LED Cube 8x8x8

by chr on November 16, 2010

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I like microcontrollers and LEDs :D

Intro: LED Cube 8x8x8

Create your own 8x8x8 LED Cube 3-dimensional display!

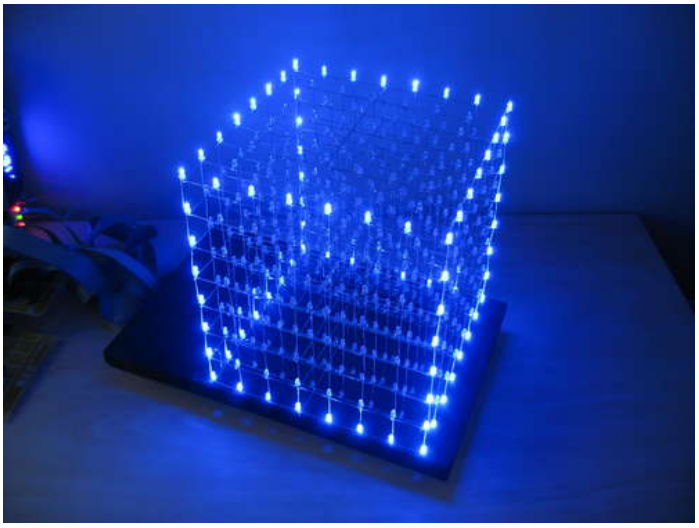
We believe this Instructable is the most comprehensive step-by-step guide to build an 8x8x8 LED Cube ever published on the intertubes. It will teach you everything from theory of operation, how to build the cube, to the inner workings of the software. We will take you through the software step by step, both the low level drivers/routines and how to create awesome animations. The software aspect of LED cubes is often overlooked, but a LED cube is only as awesome as the software it runs.

About halfway through the Instructable, you will actually have a fully functional LED cube. The remaining steps will show you how to create the software.

A video is worth a thousand words. I'll just leave it up to this video to convince you that this is the next project you will be building:

I made this LED cube together with my friend chiller. The build took about 4 days from small scale prototyping to completed cube. Then another couple of hours to debug some faulty transistors.

The software is probably another 4-5 days of work combined.



Step 1: Skills required

At first glance this project might seem like an overly complex and daunting task. However, we are dealing with digital electronics here, so everything is either on or off!

I've been doing electronics for a long time, and for years i struggled with analog circuits. The analog circuits failed over half the time even if i followed instructions. One resistor or capacitor with a slightly wrong value, and the circuit doesn't work.

About 4 years ago, I decided to give microcontrollers a try. This completely changed my relationship with electronics. I went from only being able to build simple analog circuits, to being able to build almost anything!

A digital circuit doesn't care if a resistor is 1k ohm or 2k ohm, as long as it can distinguish high from low. And believe me, this makes it A LOT easier to do electronics!

With that said, there are still some things you should know before venturing out and building this rather large project.

You should have an understanding of:

- Basic electronics. (We would recommend against building this as your very first electronics project. But please read the Instructable. You'll still learn a lot!)
- How to solder.
- How to use a multimeter etc.
- Writing code in C (optional. We provide a fully functional program, ready to go)

You should also have patience and a generous amount of free time.

Step 2: Component list

Here is what you need to make a LED cube:

- 512x LEDs (plus some extra for making mistakes!)
- 64x resistors. (see separate step for ohm value)
- 1x or 2x large prototype PCBs. The type with copper "eyes", see image.
- 1x ATmega32 microcontroller (you can also use the pin-compatible ATmega16)
- 3x status LEDs. You choose color and size.
- 3x resistors for the status LEDs.
- 8x 74HC574 ICs
- 16x PN2222 transistors
- 16x 1k resistors
- 1x 74HC138 IC
- 1x Maxim MAX232 IC
- 1x 14.7456 MHz crustal
- 2x 22pF ceramic capacitors
- 16x 0.1uF ceramic capacitors
- 3x 1000uF electrolytic capacitor
- 3x 10uF electrolytic capacitor
- 1x 100uF electrolytic capacitors
- 8x 20 pin IC sockets
- 1x 40 pin IC socket
- 2x 16 pin IC socket
- 1x 2-pin screw terminal
- 1x 2wire cable with plugs
- 9x 8-pin terminal pins
- 1x 4-pin terminal pins, right angle
- 2x 16-pin ribbon cable connector
- 1x 10-pin ribbon cable connector
- Ribbon cable
- 2x pushbuttons
- 2x ribbon cable plugs
- 9x 8-pin female header plugs
- Serial cable and 4pin female pin header
- Piece of wood for template and base
- 8x optional pull-up resistors for layers
- 5v power supply (see separate step for power supply)

Total estimated build cost: 67 USD. See attached price list.

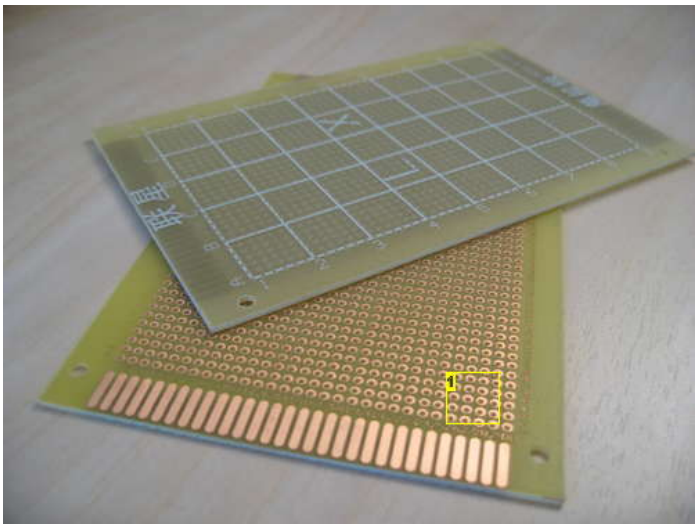


Image Notes
1. Make sure to get this type of prototyping PCB.

Image Notes
1. Lots and lots of LEDs!

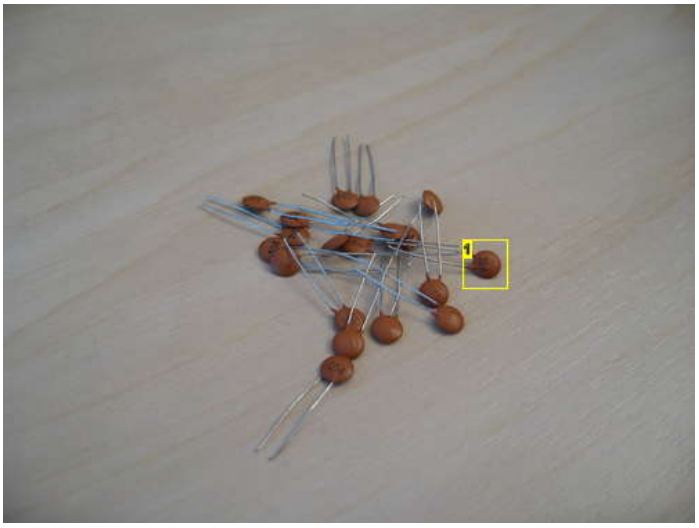


Image Notes
1. 100nF

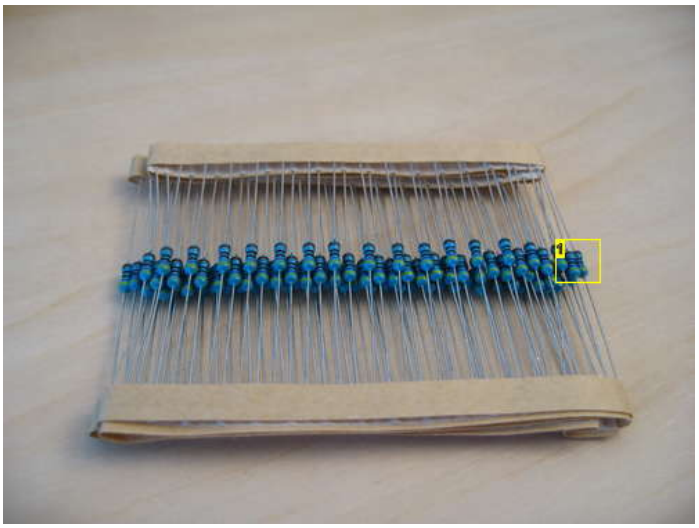


Image Notes
1. Don't look at the color codes. This is not 100ohms.

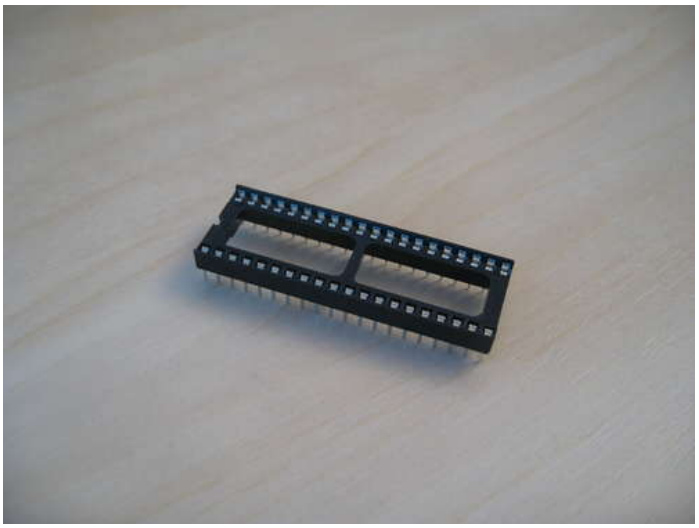


Image Notes
1. Kynar wrapping wire. 30 AWG.

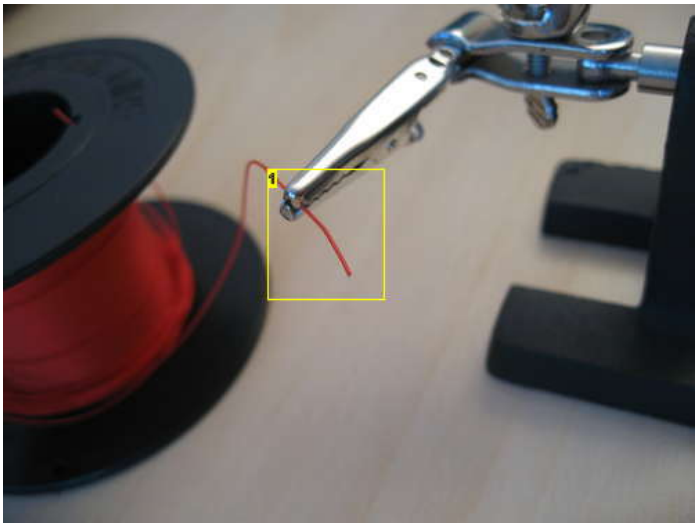


Image Notes
1. Very tiny wire. Perfect for working on prototyping PCBs.

Image Notes
1. Fan to blow away those soldering fumes.

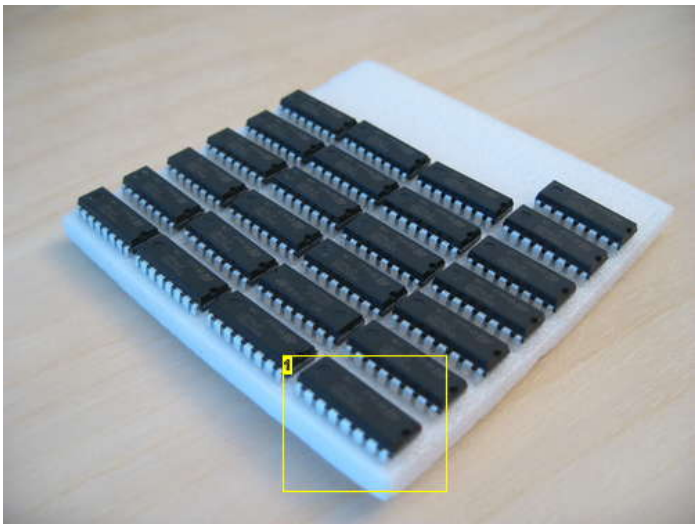


Image Notes
1. Lots of ICs

	A	B	C	D
1	**From futurlec:**	**Price**	**Units**	**Sum**
2	64x resistors. (see separate step for ohm value)	0.02	70	1.40
3	1x or 2x large prototype PCBs.(copper eyes)	2.90	2	5.80
4	1x ATmega32 microcontroller	6.90	1	6.90
5	3x status LEDs. You choose color and size.	0.08	3	0.24
6	3x resistors for the status LEDs.	0.02	10	0.20
7	8x 74HC574 ICs	0.60	8	4.80
8	16x PN2222 transistors	0.10	16	1.60
9	16x 1k resistors	0.02	20	0.40
10	1x 74HC138 IC	0.35	1	0.35
11	1x Maxim MAX232 IC	1.60	1	1.60
12	1x 14.7456 MHz crustal	0.75	1	0.75
13	2x 22pF ceramic capacitors	0.05	2	0.10
14	16x 0.1uF ceramic capacitors	0.10	16	1.60
15	3x 1000uF electrolytic capacitor	0.18	3	0.54
16	3x 10uF electrolytic capacitor	0.05	3	0.15
17	1x 100uF electrolytic capacitors	0.10	1	0.10
18	8x 20 pin IC sockets	0.09	8	0.72
19	1x 40 pin IC socket	0.15	1	0.15
20	2x 16 pin IC socket	0.07	2	0.14
21	1x 2-pin screw terminal	0.40	1	0.40

Image Notes
1. See attached excel file for full list.

File Downloads

pricelist.xls (12 KB)
[NOTE: When saving, if you see .tmp as the file ext, rename it to 'pricelist.xls']

Step 3: Ordering components

We see a lot of people asking for part numbers for DigiKey, Mouser or other big electronics stores.

When you're working with hobby electronics, you don't necessarily need the most expensive components with the best quality.

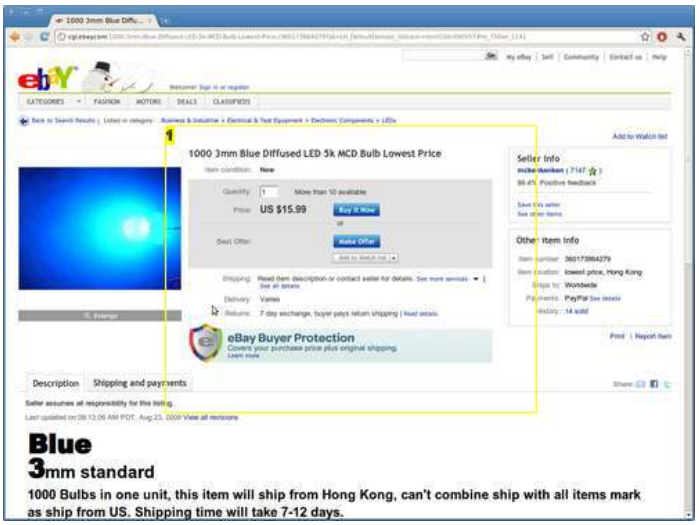
Most of the time, it is more important to actually have the component value at hand when you need it.

We are big fans of buying really cheap component lots on eBay. You can get assortments of resistor, capacitors, transistors and everything in between. If you buy these types of assortments, you will almost always have the parts you need in your part collection.

For 17 USD you can get 2000 resistors of 50 different values. Great value, and very convenient.

Try doing som eBay searches and buy some components for future projects!

Another one of our favorite stores is Futurlec (http://www.futurlec.com/). They have everything you need. The thing they don't have is 1000 different versions of that thing that you need, so browsing their inventory is a lot less confusing than buying from those bigger companies.



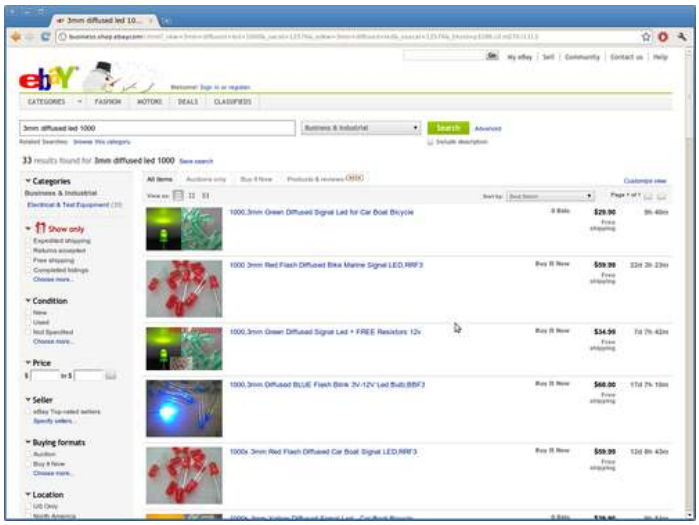
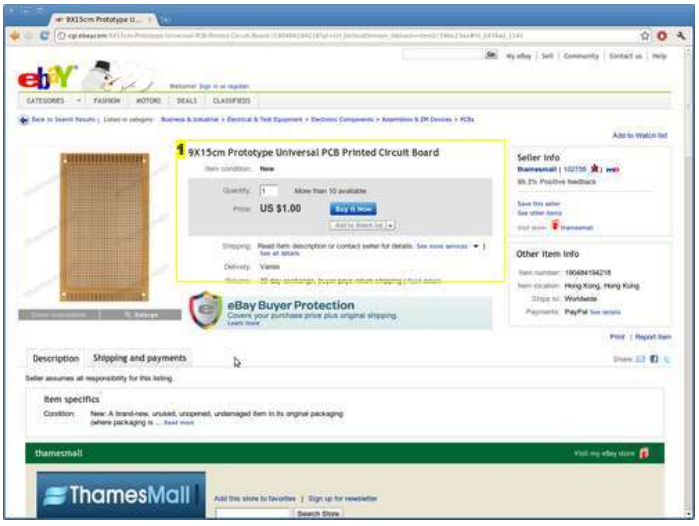


Image Notes
1. 1000 leds for 16 bucks. But beware! The descriptions aren't always that great. We ordered diffused leds and got clear ones :/



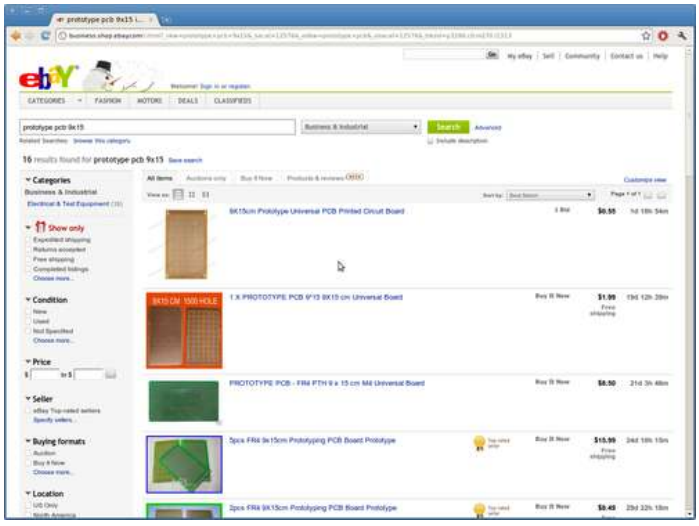
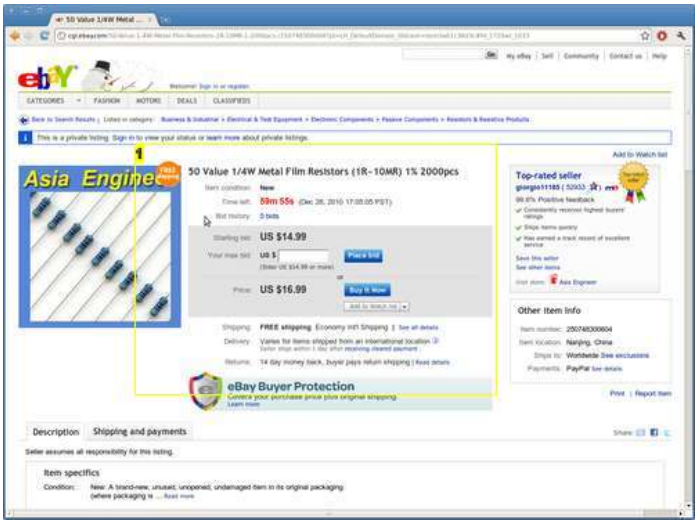


Image Notes
1. This is the type of prototype PCB we used. 1 dollar!



