

Arduino in a Nutshell



Jan Borchers

Version 1.8 (Aug 5, 2013)

for Arduino Uno R3 & Arduino IDE 1.0.5

Latest version at: hci.rwth-aachen.de/arduino

ACKNOWLEDGEMENTS



Thanks to Jeff and Drake for playing with the Arduino last night, and almost completing our plans for world domination through an army of robots doing our bidding (insert finger wiggling and evil laugh here). I wrote this booklet in about four hours after getting home last night, and illustrated it this morning. It closely follows our adventures into Arduinoland.

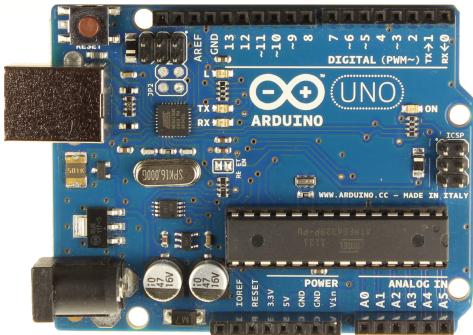
The Arduino team continues to do an awesome job providing this easy-to-use electronics platform, and all schematics were created using the excellent software from Fritzing.org. Jim Hollan at UCSD is a great host, and my students back in Germany are bravely suffering through (enjoying?) the time with me away on sabbatical. This booklet is dedicated to Ina who is always wonderfully supportive of her geek.

San Diego, Aug 9, 2012

For great feedback, thanks to the [arduino-teachers](#), [Sketching In Hardware](#) and [i10](#) mailing lists, especially CTP, David Mellis (Arduino), Gerald Ardito, Jonathan Oxer (shieldlist), Linz Craig (SparkFun), Michael Shiloh, Nick Ward, Patricia Shanahan, and Thorsten Karrer!

I. INTRODUCTION

The Arduino is a family of **microcontroller boards** to simplify electronic design, prototyping and experimenting for artists, hackers, hobbyists, but also many professionals. Use it as brains for your robot, to build a new digital music instrument, or to make your house plant tweet you when it's dry. Know a little programming, but no electronics? This book will get you started quickly.



Arduinos (we use the standard **Arduino Uno R3**) contain an ATmega **microcontroller** – that's a **complete computer** with CPU, RAM, Flash memory, and **input/output pins**, all on a single chip. Unlike, say, a Raspberry Pi, it's designed to attach all kinds of **sensors**, LEDs, small motors and speakers, servos, etc. directly to these pins, which can read in or output digital or analog voltages between 0 and 5 volts. The Arduino connects to your computer via **USB**, where you program it in a simple language (C/C++, similar to Java) inside the free **Arduino IDE** by uploading your compiled code to the board.

Once programmed, the Arduino can run with the USB link back to your computer, or stand-alone without it – no keyboard or screen needed, just power.



II. GETTING STARTED: BLINK AN LED!

1. Get the **MAKE Ultimate Microcontroller Pack** with an **Arduino Uno**

R3 from makershed.com or your local RadioShack (\$149). Also get a standard **USB** A-B cable and a **9V battery**. Or, for just the parts we'll use here, get the **Wish List** at sparkfun.com/wish_lists/46366 (\$63). **SparkFun's Inventor's Kit** or **Adafruit's Experimentation Kit** also have most parts we need, and more.

2. Download and install the **Arduino IDE** for Mac, Linux or Windows from arduino.cc. Windows users also need to install a driver .INF file, see the website.
3. Connect your board via USB. Launch the Arduino app. From the **Tools:Board** menu, select **Arduino Uno**. From the **Tools: Serial Port** menu, select the new serial port (/dev/tty.usbmodem... on Macs). Open the **sketch** (program) **File:Examples:01.Basics:Blink**. Click the toolbar button to upload it to your board.

