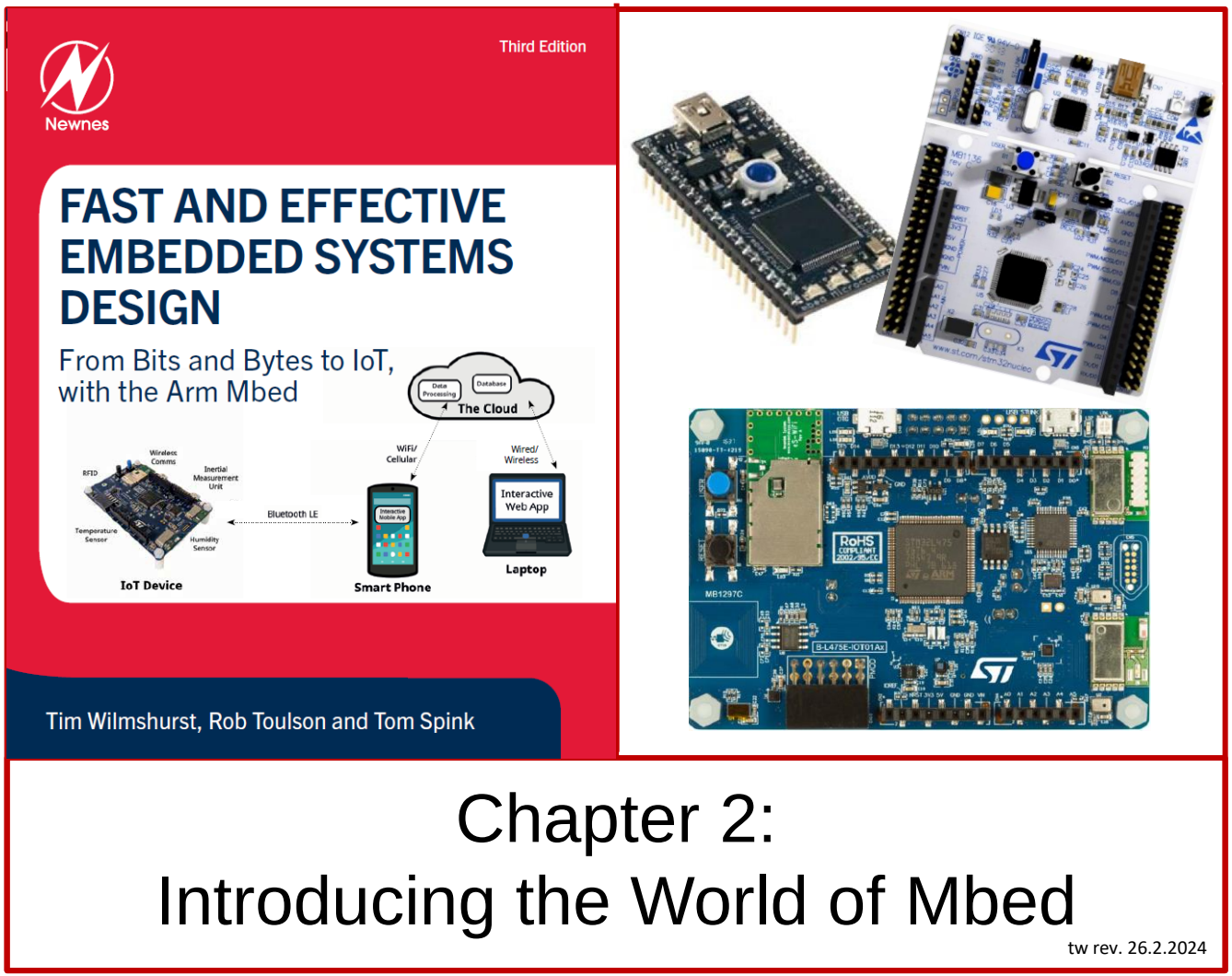


Chapter 2: Introducing the World of Mbed

tw rev. 26.2.2024

If you use or reference these slides or the associated textbook, please cite the original authors' work as follows:

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www.embedded-knowhow.co.uk

The Mbed “Eco-system”

The Mbed “eco-system” provides an embedded system development environment comprising:

- A free Operating System (OS) and Integrated Development Environment,
- A wide range of compatible development boards,
- Numerous code examples,
- An IoT orientation.



For this book we choose three example development boards:

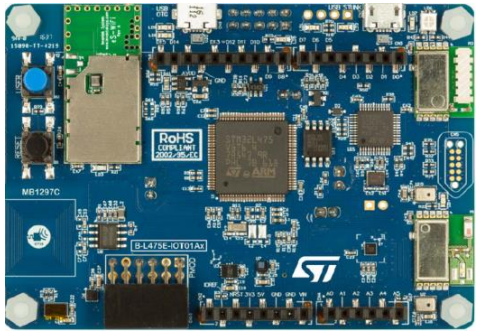
- the Mbed LPC1768,
- the STM42F401RE Nucleo-64 Development Board;
- the STM32 IoT Discovery Kit.



Mbed

Rapid IoT device development

Mbed gives you a free open source IoT operating system with connectivity, security, storage, device management and machine learning. Build your next product with free development tools, thousands of code examples and support for hundreds of microcontroller development boards.

