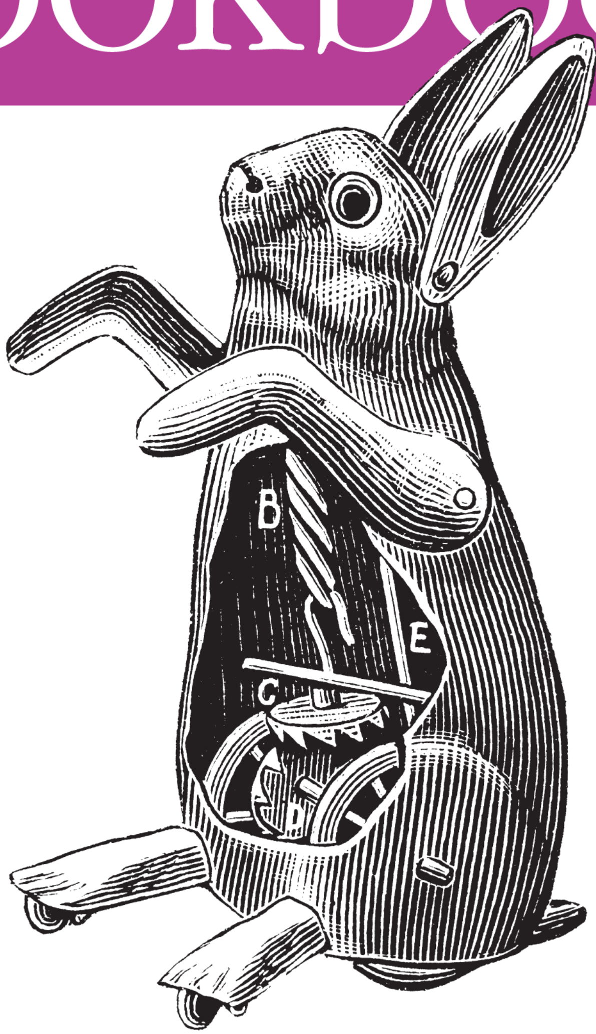
Recipes to Begin, Expand, and Enhance Your Projects

2nd Edition
Covers Arduino 1.0

Arduino Cookbook



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Michael Margolis

Electronics/Software Engineering/Robotics

Arduino Cookbook

Want to create devices that interact with the physical world? This cookbook is perfect for anyone who wants to experiment with the popular Arduino microcontroller and programming environment. You'll find more than 200 tips and techniques for building a variety of objects and prototypes such as toys, detectors, robots, and interactive clothing that can sense and respond to touch, sound, position, heat, and light.

You don't need experience with Arduino or programming to get started. Updated for the Arduino 1.0 release, the recipes in this second edition include practical examples and guidance to help you begin, expand, and enhance your projects right away—whether you're an artist, designer, hobbyist, student, or engineer.

- Get up to speed quickly on the Arduino board and essential software concepts
- Learn basic techniques for reading digital and analog signals
- Use Arduino with a variety of popular input devices and sensors
- Drive visual displays, generate sound, and control several types of motors
- Interact with devices that use remote controls, including TVs and appliances
- Learn techniques for handling time delays and time measurement
- Apply advanced coding and memory handling techniques

Michael Margolis is a technologist in the field of real-time computing, with expertise in developing hardware and software for interacting with the environment. He has more than 30 years of experience at senior levels with Sony, Microsoft, and Lucent/Bell Labs, and has written libraries and core software included in the Arduino 1.0 distribution.

"Michael Margolis's comprehensive set of recipes is a fine gift to the burgeoning Arduino community. Whatever your background or skill, the Cookbook provides solutions for that project you're wrestling with today and fuel for imagining what you'll build tomorrow. I doubt it will ever leave my workbench table."

—Mikal Hart
Arduino Uno Advisory Team

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SECOND EDITION

Arduino Cookbook

Michael Margolis

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Beijing • Cambridge • Farnham • Köln • Sebastopol • Tokyo

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by Michael Margolis

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Preface

This book was written by Michael Margolis with Nick Weldin to help you explore the amazing things you can do with Arduino.

Arduino is a family of microcontrollers (tiny computers) and a software creation environment that makes it easy for you to create programs (called *sketches*) that can interact with the physical world. Things you make with Arduino can sense and respond to touch, sound, position, heat, and light. This type of technology, often referred to as *physical computing*, is used in all kinds of things from the iPhone to automobile electronics systems. Arduino makes it possible for anyone with an interest—even people with no programming or electronics experience—to use this rich and complex technology.

Who This Book Is For

Unlike in most technical cookbooks, experience with software and hardware is not assumed. This book is aimed at readers interested in using computer technology to interact with the environment. It is for people who want to quickly find the solution to hardware and software problems. The recipes provide the information you need to accomplish a broad range of tasks. It also has details to help you customize solutions to meet your specific needs. There is insufficient space in a book limited to 700 pages to cover general theoretical background, so links to external references are provided throughout the book. See "What Was Left Out" on page xiv for some general references for those with no programming or electronics experience.

If you have no programming experience—perhaps you have a great idea for an interactive project but don't have the skills to develop it—this book will help you learn what you need to know to write code that works, using examples that cover over 200 common tasks.

If you have some programming experience but are new to Arduino, the book will help you become productive quickly by demonstrating how to implement specific Arduino capabilities for your project.

People already using Arduino should find the content helpful for quickly learning new techniques, which are explained using practical examples. This will help you to embark on more complex projects by showing how to solve problems and use capabilities that may be new to you.

Experienced C/C++ programmers will find examples of how to use the low-level AVR resources (interrupts, timers, I2C, Ethernet, etc.) to build applications using the Arduino environment.

How This Book Is Organized

The book contains information that covers the broad range of the Arduino's capabilities, from basic concepts and common tasks to advanced technology. Each technique is explained in a recipe that shows you how to implement a specific capability. You do not need to read the content in sequence. Where a recipe uses a technique covered in another recipe, the content in the other recipe is referenced rather than repeating details in multiple places.

Chapter 1, *Getting Started*, introduces the Arduino environment and provides help on getting the Arduino development environment and hardware installed and working.

The next couple of chapters introduce Arduino software development. Chapter 2, *Making the Sketch Do Your Bidding*, covers essential software concepts and tasks, and Chapter 3, *Using Mathematical Operators*, shows how to make use of the most common mathematical functions.

Chapter 4, *Serial Communications*, describes how to get Arduino to connect and communicate with your computer and other devices. Serial is the most common method for Arduino input and output, and this capability is used in many of the recipes throughout the book.

Chapter 5, *Simple Digital and Analog Input*, introduces a range of basic techniques for reading digital and analog signals. Chapter 6, *Getting Input from Sensors*, builds on this with recipes that explain how to use devices that enable Arduino to sense touch, sound, position, heat, and light.

Chapter 7, *Visual Output*, covers controlling light. Recipes cover switching on one or many LEDs and controlling brightness and color. This chapter explains how you can drive bar graphs and numeric LED displays, as well as create patterns and animations with LED arrays. In addition, the chapter provides a general introduction to digital and analog output for those who are new to this.

Chapter 8, *Physical Output*, explains how you can make things move by controlling motors with Arduino. A wide range of motor types is covered: solenoids, servo motors, DC motors, and stepper motors.

Chapter 9, *Audio Output*, shows how to generate sound with Arduino through an output device such as a speaker. It covers playing simple tones and melodies and playing WAV files and MIDI.

Chapter 10, *Remotely Controlling External Devices*, describes techniques that can be used to interact with almost any device that uses some form of remote controller, including TV, audio equipment, cameras, garage doors, appliances, and toys. It builds on techniques used in previous chapters for connecting Arduino to devices and modules.

Chapter 11, *Using Displays*, covers interfacing text and graphical LCD displays. The chapter shows how you can connect these devices to display text, scroll or highlight words, and create special symbols and characters.

Chapter 12, *Using Time and Dates*, covers built-in Arduino time-related functions and introduces many additional techniques for handling time delays, time measurement, and real-world times and dates.

Chapter 13, *Communicating Using I2C and SPI*, covers the Inter-Integrated Circuit (I2C) and Serial Peripheral Interface (SPI) standards. These standards provide simple ways for digital information to be transferred between sensors and Arduino. This chapter shows how to use I2C and SPI to connect to common devices. It also shows how to connect two or more Arduino boards, using I2C for multiboard applications.

Chapter 14, *Wireless Communication*, covers wireless communication with XBee and other wireless modules. This chapter provides examples ranging from simple wireless serial port replacements to mesh networks connecting multiple boards to multiple sensors.

Chapter 15, *Ethernet and Networking*, describes the many ways you can use Arduino with the Internet. It has examples that demonstrate how to build and use web clients and servers and shows how to use the most common Internet communication protocols with Arduino.

Arduino software libraries are a standard way of adding functionality to the Arduino environment. Chapter 16, *Using, Modifying, and Creating Libraries*, explains how to use and modify software libraries. It also provides guidance on how to create your own libraries.

Chapter 17, *Advanced Coding and Memory Handling*, covers advanced programming techniques, and the topics here are more technical than the other recipes in this book because they cover things that are usually concealed by the friendly Arduino wrapper. The techniques in this chapter can be used to make a sketch more efficient—they can help improve performance and reduce the code size of your sketches.

Chapter 18, *Using the Controller Chip Hardware*, shows how to access and use hardware functions that are not fully exposed through the documented Arduino language. It covers low-level usage of the hardware input/output registers, timers, and interrupts.

