LPC-Link: a debug probe for debugging and the target microcontroller.

3.3. LPCXpresso IDE

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

The LPCXpresso 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.

The LPCXpresso IDE is available in two editions:

- Free edition: requires free activation (details below). Supports code sizes up to 256 kB after activation.
- Pro edition: per-seat licensing fees. Supports unlimited code size.

3.3.1. Installation

To install your copy of the LPCXpresso IDE:

1. Using a web browser, navigate to the LPC Microcontroller Utilities page, then follow the LPCXpresso IDE link.
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.

3.3.2. Activation

To activate your copy of the LPCXpresso IDE:

1. Using a web browser, log into the activation web page:
   https://lpcxpresso-activation.nxp.com/registerapp.html

   Register a new account if you do not have one.

2. Follow the instructions on that page to find and submit your LPCXpresso IDE serial number, and to obtain and use your activation code.

For more information on installing and using the LPCXpresso IDE, see [lpcxpresso-ide-user-guide].

3.4. Input/Output Ports

The LPC1769 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, leaving only 28 pins of port 0 available for the user.

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.

3.4.1. Pin Layout

The pin layout of the LPC1769 LPCXpresso board is shown in the LPC1769 pin layout figure below (source: [lpc1769-schematic], page 7).

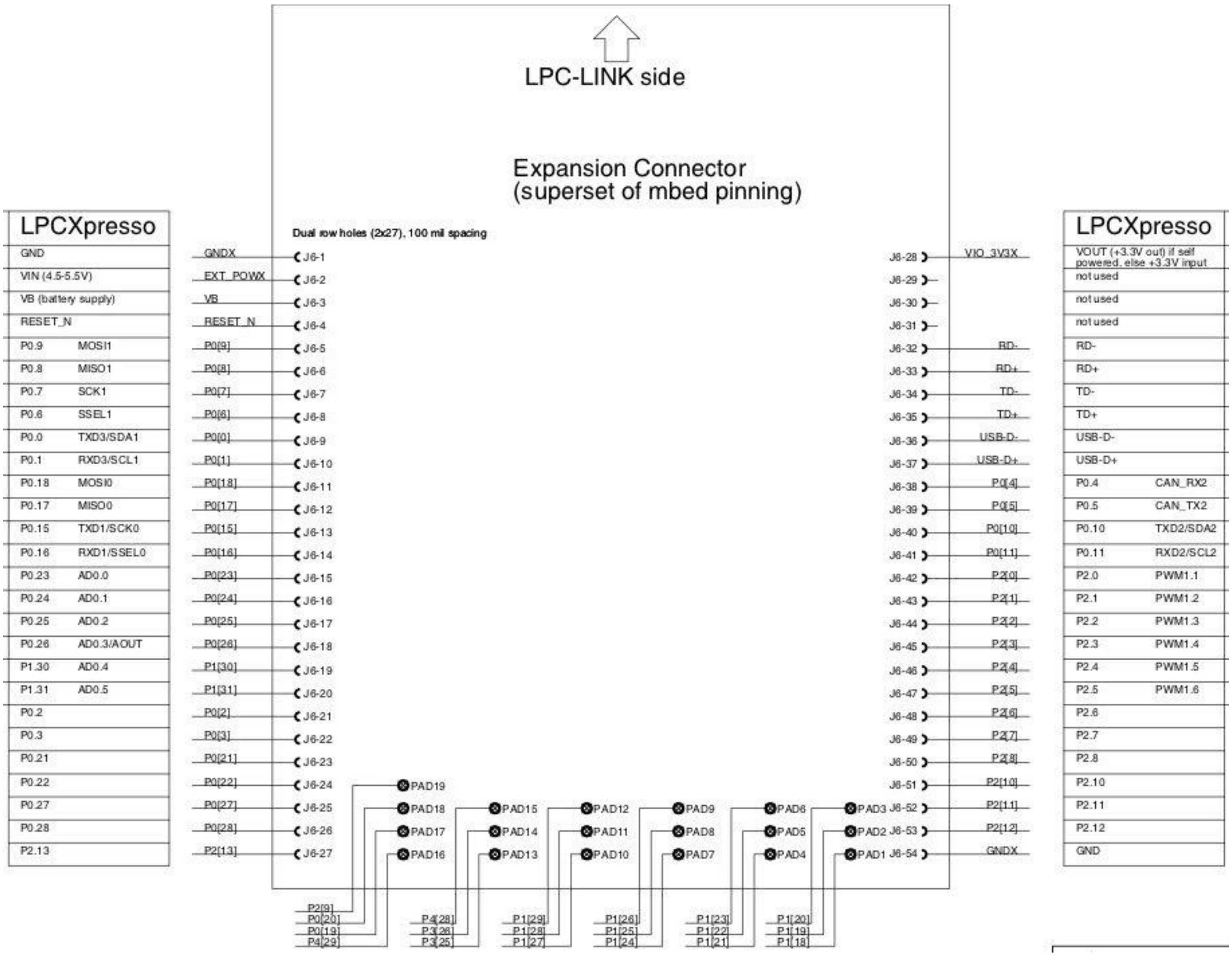


Figure 1. LPC1769 pin layout

3.4.2. 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.

3.4.3. 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.

3.4.4. 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 three examples showing how to assign names to registers:

```
#define DIR_P0  (*((volatile unsigned long *) 0x2009c000))
#define SET_P0  (*((volatile unsigned long *) 0x2009c018))
#define CLR_P0  (*((volatile unsigned long *) 0x2009c01c))
```

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 three registers!

In the first experiment, you can avoid making any external connections by using the on board LED, which is connected to `P0.22`.

3.5. 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 [cmsis-intro].

The most relevant component to us is CMSIS-CORE [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 [lpcx-cmsis].

3.6. 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.

3.6.1. 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.

3.6.2. 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, 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.

3.7. 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* > *LPC1769*.
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 LPC1769 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\LPCXpresso_<version>\lpcxpresso\Examples\NXP\LPC1000\LPC17xx\LPC17xx_LatestCMSIS_Librarie
s.zip
```

3. Keep both 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 LPC1769 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 .

4. 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. Resources

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NXP Semiconductors. *LPC1769/68/67/66/65/64/63 — Product data sheet*. Rev. 9.5. 24 June 2014. http://www.nxp.com/documents/data_sheet/LPC1769_68_67_66_65_64_63.pdf

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NXP Semiconductors. *UM10360 — LPC176x/5x User Manual*. Rev. 4.1. 19 December 2016.
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http://www.nxp.com/assets/documents/data/en/user-guides/LPCXpresso_IDE_User_Guide.pdf

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http://www.embeddedartists.com/sites/default/files/docs/schematics/LPCXpressoLPC1769revB.pdf

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Data Structures in C.
http://www.ccse.kfupm.edu.sa/~akhayyat/files/coe306-162/lab-manual/data-structures-in-c.html

6. Grading Sheet

Task	**Points**
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