

# Technical Workshop

## Academic High Altitude Conference

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Stratospheric Ballooning Association

June 23-24, 2014



# Outline

## 1 Getting Started

- What is mbed?
- mbed.org
- Nucleo Development Board

## 2 The Bare Minimum

## 3 Your First Program

## 4 Taking Control

## 5 Talking to mbed

## 6 Writing Modular Code

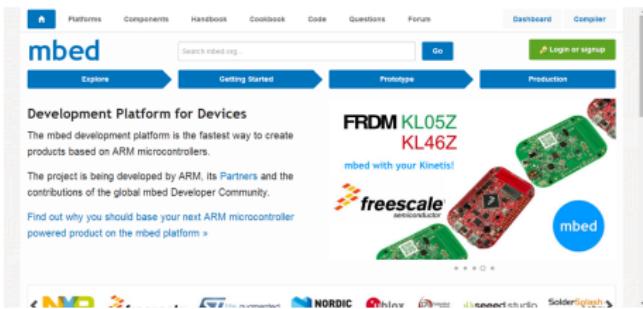
# What is mbed?

The mbed platform is a collection of open source hardware and software to allow rapid ARM based prototyping

- Professional online compiler lets you work from any computer
- Integrated version control system lets you easily find and use libraries
- CMSIS based APIs let you work high level or bare metal
- Hardware abstraction layer insulates your application from hardware changes

*Essentially a high performance Arduino with highly integrated tools to save you time!*

# Register on mbed



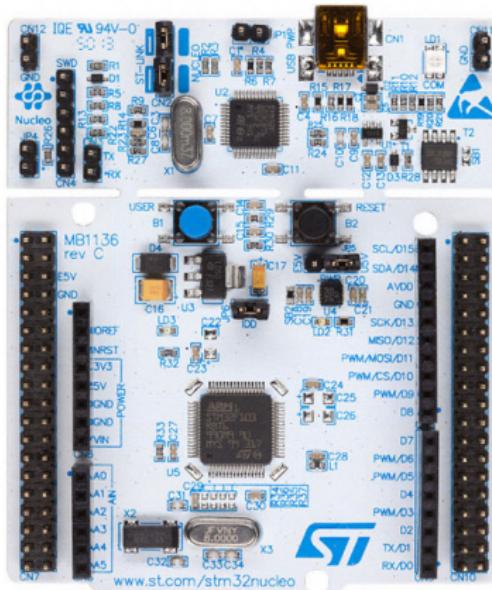
- ➊ Navigate to <http://www.mbed.org>
- ➋ Click the green "Login or signup" button
- ➌ Click the "Signup" button
- ➍ Follow the prompts
- ➎ Confirm your e-mail address

Everyone should have an mbed account. You can create a team to share code between members of your organization.

# Nucleo Development Board

The Nucleo development board combines a USB programmer with a powerful STM32 processor and Arduino compatible headers

- ARM Cortex-M4 with FPU at 84 MHz
- 512 KBytes of flash memory
- 12 bit ADC at 2.4 Msps with up to 10 channels
- Up 3xUART, 3xI2C, 4xSPI interfaces



# Add Nucleo to Your Account

The screenshot shows the mbed website interface. At the top, there are navigation links: Platforms, Components, Handbook, Cookbook, Code, Questions, Forum, Dashboard, and Compiler. A search bar with placeholder text "Search mbed.org" and a "Go" button are also present. On the right side, there is a "Login or signup" button. Below the header, the product page for the "ST Nucleo F401RE" is displayed. The page title is "ST Nucleo F401RE". It describes the board as a high-intensity platform for prototyping with an STM32F401RET6 microcontroller. A thumbnail image of the physical board is shown. A "Description" section provides more details about the board's connectivity and expansion options. To the right of the main content, there is a sidebar titled "Platform Partner" featuring the ST logo and the text "A world leader in providing the semiconductor solutions that make a positive contribution to people's lives, both today and in the future." Below this, there are two buttons: "Add to your mbed Compiler" and "Buy Now".