Appendix A, *Electronic Components*, provides an overview of the components used throughout the book.

Appendix B, *Using Schematic Diagrams and Data Sheets*, explains how to use schematic diagrams and data sheets.

Appendix C, *Building and Connecting the Circuit*, provides a brief introduction to using a breadboard, connecting and using external power supplies and batteries, and using capacitors for decoupling.

Appendix D, *Tips on Troubleshooting Software Problems*, provides tips on fixing compile and runtime problems.

Appendix E, *Tips on Troubleshooting Hardware Problems*, covers problems with electronic circuits.

Appendix F, *Digital and Analog Pins*, provides tables indicating functionality provided by the pins on standard Arduino boards.

Appendix G, *ASCII and Extended Character Sets*, provides tables showing ASCII characters.

Appendix H, *Migrating to Arduino 1.0*, explains how to modify code written for previous releases to run correctly with Arduino 1.0.

What Was Left Out

There isn't room in this book to cover electronics theory and practice, although guidance is provided for building the circuits used in the recipes. For more detail, readers may want to refer to material that is widely available on the Internet or to books such as the following:

- *Make: Electronics* by Charles Platt (O'Reilly; search for it on oreilly.com)
- *Getting Started in Electronics* by Forrest M. Mims III (Master Publishing)
- *Physical Computing* by Dan O'Sullivan and Tom Igoe (Cengage)
- *Practical Electronics for Inventors* by Paul Scherz (McGraw-Hill)

This cookbook explains how to write code to accomplish specific tasks, but it is not an introduction to programming. Relevant programming concepts are briefly explained, but there is insufficient room to cover the details. If you want to learn more about programming, you may want to refer to the Internet or to one of the following books:

- *Practical C Programming* by Steve Oualline (O'Reilly; search for it on oreilly.com)
- *A Book on C* by Al Kelley and Ira Pohl (Addison-Wesley)

My favorite, although not really a beginner's book, is the book I used to learn C programming:

- *The C Programming Language* by Brian W. Kernighan and Dennis M. Ritchie (Prentice Hall)

Code Style (About the Code)

The code used throughout this book has been tailored to clearly illustrate the topic covered in each recipe. As a consequence, some common coding shortcuts have been avoided, particularly in the early chapters. Experienced C programmers often use rich but terse expressions that are efficient but can be a little difficult for beginners to read. For example, the early chapters increment variables using explicit expressions that are easy for nonprogrammers to read:

```
result = result + 1; // increment the count
```

Rather than the following, commonly used by experienced programmers, that does the same thing:

```
result++;  // increment using the post increment operator
```

Feel free to substitute your preferred style. Beginners should be reassured that there is no benefit in performance or code size in using the terse form.

Some programming expressions are so common that they are used in their terse form. For example, the loop expressions are written as follows:

```
for(int i=0; i < 4; i++)
```

This is equivalent to the following:

```
int i;
for(i=0; i < 4; i = i+1)
```

See Chapter 2 for more details on these and other expressions used throughout the book.

Good programming practice involves ensuring that values used are valid (garbage in equals garbage out) by checking them before using them in calculations. However, to keep the code focused on the recipe topic, very little error-checking code has been included.

Arduino Platform Release Notes

This edition has been updated for Arduino 1.0. All of the code has been tested with the latest Arduino 1.0 release candidate at the time of going to press (RC2). The download code for this edition will be updated online if necessary to support the final 1.0 release, so check the book's website to get the latest code. The download contains a file named *changelog.txt* that will indicate code that has changed from the published edition.

Although many of the sketches will run on earlier Arduino releases, you need to change the extension from *.ino* to *.pde* to load the sketch into a pre-1.0 IDE. If you have not migrated to Arduino 1.0 and have good reason to stick with an earlier release, you can use the example code from the first edition of this book (available at *http://shop.oreilly.com/product/9780596802486.do*), which has been tested with releases from 0018 to 0022. Note that many recipes in the second edition have been enhanced, so we encourage you to upgrade to Arduino 1.0. If you need help migrating older code, see Appendix H.

There's also a link to errata on that site. Errata give readers a way to let us know about typos, errors, and other problems with the book. Errata will be visible on the page immediately, and we'll confirm them after checking them out. O'Reilly can also fix errata in future printings of the book and on Safari, making for a better reader experience pretty quickly.

If you have problems making examples work, check the *changelog.txt* file in the latest code download to see if the sketch has been updated. If that doesn't fix the problem, see Appendix D, which covers troubleshooting software problems. The Arduino forum is a good place to post a question if you need more help: *http://www.arduino.cc*.

If you like—or don't like—this book, by all means, please let people know. Amazon reviews are one popular way to share your happiness or other comments. You can also leave reviews at the O'Reilly site for the book.

Conventions Used in This Book

The following font conventions are used in this book:

Italic
: Indicates pathnames, filenames, and program names; Internet addresses, such as domain names and URLs; and new items where they are defined

`Constant width`
: Indicates command lines and options that should be typed verbatim; names and keywords in programs, including method names, variable names, and class names; and HTML element tags

`Constant width bold`
: Indicates emphasis in program code lines

`Constant width italic`
: Indicates text that should be replaced with user-supplied values

This icon signifies a tip, suggestion, or general note.

This icon indicates a warning or caution.

Using Code Examples

This book is here to help you make things with Arduino. In general, you may use the code in this book in your programs and documentation. You do not need to contact us for permission unless you're reproducing a significant portion of the code. For example, writing a program that uses several chunks of code from this book does not require permission. Selling or distributing a CD-ROM of examples from this book *does* require permission. Answering a question by citing this book and quoting example code does not require permission. Incorporating a significant amount of example code from this book into your product's documentation *does* require permission.

We appreciate, but do not require, attribution. An attribution usually includes the title, author, publisher, and ISBN. For example: "*Arduino Cookbook, Second Edition,* by Michael Margolis with Nick Weldin (O'Reilly). Copyright 2012 Michael Margolis, Nicholas Weldin, 978-1-4493-1387-6."

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Acknowledgments

Nick Weldin's contribution was invaluable for the completion of this book. It was 90 percent written when Nick came on board—and without his skill and enthusiasm, it would still be 90 percent written. His hands-on experience running Arduino workshops for all levels of users enabled us to make the advice in this book practical for our broad range of readers. Thank you, Nick, for your knowledge and genial, collaborative nature.

Simon St. Laurent was the editor at O'Reilly who first expressed interest in this book. And in the end, he is the man who pulled it together. His support and encouragement kept us inspired as we sifted our way through the volumes of material necessary to do the subject justice.

Brian Jepson helped me get started with the writing of this book. His vast knowledge of things Arduino and his concern and expertise for communicating about technology in plain English set a high standard. He was an ideal guiding hand for shaping the book and making technology readily accessible for readers. We also have Brian to thank for the XBee content in Chapter 14.

Brian Jepson and Shawn Wallace were technical editors for this second edition and provided excellent advice for improving the accuracy and clarity of the content.

Audrey Doyle worked tirelessly to stamp out typos and grammatical errors in the initial manuscript and untangle some of the more convoluted expressions.

Philip Lindsay collaborated on content for Chapter 15 in the first edition. Adrian McEwen, the lead developer for many of the Ethernet enhancements in Release 1.0, provided valuable advice to ensure this Chapter reflected all the changes in that release.

Mikal Hart wrote recipes covering GPS and software serial. Mikal was the natural choice for this—not only because he wrote the libraries, but also because he is a fluent communicator, an Arduino enthusiast, and a pleasure to collaborate with.

Arduino is possible because of the creativity of the core Arduino development team: Massimo Banzi, David Cuartielles, Tom Igoe, Gianluca Martino, and David Mellis. On behalf of all Arduino users, I wish to express our appreciation for their efforts in making this fascinating technology simple and their generosity in making it free.

Special thanks to Alexandra Deschamps-Sonsino, whose Tinker London workshops provided important understanding of the needs of users. Thanks also to Peter Knight, who has provided all kinds of clever Arduino solutions as well as the basis of a number of recipes in this book.

On behalf of everyone who has downloaded user-contributed Arduino libraries, I would like to thank the authors who have generously shared their knowledge.

The availability of a wide range of hardware is a large part of what makes Arduino exciting—thanks to the suppliers for stocking and supporting a broad range of great devices. The following were helpful in providing hardware used in the book: SparkFun, Maker Shed, Gravitech, and NKC Electronics. Other suppliers that have been helpful include Modern Device, Liquidware, Adafruit, MakerBot Industries, Mindkits, Oomlout, and SK Pang.

Nick would like to thank everyone who was involved with Tinker London, particularly Alexandra, Peter, Brock Craft, Daniel Soltis and all the people who assisted on workshops over the years.

Nick's final thanks go to his family, Jeanie, Emily, and Finn, who agreed to let him do this over their summer holiday, and of course, much longer after that than they originally thought, and to his parents, Frank and Eva, for bringing him up to take things apart.

Last but not least, I express thanks to the following people:

Joshua Noble for introducing me to O'Reilly. His book, *Programming Interactivity*, is highly recommended for those interested in broadening their knowledge in interactive computing.

Robert Lacy-Thompson for offering advice early on with the first edition.

Mark Margolis for his support and help as a sounding board in the book's conception and development.

I thank my parents for helping me to see that the creative arts and technology were not distinctive entities and that, when combined, they can lead to extraordinary results.