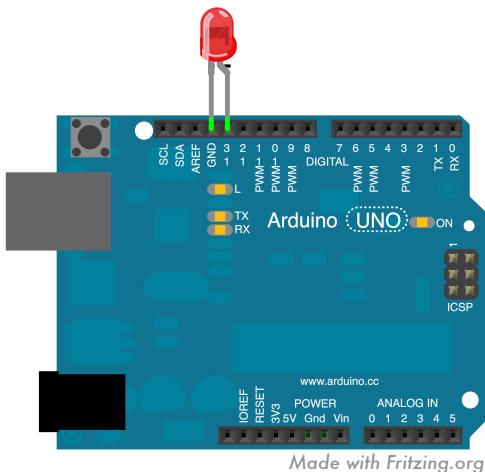
After some flickering, its tiny **yellow LED** should blink regularly (1 second on, 1 second off). **You've programmed your first microcontroller!** Change the durations in **delay()** and upload to see the effect.

III. RUN WITHOUT A COMPUTER

1. **Disconnect** the USB cable from your board.
2. Put the **9V battery** into the **battery case** (takes some fiddling).
3. Plug the **barrel plug** from the battery case into the **round socket** on the Arduino, and turn on the **switch** on the battery case if it has one.
4. Your sketch starts running as soon as the board is powered up, and the LED blinks, until you turn off power — **no computer needed!** That's a great way to build small, **autonomous** systems around an Arduino.

The Arduino **converts** the 9V from the battery down to 5V using a regulator on the board. You can also connect anything from **7–12** volts DC to the barrel plug socket (2.1 mm / 5.5 mm diameter, center positive), or stick cables directly into the **Vin** and GND (Ground) pins to power the board from 7–12 volts — great if you don't have a barrel plug on your power source.

Don't attach a 5V power source directly to the **+5V pin** though — it's a voltage **output** pin only, and you may fry your onboard regulator. Use the USB connector instead.



Made with Fritzing.org

IV. CONNECT A BIG LED

1. Always disconnect or turn off your power source before you change your circuit to avoid shorts. They may shut down your USB port, or worse.

2. Bend and stick the **longer lead (+)** of any **red, yellow or green LED** into Digital Pin 13 on the Arduino. Stick its **shorter lead (-)** into the GND pin next to pin 13, as shown.
3. **Connect USB** — now your **big LED blinks** too.

The “Blink” sketch outputs a **high signal (5V)** on pin 13 using **`digitalWrite(led,HIGH);`**; waits for 1000 ms (1 s) using **`delay(1000);`**; then outputs a **low signal (0V)** and waits another second. This makes your LED blink. The yellow onboard LED is also connected to pin 13, so it blinks along.

Every Arduino sketch has one **`setup()`** method that runs once whenever the Arduino powers up or resets, and a **`loop()`** function that is **repeated** after that until the board is powered off or reset again. No OS, no multiple apps!

V. ADD A RESISTOR

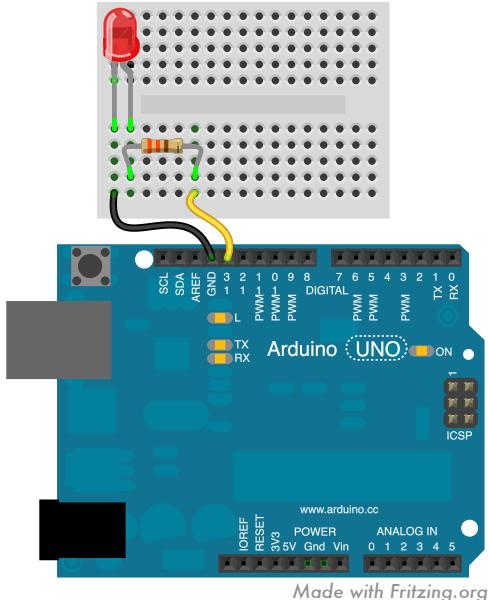
Connecting an LED directly to 5V and GND will usually **fry** it because of too much current flowing through it. It survived only because the Arduino can't provide more than **40 mA** (milliamps) of current on each pin.

That's still more than the **20 mA** standard LEDs like and need, however. LEDs also **drop** (consume) around **2V** of "forward" voltage (V_f). For precise values, google, e.g., "SparkFun red 5mm LED" ([SparkFun](#) sells great basic components and documents them well). To limit the current, add a **resistor** before or after the LED.

