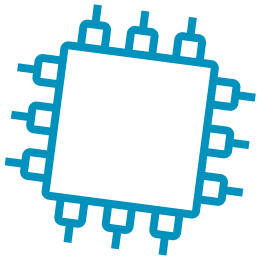
Arduino MKR

projects for schools



arm School Program

Arm Education Media is an imprint of Arm Limited, 110 Fulbourn Road, Cambridge, CBI 9NJ, UK

Permissions

Notices

Arm is committed to making the language we use inclusive, meaningful, and respectful. Our goal is to remove and replace non-inclusive language from our vocabulary to reflect our values and represent our global ecosystem.

Arm is working actively with our partners, standards bodies, and the wider ecosystem to adopt a consistent approach to the use of inclusive language and to eradicate and replace offensive terms. We recognise that this will take time. This book may contain references to non-inclusive language; it will be updated with newer terms as those terms are agreed and ratified with the wider community.

Contact us at education@arm.com with questions or comments about this course. You can also report non-inclusive and offensive terminology usage in Arm content at terms@arm.com.

ISBN: 978-1-911531-39-5

For information on all Arm Education Media publications, visit our website at https://www.arm.com/resources/education/books

To report errors or send feedback, please email edumedia@arm.com

CONTENTS

Introduction 7

1 A Flashing LED 8

2 Flashing an External LED 12

3 Responding to a Button 15

4 LED Strobes on Demand 19

5 Reading and Writing with the Serial Monitor 24

6 Introduction to the Arduino 27

7 The IoT Cloud 31

8 IoT Shopping List 35

9 Air Quality Sensor 38

10 Storing IoT Data in a Spreadsheet 42

11 Pedometer 47

12 Baseball or Cricket Bat Metrics 52

13 Biodome (Part 1) 57

14 Biodome (Part 2) 61

15 Data Analysis and Machine Learning 65

16 Using Machine Learning to Identify a Hit or a Miss 68

17 Web Scraper 74

18 GPS Treasure Hunt 79

19 Lock Box 83

20 Final Project 88

INTRODUCTION

This book introduces learners to the exciting world of microcontrollers and the Internet of Things. Learners will use both simulators and physical devices to build systems and solve real-life problems. A variety of input and output devices will be used to receive instruction from the user, sense the environment, and display both status information and complex outputs.

The book takes a gradual approach to learning, with simulations and emulators used to build confidence, before learners begin constructing basic physical circuits. A variety of Internet services are applied to turn the devices into true Internet of Things devices, both to instruct the device to carry out a task and to report data from the device's sensors.

As well as stand-alone devices and those connected to the Internet of Things, learners will experience some other exciting modern technologies such as Machine Learning-based Artificial Intelligence using the popular Python language.

All the code examples and solutions for these projects are available on Github — https://github.com/arm-university/Arduino-MKR.

Understanding the Arduino

Learners often see microcontrollers such as the Arduino as delicate, confusing and scary. While there are elements of delicacy to the Arduino, such as the pins being easy to bend, learners should not fear the Arduino. It helps to think about the Arduino—and any microcontroller—as simply being a small computer; all it does is take inputs, calculate the right thing to do, and produce some outputs. The fact that we use sensors instead of keyboards and mice, and LEDs and motors rather than a screen, should not detract from this.

The hardware

There are a multitude of Arduinos on the market, from the tiny "nano", the ubiquitous "uno", and many more. Although this book focuses on the MKR series, with in-built WiFi, the general layout of almost all Arduinos are the same. That is, with a number of ground (GND) and positive (3.3 V or 5 V) pins; and a range of digital (identified by a number) and analogue (identified by 'A' followed by a number) input/output pins, some of which support pulse width modulation (PWM, identified by a ~). With a bit of exploration any project in this book should be possible on almost any Arduino, although having built-in WiFi certainly makes things easier. See Chapter 6 for more information and diagrams on the Arduino.

1. A FLASHING LED

Setting the scene

One of the great things about microcontrollers such as the Arduino, is that they are extremely small and only include the things that are really needed—these often don't include big parts such as a screen or keyboard, which have a huge environmental impact to build and run.

This project introduces you to the idea of programming Arduino microcontrollers, but in the safe environment of an emulator. Although this project is very simple, it will form the basis of a lot of future projects. You will use the skills covered here to check that everything is working, test connections, and even output useful information.

Success criteria

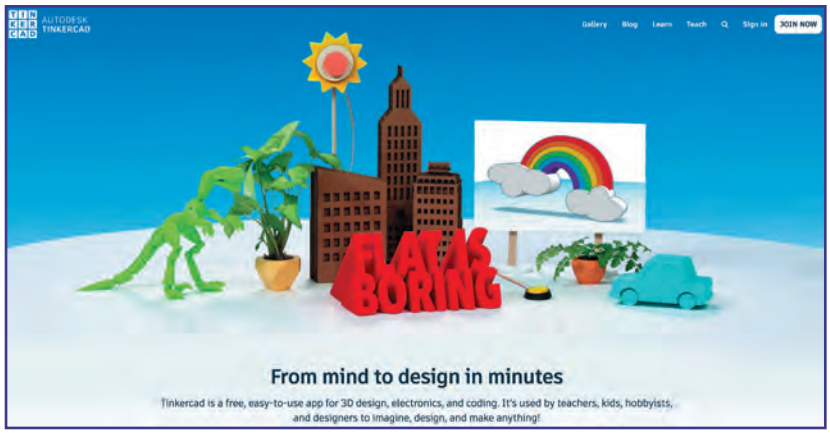
- ☑ Create a Tinkercad account and log in.
- ☑ Add an Arduino to your Tinkercad workspace.
- ☑ Create a simple program using Tinkercad and programming blocks.
- ☑ Run the program to make the LED blink.

1

Microcontrollers such as the Arduino are really just small computers. They can be programmed, just like a normal computer, and they can be connected to bits of hardware, just like a normal computer. However, because microcontrollers are so small, you have to do this programming and connecting somewhat differently. Before you start using real circuits and plugging things into them, it a good idea to test things out first. To do this you are going to use an *emulator*, a computer program that pretends to be an Arduino.

2

For your emulator you will use a website called Tinkercad. Visit the website at https://www.tinkercad.com/, create an account, and sign in.

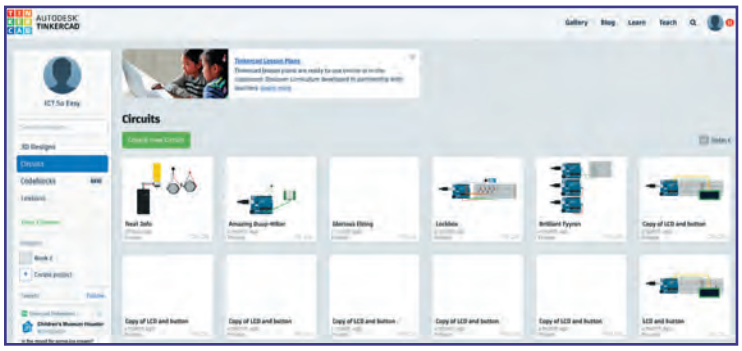


PRO *TIP*

Existing Google accounts are a great way to sign up and log in to Tinkercad quickly. However, some accounts with parental controls in place might block access to Tinkercad.

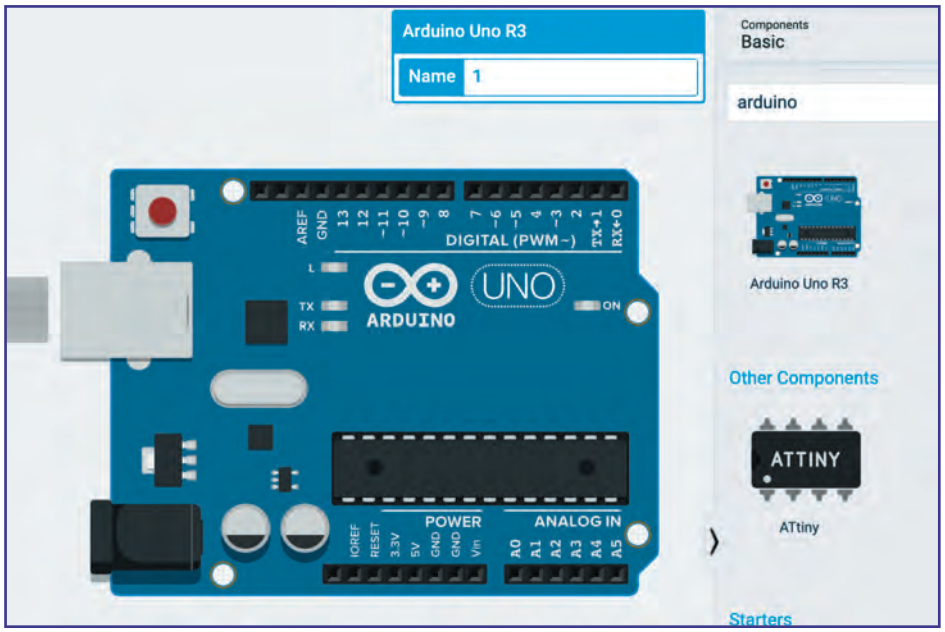
3

Throughout the following chapters you will be creating **circuits** in Tinkercad. You can have as many circuits as you need. Just select **Circuits**, then click on **Create new Circuit** whenever you need to create a new circuit.



4

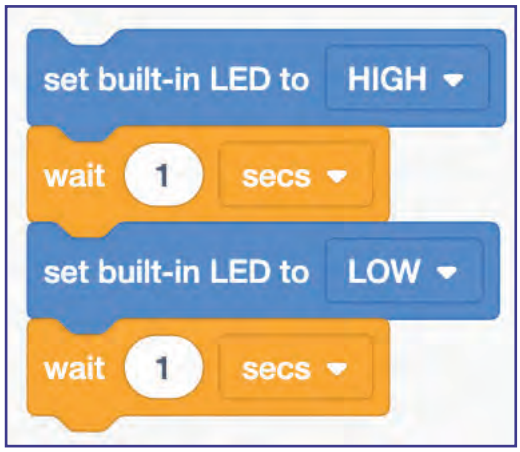
The main part of the Tinkercad screen is a workspace. You can drag **components** from the right-hand side on to the workspace and, when needed, connect them with wires. For this project you just need an Arduino on your workspace. You can either search for it or browse the list, then drag it on to your workspace.



If you have access to a real Arduino, you could compare it to the one on TinkerCad. It may look a bit different unless you have the same model. The model on TinkerCad is an Arduino Uno.

5

Microcontrollers only become useful when you tell them to do something. You do this by programming the microcontroller. The Arduino Uno, like most Arduinos, has a built in LED (light-emitting diode). An LED is like a light bulb but uses less power and is, therefore, better for the environment. Open the **Code** menu at the top right. You will see some blocks of code ready prepared. Click on the **Start Simulation** button to see the LED flash.

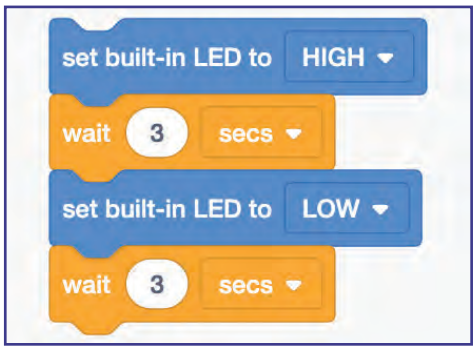


PRO *TIP*

You won't be able to change or edit the code until you click the Stop Simulation button.

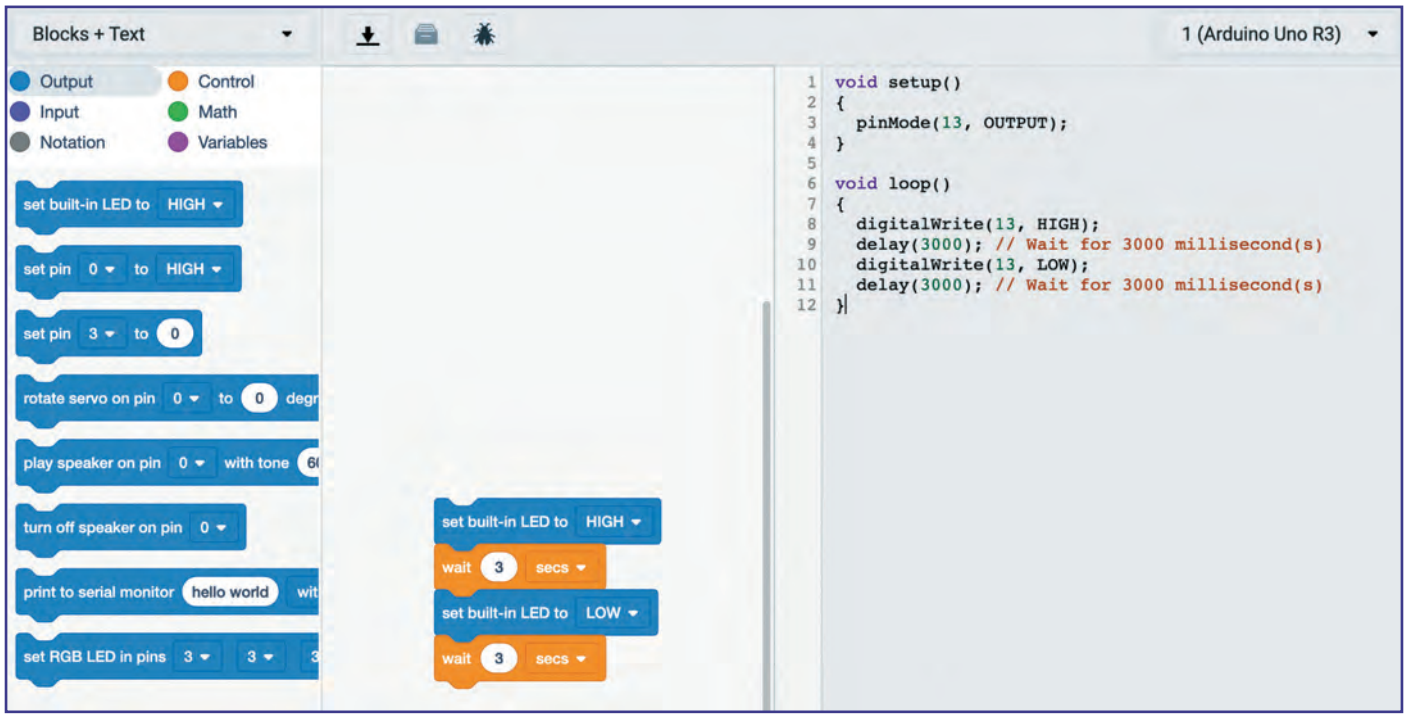
6

Change the time in the orange "wait" blocks to adjust the amount of time the LED flashes on and off. It's worth looking at the terminology used here. The terms HIGH and LOW represent the voltage that the Arduino outputs: HIGH means the Arduino outputs a high voltage, which turns the LED on; LOW means the Arduino outputs a low voltage, which turns the LED off.



7

Change the **Blocks** menu to **Blocks + Text** to see the actual programming code for this program. The code is written using a combination of the programming languages C and C++, which you will use later in this book.

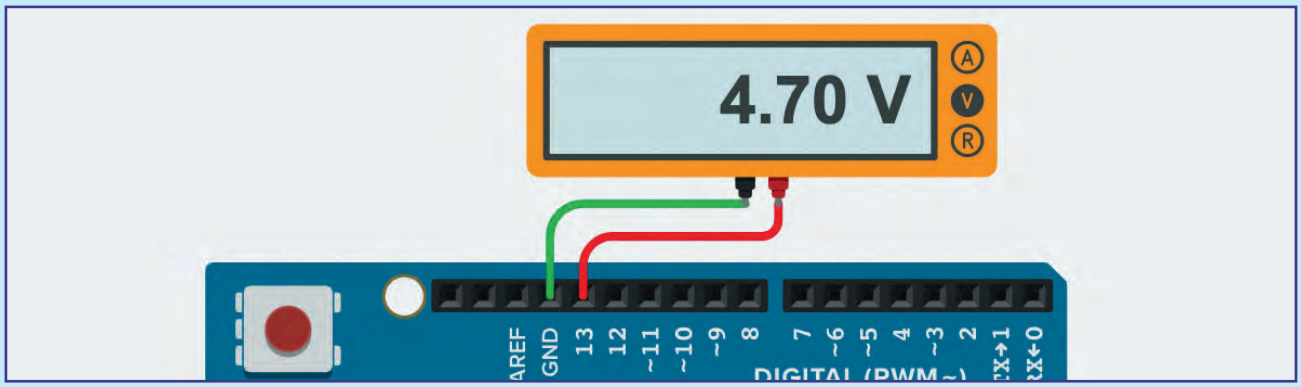


PRO *TIP*

Everything that can be done in blocks can be done in C and C++. The reverse isn't necessarily true, however, so Tinkercad blocks you from changing back from C and C++ to blocks. Make sure you know the code before you change to just the text view, in case you cannot undo the process.

Testing

The code provided is simple and has been pre-written, so it should just work. However, it is always worth checking that your circuit is giving the expected readings. Find a multimeter and drag it on to your workspace. Draw a line to connect a wire from the black terminal on the multimeter to the GND hole on your Arduino. Draw another wire from the red terminal to the 13 hole. These holes are called *pins*—if you turn an LED over you will see legs or pins sticking out of the base. The built-in LED is connected to pin 13. When you start the simulation, the multimeter should read about 4.7 V when the pin is "HIGH" and 0 V when the pin is "LOW".



Stretch tasks

- Swap the wires around on the multimeter and research why the voltage reading is now negative when the pin is "HIGH".
- Reduce the delay times between the LED being on and the LED being off. Identify the fastest flashing rate that you can manage with the LED.
- Microcontrollers don't (normally) have screens, so they often use LED flashes to indicate successes, failures and statuses. Change the flashing timings, so that the LED flashes "OK" in Morse code.

PRO *TIP*

Terminology is often used interchangeably. In this case the term "delay" (used in code) is the same as "wait" (used in blocks).

Final thoughts

LEDs are far more efficient than traditional light bulbs because they use a lot less power to produce a similar amount of light. Research the difference in the amount of electricity used by an LED light bulb and a traditional light bulb. How much of a saving would you make by swapping all the light bulbs in your home to LEDs?

2. FLASHING AN EXTERNAL LED

Setting the scene

In Chapter 1 you learned how to make the built-in LED on an Arduino flash. While this is useful for testing things, it is somewhat limited by:

- being attached to the Arduino
- only being a single LED

It is more common to want to build one or more external LEDs into your circuit and control the LEDs from your Arduino. The Arduino could form part of a larger system in which the LED could poke through a case containing your circuit, and display whether the device is working properly or not. Consumer electronics contain many precious metals, of which we a have limited supply, and being able to use a low-powered LED as an indicator, rather than installing something larger like a screen, is far better for the environment.

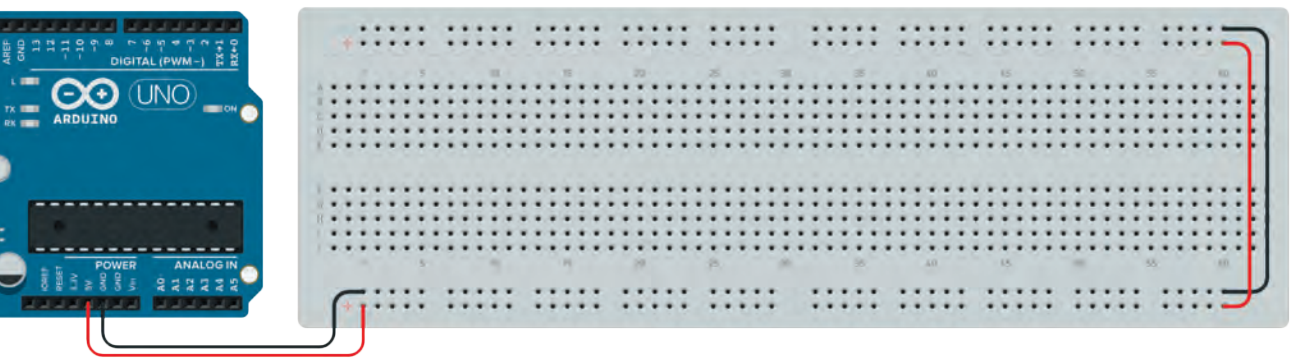
Success criteria

- ☑ Add a breadboard to the workspace.
- ☑ Add an LED to the circuit.
- ☑ Connect the LED to the Arduino with wires.
- ☑ Reduce the amount of voltage reaching the LED.
- ☑ Connect the LED to a digital pin.

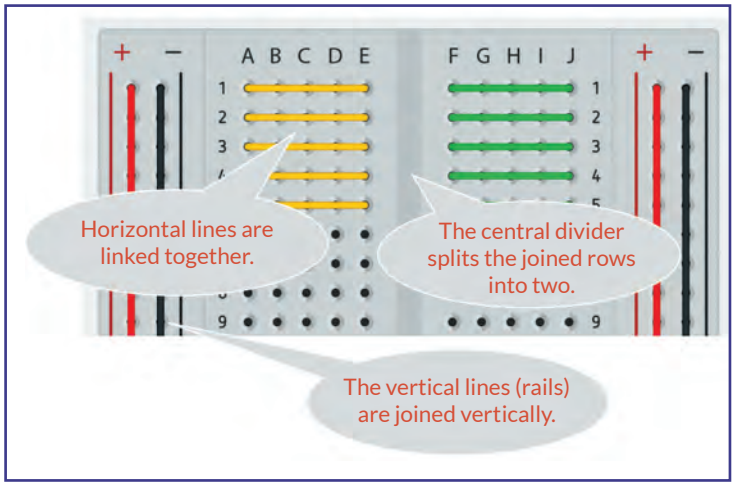
1

While it is perfectly possible to build a whole circuit by joining wires to the ends of components such as an LED, it is far more common to use a breadboard to build your circuit. Breadboards come in a variety of sizes, but most have these common features:

- There are positive (+) and negative (–) rails, which run along the top and bottom of the breadboard. This means you can easily attach components to a high voltage (the +) and to ground (the –) without running lots of wires back to the Arduino. The rails are often bridged top to bottom for even more ease of use.

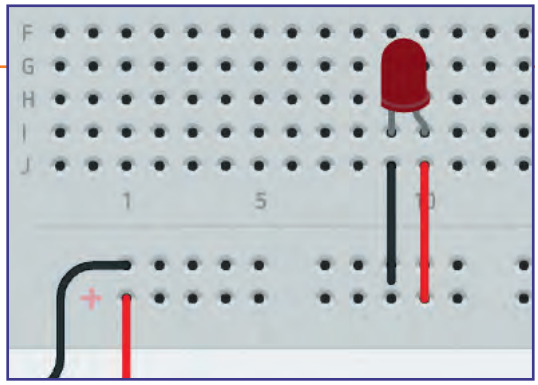


- The columns are numbered, and the rows are lettered. All the pins in a column are normally connected together, although there is usually a gap in the middle. Look at a breadboard in Tinkercad. You will see that column 1 rows A to E are connected, then there is a gap, then column 1 rows F to J are connected.
- You can insert component legs into the holes to build the circuit.



2

It is always worth building up a circuit in stages. That way you can test at each stage to ensure that everything is working. To test this circuit, set up a breadboard and drop an LED on to it. You will see the legs of the Arduino pop into two holes of consecutive columns. Because they are separate columns, they are not connected to each other.



LEDs are directional, so they will only light up if you wire them the right way around. The *cathode* (the left leg on Tinkercad and the shorter leg on a real LED) should be connected to *ground*, and the *anode* (the other one) should be connected via the + rail to the 5 V pin on the Arduino. When you start the simulation, the LED will light up. Having a 'correct' direction is known as polarity.

PRO *TIP*

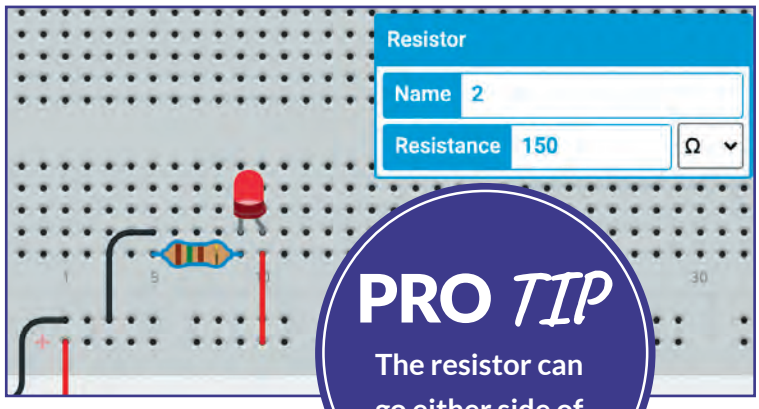
If the LED doesn't light up, it may be wired the wrong way around. The wiring should be as follows:

- **Arduino GND → negative rail → LED cathode**
- **LED anode → positive rail → LED 5 V.**

3

When you start your simulation, you will notice a red flash symbol over the LED. This indicates that there is too much voltage getting to the resistor. In a real circuit, this could burn out the LED or even set it on fire.

It is time to program the Arduino to turn the LED. Resistors are measured in ohms (Ω) and for this LED you need at least 150 Ω. When you are building real circuits, you will need to calculate the correct resistor.

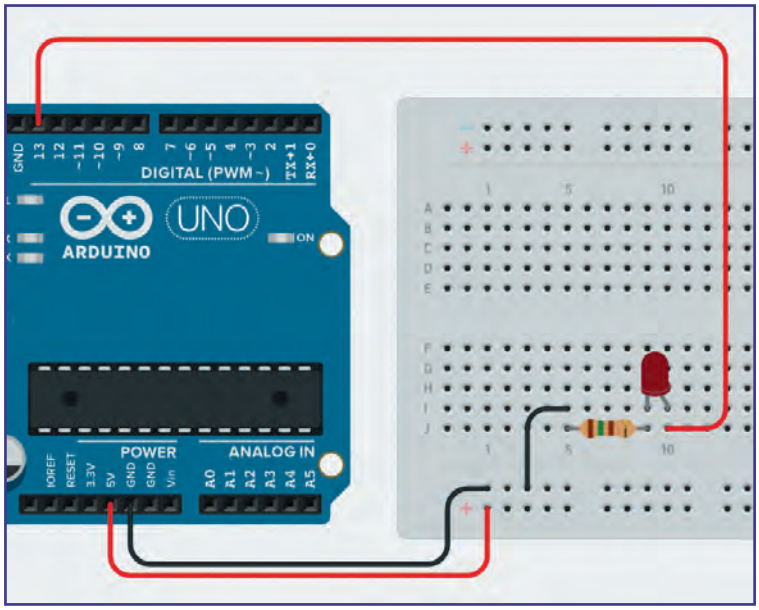


PRO *TIP*

The resistor can go either side of the LED.

4

Now that you know the LED circuit is working, it is time to have the Arduino turn the LED on and off, rather than giving it a constant power. To do this, remove the wires from the positive rail to the anode. Instead, connect the anode to pin 13 on the Arduino. Do you remember from Chapter 1 that the built-in LED is connected to pin 13? This means that the same code you used in Chapter 1 will work here, so you can go ahead and start the simulation. The LED should flash on and off.



Testing

You can test this circuit in the same way as the circuit in Chapter 1. Use a multimeter and connect the black terminal to the cathode and the red terminal to the anode. You should see intermediate values of approximately 2 V. If not, you can in turn move the multimeter wires (or probes) back through the circuit until you find the problem.

Stretch tasks

- Experiment with the value of the resistors and see what happens if you use larger or smaller values.
- Identify the highest value resistor you can use and still see the LED lit up, and the lowest which does not show an error (an explosion symbol over the LED). Note that this can be harder to identify in real-life circuits, so it is worth finding a value where it is obvious that the LED is on.
- Change the LED colour and investigate which ones need higher or lower resistors to produce full brightness.
- Research "LED resistor calculators". You already know that the Arduino produces ~5 V and the ideal resistor is ~150 Ω, so what must the forward voltage of the LED be?

Final thoughts

LEDs come in a range of sizes, shapes, and colors, and are used in all sorts of devices around the home. It can be interesting to look around your home and see how many different LEDs you can find. Consider the impact on the environment of using traditional light bulbs instead of LEDs. Similarly, look at all of the devices in your home that use LEDs and consider the impact on the environment should the developers have chosen to use LCD displays or other, larger, devices to show the status of the device.

3. RESPONDING TO A BUTTON

Setting the scene

So far, you have used the Arduino as an output device—the LED is giving you information (albeit not a lot of information at this stage) from the Arduino. The next step along your journey is to use an input device to give the Arduino some information. You will do this by using a button. The Arduino can read the state of this button and light (or not light) the LED.

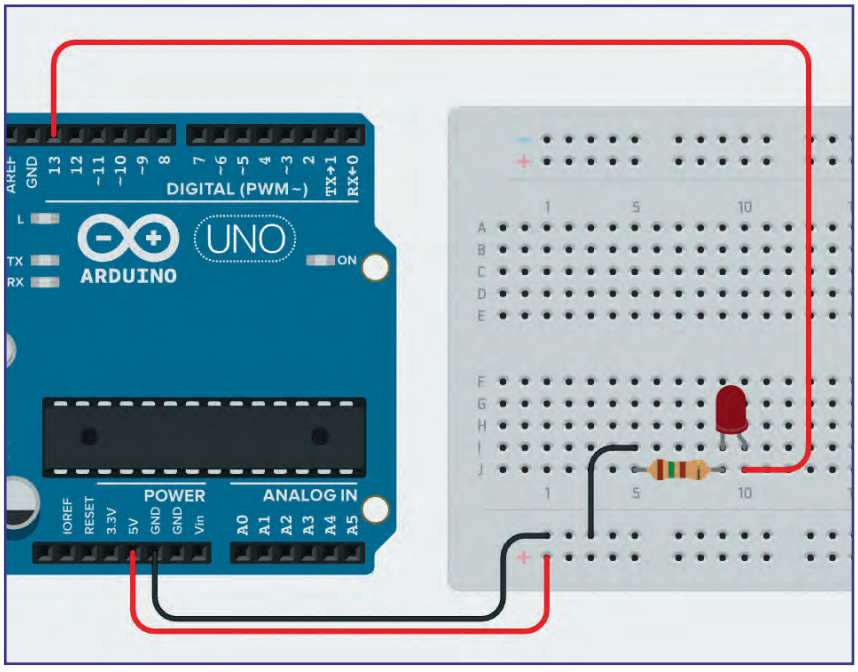
The great thing about buttons, compared to other ways of communicating with the device, is their simplicity. Unlike using a cell phone over the web or even a rotating dial, there is very little that can go wrong with a button. This means that the device will last longer, which is better for the environment.