And finally, this book would not have been started or finished without the support of my wife, Barbara Faden. My grateful appreciation to her for keeping me motivated and for her careful reading and contributions to the manuscript.

Notes on the Second Edition

The second edition of this book has followed relatively quickly from the first, prompted by the release of Arduino 1.0. The stated purpose of 1.0 is to introduce significant change that will smooth the way for future enhancements but break some code written for older software. These have necessitated changes to code in many of the chapters of this book. Most changed are Chapter 15, *Ethernet and Networking*, and Chapter 13, *Communicating Using I2C and SPI*, but all of the recipes in this edition have been migrated to 1.0, with many being updated to use features new in this release. If you are using a release prior to Arduino 1.0, then you can download code from the first edition of this book. See "Arduino Platform Release Notes" on page xv for download details.

Appendix H, *Migrating to Arduino 1.0*, has been added to describe the changes introduced by Arduino Release 1.0. This describes how to update older code to use with Arduino 1.0.

Recipes for devices that are no longer widely available have been updated to use current replacements and some new sensors and wireless devices have been added.

Errata posted on the O'Reilly site has been corrected, thanks to readers taking the time to notify us of these.

We think you will like the improvements made in Arduino 1.0 as well as the enhancements made to this edition of the *Arduino Cookbook*. The first edition was well received; the constructive criticism being divided between people that wanted more technical content and those that preferred less. In a book that we limited to only 700 or so pages (to keep it affordable and portable), that seems to indicate that the right balance has been achieved.

CHAPTER 1
Getting Started

1.0 Introduction

The Arduino environment has been designed to be easy to use for beginners who have no software or electronics experience. With Arduino, you can build objects that can respond to and/or control light, sound, touch, and movement. Arduino has been used to create an amazing variety of things, including musical instruments, robots, light sculptures, games, interactive furniture, and even interactive clothing.

> If you're not a beginner, please feel free to skip ahead to recipes that interest you.

Arduino is used in many educational programs around the world, particularly by designers and artists who want to easily create prototypes but do not need a deep understanding of the technical details behind their creations. Because it is designed to be used by nontechnical people, the software includes plenty of example code to demonstrate how to use the Arduino board's various facilities.

Though it is easy to use, Arduino's underlying hardware works at the same level of sophistication that engineers employ to build embedded devices. People already working with microcontrollers are also attracted to Arduino because of its agile development capabilities and its facility for quick implementation of ideas.

Arduino is best known for its hardware, but you also need software to program that hardware. Both the hardware and the software are called "Arduino." The combination enables you to create projects that sense and control the physical world. The software is free, open source, and cross-platform. The boards are inexpensive to buy, or you can build your own (the hardware designs are also open source). In addition, there is an active and supportive Arduino community that is accessible worldwide through the Arduino forums and the wiki (known as the Arduino Playground). The forums and the wiki offer project development examples and solutions to problems that can provide inspiration and assistance as you pursue your own projects.

The recipes in this chapter will get you started by explaining how to set up the development environment and how to compile and run an example sketch.

> Source code containing computer instructions for controlling Arduino functionality is usually referred to as a *sketch* in the Arduino community. The word *sketch* will be used throughout this book to refer to Arduino program code.

The Blink sketch, which comes with Arduino, is used as an example for recipes in this chapter, though the last recipe in the chapter goes further by adding sound and collecting input through some additional hardware, not just blinking the light built into the board. Chapter 2 covers how to structure a sketch for Arduino and provides an introduction to programming.

> If you already know your way around Arduino basics, feel free to jump forward to later chapters. If you're a first-time Arduino user, patience in these early recipes will pay off with smoother results later.

Arduino Software

Software programs, called *sketches*, are created on a computer using the Arduino integrated development environment (IDE). The IDE enables you to write and edit code and convert this code into instructions that Arduino hardware understands. The IDE also transfers those instructions to the Arduino board (a process called *uploading*).

Arduino Hardware

The Arduino board is where the code you write is executed. The board can only control and respond to electricity, so specific components are attached to it to enable it to interact with the real world. These components can be sensors, which convert some aspect of the physical world to electricity so that the board can sense it, or actuators, which get electricity from the board and convert it into something that changes the world. Examples of sensors include switches, accelerometers, and ultrasound distance sensors. Actuators are things like lights and LEDs, speakers, motors, and displays.

There are a variety of official boards that you can use with Arduino software and a wide range of Arduino-compatible boards produced by members of the community.

The most popular boards contain a USB connector that is used to provide power and connectivity for uploading your software onto the board. Figure 1-1 shows a basic board that most people start with, the Arduino Uno.

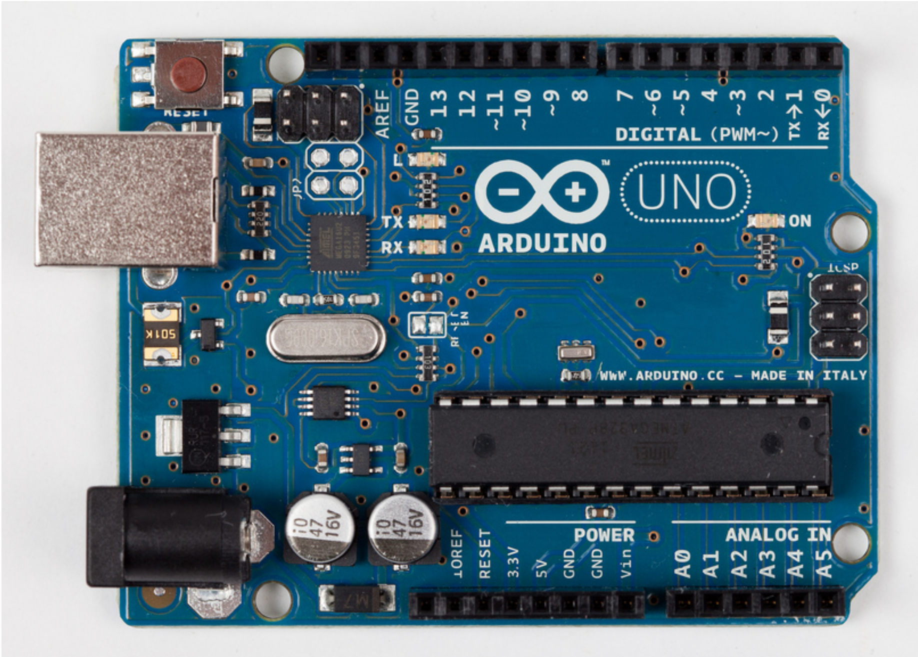

Figure 1-1. Basic board: the Arduino Uno. Photograph courtesy todo.to.it.

The Arduino Uno has a second microcontroller onboard to handle all USB communication; the small surface-mount chip (the ATmega8U2) is located near the USB socket on the board. This can be programmed separately to enable the board to appear as different USB devices (see Recipe 18.14 for an example). The Arduino Leonardo board replaces the ATmega8U2 and the ATmega328 controllers with a single ATmega32u4 chip that implements the USB protocol in software. The Arduino-compatible Teensy and Teensy+ boards from PJRC (*http://www.pjrc.com/teensy/*) are also capable of emulating USB devices. Older boards, and most of the Arduino-compatible boards, use a chip from the FTDI company that provides a hardware USB solution for connection to the serial port of your computer.

You can get boards as small as a postage stamp, such as the Arduino Mini and Pro Mini; larger boards that have more connection options and more powerful processors, such as the Arduino Mega; and boards tailored for specific applications, such as the LilyPad for wearable applications, the Fio for wireless projects, and the Arduino Pro for embedded applications (standalone projects that are often battery-operated).

Recent additions to the range include the Arduino ADK, which has a USB host socket on it and is compatible with the Android Open Accessory Development Kit, the officially approved method of attaching hardware to Android devices. The Leonardo board uses a controller chip (the ATmega32u4) that is able to present itself as various HID devices. The Ethernet board includes Ethernet connectivity, and has a Power Over Ethernet option, so it is possible to use a single cable to connect and power the board.

Other Arduino-compatible boards are also available, including the following:

- Arduino Nano, a tiny board with USB capability, from Gravitech (*http://store.gravitech.us/arna30wiatn.html*)
- Bare Bones Board, a low-cost board available with or without USB capability, from Modern Device (*http://www.moderndevice.com/products/bbb-kit*)
- Boarduino, a low-cost breadboard-compatible board, from Adafruit Industries (*http://www.adafruit.com/*)
- Seeeduino, a flexible variation of the standard USB board, from Seeed Studio Bazaar (*http://www.seeedstudio.com/*)
- Teensy and Teensy++, tiny but extremely versatile boards, from PJRC (*http://www.pjrc.com/teensy/*)

A list of Arduino-compatible boards is available at *http://www.freeduino.org/*.

See Also

An overview of Arduino boards: *http://www.arduino.cc/en/Main/Hardware*.

Online guides for getting started with Arduino are available at *http://arduino.cc/en/Guide/Windows* for Windows, *http://arduino.cc/en/Guide/MacOSX* for Mac OS X, and *http://www.arduino.cc/playground/Learning/Linux* for Linux.

A list of over a hundred boards that can be used with the Arduino development environment can be found at: *http://jmsarduino.blogspot.com/2009/03/comprehensive-arduino-compatible.html*

1.1 Installing the Integrated Development Environment (IDE)

Problem

You want to install the Arduino development environment on your computer.