What's the right resistor value? The Arduino pins provide 5V. 2V are dropped by the LED. That leaves 3V to drop over the resistor, at a current of 20 mA. Ohm's law (I use the picture on the right to remember it) says
 U (voltage) = R (resistance) $\times I$ (current), or
$$R = U / I = 3 \text{ V} / 20 \text{ mA} = 3 \text{ V} / 0.02 \text{ A} = 150 \Omega.$$

A diagram illustrating Ohm's Law. It features a large blue letter 'U' at the top, a horizontal line with a break in the middle, and a large blue letter 'R' below the line. To the right of the line, there is a vertical blue letter 'I'. This visual representation shows that Voltage (U) is equal to Resistance (R) divided by Current (I), or $U = R/I$.

Choose the **next bigger resistor** you have; in our case it's **330 Ω** (Orange–Orange–Brown–Gold). Use the **color code table** in the Make Pack booklet, google "resistor color codes", or get Adafruit's simple [Circuit Playground](#) app or the comprehensive [Electronic Toolbox Pro](#) app for your iPhone/iPad.



Made with Fritzing.org

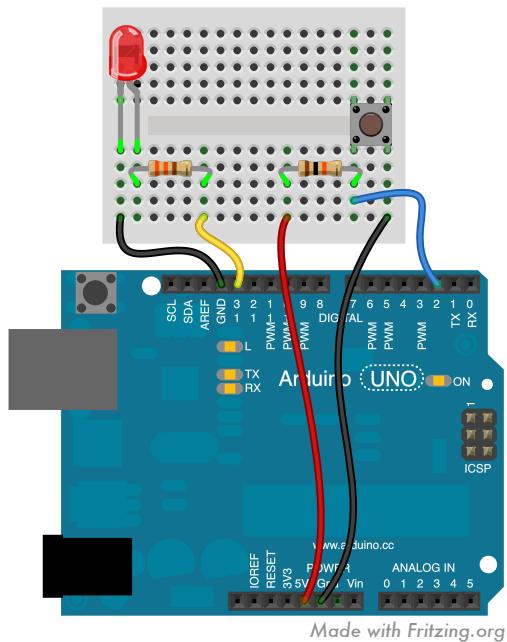
Disconnect USB. In the **mini solderless breadboard**, each vertical **column** of 5 holes is **connected** inside the board. Stick the LED, 330 Ω resistor and jumper wires in as shown. Current will now flow from Arduino **pin 13** through the **resistor** and the **LED** to **GND** when pin 13 is HIGH.

Connect USB. Your LED will glow **slightly less bright** than before, but will last forever. The current is now around $3\text{V} / 330\ \Omega = 9\text{ mA}$. Current is the same everywhere in a simple closed circuit without branches. So it doesn't matter if you put the resistor before or after the LED.

Tip: **Always** use **red wires** for connections to 5V, **black wires** for connections to GND, and other colors using a schema you like. I use **yellow wires** for outputs to LEDs, **green wires** for outputs to motors and servos, and **blue wires** for sensor inputs. It'll help avoid confusion, short-circuits, and fried components. Trust me; I've been there.

VI. DIGITAL INPUT: READ A BUTTON

Disconnect USB. Add a **pushbutton**, **10 kΩ resistor** (Brown–Black–Orange–Gold) and **wires** as shown. Orient the button so the pins that are **closer** are **next** to each other. These connect when you push it; the pins below each other are always connected.



Made with Fritzing.org

Change the **Blink** code so it only blinks the LED while pin 2 is LOW: Define a global integer (**int**) variable **pushbutton**. Set it to 2 in your **setup()**. In your **loop()** code, use **if (digitalRead(button)==LOW) {...}**. Don't forget the curly braces and the double equal sign. Now, the LED will only blink while you press the pushbutton!

We are using pin 2 as a **digital input** to detect if its voltage is closer to GND or 5V. Every digital pin 0..13 can be an input or output pin. While input is the default, it's good style to add **pinMode(button,INPUT);** to your **setup()** function to make it more readable. Remember to end each statement with a **semicolon**.