- ① Connect your Nucleo to your computer
- ② Open the external drive the connects
- ③ Double click the mbed.htm file
- ④ Click "Add to your mbed Compiler"

## Note

You only need to do this once per account!

# Install Drivers



# Outline

1 Getting Started

2 The Bare Minimum

- Creating a Program
- Importing a Library
- Program Structure
- Compiling

3 Your First Program

4 Taking Control

5 Talking to mbed

6 Writing Modular Code

# Creating a Program

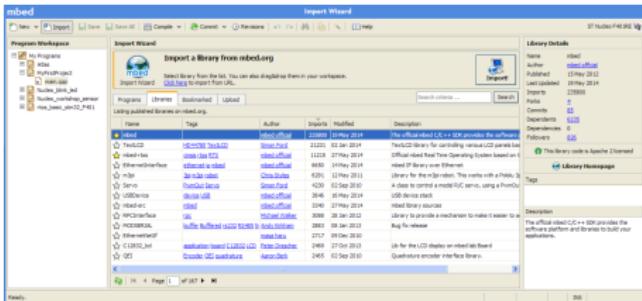
The image shows two screenshots of the mbed website. The top screenshot is the homepage, featuring the mbed logo, navigation links like Platforms, Components, Handbook, Cookbook, Code, Questions, Forum, Dashboard, and Compiler. It highlights the "STM32 Nucleo" development board and provides information about the development platform for devices. The bottom screenshot shows the "Workspace Management" interface, displaying a list of programs in the workspace and workspace details for user 'ethanharstad'.

Name	Last Modified	Description
Atte	2 days, 1 hour ago	
Nordic_nrf51822_pnrcn	2 days, 1 hour ago	
Atte_jelek_stm32_f401	2 days, 1 hour ago	

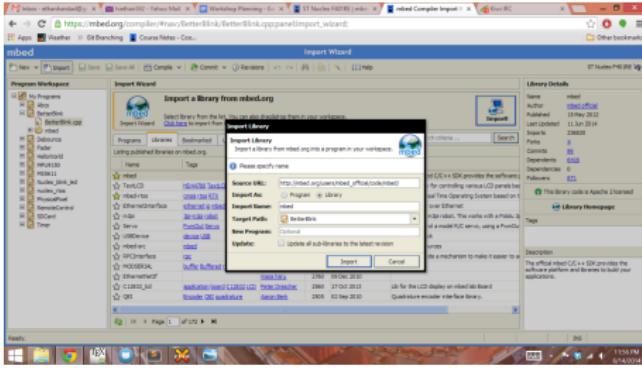
Workspace Details:  
User: ethanharstad  
Total Programs: 3  
Hosted: 2 days, 2 hours ago  
Recently Hosted: main.cpp, 2 days, 2 hours ago

- ① Navigate to the mbed homepage and click the "Compiler" button
- ② Click the "New" button and select "New Program"
- ③ Change the Template field to "Empty Program"
- ④ Give your program a name and click "OK"

# Importing a Library



- ① Click the "Import" button
- ② Search for the "mbed" library
- ③ Select the library
- ④ Click the "Import!" button
- ⑤ Make sure the Target Path is your project root
- ⑥ Click "Import" one last time



# Creating a New File

- ① Click the root directory of your project to select it
- ② Click the arrow next to "New" and select "New File"
- ③ Name the file "main.cpp" and click "OK"

## Warning

Be sure to select the folder you want your file in before creating it!

You can name this file anything but it must have the .cpp extension. It is suggested that the main file be named "main" or the same as your project name (important later on).