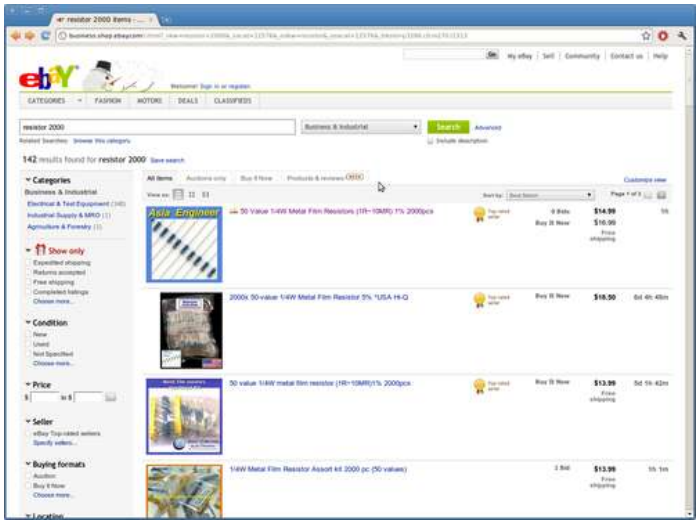


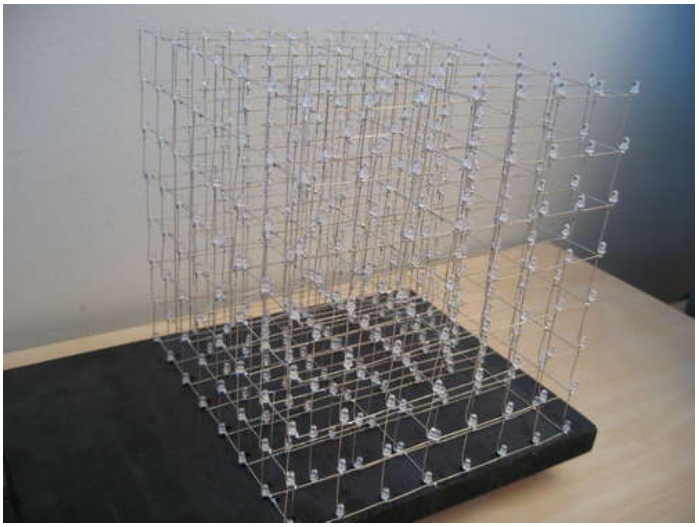
Image Notes
1. 2000 resistors for 17 USD

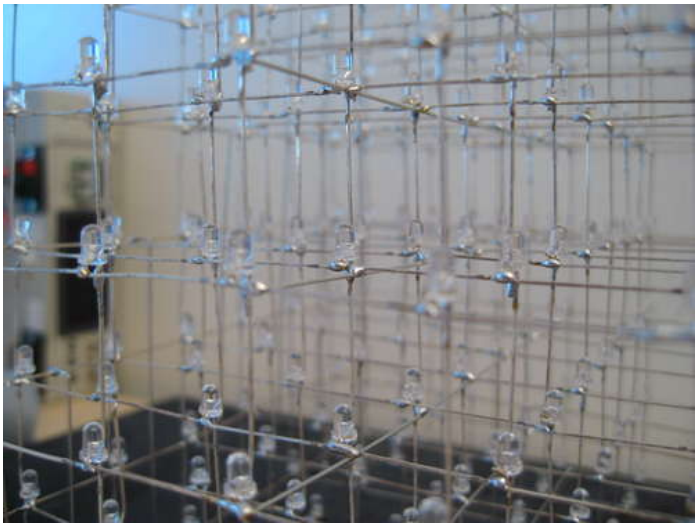
Step 4: What is a LED cube

A LED cube is like a LED screen, but it is special in that it has a third dimension, making it 3D. Think of it as many transparent low resolution displays. In normal displays it is normal to try to stack the pixels as close as possible in order to make it look better, but in a cube one must be able to see trough it, and more spacing between the pixels (actually it's voxels since it is in 3d) is needed. The spacing is a trade-off between how easy the layers behind it is seen, and voxel fidelity.

Since it is a lot more work making a LED cube than a LED display, they are usually low resolution. A LED display of 8x8 pixels is only 64 LEDs, but a LED cube in 8x8x8 is 512 LEDs, an order of magnitude harder to make! This is the reason LED cubes are only made in low resolution.

A LED cube does not have to be symetrical, it is possible to make a 7x8x9, or even oddly shaped ones.





Step 5: How does a LED cube work

This LED cube has 512 LEDs. Obviously, having a dedicated IO port for each LED would be very impractical. You would need a micro controller with 512 IO ports, and run 512 wires through the cube.

Instead, LED cubes rely on an optical phenomenon called persistence of vision (POV).

If you flash a led really fast, the image will stay on your retina for a little while after the led turns off.

By flashing each layer of the cube one after another really really fast, it gives the illusion of a 3d image, when int fact you are looking at a series of 2d images stacked ontop oneanother. This is also called multiplexing.

With this setup, we only need 64 (for the anodes) + 8 (for each layer) IO ports to control the LED cube.

In the video, the process is slowed down enough for you to see it, then it runs faster and faster until the refresh rate is fast enough for the camera to catch the POV effect.

CLICK TO PLAY VIDEO

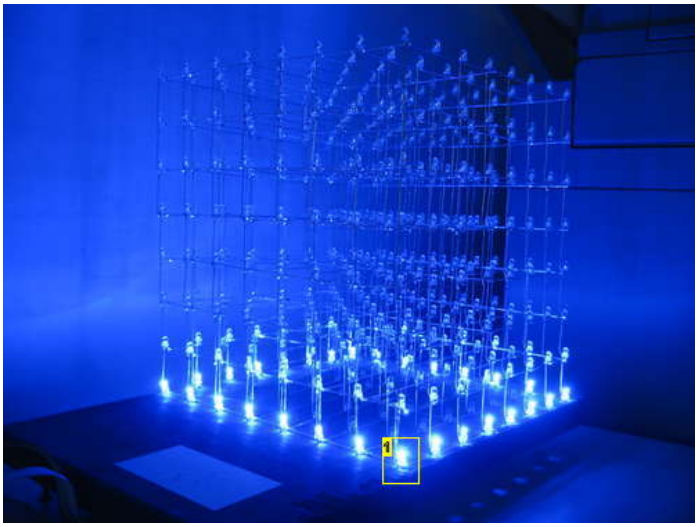


Image Notes
1. We start by flashing the bottom layer. Layer 0.

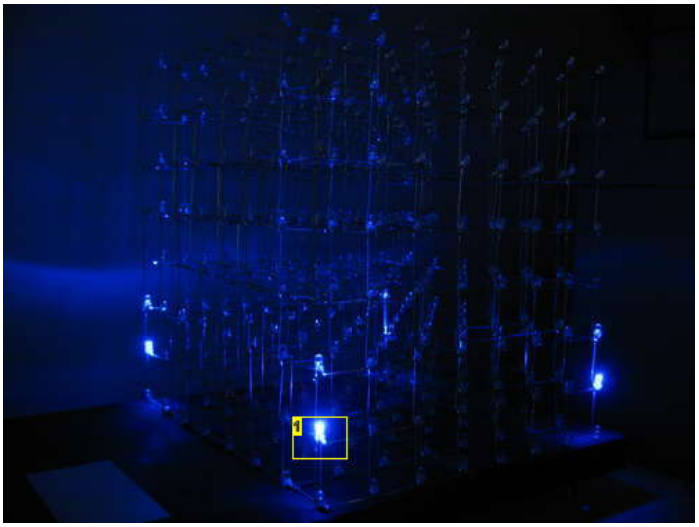


Image Notes
1. Then the second.

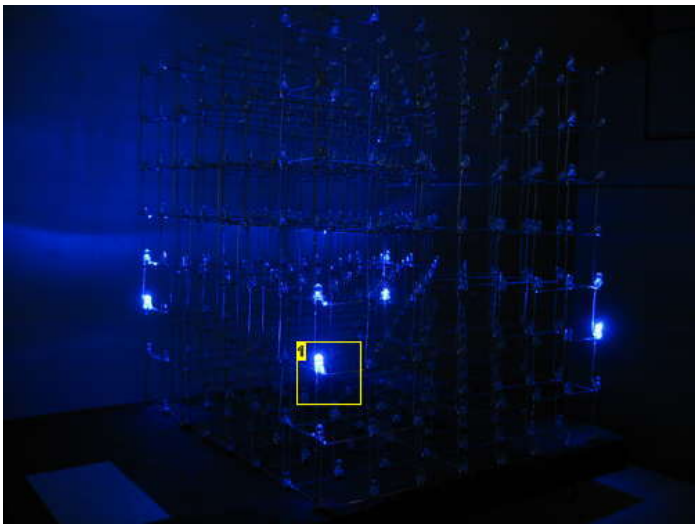


Image Notes
1. And so on..

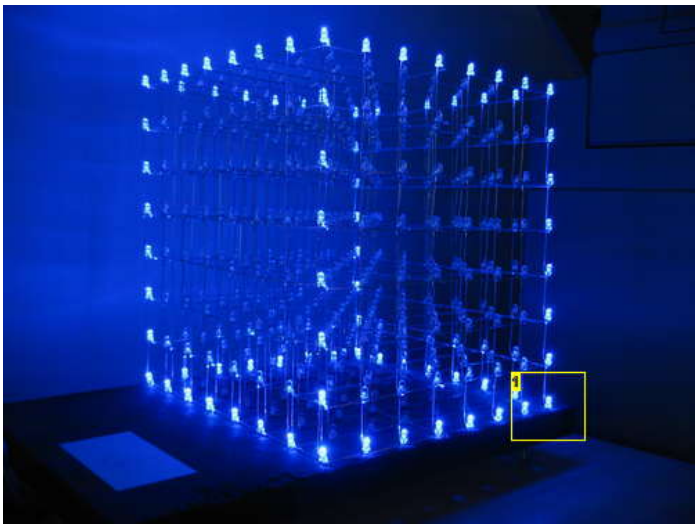


Image Notes
1. Do this fast enough, and your human eyes won't know the difference! Robots may be able to see past the illusion, though.

Step 6: The anatomy of a LED cube

We are going to be talking about anodes, cathodes, columns and layers, so lets take a moment to get familiar with the anatomy of a LED cube.

An LED has two legs. One positive (the anode) and one negative (cathode). In order to light up an LED, you have to run current from the positive to the negative leg. (If i remember correctly the actual flow of electrons is the other way around. But let's stick to the flow of current which is from positive to negative for now).

The LED cube is made up of columns and layers. The cathode legs of every LED in a layer are soldered together. All the anode legs in one column are soldered together.

Each of the 64 columns are connected to the controller board with a separate wire. Each column can be controlled individually. Each of the 8 layers also have a separate wire going to the controller board.

Each of the layers are connected to a transistor that enables the cube to turn on and off the flow of current through each layer.

By only turning on the transistor for one layer, current from the anode columns can only flow through that layer. The transistors for the other layers are off, and the image outputted on the 64 anode wires are only shown on the selected layer.

To display the next layer, simply turn off the transistor for the current layer, change the image on the 64 anode wires to the image for the next layer. Then turn on the transistor for the next layer. Rinse and repeat very very fast.

The layers will be referred to as layers, cathode layers or ground layers.
The columns will be referred to as columns, anode columns or anodes.

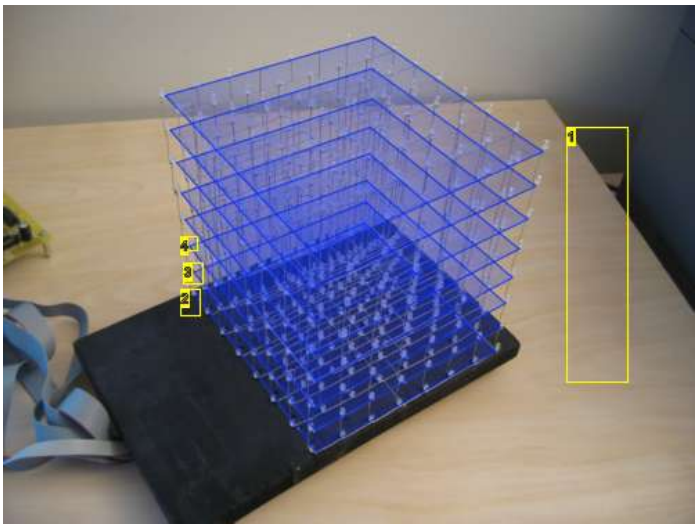


Image Notes
1. 8 layers
2. A 64x64 image is flashed first on layer 0
3. Then another image is flashed on layer 1
4. Wash rinse repeat

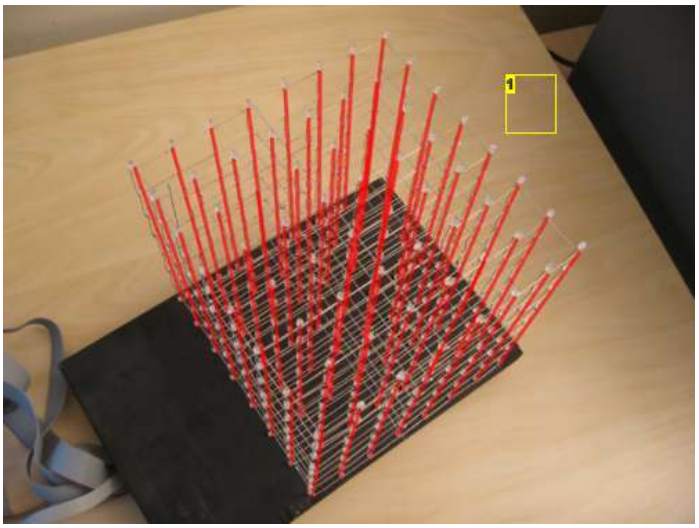


Image Notes
1. 64 columns

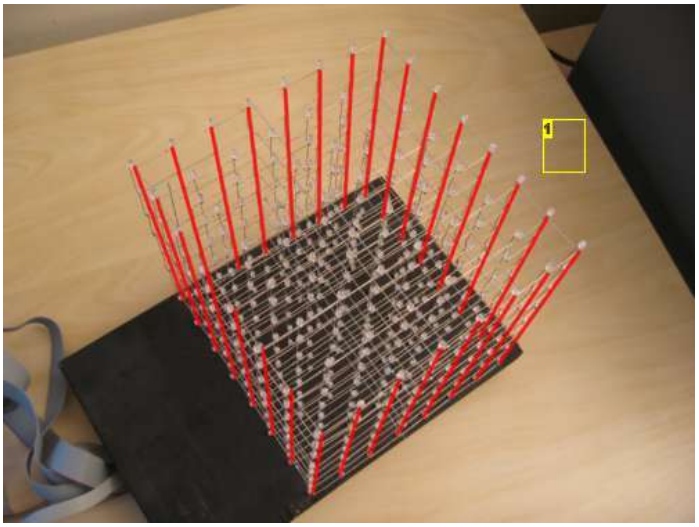


Image Notes
1. Was easier to see when I didn't draw all 64 lines

Step 7: Cube size and IO port requirements

To drive a LED cube, you need two sets of IO ports. One to source all the LED anode columns, and one to sink all the cathode layers.

For the anode side of the cube, you'll need x^2 IO ports, where x^3 is the size of your LED cube. For an 8x8x8 (x=8), you need 64 IO ports to drive the LED anodes. (8x8). You also need 8 IO ports to drive the cathodes.

Keep in mind that the number of IO ports will increase exponentially. So will the number of LEDs. You can see a list of IO pin requirement for different cube sizes in table 1.

For a small LED cube, 3x3x3 or 4x4x4, you might get away with connecting the cathode layers directly to a micro controller IO pin. For a larger cube however, the current going through this pin will be too high. For an 8x8x8 LED cube with only 10mA per LED, you need to switch 0.64 Ampere. See table 2 for an overview of power requirements for a LED layer of different sizes. This table shows the current draw with all LEDs on.

If you are planning to build a larger cube than 8x8x8 or running each LED at more than 10-ish mA, remember to take into consideration that your layer transistors must be able to handle that load.

	(x^2)	(x)	(x^2+x)
Cube size	**Anodes**	**Cathodes**	**Total**
2	4	2	6
3	9	3	12
4	16	4	20
5	25	5	30
6	36	6	42
7	49	7	56
8	64	8	72
9	81	9	90
10	100	10	110
11	121	11	132
12	144	12	156
13	169	13	182
14	196	14	210
15	225	15	240
16	256	16	272

Cube size	Leds per layer	Total mA at X mA per LED	
		10mA	20mA
2	4	40	80
3	9	90	180
4	16	160	320
5	25	250	500
6	36	360	720
7	49	490	980
8	64	640	1,280
9	81	810	1,620
10	100	1,000	2,000
11	121	1,210	2,420
12	144	1,440	2,880
13	169	1,690	3,380
14	196	1,960	3,920
15	225	2,250	4,500
16	256	2,560	5,120

Step 8: IO port expansion, more multiplexing

We gathered from the last step that an 8x8x8 LED cube requires 64+8 IO lines to operate. No AVR micro controller with a DIP package (the kind of through hole chip you can easily solder or use in a breadboard, Dual Inline Package) have that many IO lines available.