Tip: For **help** with any function, click on it, then select the **Help:Find In Reference** menu. I also use the language reference at arduino.cc/en/Reference a lot; more tutorials are at arduino.cc/en/Tutorial/Foundations.

The 10 kΩ resistor is a **pullup resistor**. It provides a defined voltage (5V) to pin 2 when the button switch is open (it “pulls it up to 5V”). Otherwise pin 2 would be connected to nothing, or “**floating**”, and pick up random electromagnetic noise like an antenna, leading to unpredictable HIGH/LOW values when you read it.

When you push the button, it pulls pin 2 low (connects it to GND = 0V), and a small current flows through the resistor and switch to GND. All 5V then “drop” across the resistor. Arduino inputs themselves just “measure” the voltage on their pins while consuming hardly any current.

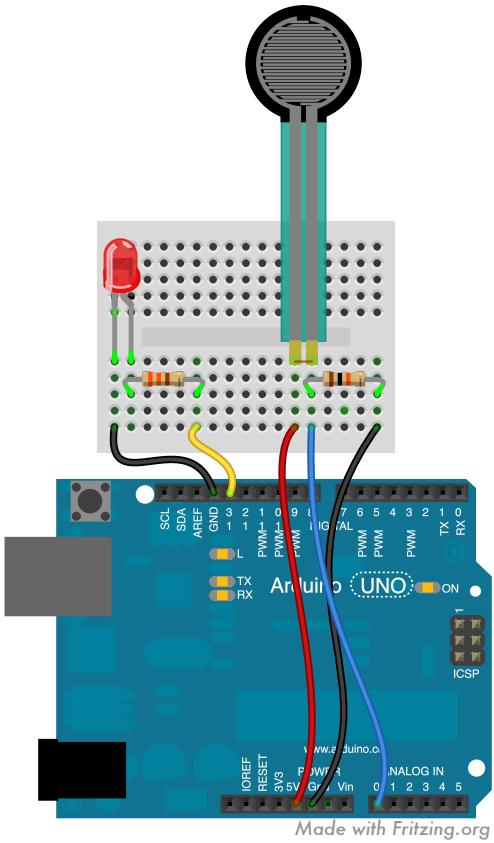
VII. INTERNAL PULLUP RESISTORS

Remove the 10 kΩ pullup resistor from the board. Now your LED may be blinking or not, since pin 2 is floating. Change `setup()` to say `pinMode(button, INPUT_PULLUP);` and upload. This connects an **internal pullup resistor** to that pin inside the ATmega chip. It works like your external pullup resistor, but you can simplify your circuit.

VIII. READING ANALOG VALUES

Disconnect USB. Remove the pushbutton and connect a **force-sensitive resistor**, the 10 kΩ resistor and wires to analog input **A0** as shown.

You've created a **voltage divider**. Normally the force sensor has a resistance much higher than 10 kΩ, so A0 gets pulled to near 0V by the 10 kΩ resistor. Press on the force sensor, and you lower its resistance. It can go way below 10 kΩ, and the voltage on A0 then goes up to almost 5V. So: more pressure – higher voltage. That's how you can read continuous (analog) values.

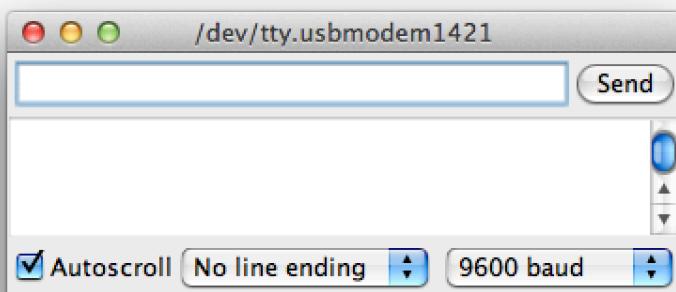
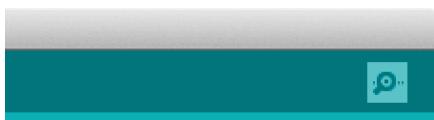


Made with Fritzing.org

Load **File:Examples:03. Analog:AnalogInput**. It uses **analogRead(...)** to read the voltage on A0, and turns the LED on and off with a delay determined by that voltage – the harder you press, the slower the LED will blink. **analogRead()** returns values from 0 (0V) to **1023** (5V).