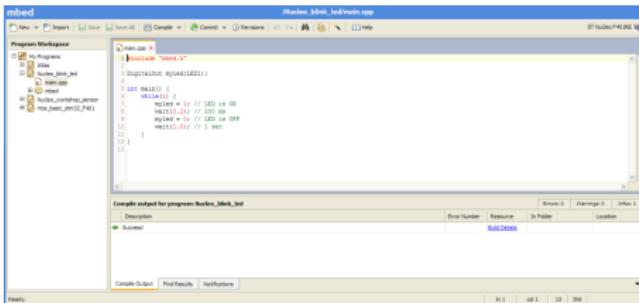
# Program Structure

```
1 /* Includes */
2 #include "mbed.h"
3
4 /* Global Variable
5    Declarations      */
6
7 /* Main Function */
8 int main() {
9     // Program code
10 }
```

Listing 1: main.cpp

- Line 2 includes the mbed library, **every** mbed program needs this.
- Line 8 is the main function, this is the entry point into your program. **Every** program needs a main function.
- Line 9 is a comment, everything after // is ignored.
- Line 4-5 is a multi line comment, everything between /\* \*/ is also ignored.

# Compiling



## Tip

Set your browsers download location  
to the Nucleo to save time

- ① Click "Compile" (Ctrl D) to compile your program
  - ② A \*.bin file will be downloaded
  - ③ Move the downloaded file to the Nucleo drive
  - ④ The Nucleo will flash red and green while programming
  - ⑤ When the lights stop, your program has started successfully!

You can also click "Build Only" (Ctrl B) to simply test your code

# Outline

- 1 Getting Started
- 2 The Bare Minimum
- 3 Your First Program
  - While Loops
  - Digital Output
  - Waiting
- 4 Taking Control
- 5 Talking to mbed
- 6 Writing Modular Code

# While Loops

```
1 while (conditional) {  
2     // Code to execute when true  
3 }
```

While loops executes the code contained within them while their conditional statement is true.

## Example

A main function should (almost) never exit:

```
1 int main() {  
2     while (true) {  
3         // Main loop code, runs forever  
4     }  
5 }
```

# Your Program

```
1 /* Includes */
2 #include "mbed.h"
3
4 /* Global Variable
5    Declarations      */
6
7 /* Main Function */
8 int main() {
9     while(true) {
10         // Program code
11     }
12 }
```

Listing 2: main.cpp

- Add an infinite while loop to your main function to prevent your program from ending.



# Digital Output

DigitalOut constructor:

```
DigitalOut(PinName pin)
```

It creates an object attached to the given pin. Anytime you see PinName, use a name from the images on the next slide.

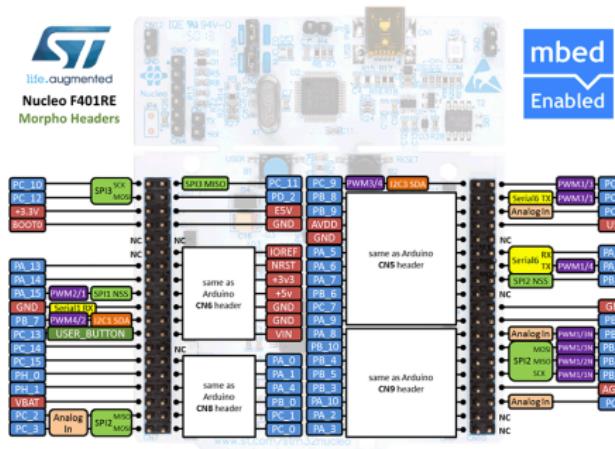
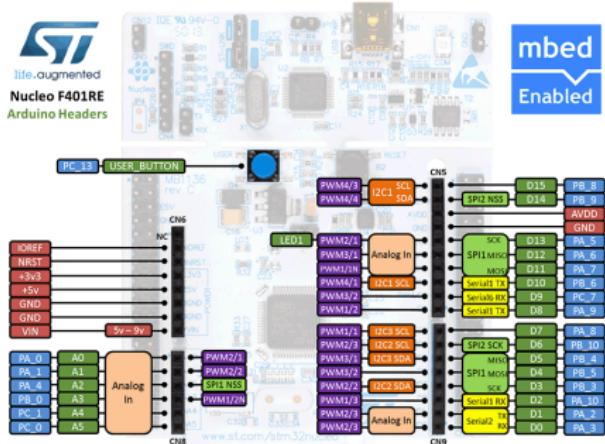
You can assign a value to the object using the equals sign. 1 turns the pin on while a 0 turns the pin off.