To get get the required 64 output lines needed for the LED anodes, we will create a simple multiplexer circuit. This circuit will multiplex 11 IO lines into 64 output lines.

The multiplexer is built by using a component called a latch or a flip-flop. We will call them latches from here on.

This multiplexer uses an 8 bit latch IC called 74HC574. This chip has the following pins:

- 8 inputs (D0-7)
- 8 outputs (Q0-7)
- 1 "latch" pin (CP)
- 1 output enable pin (OE)

The job of the latch is to serve as a kind of simple memory. The latch can hold 8 bits of information, and these 8 bits are represented on the output pins. Consider a latch with an LED connected to output Q0. To turn this LED on, apply V+ (1) to input D0, then pull the CP pin low (GND), then high (V+).

When the CP pin changes from low to high, the state of the input D0 is "latched" onto the output Q0, and this output stays in that state regardless of future changes in the status of input D0, until new data is loaded by pulling the CP pin low and high again.
To make a latch array that can remember the on/off state of 64 LEDs we need 8 of these latches. The inputs D0-7 of all the latches are connected together in an 8 bit bus.

To load the on/off states of all the 64 LEDs we simply do this: Load the data of the first latch onto the bus. pull the CP pin of the first latch low then high. Load the data of the second latch onto the bus. pull the CP pin of the second latch low then high. Load the data of the third latch onto the bus. pull the CP pin of the third latch low then high. Rinse and repeat.

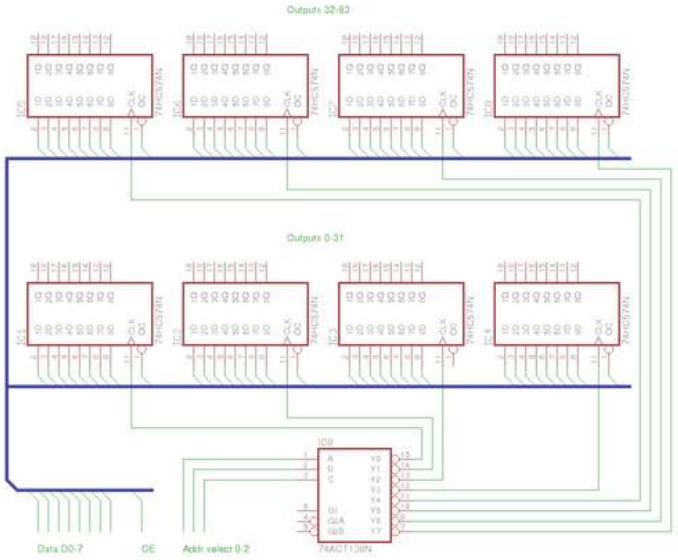
The only problem with this setup is that we need 8 IO lines to control the CP line for each latch. The solution is to use a 74HC138. This IC has 3 input lines and 8 outputs. The input lines are used to control which of the 8 output lines that will be pulled low at any time. The rest will be high. Each out the outputs on the 74HC138 is connected to the CP pin on one of the latches.

The following pseudo-code will load the contents of a buffer array onto the latch array:

```
// PORT A = data bus
// PORT B = address bus (74HC138)
// char buffer[8] holds 64 bits of data for the latch array

PORTB = 0x00; // This pulls CP on latch 1 low.
for (i=0; i < 8; i++)
{

        PORTA = buffer[i];
```

```
        PORTB = i+1;

}
```

The outputs of the 74HC138 are active LOW. That means that the output that is active is pulled LOW. The latch pin (CP) on the latch is a rising edge trigger, meaning that the data is latched when it changes from LOW to HIGH. To trigger the right latch, the 74HC138 needs to stay one step ahead of the counter i. If it had been an active HIGH chip, we could write PORTB = i; You are probably thinking, what happens when the counter reaches 7, that would mean that the output on PORTB is 8 (1000 binary)on the last iteration of the for() loop. Only the first 8 bits of PORT B are connected to the 74HC138. So when port B outputs 8 or 1000 in binary, the 74HC138 reads 000 in binary, thus completing its cycle. (it started at 0). The 74HC138 now outputs the following sequence: 1 2 3 4 5 6 7 0, thus giving a change from LOW to HIGH for the current latch according to counter i.



File Downloads

multiplex_theoretical.sch (21 KB)
[NOTE: When saving, if you see .tmp as the file ext, rename it to 'multiplex_theoretical.sch']

Step 9: IO port expansion, alternative solution

There is another solution for providing more output lines. We went with the latch based multiplexer because we had 8 latches available when building the LED cube.

You can also use a serial-in-parallel out shift register to get 64 output lines. 74HC164 is an 8 bit shift register. This chip has two inputs (may also have an output enable pin, but we will ignore this in this example).

- data
- clock

Every time the clock input changes from low to high, the data in Q6 is moved into Q7, Q5 into Q6, Q4 into Q5 and so on. Everything is shifted one position to the right (assuming that Q0 is to the left). The state of the data input line is shifted into Q0.

The way you would normally load data into a chip like this, is to take a byte and bit-shift it into the chip one bit at a time. This uses a lot of CPU cycles. However, we have to use 8 of these chips to get our desired 64 output lines. We simply connect the data input of each shift register to each of the 8 bits on a port on the micro controller. All the clock inputs are connected together and connected to a pin on another IO port.

This setup will use 9 IO lines on the micro controller.

In the previous solution, each byte in our buffer array was placed in it's own latch IC. In this setup each byte will be distributed over all 8 shift registers, with one bit in each.

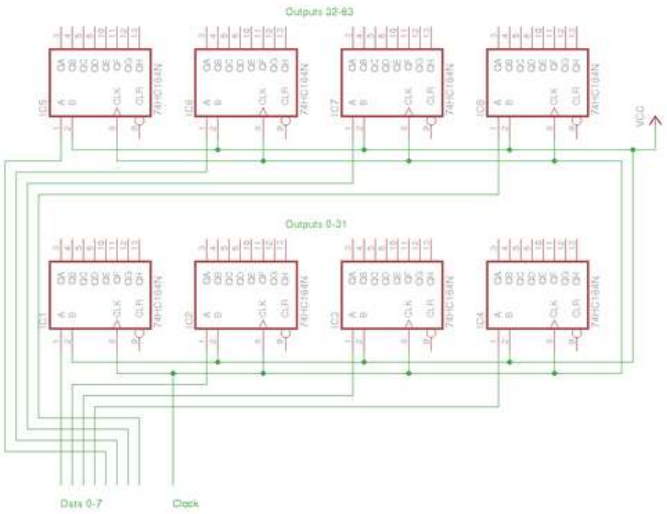
The following pseudo-code will transfer the contents of a 64 bit buffer array to the shift registers.

```
// PORT A: bit 0 connected to shift register 0's data input, bit 1 to shift register 1 and so on.
// PORT B: bit 0 connected to all the clock inputs
// char buffer[8] holds 64 bits of data

for (i=0; i < 8; i++)
{
        PORTB = 0x00; // Pull the clock line low, so we can pull it high later to trigger the shift register
        PORTA = buffer[i]; // Load a byte of data onto port A
        PORTB = 0x01; // Pull the clock line high to shift data into the shift registers.

}
```

This is perhaps a better solution, but we had to use what we had available when building the cube. For the purposes of this instructable, we will be using a latch based multiplexer for IO port expansion. Feel free to use this solution instead if you understand how they both work.

With this setup, the contents of the buffer will be "rotated" 90 degrees compared to the latch based multiplexer. Wire up your cube accordingly, or simply just turn it 90

degrees to compensate ;)



File Downloads

multiplex_alternative.sch (10 KB)
[NOTE: When saving, if you see .tmp as the file ext, rename it to 'multiplex_alternative.sch']

Step 10: Power supply considerations

This step is easy to overlook, as LEDs themselves don't draw that much current. But remember that this circuit will draw 64 times the mA of your LEDs if they are all on. In addition to that, the AVR and the latch ICs also draws current.

To calculate the current draw of your LEDs, connect a led to a 5V power supply with the resistor you intend to use, and measure the current in mA. Multiply this number by 64, and you have the power requirements for the cube itself. Add to that 15-20 mA for the AVR and a couple of mA for each latch IC.

Our first attempt at a power supply was to use a step-down voltage regulator, LM7805, with a 12V wall wart. At over 500mA and 12V input, this chip became extremely hot, and wasn't able to supply the desired current.

We later removed this chip, and soldered a wire from the input to the output pin where the chip used to be.

We now use a regulated computer power supply to get a stable high current 5V supply.

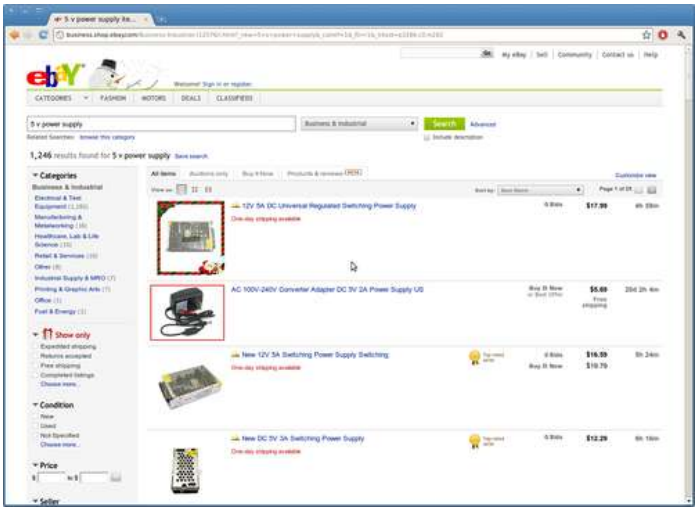
Image Notes
1. Cube drawing almost half an amp at 5 volts.

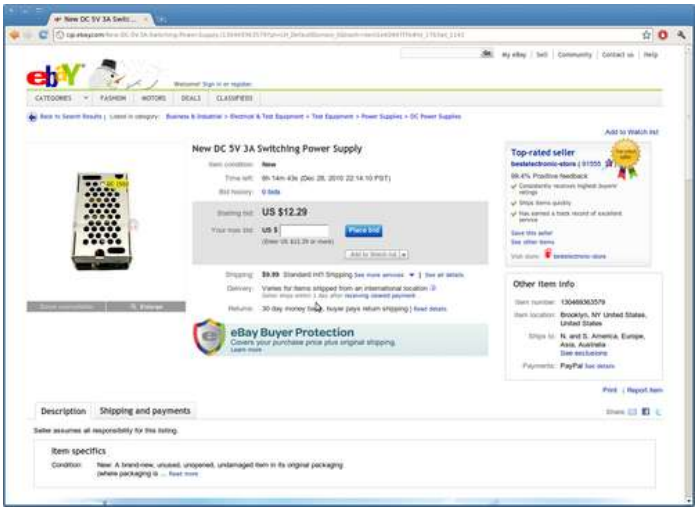
Step 11: Buy a power supply

If you don't have the parts necessary to build a 5V PSU, you can buy one.

eBay is a great place to buy these things.

Search for "5v power supply" and limit the search to "Business & Industrial", and you'll get a lot of suitable power supplies. About 15 bucks will get you a nice PSU.





Step 12: Build a power supply

A couple of years before we built the LED cube, we made our self a nice little lab power supply from an old external SCSI drive. This is what we have been using to power the LED cube.

PC power supplies are nice, because they have regulated 12V and 5V rails with high Ampere ratings.

You can use either a regular AT or ATX power supply or and old external hard drive enclosure.

If you want to use an ATX power supply, you have to connect the green wire on the motherboard connector to ground (black). This will power it up.

External hard drive enclosures are especially nice to use as power supplies. They already have a convenient enclosure. The only thing you have to do is to add external power terminals.

Power supplies have a lot of wires, but the easiest place to get the power you need is through a molex connector. That is the kind of plug you find on hard drives (before the age of S-ATA).

Black is GND Yellow is +12V Red is +5V

Here is an image of our lab PSU. We have 12V output, 5V output with an ampere meter and 5V output without an ampere meter. We use the second 5V output to power an 80mm PC fan to suck or blow fumes away when we solder.

We won't get into any more details of how to make a power supply here. I'm sure you can find another instructable on how to do that.

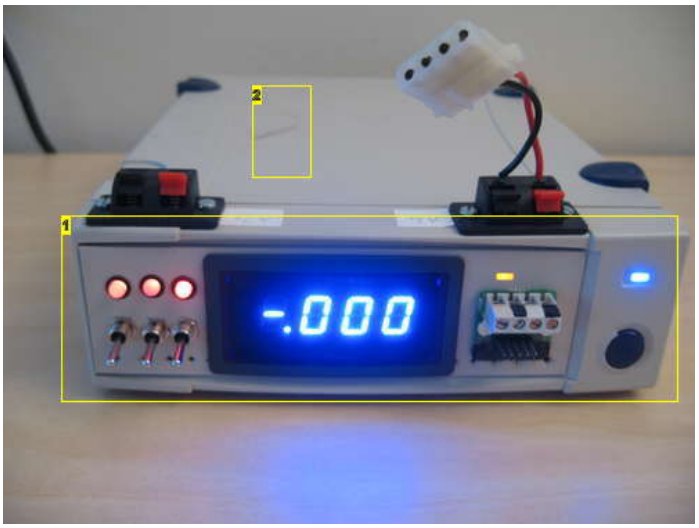


Image Notes
1. Old SCSI disk
2. Inside here is a small powersupply that used to supply the SCSI hard drive that was inside.

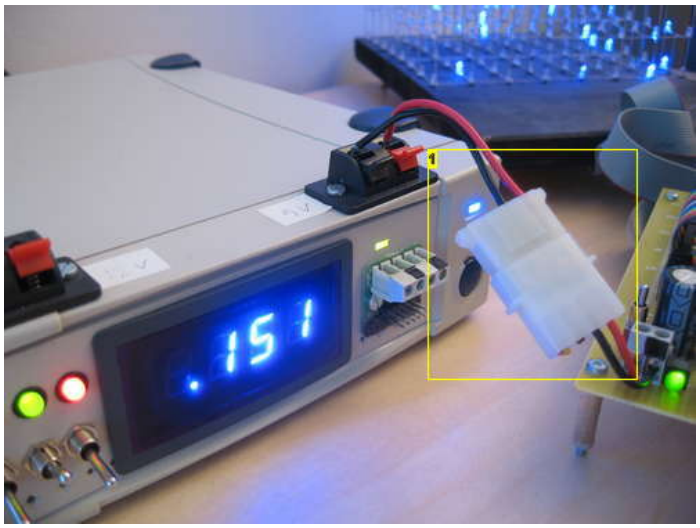
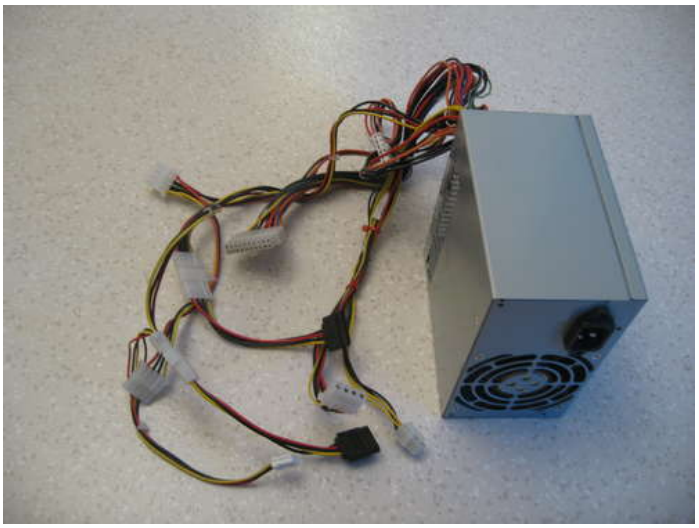


Image Notes
1. Used a Molex connector so we could disconnect the cube easily.



Step 13: Choose your LEDs

There are many things to consider when choosing LEDs.

1)
You want the LED cube to be equally visible from all sides. Therefore we strongly recommend using diffused LEDs. A clear LED will shoot the majority of it's light out the top of the LED. A diffused LED will be more or less equally bright from all sides. Clear LEDs also create another problem. If your cube is made up of clear LEDs. The LEDs will also partially illuminate the LEDs above them, since most of the light is directed upwards. This creates some unwanted ghosting effects.

We actually ordered diffused LEDs from eBay, but got 1000 clear LEDs instead. Shipping them back to China to receive a replacement would have taken too much time, so we decided to used the clear LEDs instead. It works fine, but the cube is a lot brighter when viewed from the top as opposed to the sides.

The LEDs we ordered from eBay were actually described as "Defused LEDs". Maybe we should have taken the hint ;) Defusing is something you do to a bomb when you want to prevent it from blowing up, hehe.

2)
Larger LEDs gives you a bigger and brighter pixel, but since since the cube is 8 layers deep, you want enough room to see all the way through to the furthest level. We went with 3mm LEDs because we wanted the cube to be as "transparent" as possible. Our recommendation is to use 3mm diffused LEDs.

3)
You can buy very cheap lots of 1000 LEDs on eBay. But keep in mind that the quality of the product may be reflected in it's price. We think that there is less chance of LED malfunction if you buy better quality/more expensive LEDs.

4)
Square LEDs would probably look cool to, but then you need to make a soldering template that can accommodate square LEDs. With 3mm round LEDs, all you need is a 3mm drill bit.

5)
Since the cube relies on multiplexing and persistence of vision to create images, each layer is only turned on for 1/8 of the time. This is called a 1/8 duty cycle. To compensate for this, the LEDs have to be bright enough to produce the wanted brightness level at 1/8 duty cycle.

6)
Leg length. The cube design in this instructable uses the legs of the LEDs themselves as the skeleton for the cube. The leg length of the LEDs must be equal to or greater than the distance you want between each LED.

Image Notes
1. So many choices..