Success criteria

- Add a button to the circuit from Chapter 2.
- Connect the button to pin 13.
- Read the input from the button.
- Turn the LED on when the button is pressed.
- Turn the LED off when the button is unpressed. button

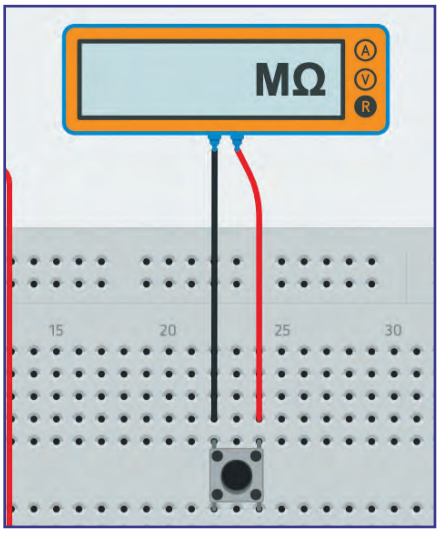
1

Start this project using the same circuit you finished with at the end of Chapter 2. The LED should be connected to ground and pin 13, via a 150 Ω resistor. If you try this on a real-life Arduino, you may not have exactly the right resistor; you may have a resistor in the region of 220–270 Ω. Anything around that value will be fine.



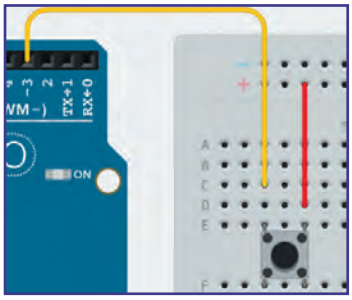
2

The button has legs or *terminals*—like the pins on the Arduino. If you hover your mouse over them, the terminal names will show up. Add a button to your breadboard. The button will fit nicely across the middle section of the breadboard. The "switching" happens between the numbered terminals—between 1a and 2a or between 1b and 2b.



Connect the multimeter to two of the terminals, then press the R button on the multimeter to measure the resistance. When the button is unpressed, the multimeter will read MΩ, which means there is infinite resistance. When you press the button, the reading should change to 0 Ω, which means there is no resistance.

3



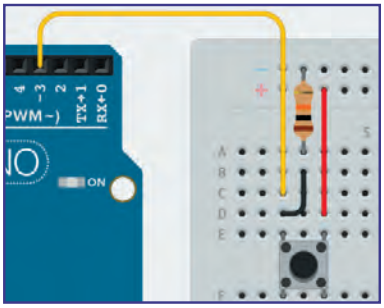
To connect the button, connect a 2 terminal to the positive rail, and connect a 1 terminal to a digital pin on the Arduino, such as D3. When the button is unpressed, the Arduino will not receive any voltage and will see a "LOW" signal. When the button is pressed, voltage gets through and the Arduino will see a "HIGH" signal (which you can see as a positive voltage if you connect a multimeter).

PRO *TIP*

Hover your mouse over the terminals of the button to see the labels showing what each terminal is called.

4

However, in real life connecting the button in this way can cause a problem. If you try to make this circuit, when the button is not pressed you will see the LED flickering slightly. This is due to the open circuit voltage *floating*—this means that the signal doesn't know if it should be low or high, and any stray signal can cause it to be misread.



PRO *TIP*

The exact resistance doesn't matter here. If you are doing this project on a real circuit, a resistance of about 1 kΩ (1000 Ω) will be fine.

To prevent this problem, connect a high-resistance (10 kΩ or 10,000 Ω) resistor between the open side of the button (the side that goes to the Arduino) and ground. This resistor pulls the voltage down to ground when the button is not pressed, so there is a definite "LOW" signal. When the button is pressed, it is easier for the electricity to flow to the Arduino and so a "HIGH" signal is read. This type of resistor is called a *pulldown resistor*.

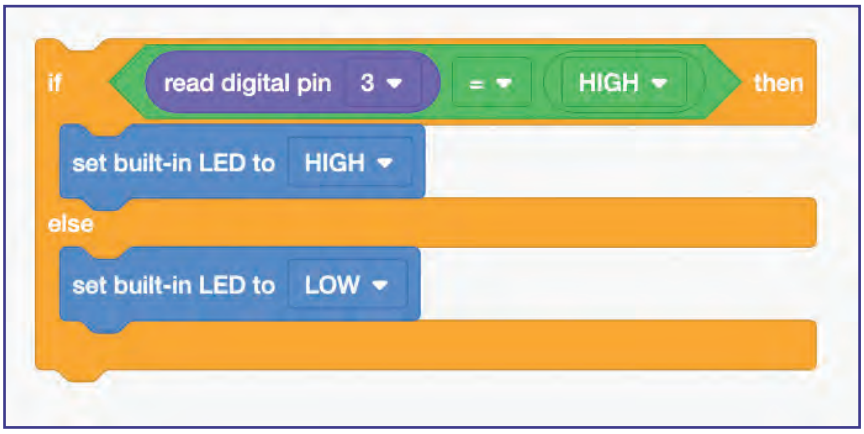
5

The fun bit, of course, is to make the Arduino read the button and act accordingly. Delete the existing code blocks and build up some code to look like those shown here. What is happening is the Arduino reads the signal at digital pin 3 and compares it to what it wants it to be, "HIGH". *If* the signal and the desired reading are equal, then it sets the LED to be "HIGH", *else* (the programming term for "otherwise") it sets the LED to be "LOW".

Because your LED is connected to the same pin as the built-in LED, you can use the "set built-in LED to…" block. The "set pin *n* to…" block will work just as well—just change the *n* to 13. Almost every programming language has an "if…then…else" (sometimes just an "if…else") statement. These are called *conditional* statements and allow you to alter the flow of a program.

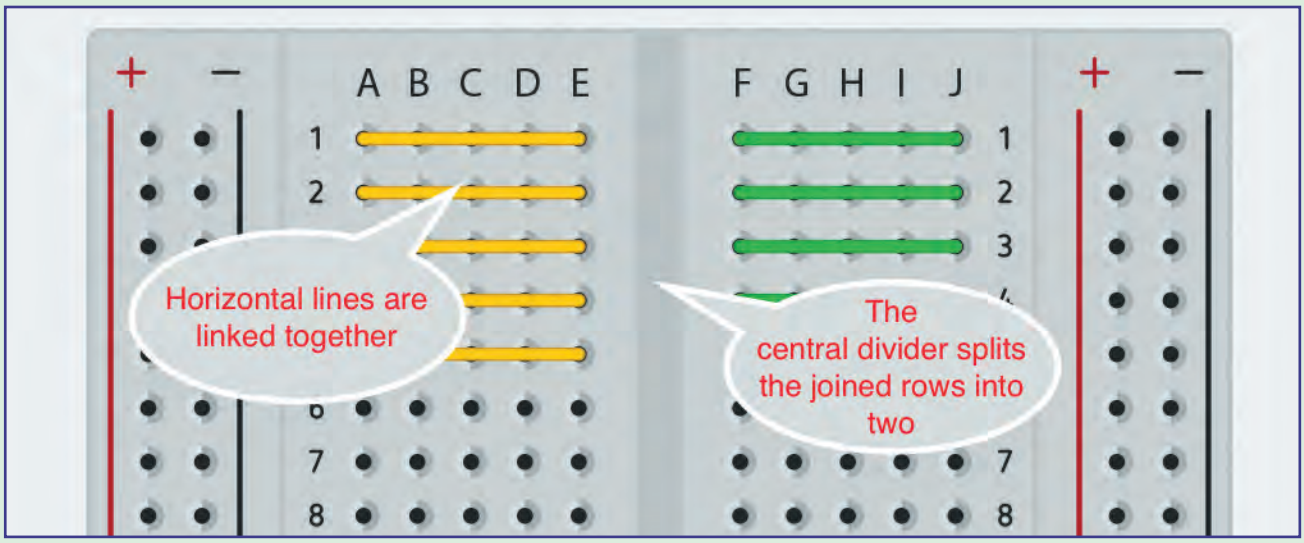
PRO *TIP*

Make sure you disconnect the multimeter from the button. The current that goes through the multimeter can make the Arduino think the button is being pressed!



Testing

You can (carefully) measure the circuit using the multimeter again. When testing, try pressing the button on and off and watch the LED carefully. It is always worth color-coding your wires to help with tracing them, it is normal for + (positive) wires to be red and – (ground) wires to be black. Signal wires can be a different color—yellow is quite commonly used.



Stretch tasks

- Pullup resistors work in a similar way. However, one terminal of the button is connected to ground and the signal terminal connects to the “read digital pin” and to a positive voltage via a high-resistance resistor. Build a pullup resistor and explore how they work.
- Research and consider situations where either a pullup or a pulldown resistor would be preferable. Being able to produce both is useful.
- Add a second button to turn a second LED on or off.
- Add a third LED, which lights up only when both buttons are pressed.

Final thoughts

Buttons and switches are two of the most common types of input device for microcontroller circuits. Spend some time walking around your home to find out how many switches and buttons there are. It is also interesting to see what other input devices and components you can find.

Part of solving an engineering problem is to use the right tool for the job; why do you think a TV remote has buttons rather than a touch screen? Often the reason is because buttons are cheap, robust and low power, all of which have a positive impact on the longevity of the device.

4. LED STROBES ON DEMAND

Setting the scene

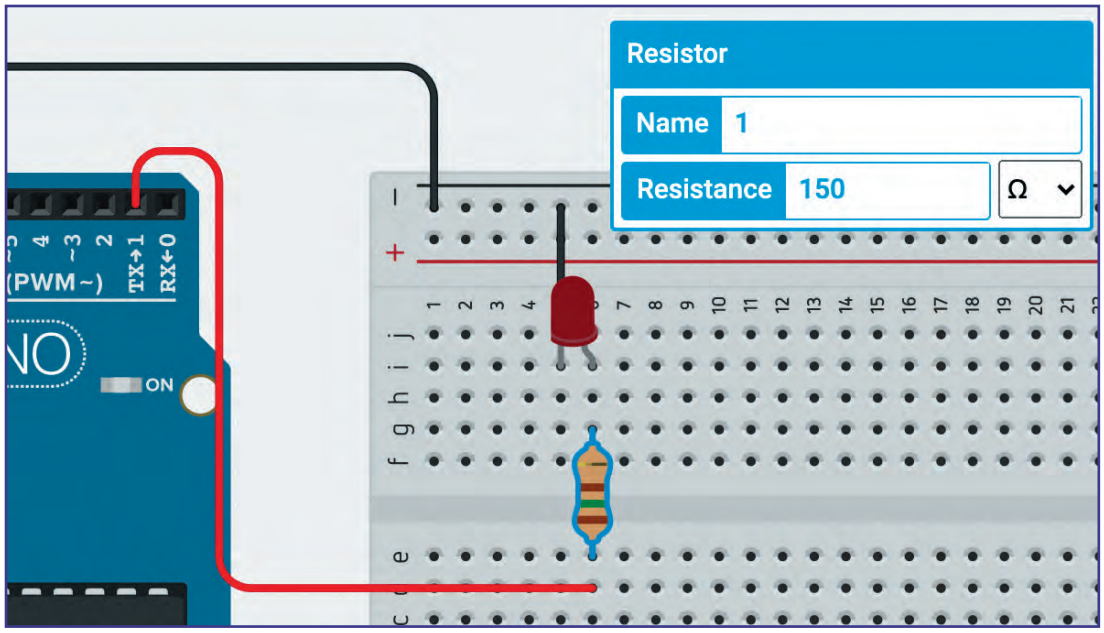
Learning to manipulate multiple outputs is a crucial skill. In this chapter you will be controlling no less than five different LEDs at once. You will notice that things start getting a bit confusing at this point—your code blocks get quite repetitive. Therefore, in this chapter, you will also take your first steps into the wonderful world of C and C++ programming and create some sub-routines. Problems that are too big to solve easily often end up getting solved poorly, which can lead to inefficiencies or even critical mistakes. Instead, we decompose the problem, or break it down into simpler steps, which can be solved and tested far easier.

Success criteria

- Connect five LEDs up to five digital pins.
- Test that all five LEDs can be turned on and off.
- Create sub-routines to strobe the LEDs left and right.
- Connect a second button to control which way the lights strobe.

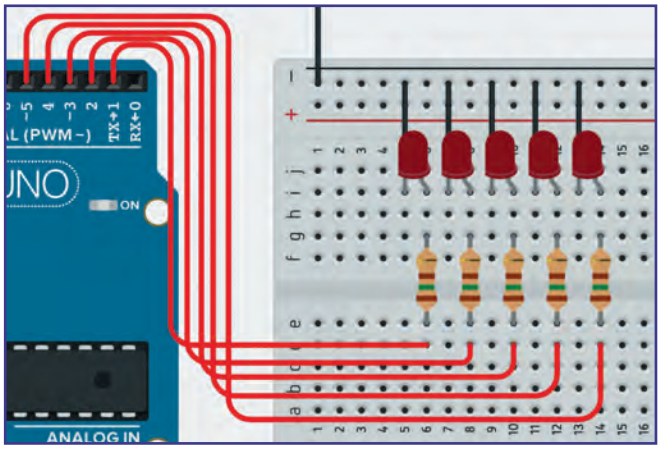
1

Connecting the LEDs is not really any more difficult than the connection you made in Chapter 2. Each LED has its cathode connected to ground via the negative rail, and its anode connected, via a 150 Ω resistor, to a digital pin. For simplicity, use digital pins 1 to 5.

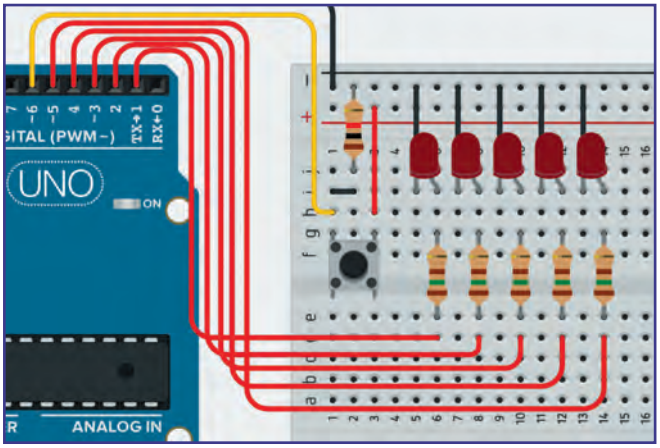


2

In Chapter 2, you learned how important it is to build and test circuits one stage at a time. The first test you need to do is check you have the LEDs wired up correctly. To do this, simply delete the existing code and replace it with five "set pin *n* to…" blocks, all set to HIGH and changing the pin numbers to 1 to 5. When you run the simulation, all five LEDs should light up.



3



The aim of this project is to make the LEDs strobe when a button is pressed. To do this, add a pulldown button in the same way as you did in Chapter 3.

4

Now build your code. The code will be similar to the program in Chapter 3, with the difference here that after each LED is lit it needs to be turned off again. You also need to add some delays to create the strobe effect. A microprocessor is slow compared to a modern PC or laptop, but still works at a rate of about 20,000,000 instructions per second! The code shown here adds delays of 200 milliseconds (one-fifth of a second), so the whole "strobe" takes one second.

5

Now comes the tricky part. You need to add a second button and program the LEDs to strobe in different directions depending on which button is pressed. It is possible to do this using code blocks, but the blocks are going to become very long and unwieldy.

A more efficient method is to split your code into "chunks" and give each chunk of code a name such as `strobeLeft` and `strobeRight`. To do this, change to **Text** code and create two empty blocks of code for your strobing:

```
void strobeLeft() {
}
```

and

```
void strobeRight() {
}
```

PRO *TIP*

Get your code working in blocks first before you convert them to text. Then play around and explore. Don't worry if things don't work out; you can always "undo".

```
void strobeRight()
{
    digitalWrite(1, HIGH);
    delay(200); // Wait for 200 millisecond(s)
    digitalWrite(1, LOW);
    digitalWrite(2, HIGH);
    delay(200); // Wait for 200 millisecond(s)
    digitalWrite(2, LOW);
    digitalWrite(3, HIGH);
    delay(200); // Wait for 200 millisecond(s)
    digitalWrite(3, LOW);
    digitalWrite(4, HIGH);
    delay(200); // Wait for 200 millisecond(s)
    digitalWrite(4, LOW);
    digitalWrite(5, HIGH);
    delay(200); // Wait for 200 millisecond(s)
    digitalWrite(5, LOW);
}
```

Note that the capitalization (and lack of spaces) in the names is very important! Void just means the block of code (which is called a *function*) will not return an "answer".

Now add the lines of code that strobe the LEDs. Cut and paste the `digitalWrite()` lines and the `delay()` lines frome the `loop()` sub-routine into the `strobeRight()` sub-routine (between the {braces}).

PRO *TIP*

You will see that some of the identifiers (names of things in code) have a strange capitalization, such as digitalWrite(). As you can't use spaces in names, it is common to start a name with lower case and then start each new word with a capital. This is called "camel case" and is one of the more commonly used syntax styles.

6

Copy and paste the same lines of code into `strobeLeft()` and adjust them as needed. You could also make a function called `allOff()` to turn all the LEDs off.

```
void strobeLeft()
{
    digitalWrite(5, HIGH);
    delay(200); // Wait for 200 millisecond(s)
    digitalWrite(5, LOW);
    digitalWrite(4, HIGH);
    delay(200); // Wait for 200 millisecond(s)
    digitalWrite(4, LOW);
    digitalWrite(3, HIGH);
    delay(200); // Wait for 200 millisecond(s)
    digitalWrite(3, LOW);
    digitalWrite(2, HIGH);
    delay(200); // Wait for 200 millisecond(s)
    digitalWrite(2, LOW);
    digitalWrite(1, HIGH);
    delay(200); // Wait for 200 millisecond(s)
    digitalWrite(1, LOW);
}

void allOff()
{
    digitalWrite(1, LOW);
    digitalWrite(2, LOW);
    digitalWrite(3, LOW);
    digitalWrite(4, LOW);
    digitalWrite(5, LOW);
}
```

PRO *TIP*

Anything after the // is a comment—a note for the programmer, which is completely ignored by the computer.

7

Finally, you need to call the `strobeLeft()` and `strobeRight()` functions at the appropriate time. You can do this using an `if..else..if..else` statement and calling each function by name.

```
void loop()
{
  if (digitalRead(6) == HIGH) {
    strobeRight();
  } else {
    if (digitalRead(7) == HIGH) {
      strobeLeft();
    } else {
      allOff();
    }
  }
}
```

PRO *TIP*

If your code doesn't run, start with the line the error states the problem is on, and work upwards. Sometimes the error, such as a missing bracket, is just a few lines before!

Testing

Finding and removing errors from code is called *debugging*. This can be stressful, but only if you let it be! A good rule of thumb is to write as few lines as possible before trying the code out. The fewer things you change, the fewer places an error can creep in. Therefore, start by creating an (empty) function and test the code, then put some code inside the function and test it again… and again at the next stage.

Stretch tasks

- Add more buttons and more sub-routines to create a range of strobe patterns.
- Try to combine existing sub-routines rather than rewriting them from scratch. Create a `rightWave()` routine which strobes right three times.
- Research the Arduino `random()` function and the `if()` construct.
- Make a randomized routine play when the button is pressed.

Final thoughts

Decomposition and pattern recognition are two of the corner stones of computational thinking.

- When you split your code into sub-routines, you *decomposed* the problem, which means you converted it into simpler problems to solve. Computer scientists do this when they are designing a solution rather than afterwards.
- Looking for patterns is another way to make code more efficient. For example, if you add a third button which strobes left then right, it would be more efficient to call the two existing sub-routines one after the other rather than to write a whole new section of code.

Sub-routines and sub-systems are a critical part of engineering design; whenever you look at something that has been made—a car, a computer, or a house—try to get into the habit of looking for the sub-systems that have been developed independently of the whole.

5. READING AND WRITING WITH THE SERIAL MONITOR

Setting the scene

This is the final chapter in which you will use an emulator. This chapter introduces you to two exciting new topics.

- Firstly, you will learn to input data from an analogue device. In the real world many devices are analogue (continuous) such as the temperature sensor in your refrigerator, the smoke detector in your smoke alarms.
- Secondly, you will learn to output data from the Arduino to the serial monitor, a text window on your computer.

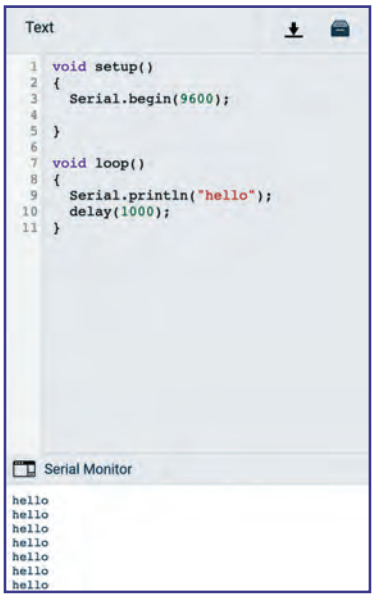
Once you start playing with real Arduinos, from the next chapter onwards, you will quickly learn how much of a pain it can be trying to figure out what is going on. Using the serial monitor allows you to output text back to your computer, which can help you work out what is happening.

Success criteria

- ☑ Connect + and – rails.
- ☑ Connect a potentiometer to the Arduino.
- ☑ Open the serial monitor.
- ☑ Read from the potentiometer.
- ☑ Write to the serial monitor.
- ☑ Read from the serial monitor.

1

The first thing you need to do is make sure you can output data on the serial monitor. You will be doing this entirely in C and C++ code, so make sure you open the code in **Text** format. You need to do two things to make the serial monitor work:



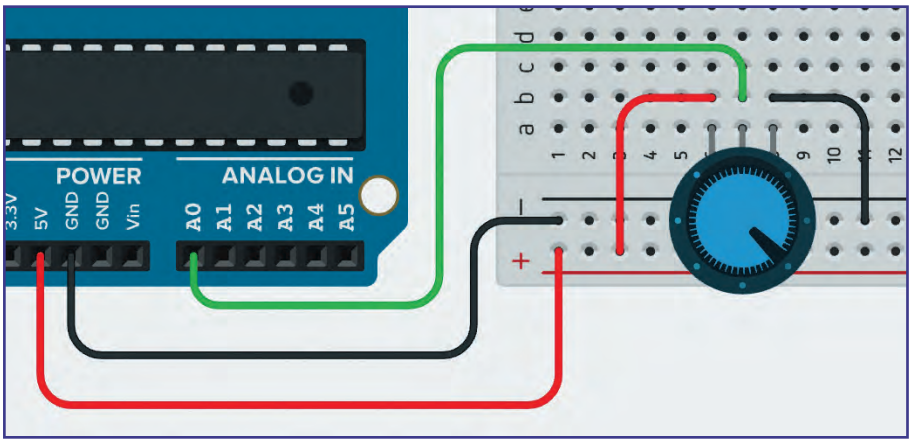
1. Tell the Arduino to begin communicating, and how fast. The speed is known as the *baud rate*. Set the speed to 9,600 in the `setup()` function. Note: the majority of the sub-routine you will see in this book will have void at the start. `void setup()` means it is a sub-routine called "setup," which does not receive any extra information (called "parameters") inside the brackets, and does not give a result back (void means "nothing" comes back).
2. Tell the Arduino to output something to the serial monitor. Use the code `Serial.println("some text")` in the `loop()` function. `println()` is short for "print line".

It is also a good idea to have a delay after outputting or the text will appear faster than you can read it! Open the **Serial Monitor** at the bottom of the screen before running the code.

2

So far, you have been reading *digital data*, which is data that can have only discrete values. Specifically, you have been reading buttons which are either pressed or not pressed. You are now going to read an analog device called a *potentiometer*. A potentiometer rotates so it can have an infinite number of positions. This is known as a continuous input. The Arduino cannot handle infinite positions—it has a range of 1,024 values and assigns the one that is closest to the potentiometer reading. Data which has a continuous range of values is analog, and so the potentiometer must be connected to an analogue pin: the opposite of this digital data which has discrete values (most often "on" or "off").

Connect up your breadboard as in previous chapters and wire up a potentiometer with the left-hand pin connected to positive, the right-hand pin connected to negative, and the middle (signal) pin connected to one of the analog (A) pins on the Arduino.



PRO *TIP*

Make sure you connect the wires the right way round or you may get strange readings from the potentiometer.

3

Follow this process for reading an analog input:

1. Create a *variable* (a memory location to which you give a name) to store the value. This will be a whole number, which is called an *integer*.
2. Set the analog pin as an input in the `setup()` function.
3. In the main loop, use `analogRead()` to get the value of the input (from the potentiometer) and store it in the variable.
4. Act on the data read. In this case, use `Serial.println()` but, instead of outputting a string in quotation marks, output the contents of the variable.

```
int sensorValue = 0;
int incomingByte = 0;

void setup()
{
  pinMode(A0, INPUT);
  Serial.begin(9600);

}

void loop()
{
  sensorValue = analogRead(A0);
  Serial.println(sensorValue);
  delay(100);
}
```

Serial Monitor

```
348
327
593
737
818
839
859
859
```

4

You can also use the serial monitor to read text from the keyboard and send it to the Arduino. To do this, follow these steps:

1. Declare an integer to hold the input data. The input data is read one byte (8 bits) at a time as a numerical code and so is stored as an integer.
2. Check if there is data available on the serial monitor.
3. If so, act on it. This action could be as simple as echoing the code back to the serial monitor, or it could be much more complex.

```
void loop()
{
  sensorValue = analogRead(A0);
  Serial.println(sensorValue);
  if (Serial.available() > 0) {
    // read the incoming byte:
    incomingByte = Serial.read();

    // say what you got:
    Serial.print("I received: ");
    Serial.println(incomingByte);
  }

  delay(100);
}
```

PRO *TIP*

The output numbers are ASCII codes. You can easily find a list of ASCII codes online. Be aware that the codes for upper case and lower case letters (and numeric digits) differ. For example, if you want to check if the user enters "A", you need `if (incomingByte == 65)` but if you want to check if they enter "a", you need `if (incomingByte == 97)`

Testing

If you see numbers instead of text on the serial monitor, you may have used single quotation marks instead of double. Move the dial on the potentiometer to vary the reading. If you implement an echo in Step 4 but the text zips past too fast, try increasing your delay to 200 ms or more.

Stretch tasks

- Add a second potentiometer and echo the readings to the serial monitor.
- Swap a potentiometer for a temperature sensor and test your circuit. How would you identify the temperature with a real temperature sensor?
- Add a test so that: if you type "a" into the serial monitor, the reading of the first potentiometer is shown; if you type "b", the reading of the second potentiometer is shown; if nothing is typed then nothing is shown.
- Amend the previous stretch task to toggle between the two potentiometers by having a button that is pressed to toggle between them.

Final thoughts

Many sensors you will come across in the Internet of Things (IoT) are analog, and most are read in a very similar manner to the potentiometer. This project used the potentiometer because it's easy to vary the reading for testing. Sensors are one of the key things that make the IoT so powerful. Being able to sense (read) the condition of something means you can report or act upon that reading. Consider which conditions you could sense around your home and how you could act upon those readings to improve your quality of life or save electricity.

6. INTRODUCTION TO THE ARDUINO

Setting the scene

In this project you will start exploring the possibilities that an Arduino gives you to explore the world of the Internet of Things (IoT). You will do this by looking at what is included on the Arduino and how you can connect the Arduino to a computer. For the first time, you will be using a real piece of hardware. Many developers use emulators such as Tinkercad to develop their solutions, but it is essential to then test these thoroughly on real hardware, as sometimes things work differently in real life. While this project is in itself very simple, it will give you the skills needed to progress with the future projects.

Success criteria

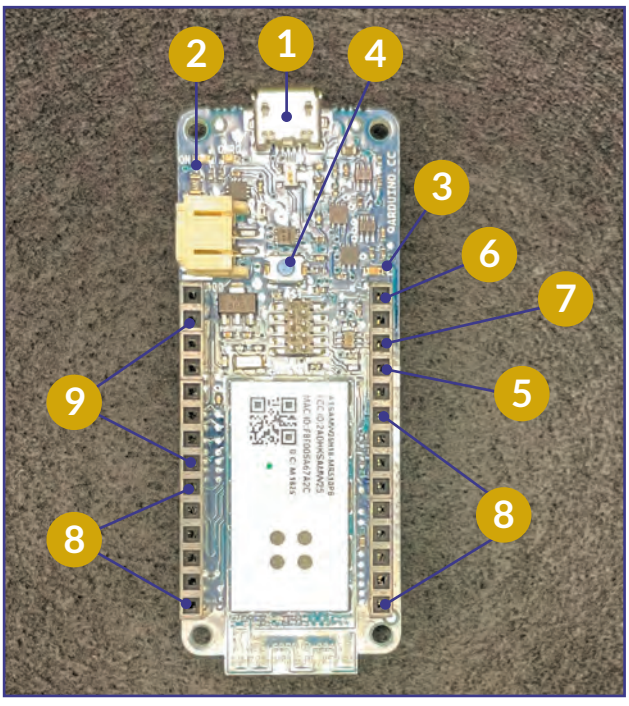
- Identify the key parts of an Arduino.
- Connect a shield to an Arduino.
- Connect an Arduino to a computer.
- Sign into Arduino Cloud.
- Load a sketch to an Arduino.