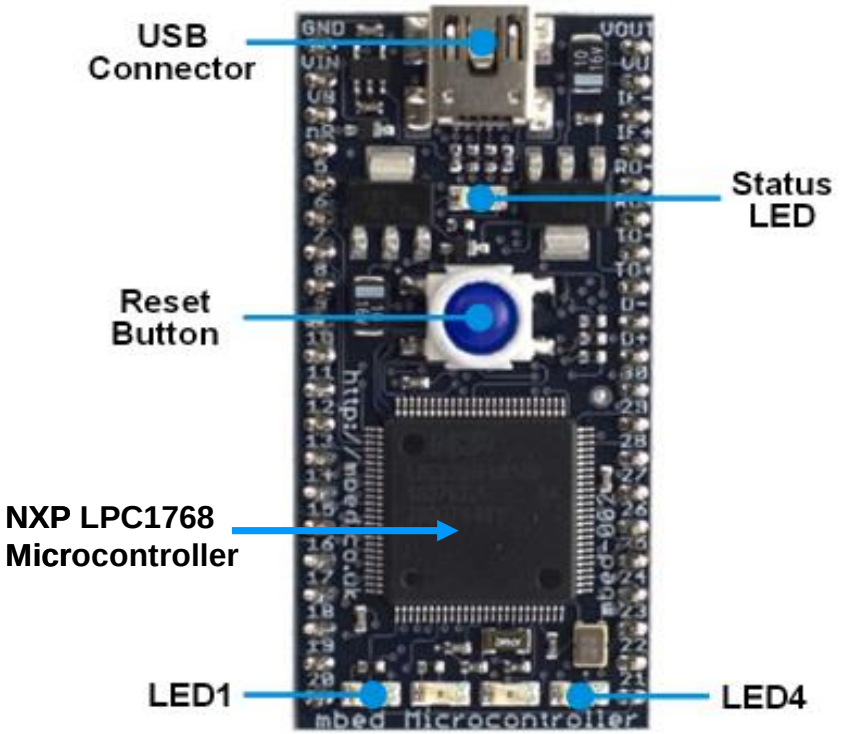


https://os.mbed.com/

Introducing the Mbed LPC1768

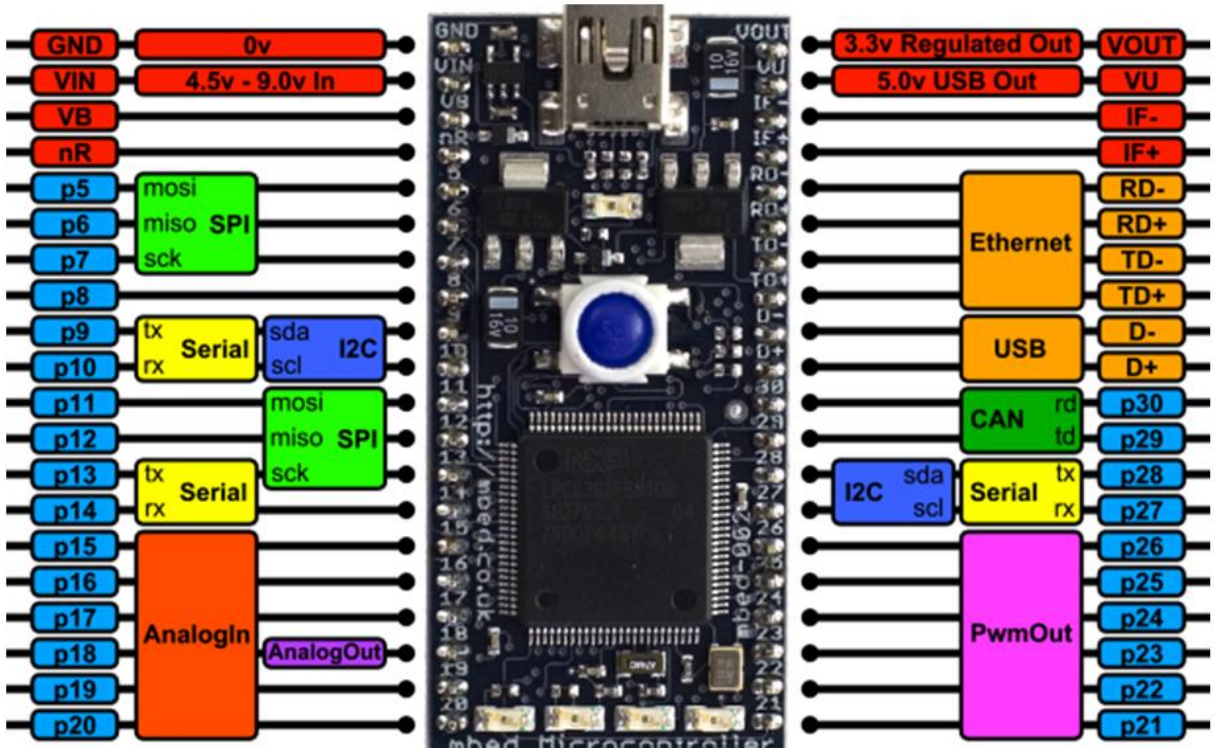
This, the first of all “Mbed Enabled” devices, takes the LPC1768 microcontroller, and surrounds it with some very useful support circuitry. It places this on a conveniently-sized little printed circuit board (PCB).





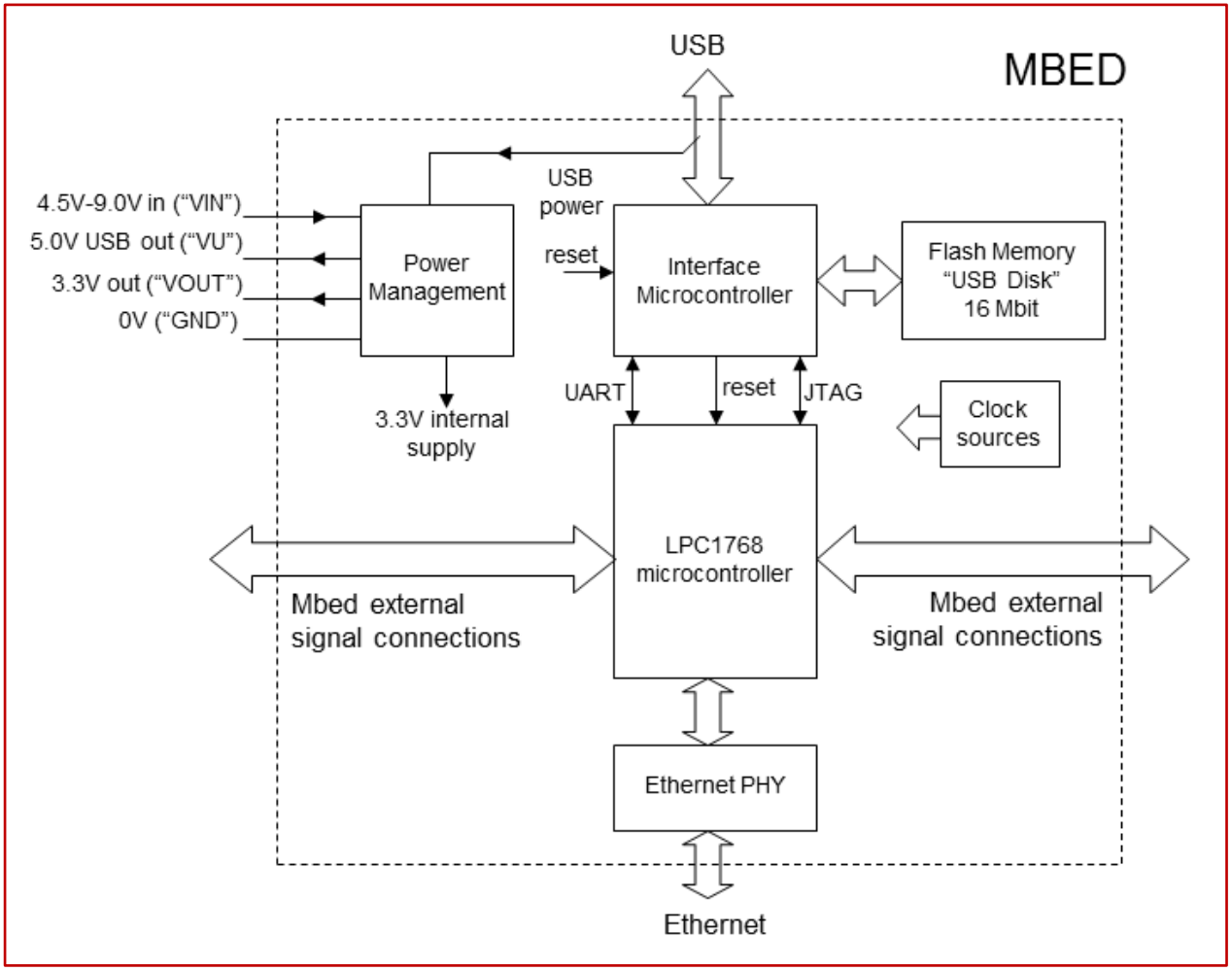
Introducing the Mbed LPC1768

The Mbed LPC1768 takes the form of a 2 inch by 1 inch printed circuit board, with 40 pins arranged in two rows of 20, with 0.1 inch spacing between the pins. There are five LEDs on the board, one for status and four which are connected to four microcontroller digital outputs. A reset switch is included, to force restart of the current program.