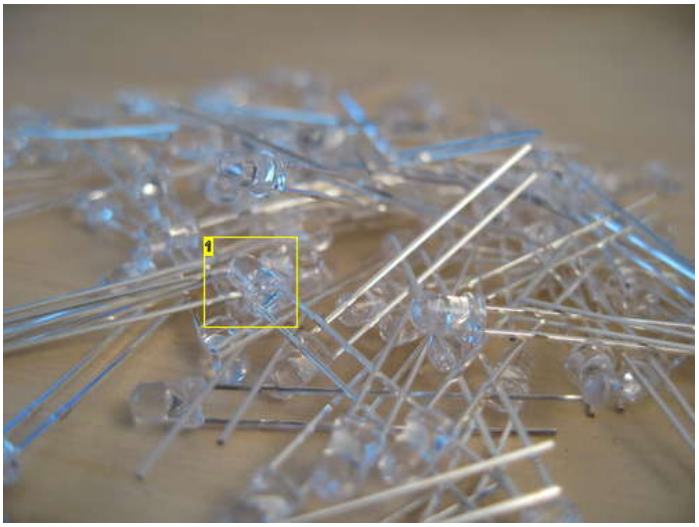


Image Notes
1. These are the ones we ended up using

Image Notes
1. BAD This is not what we ordered! Damn you ebay!

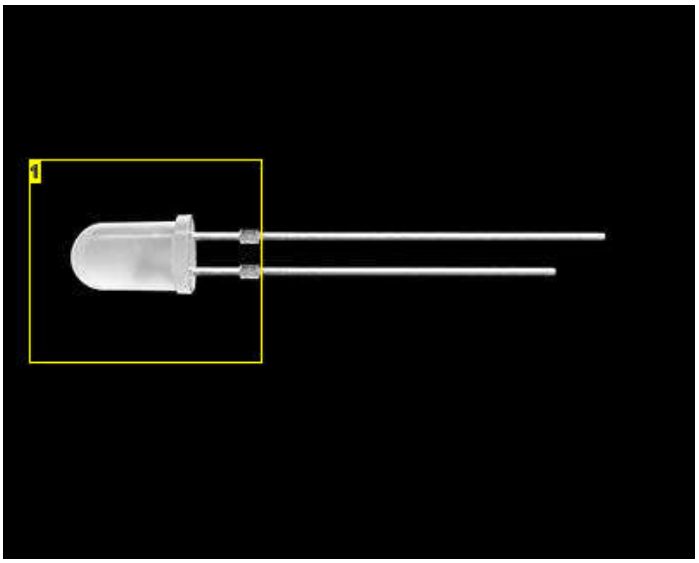


Image Notes
1. GOOD This is what we expected to receive. Diffused LED.

Step 14: Choose your resistors

There are three things to consider when choosing the value of your resistors, the LEDs, the 74HC574 that drive the LEDs, and the transistors used to switch the layers on and off.

1)
If your LEDs came with a data sheet, there should be some ampere ratings in there. Usually, there are two ratings, one mA for continuous load, and mA for burst loads. The LEDs will be running at 1/8 duty cycle, so you can refer to the burst rating.

2)
The 74HC574 also has some maximum ratings. If all the LEDs on one anode column are on, this chip will supply current 8/8 of the time. You have to keep within the specified maximum mA rating for the output pins. If you look in the data sheet, You will find this line: DC Output Source or Sink Current per Output Pin, IO: 25 mA. Also there is a VCC or GND current maximum rating of 50mA. In order not to exceed this, your LEDs can only run at 50/8 mA since the 74HC574 has 8 outputs. This gives you 6.25 mA to work with.

3)
The transistors have to switch on and off 64 x the mA of your LEDs. If your LEDs draw 20mA each, that would mean that you have to switch on and off 1.28 Ampere. The only transistors we had available had a maximum rating of 400mA.

We ended up using resistors of 100 ohms.

While you are waiting for your LED cube parts to arrive in the mail, you can build the guy in the picture below: http://www.instructables.com/id/Resistor-man/

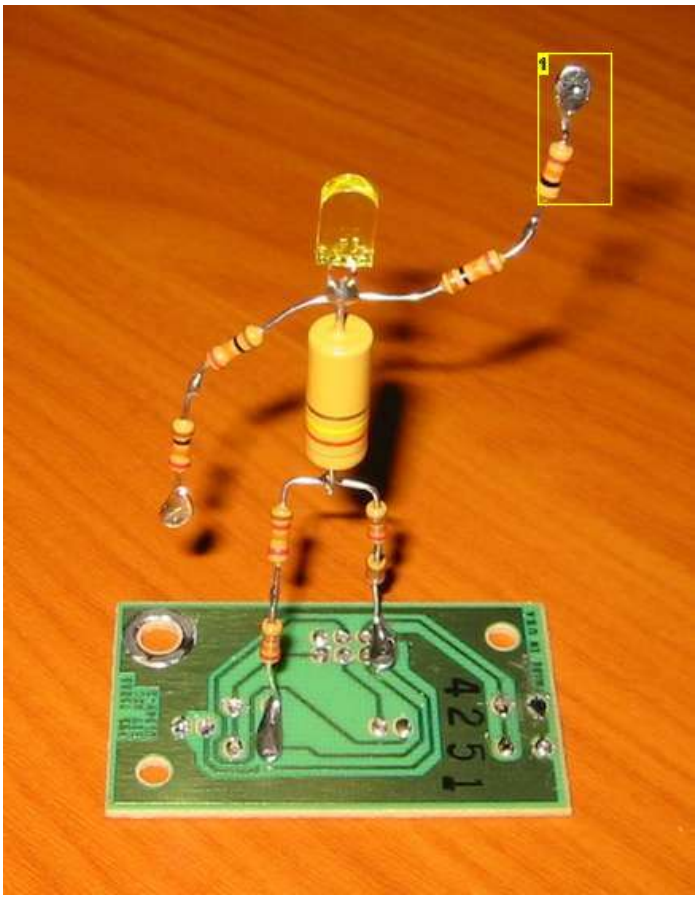


Image Notes
1. Viva la resistance!!

Step 15: Choose the size of your cube

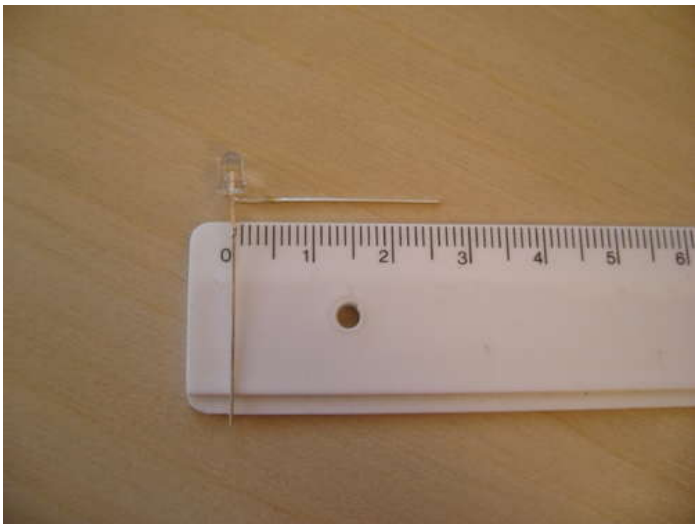
We wanted to make the LED cube using as few components as possible. We had seen some people using metal rods for their designs, but we didn't have any metal rods. Many of the metal rod designs also looked a little crooked.

We figured that the easiest way to build a led cube would be to bend the legs of the LEDs so that the legs become the scaffolding that holds the LEDs in place.

We bent the cathode leg on one of the LEDs and measured it to be 26 mm from the center of the LED. By choosing a LED spacing of 25mm, there would be a 1mm overlap for soldering. (1 inch = 25.4mm)

With a small 3mm LED 25mm between each led gave us plenty of open space inside the cube. Seeing all the way through to the furthest layer wouldn't be a problem. We could have made the cube smaller, but then we would have to cut every single leg, and visibility into the cube would be compromised.

Our recommendation is to use the maximum spacing that your LED can allow. Add 1mm margin for soldering.



Step 16: How to make straight wire

In order to make a nice looking LED Cube, you need some straight steel wire. The only wire we had was on spools, so it had to be straightened.

Our first attempt at this failed horribly. We tried to bend it into a straight wire, but no matter how much we bent, it just wasn't straight enough.

Then we remembered an episode of "How it's made" from the Discovery Channel. The episode was about how they make steel wire. They start out with a spool of really thick wire, then they pull it through smaller and smaller holes. We remembered that the wire was totally straight and symmetrical after being pulled like that.

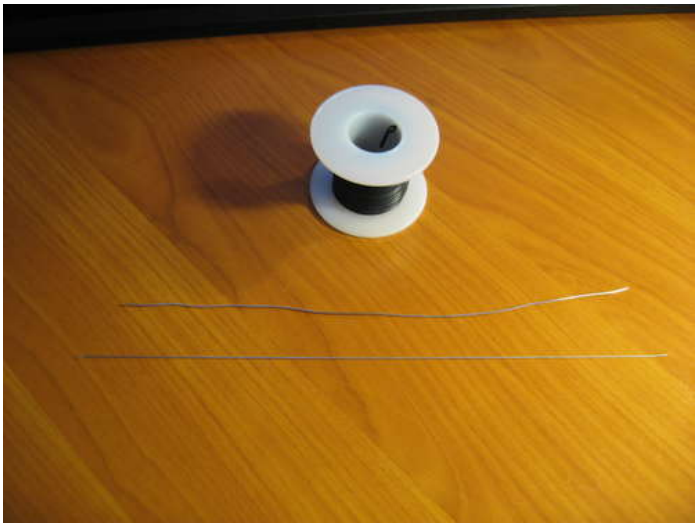
So we figured we should give pulling a try, and it worked! 100% straight metal wire from a spool!

Here is how you do it.

- cut of the length of wire you need from the spool, plus an inch or two.
- Remove the insulation, if any.
- Get a firm grip of each end of the wire with two pairs of pliers
- Pull hard!
- You will feel the wire stretch a little bit.

You only need to stretch it a couple of millimeters to make it nice and straight.

If you have a vice, you can secure one end in the vice and use one pair of pliers. This would probably be a lot easier, but we don't own a vice.



Step 17: Practice in small scale

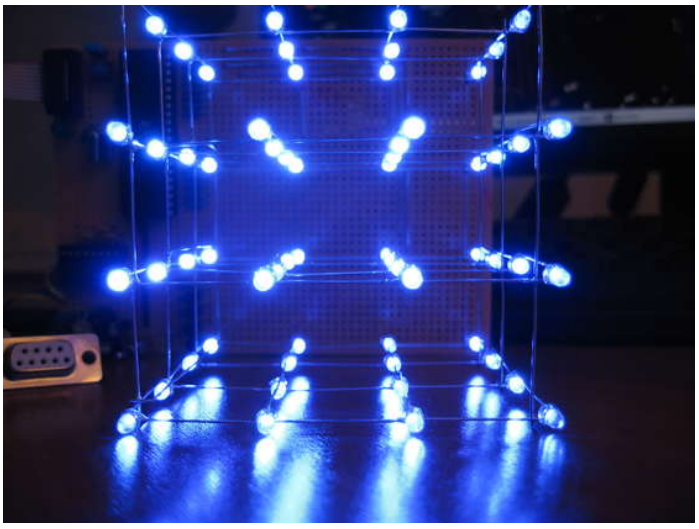
Whenever Myth Busters are testing a complex myth, they start by some small scale experiments.

We recommend that you do the same thing.

Before we built the 8x8x8 LED cube, we started by making a smaller version of it, 4x4x4. By making the 4x4x4 version first, you can perfect your cube soldering technique before starting on the big one.

Check out our 4x4x4 LED cube instructable for instructions on building a smaller "prototype".

http://www.instructables.com/id/LED-Cube-4x4x4/



Step 18: Build the cube: create a jig

In order to make a nice looking LED cube, it is important that it is completely symmetrical, that the space between each LED is identical, and that each LED points the same way. The easiest way to accomplish this is to create a temporary soldering jig/template.

1)
Find a piece of wood or plastic that is larger than the size of your cube.

2)
Find a drill bit that makes a hole that fits a LED snugly in place. You don't want it to be to tight, as that would make it difficult to remove the soldered layer from the jig without bending it. If the holes are too big, some of the LEDs might come out crooked.

3)
Use a ruler and an angle iron to draw up a grid of 8 by 8 lines intersecting at 64 points, using the LED spacing determined in a previous step.

4)
Use a sharp pointy object to make indentions at each intersection. These indentions will prevent the drill from sliding sideways when you start drilling.

5)
Drill out all the holes.

6)
Take an LED and try every hole for size. If the hole is too snug, carefully drill it again until the LED fits snugly and can be pulled out without much resistance.

7)
Somewhere near the middle of one of the sides, draw a small mark or arrow. A steel wire will be soldered in here in every layer to give the cube some extra stiffening.

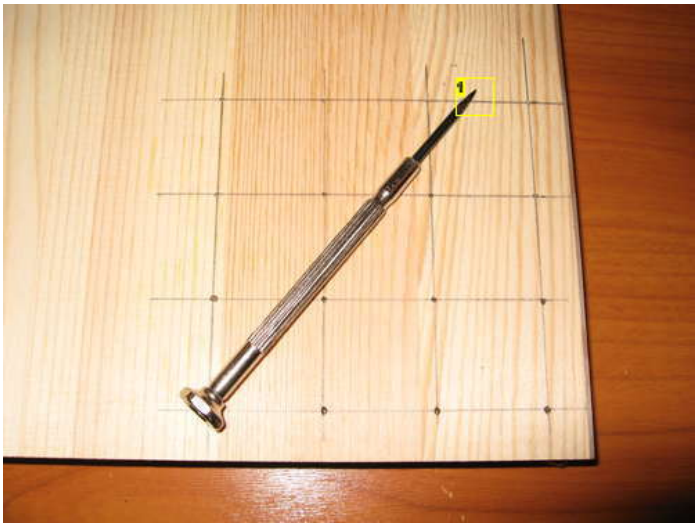


Image Notes
1. If you make a small indentation before drilling, the drill won't slide sideways.

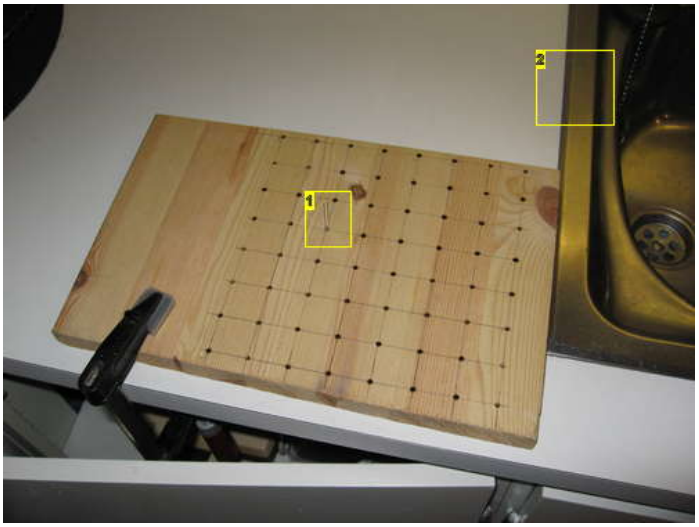


Image Notes
1. All done. We used this LED to test all the holes.
2. Everything but the kitchen sink? We sort of used the kitchen sink to hold the jig in place ;)

Step 19: Build the cube: soldering advice

You are going to be soldering VERY close to the LED body, and you are probably going to be using really cheap LEDs from eBay. LEDs don't like heat, cheap LEDs probably more so than others. This means that you have to take some precautions in order to avoid broken LEDs.

Soldering iron hygiene

First of all, you need to keep your soldering iron nice and clean. That means wiping it on the sponge every time you use it. The tip of your soldering iron should be clean and shiny. Whenever the you see the tip becoming dirty with flux or oxidizing, that means loosing it's shinyness, you should clean it. Even if you are in the middle of soldering. Having a clean soldering tip makes it A LOT easier to transfer heat to the soldering target.

Soldering speed

When soldering so close to the LED body, you need to get in and out quickly. Wipe your iron clean. Apply a tiny amount of solder to the tip. Touch the part you want to solder with the side of your iron where you just put a little solder. Let the target heat up for 0.5-1 seconds, then touch the other side of the target you are soldering with the solder. You only need to apply a little bit. Only the solder that is touching the metal of both wires will make a difference. A big blob of solder will not make the solder joint any stronger. Remove the soldering iron immediately after applying the solder.

Mistakes and cool down

If you make a mistake, for example if the wires move before the solder hardens or you don't apply enough solder. Do not try again right away. At this point the LED is already very hot, and applying more heat with the soldering iron will only make it hotter. Continue with the next LED and let it cool down for a minute, or blow on it to remove some heat.

Solder

We recommend using a thin solder for soldering the LEDs. This gives you a lot more control, and enable you to make nice looking solder joints without large blobs of solder. We used a 0.5 mm gauge solder. Don't use solder without flux. If your solder is very old and the flux isn't cleaning the target properly, get newer solder. We haven't experienced this, but we have heard that it can happen.

Are we paranoid?

When building the 8x8x8 LED Cube, we tested each and every LED before using it in the cube. We also tested every LED after we finished soldering a layer. Some of the LEDs didn't work after being soldered in place. We considered these things before making a single solder joint. Even with careful soldering, some LEDs were damaged. The last thing you want is a broken LED near the center of the cube when it is finished. The first and second layer from the outside can be fixed afterwards, but any further in than that, and you'll need endoscopic surgical tools ;)

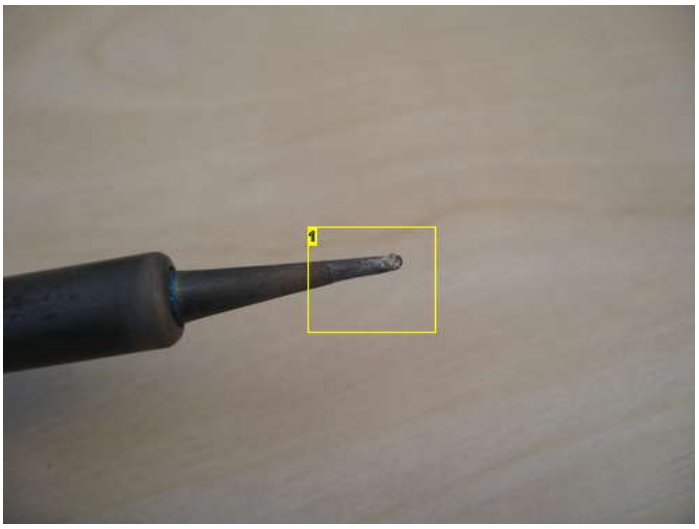


Image Notes

1. If the tip of your soldering iron looks like this, it is time to clean it!

Image Notes

1. This little gadget is great for cleaning your soldering iron

Step 20: Build the cube: test the LEDs

We got our LEDs from eBay, really cheap!