## Example

Attach a DigitalOut to the LED1 pin on the Nucleo and turn it on:

```
DigitalOut led(LED1);  
led = 1;
```

## Nucleo Pin Names



## Warning

You can only use the labels in blue and green!

Full size versions are available at  
<https://mbed.org/platforms/ST-Nucleo-F401RE/>



# Your Program

```
1 /* Includes */
2 #include "mbed.h"
3
4 /* Global Variable
5    Declarations      */
6 DigitalOut led(LED1);
7
8 /* Main Function */
9 int main() {
10     while(true) {
11         led = 1; // Turn LED on
12         led = 0; // Turn LED off
13     }
14 }
```

Listing 3: main.cpp

- Declare a global DigitalOut object
- Turn the output on and off in your main loop

## Note

The LED won't seem to be flashing, but it actually is at about 42 MHz, much faster than your eye.

# Waiting

There are three statements that can slow down execution:

```
void wait(float s);  
void wait_ms(int ms);  
void wait_us(int us);
```

All three will pause execution for the amount of time specified. Use these statements any time you need a controlled delay.

## Notice

Wait and other block statements can have some unintended side effects.  
This will be demonstrated later.

# Your Program

```
1 /* Includes */
2 #include "mbed.h"
3
4 /* Global Variable
5    Declarations      */
6 DigitalOut led(LED1);
7
8 /* Main Function */
9 int main() {
10     while(true) {
11         led = 1;      // Turn LED on
12         wait(0.2);   // Wait a bit
13         led = 0;      // Turn LED off
14         wait(0.8);   // Wait longer
15     }
16 }
```

Listing 4: main.cpp

- Add a wait statement after each write to your output
- You should now be able to see your LED flashing
- Try making your own patterns!

# Outline

- 1 Getting Started
- 2 The Bare Minimum
- 3 Your First Program
- 4 Taking Control
  - Variables
  - Digital Input
  - Conditional Statements
  - A Better Blinker
- 5 Talking to mbed
- 6 Writing Modular Code

# Variables

A variable is a container that has:

Type What data it can hold

Identifier The name you access it with

Value The data it holds

Scope Where you can access it from

You must declare a variable before you can use it:

```
type identifier = value;
```

The value is optional if you do not need a starting value.

# Variable Types

Format	Type	Bits	Range
Integer	char	8	0 – 255
	signed char	8	-128 – 127
	unsigned short	16	0 – 65,535
	short	16	-32,768 – 32,767
	unsigned int	32	0 – 4,294,967,295
	int	32	$2.1 \times 10^9$ – $2.1 \times 10^9$
	unsigned long long	64	0 – $1.8 \times 10^{19}$
	long long	64	$-9 \times 10^{18}$ – $9 \times 10^{18}$
Floating	float	32	$-3.4 \times 10^{38}$ – $3.4 \times 10^{38}$
	double	64	$-1.7 \times 10^{308}$ – $1.7 \times 10^{308}$

## Note

The mbed natively works with 32 bit types, a huge advantage over 8 and 16 bit processors

# Variable Scope

Variable scope is set by where a variable is declared:

```
int a = 0;  
  
int main() {  
    float b = 0.0f;  
    while(true) {  
        double c = 0.0;  
    }  
}
```

- a is outside any functions and can be seen anywhere in the file
- b can be seen anywhere inside main()
- c can only be seen inside the while loop

A simple rule of thumb is a variable can only be seen inside its enclosing braces.