1

Arduinos vary by model, so it's a good idea to get to know the essential parts of your Arduino before you start plugging components into it. At best, if you get things wrong, your project won't work. At worst, you could damage components or your Arduino itself.

The essential parts you need to identify are:

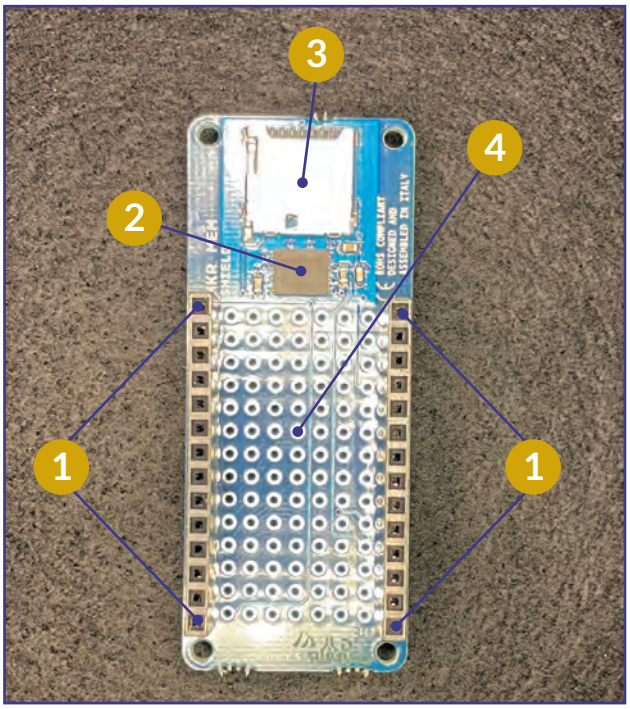
1. **USB socket:** *where you connect your Arduino to your computer*
2. **power LED:** *showing that the Arduino is plugged in and receiving power*
3. **built-in LED:** *useful for testing and indicating that things are happening*
4. **reset button:** *quicker than disconnecting and reconnecting your USB cable*
5. **ground pins:** *all circuits need to return to ground*
6. **5 V and 7 3.3 V pins:** *for providing power to your circuits*
8. **digital and 9 analog pins:** *for controlling components or reading from sensors*



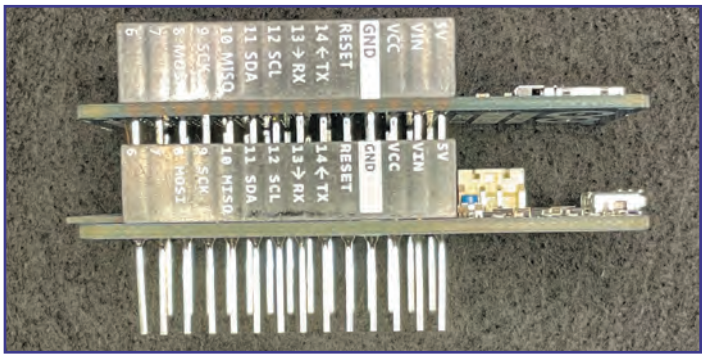
2

There is also a wide range of shields that you can use with your Arduino. Shields expand the functionality or connectivity of the Arduino. You can often build circuits on a shield before connecting it to the Arduino. Each type of shield has different parts. The MemShield has these parts:

1. **pins that mirror those of the Arduino**
2. **a memory chip**
3. **an SD card slot**
4. **a prototyping area where you can build circuits**



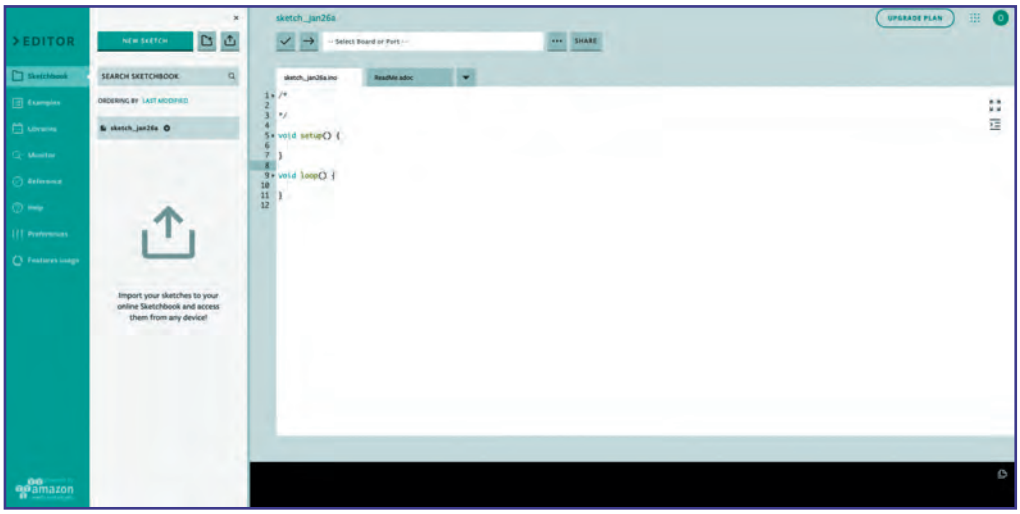
3



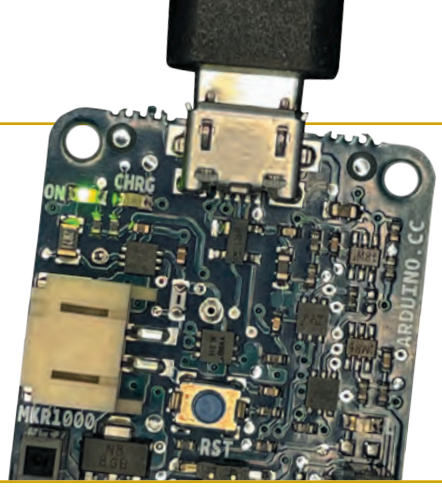
It is really important to plug the shield into the Arduino slowly and carefully. The pins are easily bent and can even snap off. It is just as important to unplug the shield carefully, as the shield has a tendency to twist as it comes out, which can bend the pins out of line.

4

When you are programming Arduinos, there are several applications that you can use. For the projects in this book, you will be using the web-based editor available at https://create.arduino.cc/. You will need to install the agent so that your web browser can connect to the Arduino.



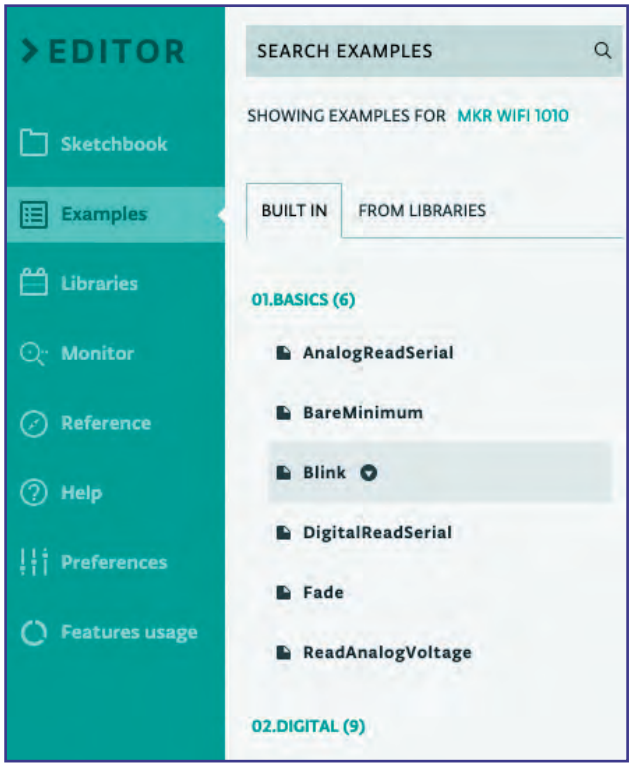
5



First, check that the Arduino and USB cable are working. When you plug one end of the USB cable into your computer and the other into the Arduino, the green power LED on the Arduino should light up. The built-in LED may or may not light up or flash depending on whether a test program was pre-loaded.

6

Next, ensure that the computer can connect to and program the Arduino. You should be able to select your Arduino from the drop-down menu at the top of the web editor. You can then choose **>EDITOR** from the left-hand side of the window, select **Examples** and then under **01.BASICS** select **Blink**. This will load the Blink code—called a sketch—into the editor. If the code looks familiar, that is because it is similar to the first program you emulated in Chapter 1!

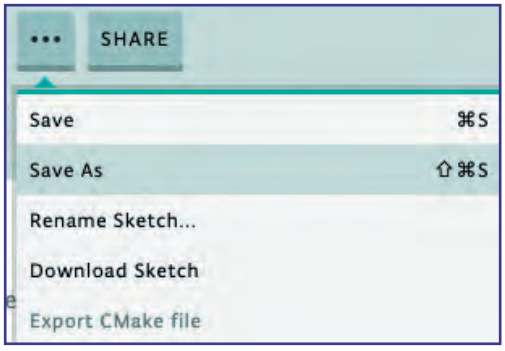


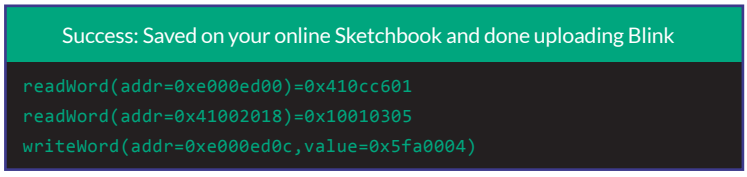
7

You now have two options. When you are typing in your own programs you can click on the **Verify** button (the check mark) to ensure your code will compile correctly. Once you are confident that your code will compile correctly, you can click on the **Upload** button (the arrow) to compile the code and transfer the program on to the Arduino. If this doesn't work, make sure you read the output carefully!

PRO *TIP*

If you want to read (and experiment with) the code, you will need to click the ellipsis (three dots) and save a copy of the code in your own area.





8

Hopefully this project will work out fine. (It should if you haven't changed any code!) Once the compilation and transmission are complete, the build-in LED on the Arduino should start flashing.

PRO TIP

As long as you don't change anything, there is no need to verify the Blink code. However, when you write your own sketches, verifying the code will help you track down problems and save you some time.

Testing

As this is only an introduction, not a lot should go wrong. If your Arduino does not show up in the window or the sketch fails to upload, check your USB cable connection. Try changing the cable, the USB socket, the adaptor if you use one, and ultimately the computer. If none of these changes fixes the problem, you may have a faulty Arduino.

Stretch tasks

This chapter was simply an introduction to the Arduino: what an Arduino looks like and how to connect it.

- In Chapters 1 to 4 you used an emulator to create some simple but useful circuits. Re-create those circuits and code using your real Arduino, to get used to using physical devices.
- Spend some time looking at the different Arduinos available at https://www.okdo.com/c/arduino-shop/arduino/. Identify the different features of each model. Create a comparison table.
- Spend some time looking at the different shields available at https://www.okdo.com/c/arduino-shop/arduino/. Create a comparison table for them. Identify the projects that you could complete with the different types of shield and add them to your table. Try ideating some ideas—you may be able to use your ideas in future projects.
- Run your Arduino on a battery without being plugged in to your computer. You may need to research how to "unblock" your serial port monitor as the Arduino won't be able to connect to the computer.

Final thoughts

Arduinos are powerful, yet tiny enough to fit almost anywhere. Most can run on batteries, and you have already seen some of the shields that can be used to extend their functionality. Think about some of the problems you could solve at home, at school, or in your community by linking an Arduino project to the Internet.

7. THE IOT CLOUD

Setting the scene

This chapter introduces the use of the Cloud. The Cloud forms an interface between us (using a web browser) and the hardware (the IoT) which enables us to control the hardware and react to sensor readings from anywhere. You will start by programming a simple button to turn on the LED.

The "Cloud" is one of the most exciting developments of recent years, with Internet-enabled heating systems, error-reporting fridges and even IoT coffee machines all helping everyday people to reduce their environmental impact; we are now able to control devices regardless of where we are and only when we need them, rather than relying on a "best fit" timer.

Success criteria

- Connect an external LED to the Arduino and ensure it works.
- Create a sketch that listens for a button press from the IoT Cloud and turns the LED on or off.
- Create a button in the IoT Cloud.
- Link the Cloud button to the sketch.

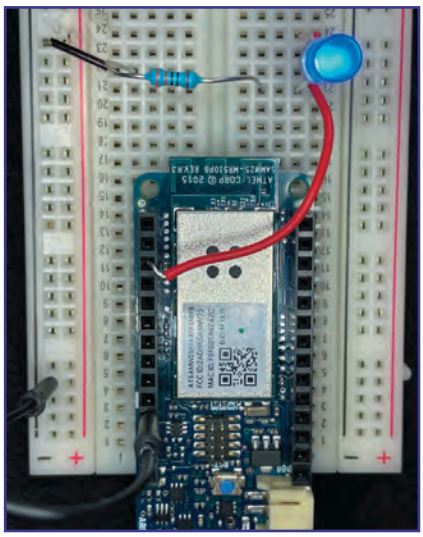
1

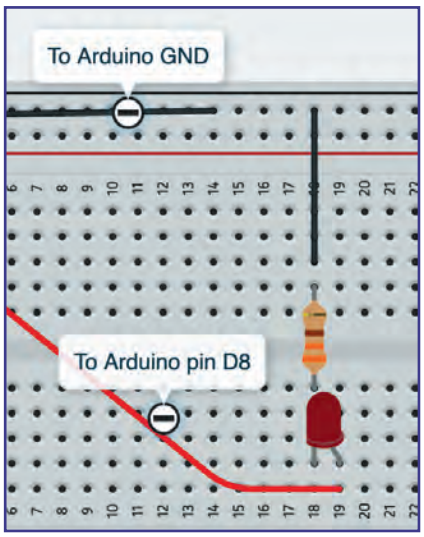
In this chapter you will build your first simple Cloud-based device. There are three main parts to this:

- a circuit, which will be controlled
- a piece of code on the Arduino, which will control the circuit and communicate with a web server
- a web-based dashboard, which will communicate via the web server with the Arduino code

2

The circuit you are going to create is a simple one. Connect an LED between the Arduino pin D8 and ground, via a resistor. The example shown here uses a 330 Ω resistor, but any resistor between 220 Ω and 470 Ω should be fine.





3

It is always a good idea to decompose problems and test each section separately. In this case, it is worth testing the circuit before you try to control it via the web. The **TheIoTCloud_Program1** sketch on the Arm GitHub repository will test the LED.

```
/*
  Test program to ensure external LED is working.
*/

int LED1 = 8;

// the setup function runs once when you press reset or power the board
void setup() {
  // initialize specified pin as an output.
  pinMode(LED1, OUTPUT);
}

// the loop function runs over and over again forever
void loop() {
  digitalWrite(LED1, HIGH);   // turn the LED on (HIGH is the voltage level)
  delay(1000);                // wait for a second
  digitalWrite(LED1, LOW);    // turn the LED off by making the voltage LOW
  delay(1000);                // wait for a second
}
```

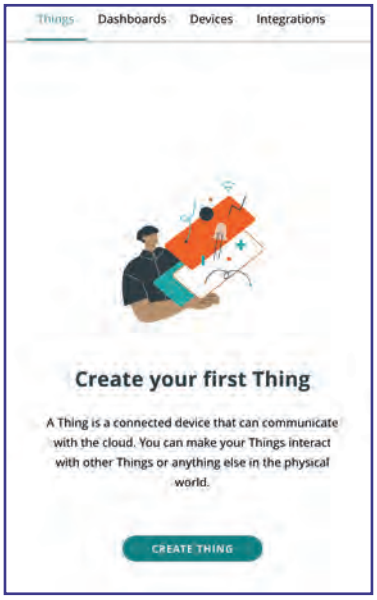
4

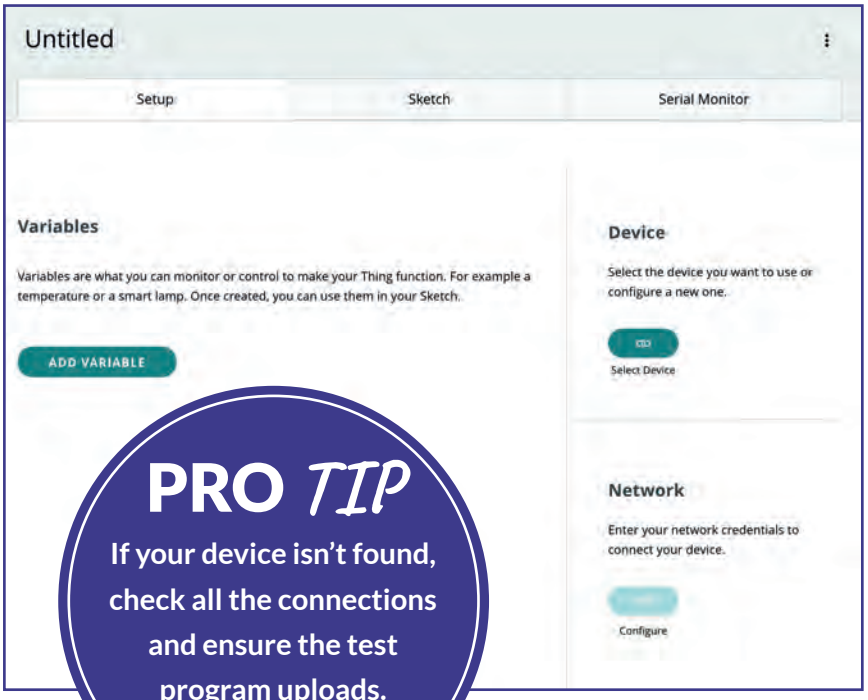
The first real difference to your work in Chapter 6 is that, instead of going to Arduino Web Editor, you will need to go to IoT Cloud. This allows you to create a *thing* (remember that IoT stands for Internet of Things).

5

To make Thing work you will need to do a bit of setup, which involves:

- adding a device (your Arduino), so the Thing knows which device will control the circuit.
- configuring network settings to enable the Arduino to connect to your WiFi network. The network settings will need to be the same SSID and password for wherever the device is going to be situated.
- adding a variable, which enables Things to happen. The dashboard you are going to create will change that variable, and the Arduino code will monitor the variable and act accordingly.





PRO *TIP*

If your device isn't found, check all the connections and ensure the test program uploads.

PRO *TIP*

If your device is showing as disconnected, come back and check this step. Both the SSID and password are case sensitive and must be exact!

6

The circuit in this project will light (or not light) an LED. The LED being lit will be a True or False state, called a Boolean. Create your variable and give it a sensible name (it is called **`LEDStatus`** in this example), set it to a Boolean, enable it to be both **Read & Write** and set it to update **On change**. Note that web editor will change some declarations to use a lower-case letter at the start. When this happens it is important that you use the same case when referring to it.

7

Once you have completed the setup, enter the sketch section of the thing. Happily, a lot of the code has been automatically generated for you! Use the same settings as in the test program.

- Create an integer variable to store the LED pin.
- Set the pin mode to output.

```
int LED1 = 8;

void setup() {
  // Initialize serial and wait for port to open:
  Serial.begin(9600);
  // This delay gives the chance to wait for a Serial Monit
  delay(1500);

  // Defined in thingProperties.h
  initProperties();

  // Connect to Arduino IoT Cloud
  ArduinoCloud.begin(ArduinoIoTPreferredConnection);
                     Text
  /*
     The following function allows you to obtain more infor
     related to the state of network and IoT Cloud connecti
     the higher number the more granular information you'll
     The default is 0 (only errors).
     Maximum is 4
  */
  setDebugMessageLevel(2);
  ArduinoCloud.printDebugInfo();

  // initialize specified pin as an output.
  pinMode(LED1, OUTPUT);
}
```

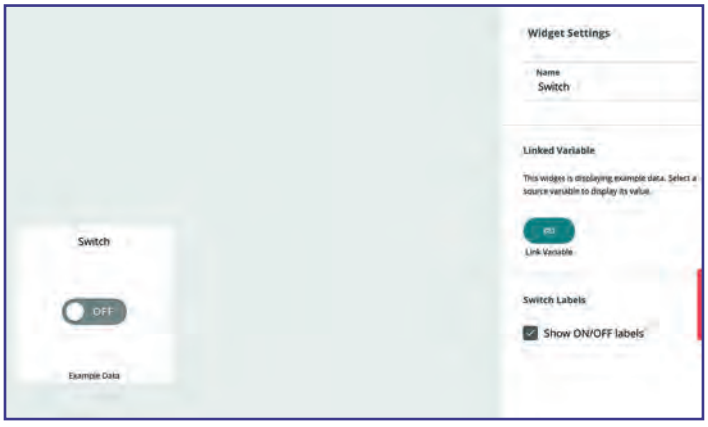
8

```
void onLEDStatusChange() {
  if (lEDStatus == true) {
      digitalWrite(LED1, HIGH);
  } else {
      digitalWrite(LED1, LOW);
  }
}
```

A function called **`onLEDStatusChange()`** will have been automatically created. This is called whenever the **`lEDStatus`** variable is changed by the web server. The LED can be turned on or off depending on the value of the variable. You can find the final code, **TheIoTCloud_Program2** on the Arm GitHub repository. A bit of extra code has been included for testing.

9

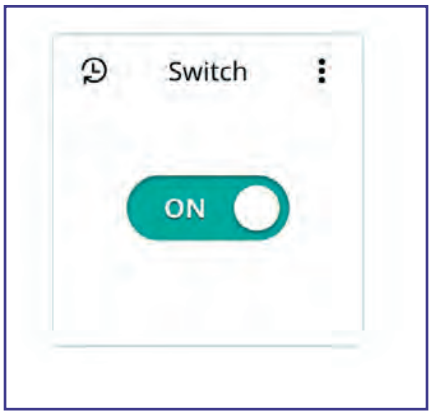
Once the code is all set up, you can develop the dashboard. While this sounds complicated, it is just a case of following a wizard to create a web page with your switch on **itClick** on the **Dashboard** link and add a widget—the LED is a Boolean, which can be either off or on, so it makes sense to choose a **switch** widget. Then link the switch to the variable **`lEDStatus`** that you created in Step 8.



10

Finally, transfer the completed sketch to the Arduino. To do this, go back to **Things** and, just like in Arduino Cloud, click on the **Upload** arrow. If all is well, you will see the usual blinking transfer lights and confirmation text.

11



Of course, the fun part is to test the whole thing out. Once your sketch has uploaded, go back to the dashboard and click the switch. The LED on the Arduino should mirror the status of the switch.

Testing

Flick the web-based switch to test that the LED turns on and off. Ask someone to log into a different WiFi network (or use a smartphone on cellular data) to prove that the connection is going across the Internet, not via the serial cable.

Stretch tasks

- Add a second LED that turns off when the main LED is on, and vice versa.
- Read the **TheIoTCloud_Program2** code on the GitHub repository to find out how to output serial messages. Include a message to state which LED is turning on or off.
- Keep a count of how many times the LED is turned on and output this count to the serial monitor.

Final thoughts

Wasted electricity is a worldwide problem. In 2018 it was estimated that £4.4 billion was wasted in Britain alone through lights being left on. The example in this project could simulate the lighting in your home, with each LED being a lightbulb in a room. Consider which other electrical devices you could turn on and off remotely using a website accessed from your mobile phone. You could decompose all of the connectable systems in your home and plan a series of sub-systems. How else could you use this technology to improve your lifestyle, while protecting the environment? This project has been one-directional with the Cloud service 'pushing' to the Arduino. In the next chapter you will look at communication in the opposite direction.

8. IOT SHOPPING LIST

Setting the scene

One of the major limitations of Arduinos is that they only have a finite number of pins. If you want to have a lot of inputs or outputs, you can very quickly run out of pins. In this chapter you will learn how to reduce the number of pins used by inputs by daisy-chaining several buttons together. You are going to set up an IoT shopping list, with a button for each item you wish to add to the shopping list. Not only are you learning useful skills, but you are also saving food waste!

Success criteria

- Connect a single button using a pulldown resistor.
- Connect additional buttons using a daisy chain of resistors.
- Read which button has been pressed.
- Codify which button is being pressed.
- Connect to the IoT server.
- Store data on the IoT server.

1

This project uses the power of resistors to reduce voltage flow, and the ability of the Arduino's analog pins to read a flow as a value between 0 and 1,023. You will use a simple analog reader code (similar to that used in Chapter 5) to echo the reading to the serial monitor.

```
int reading = 0;

void setup()
{
  pinMode(A0, INPUT);
  Serial.begin(9600);
}

void loop()
{
  reading = analogRead(A0);
  Serial.println(reading);
  delay(100);
}
```

2

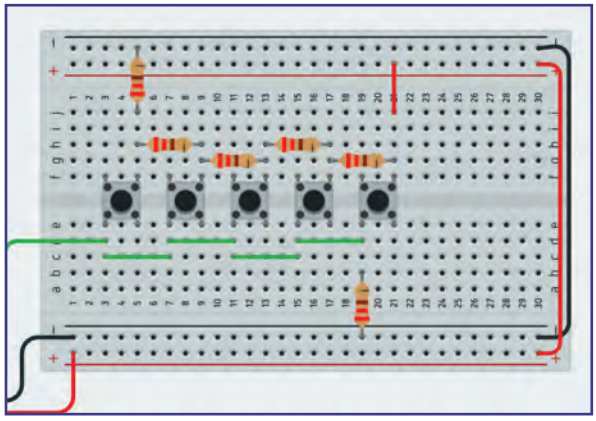
Put several buttons on the breadboard (daisy-chaining).

- Connect the left-hand legs together with short jumper wires.
- Connect the right-hand legs together with 220 Ω resistors.
- Connect the left-hand leg of the first resistor to the analog pin.
- Connect the right-hand leg of the first resistor with another 220 Ω resistor to ground.

PRO *TIP*

The exact value of the resistors isn't too important. 220 Ω resistors are commonly used with LEDs, so most makers often have lots of them!

- Connect the left-hand leg of the final button with yet another 220 Ω resistor to ground.
- Connect the 5 V wire to the right-hand leg of the final button.

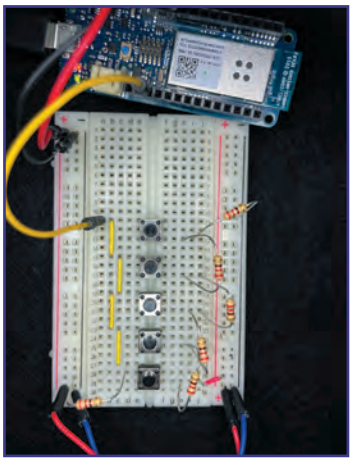


PRO *TIP*

Set the delay quite high so a single push is not recorded several times.

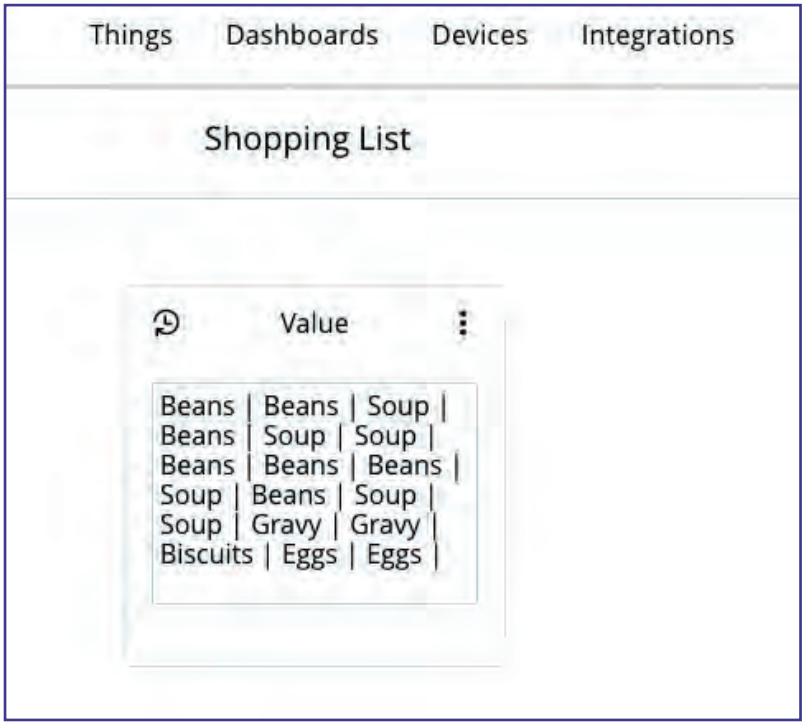
3

This type of circuit is called a *voltage divider* because the voltage of 5 V is split between the signal wire (the analog pin) and ground. When no buttons are pressed, the power flows through all the linked resistors to ground and nothing gets to the signal (which is pulled to ground by the final resistor you put in). When you press a button, the further along the row that button is, the more resistors the voltage has to flow through and so the more it is reduced. Write down the values of each resistor when you press each button.



4

Of course, shopping lists aren't much use if you can't access them in the shop! To make the device Internet-enabled, start by creating a new thing on Arduino Cloud. You will communicate using a string variable. Every time you press a button, you add a new food on to the end of the string. You will also need a dashboard with a "value" widget linked to the variable.



PRO *TIP*

If your Arduino shows as "disconnected" in the dashboard, double check the WiFi settings and try refreshing everything.