Solution

The Arduino software for Windows, Mac, and Linux can be downloaded from *http://arduino.cc/en/Main/Software*.

The Windows download is a ZIP file. Unzip the file to any convenient directory—*Program Files/Arduino* is a sensible place.

A free utility for unzipping files, called 7-Zip, can be downloaded from *http://www.7-zip.org/*.

Unzipping the file will create a folder named *Arduino-00<nn>* (where *<nn>* is the version number of the Arduino release you downloaded). The directory contains the executable file (named *Arduino.exe*), along with various other files and folders. Double-click the *Arduino.exe* file and the splash screen should appear (see Figure 1-2), followed by the main program window (see Figure 1-3). Be patient, as it can take some time for the software to load.

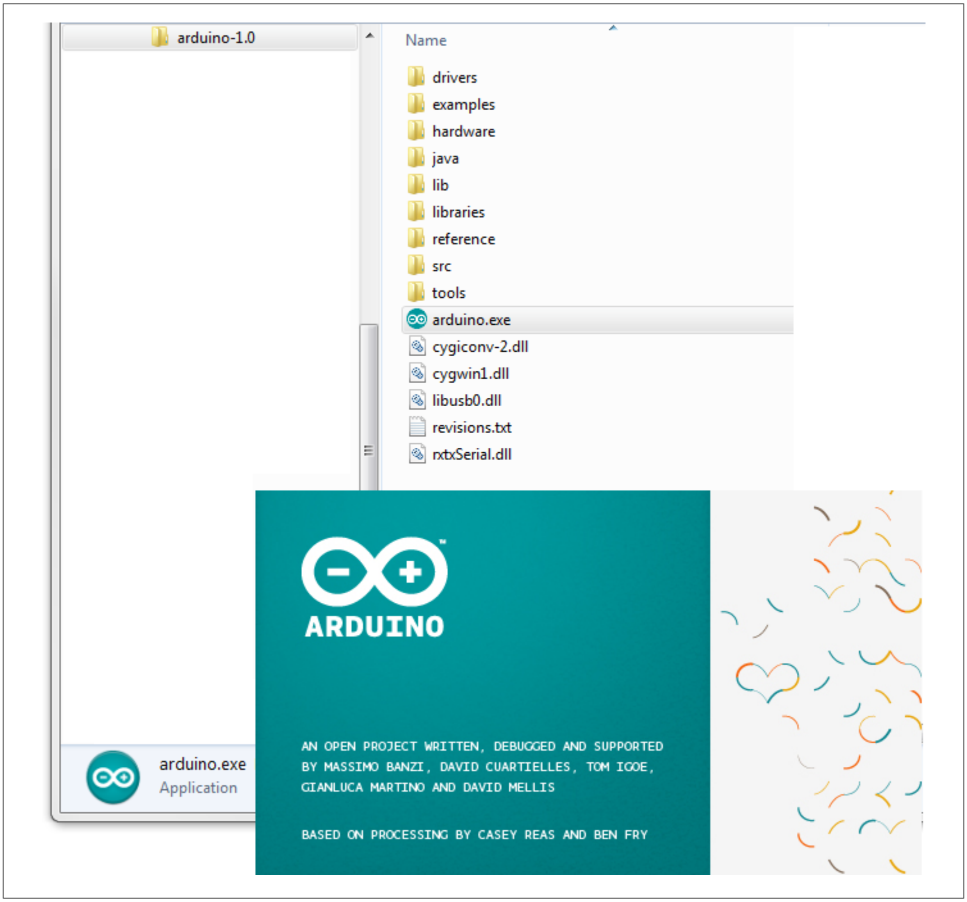

Figure 1-2. Arduino splash screen (Version 1.0 in Windows 7)

The Arduino download for the Mac is a disk image (*.dmg*); double-click the file when the download is complete. The image will mount (it will appear like a memory stick

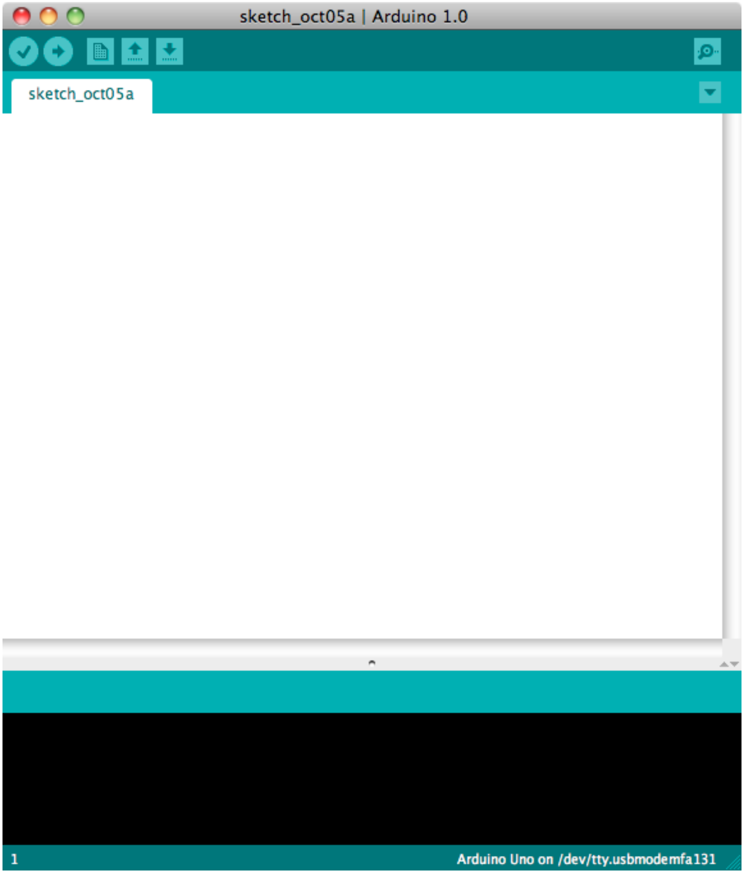

Figure 1-3. IDE main window (Arduino 1.0 on a Mac)

on the desktop). Inside the disk image is the Arduino application. Copy this to somewhere convenient—the *Applications* folder is a sensible place. Double-click the application once you have copied it over (it is not a good idea to run it from the disk image). The splash screen will appear, followed by the main program window.

Linux installation varies depending on the Linux distribution you are using. See the Arduino wiki for information (*http://www.arduino.cc/playground/Learning/Linux*).

To enable the Arduino development environment to communicate with the board, you need to install drivers.

On Windows, use the USB cable to connect your PC and the Arduino board and wait for the Found New Hardware Wizard to appear. If you are using an Uno board, let the wizard attempt to find and install drivers. It will fail to do this (don't worry, this is the expected behavior). To fix it you now need to go to Start Menu→Control Panel→System and Security. Click on System, and then open Device Manager. In the listing that is displayed find the entry in COM and LPT named `Arduino UNO (COM nn)`. `nn` will be the number Windows has assigned to the port created for the board. You will see a warning logo next to this because the appropriate drivers have not yet been assigned. Right click on the entry and select Update Driver Software. Choose the “Browse my computer for driver software” option, and navigate to the *Drivers* folder inside the Arduino folder you just unzipped. Select the `ArduinoUNO.inf` file and windows should then complete the installation process.

If you are using an earlier board (any board that uses FTDI drivers) with Windows Vista or Windows 7 and are online, you can let the wizard search for drivers and they will install automatically. On Windows XP (or if you don’t have Internet access), you should specify the location of the drivers. Use the file selector to navigate to the *FTDI USB Drivers* directory, located in the directory where you unzipped the Arduino files. When this driver has installed, the Found New Hardware Wizard will appear again, saying a new serial port has been found. Follow the same process as before.

> It is important that you go through the sequence of steps to install the drivers two times, or the software will not be able to communicate with the board.

On the Mac, the latest Arduino boards, such as the Uno, can be used without additional drivers. When you first plug the board in a notification will pop up saying a new network port has been found, you can dismiss this. If you are using earlier boards (boards that need FTDI drivers), you will need to install driver software. There is a package named *FTDIUSBSerialDriver*, with a range of numbers after it, inside the disk image. Double-click this and the installer will take you through the process. You will need to know an administrator password to complete the process.

On Linux, most distributions have the driver already installed, but follow the Linux link given in this chapter’s introduction for specific information for your distribution.

Discussion

If the software fails to start, check the troubleshooting section of the Arduino website, *http://arduino.cc/en/Guide/Troubleshooting*, for help solving installation problems.

See Also

Online guides for getting started with Arduino are available at *http://arduino.cc/en/Guide/Windows* for Windows, *http://arduino.cc/en/Guide/MacOSX* for Mac OS X, and *http://www.arduino.cc/playground/Learning/Linux* for Linux.

1.2 Setting Up the Arduino Board

Problem

You want to power up a new board and verify that it is working.

Solution

Plug the board in to a USB port on your computer and check that the green LED power indicator on the board illuminates. Standard Arduino boards (Uno, Duemilanove, and Mega) have a green LED power indicator located near the reset switch.

An orange LED near the center of the board (labeled “Pin 13 LED” in Figure 1-4) should flash on and off when the board is powered up (boards come from the factory preloaded with software to flash the LED as a simple check that the board is working).