We tested some of the LED before we started soldering, and randomly stumbled on a LED that was a lot dimmer than the rest. So we decided to test every LED before using it. We found a couple of dead LEDs and some that were dimmer than the rest.

It would be very bad to have a dim LED inside your finished LED cube, so spend the time to test the LEDs before soldering! This might be less of a problem if you are using LEDs that are more expensive, but we found it worth while to test our LEDs.

Get out your breadboard, connect a power supply and a resistor, then pop the LEDs in one at a time. You might also want to have another LED with its own resistor permanently on the breadboard while testing. This makes it easier to spot differences in brightness.

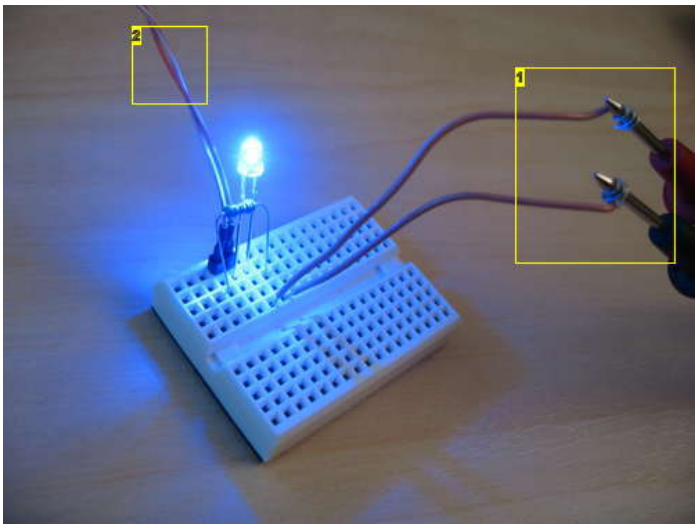


Image Notes
1. Multimeter connected in series to measure mA.
2. 5 volts from power supply

Step 21: Build the cube: solder a layer

Each layer is made up of 8 columns of LEDs held together by the legs of each LED. At the top of each layer each LED is rotated 90 degrees clockwise, so that the leg connects with the top LED of the next column. On the column to the right this leg will stick out of the side of the layer. We leave this in place and use it to connect ground when testing all the LEDs in a later step.

1) Prepare 64 LEDs
Bend the cathode leg of each LED 90 degrees. Make sure the legs are bent in the same direction on all the LEDs. Looking at the LED sitting in a hole in the template with the notch to the right, we bent the leg upwards.

2) Start with the row at the top
Start by placing the top right LED in the template. Then place the one to the left, positioning it so that it's cathode leg is touching the cathode leg of the previous LED. Rinse and repeat until you reach the left LED. Solder all the joints.

3) Solder all 8 columns
If you are right handed, we recommend you start with the column to the left. That way your hand can rest on the wooden template when you solder. You will need a steady hand when soldering freehand like this. Start by placing the LED second from the top, aligning it so it's leg touches the solder joint from the previous step. Then place the LED below that so that the cathode leg touches the LED above. Repeat until you reach the bottom. Solder all the joints.

4) Add braces
You now have a layer that looks like a comb. At this point the whole thing is very flimsy, and you will need to add some support. We used one bracing near the bottom and one near the middle. Take a straight peace of wire, roughly align it where you want it and solder one end to the layer. Fine tune the alignment and solder the other end in place. Now, make solder joints to the remaining 6 columns. Do this for both braces.

5) Test all the LEDs
This is covered in the next step. Just mentioning here so you don't remove the layer just yet.

6) Remove the layer
The first layer of your LED cube is all done, now all you have to do is remove it from the template. Depending on the size of your holes, some LEDs might have more resistance when you try to pull it out. Simply grabbing both ends of the layer and pulling would probably break the whole thing if a couple of the LEDs are stuck.

Start by lifting every single LED a couple of millimeters. Just enough to feel that there isn't any resistance. When all the LEDs are freed from their holes, try lifting it carefully. If it is still stuck, stop and pull the stuck LEDs out.

Repeat 8 times!

Note on images:
If you are having trouble seeing the detail in any of our pictures, you can views the full resolution by clicking on the little *i* icon in the top left corner of every image. All our close up pictures are taken with a mini tripod and should have excellent macro focus. On the image page, choose the original size from the "Available sizes" menu on the left hand side.

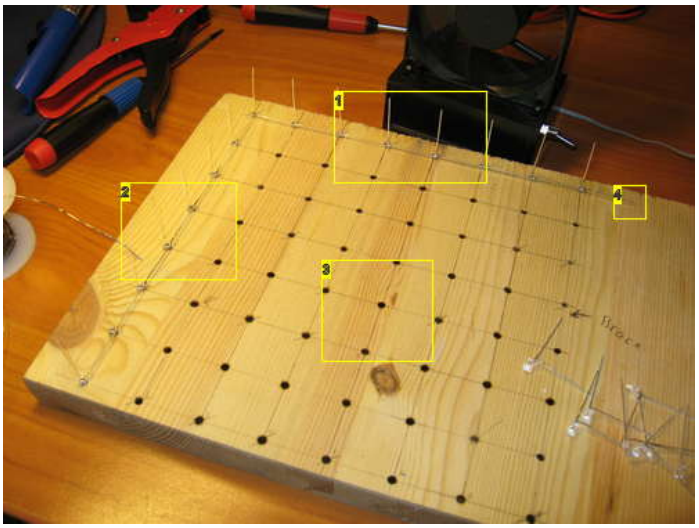


Image Notes
1. Start with this row
2. Then do this column
3. And then the rest..
4. Don't remove the leg that sticks out to the side. It is convenient to connect ground to it when testing the LEDs.

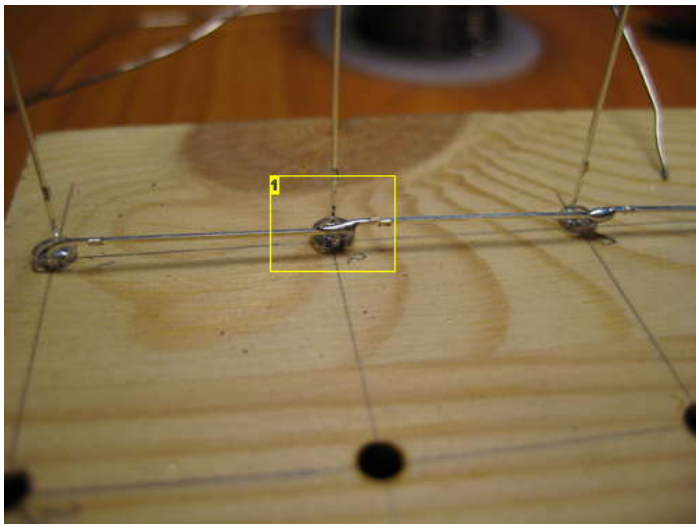


Image Notes
1. About 1mm overlap. Perfect!

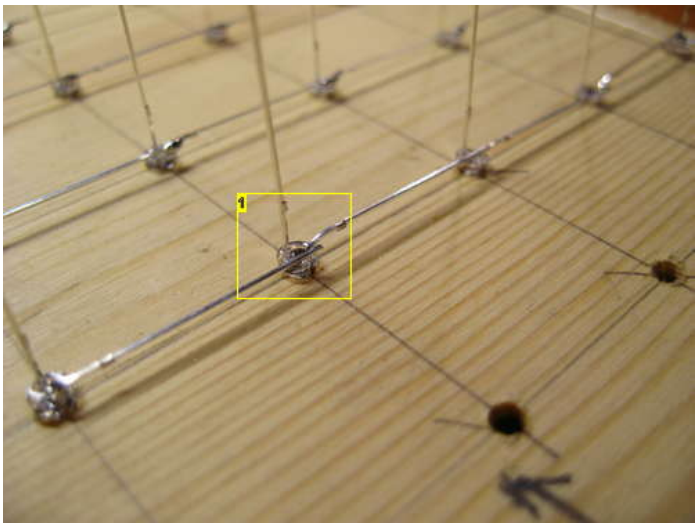


Image Notes
1. LED ready to be soldered. Look how nicely they line up.

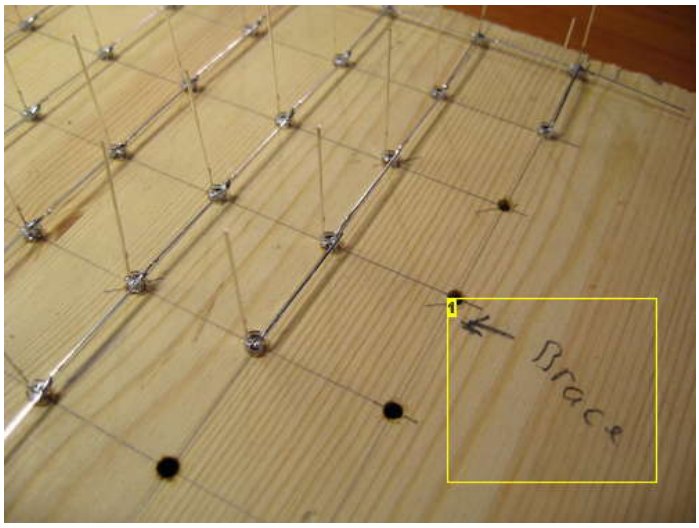
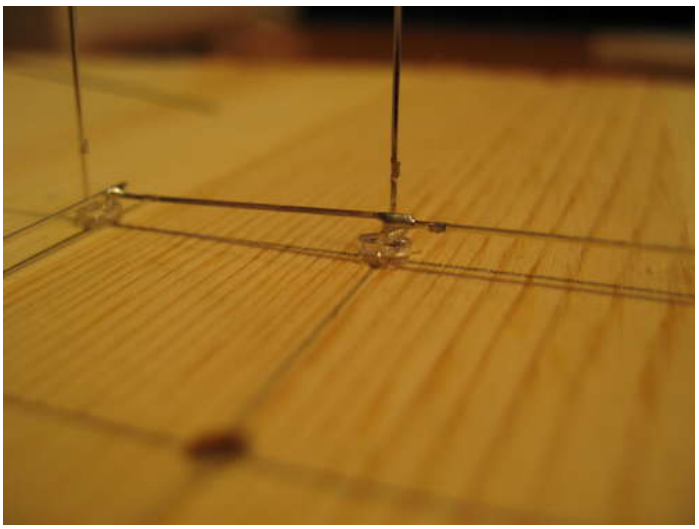
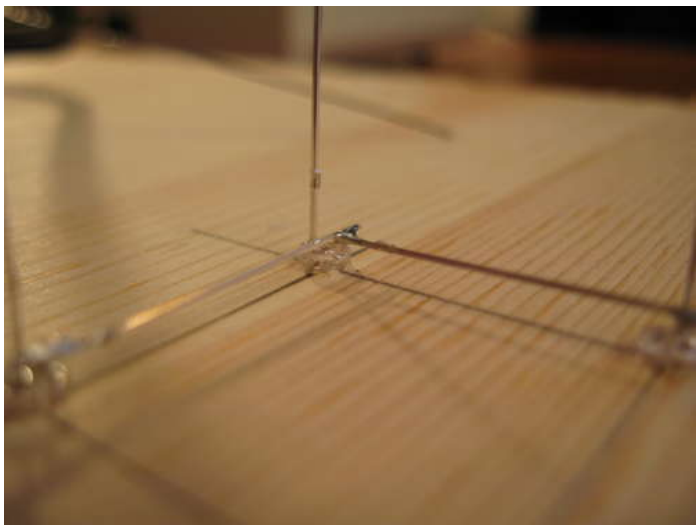


Image Notes
1. We marked off where we wanted to have the midway bracing, so we didn't accidentally put it in different locations in each layer :p





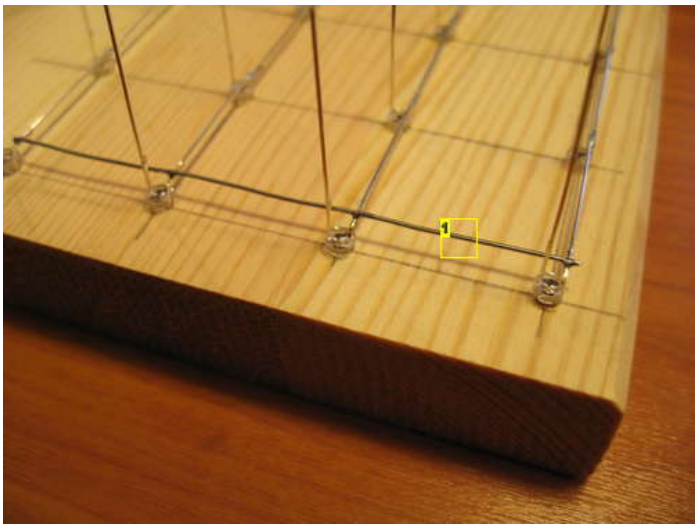


Image Notes
1. Brace

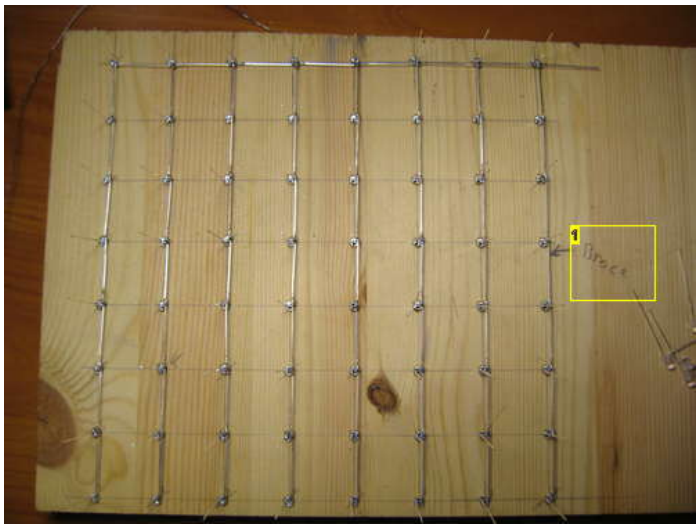


Image Notes
1. Almost done, just need the braces.

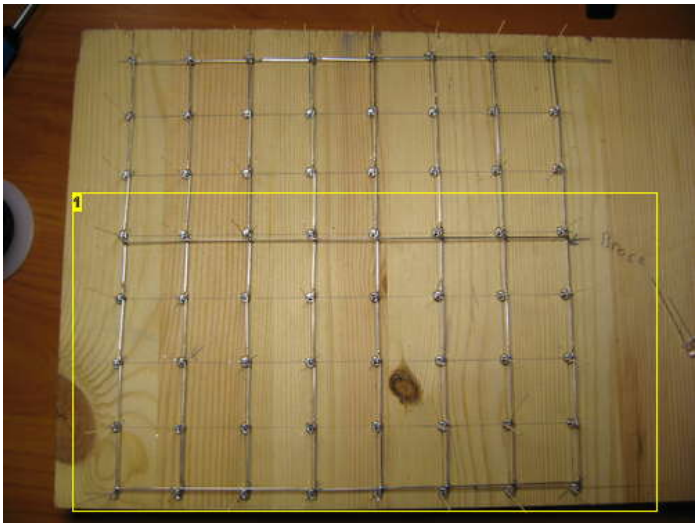
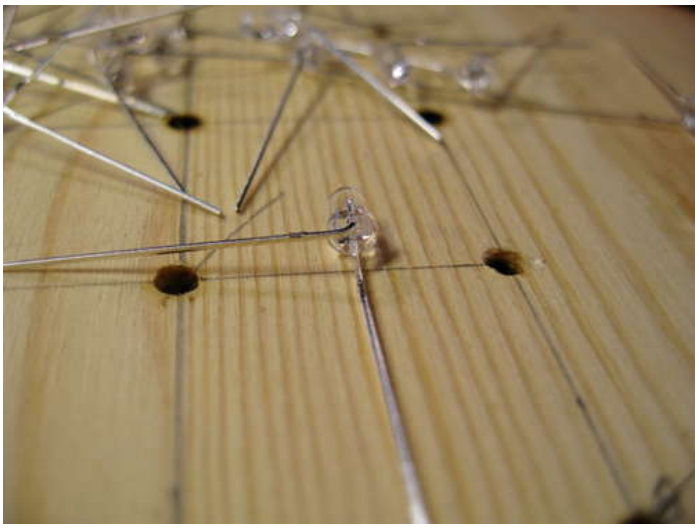
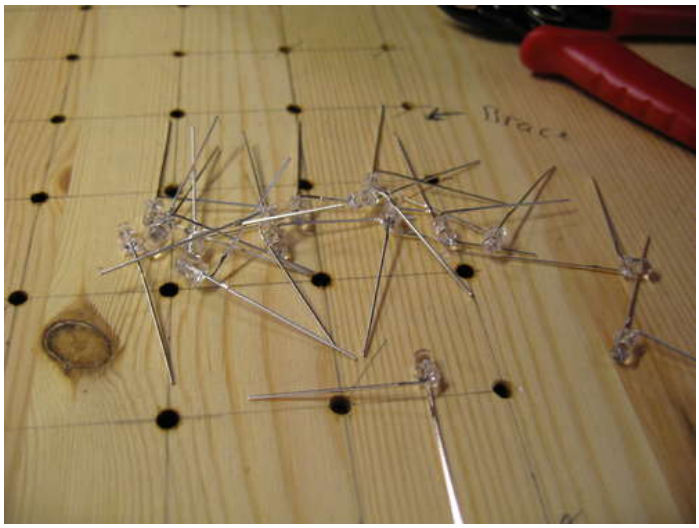


Image Notes
1. All done.





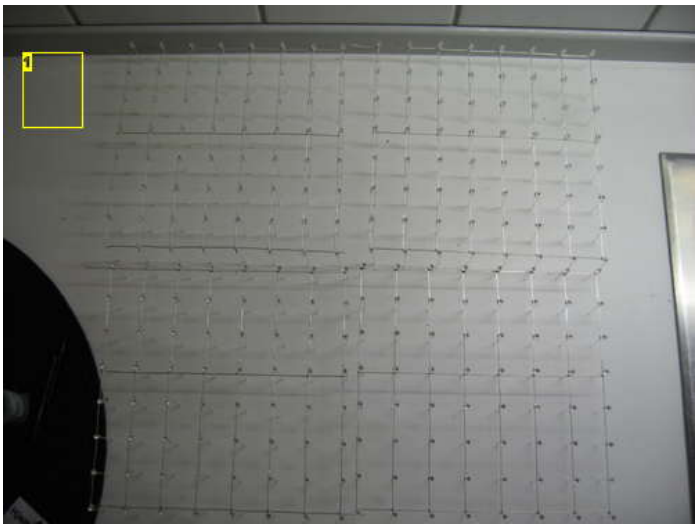


Image Notes
1. 4 down 4 to go!