5

The code in the loop needs to check which button has been pressed. To do this, use an `if..else..if..else..if.. else` construct like the one you used in Chapter 4. However, due to variations in temperature and outside influences, you won't always get a nice steady number from the real buttons in the same way as when using the emulator. Therefore, it is important to test a range of values. Try testing about 30 either side of the values you wrote down in Step 4, just to be sure.

```
void loop() {
  ArduinoCloud.update();
  // Your code here
  reading = analogRead(A1);
  Serial.println(reading);
  if (reading > 150 && reading < 200) {
    shoppingList = shoppingList + "Beans | ";
  } else if  (reading > 230 && reading < 330) {
    shoppingList = shoppingList + "Soup | ";
  } else if  (reading > 400 && reading < 460) {
    shoppingList = shoppingList + "Gravy | ";
  } else if  (reading > 660 && reading < 720) {
    shoppingList = shoppingList + "Biscuits | ";
  } else if  (reading > 1000) {
    shoppingList = shoppingList + "Eggs | ";
  }
  delay(200);
}
```

Testing

The breadboard is getting quite busy with this project, so if things aren't working as expected, make sure everything is in exactly the right place. It's very easy to plug a resistor into the wrong column and then nothing works! Test your device with short and long presses or several presses at once. Adjust the timings or delays to make sure everything works as well as possible. Keep an eye on the serial monitor to see what is happening behind the scenes.

Stretch tasks

- Can you edit the code to enable you to reset the shopping list?
- Explore how many buttons you can add. (There are rumors of up to 50!)
- Can you add a button that sends the choice to the dashboard after the choice has been selected?
- Can you add indicator LEDs to show which button has been pressed?
- Sometimes you might accidentally double press a button. Explore "debouncing" to prevent this.
- In the testing section you ensured that long presses of the button only count as a single item. Adjust this so that for presses of longer than one second, each second the button is held adds another item of the same type (so holding the "beans" button for three seconds will add three tins of beans).

Final thoughts

Although this may seem like a silly little project, up to 6.6 million tonnes of food waste a year are thrown away in the UK alone. Shopping smart and only buying what is needed is the best way to combat food waste. How many buttons, and how many devices, would you need to create a shopping list that combats food waste in your home? Consider whether you would need to have a single set of buttons, or some near the refrigerator, some near the cupboards, and so on.

9. AIR QUALITY SENSOR

Setting the scene

In previous chapters you have read data, both digital (on or off) and analog (continuous), from devices such as buttons and potentiometers. With enough knowledge, time, and perseverance, you can build complex devices using combinations of simple input devices and sensors. More commonly, however, you will find a sensor device that has already been created for your purpose, so you just need to apply your experience of reading values from a pin and acting on those values.

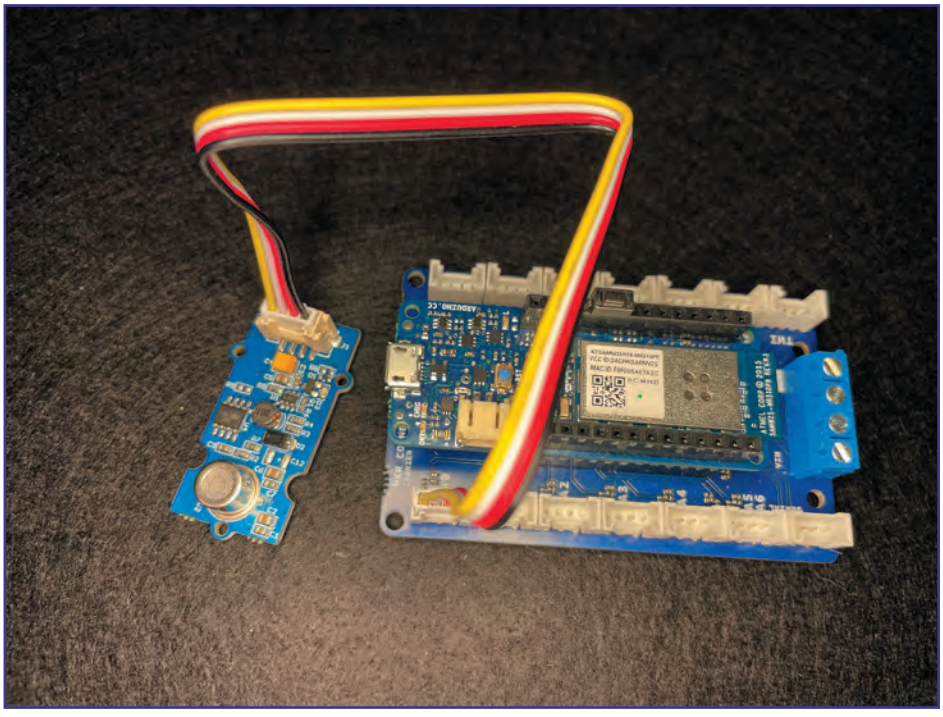
In this chapter, you will use an air quality sensor, pre-developed by Grove, to read the air quality around you and report it to the serial monitor.

Success criteria

- Connect the Arduino to the Grove MKR connector carrier.
- Connect the air quality sensor to the carrier.
- Initialize the sensor.
- Read and output the current air quality reading.
- Read and output the current air quality pollution value.

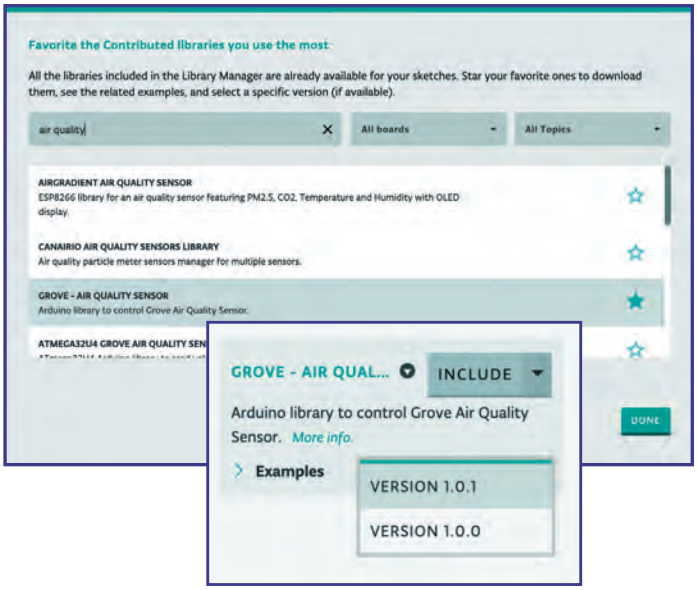
1

The air sensor used here is part of the Grove system. Grove has a connectivity system used across their range of sensors. You simply push your Arduino into the carrier, being careful not to bend the legs of the Arduino. Then plug the wire from the sensor into one of the slots on the carrier. The image shows the wire plugged into A0, which is linked to Analog 0 on the Arduino.



2

Libraries are often available to help you use additional hardware or software without having to write the low-level code yourself. Grove produces a library called "Air_Quality_Sensor.h" to connect with the sensor. You may have it installed already, but if not, it is available from the Grove website and needs to be installed before you can use it.



3

Sensors often have to be initialized within the code. The first part of initialization is to create a reference to the code object, giving it a name, and in this case telling the object which pin to use to communicate with the sensor.

```
AirQualitySensor sensor(A0);
```

4

Grove states that the sensor takes 2 minutes (120,000 ms) to warm up, although it should start working within about 20 seconds (20,000 ms). Therefore, it is worth inserting a message in the code to tell the user there will be a delay, and adding the delay to the code before the initialization routine is called, `init()`.

`init()` is quite helpful because it returns "True" if it initializes, so you can use an "if" construct to check whether it worked or not.

```
Waiting for sensor to initialize.
Sensor ready.
Attempting to connect to SSID:
LinkDog
Connected to wifi
SSID: LinkDog
IP Address: 192.1681.72
signal strength (RSSI):-43 dBm
Sensor value: 54
Fresh air.

Sending Data to Server...

Data Sent
Sensor value: 49
Fresh air.

Sending Data to Server...

Data Sent
```

PRO *TIP*

If the first message doesn't show, this is because the serial monitor isn't ready yet either. Some sketches use `while (!Serial)` to wait for the serial monitor to initialize, but this will block the whole program if the device has no serial monitor (for example, if it is running off a battery and not plugged in to a computer), so a 10-second delay before outputting anything may be a better choice!

5

For the sensor to work properly, you need to tell the sensor to work out the variation from the previous reading. To do this, call the `.slope()` function.

Then, to get the air quality, call the `.getValue()` function of the `sensor` object. This value could be printed out directly or stored in an integer variable for later use.

Both `.slope()` and `.getValue()` are *methods* that belong to the `sensor` *object*. Objects form the basis of object-oriented programming.

```
void loop() {
  sensor.slope(); //Update variation
  int quality = sensor.getvalue(); //Get the sensor reading
  Serial.print("Sensor value: ");
  Serial.println(quality); //Output the reading
  delay(10000); //10s delay
}
```

PRO *TIP*

If nothing is changing, your air quality must be super stable! Try breathing on the sensor for a while to increase the carbon dioxide levels.

6

Although you now have a value representing the air quality, it's not clear what this value means. Luckily the "AirQualitySensor.h" module has some pre-defined values that you can use. These equate to integer values, and are returned by the `.slope()` function that you used earlier. If you save that value in an integer, you can use `if..else..if..` statements to output relevant messages. To access built in values, use the module name, two colons, and then the name of the value, for example:

```
if (pollutionValue == AirQualitySensor::FORCE_SIGNAL) { … }
```

The values available are `FRESH_AIR` (hurrah), `LOW_POLLUTION` (not great), `HIGH_POLLUTION` (this could be a problem), and `FORCE_SIGNAL` (you really need to get out of there!)

```
int pollutionValue = sensor.slope(); //Update variation
int quality = sensor.getValue(); //Get the sensor reading
Serial.print("Sensor value: ");
Serial.println(quality); //Output the reading
if (pollutionValue == AirQualitySensor::FORCE_SIGNAL) {
  Serial.println("Force signal - get out now!");
} else if (pollutionValue == AirQualitySensor::HIGH_POLLUTION) {
  Serial.println("High pollution - this could be bad!");
} else if (pollutionValue == AirQualitySensor::LOW_POLLUTION) {
  Serial.println("Low pollution - this could be worse but it's not great.");
} else if (pollutionValue == AirQualitySensor::FRESH_AIR) {
  Serial.println("Fresh air - hurrah!");
}
delay(10000); //10s delay
```

Testing

It's quite hard to test the values thoroughly, but it can be interesting to leave the sensor somewhere where the air quality gets quite bad—if you use a laptop, you could put it near the back of a car. Just be careful not to breathe any polluted air yourself: make sure you step away from the vehicle before the engine is started. This project really does show the limitations of tethered devices (devices which are connected to a computer). You will learn how to de-tether your device from the computer in the next chapter.

Stretch tasks

- Most devices are not linked to a computer that can display serial output—it would be more useful to use a visual indicator at this point. Add LEDs that show what is happening. You could use green for clean air, orange for low pollution, and red for high pollution.
- Try making the LEDs flash when pollution is very high and then run the device from a USB battery pack without being connected to a computer.
- Explore different locations around your home that may have differing air quality. Record the values in your bedroom, the kitchen, the lounge, and differing parts of your garden and compare the results.
- Push the readings to the Arduino Cloud IoT dashboard and use the built-in widgets to display as a graph.

Final thoughts

Grove has a large system of sensors. Explore the Grove website and identify some of the other sensors that are available. What sensors could you combine to make a system that would benefit your local environment? Consider whether that system would need to be IoT-enabled or whether it could provide all the necessary information without linking to the Internet through the use of lights or sounds. Air pollution in the UK alone is believed to contribute to 40,000 premature deaths a year; so if you discover any interesting results, do consider sharing your findings to raise awareness.

10. STORING IOT DATA IN A SPREADSHEET

Setting the scene

In Chapter 9, you used the Grove air quality sensor to collect air quality data and, if you completed the Stretch task, published it to the Arduino Cloud as a graph. Sometimes, however, you might just want to log data in a spreadsheet so you can do your own analysis.

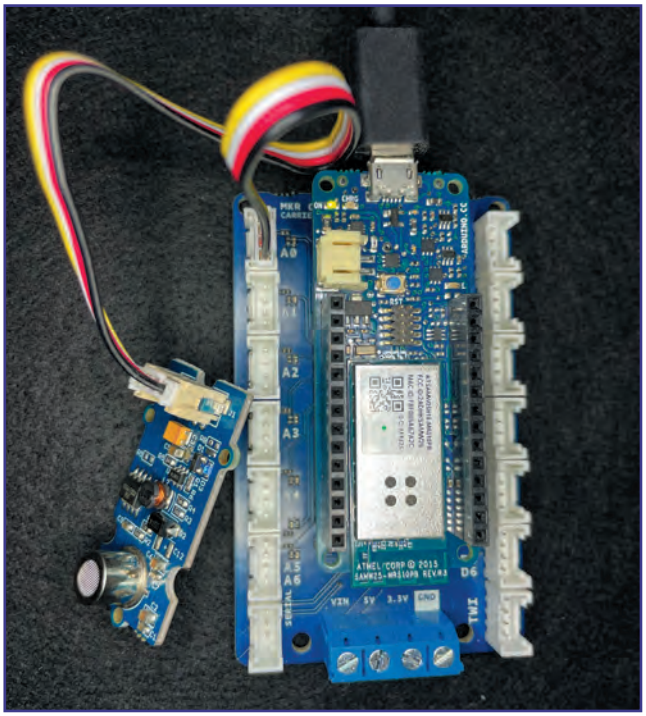
In this chapter you will learn a lot of new concepts: you will write code to handle the WiFi connection; you will use a "middleware" service; and you will store data in the Google Cloud Platform. By logging data into a spreadsheet, we are then able to carry out detailed analysis that will enable us to spot trends and, hopefully, to act upon them. If you identify poor air quality in your bedroom at certain points of the day (such as rush hour) you can close your window at these times to protect your own health.

Success criteria

- Create a Google Sheets spreadsheet to store data.
- Create a Google script to insert data to the spreadsheet.
- Create a middleware link between the Arduino and the Google script.
- Connect to WiFi directly from the Arduino.
- Write the data from the Arduino to the Google spreadsheet.
- Automatically identify concerning values on the spreadsheet.

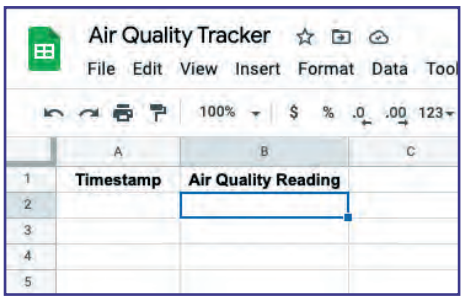
1

This chapter will cut out the Arduino Cloud, so you need to connect your Arduino to the air quality sensor and collect data periodically in Arduino Cloud. This is very similar to what you did in the previous chapter, although you only need to collect data every 10 seconds or so. Do note that this chapter has quite a lot of detail to complete and may take longer than previous chapters.



2

The best way to complete this project is in reverse, building the system from the spreadsheet backwards. First, create a Google sheet with the headings you want; in this case a timestamp and an air-quality reading. You will need to copy the part of the sheet URL between /d/ and /edit and save it somewhere—this is called the **sheet reference**. You should make any formatting changes to your spreadsheet at this time.

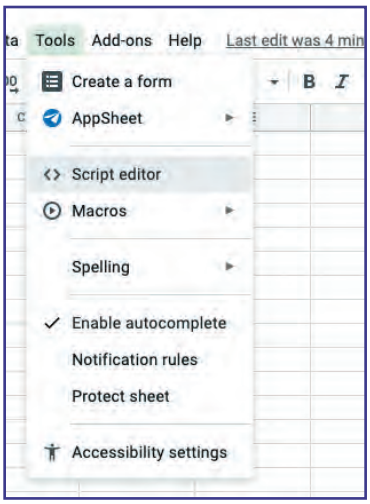


PRO *TIP*

Rather than trying to copy down long alphanumeric strings by hand for Steps 2 and 4, create a notepad file where you can paste these strings for future reference.

3

You are going to create a script (**Tools > Script editor**) that is attached to the spreadsheet and will receive the data from the sensor and put it in the right place. A script is a piece of programming that acts as *middleware* that sits on the server to receive data from the Arduino and put it into the spreadsheet.



4

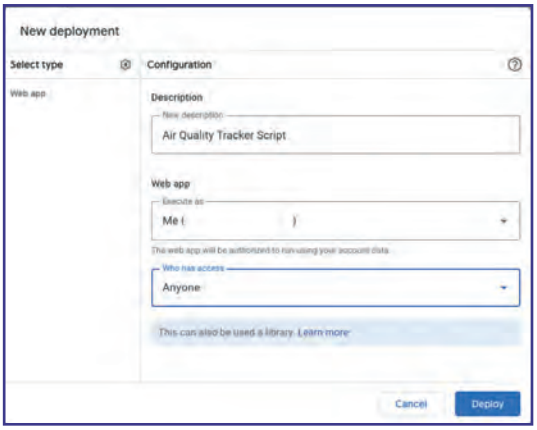
You can get the Google script code directly from the Arm GitHub repository and paste it into your project. This code has two functions:

- One function simply removes quotation marks that can cause problems.
- The other function goes through the data received from the sensor, adds a timestamp, and then adds the data into a new row on the spreadsheet. All you have to do is enter your sheet reference where indicated.

```
//---------------------------------------------
// Based on code byWe  Mogsdad@Stackoverflow,
// jarkomdityaz.appspot.com and Stephen Borsay
//---------------------------------------------

//Receives parameters on query string and inserts
//in order.

//Add data to spreadsheet on next available row
function doGet(e) {
  var result = 'Ok'; //assume success
  if (e.parameter == undefined) {
    result = 'No parameters provided';
  } else {
    var id = 'enter sheet reference here';
    var sheet = SpreadsheetApp.openById(id).getActiveSheet();
    var newRow = sheet.getLastRow() + 1;
    var rowData = []
    rowData[0] = new Date(); //Add the timestamp in to column A
    for (var param in e.parameter) {
      var value = stripQuotes(e.parameter[param]);
      rowData[rowData.length] = value; //Add parameter to rowData
    }
    var newRange = sheet.getRange(newRow,1,1,rowData.length);
    newRange.setValues([rowData]); //Write the new row to the sheet
  }
  return ContentService.createTextOutput(result);
}

function stripQuotes(value) {
  return value.replace(/^["']|['"]$/g, "");
}
```

5

After saving the script, make sure you deploy the script as a new **Web app**, ensuring that **Anyone** can access it. Then authorize the script. Make sure you copy the web app URL.



PRO *TIP*

If you edit the script, you will have to redeploy it; just pressing save won't pass the changes through to the active code.

6

Assuming your Arduino code is reading the sensor data into `aqReading` correctly, there are just a few steps you need to carry out in order to connect to the WiFi network and send the data through. You will need to:

```
AirQualitySensor sensor(A0);
const char WEBSITE[] = "script.google.com";
const int SSLPORT = 443;
const char* MY_SSID = "GDog";
const char* MY_PWD =  "AnnaDillan69^^";
const char DEPLOYMENTID[] = "AKfycbw18w4KH-41l1sFI6Hn5LbKjppGixVUS-zPwL7E2z0ZW1IDKk-GM-GH";

int status = WL_IDLE_STATUS;

WiFiSSLClient wifi; //Wifi connection
HttpClient client = HttpClient(wifi, WEBSITE, SSLPORT); //SSL client
```

1. Include the WiFi101 library.
2. Include a character string pointing to the website (api.pushingbox.com) and another with your device ID from PushingBox.
3. Define your WiFi SSID and password.
4. Set up a status integer.

7

Connecting to WiFi is as simple as `status = WiFi.begin(MY_SSID, MY_PWD)` ; in the set-up routine. Sending data, however, is a bit harder. A client WiFiClient object needs to be created, and then connected to the website on port 443 (the default port for secure connections). Once connected, it needs to send a request to the server (using client.get), which sends the data string to the server. The server will return a code—Google normally returns 302 (which points you to go to a different URL) or 200 (which means ok). These need to be handled and, if the code is 302, then the data needs to be resent to that location.

```
//Send data to Google sheet
Serial.println("\nSending Data to Server...");
//Build send string
String URL = (String) "/macros/s/"+DEPLOYMENTID+"/exec?"
  + "aqReading=" + (String) aqReading;
String newFullURL; //Create new full URL in case of redirect
client.get(URL); //call the web file
int statusCode = client.responseStatusCode(); //Get the response code
Serial.print("Status code: ");
Serial.println(statusCode);
if (statusCode == 302) { //Response code 302 means redirect
  while(client.headerAvailable()) //Go through headers
  {
    String headerName = client.readHeaderName();
    String headerValue = client.readHeaderValue();
    if (headerName == "Location") { //Get the location header for redirect
      newFullURL = headerValue;
    }
  }
  newFullURL.remove(0,8); //Remove protocol
  String newHOST = newFullURL.substring(0,newFullURL.indexOf("/")); //Get host
  String newURL = newFullURL.substring(newFullURL.indexOf("/")); //Get file link
  HttpClient client2 = HttpClient(wifi, newHOST, SSLPORT); //Connect to new web file
  client2.get(newURL); //Get the new response
  statusCode = client2.responseStatusCode(); //Check the new status code - should be 200
  Serial.print("Status code: ");
  Serial.println(statusCode);
}
```

8

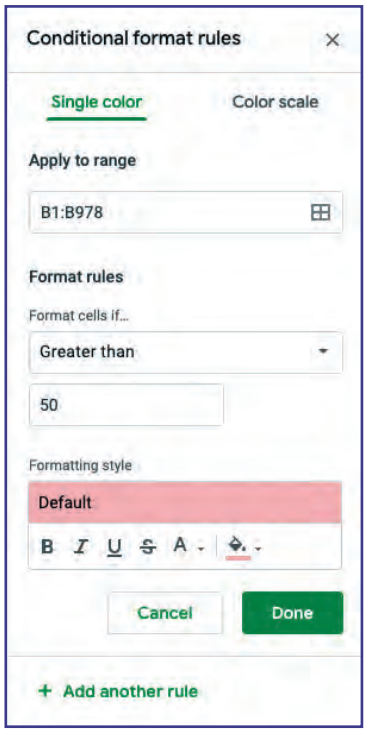
If all goes as plan, you should see your Arduino connect in the serial monitor, and then data starts appearing in your spreadsheet.

```
Waiting for sensor to initialise.
Sensor ready.
Attempting to connect to SSID:
LinkDog
Connected to wifi
SSID: LinkDog
IP Address: 192.1681.72
signal strength (RSSI):-43 dBm
Sensor value: 54
Fresh air.

Sending Data to Server...

Data Sent
Sensor value: 49
Fresh air.

Sending Data to Server...

Data Sent
```

A	B
Timestamp	**Air Quality Reading**
2/19/2021 16:19:46	30
2/19/2021 16:19:56	30
2/19/2021 16:20:06	62
2/19/2021 16:20:16	36
2/19/2021 16:20:26	33
2/19/2021 16:20:36	32
2/19/2021 16:20:46	31

9

Google sheets has a function called **Conditional formatting** (Format > Conditional formatting). By selecting column B, then conditional formatting, you can set all values above a trigger value to highlight as red.



PRO *TIP*

If all does not go as planned, there is a `printWiFiStatus()` routine in our sketch that might help you track down WiFi related problems.

Testing

Don't be tempted to increase the delay speed between posts too much because Google might think you are a spammer and block you. If things don't work out, try working backwards one step at a time from the spreadsheet.

If the air quality where you are is too good to vary much, try breathing on to the sensor while it is reading. The CO_2 in your breath will appear to be pollution.

Stretch tasks

- The serial monitor tells you what the different signals mean as well as the raw reading. Log this data to a separate column in the spreadsheet.
- Add conditional formatting to highlight clean air as green, and air which is moving towards unclean but not yet polluted as yellow.
- Can you alter the Arduino code to only log changes in value?
- Identify changes which are minimal (caused by the sensor fluctuating) and adjust your code so that it does not record these; for example, if the changes are less than ±2 of the previous reading, you may choose to disregard them.

Final thoughts

This has been quite a complex project with a number of sub-systems (Google Sheets, Google scripts, PushingBox and Arduino) all having to work together to achieve your goal. This is quite a common scenario. Remember, the systems used in-between are called *middleware*.

Where could you place your air quality sensor to capture useful data about air quality? What adjustments do you think you would need to make to the device to make it work in the real world? In the previous chapter we discussed the impact of pollution on health; large scale monitoring is important but requires consideration of power and connectivity. It may be worth contacting local groups who might collaborate to share data and build up a larger map of pollution levels.

11. PEDOMETER

Setting the scene

Step counters, better known as pedometers, are very widely used. Many people set themselves a target of 10,000 steps a day. What you might not know is that this number became the standard because it was included in the name of an early Japanese pedometer from 1964. The pedometer was called "Manpo-kei", which means "10,000 steps meter". Possibly more important than achieving a number of steps is walking at an appropriate rate, which is surprisingly hard to do.

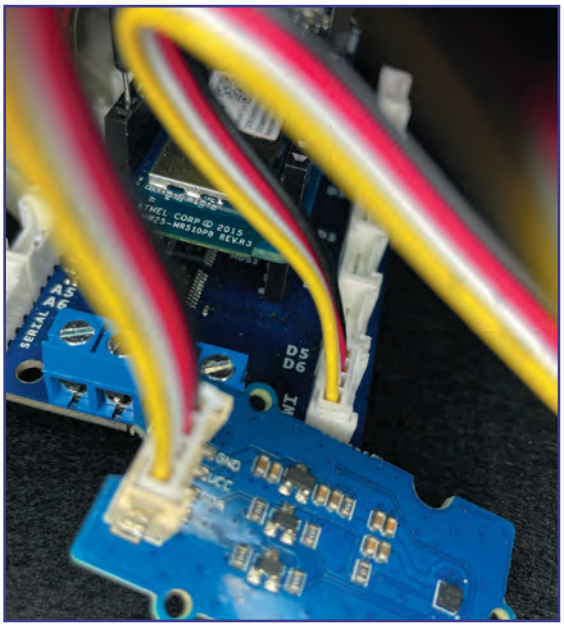
In this chapter, you will learn some new skills: how to translate accelerometer data into a number of steps; how to produce audible output using a piezo buzzer; how to use an RGB LED; and how to use an Arduino that is stand-alone and not connected to a computer. All of this will support you in building a device that will help you learn to walk at an appropriate rate and maintain that rate.

Success criteria

- Connect an accelerometer and piezo buzzer to the Arduino.
- Read data from the accelerometer data and display it on the serial monitor.
- Analyze the data to identify walking rates.
- Connect an RGB LED and piezo buzzer to the Arduino.
- Make the RGB LED change color and the piezo buzzer sound depending on walking rates.
- Give audio output given when the walking rate becomes too slow.

1

In this chapter you will be connecting an external device, an accelerometer, to the Arduino. The example shown in this chapter uses a Grove accelerometer. Grove devices have special connectors so you will need to plug the Arduino into a Grove shield and then connect the accelerometer into the socket labelled TWI.



2

Once connected, you might need to install a library. The 16g accelerometer used in the images requires the Grove 3-Axis Digital Accelerometer library, which you can download from the GitHub repository. It comes with a test program which outputs the raw data to the serial monitor. Although the numbers in the raw data seem meaningless as they are, you will notice that they vary when you move your accelerometer (and you can shake it quite hard to get some large readings!).

```
-171.87,-429.69,916.02,23
-158.20,-427.73,912.11,23
-164.06,-431.64,923.83,23
-167.97,-429.69,917.97,23
-169.92,-421.87,917.97,23
-179.69,-421.87,917.97,23
-160.16,-425.78,925.78,23
-167.97,-427.73,912.11,23
-169.92,-427.73,910.16,23
-162.11,-419.92,917.97,23
-167.97,-421.87,914.06,23
-169.92,-431.64,923.83,23
-164.06,-437.50,925.78,23
-162.11,-425.78,914.06,23
-164.06,-425.78,919.92,23
-164.06,-423.83,925.78,23
-173.83,-421.87,916.02,23
-167.97,-421.87,925.78,23
-164.06,-433.59,914.06,23
-167.97,-429.69,921.87,23
-162.11,-421.87,917.97,23
-179.69,-421.87,929.69,23
-162.11,-427.73,914.06,23
-166.02,-421.87,904.30,23
-167.97,-435.55,919.92,23
-162.11,-429.69,912.11,23
-167.97,-425.78,917.97,23
-171.87,-437.50,914.06,23
-173.83,-425.78,908.20,23
-162.11,-429.69,916.02,23
-166.02,-421.87,904.30,23
-167.97,-429.69,917.97,23
-164.06,-421.87,910.16,23
-164.06,-429.69,923.83,23
-164.06,-425.78,904.30,23
-169.92,-433.59,921.87,23
-164.06,-425.78,923.83,23
-162.11,-421.87,917.97,23
-167.97,-419.92,919.92,23
-164.06,-435.55,925.78,23
-164.06,-429.69,921.87,23
-164.06,-423.83,916.02,23
-158.20,-431.64,925.78,23
-166.02,-423.83,919.92,23
-166.02,-429.69,923.83,23
```

There are a variety of complex mathematical methodologies, often involving Machine Learning, which you can implement over the data to detect steps. However, if you simulate stepping by holding the accelerometer flat and tapping your hand against the table, you may notice something in the data; as you tap the table, some of the values (in our case, x) change from negative to positive. You can capture that change to identify a step.

3

It is often useful to base your program on existing working code—you could use the example code which comes with the accelerometer, for example. By adding some new floats (**oldX**, **oldY**, and **oldZ**) it is possible in the loop to copy the existing **x**, **y**, and **z** readings into the **oldX**/**oldY**/**oldZ** variables, then get new values and compare the two. If the old value was < 0 and the new one is > 0, then they have changed! It is worth experimenting with your pedometer to find out whether x, y or z is going to give you the best step detection.

```
void loop(void) {
  oldx = x; //Save the old values
  oldy = y;
  oldz = z;
  bma400.getAcceleration(&x, &y, &z); //Get the new values

  if (oldx < 0 && x > 0) { //If it changed in x from negative to positive G
    step(); //have a step
  }

  delay(50); //Wait before checking again.
}
```

Note: Floats are *real* numbers that have decimal parts, unlike the *integers* (whole numbers) that we have been using so far.