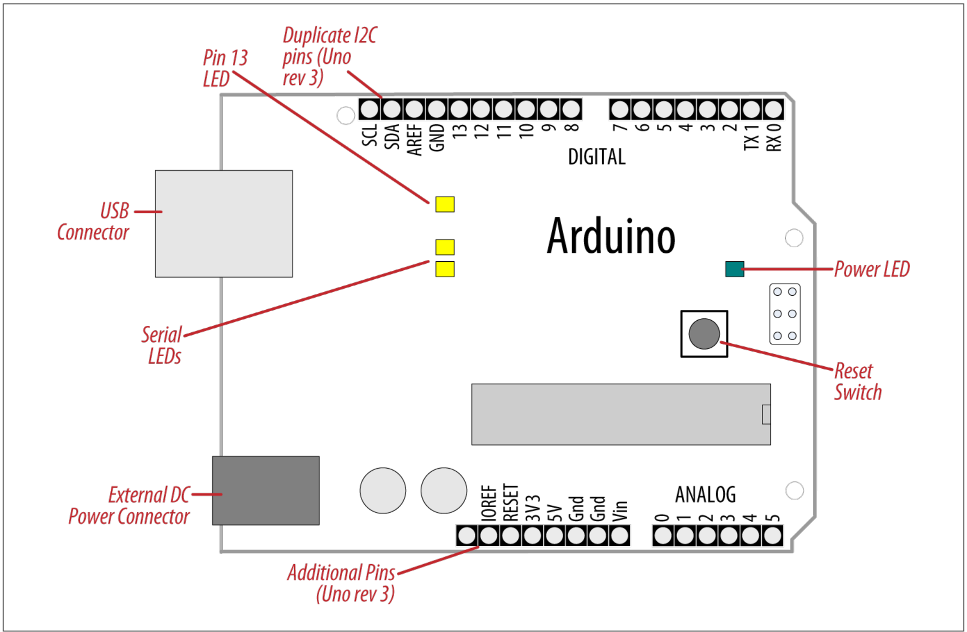

Figure 1-4. Basic Arduino board (Duemilanove and Uno)

New boards such as Leonardo have the LEDs located near the USB connector; see Figure 1-5. Recent boards have duplicate pins for use with I2C (marked `SCL` and `SDA`). These boards also have a pin marked `IOREF` that can be used to determine the operating voltage of the chip.

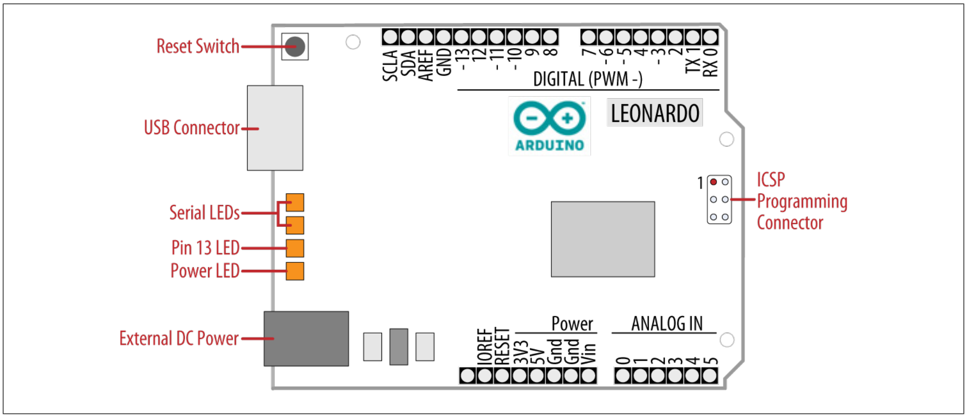

Figure 1-5. Leonardo Board

> The latest boards have three additional connections in the new standard for connector layout on the board. This does not affect the use of older shields (they will all continue to work with the new boards, just as they did with earlier boards). The new connections provide a pin (IOREF) for shields to detect the analog reference voltage (so that analog input values can be calibrated to the supply voltage), SCL and SDA pins to enable a consistent connection for I2C devices (the location of the I2C pins has differed on previous boards due to different chip configurations). Shields designed for the new layout should work on any board that uses the new pin locations. An additional pin (next to the IOREF pin) is not being used at the moment, but enables new functionality to be implemented in the future without needing to change the pin layout again.

Discussion

If the power LED does not illuminate when the board is connected to your computer, the board is probably not receiving power.

The flashing LED (connected to digital output pin 13) is being controlled by code running on the board (new boards are preloaded with the Blink example sketch). If the pin 13 LED is flashing, the sketch is running correctly, which means the chip on the board is working. If the green power LED is on but the pin 13 LED is not flashing, it could be that the factory code is not on the chip; follow the instructions in Recipe 1.3 to load the Blink sketch onto the board to verify that the board is working. If you are not using a standard board, it may not have a built-in LED on pin 13, so check the documentation for details of your board. The Leonardo board fades the LED up and down (it looks like the LED is "breathing") to show that the board is working.

See Also

Online guides for getting started with Arduino are available at *http://arduino.cc/en/Guide/Windows* for Windows, *http://arduino.cc/en/Guide/MacOSX* for Mac OS X, and *http://www.arduino.cc/playground/Learning/Linux* for Linux.

A troubleshooting guide can be found at *http://arduino.cc/en/Guide/Troubleshooting*.

1.3 Using the Integrated Development Environment (IDE) to Prepare an Arduino Sketch

Problem

You want to get a sketch and prepare it for uploading to the board.

Solution

Use the Arduino IDE to create, open, and modify sketches that define what the board will do. You can use buttons along the top of the IDE to perform these actions (shown in Figure 1-6), or you can use the menus or keyboard shortcuts (shown in Figure 1-7).

The Sketch Editor area is where you view and edit code for a sketch. It supports common text-editing keys such as Ctrl-F (⌘+F on a Mac) for find, Ctrl-Z (⌘+Z on a Mac) for undo, Ctrl-C (⌘+C on a Mac) to copy highlighted text, and Ctrl-V (⌘+V on a Mac) to paste highlighted text.

Figure 1-7 shows how to load the Blink sketch (the sketch that comes preloaded on a new Arduino board).

After you've started the IDE, go to the File→Examples menu and select 1. Basics→Blink, as shown in Figure 1-7. The code for blinking the built-in LED will be displayed in the Sketch Editor window (refer to Figure 1-6).

Before the code can be sent to the board, it needs to be converted into instructions that can be read and executed by the Arduino controller chip; this is called *compiling*. To do this, click the compile button (the top-left button with a tick inside), or select Sketch→Verify/Compile (Ctrl-R; ⌘+R on a Mac).

You should see a message that reads "Compiling sketch..." and a progress bar in the message area below the text-editing window. After a second or two, a message that reads "Done Compiling" will appear. The black console area will contain the following additional message:

```
Binary sketch size: 1026 bytes (of a 32256 byte maximum)
```

The exact message may differ depending on your board and Arduino version; it is telling you the size of the sketch and the maximum size that your board can accept.

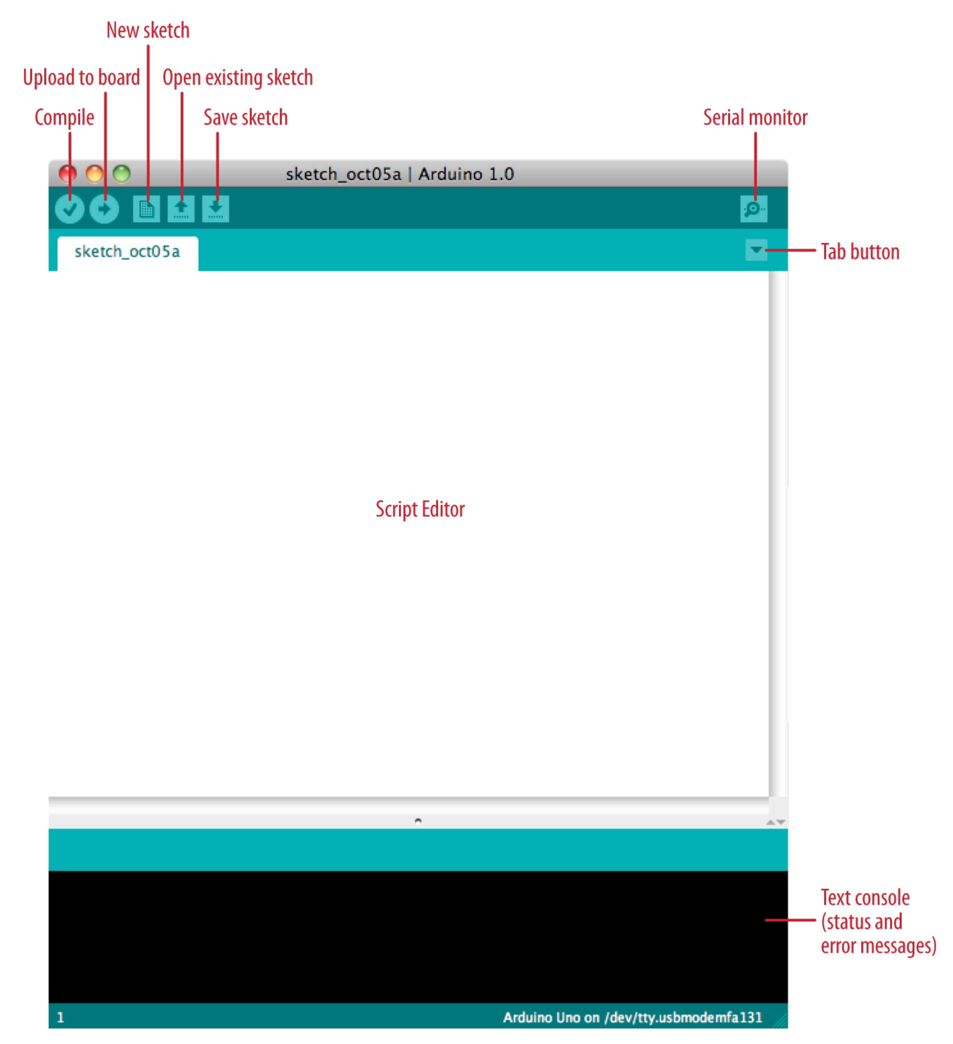

Figure 1-6. Arduino IDE

Discussion

Source code for Arduino is called a *sketch*. The process that takes a sketch and converts it into a form that will work on the board is called *compilation*. The IDE uses a number of command-line tools behind the scenes to compile a sketch. For more information on this, see Recipe 17.1.