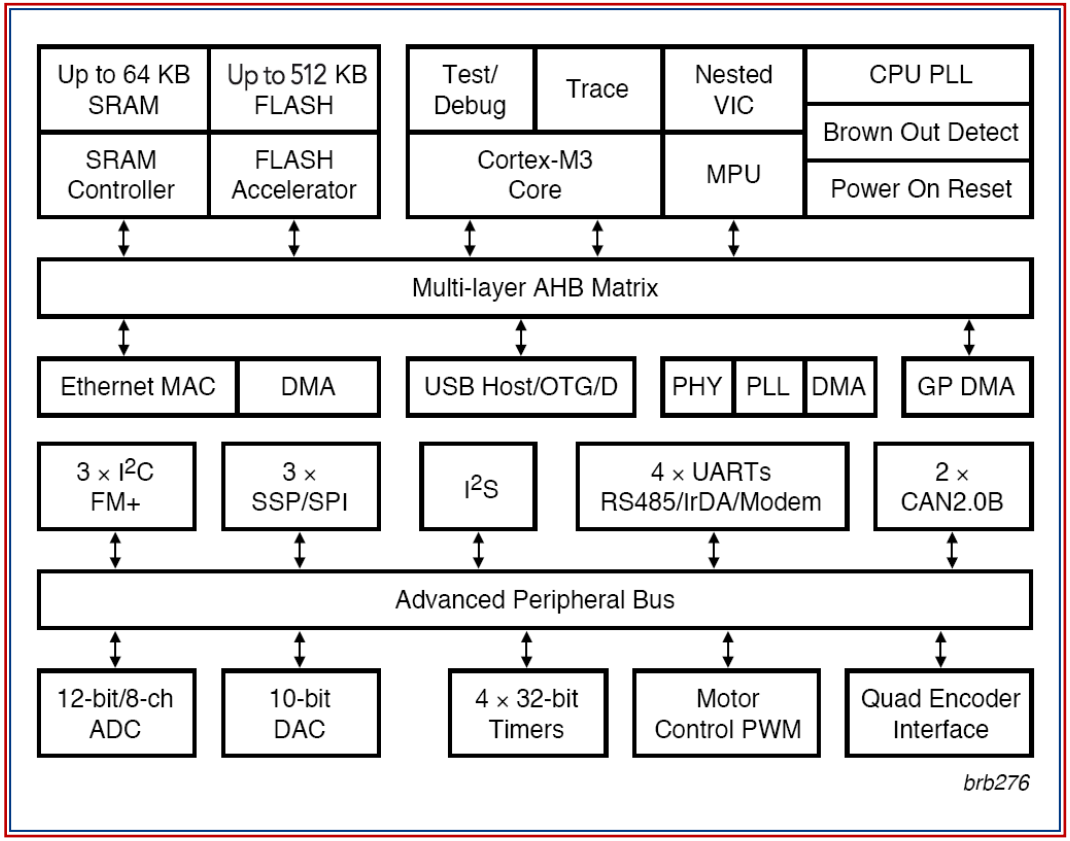
The Mbed LPC1768 Architecture

At the heart is the LPC1768 microcontroller. The signal pins of this Mbed connect directly to the microcontroller. There is a second microcontroller (the “interface microcontroller”), which interfaces with the USB connector. This manages the USB link, and acts as a USB terminal to the host computer. It also receives program code files through the USB, and transfers them to a 16 Mbit memory, the “USB Disk”.



The LPC1768 Microcontroller

This figure is complex, and we don't want to get into all its details. However, it contains the main capability of the Mbed board, so it's worth getting a feel for its features, remembering that a microcontroller is made up of microprocessor core *plus* memory *plus* peripherals.



Key

ADC:	Analog-to-Digital Converter	MAC:	Media Access Control
AHB:	Advanced High-performance Bus	MPU:	Memory Protection Unit
CPU:	Central Processing Unit	PHY:	Physical Layer
D:	Device (USB)	PLL:	Phase Locked Loop
DAC:	Digital-to-Analog Converter	OTG:	On-the-go (USB)
DMA:	Direct Memory Access	SPI:	Serial Peripheral Interface
FM+:	Fast-mode Plus (I2C)	SRAM:	Static RAM
GP:	General Purpose (DMA)	SSP:	Synchronous Serial Port
I²C:	Inter Integrated Circuit	UART:	Universal Asynchronous Receiver/Transmitter
I²S:	Inter Integrated Circuit Sound	VIC:	Vectored Interrupt Controller
IrDA:	Infrared Data Association		

Notes: The LPC1768 has 64 KB of Static RAM, and 512 KB of Flash
The Cortex core is made up of those items enclosed within the dashed line
See also key to Figure 2.1
Reproduced from: mbed NXP LPC1768 prototyping board. 2009. NXP B.V. Document no. 9397 750 16802

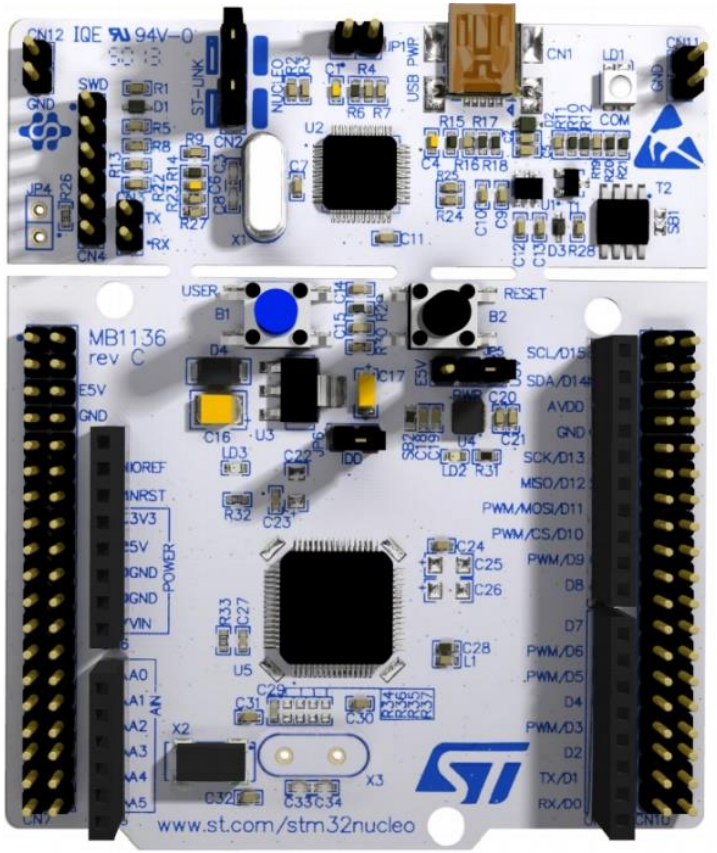
Nucleo, and the F401RE Development Board

This board, made by ST Microelectronics, was produced much later than the original Mbed LPC1768. It has less on-board capability, but is cheaper.