4

To detect the *rate* of walking, the easiest thing to do is measure the time between the current step and the previous one. The Arduino includes a function called **millis()**, which tells you how many milliseconds have passed since it powered on. Take the time of the previous step away from the current time to find the elapsed time. You can then decide on "good" intervals, "bad" intervals, and "risky" intervals, and act accordingly.

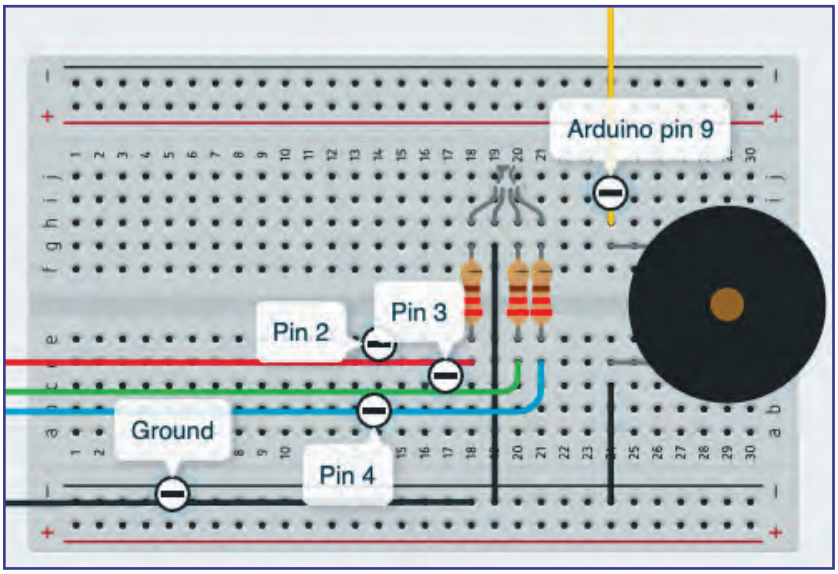
```
void step() { //A step has happened
  oldTime = newTime; //Save the old time
  newTime = millis(); //Get the new time
  elapsedTime = newTime - oldTime; //Figure out the difference
  Serial.print(elapsedTime);
  Serial.println();
  if (elapsedTime > badRate) { //Step was too long?
    //do something bad!
  } else if (elapsedTime > warnRate) { //Almost too long!
    //do somthing less bad
  }
  else { //All good
    //do something good
  }
  delay(100); //Wait so as to avoid double-steps
}
```

millis() is a built-in function which is included (automatically) in the Arduino libraries.

5

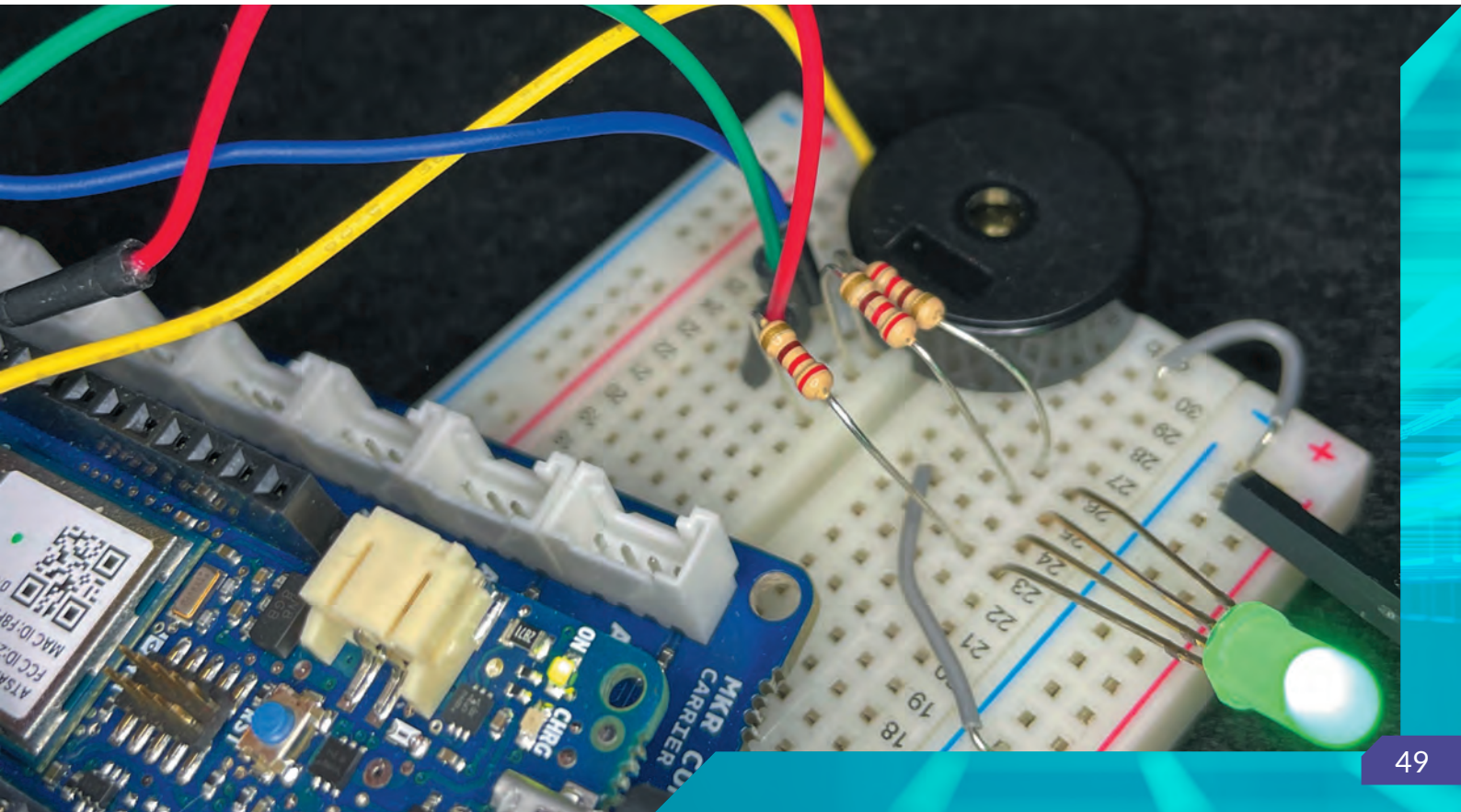
It is a fair assumption that you won't be carrying your computer around with you when you go out for a walk. The Arduino will have to work from a battery pack and communicate with you in some other way. You can use a piezo buzzer, to which we can send signals. (The higher the signal in hertz, the higher the sound.) You can also use an RGB LED, which is actually three LEDS (red, green, and blue) in one component. By mixing how much power each LED receives, you can produce almost any color!

- Connect the buzzer to an output pin, such as 9, and ground.
- Connect the RGB LED to three output pins that support PWM (Pulse Width Modulation). These are normally labelled with a ~. In the example in the image, pins 2, 3, and 4 have been used.
- Run each of the pins through a 220 Ω resistor, and connect the final pin to ground.



PRO *TIP*

You can identify the RGB LED pins as follows: the longest pin is normally ground; the single pin next to ground is red; the shortest pin is blue; the remaining pin, between blue and ground, is green.



6

Arduinos are well set up for controlling buzzers. The `tone()` function takes two parameters: the pin the button is connected to, and the signal (in hertz or Hz) to play. (A parameter is a piece of information that is passed into a routine for it to use `tone(buzzer, 1000);` will therefore play a 1,000 Hz signal. 1,000 Hz is quite a high tone, while 200 Hz is quite a low tone. After a delay, `noTone(buzzer)` will turn the buzzer off.

```
void descending() { //A descending tone for signalling
  tone(buzzer, 1000); // Send 1KHz sound signal...
  delay(200);
  tone(buzzer, 500); // Send 500Hz sound signal...
  delay(200);
  tone(buzzer, 200); // Send 200Hz sound signal...
  delay(200);
  noTone(buzzer);     // Stop sound...
}

void buzz() { //The warning 'buzz'
  tone(buzzer, 1000); // Send 1KHz sound signal...
  delay(200);         // ...for 1 sec
  noTone(buzzer);     // Stop sound...
}
```

The function `descending()` plays 1,000 Hz, then 500 Hz, then 200 Hz for 200 ms each. This function is used as a signal to tell the user that the Arduino is working.

The function `buzz()` plays 1,000 Hz for 200 ms when the user takes too long to take a step.

PRO *TIP*

If you are running your Arduino from a battery and the buzzer doesn't buzz, make sure you've disabled the `while(!Serial)` line. This line blocks the program until it can set up a serial connection, and if there's no wire, there's no serial connection!

7

It is a little harder to control RGB LEDs. To make a particular color, you need to know how much of each color (red, green, blue) is needed, using a value for each color between 0 and 255. You can find the RGB values by searching the Internet for "RGB [color name]", e.g., "RGB pink". Use an `analogWrite()` command to send the relevant value to each pin of the RGB LED. The function `RGB_color()`, shown here, takes the three values (red, green, and blue) and writes the values to the pins.

```
void RGB_color(int red_light_value, int green_light_value, int blue_light_value) {
  //Write an RGB colour to the RGB LED
  analogWrite(red, red_light_value);
  analogWrite(green, green_light_value);
  analogWrite(blue, blue_light_value);
}
```

8

The `step()` function makes calls to the `RGB_color()` and `buzz()` commands as appropriate. You will probably need to experiment a bit to get the correct values for the time differences!

```
void step() { //A step has happened
  oldTime = newTime; //Save the old time
  newTime = millis(); //Get the new time
  elapsedTime = newTime - oldTime; //Figure out the difference
  Serial.print(elapsedTime);
  Serial.println();
  if (elapsedTime > badRate) { //Step was too long?
      buzz(); //Buzzing
      Serial.println("Step - bad rate"); //Notify
      RGB_color(255,0,0); //Red light!
  } else if (elapsedTime > warnRate) { //Almost too long!
      Serial.println("Step - warning rate"); //Notify
      RGB_color(255,255,0); //Yellow light
  }
  else { //All good
      Serial.println("Step - good"); //Notify
      RGB_color(0,255,0); //Green light
  }
  delay(100); //Wait so as to avoid double-steps
}
```

Testing

This project may well need a lot of testing.

- First, decide on an orientation for your accelerometer and stick to it.
- Then take a really good look at the data and decide which plane you will take for registering the step: x, y or z.

  If double steps are being counted, increase the delay time.

  If not enough steps are being counted, try reducing the delay time.
- Finally, plug in a battery (such as a mobile phone auxiliary battery pack) and go for a walk. You will probably have to tweak, or "dial in", the elapsed times you use to trigger a warning as well as what counts as a "good" pace.

Stretch tasks

- Alter the buzzes to give different messages rather than just "good".
- Add buttons or potentiometers to adjust the elapsed times without having to reprogram.
- Research "pedometer code" on the Internet to allow the program to identify a step regardless of the accelerometer orientation.
- Carrying an Arduino around in your hand isn't comfortable. Build a way of attaching the pedometer and a battery pack to your arm or to your clothing.

Final thoughts

IoT devices are very rarely plugged into computers and often have to go relatively long periods of time before reporting back to base. This project has shown you two ways to interact with a user when "offline".

Pedometers have been around for a long time (the 10,000 step pedometer was launched in 1964!), but with the advent of IoT it is not necessary for devices to be completely stand-alone. Think about how you could boost the power of your pedometer warning device by adding functionality and taking it online. What impact could this have on your own exercise?

12. BASEBALL OR CRICKET BAT METRICS

Setting the scene

More and more professional sportspeople are using Machine Learning and wearable technology during training to monitor and improve their performance. If a runner can identify small changes in their posture that reduce muscle strain, or a cyclist can identify a slightly more effective stance that will reduce wind resistance, then they increase their chances of winning. The knock-on effect is that developments in techniques and equipment like running shoes is passed down to ordinary people, so we can all run with fewer injuries and cycle with less resistance.

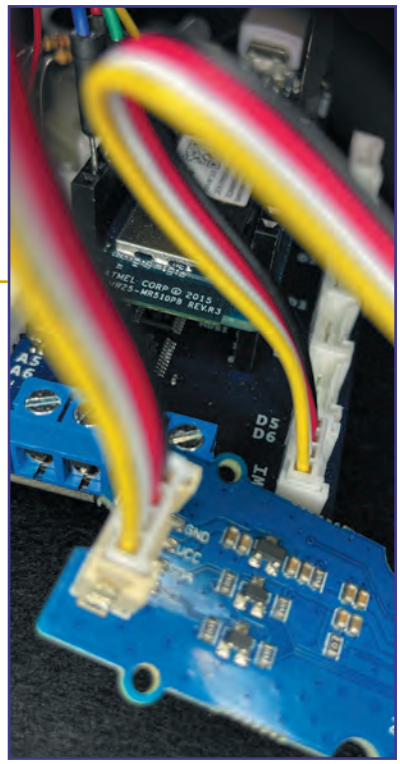
In this chapter you will learn how to attach an accelerometer to a cricket or baseball bat and measure wirelessly how G-forces change during a swing.

Success criteria

- ☑ Connect an accelerometer to the Arduino.
- ☑ Use the Arduino to measure G-forces.
- ☑ Connect a button to the Arduino to collect a sequence of G-forces.
- ☑ Write the G-force sequence to a Google Sheets spreadsheet ready for analysis.
- ☑ Connect the system to a baseball bat or cricket bat.
- ☑ Analyze the data to identify a "hit" and a "miss".

1

As in previous chapters, the accelerometer is connected to the Arduino by using a Grove plug to the MKR connector carrier.
It is essential that the accelerometer is plugged into the TWI socket (see https://www.arduino.cc/en/reference/wire).



2

After including the BMA400.h file, and the accelerometer has been connected, initialize it. As this may take some time, it is worth putting it into a loop with a delay and outputting to the serial monitor when it is completed. You won't have access to the serial monitor in the final system, but this will help you get a feel for when the accelerometer is ready.

```
while (1) {
    if (bma400.isConnection()) {
        bma400.initialize();
        Serial.println("BMA400 is connected");
        break;
    } else {
        Serial.println("BMA400 is not connected");
    }

    delay(2000);
}
```

3

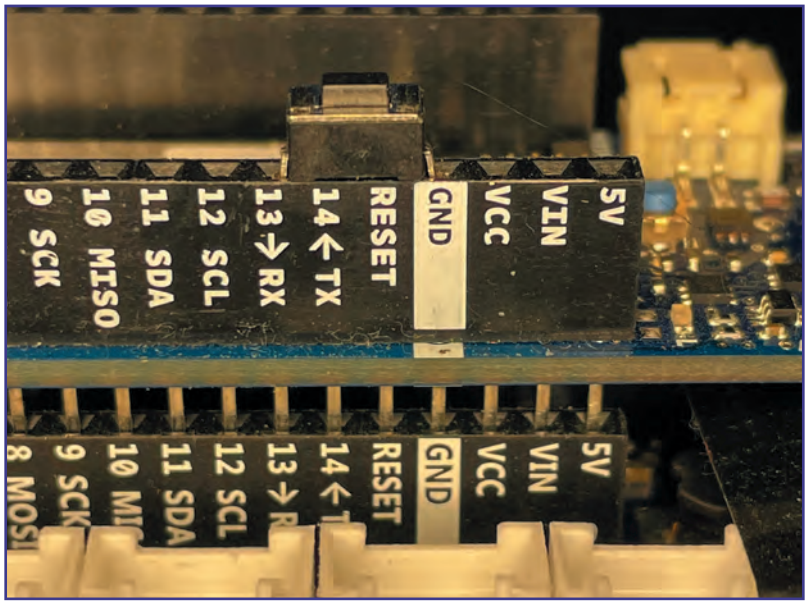
The G-force measurement requires a little bit of maths. The X, Y and Z acceleration can be read into three floats (x, y and z seem like suitable names!). These give you measurements in three planes. You can use Pythagoras' theorem to calculate the overall force.

- Square each of the forces.
- Add them together and then find the root of the sum. This will give you a micro-G-force (g).
- Divide by 1,000 to get the overall G-force.

```
bma400.getAcceleration(&x, &y, &z);
double g = sqrt(x*x+y*y+z*z);
g = g / 1000;
```

4

One G-force reading isn't going to be a lot of use for analysis, however. You need the system to read a sequence of G-forces quickly over time. To do this, connect a small button between the GND and pin 14 on the Arduino. Set this up as `INPUT_PULLUP`, so it can be checked and used to trigger a sequence of measurements.



5

After a bit of experimentation, 200 seems to be a good number of readings to capture.

Set up an array of 200 doubles using the line `double readings[200];`. Then use a loop over a pre-set counter (initialized to –1) to take 200 readings at 20 ms intervals and add them into the array. The readings are triggered by the button setting the counter to 0.

Note that an array is a clever way for us to structure data. We can contain, in this case, 200 related pieces of the same type, all in the same variable, and access them just by using an *index* number.

```
while (readingsCount >=0 and readingsCount < 200) {
  bma400.getAcceleration(&x, &y, &z);
  double g = sqrt(x*x+y*y+z*z);
  Serial.print((g/1000));
  Serial.print(",");
  readings[readingsCount] = g/1000;
  readingsCount++;
  delay(20);
}
```

6

The method for sending data to the Google Sheets spreadsheet for analysis is very similar to the methods you used in Chapter 10. Two key points are:

- Remember to update the deployment ID so you are sending data to the correct Google spreadsheet.
- Concatenate (join together) the 200 readings into a comma-separated list so that they can be sent as a single variable. You know that there are 200 readings, so you can use a **for** loop.

As a rule of thumb, if you know how many times you are going to do a loop, then you use a *for* loop; if you don't, you use either a *do…while* loop (if you need to repeat at least once) or a *while* loop (if you might not need to repeat at least once).

```
String URL = (String) "/macros/s/"+DEPLOYMENTID+"/exec?"
  + "data=";
for (int i = 0; i < 200; i++) {
  Serial.print(readings[i]);
  Serial.print(",");
  URL += readings[i];
  URL += ",";
}
```

7

```
var newRow = sheet.getLastRow() + 1;
var rowData = [];
rowData[0] = ""; //Leave blank for name
for (var param in e.parameter) {
  var value = stripQuotes(e.parameter[param]);
}
Logger.log("Here");
Logger.log(value);
var datapoints = [{}];
datapoints = value.split(",");
Logger.log(datapoints);
for (var dp in datapoints) {
  rowData.push(datapoints[dp]);
}
var newRange = sheet.getRange(newRow,1,1,rowData.length);
newRange.setValues([rowData]); //Write the new row to the sheet
```

The script attached to the Google spreadsheet will have to be a little bit different for this application. It needs to take the single data string, split it on the commas to give the 200 readings again, and loop through that array to insert them into the spreadsheet. The full script code (**Code.gs**) is available on the Arm GitHub repository.

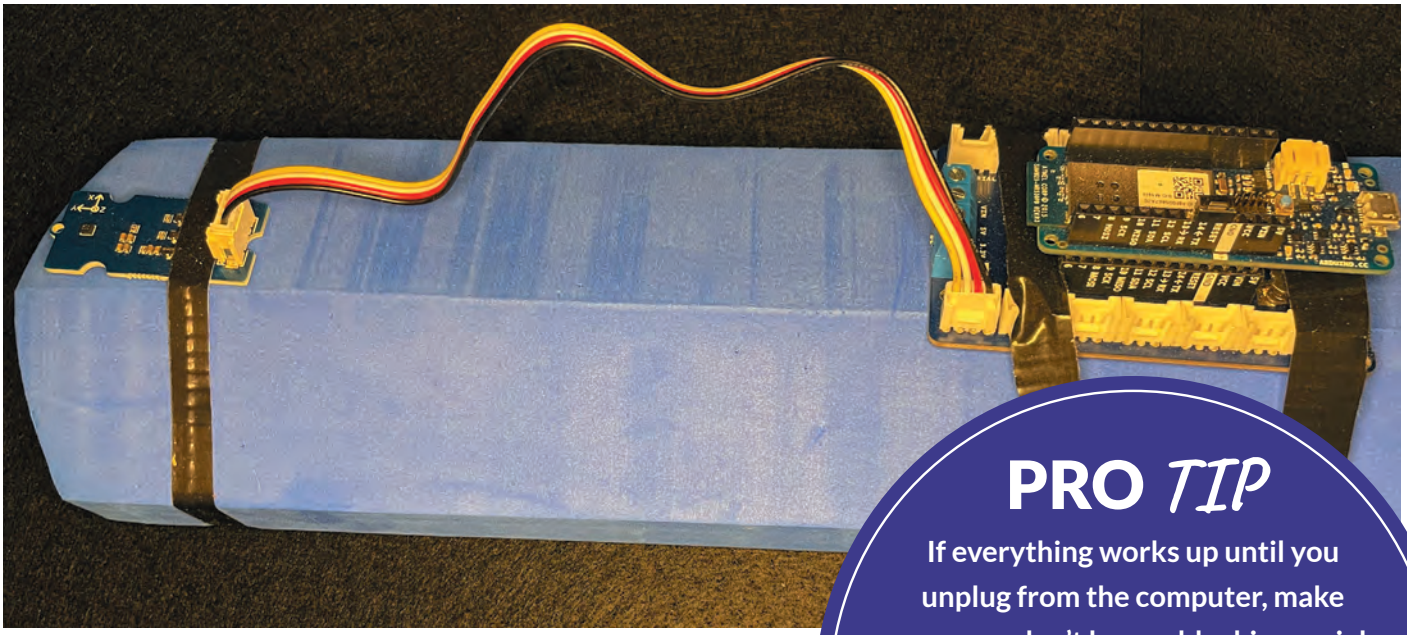
8

At this point, once you have checked that everything is working, you can set up your bat. The type of bat doesn't really matter. The bat shown in the image below is a soft cricket bat, which has flat surfaces for attaching the equipment. Because it is soft, it is less likely to do too much damage if you accidentally let go of it.

PRO *TIP*

Once the battery is in use, you will no longer be able to see data on the serial monitor. It is a good idea to test everything with the system connected to the bat but still connected to the computer, before you finally plug in the battery.

It is absolutely essential to use non-conductive tape and that the tape is as strong as possible. The image shows thin strips of duct tape wrapped right all the way around the bat.
The accelerometer needs to be as close to the tip of the bat as possible, as that is probably where the G-forces will change the most. The cable is connected to a battery pack, which the user puts in their pocket.

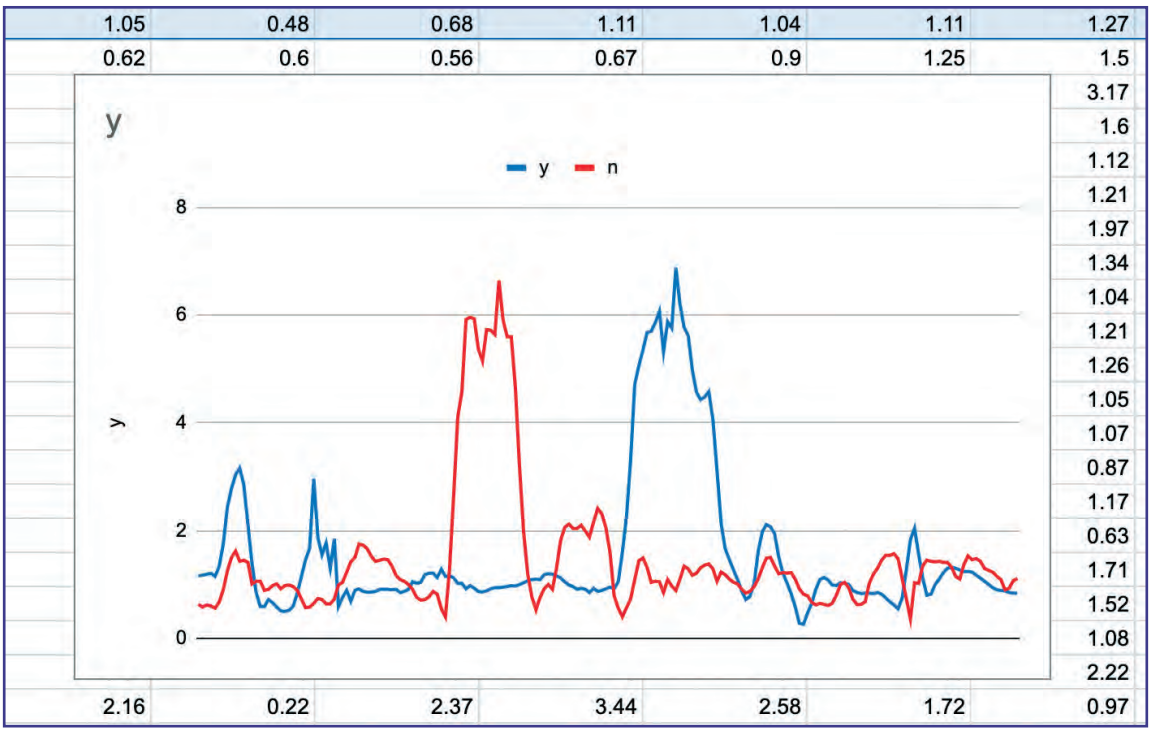


PRO *TIP*

If everything works up until you unplug from the computer, make sure you don't have a blocking serial monitor. Begin the serial monitor then wait (for example, for 10,000 ms) rather than using a `while (1)` or `while (!Serial)` loop around it. This is one of the essential parts of de-tethering.

9

Once everything is connected securely, take some test swings and make sure the data is feeding through. Create some charts of the data to aid in your analysis. It is up to you to draw your own conclusions about what the data means!



1.05	0.48	0.68	1.11	1.04	1.11	1.27
0.62	0.6	0.56	0.67	0.9	1.25	1.5
						3.17
						1.6
						1.12
						1.21
						1.97
						1.34
						1.04
						1.21
						1.26
						1.05
						1.07
						0.87
						1.17
						0.63
						1.71
						1.52
						1.08
						2.22
2.16	0.22	2.37	3.44	2.58	1.72	0.97

Testing

This project will take quite a bit of time to test. It is best to work in a group of three: one to throw the ball, one to (hopefully) hit the ball, and one to record whether the result is a hit or a miss. It is worth deleting any glancing blows, as you may find you have more parity between your results without these distractors.

Stretch tasks

- This project collects a single, non-directional G-force. Adjust the system in order to record the forces in the x, y, and z planes as well as the non-directional force.
- Look at the results you have logged (either for non-directional or separate planes) and see if you can identify patterns. It may be easier if you plot some of the results on a chart. Can you, as a human, detect the difference between a "hit" and a "miss"?
- Change the number of readings being made. Identify the optimal number without wasting data.
- Change the frequency of readings being made. Identify how quickly you can read them before you run into problems.

Final thoughts

In 1912 the men's indoor pole-vaulting World record was 4.02 m. In 2020, the world record was 6.18 m, which is over 50% higher. This same pattern can be seen throughout sport. There is no one magic bean that allows sportspeople suddenly to become better, but better knowledge about what they are doing and how they are doing it has a large impact. Find out about the ethical arguments for and against the use of technology to improve sporting performance. What are your own opinions on this issue?

Anyone who spends time in the gym or has a heart monitor on their wrist knows that IoT devices abound in the sporting world. Every advance in the technology gives us more data and more opportunity to increase the general health of everyone. Consider whether you are willing to share your personal data from IoT devices, knowing that the data may be used for other purposes as well as monitoring health.

13. BIODOME (PART 1)

Setting the scene

A biodome is a sealed and self-contained environment designed to sustain life. In this chapter you will explore some of the functionality provided by the Arduino MKR ENV Shield. You will use this functionality to monitor and control your own biodome environment by turning on lights as needed and enabling an air circulation fan.

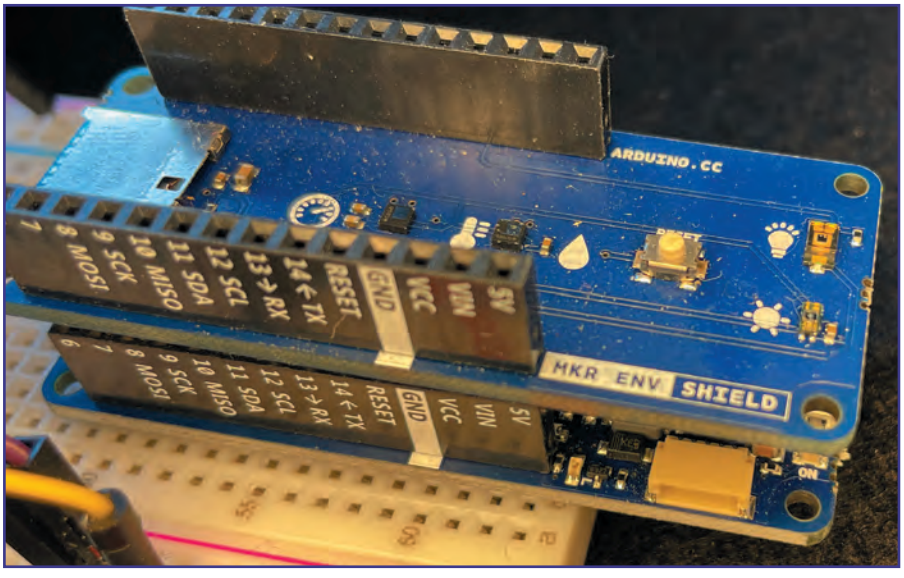
It is not suggested that you try to maintain any form of animal living accommodation with this system without very careful supervision. Plants are a lot hardier than the average hamster, gold fish or sibling.

Success criteria

- Connect the MKR ENV Shield to the Arduino and examine the sensor readings available.
- Connect and enable four bright white LEDs on a timer.
- Connect and enable a fan motor using a motor driver on a timer.
- Make the lights also turn on according to a sensor reading.
- Make the fan also turn on based on a sensor reading.

1

The Arduino MKR ENV Shield is a tremendously powerful piece of hardware. It provides information on temperature, humidity, pressure, illuminance, and a range of ultraviolet information. Connect the shield by plugging it directly into your Arduino headers (the sockets at the top of the Arduino). Be very careful not to bend the pins.