## Best Practice

Use the narrowest scope possible

# Using Variables

## Arithmetic Operators

=	assignment
+	addition
-	subtraction
*	multiplication
/	division
%	modulus

## Bitwise Operators

&	bitwise and
	bitwise or
^	bitwise xor
~	bitwise not
«	bitshift left
»	bitshift right

## Compound Operators

++	increment
--	decrement
+=	compound addition
-=	compound subtraction
*=	compound multiplication
/=	compound division
&=	compound bitwise and
=	compound bitwise or

# Digital Input

```
DigitalIn(PinName pin, PinMode mode);
```

DigitalIn operates nearly identically to DigitalOut, except you can optionally specify a pin mode:

**PullNone** Standard mode, default

**PullUp** Weak pull up resistor enabled

**PullDown** Weak pull down resistor enabled

Access the value of the pin by treating it like any other variable.

## Example

```
DigitalIn btn(USER_BUTTON);
int state = btn;
```

# A New Program

Create a new program with:

- `DigitalIn` on the button
- `DigitalOut` on the LED
- Infinite main loop
- Button controlling the LED

## Tip

Look at the pin diagrams to determine what `PinName` to use

# A New Program

Create a new program with:

- DigitalIn on the button
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- Infinite main loop
- Button controlling the LED

## Tip

Look at the pin diagrams to determine what PinName to use

```
1 #include "mbed.h"
2
3 DigitalOut out(LED1);
4 DigitalIn in(USER_BUTTON);
5
6 int main() {
7     while(true) {
8         out = in;
9     }
10 }
```

Listing 6: TakingControl.cpp

# Conditional Statements

Conditional statements are constructed from comparison and boolean operators:

## Comparison Operators

<code>==</code>	equal to
<code>!=</code>	not equal to
<code>&lt;</code>	less than
<code>&gt;</code>	greater than
<code>&lt;=</code>	less than or equal to
<code>&gt;=</code>	greater than or equal to

## Boolean Operators

<code>&amp;&amp;</code>	and
<code>  </code>	or
<code>!</code>	not

# If Statements

An if statement executes different code based on the result of a conditional statement:

```
if(x > 0) {  
    // Run if x is positive  
} else if(x < 0) {  
    // Run if x is negative  
} else {  
    // Run otherwise  
}
```

The else if and else clauses are optional. For simple cases, so are the braces:

```
if(x < 0) x = 0;
```

# Revisiting Our Last Program

Try to rewrite the last program using an if statement instead of simple assignment

# Revisiting Our Last Program

Try to rewrite the last program using an if statement instead of simple assignment

```
1 #include "mbed.h"
2
3 DigitalOut out(LED1);
4 DigitalIn in(USER_BUTTON);
5
6 int main() {
7     while(true) {
8         if(in == 0) { // Button is pushed
9             out = 1;
10        } else {      // Button is not pushed
11            out = 0;
12        }
13    }
14 }
```

Listing 8: TakingControl.cpp



# A Note on Logic Levels

A common practice is to use a pull-up resistor on buttons:

- Forces a known logic state
- **Inverts logic levels!**
- You can do this yourself using the PinMode parameter of DigitalIn objects

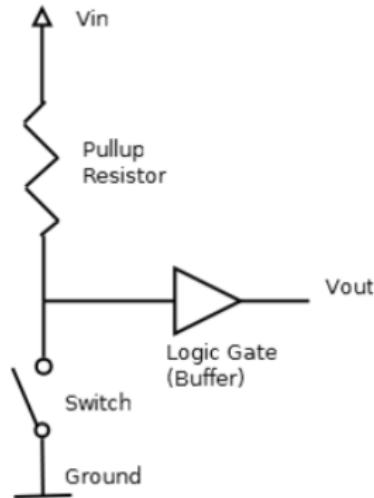


Image from Wikipedia

# A Better Blinker

Lets try rewriting the blinky LED program to be a little more useful: use the button to change the delay time