IX. DEBUGGING USING SERIAL OUTPUT

It's hard to really see what values you're getting from the force sensor through the analog pin just by looking at the blink frequency of that LED. To see the actual numbers, open **File:Examples:01.Basics:AnalogReadSerial**. Upload it, then click on the **magnifier** toolbar button in the top right to open the **Serial Monitor** window. You'll see values changing as you press the sensor.

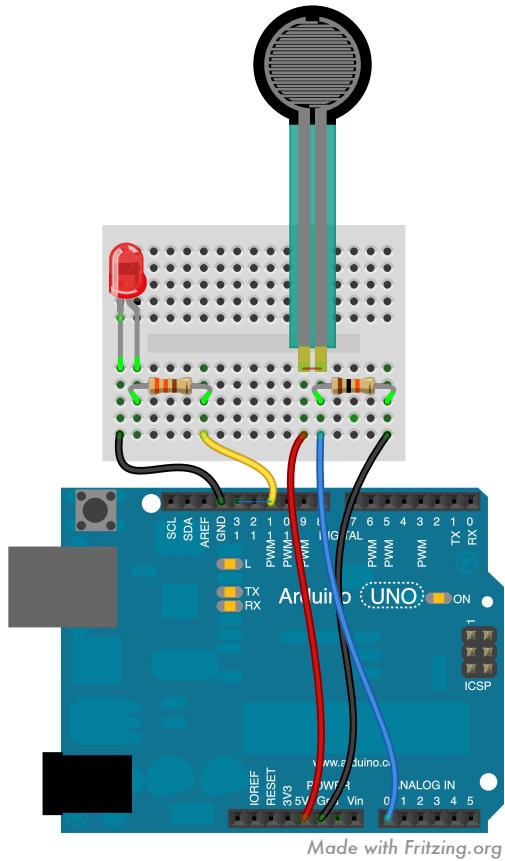


The code uses **Serial.begin(9600)** to open a serial connection back to your computer in **setup()**, and **Serial.println(...)** to output ("print") numbers to that serial connection, which end up in the Serial Monitor window on your screen. It's also possible to send data back to the Arduino that way, using **Serial.read(...)**.

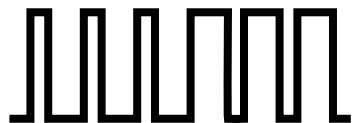
X. ANALOG OUTPUT AND PWM

Disconnect USB. Move the yellow wire from pin 13 to pin 11. Pin 11 has a **tilde (~)** on the board, which means it can output analog values.

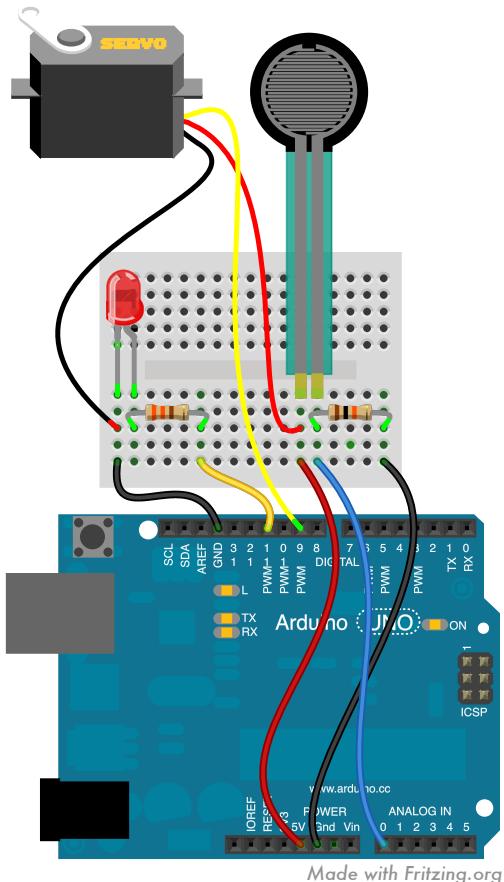
Change your `loop()` to control the LED with `analogWrite(...)`. Analog values for output go from 0 to **255**, not 1023, so divide the value from `analogRead(...)` by 4 before writing it to the LED pin.