The F401RE is one of a family of similar boards, each based on a different microcontroller in the STM32 family, with each board hence reflecting those microcontroller features.

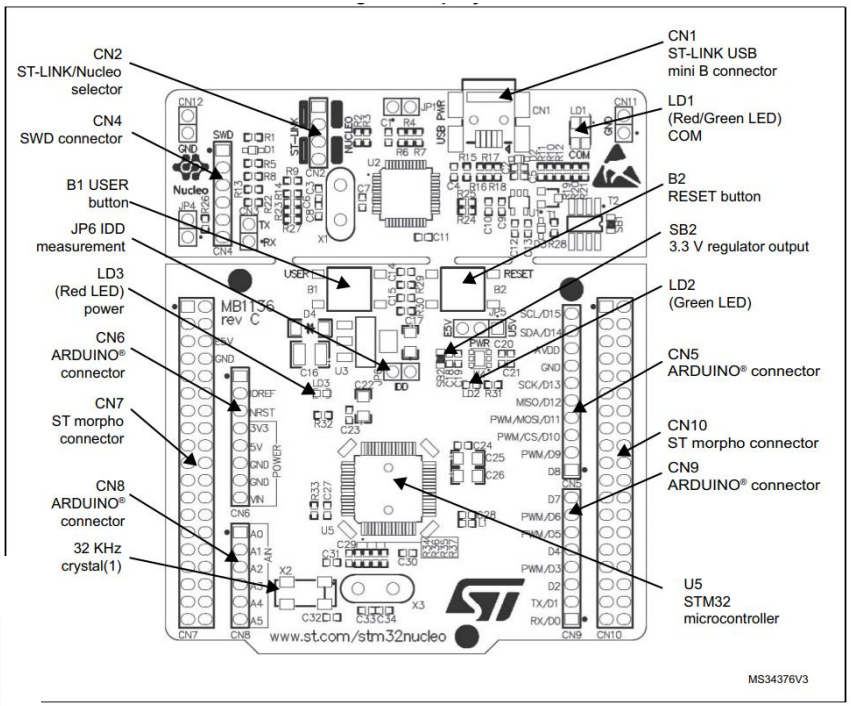
The board is based on the 64-pin version of the STM 32F401RE 32-bit microcontroller, with its Cortex-M4 core.

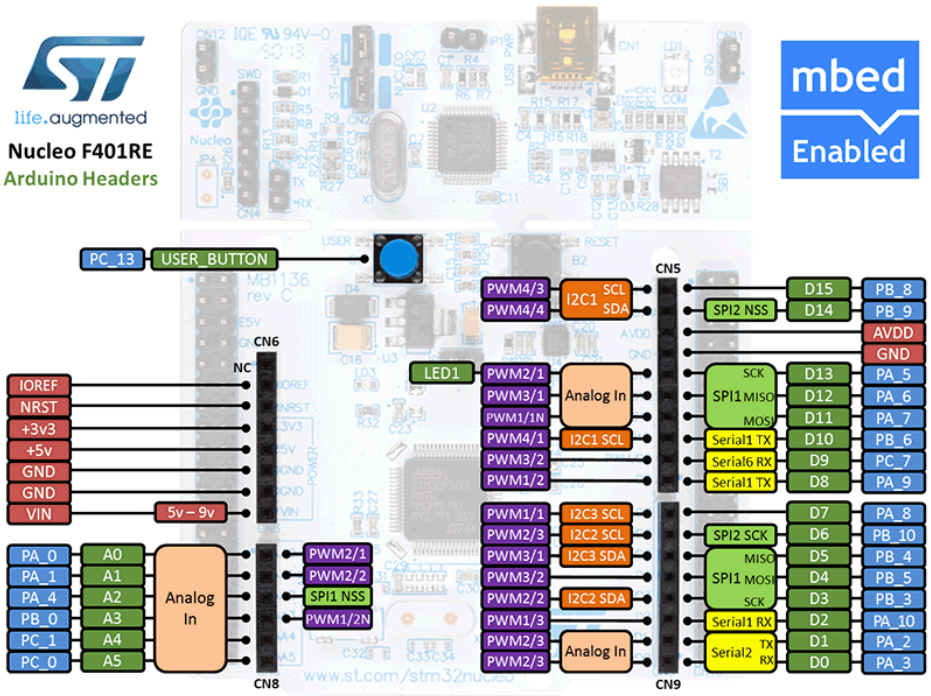
The printed circuit board (PCB) is perforated, with interface circuitry on an upper sub-board - which can be broken off if no longer needed - and the main circuit on a lower, larger one.