# A Better Blinker

Lets try rewriting the blinky LED program to be a little more useful: use the button to change the delay time

- Use a global variable to count button presses
- Remember the button has inverted logic levels
- Check the bounds of your count
- Try using math instead of discrete states

# One Solution

```
1 #include "mbed.h"
2
3 DigitalOut out(LED1);
4 DigitalIn in(USER_BUTTON);
5 int count = 0;
6
7 int main() {
8     while(true) {
9         if(in == 0) count++;
10        if(count == 0) {
11            out = 1;
12            wait_ms(500);
13            out = 0;
14            wait_ms(500);
15        } else if(count == 1) {
16            out = 1;
17            wait_ms(250);
18            out = 0;
19            wait_ms(250);
20        } else {
21            count = 0;
22        }
23    }
24 }
```

Listing 9: BetterBlink.cpp

# A More Elegant Solution

```
1 #include "mbed.h"
2
3 DigitalOut out(LED1);
4 DigitalIn in(USER_BUTTON);
5 int divisor = 1;
6
7 int main() {
8     while(true) {
9         if(in == 0) { // Button is pushed
10             divisor *= 2;
11             if(divisor >= 16) divisor = 1;
12         }
13         out = 1;    wait_ms(500 / divisor);
14         out = 0;    wait_ms(500 / divisor);
15     }
16 }
```

Listing 10: BetterBlink.cpp



# Outline

- 1 Getting Started
- 2 The Bare Minimum
- 3 Your First Program
- 4 Taking Control
- 5 Talking to mbed
  - Serial Ports
  - Switch/Case Statements
  - Functions
  - For Loops
- 6 Writing Modular Code

# Serial Ports

The Nucleo has one serial port that connects to the computer over USB:

```
Serial pc(USBTX, USBRX);
```

Every serial port has an associated baud rate (9600, 19200, 115200):

```
pc.baud(int baudrate);
```

There are methods to test if the port is ready to read or write:

```
pc.readable();
```

```
pc.writeable();
```

These methods return true if the port is ready.

# Reading and Writing Characters

The simplest way to talk is a character at a time:

```
char in = pc.getc();          pc.putc(char out);
```

To write formatted output:

```
printf(string format (%[flags][width].[precision][key]), ...);
```

Flag	Description	Key	Output
-	Left justify	d or i	Signed decimal integer
+	Force sign character	u	Unsigned decimal integer
(space)	Leave a space for sign	f	Decimal floating point
0	Zero padding	e	Scientific notation
		c	Character
		s	String of characters



# printf Examples

```
1 printf("Characters: %c %c \n", 'a', 65);
2 printf("Decimals: %d %ld\n", 1977, 650000L);
3 printf("Preceding with blanks: %10d \n", 1977);
4 printf("Preceding with zeros: %010d \n", 1977);
5 printf("floats: %4.2f %+0e %E \n", 3.1416, 3.1416, 3.1416);
6 printf("Width trick: %*d \n", 5, 10);
7 printf("%s \n", "A string");
```

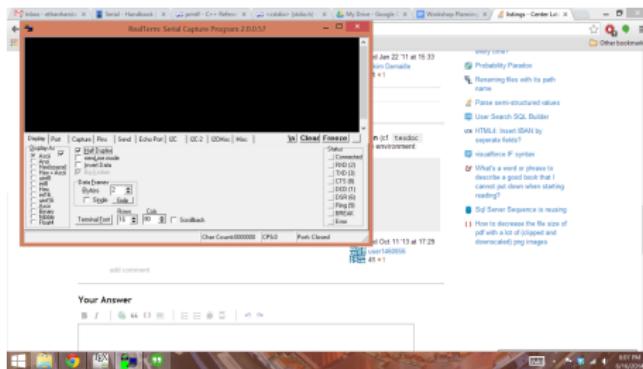
Listing 11: Code

```
1 Characters: a A
2 Decimals: 1977 650000
3 Preceding with blanks: 1977
4 Preceding with zeros: 0000001977
5 floats: 3.14 +3e+000 3.141600E+000
6 Width trick: 10
7 A string
```