Connect USB and upload your code. Now you can control the brightness of your LED by pressing on the force sensor.



Arduino uses **Pulse-Width Modulation (PWM)** to create analog values – it'll turn the output on (5V) and off (0V) at 500 Hz, and increase the duty cycle (relative on-time) of that square wave signal to represent higher analog values. 500 Hz is too fast for the human eye, so the LED looks like it's always on, just more or less bright.



XI. CONTROLLING SERVOS

Disconnect USB, and add a servo to your setup:
Connect its **black or dark brown lead to GND**, its **red lead to 5V**, and its **orange, yellow or white lead** (the “**signal**” lead) to pin 9, by sticking jumper wires into the servo connector.

Load the sample sketch
File:Examples:Servo:Knob
(it's further down in the list). Instead of the

potentiometer (an adjustable resistor) mentioned in the code we'll just use the force sensor voltage divider we already have to provide an analog value to input A0.

Run the code, and you can **control the angular turning position of the servo by pressing on the sensor**.

Internally, servos are also controlled by PWM – the longer the signal, the further to the right they turn, usually in a range of 0..180 degrees.

However, the **Servo library** for Arduino takes care of all this. Note the **#import** statement, the **Servo** object declaration, and how the sample code then sends data to the servo using angular values. You can easily declare, create, and control two or more Servo objects this way – essential for your robot!

Servos can take around 0.5–1s to reach their target position. For a simple walking movement, you can just send the maximum angle, wait, then send the minimum angle, wait, and so on.

Tip: If you run out of 5V pins on the Arduino, **bring 5V over to a column** on the breadboard, and connect things from there (similar for GND). Use red and black wires to keep your sanity! On larger breadboards like the large one in the MAKE Pack, use the horizontal connector **rows** (“rails”) along the top and bottom – put 5V only to the top red rail, and GND only to the bottom blue rail, to avoid plugging things into the wrong one.

XII. SHIELDS

Shields are PCBs that **stack on top of the Arduino** and connect to all Arduino pins to add all kinds of hardware features. There are shields to play MP3 files, for WiFi, Bluetooth, Ethernet, Zigbee, MIDI, GPS, to log data, drive big motors, etc. — shieldlist.org lists over 200!

Good shields are **stackable** — they have the same female header pins as the Arduino on top.

The MAKE Pack contains a kit for a [**MakerShield**](#) prototyping shield (see photo). **Solder** it together (URL for instructions on the pack), stick the mini breadboard onto it, and you have a very useful board with some built-in LEDs, buttons, even a potentiometer for quick experiments. It's not a perfect fit for the Arduino, but it works well enough. **SparkFun** has a similar [**ProtoShield**](#).

RadioShack also carries a simpler, but more **modern prototyping shield** designed by the Arduino team, to solder your own parts onto. In the future, look for shields like that one, with **18 pins at the top**, which is the **new Arduino standard**.

XIII. SOME POINTERS

To learn more about Arduino and build fun projects, check out these resources:

arduino.cc is your first stop for help with the IDE, the Arduino language reference, board specifications, new boards and software versions, excellent mostly up-to-date tutorials, and libraries for a lot of stuff you may want to hook up to your Arduino.

Sparkfun.com has great components, shields, sensors, breakout boards, etc. They support open-source hardware and have all schematics online. Decent pricing, great community. Epic Friday New Product Post videos.

Adafruit.com is smaller but similar, with great products, learning resources and community support.

MAKE Magazine has an Arduino blog with great tutorial videos at blog.makezine.com/arduino/ and lots of Arduino projects at makeprojects.com/c/Arduino. The paper magazine is also great fun, especially with kids.

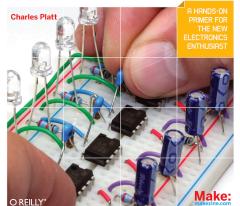
RadioShack.com has all essential parts, a bit pricey, but lets you check online if a part is available at your local store around the corner – perfect for those last-minute needs that always seem to come up.