Nucleo, and the F401RE Development Board

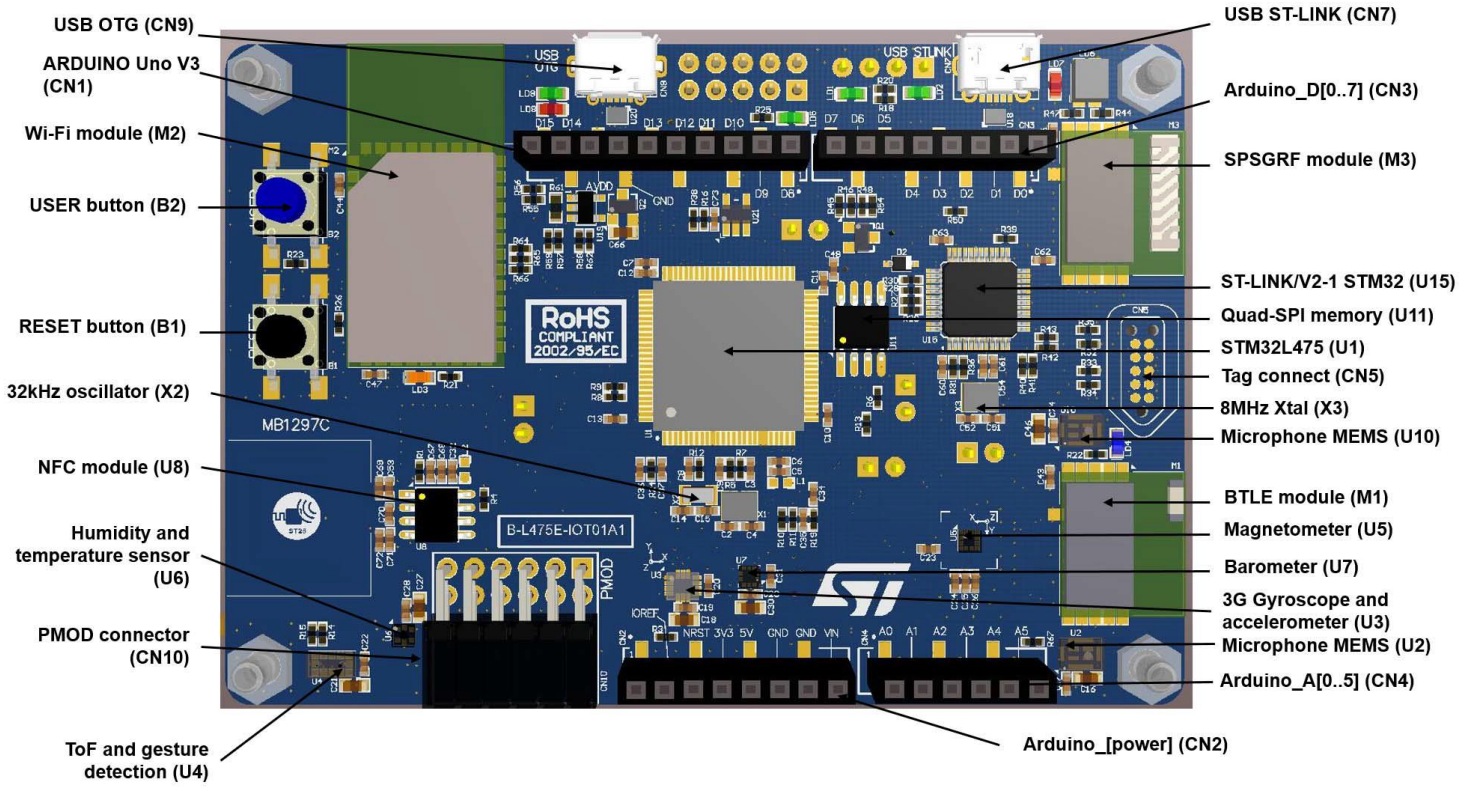
The board has the features shown, including two main sets of connectors. One set (CN5, CN6, CN8, CN9) allows direct connection to Arduino expansion boards, while the other (CN7 and CN10) provides more complete interface capability. Labelling of the interconnect pins is compatible with the Mbed OS.





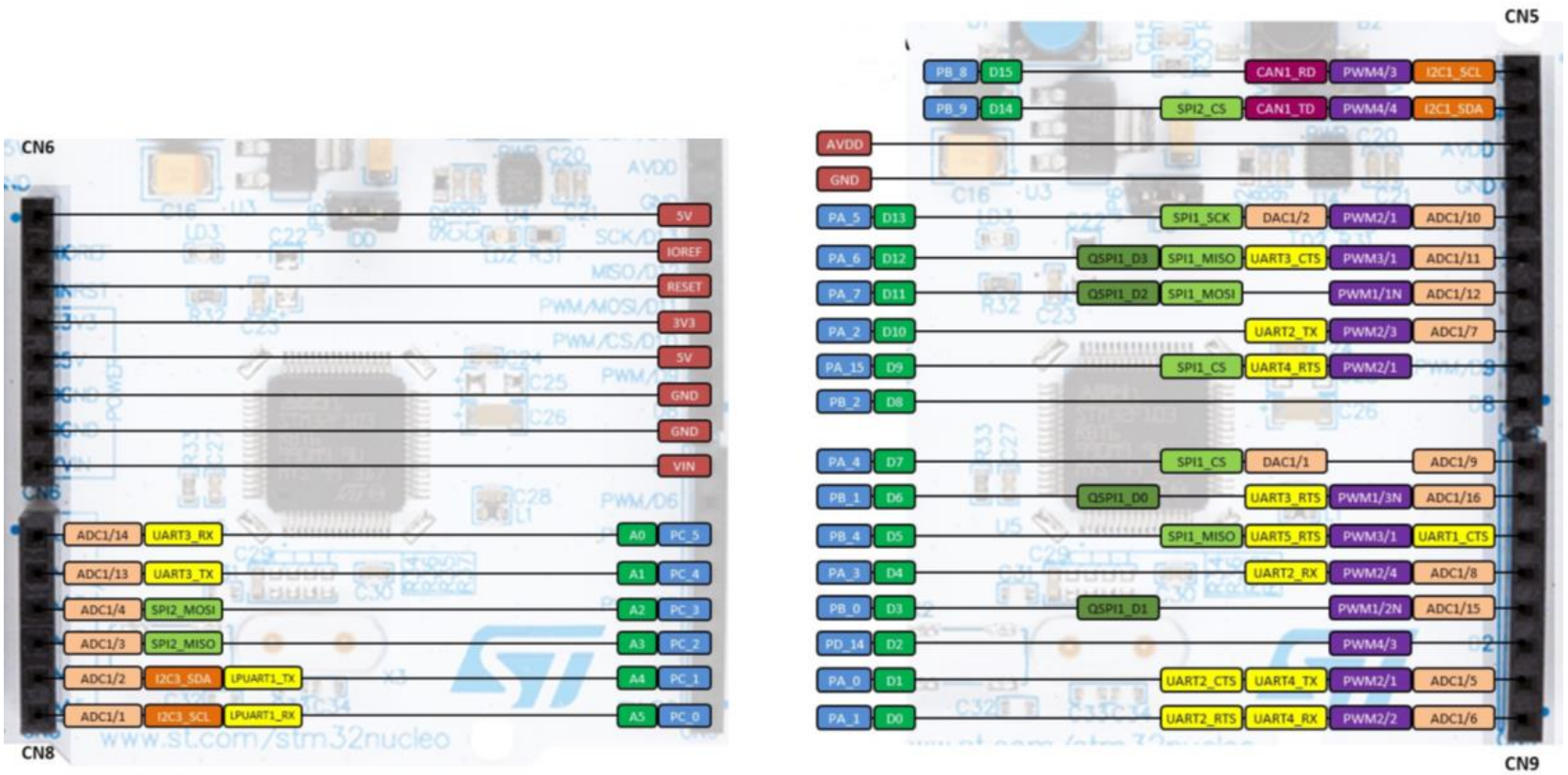
The STM32 IoT Discovery Kit IoT

- This kit provides a sophisticated combination of networked sensors and wireless connectivity. It is based on the STM32L475 microcontroller, containing an Arm Cortex-4 core.
- Sensors include accelerometer, barometer, humidity, microphone, temperature and time-of-flight.
- Wireless connectivity includes Bluetooth low energy, Wi-fi, and Sub GHz RF.



The STM32 IoT Discovery Kit IoT

A set of Arduino-compatible connectors allows external connection. Labelling of the interconnect pins is compatible with the Mbed OS.