Step 22: Build the cube: test the layer

Soldering that close to the body of the LED can damage the electronics inside. We strongly recommend that you test all LEDs before proceeding.

Connect ground to the tab you left sticking out at the upper right corner. Connect a wire to 5V through a resistor. Use any resistor that lights the LED up and doesn't exceed its max mA rating at 5V. 470 Ohm would probably work just fine.

Take the wire and tap it against all 64 anode legs that are sticking up from your template. If a LED doesn't flash when you tap it, that means that something is wrong.

1) Your soldering isn't conducting current.
2) The LED was overheated and is broken.
3) You didn't make a proper connection between the test wire and the led. (try again).

If everything checks out, pull the layer from the cube and start soldering the next one.

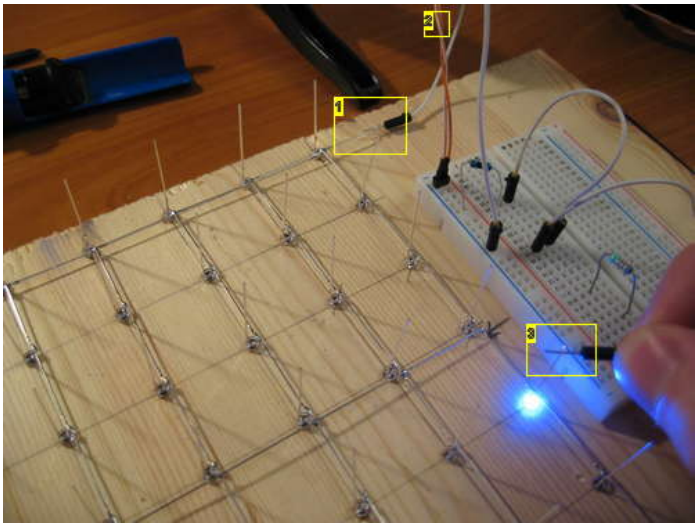


Image Notes
1. Ground connected to the layer
2. 5v from power supply
3. 5 volts via resistor.

Step 23: Build the cube: straigthen the pins

In our opinion, a LED cube is a piece of art and should be perfectly symmetrical and straight. If you look at the LEDs in your template from the side, they are probably bent in some direction.

You want all the legs to point straight up, at a 90 degree angle from the template.

While looking at the template from the side, straighten all the legs. Then rotate the template 90 degrees, to view it from the other side, then do the same process.

You now have a perfect layer that is ready to be removed from the template.

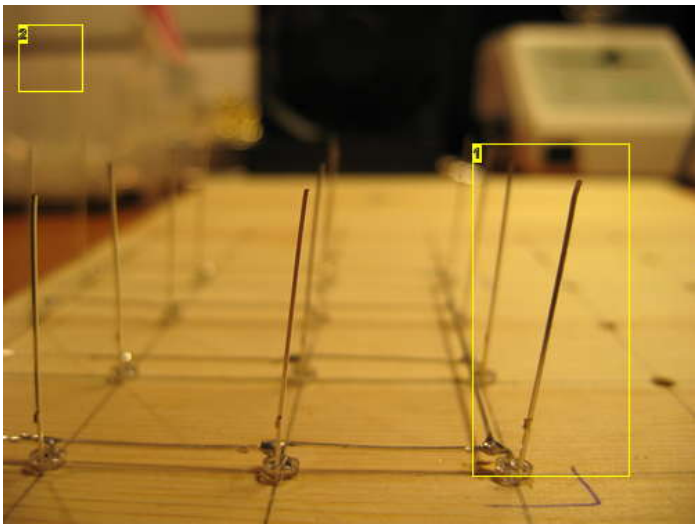


Image Notes
1. This isn't going to be a very nice LED cube!
2. We use a 4x4x4 cube here to demonstrate.

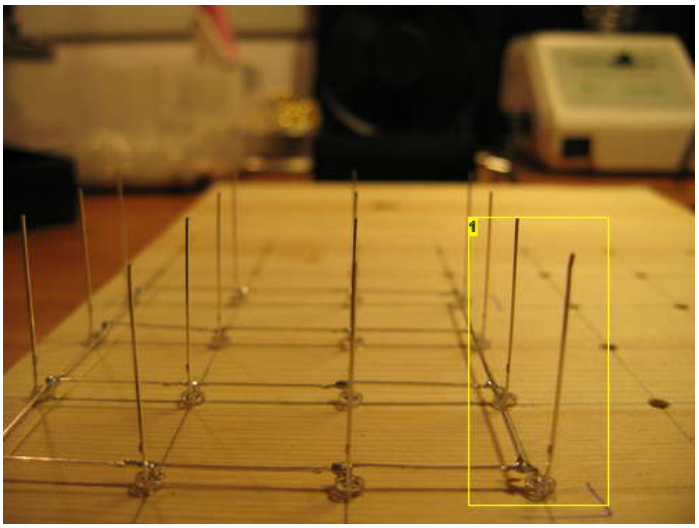


Image Notes
1. This is better

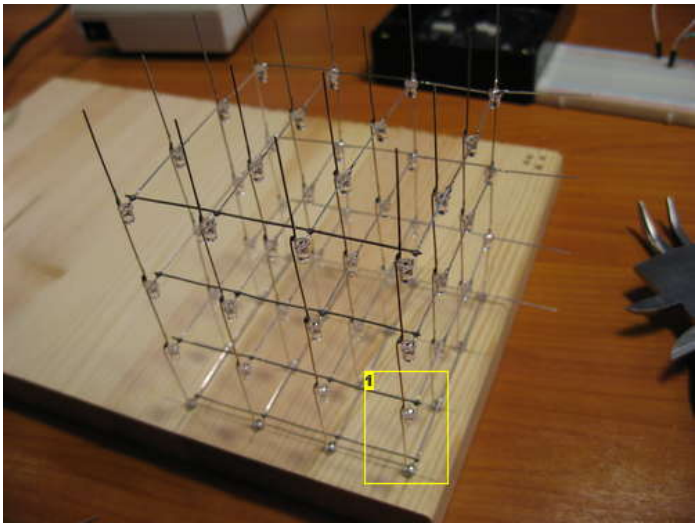
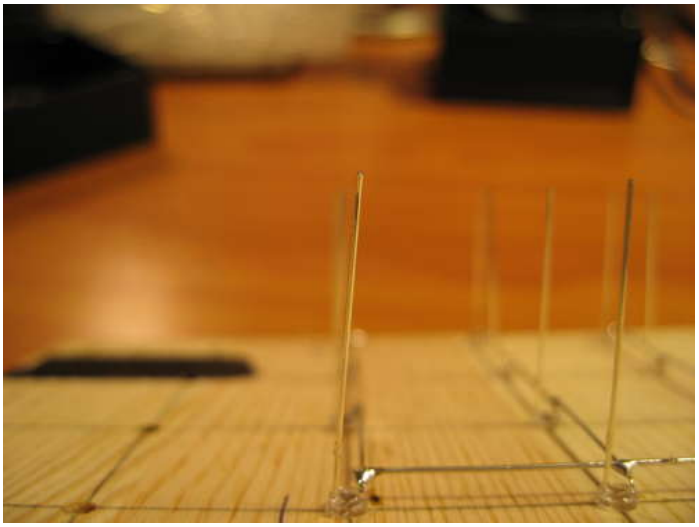
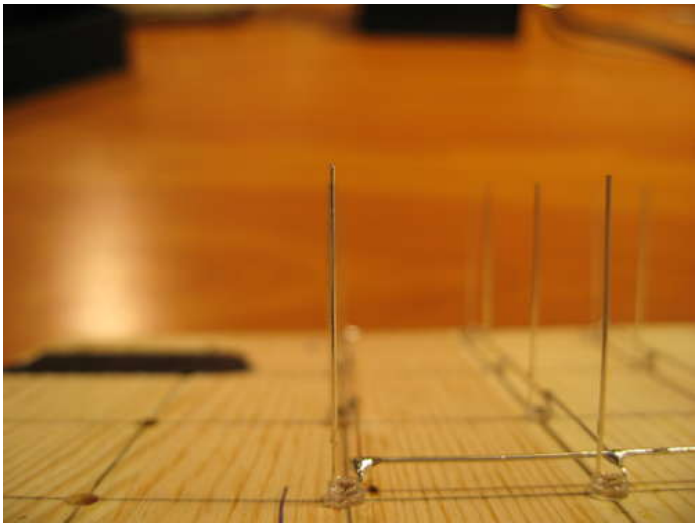


Image Notes
1. Pin straightening paid off.. see how straight the cube is





Step 24: Build the cube: bend the pins

In the LED cube columns, we want each LED to sit centered precisely above the LEDs below. The legs on the LEDs come out from the LED body half a millimeter or so from the edge. To make a solder joint, we have to bend the anode leg so that it touches the anode leg on the LED below.

Make a bend in the anode leg towards the cathode leg approximately 3mm from the end of the leg. This is enough for the leg to bend around the LED below and make contact with it's anode leg.

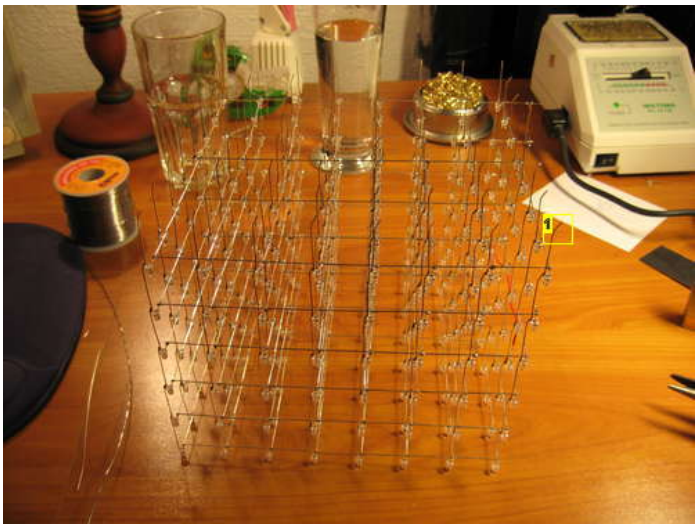


Image Notes
1. Pins are bent in order to make contact with the next LED

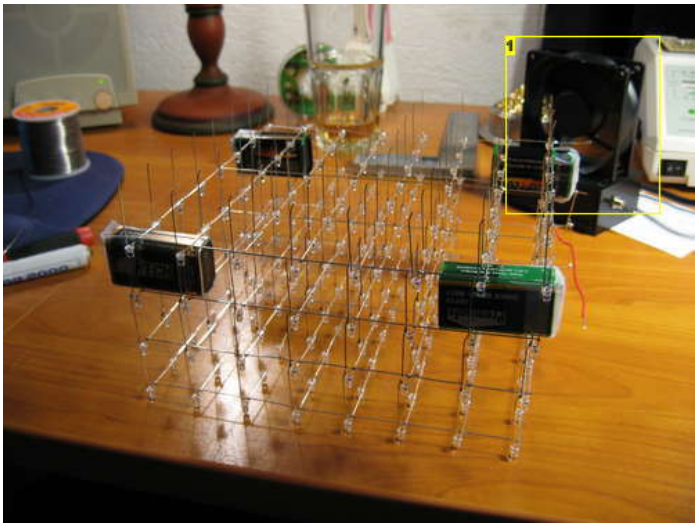


Image Notes

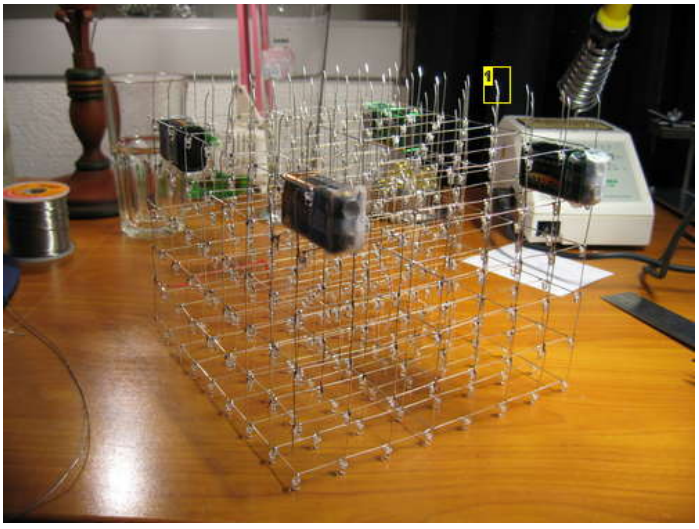


Image Notes

1. Fan to blow the fumes away from my face.

1. All the pins are bent and ready to receive the next layer.

Step 25: Build the cube: solder the layers together

Now comes the tricky part, soldering it all together!

The first two layers can be quite flimsy before they are soldered together. You may want to put the first layer back in the template to give it some stability.

In order to avoid total disaster, you will need something to hold the layer in place before it is soldered in place. Luckily, the width of a 9V battery is pretty close to 25 mm. Probably closer to 25.5-26mm, but that's OK.

Warning: The 9 volts from a 9V battery can easily overload the LEDs if the contacts on the battery comes in contact with the legs of the LEDs. We taped over the battery poles to avoid accidentally ruining the LEDs we were soldering.

We had plenty of 9V batteries lying around, so we used them as temporary supports.
Start by placing a 9V battery in each corner. Make sure everything is aligned perfectly, then solder the corner LEDs.

Now solder all the LEDs around the edge of the cube, moving the 9V batteries along as you go around. This will ensure that the layers are soldered perfectly parallel to each other.
Now move a 9V battery to the middle of the cube. Just slide it in from one of the sides. Solder a couple of the LEDs in the middle.

The whole thing should be pretty stable at this point, and you can continue soldering the rest of the LEDs without using the 9V batteries for support.

However, if it looks like some of the LEDs are sagging a little bit, slide in a 9V battery to lift them up!

When you have soldered all the columns, it is time to test the LEDs again. Remember that tab sticking out from the upper right corner of the layer, that we told you not to remove yet? Now it's time to use it. Take a piece of wire and solder the tab of the bottom layer to the tab of the layer you just soldered in place.

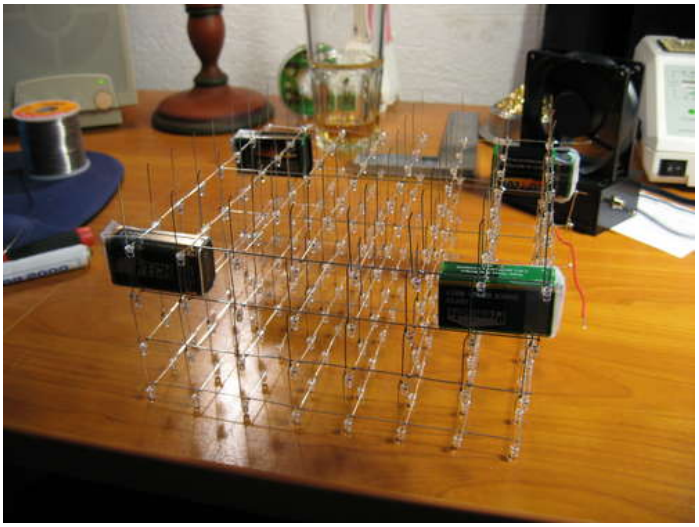
Connect ground to the the ground tab.

Test each led using the same setup as you used when testing the individual layers. Since the ground layers have been connected by the test tabs, and all the anodes in each columns are connected together, all LEDs in a column should light up when you apply voltage to the top one. If the LEDs below it does not light up, it probably means that you forgot a solder joint! It is A LOT better to figure this out at this point, rather than when all the layers are soldered together. The center of the cube is virtually impossible to get to with a soldering iron.

You now have 2/8 of your LED cube soldered together! Yay!

For the next 6 layers, use the exact same process, but spend even more time aligning the corner LEDs before soldering them. Look at the cube from above, and make sure that all the corner LEDs are on a straight line when looking at them from above.

Rinse and repeat!



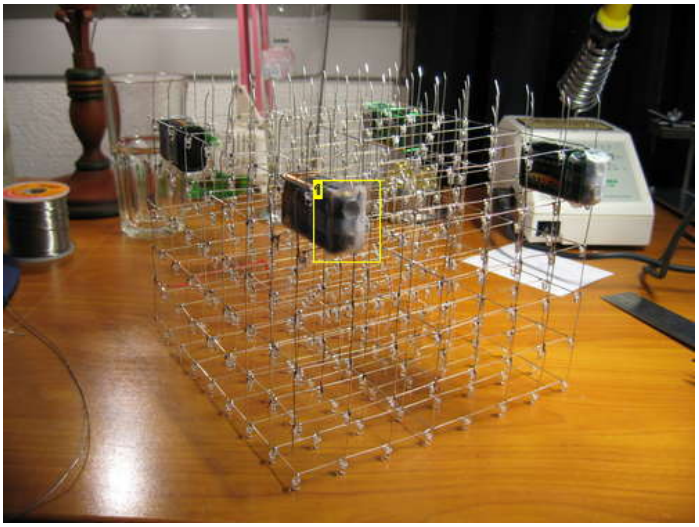
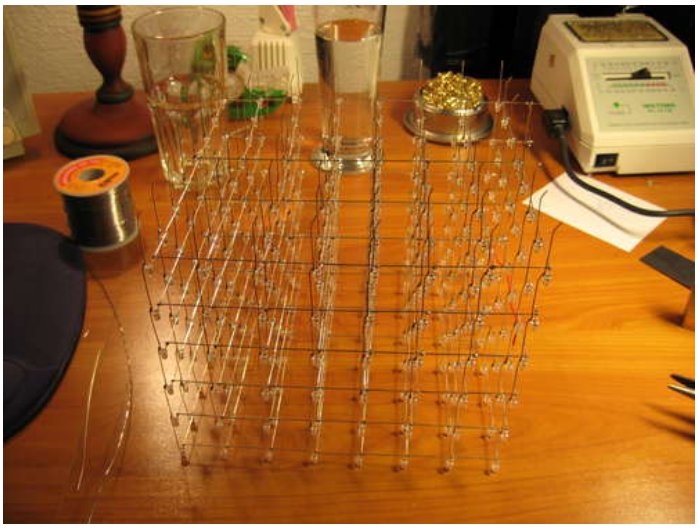
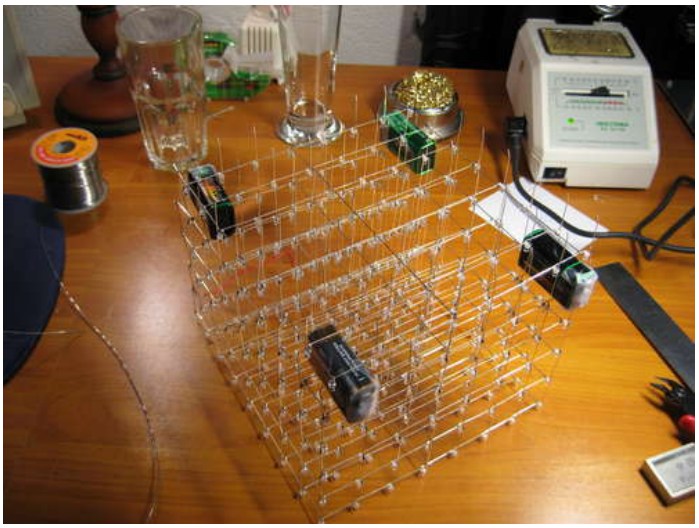
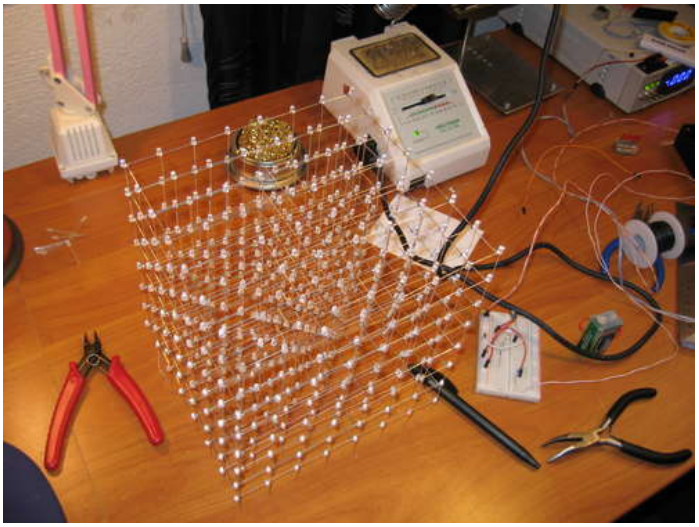


Image Notes
1. We taped over the battery terminals to avoid any disasters!