Digikey.com, Mouser.com, and Farnell.com are professional electronic component vendors. They carry and have datasheets for **everything**, at the best prices if you know what you're looking for, but they are **overwhelming** to beginners — try SparkFun, MakerShed, Adafruit or RadioShack at first.

Fritzing.org has a nice free tool to document your Arduino breadboard designs, and to design shields that can then be made by submitting your files to an online PCB maker. I used it for all the Arduino diagrams here.

In general, if you want to hook up X to an Arduino, **google “Arduino X”** and you’re likely to find a solution. :) Look for the above sites among the search results.

There are countless Arduino **books** out there; the gentlest is probably Massimo Banzi’s **Getting Started With Arduino** (he designed the Arduino board). The PDF is ten bucks at the Makershed. Tom Igoe’s **Making Things Talk** is excellent and beautifully designed, focusing on making Arduinos and other electronic devices connect and share information. **Arduino Bots and Gadgets** is interesting if you want to build robots. However, **all** Arduino books become **outdated quickly** because the Arduino boards and IDE have changed slightly almost every year so far. Look for a book edition that’s **no older than a year**.



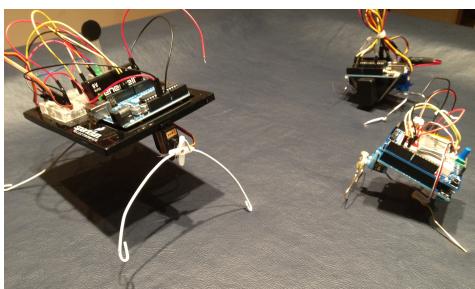
For a current book on **basic electronics** (not Arduino), there is no better choice than **Make: Electronics** by Charles Platt. Beautifully illustrated, starts with the basics, very accessible and fun. And experiment #1 is licking a 9V battery. I read it cover to cover to refresh my electronics knowledge.

In general, OReilly.com has excellent books on Arduino and other techie topics, with DRM-free versions for iPads and in PDF, lifetime access and dropbox syncing, **frequent updates** of their PDF editions, 3-for-2 deals, and special pricing if you own the printed book.

There are dozens of **different Arduino boards** out there. Stick with those documented on arduino.cc at first. Their new **Leonardo** board, e.g., can act as a USB keyboard or mouse, the new **Due** is faster, and SparkFun's **Arduino Pro Micro** (right) is a great tiny option, but for a beginner they're not quite as smooth to use yet.



Without a doubt this version of this guide will become outdated just as quickly as all those books. **Check back** at the URL on the front cover for **updates**, and meanwhile, have fun hacking and making with Arduino!



About the author

Jan Borchers is a professor of computer science and head of the Media Computing Group at RWTH Aachen University. He works in human-computer interaction, usability, and digital fabrication, and has taught Arduino to students and kids since 2008.

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Version history

2013-08-05 (1.8): Added QR code, adjusted cover page graphics.

2013-07-31 (1.7): Clarified p.4, updated SparkFun prices, corrected pinMode typo, updated for IDE 1.0.5.

2013-01-24 (1.6): Added target audience, author info, premium headers on wishlist. Updated pushbutton declaration. Updated for IDE 1.0.2 & 1.0.3. Cosmetic corrections throughout.

2012-08-17 (1.5): Corrected button use in Ch.VI. Changed title page, tips layout, last page layout.

2012-08-15 (1.4): Added shieldlist.org.

2012-08-15 (1.3): Updated acknowledgements, Java reference, +5V pin, enabling pullups, page footers, layout. Added Creative Commons license terms.

2012-08-15 (1.2): Added: cropmarks, boldface in first chapters, Raspberry Pi, SparkFun wish list, other starter kits, Electronic Toolbox, Arduino Pro Micro, Make: Electronics cover, double-sided layout for binding. Edited: shields, O'Reilly, title, headings.

2012-08-12 (1.1): Added: missing sensor wire in ch. X+XI diagrams, Circuit Playground, different boards, version history. Fixed typos.

2012-08-09 (1.0): Initial release, see Acknowledgements.