The final message telling you the size of the sketch indicates how much program space is needed to store the controller instructions on the board. If the size of the compiled

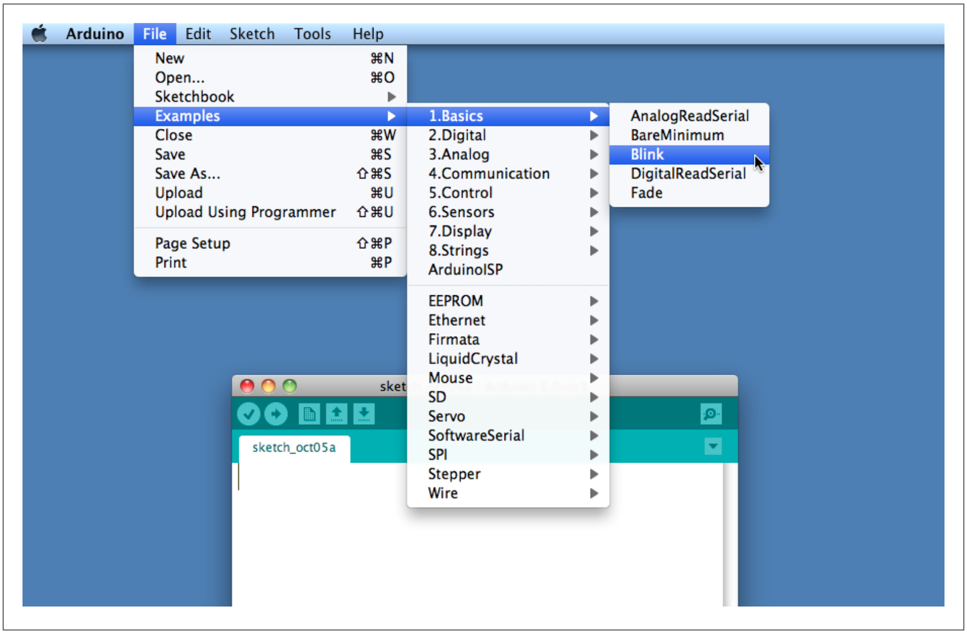

Figure 1-7. IDE menu (selecting the Blink example sketch)

sketch is greater than the available memory on the board, the following error message is displayed:

```
Sketch too big; see http://www.arduino.cc/en/Guide/Troubleshooting#size
 for tips on reducing it.
```

If this happens, you need to make your sketch smaller to be able to put it on the board, or get a board with higher capacity.

If there are errors in the code, the compiler will print one or more error messages in the console window. These messages can help identify the error—see Appendix D on software errors for troubleshooting tips.

> To prevent accidental overwriting of the examples, the Arduino IDE does not allow you to save changes to the provided example sketches. You must rename them using the Save As menu option. You can save sketches you write yourself with the Save button (see Recipe 1.5).

As you develop and modify a sketch, you should also consider using the File→Save As menu option and using a different name or version number regularly so that as you implement each bit, you can go back to an older version if you need to.

Code uploaded onto the board cannot be downloaded back onto your computer. Make sure you save your sketch code on your computer. You cannot save changes back to the example files; you need to use Save As and give the changed file another name.

See Also

Recipe 1.5 shows an example sketch. Appendix D has tips on troubleshooting software problems.

1.4 Uploading and Running the Blink Sketch

Problem

You want to transfer your compiled sketch to the Arduino board and see it working.

Solution

Connect your Arduino board to your computer using the USB cable. Load the Blink sketch into the IDE as described in Recipe 1.3.

Next, select Tools→Board from the drop-down menu and select the name of the board you have connected (if it is the standard Uno board, it is probably the first entry in the board list).

Now select Tools→Serial Port. You will get a drop-down list of available serial ports on your computer. Each machine will have a different combination of serial ports, depending on what other devices you have used with your computer.

On Windows, they will be listed as numbered COM entries. If there is only one entry, select it. If there are multiple entries, your board will probably be the last entry.

On the Mac, your board will be listed twice if it is an Uno board:

```
/dev/tty.usbmodem-XXXXXXX
/dev/cu.usbmodem-XXXXXXX
```

If you have an older board, it will be listed as follows:

```
/dev/tty.usbserial-XXXXXXX
/dev/cu.usbserial-XXXXXXX
```

Each board will have different values for *XXXXXXX*. Select either entry.

Click on the upload button (in Figure 1-6, it's the second button from the left), or choose File→Upload to I/O board (Ctrl-U, ⌘+U on a Mac).

The software will compile the code, as in Recipe 1.3. After the software is compiled, it is uploaded to the board. If you look at your board, you will see the LED stop flashing, and two lights (labeled as Serial LEDs in Figure 1-4) just below the previously flashing

LED should flicker for a couple of seconds as the code uploads. The original light should then start flashing again as the code runs.

Discussion

For the IDE to send the compiled code to the board, the board needs to be plugged in to the computer, and you need to tell the IDE which board and serial port you are using.

When an upload starts, whatever sketch is running on the board is stopped (if you were running the Blink sketch, the LED will stop flashing). The new sketch is uploaded to the board, replacing the previous sketch. The new sketch will start running when the upload has successfully completed.

> Older Arduino boards and some compatibles do not automatically interrupt the running sketch to initiate upload. In this case, you need to press the Reset button on the board just after the software reports that it is done compiling (when you see the message about the size of the sketch). It may take a few attempts to get the timing right between the end of the compilation and pressing the Reset button.

The IDE will display an error message if the upload is not successful. Problems are usually due to the wrong board or serial port being selected or the board not being plugged in. The currently selected board and serial port are displayed in the status bar at the bottom of the Arduino window

If you have trouble identifying the correct port on Windows, try unplugging the board and then selecting Tools→Serial Port to see which COM port is no longer on the display list. Another approach is to select the ports, one by one, until you see the lights on the board flicker to indicate that the code is uploading.

See Also

The Arduino troubleshooting page: *http://www.arduino.cc/en/Guide/Troubleshooting*.

1.5 Creating and Saving a Sketch

Problem

You want to create a sketch and save it to your computer.

Solution

To open an editor window ready for a new sketch, launch the IDE (see Recipe 1.3), go to the File menu, and select New. Paste the following code into the Sketch Editor window (it's similar to the Blink sketch, but the blinks last twice as long):

```
const int ledPin =  13;    // LED connected to digital pin 13

void setup()
{
  pinMode(ledPin, OUTPUT);
}

void loop()
{
  digitalWrite(ledPin, HIGH);   // set the LED on
  delay(2000);                  // wait for two seconds
  digitalWrite(ledPin, LOW);    // set the LED off
  delay(2000);                  // wait for two seconds
}
```

Compile the code by clicking the compile button (the top-left button with a triangle inside), or select Sketch→Verify/Compile (see Recipe 1.3).

Upload the code by clicking on the upload button, or choose File→Upload to I/O board (see Recipe 1.4). After uploading, the LED should blink, with each flash lasting two seconds.

You can save this sketch to your computer by clicking the Save button, or select File→Save.

You can save the sketch using a new name by selecting the Save As menu option. A dialog box will open where you can enter the filename.

Discussion

When you save a file in the IDE, a standard dialog box for the operating system will open. It suggests that you save the sketch to a folder called *Arduino* in your *My Documents* folder (or your *Documents* folder on a Mac). You can replace the default sketch name with a meaningful name that reflects the purpose of your sketch. Click Save to save the file.

> The default name is the word *sketch* followed by the current date. Sequential letters starting from *a* are used to distinguish sketches created on the same day. Replacing the default name with something meaningful helps you to identify the purpose of a sketch when you come back to it later.

If you use characters that the IDE does not allow (e.g., the space character), the IDE will automatically replace these with valid characters.

Arduino sketches are saved as plain text files with the extension *.ino*. Older versions of the IDE used the *.pde* extension, also used by Processing. They are automatically saved in a folder with the same name as the sketch.

You can save your sketches to any folder on your computer, but if you use the default folder (the *Arduino* folder in your *Documents* folder) your sketches will automatically appear in the Sketchbook menu of the Arduino software and be easier to locate.

> If you have edited one of the examples from the Arduino download, you will not be able to save the changed file using the same filename. This preserves the standard examples intact. If you want to save a modified example, you will need to select another location for the sketch.

After you have made changes, you will see a dialog box asking if you want to save the sketch when a sketch is closed.