If you want to mount the shield somewhere at the top of your biodome, you might need to extend it using jumper wires. In this case, you will need to extend +5V, GND, 6, 7, 11, and 12 for most of the sensors, and A2 for the light sensor. If you want to use the SD card, you will need yet more jumper wires! You can then search for ENV in the Arduino examples file and look at the sensor readings on the serial monitor.

2

Connect four bright LEDs independently to resistors (220 Ω is a good value) and to a common ground. Then connect each LED to one of the unused digital pins (you can use pins 1, 2, 3 and 5 as 4 is used by the SD card). Set these as output pins and set them as "HIGH" for 12 hours of the day, and "LOW" for 12 hours of the day.

Without an Internet connection, an Arduino does not know the current time. You could get the current time over WiFi, but let's save that for a later chapter (you will learn the skills in Chapter 17). For now, assume that you will turn on the Arduino at midday exactly. Include `<Time.h>` in your code to make time functions accessible. Then use `setTime()` at the start of the `setup()` routine to initialize the time to 12:00 (the date doesn't matter).

You can then implement one or more conditions. For example, if you want the lights to be on all night, the conditions would be:

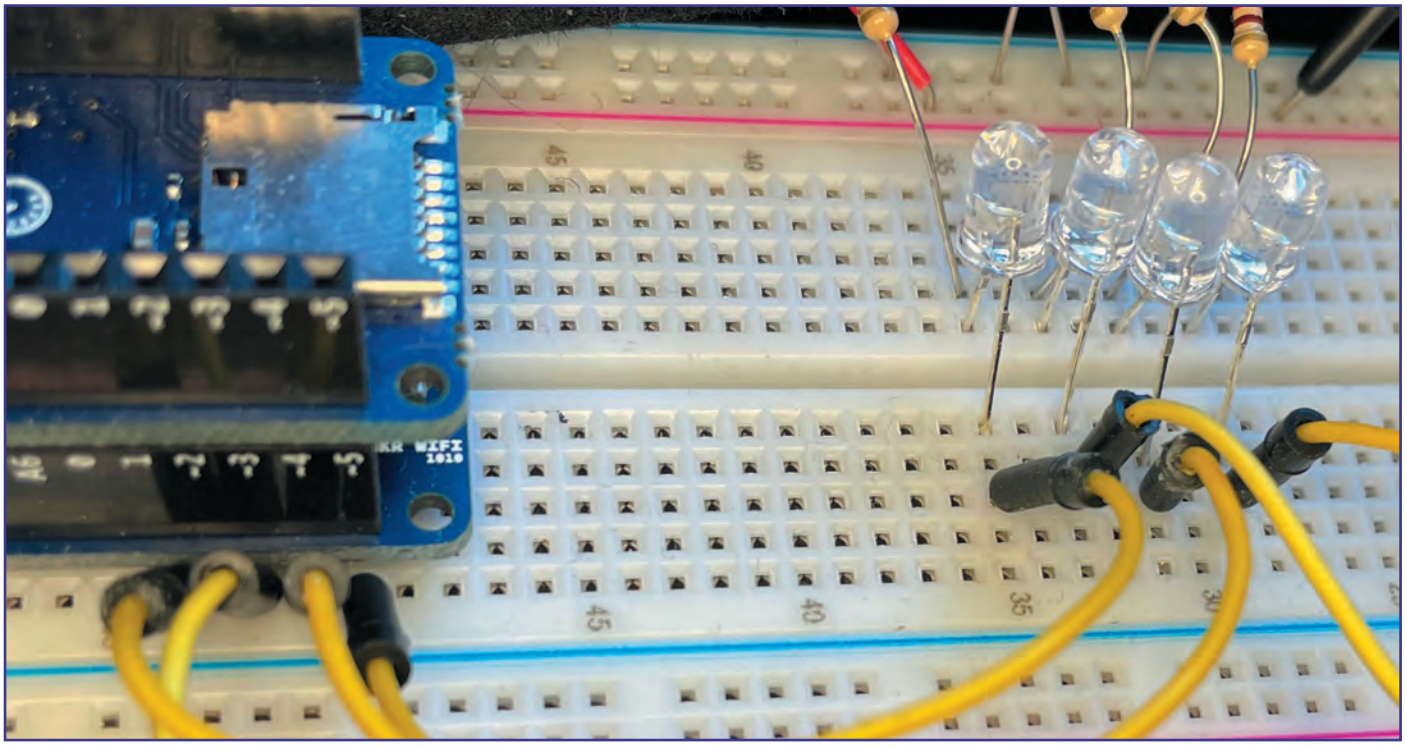
```
time_t t = now(); //get the time
if (hour(t) >=19 or hour(t) < 7) {
turnOnLights();
} else {
turnOffLights();
}
```

This enables the lights between 19:00 and 06:59.

PRO *TIP*

Sometimes even LEDs demand more power than an Arduino can provide. If this is the case, you can use transistors in a way similar to the motor driver for the fan to use an external power supply.

Note that these LEDs may not produce the light that plants need to grow. They do, however, work as a good indicator that the plants need more light.

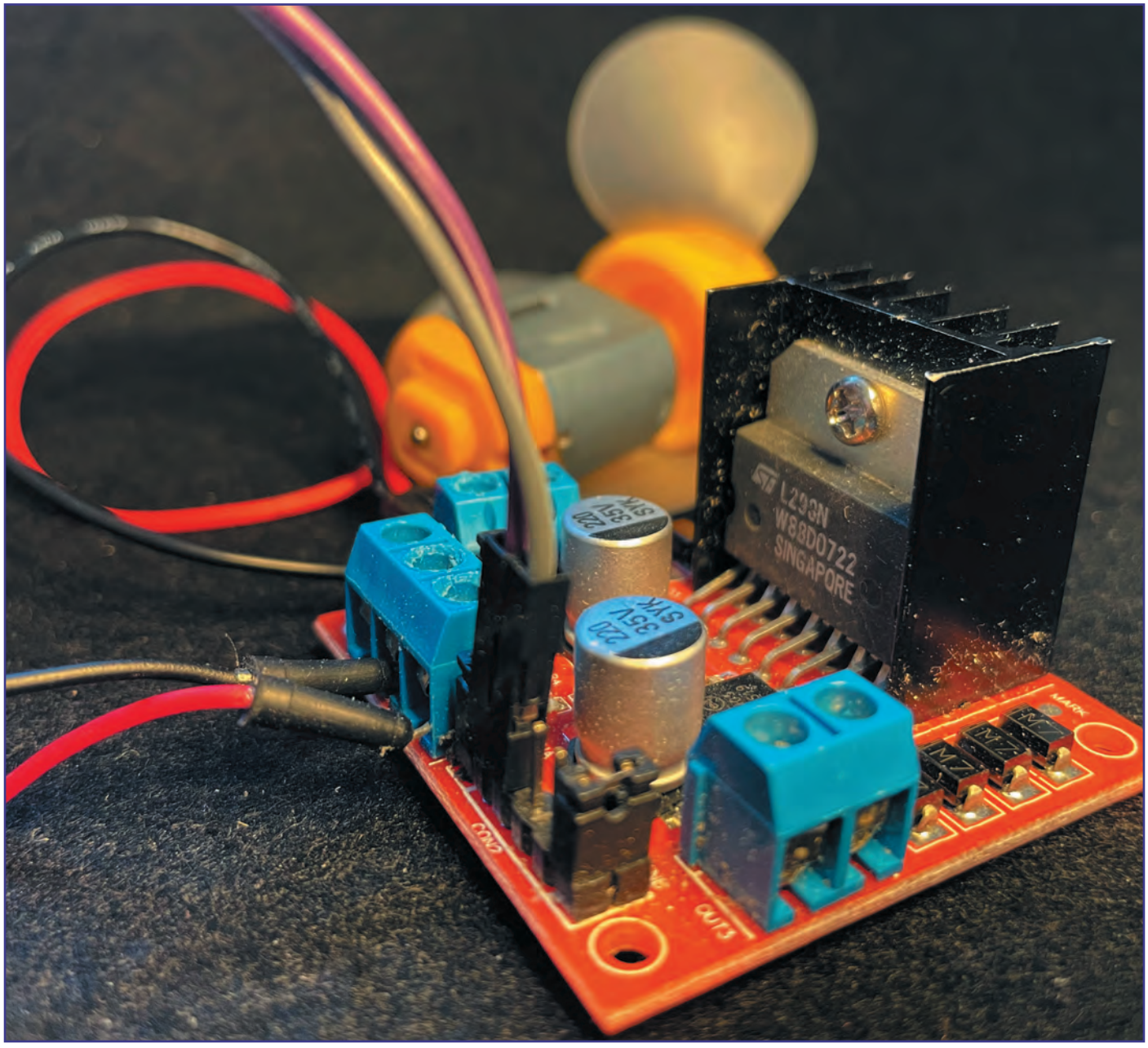


3

Fans are a bit trickier to set up than LEDs. Fans use motors, which draw a lot more power, particularly on start-up, than an Arduino can provide. An L298N device can enable an Arduino to turn a motor on or off, while allowing the power to be drawn from somewhere more suitable such as batteries or a mains adaptor.

The simple circuit shown in this example is connected as follows:

- The motor of the fan is connected to OUT1 and OUT2 (it doesn't matter which way round).
- The power supply is then connected to the power block on the front, with ground in the middle and +5 V from a battery pack on the right.
- Finally, Arduino pins 8 and 9 are connected to the L298N pins IN1 and IN2. When both are high (or both low) the motor stops; when they are opposite the motor spins. Condition can be used, testing the current minute and spinning the fan for the first 15 minutes of every hour in a similar way to the code at the end of step 2.



4

Decide what the minimum luminescence should be. Set this as a constant to be easily changeable. Then combine the condition that turns the lights on or off with an **or** operator that compares the current illuminance reading with the minimum needed.

```
//Turn the lights on or off
time_t t = now();
Serial.println(hour(t));
Serial.println(minute(t));
if (hour(t)>=22 or hour(t)<7 or illuminance < minIllum) {
  turnOnTheLights();
} else {
  turnOffTheLights();
}
```

5

Decide on a maximum temperature and set this as a constant. Then combine this into the condition that turns on the fan.

```
if (minute(t)<0 or temperature > maxTemp) {
  turnOnFan();
} else {
  turnOffFan();
}
```

Testing

You can test this project quite easily by varying the current time you set. To test the illuminance, simply put your hand over the MKR ENV Shield and see if the LEDs turn on. To test the fan, set the maximum temperature to just below the current temperature, then hold the fan close to the sensor. The fan will cool the sensor down, which should turn the fan off. The sensor will then heat up again and repeat the process.

Stretch tasks

- The code used in Steps 4 and 5 used constants. No numbers should be hard-coded into working code, so go through the code and replace all numbers with named constants.
- The MKR ENV Shield has an SD slot on it. Research how this works and log the times and readings to the SD card for later analysis.

Final thoughts

This system is an example of a *control system*. A control system reads sensors and changes something based on the readings, which in turn can have further impact on the sensors. Control systems can result in increased efficiency. For example, consider how much energy is wasted when growing crops that have too much or too little light, water, or heat. Spend some time researching control systems used for crop management.

14. BIODOME (PART 2)

Setting the scene

In the previous chapter you set up some of the basic elements of a biodome. In this chapter you will extend your biodome by adding some new components and logging the data to the Cloud.

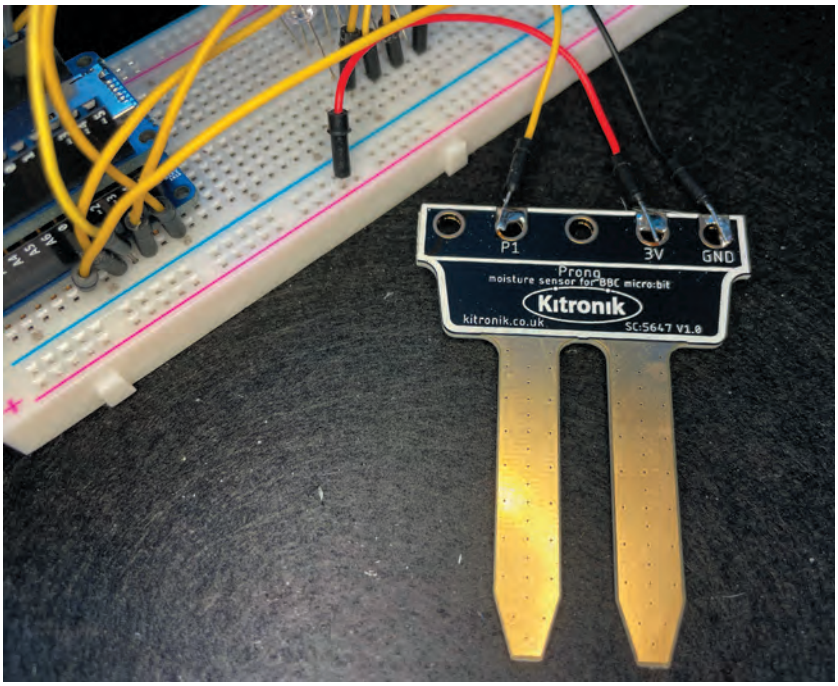
The reason for logging the data is pretty simple: you won't get the settings right first time. For example, you may get a notification to water the biodome, but find that it is already moist enough. Of course, your Arduino won't be plugged into a computer, so the only way for you to know what is happening is to look at logged data.

Success criteria

- Connect a moisture sensor and show the readings.
- Connect a servo to raise a "water me" flag.
- Log data to the Internet.
- Analyze the data to identify problems.

1

The first new component you will add is a soil moisture detector. The example shown in the image is built for a different microcontroller, a BBC micro:bit, and it does not have a direct interface with the Arduino. You may be able to use the holes and supplied bolts to connect wires to ground, 3.3 V (**not** 5 V!) and an analog input pin. Alternatively, you could use a soldering iron to attach some jumper wires (as in the example shown).



2

The moisture detector is very simple—it is read on an analog pin just like some of the other sensors you have used, and the value can then be output to the screen. Use a conditional statement to note that the soil is too dry if the reading is below a certain value (which you will have to find out by experimentation).

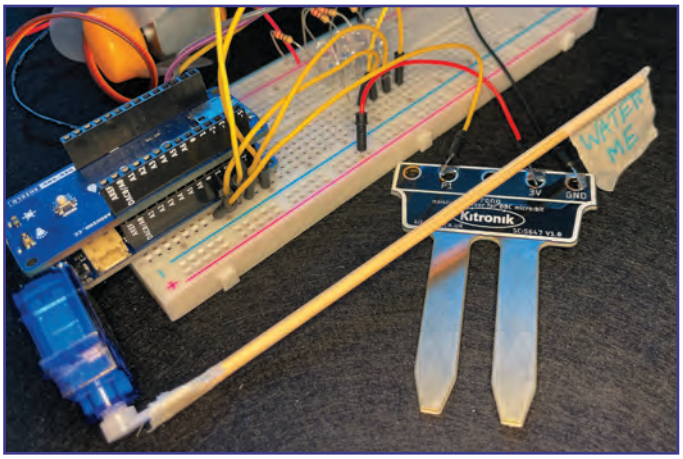
```
float moisture = analogRead(moistureSensor);
Serial.print("M: ");
Serial.println(moisture);
if (moisture < 200) {
  Serial.println("Too dry!");
} else {
  Serial.println("Moisture acceptable.");
}
```

PRO *TIP*

If you do not have any moist soil available, you can test the moisture detector by laying the prongs over a moist paper towel, or even by wetting a finger and joining the prongs.

3

An identifier to water the biodome would be really useful. You could use LEDs, but these don't show up very well during the day. You could also use buzzers, but these will become annoying if you don't have time to water the biodome straight away! Instead, you will use a *servo* (a small rotational motor) to—literally—raise a flag saying watering is needed. Use jumper wires to connect the red (5 V), black/brown (ground) and yellow/orange (signal) wires to 5 V, ground, and a digital pin on the Arduino.



4

Servos have their own libraries, **`Servo.h`**, which you need to include in the code. Then create a servo object—in the example it is called **`flag`**:

```
Servo flag;
```

Attach the servo object to the correct pin at setup:

```
flag.attach(flagPin);
```

Set the angle for the servo in the conditional statement, using **`flag.write(angle);`**. Try a 90° angle to make the flag stand upright and 0° to make it lie down, but you may need to test these to check they work as required.

```
float moisture = analogRead(moistureSensor);
Serial.print("M: ");
Serial.println(moisture);
if (moisture < 200) {
  flag.write(90);
} else {
  flag.write(0)
}
```

5

In Chapter 12, you logged data to a Google Sheets spreadsheet. You can use exactly the same techniques for this project. As a minimum, you should be logging temperature, humidity, illuminance, and moisture. It is also be a good idea to include status fields for the fan, lights, and flag.

```
for (var param in e.parameter) {
  var value = stripQuotes(e.parameter[param]);
  switch (param) {
    case 'temp':
      colpos = 1; break;
    case 'humid':
      colpos = 2; break;
    case 'illum':
      colpos = 3; break;
    case 'moist':
      colpos = 4; break;
    case 'lights':
      colpos = 5; break;
    case 'fan':
      colpos = 6; break;
    case 'flag':
      colpos = 7  ; break;
  }
  rowData[colpos] = value; //Add parameter to rowData
}
```

The only difference for this project is the Google Apps script. The parameters of the URL are not necessarily read in order, so if you use the script from earlier projects your data will appear jumbled. You need to update the script to check the variable name of each parameter (which needs to match the name in the Arduino code) and put them in the relevant position.

PRO *TIP*

Every time you update a Google Apps script, you need to redeploy and update the deployment ID in the Arduino code. If you forget this step, you can spend a long time trying to debug something that is never being called!

6

Once you have a reasonable amount of data in your spreadsheet, you can analyze the data and identify any problems.

From the data we initially captured in the example system, we identified that some of the flags are the wrong way around: 0 is normally used for False, and 1 for True. Also check that the flags for the output devices (lights, fan, and flag) correspond to the correct deviations in the data.

TimeStamp	Temperature	Humidity	Illuminance	Moisture	LightsOn	FanOn	FlagUp
3/18/2021	21.84	52.29	13.55	1	1	0	1
3/18/2021	21.72	52.22	13.55	101	1	0	1
3/18/2021	21.59	52.21	13.55	821	1	0	0
3/18/2021	21.48	52.49	14.19	12	1	0	1
3/18/2021	21.45	52.5	14.19	4	1	0	1
3/18/2021	21.45	52.25	14.19	10	1	0	1
3/18/2021	21.48	52.04	16.13	1	1	0	1
3/18/2021	21.41	52.86	15.48	2	1	0	1
3/18/2021	21.37	53.35	16.13	1	1	0	1
3/18/2021	21.41	52.59	15.48	1	1	0	1
3/18/2021	21.61	48.04	1.29	8	1	0	1
3/18/2021	27.56	49.43	16.77	2	1	1	1
3/18/2021	24.96	47.59	5.81	5	1	0	1
3/18/2021	23.27	48.07	5.16	2	1	0	1
3/18/2021	22.34	49.68	5.16	4	1	0	1
3/18/2021	21.78	50.49	5.16	3	1	0	1
3/18/2021	21.37	50.34	2.58	2	1	0	1

Testing

You will need to use a lot of trial and error with this project. Once you have made a biodome and connected your IoT device, you will need to watch both the data and the plants carefully to ensure that the settings you have chosen for temperature, moisture content, and light levels are resulting in appropriate growth. You may need to adjust the settings up or down accordingly. Make sure you keep records of everything you change and all your findings along the way.

It is worth splitting your testing to cover the individual sub-systems—test the temperature with the fan, the moisture sensor with the flag, and so on. In larger engineering projects, systems are split into sub-systems for development, implementation, testing, and maintenance; this is normally reflected in the code, which is also sub-divided into modules.

Stretch tasks

- The Arduino automatically sets the time to midday on the 1st of January 2020 when it is powered on. Try replacing this default time with the current time obtained from the Internet. The website worldtimeapi.org will return the current date/time for wherever you are in the world. For example, accessing http://worldtimeapi.org/api/timezone/Europe/London.txt will give plain text information that you can parse to set the time in the Arduino correctly.
- Once the Arduino is unplugged from the computer, there is no way of knowing if it is connected to the Internet. Unblock the serial monitor check and add an LED to indicate whether the Arduino managed to connect. You could use an RGB LED to provide more discrete information.
- The fan is turned either on or off. Adjust this so that the fan speed increases as the temperature goes further over the designated trigger level.
- Plan a system to add more water to the system should the soil moisture levels become too low.

Final thoughts

The biodome in this project is quite autonomous, although there you will still need to monitor it and add water if necessary. There have been several research projects into biodomes that can support human life—such biodomes will be essential to allow future habitation of other planetary objects, including the Moon and Mars. Look for some of the fascinating videos on YouTube about current human-habitable biodome projects, planned future projects, and past projects that have not necessarily turned out as planned.

Consider how much automation is optimal. With enough planning, you could automate entire farms, but would the benefits (such as cost savings and improved productivity) outweigh the drawbacks (such as reduced employment opportunities and the need to provide power for such a large system)?

15. DATA ANALYSIS AND MACHINE LEARNING

Setting the scene

There is a tendency to think of Artificial Intelligence (AI) as machines behaving like humans. Thankfully, this is still a long way in the future—one of the most common uses of AI in current computing is for Machine Learning (ML). Being able to categorize data using AI is used in many fields, including medicine, where recent developments have found that an AI system is more effective at spotting some cancers than human doctors.

In this chapter you will analyze some data using the popular programming language Python. You will analyze a set of data (training data) and identify links between the data. This model can then be used to make predictions. The model in this chapter uses a famous set of data about three species of iris flowers. Four criteria were measured for 150 flowers.

Success criteria

- Import the libraries needed for this project.
- Import and check data.
- Split the data into training data and test data.
- Train the classifier with a range of different settings.
- Identify the number of neighbors to use for classifier.
- Show the accuracy of the model on the test data.
- Test the classifying using sample data.

1

Machine Learning is not a simple process. Luckily, lots of libraries have already been created to perform many of the more complex processing for us. The examples shown in this chapter were created using the popular website replit.com, which automatically installs and updates the libraries. If you are using Python on your computer or on another site, you may have to install these libraries yourself.

```
import pandas as pd #a data analysis library
import seaborn as sns #used for data visualisation
sns.set_palette('husl') #sets the colours for visualisation
import matplotlib.pyplot as plt #enables the graphs
from sklearn import metrics #measures performance
from sklearn.neighbors import KNeighborsClassifier #classifier
from sklearn.linear_model import LogisticRegression #used for accuracy
from sklearn.model_selection import train_test_split #split's data
```

PRO *TIP*

Python is sensitive to both space and case, so make sure you are extra careful in your coding. The lines after a # symbol are comments and are just for your information.

2

Next, give Python some data to analyze. Download **iris.csv** from the Arm GitHub repository. This CSV (comma-separated value) file contains the data you will be analyzing. The data is read into a data frame using a system called Pandas. Pandas lets you view parts of the data and check on some common statistics.

```
data = pd.read_csv('iris.csv')
input('Show data [Press ENTER]')
print(data)
input('Show head [Press ENTER]')
print(data.head())
input('Show info [Press ENTER]')
print(data.info())
input('Show description [Press ENTER]')
print(data.describe())
```

3

You need to organize the data by:

- splitting it into the columns of data (X) and the data you are trying to find out (y)
- splitting the data further into *training data* (which will be used to build the neural network) and *test data* (which will be used to test that the neural network is effective)

Splitting the data is really important, as if you train the network using the whole data set, there will be no way of testing how accurate it will be (it will "over fit").

```
X = data.drop(['Species'], axis=1)
y = data['Species']
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.4,
random_state=5)
```

4

The machine learning code will look at links between the data and the correct classification, organizing the data into nodes. The nodes which have data which is close to that of other nodes are called *neighbors*.

```
k_range = list(range(1,26))
scores = []
for k in k_range:
    knn = KNeighborsClassifier(n_neighbors=k)
    knn.fit(X_train, y_train)
    y_pred = knn.predict(X_test)
    scores.append(metrics.accuracy_score(y_test, y_pred))
```

Without going into too much detail, the number of neighbors used in the neural network can affect accuracy significantly. In the test model, for example, one neighbor gives just under 97% accuracy, two neighbors give less than 92%, and so on. The model is tried automatically on a range of values and compared to the test data.

More information on how a "k-nearest neighbors algorithm" works is available online; searching for KNN on Wikipedia is a great place to start.

5

The results of the tests are plotted on a graph to show the user the variation in visual format.

```
plt.plot(k_range, scores)
plt.xlabel('Value of k for KNN')
plt.ylabel('Accuracy Score')
plt.title('Accuracy Scores for Values of k of k-Nearest-Neighbors')
plt.show(block=False)
```

PRO *TIP*

Sometimes the graph can take some time to show up. If it does not display after a couple of minutes, try refreshing.

6

Following some more mathematics, the final accuracy of the model can be displayed. The test model returned an accuracy of over 98%, extremely good results for such a small dataset.

```
logreg = LogisticRegression()
logreg.fit(X_train, y_train)
y_pred = logreg.predict(X_test)
print("Accuracy:",metrics.accuracy_score(y_test, y_pred))
```

7

```
neighboursChoice = int(input('What value of n gives best accuracy? (We
think 12 works well!): '))
knn = KNeighborsClassifier(n_neighbors=neighboursChoice)
knn.fit(X, y)

SepalLengthCm = float(input('Sepal length?'))
SepalWidthCm = float(input('Sepal width?'))
PetalLengthCm = float(input('Petal length?'))
PetalWidthCm = float(input('Petal width?'))
print("Prediction:",knn.predict([[SepalLengthCm, SepalWidthCm,
PetalLengthCm, PetalWidthCm]]))
```

Once you have built and tested the model, you can build a classifier using the number of neighbors that you identified from the graph. Then use the classifier to test new data against the model.

Testing

Although the model is self-testing, you can test it yourself by entering new data that the system has not seen before. You could delete a couple of lines from the model before running it and use that. Alternatively, you could search on the Internet for more measurements to try out with the model.

PRO *TIP*

Machine Learning requires a significant amount of processing power. More data leads to more accurate systems—data sets that require specialist hardware such as graphics processing units (GPUs) and multiple hours of computation are not uncommon.

Stretch tasks

- Reduce the amount of data significantly and explore the impact of this on the accuracy of the system.
- Create a graph from the data in the above task to show the impact on accuracy.
- The 0.4 in `train_test_split` shows the amount of data (as a percentage) to be used for the test data. Try adjusting this upwards to explore the impact on the accuracy of the model.
- Further data sets are available from https://www.kaggle.com/datasets. Try to build a similar system to try and predict strokes.

Final thoughts

The classifier used in this system is called a *k-nearest neighbor* (*KNN*) classifier. Common uses of KNN classifiers include forecasting stock market trends, customer profiling, and identifying the chances of certain medical conditions given pre-existing knowledge about a patient. These are incredibly useful tools, but there are many potential problems. For example, facial recognition, another form of Machine Learning, has been shown to be biased against some skin tones.

Consider what problems in the world will become solvable as our understanding of what is possible with Machine Learning expands. Also consider what could go wrong if bias is introduced into the training data.

16. USING MACHINE LEARNING TO IDENTIFY A HIT OR A MISS

Setting the scene

In this chapter, you will apply Machine Learning (ML) techniques to the ball-hitting data you collected in Chapter 12. Your aim in this chapter is to try to train a model to identify whether each swing of the bat was a "hit" or a "miss".

In Chapter 14, you ran a ML system on a remote server. ML algorithms using neural networks such as the one for this chapter require a bit more power, and it is recommended that you use Jupyter notebooks and, in this case, run this on your own computer. The easiest way to install Jupyter is via Anaconda (www.anaconda.com). This allows you to run pieces of code in individual cells, so you can monitor what is happening much more easily.

Success criteria

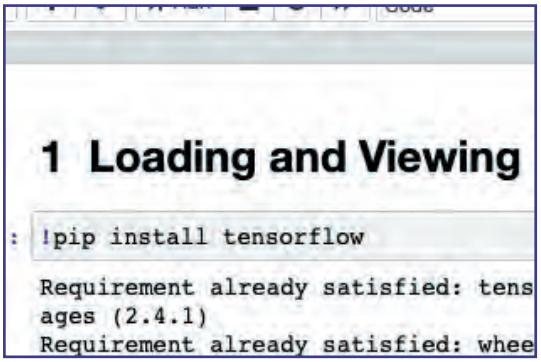
- Install TensorFlow.
- Import modules, set up some basic settings and create some useful sub-routines.
- Load data into the system and plot sample data.
- Split the data set into test and training data.
- Add some more useful sub-routines and build a model.
- Classify the test data and review the accuracy.

1

Once you have installed Jupyter and created a new notebook, you need to make sure you have the correct software libraries installed to run your code. Luckily, Jupyter gives you easy access to an installation method called pip—all you have to do is type the following "magic" command in the top cell and hit the run button, and Jupyter will install TensorFlow for you.

PRO TIP

If any other libraries are missing, you can use the same command to install them.




```
!pip install tensorflow
```

TensorFlow has a whole host of professional-level tools for ML and will make a lot of your tasks much simpler!

2

You need to include a large number of Python modules, some of which were included in the previous chapter, and some of which are new to this chapter. As there is a lot of detail here, it is worth downloading and reviewing the full code (**bat hits**) from the Arm Git Repository.