The Mbed API

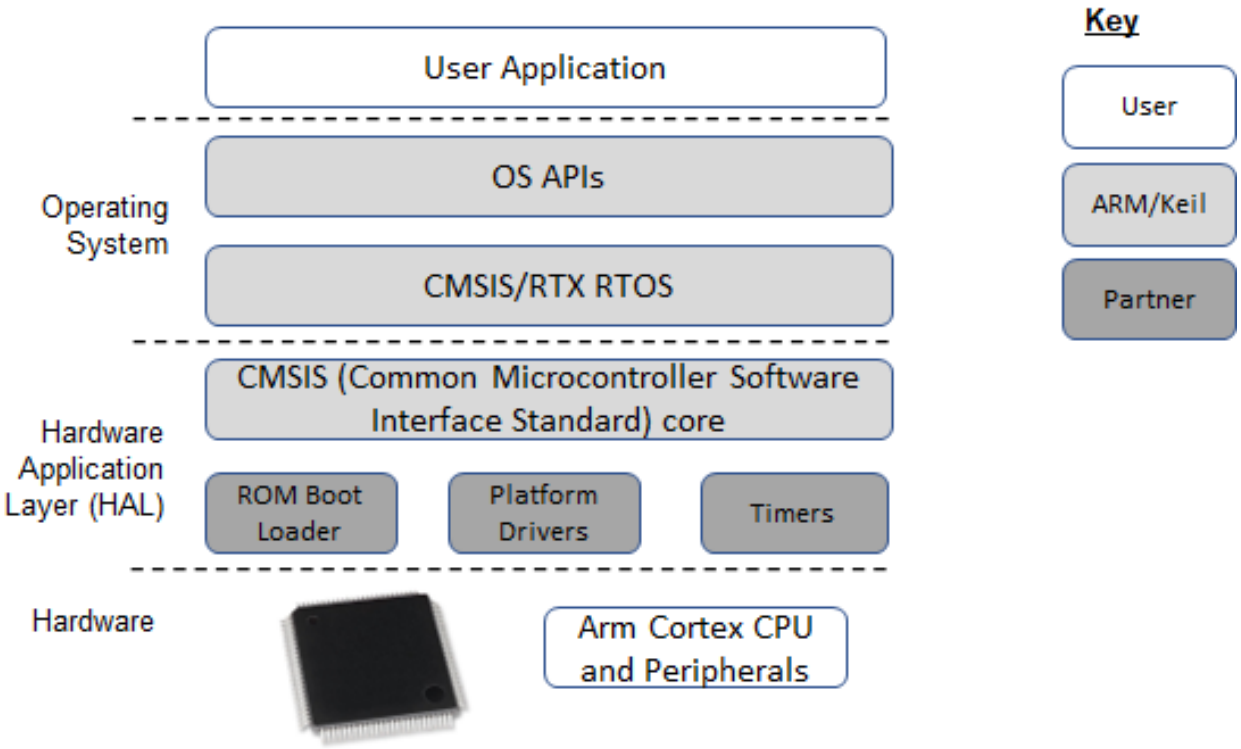
The Application Programming Interface (API) is a set of code building blocks, summarised below, which allow programs to be devised quickly and reliably. These exist for the main features of the Mbed enabled target boards, as well as for external devices.

API Category and Group	Summary
Scheduling	**Contains the main features of the RTOS.**
RTOS	The main RTOS features, of threads, mutex, semaphores, and queues.
Event handling	Configures events and related timing.
Drivers	**Driver APIs for main inputs and outputs of the target platform.**
Serial (UART) drivers	Creates and operates Universal Asynchronous Receive/Transmit nodes.
SPI drivers	Creates and operates master and slave Serial Peripheral Interface nodes.
Input/Output drivers	Creates and operates analog and digital inputs and outputs, interrupt inputs, and pulse width modulation (PWM) outputs.
USB drivers	Creates and operates Universal Serial Bus utilities.
Other drivers	Creates and operates CAN (Controller Area Network), I2C (Inter Integrated Circuit) serial interfaces, and Watchdog Timer.
Platform	**Contains microcontroller management features, may need to be adapted to the particular target.**
Time	Creates and operates a range of timing facilities, including Timer, Ticker, Timeout, and RTC (Real Time Clock).
Power	Provides power management and facilitates low power consumption.
Memory	Manages microcontroller memory.
Other Platform APIs	A range of platform-specific APIs, including debug and error handling.
Data Storage	**APIs to manage data file systems**
File system APIs	Includes management of directory, file, FAT (File Allocation Table) files, Block devices, SD cards.
Connectivity	**APIs to provide connectivity through different network protocols, examples appear below, others are available.**
Network Interface	APIs to support internet connectivity, including for Ethernet and Wi-Fi.
Bluetooth	APIs to support Bluetooth connectivity
Security	**APIs to provide security, e.g. for IoT systems.**

The Mbed Operating System

The Mbed OS is shown in simplified form. At the bottom is the microcontroller hardware itself, at the top is the user-written code. Above the hardware is the Hardware Application Layer (HAL), which interfaces directly with target hardware. This code may be contributed by the hardware manufacturer.

The Common Microcontroller Software Interface Standard (CMSIS), contributed by Arm, acts as a standard interface between Cortex cores, and the upper levels. CMSIS merges with RTX, the RTOS (Real Time Operating System) created by the software company Keil (now owned by Arm).

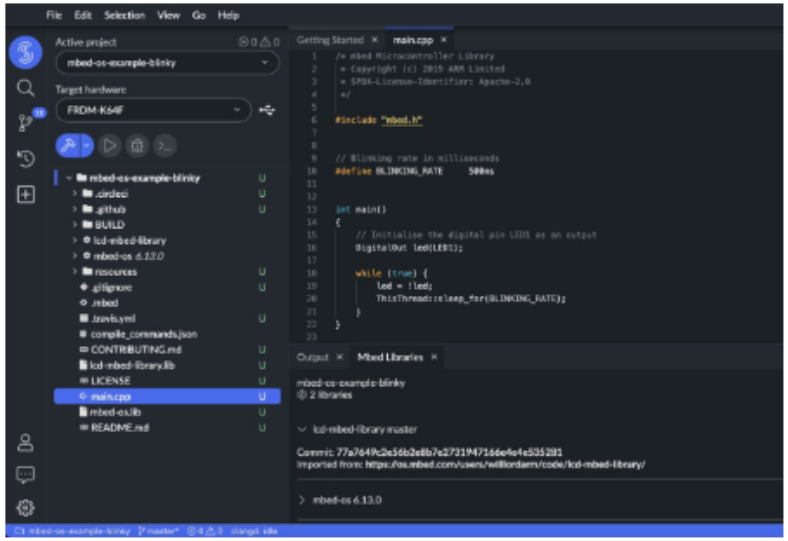


The Studio Development Environments

There are two closely related IDEs available for use for Mbed development. Both are free.