> The § symbol following the name of the sketch in the top bar of the IDE window indicates that the sketch code has changes that have not yet been saved on the computer. This symbol is removed when you save the sketch.

The Arduino software does not provide any kind of version control, so if you want to be able to revert to older versions of a sketch, you can use Save As regularly and give each revision of the sketch a slightly different name.

Frequent compiling as you modify or add code is a good way to check for errors as you write your code. It will be easier to find and fix any errors because they will usually be associated with what you have just written.

> Once a sketch has been uploaded onto the board there is no way to download it back to your computer. Make sure you save any changes to your sketches that you want to keep.

If you try and save a sketch file that is not in a folder with the same name as the sketch, the IDE will inform you that this can't be opened as is and suggest you click OK to create the folder for the sketch with the same name.

> Sketches must be located in a folder with the same name as the sketch. The IDE will create the folder automatically when you save a new sketch.
>
> Sketches made with older versions of Arduino software have a different file extension (*.pde*). The IDE will open them, when you save the sketch it will create a file with the new extension (*.ino*). Code written for early versions of the IDE may not be able to compile in version 1.0. Most of the changes to get old code running are easy to do. See Appendix H for more details.

See Also

The code in this recipe and throughout this book use the `const int` expression to provide meaningful names (`ledPin`) for constants instead of numbers (`13`). See Recipe 17.5 for more on the use of constants.

1.6 Using Arduino

Problem

You want to get started with a project that is easy to build and fun to use.

Solution

This recipe provides a taste of some of the techniques that are covered in detail in later chapters.

The sketch is based on the LED blinking code from the previous recipe, but instead of using a fixed delay, the rate is determined by a light-sensitive sensor called a light dependent resistor or LDR (see Recipe 6.2). Wire the LDR as shown in Figure 1-8.

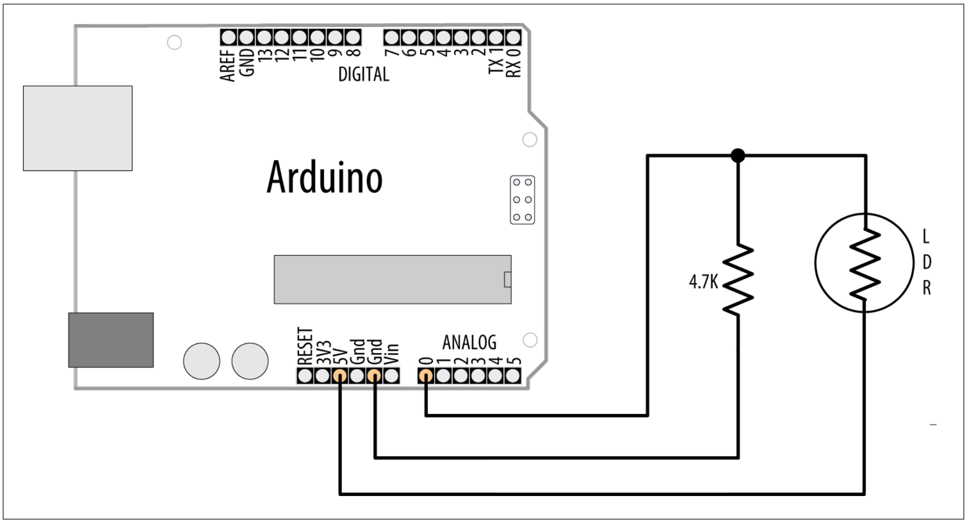

Figure 1-8. Arduino with light dependent resistor

> If you are not familiar with building a circuit from a schematic, see Appendix B for step-by-step illustrations on how to make this circuit on a breadboard.

The following sketch reads the light level of an LDR connected to analog pin 0. The light level striking the LDR will change the blink rate of the internal LED connected to pin 13:

```
const int ledPin =  13;     // LED connected to digital pin 13
const int sensorPin = 0;    // connect sensor to analog input 0

void setup()
{
  pinMode(ledPin, OUTPUT);  // enable output on the led pin
}

void loop()
{
  int rate = analogRead(sensorPin);    // read the analog input
  digitalWrite(ledPin, HIGH);   // set the LED on
  delay(rate);                  // wait duration dependent on light level
  digitalWrite(ledPin, LOW);    // set the LED off
  delay(rate);
}
```

Discussion

The value of the 4.7K resistor is not critical. Anything from 1K to 10K can be used. The light level on the LDR will change the voltage level on analog pin 0. The `analogRead` command (see Chapter 6) provides a value that ranges from around 200 when the LDR is dark to 800 or so when it is very bright. This value determines the duration of the LED on and off times, so the blink time increases with light intensity.

You can scale the blink rate by using the Arduino `map` function as follows:

```
const int ledPin =  13;     // LED connected to digital pin 13
const int sensorPin = 0;    // connect sensor to analog input 0

// the next two lines set the min and max delay between blinks
const int minDuration = 100;  // minimum wait between blinks
const int maxDuration = 1000;  // maximum wait between blinks


void setup()
{
  pinMode(ledPin, OUTPUT);  // enable output on the led pin
}

void loop()
{
  int rate = analogRead(sensorPin);    // read the analog input
  // the next line scales the blink rate between the min and max values
  rate = map(rate, 200,800,minDuration, maxDuration); // convert to blink rate
  rate = constrain(rate, minDuration,maxDuration);    // constrain the value
```

```
  digitalWrite(ledPin, HIGH);   // set the LED on
  delay(rate);                  // wait duration dependent on light level
  digitalWrite(ledPin, LOW);    // set the LED off
  delay(rate);
}
```

Recipe 5.7 provides more details on using the `map` function to scale values. Recipe 3.5 has details on using the `constrain` function to ensure values do not exceed a given range.

If you want to view the value of the rate variable on your computer, you can print this to the Arduino Serial Monitor as shown in the revised loop code that follows. The sketch will display the blink rate in the Serial Monitor. You open the Serial Monitor window in the Arduino IDE by clicking on the icon on the right of the top bar (see Chapter 4 for more on using the Serial Monitor):

```
const int ledPin =  13;     // LED connected to digital pin 13
const int sensorPin = 0;    // connect sensor to analog input 0

// the next two lines set the min and max delay between blinks
const int minDuration = 100;  // minimum wait between blinks
const int maxDuration = 1000;  // maximum wait between blinks


void setup()
{
  pinMode(ledPin, OUTPUT);  // enable output on the led pin
  Serial.begin(9600);       // initialize Serial
}

void loop()
{
  int rate = analogRead(sensorPin);    // read the analog input
  // the next line scales the blink rate between the min and max values
  rate = map(rate, 200,800,minDuration, maxDuration); // convert to blink rate
  rate = constrain(rate, minDuration,maxDuration);    // constrain the value

  Serial.println(rate);         // print rate to serial monitor
  digitalWrite(ledPin, HIGH);   // set the LED on
  delay(rate);                  // wait duration dependent on light level
  digitalWrite(ledPin, LOW);    // set the LED off
  delay(rate);
}
```

You can use the LDR to control the pitch of a sound by connecting a small speaker to the pin, as shown in Figure 1-9.

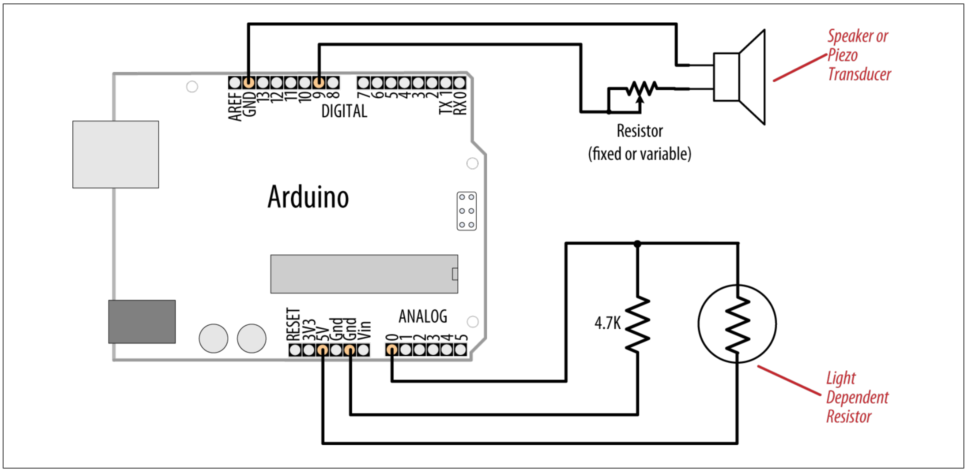

Figure 1-9. Connections for a speaker with the LDR circuit

You will need to increase the on/off rate on the pin to a frequency in the audio spectrum. This is achieved, as shown in the following code, by decreasing the min and max durations:

```
const int outputPin = 9;    // Speaker connected to digital pin 9
const int sensorPin = 0;    // connect sensor to analog input 0

const int minDuration = 1;   // 1ms on, 1ms off (500 Hz)
const int maxDuration = 10;  // 10ms on, 10ms off (50 hz)

void setup()
{
  pinMode(outputPin, OUTPUT);  // enable output on the led pin
}

void loop()
{
  int sensorReading = analogRead(sensorPin);    // read the analog input
  int rate = map(sensorReading, 200,800,minDuration, maxDuration);
  rate = constrain(rate, minDuration,maxDuration);    // constrain the value

  digitalWrite(outputPin, HIGH);   // set the LED on
  delay(rate);                     // wait duration dependent on light level
  digitalWrite(outputPin, LOW);    // set the LED off
  delay(rate);
}
```

See Also

See Recipe 3.5 for details on using the `constrain` function.