You also need to set up some basic settings:

- Use the `set_style` function (in the Python data visualization library Seaborn) to set up the plots with a white grid background.
- Create a list of the names of the classifications (0 will be a "hit" and 1 will be a "miss").
- Create a list of the colors for the classifications when plotting on the grid—the example shown here uses dark orange for hits and steel blue for misses.

```
# General settings
sns.set_style('whitegrid') # Plots will have a white grid
# Variables that will help us work with the classes
class_names = ['hit', 'miss']
class_colors = ['darkorange', 'steelblue']
```

3

The code to instigate ML is long and complex. As with all programming projects, it is a good idea to split the code up into named sub-routines that carry out a specific task. For this part of the project, you need sub-routines to:

- load data from a csv file and convert it to the right format
- plot the data samples
- plot a single sample

```
def load_data(filename):
    hits_df = pd.read_csv(filename, header=None) # Use Pandas to load the data into a Panda
    print('Loaded from', filename)
    hits_data = hits_df.values # Convert from a Pandas DataFrame to a numpy array
    print('The shape of hits_data is', hits_data.shape)
    print('Number of samples of class 0 (hit)', (hits_data[:,0].astype(int) == 0).sum())
    print('Number of samples of class 1 (miss)', (hits_data[:,0].astype(int) == 1).sum())
    print('')
    return hits_data
```

Once again, you can download the full code from the GitHub Repository.

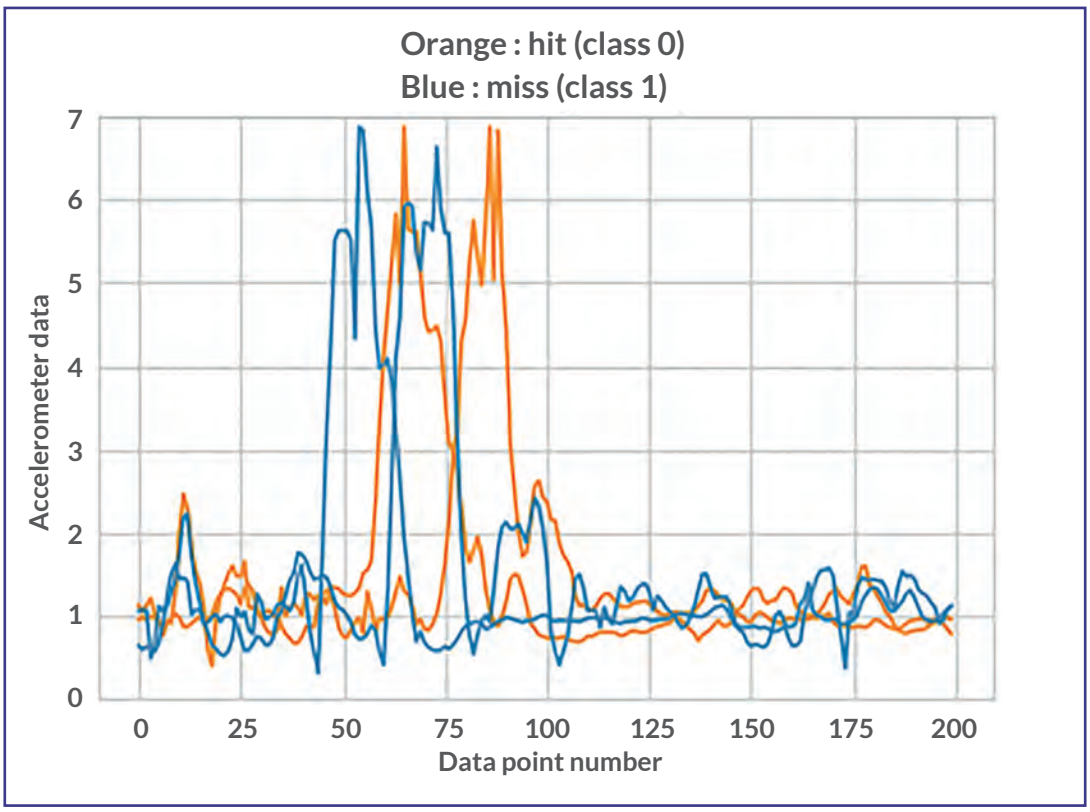
4

Now load the data into the system. Start by downloading your original data from your Google Sheets spreadsheet as a csv file. You need to make sure you put 0 (hit) or 1 (miss) in the first column and remove the headings. Save the csv file into the same folder as your Jupyter notebook so that you can access it. As there is a sub-routine for it, loading the data is as simple as calling `load_data()` with the filename as a parameter. You can see in the screenshot that there were 39 samples: this really isn't enough for this kind of system—hundreds would be better!

```
filename = 'BatHits_TSD.csv'
hits_data = load_data(filename) # This is a

Loaded from BatHits_TSD.csv
The shape of hits_data is (39, 201)
Number of samples of class 0 (hit) 14
Number of samples of class 1 (miss) 25
```

5

You can show the *shape* of the data as a matrix using `data.shape`, which is useful for checking that the data looks right. To create a visual of the data, call `plot_data_samples()` to show what the data looks like on a graph. The example shown here used four random samples, 0, 1, 6 and 7 to get an idea of how the data compared. You can notice some variations—the misses have a rounded first peak, whereas the peaks for the hits are spikier.



6

With most ML, the idea is to split your data into:

- training data, which the model uses to identify the categories and teach itself how to differentiate between them
- test data, which the model doesn't get to see until it has been trained

As the example used only 39 samples, the `test_size` chosen was 10. The more samples you have to train the system the better, but you also need to leave enough test data to check the system properly!

```
test_size = 10 ### CHANGE PARAMETER HERE ###

data_train, data_test, labels_train, labels_test = train_test_split(
    data, labels, test_size=test_size, random_state=21, stratify=labels)

print('The shape of train_data is', data_train.shape)
print('The shape of test_data is', data_test.shape)
print('Training data:')
print('Number of samples of class 0', (labels_train == 0).sum())
print('Number of samples of class 1', (labels_train == 1).sum())
print('Test data:')
print('Number of samples of class 0', (labels_test == 0).sum())
print('Number of samples of class 1', (labels_test == 1).sum())
```

7

Now that you have uploaded your data into the system and checked that it looks right, the next stage is to build a model. You need new sub-routines to:

- plot a comparison between the test data and the training data
- plot the accuracy and the loss
- then build the model itself

These sub-routines are all available in the GitHub Repository.

PRO *TIP*

If you struggle to get Anaconda and Jupyter to work, this code should still run in replit.com. However, the graphs may not show up!

```
def build_model(print_summary=False):
    ''' Return a model with randomly initialised weights '''
    model = Sequential([
        Dense(8, input_dim=input_dim, activation='relu', name='Layer1'),
        Dense(4, activation='relu', name='Layer2'),
        Dense(1, activation='sigmoid', name='OutputLayer')
    ])

    optimizer = keras.optimizers.Adam()
    model.compile(loss='binary_crossentropy', optimizer=optimizer, metrics=['accuracy'])
    if print_summary:
        print(model.summary())
    return model
```

8

To build the model, set the input dimensions (from the training data shape) and then call the `build_model` routine.

Then run through the *epochs*. (You can think of epochs as "training sessions" of the ML system.) For each epoch, the loss is calculated and the weightings of the model are adjusted to try to reduce the loss next time around, while (hopefully) also increasing the accuracy. (All of this happens behind the scenes with some very complicated mathematics!)

```
Epoch 1/20
4/4 [==============================] - 0s 49ms/step - loss: 1.5131 - accuracy: 0.6358 - val_l
oss: 0.7120 - val_accuracy: 0.7000
Epoch 2/20
4/4 [==============================] - 0s 11ms/step - loss: 0.7485 - accuracy: 0.5681 - val_l
oss: 0.6975 - val_accuracy: 0.5000
Epoch 3/20
4/4 [==============================] - 0s 12ms/step - loss: 0.7362 - accuracy: 0.3697 - val_l
oss: 0.7474 - val_accuracy: 0.3000
Epoch 4/20
4/4 [==============================] - 0s 11ms/step - loss: 0.7668 - accuracy: 0.3530 - val_l
oss: 0.7362 - val_accuracy: 0.4000
```

9

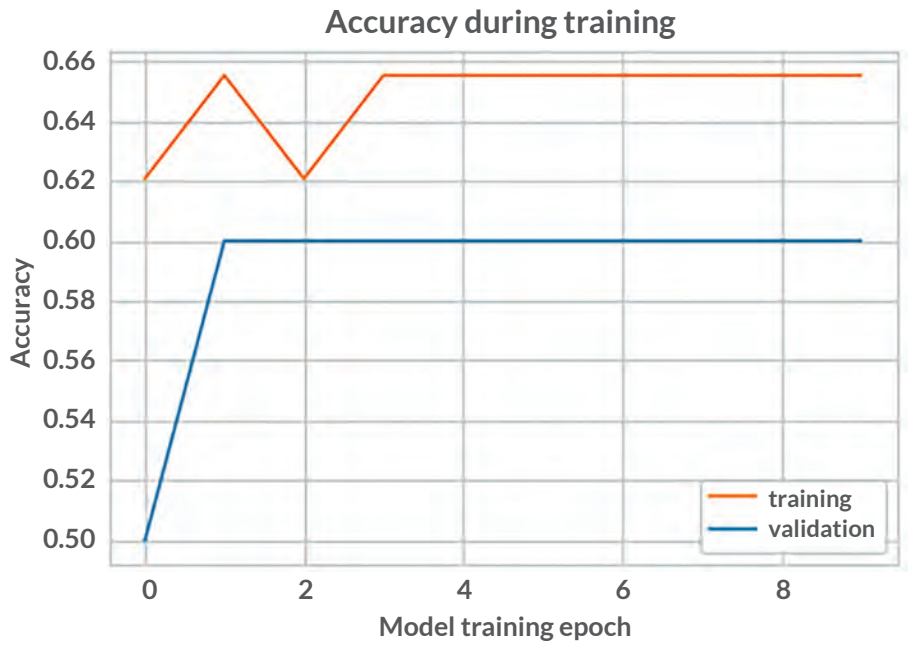
Now that you have a model that is trained, the next step is to run the model on the test data to classify the data. If you have enough training data (and good data to start with), you should see reasonable accuracy and relatively low loss. If these values are not what you would like, you will need to go get more data or adjust some of the parameters.

```
2/2 [==============================] - 0s 2ms
Validation accuracy:      0.5
Validation loss:          0.7777040600776672
test_size:        10
batch_size:       8
epochs:           20
```

10

You can visualize the losses and accuracy by using the plot sub-routines you produced in Step 7. These can also help you adjust the training parameters to maximize accuracy.

```
# Plot the training log's accuracy data.
plot_accuracy(log)
```



PRO *TIP*

If you find your results are disappointing, there is a good chance you need to add a lot more data. Ideally for this project, try to get at least 200–300 samples of 200 data points.

11

Finally, start using your classifier, either with new data or with existing data that you present to the model as "new" data. In the screenshot you can see that sample number 3 was chosen, randomly—which the classifier identified correctly! Make sure you try a range of samples to get to know your model.

```
sample_num = 3 ### CHANGE PARAMETER HERE ###
data_sample = data_test[sample_num]
data_sample = np.array( [data_sample,] ) # Convert the data sample into the
probability = model.predict(data_sample)
print('Model: probability of belonging to class 1:', probability[0][0])
print('Predicted class:\t', (np.round(probability)[0][0].astype(int))) # \t
print('True class:\t\t', labels_test[sample_num])
```

```
Model: probability of belonging to class 1: 0.50909096
Predicted class:        1
True class:             1
```

Testing

There are lots of things you can vary in this project, particularly the batch sizes (the amount of data analyzed at a time) and the number of epochs. Experiment with varying these and re-run the project several times to explore the impact they have. Then test the system with a new set of test data.

Stretch tasks

- The code used in this chapter is an adjusted sub-set of that in https://github.com/jarusgnuj/ai-ml-wksh from an Open University workshop in which data was collected about the floor a robot was walking on. Explore the sample code in the workshop notes and identify what increased the accuracy of the robot walking code.
- Identify other ML-based experiments you could do with the accelerometer and carry them out. What kind of movements give more clearly differentiated data?
- https://www.kaggle.com/ has time-series data on the daily climate change. Use your skills from this chapter to build a model and predict the temperature on a specific date, given the atmospheric readings.

Final thoughts

ML is one of the most exciting up-and-coming areas of Computing and is just starting to make its way into degree and post-graduate education. With enough development, Machine Learning could become more accurate at classification and problem-solving than humans. Recent developments have resulted in software that is more accurate than human doctors at detecting breast cancer, for example.

Consider what other aspects of health and well-being could be improved if ML systems become more prevalent in early diagnosis procedures. However, it is also important to consider who is deemed at fault if (and when) things do go wrong.

17. WEB SCRAPER

Setting the scene

The Internet holds vast amounts of data. It is estimated that, in 2020, 2.5 quintillion bytes of data were produced by humans *every single day*. A lot of this data is produced, processed, and stored in specialist systems. However, an awful lot is in far less structured and much of this data just passes us by.

This project introduces two new concepts: how to use the Arduino as an IoT device that pulls and displays data (rather than sensing and sending to the Cloud); how to connect a display to allow the device to work when disconnected from a computer. Modern websites are hugely complex, with the useful data hidden away inside layer after layer of HTML code. This chapter involves a simple website that just shows a random joke every time you access it.

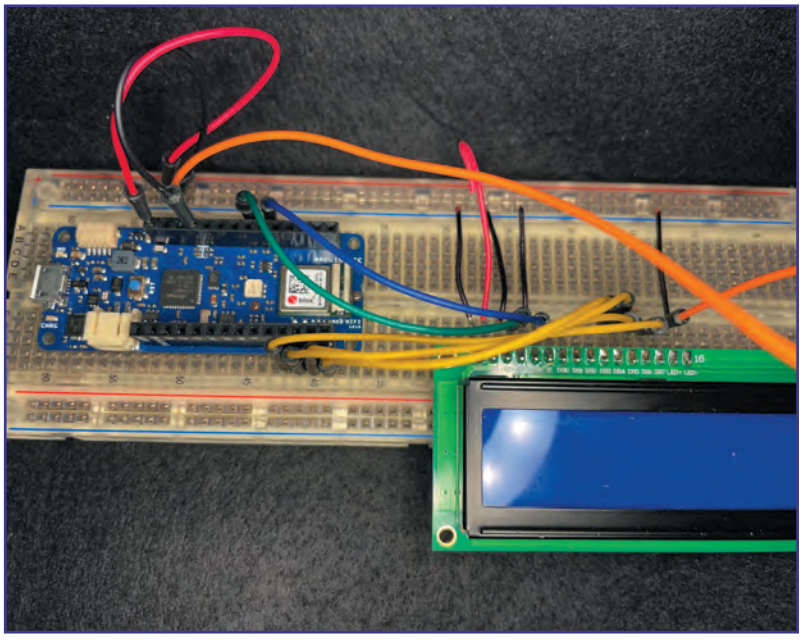
Success criteria

- ☑ Connect and test an LCD display screen.
- ☑ Connect a button to the Arduino to "trigger" data scraping.
- ☑ Use a web library to retrieve data.
- ☑ Parse useful elements from web data.
- ☑ Display those useful elements.

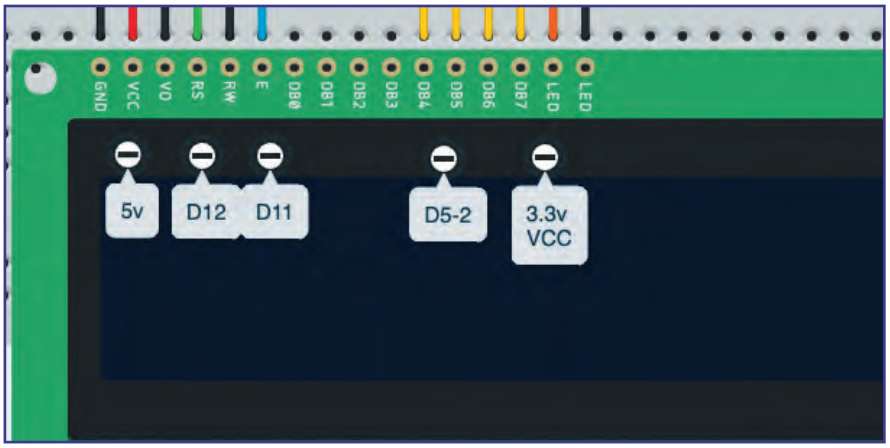
1

LCD screens are a great way of displaying simple text-based data. A variety of types and configurations are available. Although LCD screens have quite a lot of wires, they are not too difficult to set up. The trick is to work along the named pins at the top of the display:

- GND is the ground of the LED itself—connect it to the ground rail (and hence to the Arduino).
- VCC powers the display—connect it to the Arduino 5 V pin.
- The VO pin allows you to vary the contrast—connect it to ground (0 V) for the maximum contrast.
- Connect the RS pin to pin D12. This allows the Arduino to switch the LCD between "instruction" mode and "character" mode.



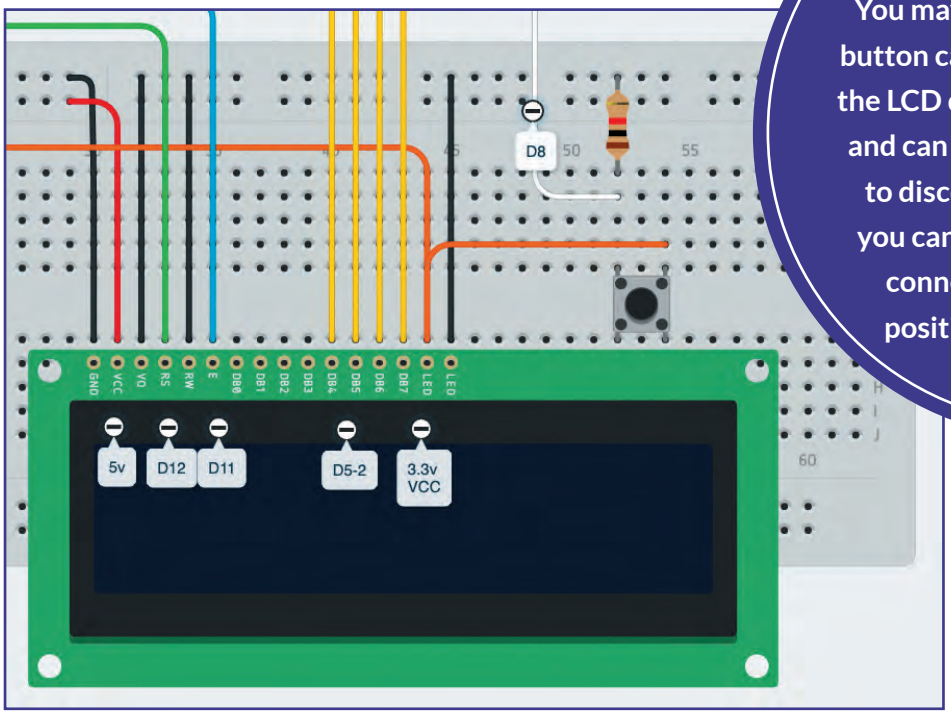
- Connect the RW pin to ground. Very occasionally, the LCD may need writing. For this project, it is not needed, so the mode can be set to Read (by pulling to 0 V)
- The E pin instructs the LCD that it should take on board the data being sent—connect it to Arduino pin D13.
- For this project, you only need half the data pins. Connect pins DB4, DB5, DB6, and DB7 to Arduino pins D5, D4, D3, and D2 respectively.
- Finally, the LCD has a backlight which enables you to see it. Connect the LED+ pin to 3.3 V (VCC on the Arduino) and connect the LED pin to ground.



You can use the **16x2_LCD_Test** code, available on the Arm GitHub repository, to ensure that your LCD is working properly.

2

To trigger a "scrape", you need to connect a pulldown button. If you are following the example code, connected the button to pin D8.

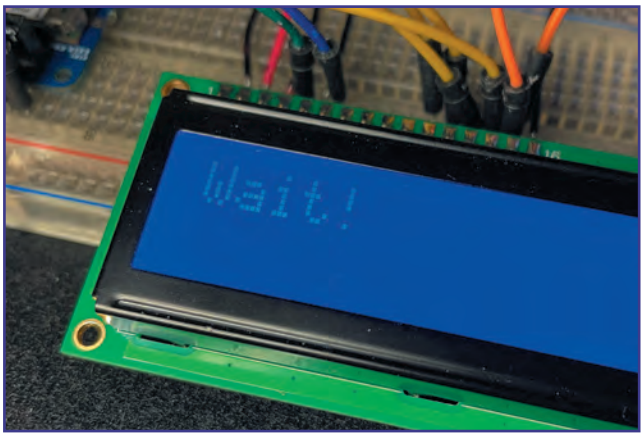


PRO *TIP*

You may find that the pulldown button causes fluctuations within the LCD display when it is pressed and can cause the serial monitor to disconnect. If this happens, you can link to the 3.3 V power connected to LCD+ for the positive side of the button.

3

As well as telling the user what is happening on the serial monitor, it is a good idea to use the LCD screen too. Use the skills you learned from storing IoT data in the Cloud to setup a web client connection. This time, however, use the LCD screen to print "Wait!" at the start, and then "Ready!" once a connection is made.



PRO *TIP*

Different Arduinos use different libraries for WiFi connectivity. The example code for this project (Web_Scraper) includes the references for the MKR1000 and MKR1010—you might need to change these to references for other boards. The best way of finding the correct libraries is by joining the Arduino forums and discussing with others that share a board with you.

In Chapter 10 you used "WiFiClient". This time, use "WiFiSSLClient" instead to allow the Arduino to access websites that use https://.

4

There are three key stages involved in getting, manipulating, and displaying the data from the website.

The first stage is to tell the website to send you the data. The line `client.connect(serverName, 443)` is used when the button is pressed to connect to the server on port 443 (which is the port for https). By wrapping this up in an `if` statement, you can ensure that data is only requested if the connection worked. Add these three lines that need to be sent to the server:

- `GET /path/to/website.html HTTP/1.1` will instruct the server to send a particular web page.
- `Host: theWebsite.com` will ensure the server knows which site you're trying to access.
- `Connection: close` followed by a blank line will tell the server that you've finished with it.

```
//Tell the website to send data
if (digitalRead(btn) == HIGH) {
  //Button pressed
  Serial.println("\nStarting connection to server...");

  // if you get a connection, report back via serial:
  if (client.connect(serverName, 443)) {
    Serial.println("connected to server");
    // Make a HTTP request:
    client.print("GET ");
    client.print(path);
    client.println(" HTTP/1.1");
    client.print("Host: ");
    client.println(serverName);
    client.println("Connection: close");
    client.println();
  }
} else {
  //Buton not pressed
}
```

In this example, the jokes can be accessed at https://random-ize.com/bad-jokes/bad-jokes-f.php so the host is `random-ize.com` and the path is `/bad-jokes/bad-jokes-f.php`.

5

The second stage is to continue reading data from the server for as long as it is available. This uses `client.read()` and reads one character at a time. This gets appended on to an empty string to hold all the HTML content.

```
while (client.available()) {
  char c = client.read();
  htmlContent += c;
}
```

6

The third stage is to parse the HTML content for the bits you want. This webpage is very simple: it gives a joke prompt and punchline, separated by two `<br>` tags, all inside some `<font>` tags.

We can use `indexOf()` to search for key parts of the code and `substring()` to split the code into strings for the prompt and the punchline.

```
if (!client.connected() && htmlContent != "") {
  client.stop(); //Close the client connection

  //Get the prompt and punchline
  int start = htmlContent.indexOf(">")+1;
  prompt = htmlContent.substring(start);
  int end = prompt.indexOf("<");
  punchline = prompt.substring(end+8);
  prompt = prompt.substring(0,end);
  end = punchline.indexOf("<");
  punchline = punchline.substring(0,end);
  //Display on serial for debugging
  Serial.print("Prompt: ");
  Serial.println(prompt);
  Serial.print("Punchline: ");
  Serial.println(punchline);
```

7

```
String padding = "                ";
prompt = padding + prompt + padding;
punchline = padding + punchline + padding;
lcd.setCursor(15, 0);
lcd.clear();

int s = 0;
int e = 16;
String l = "";
int smax = prompt.length()-16;
while (s <= smax) {
  l = prompt.substring(s,e);
  lcd.setCursor(0,0);
  lcd.print(l);
  s += 1;
  e += 1;
  delay(200);
}

s = 0;
e = 16;
smax = punchline.length()-16;
while (s <= smax) {
  l = punchline.substring(s,e);
  lcd.setCursor(0,1);
  lcd.print(l);
  s += 1;
  e += 1;
  delay(200);
}
htmlContent = "";
```

The LCD module has a very handy function for autoscrolling text across the lines. However, the lines must be less than 40 characters long—and the jokes are often longer than that! Instead, you can use a `while` loop to print 16 characters at a time, and just take a section of the joke at a time. You can use padding and carefully timed delays, to simulate autoscrolling.

PRO *TIP*

Updating the screen is quite fast—you can experiment with the padding, delays, and so on to be quite creative.

Testing

This project uses a lot of wires—just one wire out of place can cause all sorts of problems. Connecting to WiFi can also cause lots of problems. Ensure that you output as much as possible to the serial monitor while you are developing your code. You can always comment the `print` statements out later if they are not needed.

When you are figuring out how to "chop down" HTML code, you need to work iteratively. Explore the source code and find one bit at a time, display it to the serial monitor, then do the next bit.

Stretch tasks

- Most LCD screens allow you to alter the brightness of the backlight. Use a potentiometer and vary the voltage between 0 V (full brightness) and 5 V (no backlight).
- Strings are simple to use, but wasteful of memory. Try to amend the code to use char arrays wherever possible instead.
- Use the source code inspector (by pressing F12 if you use the Chrome browser) to explore the contents of a Twitter stream. Extend your code to find and display the latest tweet for a given hashtag.
- Extend the previous task to include using a button to move on to displaying the next tweet in a stream.

Final thoughts

The joke site used in this chapter is one of the simplest available. Building a scraper for more complex websites is far more complex. However, data is incredibly powerful. For example, you could create a gardening project by scraping weather data and programming your Arduino to alter how much light, shade, or water it provides to the garden. What other data can you find online that you can scrape and use with your Arduino to support future projects?

18. GPS TREASURE HUNT

Setting the scene

Not so long ago the only way to know where you were was by using a mixture of map reading and dead reckoning (calculating your position), together with a reasonable amount of luck. Now, the latest GPS devices can pinpoint you to within 30 cm! GPS, and the associated sat-nav systems, help reduce wasted journeys and are invaluable for locating people in an emergency.

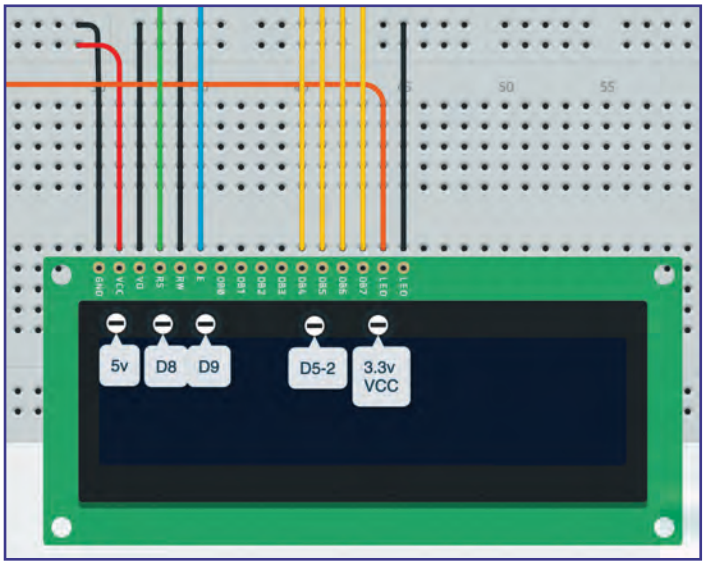
GPS is one example of the huge amounts of data that are all around us. All we need is a sensor to receive the data. In this chapter you will use the inexpensive Arduino MKR GPS Shield to identify your location. To make things a bit more fun, the final part of the chapter shows you how to use this device to play a treasure hunt game.

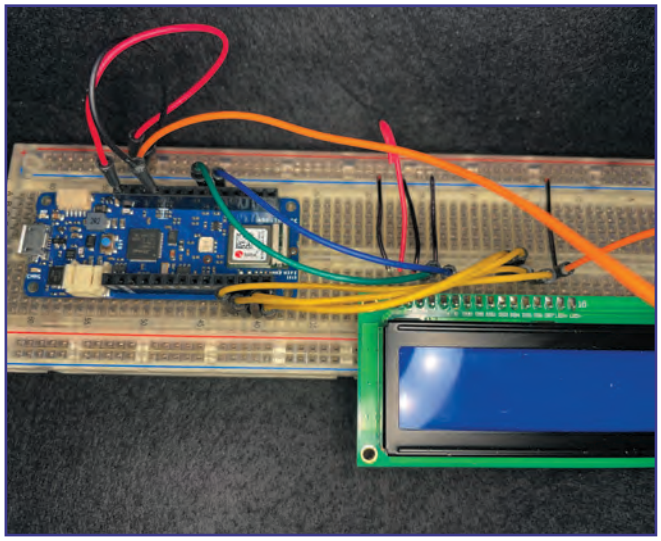
Success criteria

- Connect and test the LCD display screen.
- Connect and test the GPS shield module.
- Display the GPS details on the serial monitor.
- Display the GPS details on the LCD screen.

1

The circuit in this chapter should be quite familiar. In fact, if you still have it, you can re-use the circuit from Chapter 17.





Just remove the button and move the wires that are attached to D10 and D11 to D8 and D9 respectively, as they interfere with the GPS receiver.

2

This device is designed to be used when you are out walking. Unless you also want to carry a computer with you, it is a good idea to use the LCD to mirror anything you put on to the serial monitor. You can test the LCD at the same time as (trying) to start the serial monitor in the setup routine.

```
//Initialise serial monitor
lcd.begin(16,2);
lcd.setCursor(0,0);
lcd.print("Trying serial");
// initialise serial communications and wait for port to open:
Serial.begin(9600);
delay(10000); //Wait 10s for serial monitor if connected
lcd.setCursor(0,0);
if (!Serial) {
  lcd.print("No serial.   ");
} else {
  lcd.print("Serial ready ");
}
```

3

You can plug the Arduino MKR GPS Shield directly into the MKR1010 5-pin socket. If you are using a different Arduino without the socket, you will have to either mount headers or figure out which pin in the plug needs connecting to which pin on the Arduino and use jumper wires. Connecting using the attached plug enables you to put the GPS Shield near a window for better reception.