Keil Studio Cloud

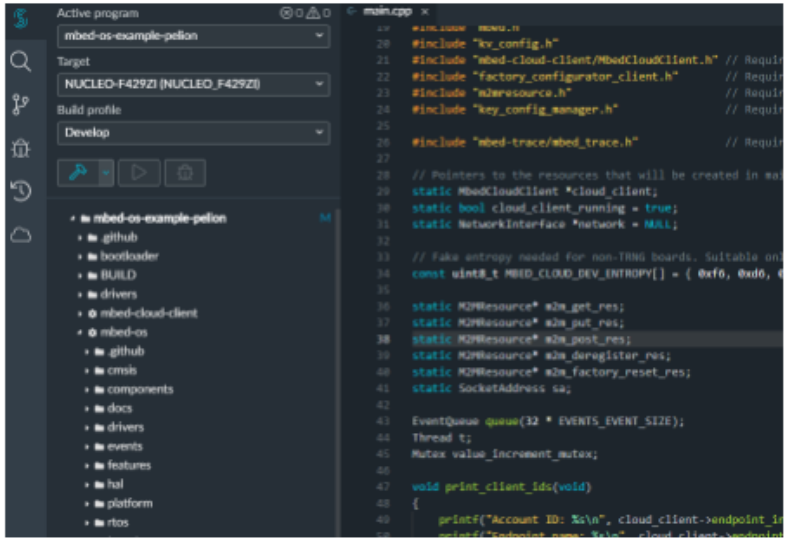
The easiest way to get started.



A modern, zero-installation Mbed development environment in your browser, with code highlighting, WebUSB flash and debug and version control. Create an account to get started.

Mbed Studio

The desktop IDE for Mbed OS.

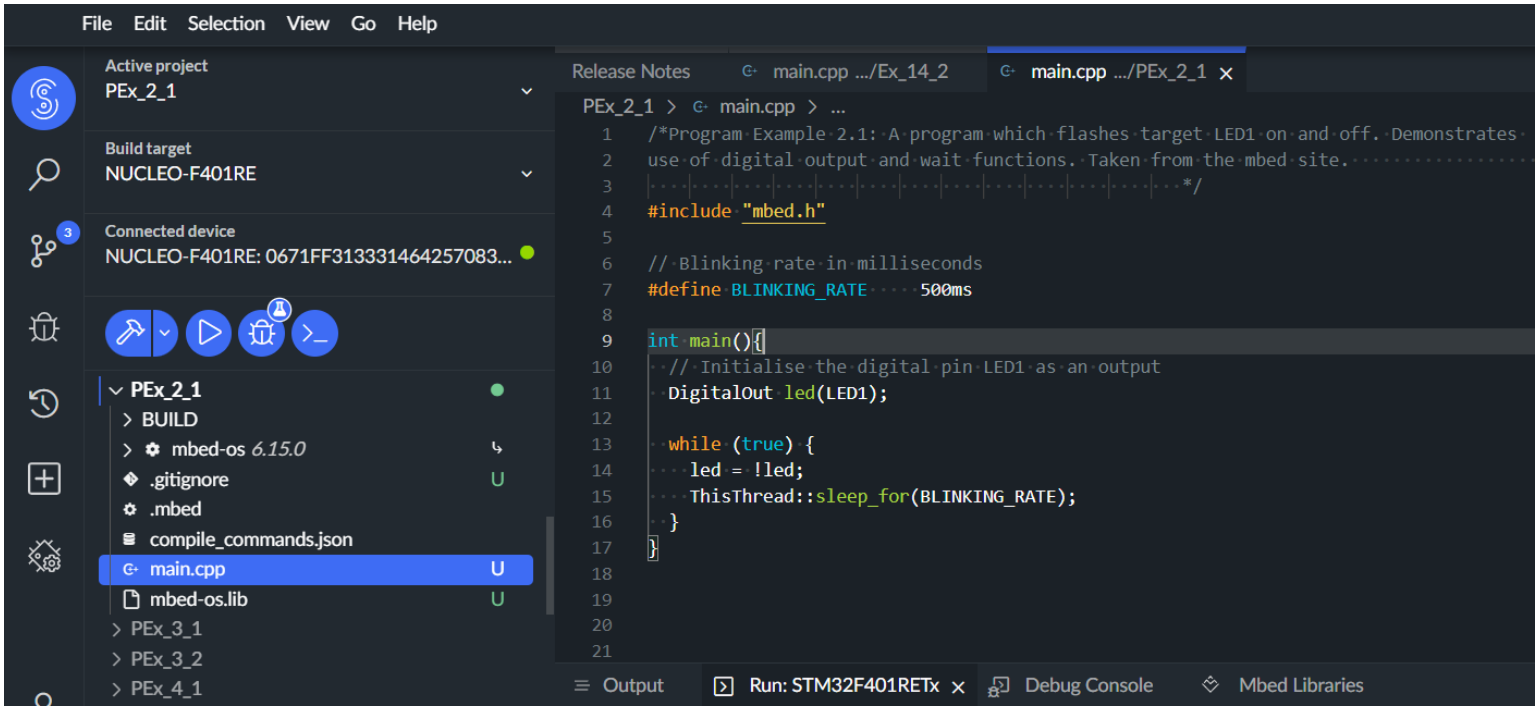


Mbed Studio is an IDE for application and library development. A single environment with everything you need to create, compile and debug your Mbed programs.