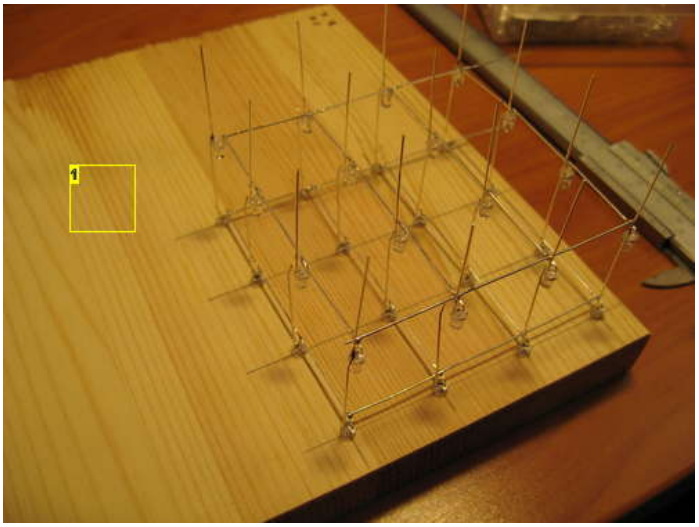
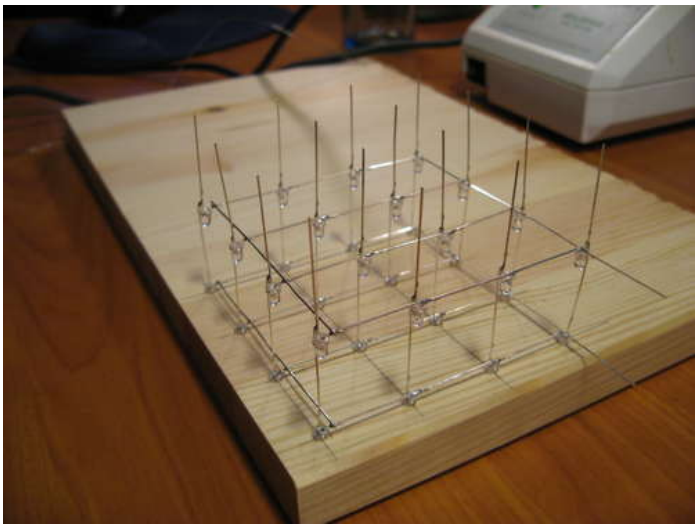
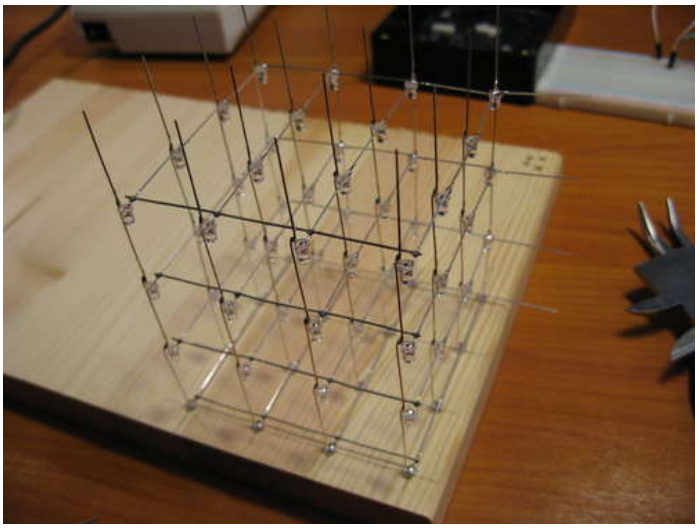
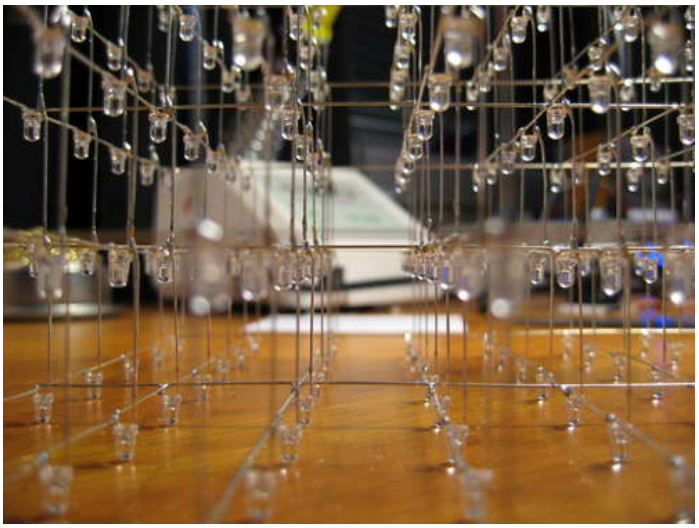


Image Notes
1. We added these 4x4x4 images to help illustrate the process.







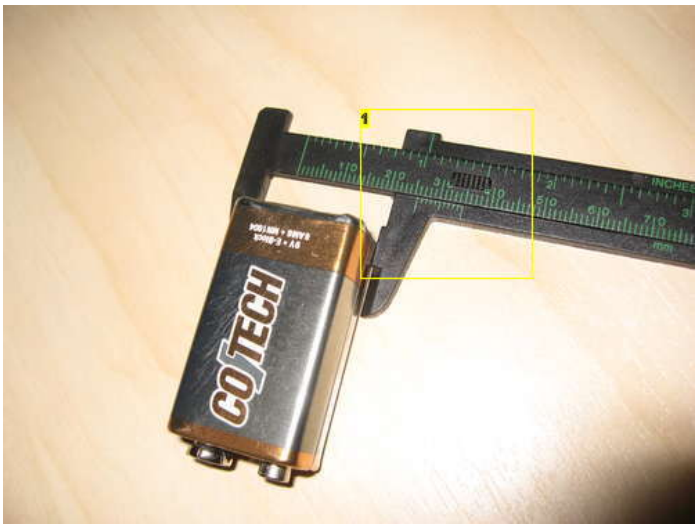


Image Notes
1. Almost exactly 25m!

Step 26: Build the cube: create the base

We didn't have any fancy tools at our disposal to create a fancy stand or box for our LED cube. Instead, we modified the template to work as a base for the cube.

We encourage you to make something cooler than we did for your LED cube!

For the template, we only drilled a couple of mm into the wood. To transform the template into a base, we just drilled all the holes through the board. Then we drilled 8 smaller holes for the 8 cathode wires running up to the 8 cathode layers.

Of course, you don't want to have your LED cube on a wood colored base. We didn't have any black paint lying around, but we did find a giant black magic marker! Staining the wood black with a magic marker worked surprisingly well! I think the one we used had a 10mm point.

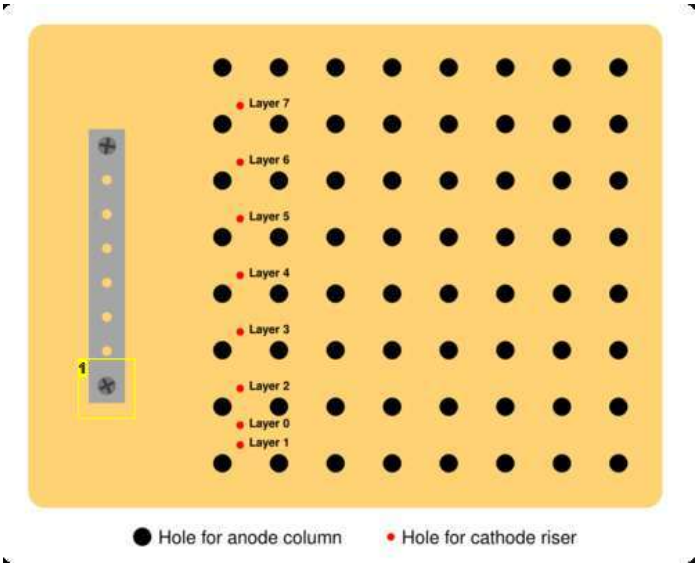


Image Notes
1. This is mounted on the underside of the board to hold the wires in place.

Image Notes
1. Drill all the way through.

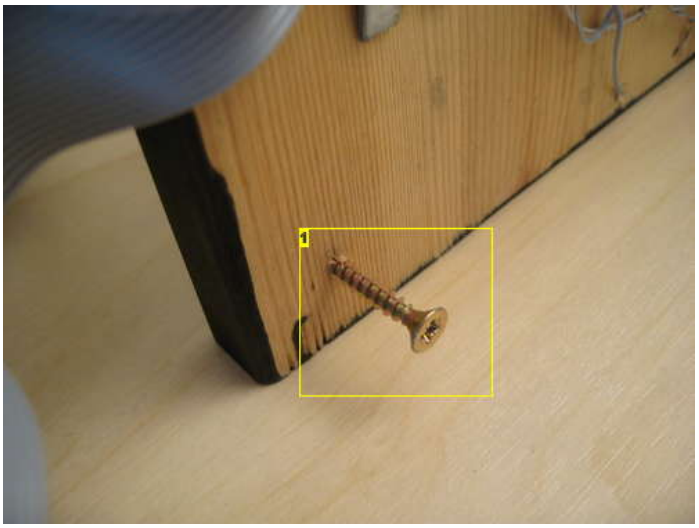


Image Notes
1. Didn't have any rubber feet that were high enough.

Image Notes
1. This is what we used to "paint" the base ;)

Step 27: Build the cube: mount the cube

Mount the cube. That sounds very easy, but it's not. You have to align 64 LED legs to slide through 64 holes at the same time. It's like threading a needle, times 64.

We found it easiest to start with one end, then gradually popping the legs into place. Use a pen or something to poke at the LED legs that miss their holes.

Once all 64 LED legs are poking through the base, carefully turn it on it's side. Then bend all 64 legs 90 degrees. This is enough to hold the cube firmly mounted to the base. No need for glue or anything else.

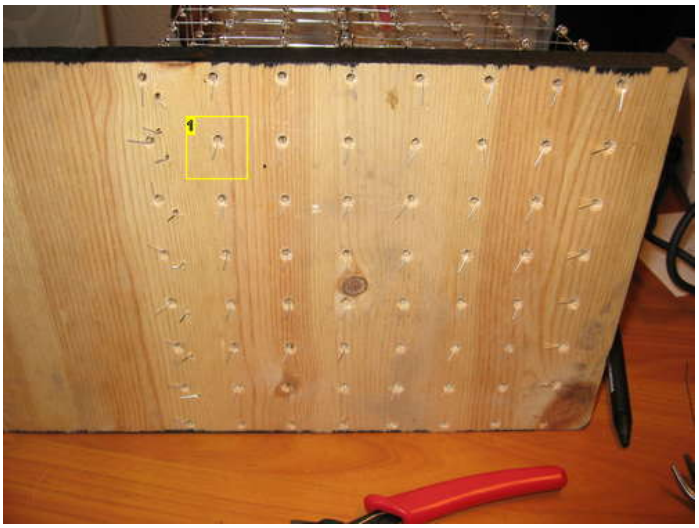


Image Notes
1. All the wires are bent 90 degrees. This is more than enough to hold the cube in place.

Step 28: Build the cube: cathode risers

You now have a LED cube with 64 anode connections on the underside of the base. But you need to connect the ground layers too.

Remember those 8 small holes you drilled in a previous step? We are going to use them now.

Make some straight wire using the method explained in a previous step.

We start with ground for layer 0. Take a short piece of straight wire, Make a bend approximately 10mm from the end. Poke it through the hole for ground layer 0. Leave 10mm poking through the underside of the base. Position it so that the bend you made rests on the back wire of ground layer 0. Now solder it in place.
Layer 1 through 7 are a little trickier. We used a helping hand to hold the wire in place while soldering.

Take a straight piece of wire and bend it 90 degrees 10mm from the end. Then cut it to length so that 10mm of wire will poke out through the underside of the base. Poke the wire through the hole and let the wire rest on the back wire of the layer you are connecting. Clamp the helping hand onto the wire, then solder it in place.

Rinse and repeat 7 more times.

Carefully turn the cube on it's side and bend the 8 ground wires 90 degrees.

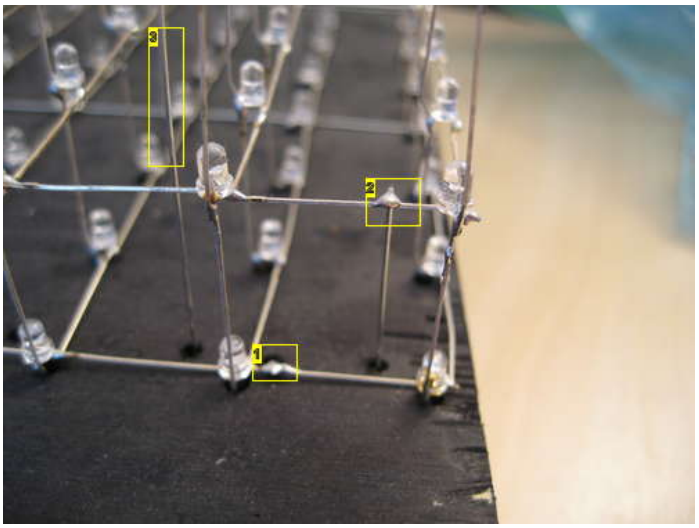


Image Notes
1. Ground wire for layer 0
2. Ground for layer 1
3. Ground for layer 2

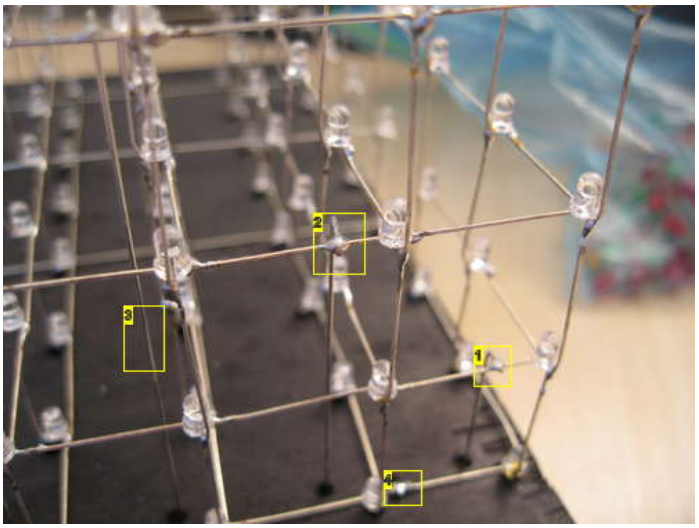


Image Notes
1. Layer 1
2. Layer 2
3. Layer 3
4. Layer 0

Step 29: Build the cube: attach cables

64+8 wires have to go from the controller to the LED cube. We used ribbon cable to make things a little easier.

The ground layers use an 8-wire ribbon cable.

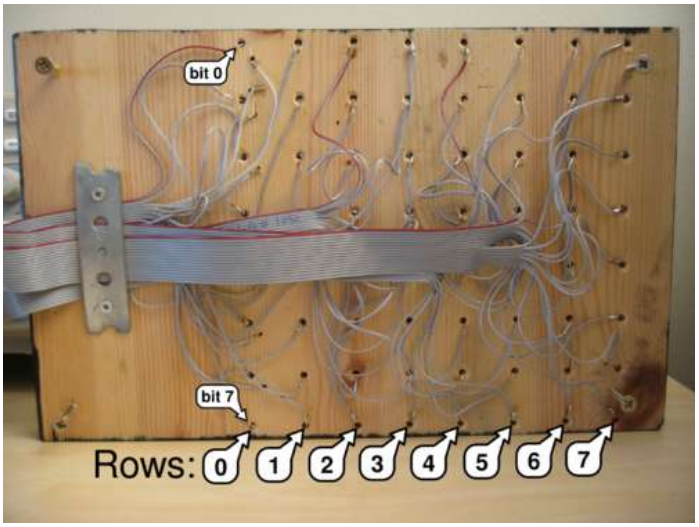
The cathodes are connected with 4 16-wire ribbon cables. Each of these ribbon cables are split in two at either end, to get two 8-wire cables.

At the controller side, we attached 0.1" female header connectors. These plug into standard 0.1" single row PCB header pins.

The header connector is a modular connector that comes in two parts, metal inserts and a plastic body.

The metal inserts are supposed to be crimped on with a tool. We didn't have the appropriate tool on hand, so we used pliers. We also added a little solder to make sure the wires didn't fall of with use.