4

The GPS module uses the **`Arduino_MKRGPS.h`** library. To initialize the GPS module, simply use **`GPS.begin()`** in the setup routine. As with the serial monitor, it is worth reporting whether this works (it returns 1 or True) or doesn't work (it returns 0 or False) on the LCD as well as on the serial monitor.

```
lcd.setCursor(0,1);
lcd.print("Trying GPS");
Serial.println("Trying GPS");
delay(3000);
lcd.setCursor(0,1);
if (GPS.begin()) {
  lcd.print("GPS ready.");
  Serial.println("GPS ready");
} else {
  lcd.print("GPS failed.");
  Serial.println("GPS failed");
}
```

5

The GPS module has functions for returning all the relevant information.

- As long as `GPS.available()` returns True, you can call `GPS.latitude()`, `GPS.longitude()`, and `GPS.altitude()` (all floats), and `GPS.satellites()`, an integer.
- If `GPS.available()` returns False, then there is no data available to be read.

```
void loop() {
  if (GPS.available()) {
    // read GPS values
    float latitude   = GPS.latitude();
    float longitude  = GPS.longitude();
    float altitude   = GPS.altitude();
    int   satellites = GPS.satellites();
    Serial.print("LAT: ");
    Serial.println(latitude, 7);
    Serial.print("LON: ");
    Serial.println(longitude, 7);
    Serial.print("ALT: ");
    Serial.print(altitude);
    Serial.println("m");
    Serial.print("SAT: ");
    Serial.println(satellites);
  }
}
```

PRO *TIP*

If the GPS Shield cannot see any satellites, it will not return any errors—it will simply return False from `GPS.available()`. You may be able to get a signal near a big window, but you may have to go outside to get a good signal.

6

As well as outputting everything to the serial monitor, it is a good idea show the most important data (the latitude and longitude) on the LCD screen so that you can check your position when running from a battery.

```
lcd.setCursor(0,0);
lcd.print("LAT:");
lcd.print(latitude, 7);
Serial.print("LON: ");
Serial.println(longitude, 7);
lcd.setCursor(0,1);
lcd.print("LON:");
lcd.print(longitude, 7);
```

7

It is easy to use your GPS device to create a game. Hide objects at several different locations, and write down the GPS coordinates of each location. Ask a partner to use your GPS device to navigate to the locations and find the objects.

For even more fun, instead of objects, hide words encrypted using a Caesar cipher. The words could make up a message, which your friend has to decrypt.

PRO *TIP*

You may need to do this activity outside. Remember that accuracy may vary, so keep an eye on how much your readings are fluctuating when choosing your locations.

Testing

There is a really simple way to test your GPS location. If you copy the latitude and longitude, separated by a comma, into the search bar of Google Maps, you should see your current location highlighted. If the device isn't working as expected, compare the results of both the serial monitor and the LCD display to identify where the problem might be.

Stretch tasks

- Latitude identifies how far North or South you are from the Equator; longitude identifies how far East or West you are from the Prime Meridian. You can compare the target location and the current location to identify the direction and distance between them. Try making the LCD screen alternately display current locations and direction information.
- You will notice that the current location fluctuates even when you are standing still. You can measure the variation over several readings and use an RGB LED to identify the stability of the signal: the more stable the signal is the less fluctuation there will be and, correspondingly, the smaller the area of potential error will be.
- Allow a user to enter a GPS location over the serial monitor and store it into memory (research into PROGMEM). Use Pythagoras' theorem to identify the distance to the target location.
- Add a servo with an arrow on to point left/right/centrally to direct the user towards the given location.

Final thoughts

Geocaching is a popular activity, which encourages individuals, groups, and families to go out into nature, get some exercise, and solve problems together. You can find out more at geocaching.com. You could use your device to take part in geocaching activities, building your experience and improving your fitness. You could even set up your own geocaching activities for your family and friends.

19. LOCK BOX

Setting the scene

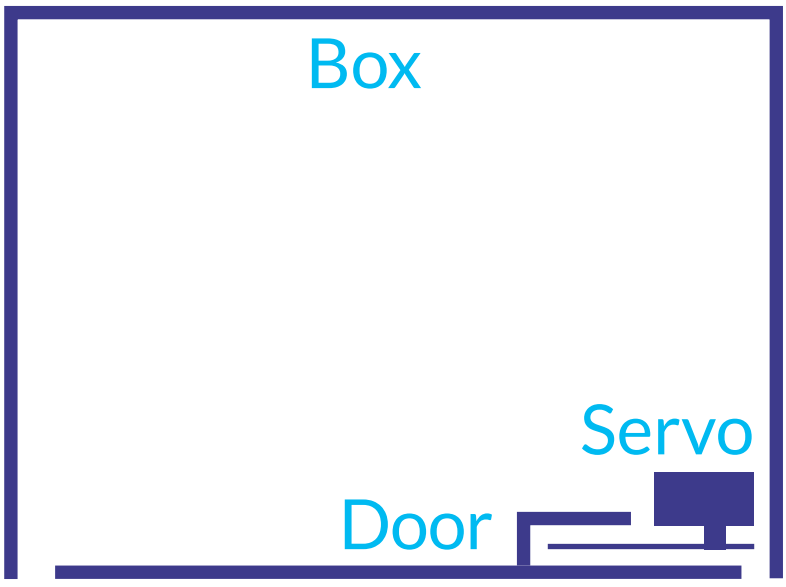
This chapter combines several concepts that you have studied in previous chapters, and also introduces some new methods of solving problems. You will use a servo as an *actuator* (an output device that moves part of a machine or device) to lock or unlock a box. The servo arm will move into place to stop the door opening and rotate out of the way to allow the door to swing open. To activate the servo and unlock the box, the user must enter a code on a series of buttons. To lock the box again, they must enter a new code. Each button will have a corresponding dual-purpose red LED to indicate a press or an error; a green LED will indicate a correct code. This project will encourage you to think creatively to solve problems by considering how sub-systems can interact.

Success criteria

- Design a lock box.
- Build a circuit built with buttons, LEDs to indicate error and OK, and a servo.
- Declare the variables and constants.
- Initialize the device.
- Write helper routines to reset the entered code, lock and unlock the box, clear the red LEDs, and show the current digits entered.
- Write a helper routine written to check the code entered and act accordingly.
- Write a helper routine to deal with the buttons being pressed and to check for the button press in the main loop.

1

The lock box can be as simple or as complex as you wish. There are numerous online tutorials with instructions for building a servo-operated lock box. You could use wood, card, foam board, or any other material you wish. Make sure your design includes a servo arm which can be deployed to stop the door opening and can also be rotated out of the way to allow the door to swing open.



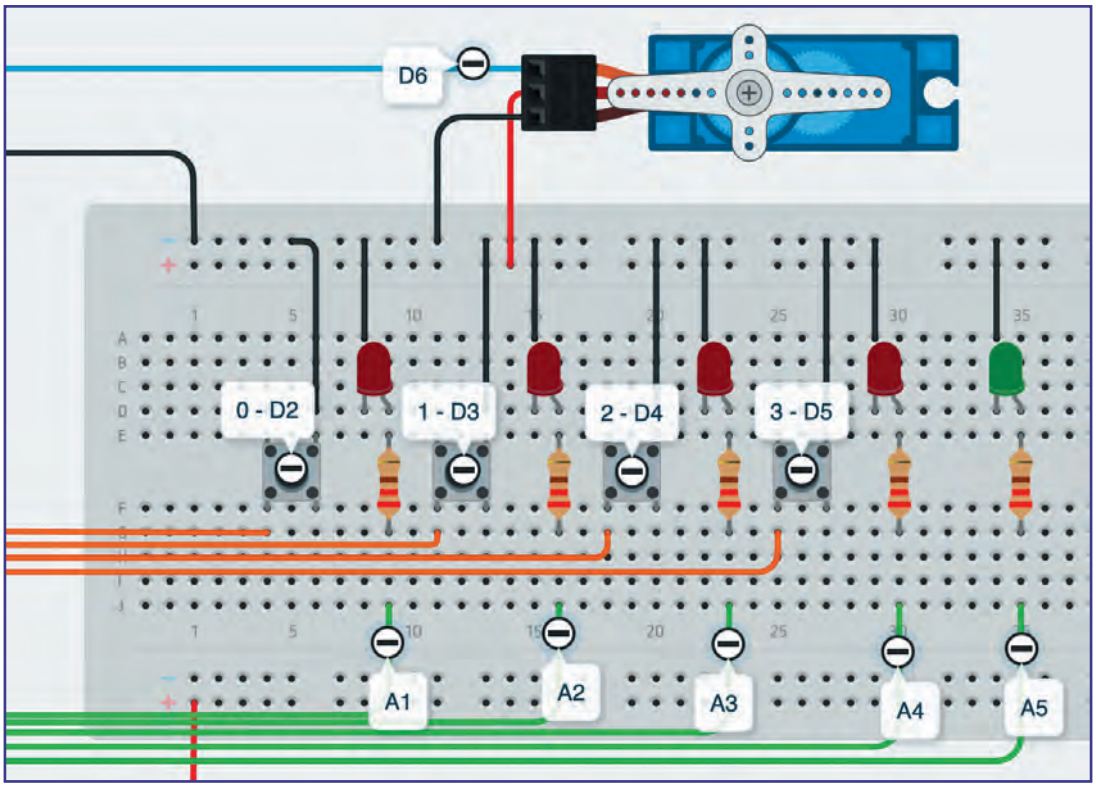
2

The circuit is similar to many others you have explored in this book. You will need:

- four red LEDs and one green LED, all with 220 Ω resistors, connected to A1–A4 (for the error red LEDs 0–3) and A5 (for the OK green LED)
- four buttons connected between ground and D2–D5 (D2 for button 0 and D5 for button 3)

(Note: The Arduino includes built-in pullup resistors so there is no need to use resistors to pull the buttons down to ground as in Chapter 3. However, be aware that pull*up* resistors mean that the button is "LOW" when pressed and "HIGH" when unpressed, which is counterintuitive.)

- a servo connected to D6 for its signal



3

You will need to use several constants (the servo positions) and variables (such as whether the box is locked or not). There are a number of new things introduced here: for example, **`Locked`** is a *bool* (short for Boolean), which can have either a "True" or "False" value. A concept re-introduced is arrays; **`Buttons[]`** is an *array* of integers and has been initialized to **`{2,3,4,5}`**. This means that Buttons has four slots, identified by their index number: **`Buttons[0]`** contains 2, **`Buttons[1]`** contains 3, and so on.

```
int ErrorLEDs[] = {A1,A2,A3,A4};
int OKLED = A5;
int Buttons[] = {2,3,4,5};
int ServoSignal = 6;
const int LockedPos = 90;
const int UnlockedPos = 0;
Servo Lock;
bool Locked = true;
int CorrectCode[] = {0,1,2,3};
int EnteredCode[] = {-1,-1,-1,-1};
int CurrentDigit = 0;
```

Note that in Computing we start counting at 0 not 1, so **`Buttons[0]`** is the first element of the Buttons array.

4

Using arrays allows you to loop or iterate over a group of variables. As you know how many elements are in your arrays, you can use a **for** loop.

For example, in the setup routine, you can declare an integer, p (for pin), and repeat while p is less than or equal to 3 (<=3), incrementing p by 1 each time around. Inside the loop, you can use p instead of the index number to access elements of the array. This allows you very quickly to set the button pins to be pullup inputs and the LED pins to be outputs. You will be using a lot more of these **for** loops in this chapter!

Of course, you also need to include the "OK" LED and servo in the setup.

```
Serial.begin(9600);
for (int p = 0;p <= 3;p++) {
  pinMode(Buttons[p],INPUT_PULLUP);
  pinMode(ErrorLEDs[p],OUTPUT);
}
pinMode(OKLED,OUTPUT);
Lock.attach(ServoSignal);
Lock.write(LockedPos);
```

PRO *TIP*

Arrays are a complex concept. Think of them as being like a book, with the variable name as the book name, and each indexed position as a page that can hold some information.

5

This is quite a complex project. Instead of using lots of code written multiple times in one long loop, it is sensible to separate the code into *helper routines*. Helper routines are just like the main loop, but you give each helper routine a meaningful name its own:

- **void resetEntered()** can use a **for** loop to reset the elements of the **EnteredCode** array to -1. (-1 is used to identify nothing entered for that digit.);
- **void lock()** and **void unlock()** can set the **Locked** variable to True or False, and write the correct position to the servo;
- **void clearErrorLEDs()** can use a for loop to go through the **ErrorLEDs** array and set each one to "LOW";
- **void showCurrentDigits()** can use a **for** loop to go through the **EnteredCode** array and output each digit to the serial monitor for checking.

```
void showCurrentDigits() {
  Serial.print("Currently entered: ");
  for (int p = 0;p <= 3;p++) {
    Serial.print(EnteredCode[p]);
  }
  Serial.println("");
}
```

PRO *TIP*

***Decomposition* is the term for breaking problems down into smaller chunks that are easier to deal—it is a fundamental concept in Computing.**

6

The routine to check the code (**`void checkCode()`**) needs to carry out a number of tasks:

- Firstly, it has to loop through and check each element of the **`EnteredCode`** against the same element of **`CorrectCode`**.
- If any elements of the codes are different, the corresponding LED needs to be lit, and a flag set to identify that the codes are different.
- If the codes are the same, the "OK" LED must be lit for a short while and the unlock routine must be called. If the codes are not the same, then the error LEDs need to remain lit for a while, before the LEDs are reset.

```
void checkCode() {
  bool codeCorrect = true;
  for (int p = 0;p <= 3;p++) {
    if (EnteredCode[p] != CorrectCode[p]) {
      codeCorrect = false;
      digitalWrite(ErrorLEDs[p],HIGH);
    }
  }
  resetEntered();
  if (codeCorrect) {
    Serial.println("Correct code!");
    digitalWrite(OKLED,HIGH);
    unlock();
    delay(500);
    digitalWrite(OKLED,LOW);
  } else {
    Serial.println("Incorrect code!");
    delay(1000);
    clearErrorLEDs();
  }
}
```

7

The most important routine in this code is **`void ButtonPressed`**, which takes a parameter, **`buttonID`**. A *parameter* is a piece of information that is passed into a routine for it to use—this means that you can use the same routine regardless of which button is pressed.

When a button is pressed, the corresponding LED is lit temporarily and the corresponding button number is put into the **`EnteredCode`** array at the **`CurrentDigit`** position. If the current digit is 4, then four digits have been entered. In that case, if the box is currently locked, then the **`checkCode()`** routine is called. If the box is not locked, then the entered code is copied one digit at a time into the correct code array, and the **`lock()`** routine is called.

```
void buttonPressed(int buttonID) {
  Serial.print("Button ");
  Serial.print(buttonID);
  Serial.println(" pressed.");
  digitalWrite(ErrorLEDs[buttonID],HIGH);
  EnteredCode[CurrentDigit] = buttonID;
  CurrentDigit++;
  showCurrentDigits();
  delay(500);
  clearErrorLEDs();
  if (CurrentDigit == 4) {
    if (Locked) {
      checkCode();
    } else {
      for (int p = 0;p <= 3;p++) {
        CorrectCode[p] = EnteredCode[p];
      }
      resetEntered();
      lock();
    }
    CurrentDigit = 0;
  }
}
```

Testing

This project involves both physical testing and software testing. Make sure you watch the serial monitor carefully, noticing what button presses are registered when the buttons are being pressed. The most common error is to forget that you must identify array elements by their index, and that indexes start at 0.

The problem with the physical lock box is that, when it is locked, you can't see inside it and fix any problems. It may be worth building the box in such a way that you can temporarily remove one of the sides or the top until you are confident the lock will work reliably and smoothly.

Stretch tasks

- In an earlier chapter you learned how to use multiple inputs on a single pin. Could you add more buttons to have the full range of digits 0–9?
- At the moment, the lock box is a normal device. Try turning it into an IoT device by logging all attempts to enter the box to the Cloud. You could also have a remote unlock button in case you forget your pin code.
- At the moment, it would take only a short time for someone to try every possible code and eventually get into the lock box. Consider what you could add to make it significantly more difficult to "hack" the box.

Final thoughts

As mentioned in "Setting the scene" above, the servo is a type of actuator. Physical devices often need to move to enable an action or display a variation. Motors are another type of actuators, and there is a wide range, such as screw jacks for producing linear motion.

Although the lock box device you built in this chapter is quite simple, the concept is used worldwide to operate delivery lockers used by companies such as Amazon. Consider the environmental benefits of using delivery lockers rather than delivering every parcel to individual addresses.

20. FINAL PROJECT

Setting the scene

The chapters in this book have introduced many new concepts, from simple inputs and outputs using buttons and LEDs, to more complex input sensors and physical outputs using motors, buzzers, and servos. Completing all these projects should give you a great sense of achievement, but now you have come to the end it is time to put all your skills into practice and complete a project of your own. You will find some ideas below, along with some helpful tips; see also https://www.kaggle.com/.

To give you a starting point, try to design a project that meets the following success criteria.

Success criteria

Create a device that:

- ☑ has at least two inputs and two outputs
- ☑ is an IoT device, using the Internet either for input or for displaying and logging data
- ☑ uses as many recycled products or materials as possible
- ☑ has a practical purpose, either for you or for someone you know.

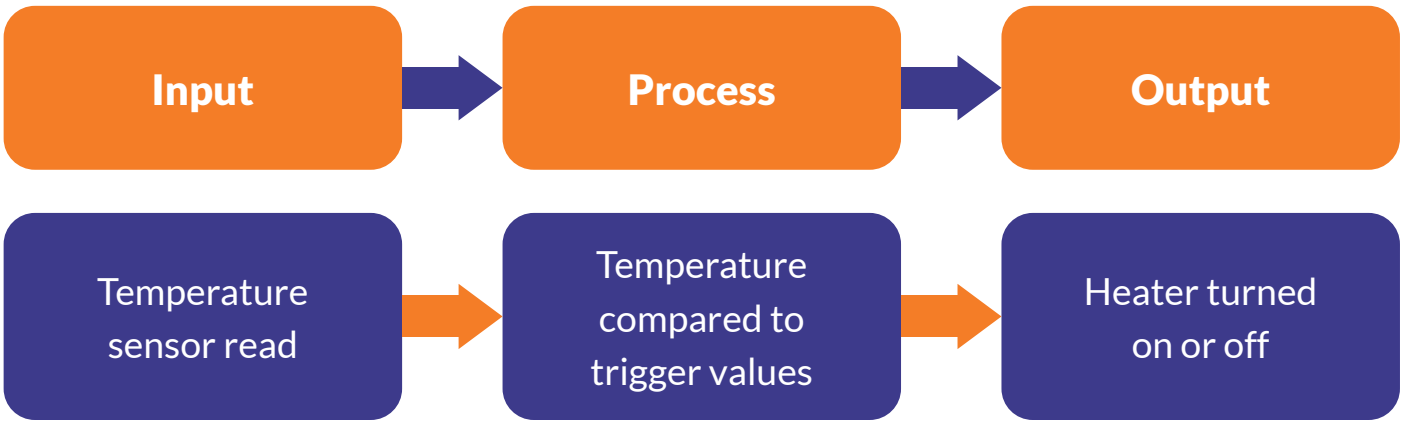
1

When you are designing your project, consider the IPO: inputs, processes, and outputs.

- What do you want to happen? These are the outputs.
- What will cause the outputs to happen? These are the inputs.
- In what situations will the inputs cause the outputs to happen? These are the processes.

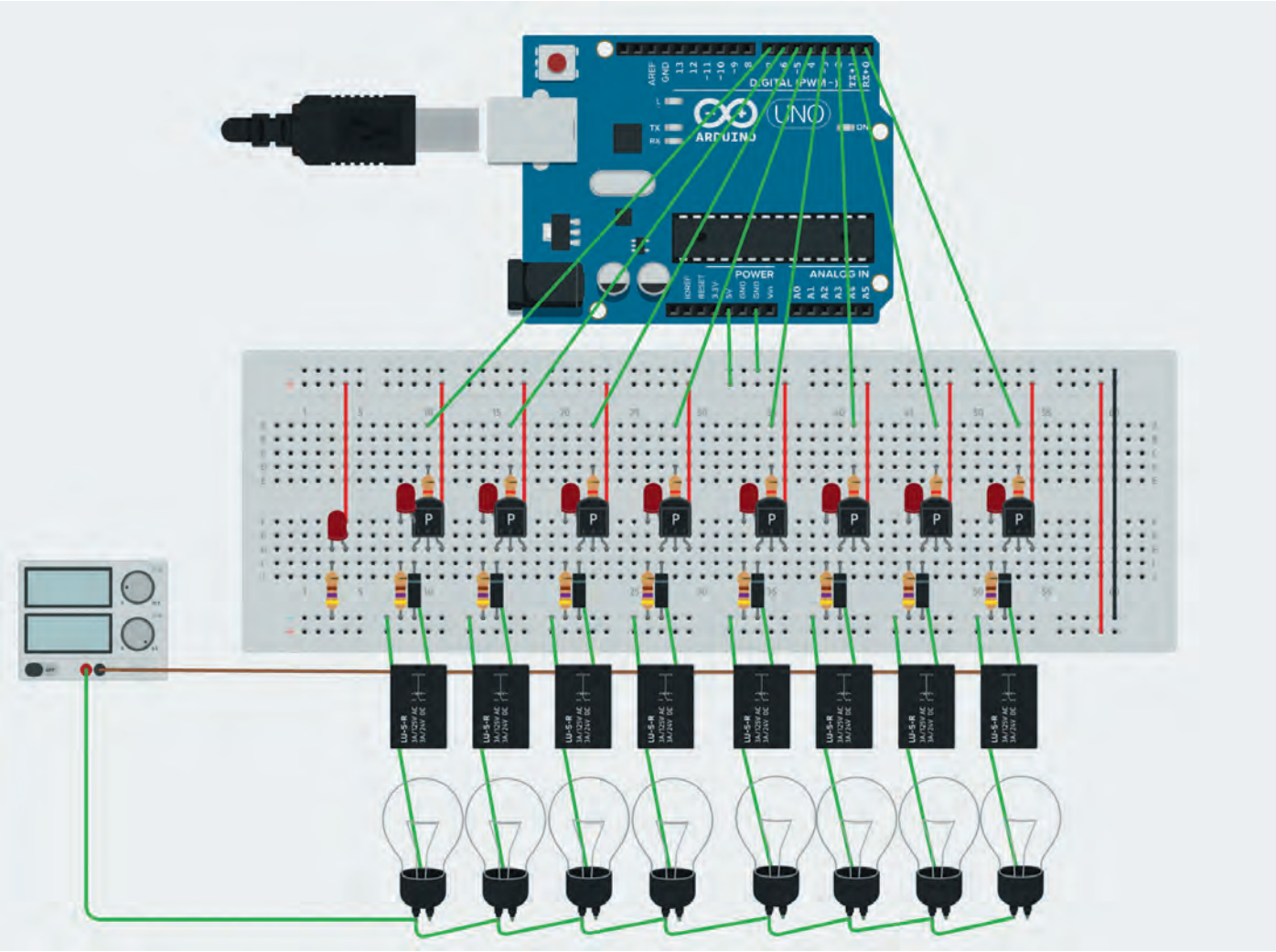
The diagram gives an example of each.

Remember that inputs and outputs are not just buttons being pressed, LEDs lighting, or fans turning on, but also data being entered into a spreadsheet online or an Internet switch being flicked.



2

When you design your circuit, try the inputs and the outputs individually by echoing data to the serial monitor or sending a direct message to the output pins. Once each is working as expected, it is time to move on to the coding.

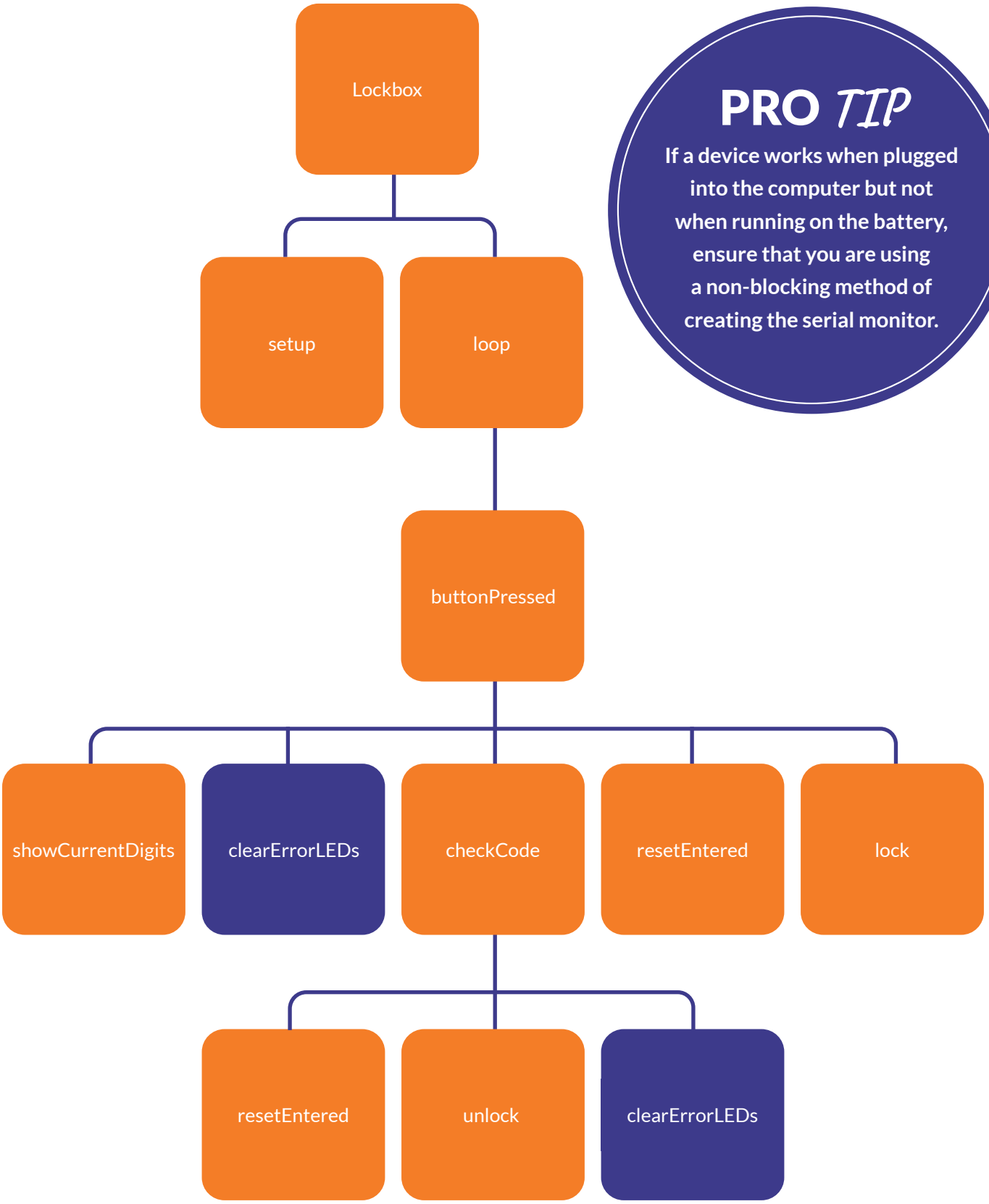


PRO *TIP*

Sometimes certain pins on the Arduino are withheld for different purposes. In Chapter 18, you had to move two of the LCD pins as the GPS module was using those pins. If something isn't working as expected, try moving the code and the connection to a different pin.

3

Decomposition is the programmer's best friend. One method of decomposition is *top-down design*. This is a hierarchical design methodology. At the top is your main program. Each "thing" the program needs to carry out becomes a sub-routine of its own below the top level. If a sub-routine becomes complex, split it again into more sub-routines until each sub-routine is simple enough to program.



PRO *TIP*

If a device works when plugged into the computer but not when running on the battery, ensure that you are using a non-blocking method of creating the serial monitor.

4

When you are programming the designed solution, program one piece at a time. In Chapter 19, you started by making the lock work, then the buttons and indicator LEDs, then the comparison of codes, and so on. You should have tested each section of code fully before moving on, and you may have saved the code using a different version number at each point. Using version numbers means that, if something goes wrong, you can easily find the last code that you know worked OK.

Testing

Formal testing takes some time. For each possible input, you need carry out the following tests:

- "Normal" tests involve inputs that should work—pressing a button, for example.
- "Erroneous" tests involve inputs that should not work—for example (in normal programming) typing a letter when the program expects a number; (in physical computing) **not** pressing a button when the program expects you to.
- "Edge cases" involve inputs that should (or should not) work, but only just—pressing two buttons at once or pressing a button really fast or really slowly, for example.
- The most important thing is to be thorough. Test each possible input and fix any problems.

Stretch tasks

- Creating a device once is an interesting project for you. Creating a device that can be reproduced could be useful for many people, so consider writing up your project to share with the wider world. Instructables.com is a popular website for makers to share their project stories.
- Once your project is complete, consider what extensions you could add to it. If your project involves logging data, can you analyze the data using either spreadsheet tools or Machine Learning techniques?
- Is your device fully IoT enabled? Does it transmit data both to and from the device? If not, add this as an extension.
- Part of documenting a project is completing a full circuit diagram. Draw up your circuit as a diagram using the proper symbols. You might like to use a site such as circuit-diagram.org to help you.

Final thoughts

The use of microcontrollers, and the IoT in particular, is a hugely growing field. Many homes now have several Internet-enabled devices and they may have many more microcontroller-based devices that are not (yet) online. The projects in this book have given you a taster of many concepts and encouraged you to continue exploring. Now it is over to you to dream big, solve problems, and use the skills you have developed to come up with new concepts to benefit the world around you.