https://os.mbed.com/

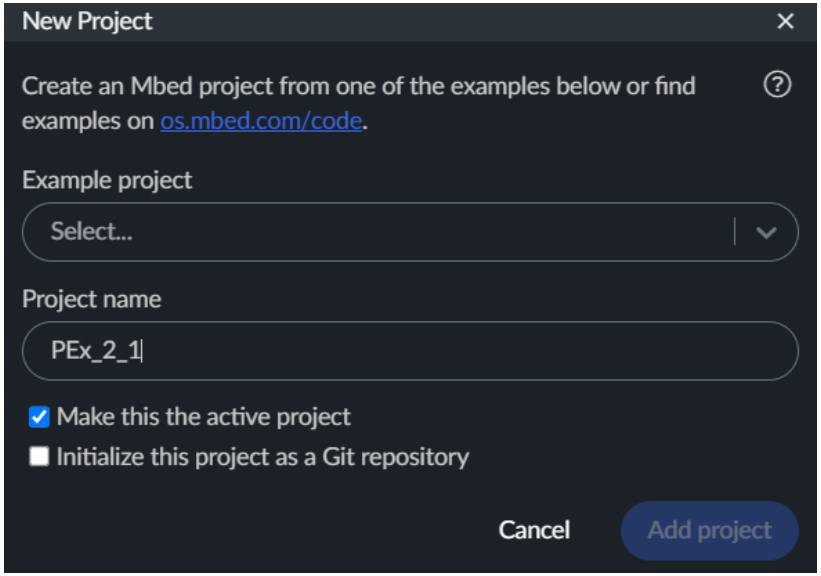
Getting Started Keil Studio Cloud

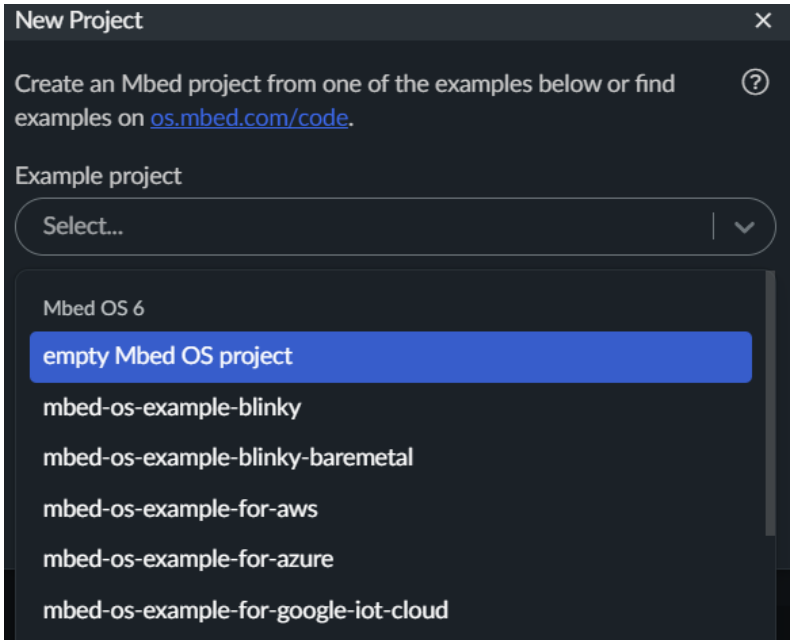
A typical Studio Cloud screen setup, with a program already active, is shown. Notice the display of Active Project, Build Target, and Connected Device, towards the top left of the screen. The important control buttons of Build (hammer), Run (arrowhead), Debug (the bug!) and Serial Monitor lie immediately below this. These are illuminated blue when there is an active program, and a recognised target system has been connected and selected. Available files and folders are listed below left. Program source code is shown opposite. Across the top of the screen are the familiar tabs of File, Edit, View, Help and so on.



Getting Started Keil Studio Cloud

To develop a program, start with **File > New > Mbed Project**. You will be invited to select a program template, below left. Choices are shown below right; for your first program select **mbed-os-example-blinky**. Enter also your own program name (we have entered PEx_2_1, anticipating all the forthcoming Program Examples through the book). You can follow this selection process for just about all the C/C++ programs in the book.





Program Example 2.1, the Opening Program

```
#include "mbed.h"

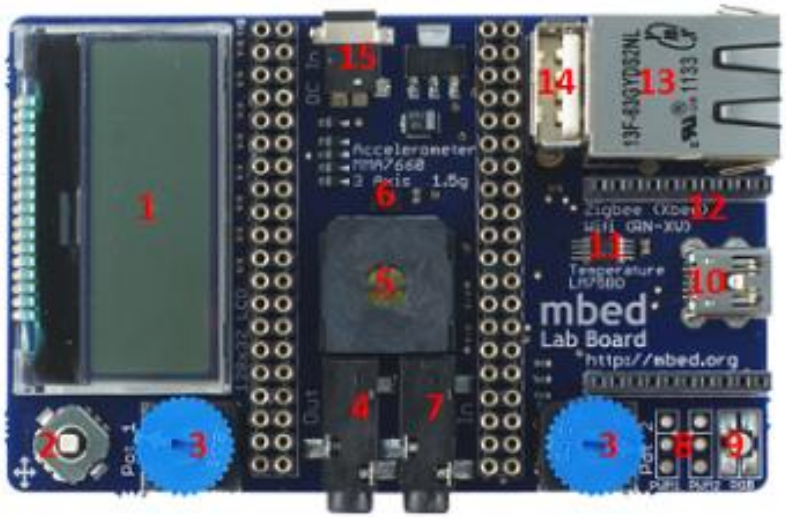
// Blinking rate in milliseconds
#define BLINKING_RATE     500ms

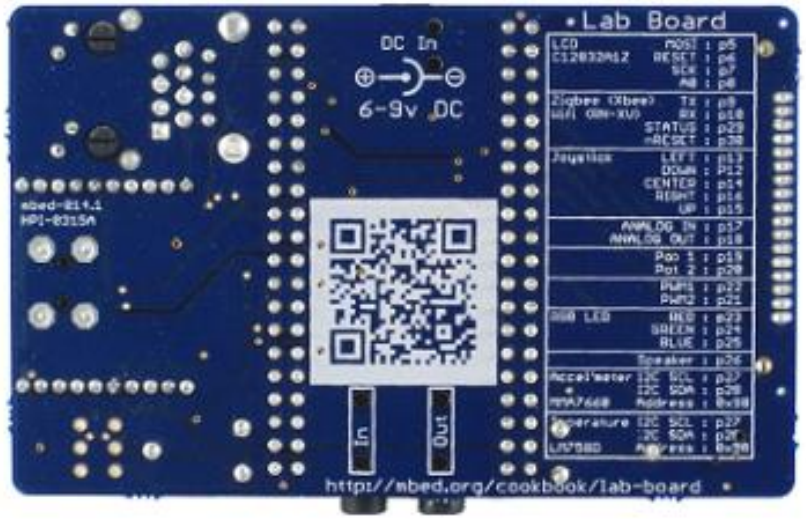
int main(){
  // Initialise the digital pin LED1 as an output
  DigitalOut led(LED1);

  while (true) {
    led = !led;
    ThisThread::sleep_for(BLINKING_RATE);
  }
}
```

The Mbed Application Board

This board has a number of the most interesting peripheral devices that we might want to connect to an Mbed target, like display, joystick, potentiometers, certain sensors and connectors. The Mbed LPC1768 plugs into the board, and a physical connection with all the peripheral devices is then immediately made. Other target boards can be wired across to the application board.





1. Graphics LCD (128x32)
2. 5 Way Joystick
3. 2 x Potentiometers
4. 3.5mm Audio Jack (Analog Out)
5. Speaker, PWM Connected
6. 3 Axis +/1 1.5g Accelerometer
7. 3.5mm Audio Jack (Analog In)
8. 2 x Servo Motor Headers
9. RGB LED, PWM connected
10. USB-mini-B Connector
11. Temperature Sensor
12. Socket for Xbee (Zigbee) or RN-XV (Wifi)
13. RJ45 Ethernet Connector
14. USB-A Connector
15. 1.3mm DC Jack input

Chapter Review

- The Mbed ecosystem provides a complete environment for rapid development of embedded products.
- The Mbed LPC1768 and the Nucleo F401RE are compact, general-purpose Mbed enabled development platforms, each capable of working in the Mbed ecosystem.
- The STM32 Discovery Kit IoT node is a sophisticated Mbed enabled development platform, targeted towards the IoT environment.
- Communication to these development boards from a host computer is by USB cable; power can also be supplied through this link.
- Each development board above contains some on-board features which allow user interaction, and connectors to link with many of the on-board microcontroller pins.
- The development boards above are each based around a microcontroller containing an Arm Cortex core, either M3 or M4.
- The Mbed ecosystem includes an Operating System, which is built from the Application Programming Interface (API) and other elements.
- Mbed programs invoke the APIs, and may (but don’t have to) use the OS.
- Mbed Studio and Keil Studio Cloud are IDEs (Integrated Development Environments) that can be used to develop programs in the Mbed ecosystem.
- The Mbed application board contains a set of the popular peripheral devices.