Listing 12: Output



# Viewing the Serial Port



- ① Open RealTerm
- ② Enable "Half Duplex"
- ③ Click the "Port" tab
- ④ Baud: 9600 and the correct port
- ⑤ Click "Change"

Try running a simple sample program:

```
Serial pc(USBTX, USBRX);
int main() {
    pc.printf("Hello world!");
    while(true) {
        pc.putc(pc.getc() + 1);
    }
}
```

# Switch/Case Statements

Switch statements can replace some types of if/else statements:

```
switch(variable) {  
    case value1:  
        // Code for value1  
        break;  
    case value2:  
    case value3:  
        // Code for value2 and 3  
        break;  
    default:  
        // Code  
}
```

## Warning

A break statement is required between cases. Forgetting can cause many bugs!

Switch statements can only be used with integral type variables. You can group multiple cases together like 2 and 3 above.

# A New Program

Create a new program with:

- A serial port connected to USB
- A DigitalOut connected to the LED
- A switch statement
  - One character turns the LED on
  - Another character turns the LED off



# A New Program

Create a new program with:

- A serial port connected to USB
- A DigitalOut connected to the LED
- A switch statement
  - One character turns the LED on
  - Another character turns the LED off

```
1 #include "mbed.h"
2
3 DigitalOut led(LED1);
4 Serial pc(USBTX, USBRX);
5
6 int main() {
7     while(true) {
8         switch(pcgetc()) {
9             case 'H':
10                 led = 1;
11             case 'L':
12                 led = 0;
13         }
14     }
15 }
```

Listing 14: RemoteControl.cpp

# Functions

Functions repackage code into reusable groups:

```
type name(parameter1, parameter2, ...) {statements}
```

**type** The type of data returned by the function

**name** The name the function can be called by

**parameters** Variables used as inputs/outputs for the function

**statements** Code statements that define what the function does

Parameters are essentially local variable declarations that are passed to the function, use as many (or as few) as needed:

```
int uselessFunction(int a, float b, double c) {...}
```



# Using Functions

Call a function by using its name and your parameters in parenthesis:

```
int add(int x, int y) {  
    return x + y;  
}  
  
int a = add(2, 3)  
  
a = 5
```

Some functions do not require a return type:

```
void hello(char * name) {  
    printf("Hello %s\n!", name);  
}  
  
hello("everyone");  
  
>Hello everyone!
```

# Revisiting Your Earlier Program

Lets rewrite the earlier remote control program to use a function to handle the input. This helps us stay organized.

# Revisiting Your Earlier Program

Lets rewrite the earlier remote control program to use a function to handle the input. This helps us stay organized.

*Only changed lines are shown to save space*

```
6 void handler(char in) {  
7     switch(in) {  
8         case 'H':  
9             led = 1;  
10        case 'L':  
11            led = 0;  
12    }  
13}  
14  
15 int main() {  
16     while(true) {  
17         handler(pc.getc());  
18     }  
19 }
```

Listing 16: RemoteControl.cpp

# Function Prototypes

Like variables, functions must be declared before they can be used.  
This is why handler was above main in the last example.

You can declare a function prototype separate from the implementation to avoid this:

```
void handler(char in);

int main() { ... }

void handler(char in) { ... }
```

Put the prototype with the rest of your global declarations and the function where ever it fits best.

# Outline

- 1 Getting Started
- 2 The Bare Minimum
- 3 Your First Program
- 4 Taking Control
- 5 Talking to mbed
- 6 Writing Modular Code
  - Analog Input
  - PWM Output
  - Classes

# Outline

## 1 mbed Platform

# What is mbed?

# Outline

## 1 Open Session

# What is mbed?