See Recipe 5.7 for a discussion on the `map` function.

If you are interested in creating sounds, see Chapter 9 for a full discussion on audio output with Arduino.

CHAPTER 2

Making the Sketch Do Your Bidding

2.0 Introduction

Though much of an Arduino project will involve integrating the Arduino board with supporting hardware, you need to be able to tell the board what to do with the rest of your project. This chapter introduces core elements of Arduino programming, shows nonprogrammers how to use common language constructs, and provides an overview of the language syntax for readers who are not familiar with C or C++, the language that Arduino uses.

Since making the examples interesting requires making Arduino do something, the recipes use physical capabilities of the board that are explained in detail in later chapters. If any of the code in this chapter is not clear, feel free to jump forward, particularly to Chapter 4 for more on serial output and Chapter 5 for more on using digital and analog pins. You don't need to understand all the code in the examples, though, to see how to perform the specific capabilities that are the focus of the recipes. Here are some of the more common functions used in the examples that are covered in the next few chapters:

`Serial.println(value);`
: Prints the value to the Arduino IDE's Serial Monitor so you can view Arduino's output on your computer; see Recipe 4.1.

`pinMode(pin, mode);`
: Configures a digital pin to read (input) or write (output) a digital value; see the introduction to Chapter 5.

`digitalRead(pin);`
: Reads a digital value (`HIGH` or `LOW`) on a pin set for input; see Recipe 5.1.

`digitalWrite(pin, value);`
: Writes the digital value (`HIGH` or `LOW`) to a pin set for output; see Recipe 5.1.

2.1 Structuring an Arduino Program

Problem

You are new to programming and want to understand the building blocks of an Arduino program.

Solution

Programs for Arduino are usually referred to as *sketches*; the first users were artists and designers and *sketch* highlights the quick and easy way to have an idea realized. The terms *sketch* and *program* are interchangeable. Sketches contain code—the instructions the board will carry out. Code that needs to run only once (such as to set up the board for your application) must be placed in the `setup` function. Code to be run continuously after the initial setup has finished goes into the `loop` function. Here is a typical sketch:

```
const int ledPin =  13;    // LED connected to digital pin 13

 // The setup() method runs once, when the sketch starts
 void setup()
 {
   pinMode(ledPin, OUTPUT);      // initialize the digital pin as an output
 }

 // the loop() method runs over and over again,
 void loop()
 {
   digitalWrite(ledPin, HIGH);   // turn the LED on
   delay(1000);                  // wait a second
   digitalWrite(ledPin, LOW);    // turn the LED off
   delay(1000);                  // wait a second
 }
```

When the Arduino IDE finishes uploading the code, and every time you power on the board after you've uploaded this code, it starts at the top of the sketch and carries out the instructions sequentially. It runs the code in `setup` once and then goes through the code in `loop`. When it gets to the end of `loop` (marked by the closing bracket, `}`) it goes back to the beginning of `loop`.

Discussion

This example continuously flashes an LED by writing `HIGH` and `LOW` outputs to a pin. See Chapter 5 to learn more about using Arduino pins. When the sketch begins, the code in `setup` sets the pin mode (so it's capable of lighting an LED). After the code in `setup` is completed, the code in `loop` is repeatedly called (to flash the LED) for as long as the Arduino board is powered on.

You don't need to know this to write Arduino sketches, but experienced C/C++ programmers may wonder where the expected `main()` entry point function has gone. It's there, but it's hidden under the covers by the Arduino build environment. The build process creates an intermediate file that includes the sketch code and the following additional statements:

```
int main(void)
{
    init();

    setup();

    for (;;)
        loop();

    return 0;
}
```

The first thing that happens is a call to an `init()` function that initializes the Arduino hardware. Next, your sketch's `setup()` function is called. Finally, your `loop()` function is called over and over. Because the `for` loop never terminates, the `return` statement is never executed.

See Also

Recipe 1.4 explains how to upload a sketch to the Arduino board.

Chapter 17 and *http://www.arduino.cc/en/Hacking/BuildProcess* provide more on the build process.

2.2 Using Simple Primitive Types (Variables)

Problem

Arduino has different types of variables to efficiently represent values. You want to know how to select and use these Arduino data types.

Solution

Although the `int` (short for *integer*, a 16-bit value in Arduino) data type is the most common choice for the numeric values encountered in Arduino applications, you can use Table 2-1 to determine the data type that fits the range of values your application expects.

Table 2-1. Arduino data types

Numeric types	Bytes	Range	Use
`int`	2	–32768 to 32767	Represents positive and negative integer values.
`unsigned int`	2	0 to 65535	Represents only positive values; otherwise, similar to `int`.
`long`	4	–2147483648 to 2147483647	Represents a very large range of positive and negative values.
`unsigned long`	4	4294967295	Represents a very large range of positive values.
`float`	4	3.4028235E+38 to –3.4028235E+38	Represents numbers with fractions; use to approximate real-world measurements.
`double`	4	Same as `float`	In Arduino, `double` is just another name for `float`.
`boolean`	1	`false` (0) or `true` (1)	Represents true and false values.
`char`	1	–128 to 127	Represents a single character. Can also represent a signed value between –128 and 127.
`byte`	1	0 to 255	Similar to `char`, but for unsigned values.
Other types	**Use**		
`String`	Represents arrays of `char`s (characters) typically used to contain text.		
`void`	Used only in function declarations where no value is returned.		

Discussion

Except in situations where maximum performance or memory efficiency is required, variables declared using `int` will be suitable for numeric values if the values do not exceed the range (shown in the first row in Table 2-1) and if you don't need to work with fractional values. Most of the official Arduino example code declares numeric variables as `int`. But sometimes you do need to choose a type that specifically suits your application.

Sometimes you need negative numbers and sometimes you don't, so numeric types come in two varieties: `signed` and `unsigned`. `unsigned` values are always positive. Variables without the keyword `unsigned` in front are signed so that they can represent negative and positive values. One reason to use `unsigned` values is when the range of `signed` values will not fit the range of the variable (an unsigned variable has twice the capacity of a signed variable). Another reason programmers choose to use `unsigned` types is to clearly indicate to people reading the code that the value expected will never be a negative number.

`boolean` types have two possible values: `true` or `false`. They are commonly used for things like checking the state of a switch (if it's pressed or not). You can also use `HIGH` and `LOW` as equivalents to `true` and `false` where this makes more sense; `digitalWrite(pin, HIGH)` is a more expressive way to turn on an LED than `digitalWrite(pin, true)` or `digitalWrite(pin,1)`, although all of these are treated identically when the sketch actually runs, and you are likely to come across all of these forms in code posted on the Web.

See Also

The Arduino reference at *http://www.arduino.cc/en/Reference/HomePage* provides details on data types.

2.3 Using Floating-Point Numbers

Problem

Floating-point numbers are used for values expressed with decimal points (this is the way to represent fractional values). You want to calculate and compare these values in your sketch.

Solution

The following code shows how to declare floating-point variables, illustrates problems you can encounter when comparing floating-point values, and demonstrates how to overcome them:

```
/*
 * Floating-point example
 * This sketch initialized a float value to 1.1
 * It repeatedly reduces the value by 0.1 until the value is 0
 */


float  value = 1.1;

void setup()
{
  Serial.begin(9600);
}

void loop()
{
  value = value - 0.1;   // reduce value by 0.1 each time through the loop
  if( value == 0)
     Serial.println("The value is exactly zero");
  else if(almostEqual(value, 0))
  {
    Serial.print("The value ");
    Serial.print(value,7); // print to 7 decimal places
    Serial.println(" is almost equal to zero");
  }
  else
    Serial.println(value);

  delay(100);
```

```
}

// returns true if the difference between a and b is small
// set value of DELTA to the maximum difference considered to be equal
boolean almostEqual(float a, float b)
{
  const float DELTA = .00001; // max difference to be almost equal
  if (a == 0) return fabs(b) <= DELTA;
  if (b == 0) return fabs(a) <= DELTA;
  return fabs((a - b) / max(fabs(a), fabs(b))) <= DELTA ;
}
```

Discussion

Floating-point math is not exact, and values returned can have a small approximation error. The error occurs because floating-point values cover a huge range, so the internal representation of the value can only hold an approximation. Because of this, you need to test if the values are within a range of tolerance rather than exactly equal.

The Serial Monitor output from this sketch is as follows:

```
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
The value -0.0000001 is almost equal to zero
-0.10
-0.20
```

The output continues to produce negative numbers.

You may expect the code to print `"The value is exactly zero"` after `value` is `0.1` and then 0.1 is subtracted from this. But `value` never equals exactly zero; it gets very close, but that is not good enough to pass the test: `if (value == 0)`. This is because the only memory-efficient way that floating-point numbers can contain the huge range in values they can represent is by storing an approximation of the number.

The solution to this is to check if a variable is close to the desired value, as shown in this recipe's Solution.

The `almostEqual` function tests if the variable `value` is within 0.00001 of the desired target and returns true if so. The acceptable range is set with the constant `DELTA`, you can change this to smaller or larger values as required. The function named `fabs` (short for *floating-point absolute value*) returns the absolute value of a floating-point variable and this is used to test the difference between the given parameters.