1) Prepare one 8-wire ribbon cable and 4 16-wire ribbon cables of the desired length
2) Crimp or solder on the metal inserts.
3) Insert the metal insert into the plastic connector housing.
4) Solder the 8-wire ribbon cable to the cathode risers. Pre-tin the cables before soldering!
5) Solder in the rest of the cables. The red stripe on the first wire indicates that this is bit 0.
6) Tighten the screws on the strain relief to make sure everything stays in place.
7) Connect all the ribbon cables to the PCBs in the correct order. See pictures below. Our 8 wire ribbon cable didn't have a red wire. Just flip the connector 180 degrees if your cube is upside-down.



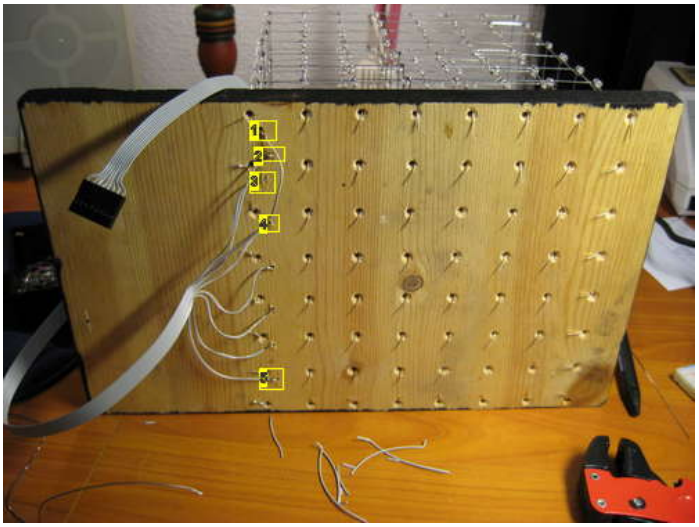
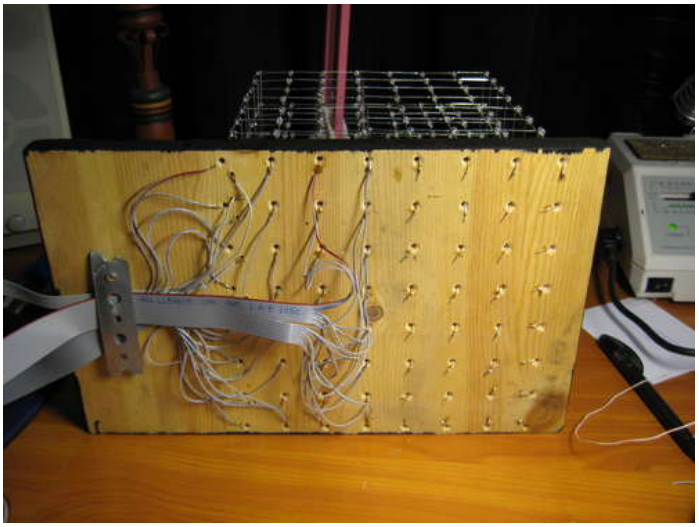
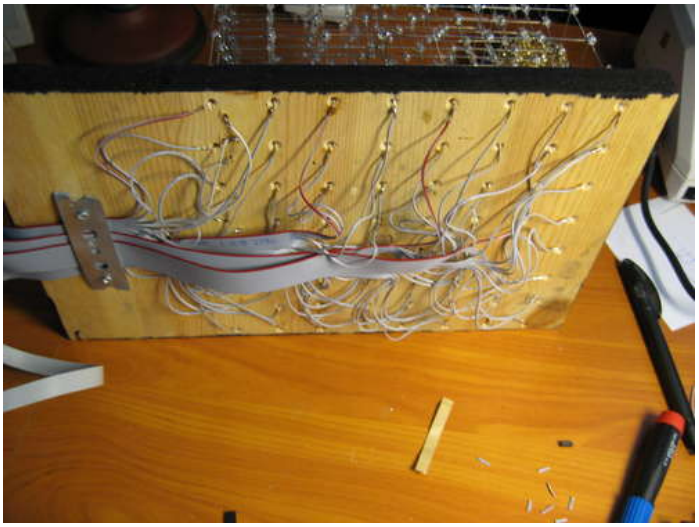
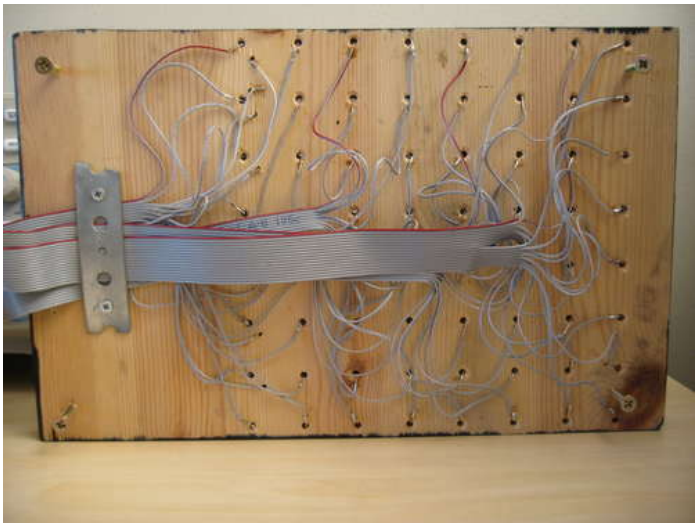


Image Notes
1. layer 1
2. Layer 0
3. layer 2
4. layer 4
5. layer 7







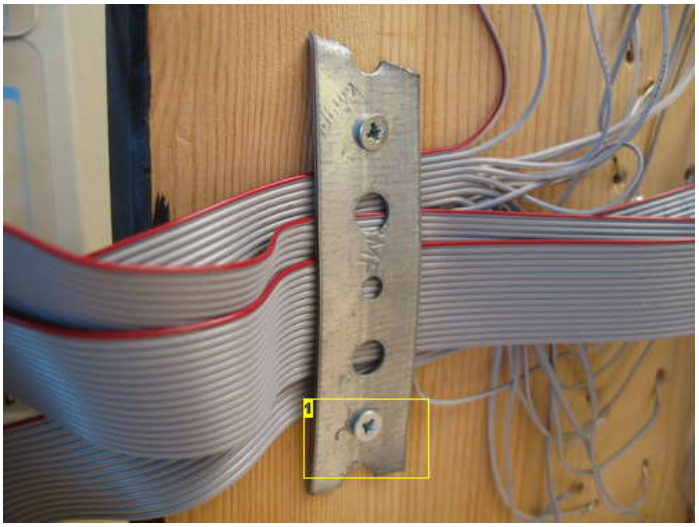
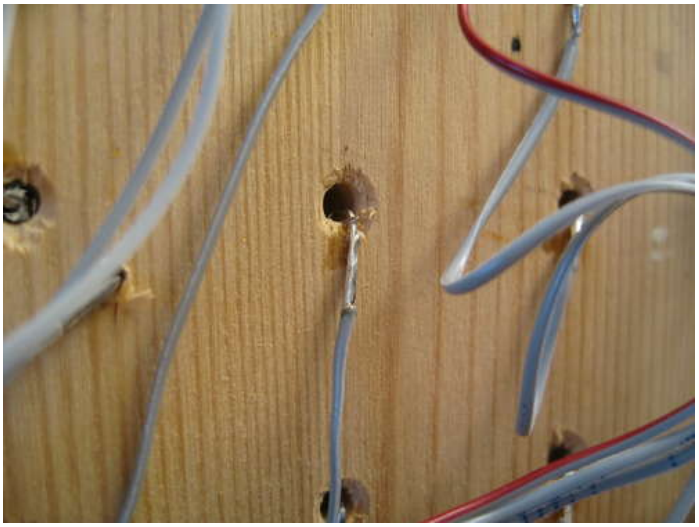
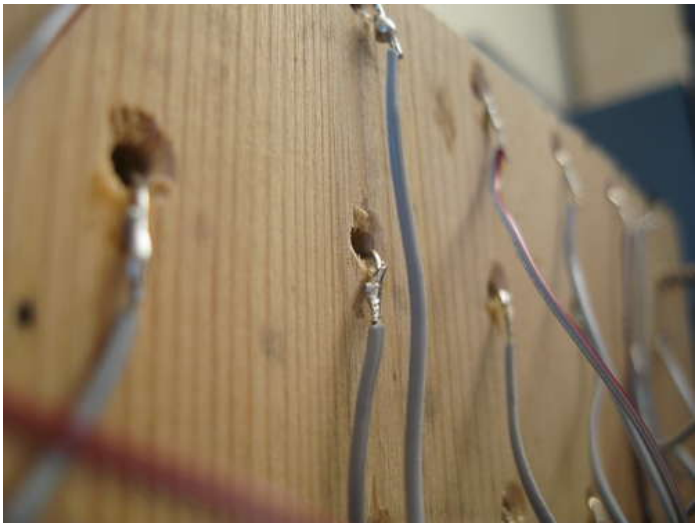
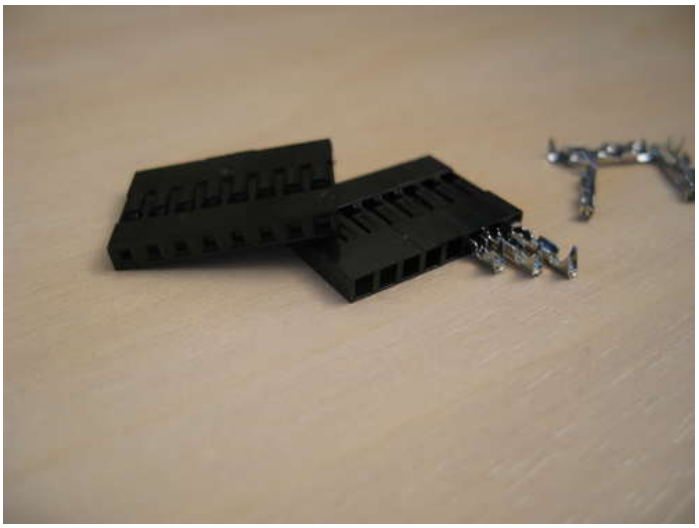


Image Notes
1. The connections are a bit flimsy. The cube will last a lot longer with this strain relief.







Step 30: Build the controller: layout

We took out the biggest type of PCB we had available (9x15cm) and started experimenting with different board layouts. It soon became clear that cramming all the components onto one board wasn't a good solution. Instead we decided to separate the latch array and power supply part of the circuit and place it on a separate board. A ribbon cable transfers data lines between the two boards.

Choosing two separate boards was a good decision. The latch array took up almost all the space of the circuit board. There wouldn't have been much space for the micro controller and other parts.

You may not have the exact same circuit boards as we do, or may want to arrange your components in a different way. Try to place all the components on your circuit board to see which layout best fits your circuit board.

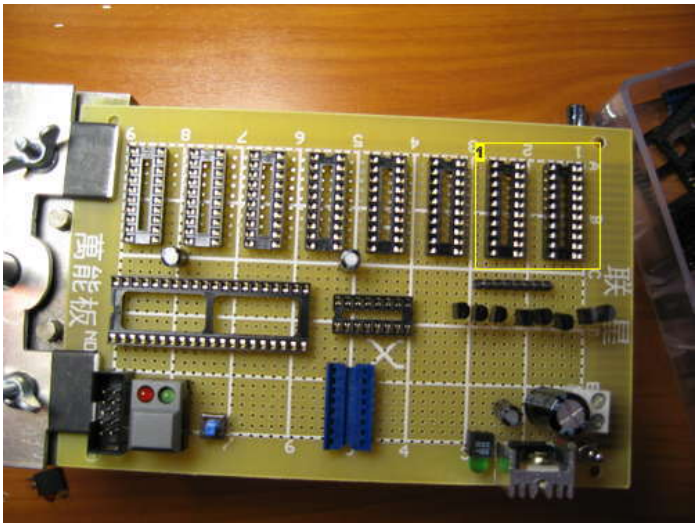


Image Notes
1. Way to little space in between the ICs. No room for resistors and connectors.

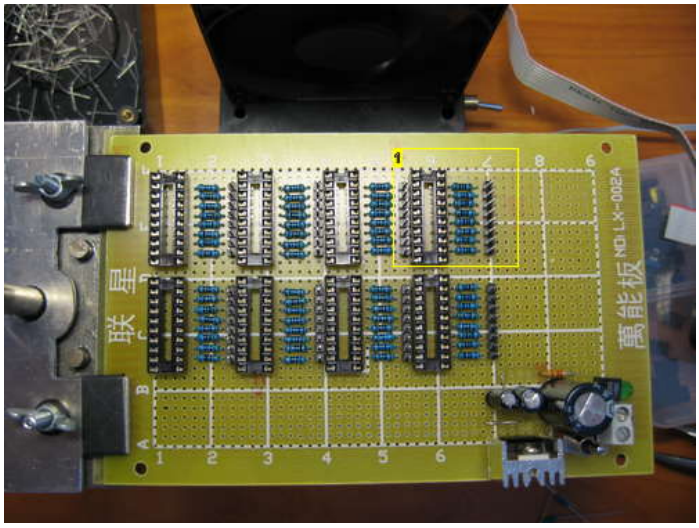
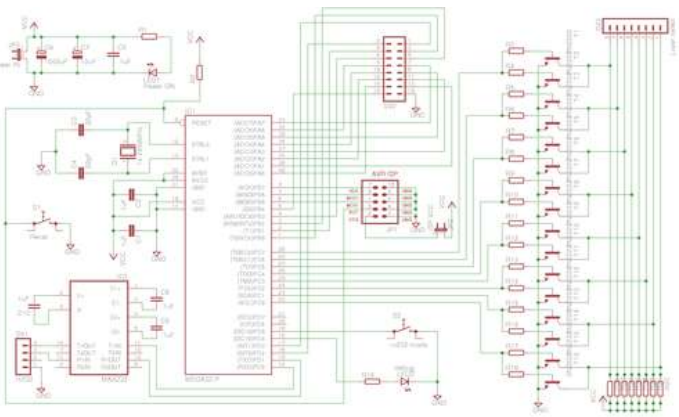
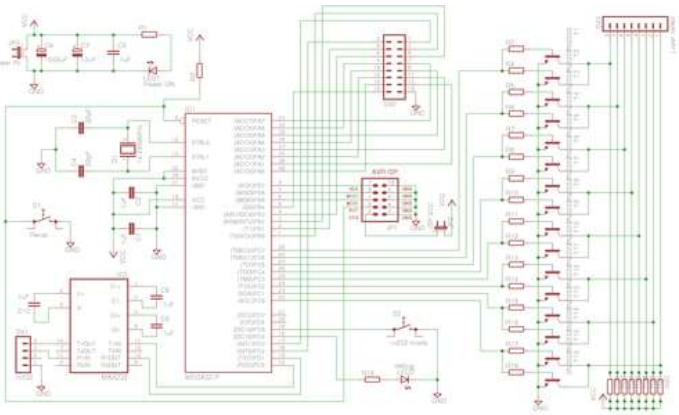
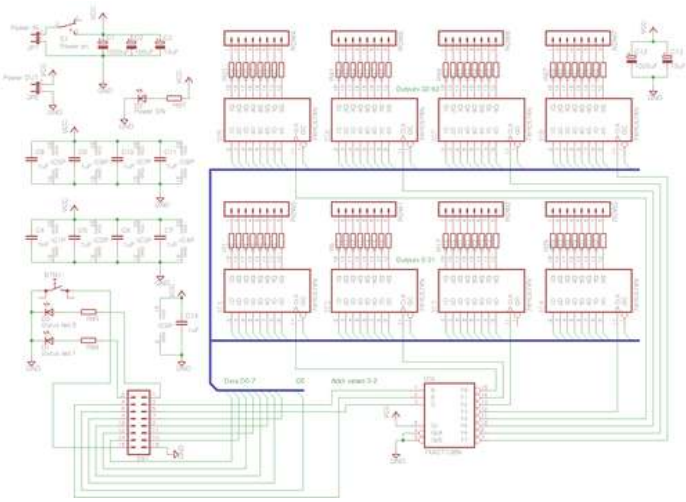


Image Notes
1. This is better.







File Downloads

multiplexer_board.sch (238 KB)
[NOTE: When saving, if you see .tmp as the file ext, rename it to 'multiplexer_board.sch']

avr_board.sch (249 KB)
[NOTE: When saving, if you see .tmp as the file ext, rename it to 'avr_board.sch']

Step 31: Build the controller: clock frequency

We use an external crystal of 14.7456 MHz to drive the ATmega system clock.

You may be thinking that this is an odd number to use, and why we didn't run the ATmega at the 16MHz it is rated for.

We want to be able to control the LED cube from a computer, using RS232. Serial communication requires precise timing. If the timing is off, only by a little bit, some bits are going to be missed or counted double from time to time. We won't be running any error correcting algorithms on the serial communications, so any error over the line would be represented in the LED cube as a voxel being on or off in the wrong place.

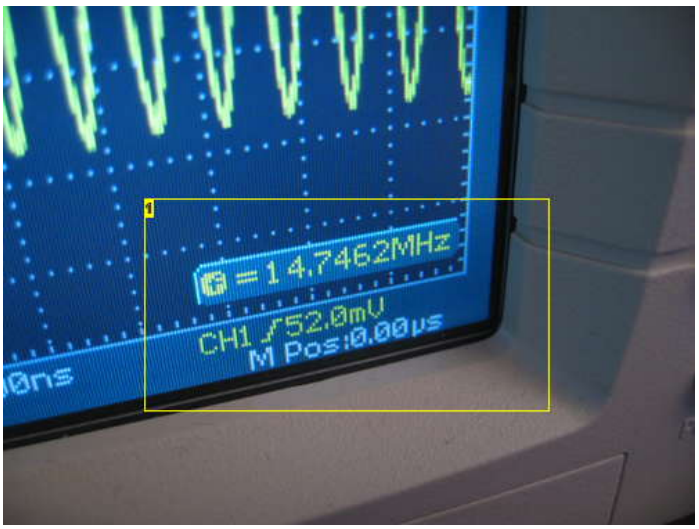
To get flawless serial communication, you have to use a clock frequency that can be divided by the serial frequency you want to use.

14.7456 MHz is dividable by all the popular RS232 baud rates.

- (14.7456MHz*1000*1000) / 9600 baud = 1536.0
- (14.7456MHz*1000*1000) / 19200 baud = 768.0
- (14.7456MHz*1000*1000) / 38400 baud = 384.0
- (14.7456MHz*1000*1000) / 115200 baud = 128.0

The formula inside the parentheses converts from MHz to Hz. First *1000 gives you KHz, the next Hz.

As you can see all of these RS232 baud rates can be cleanly divided by our clock rate. Serial communication will be error free!



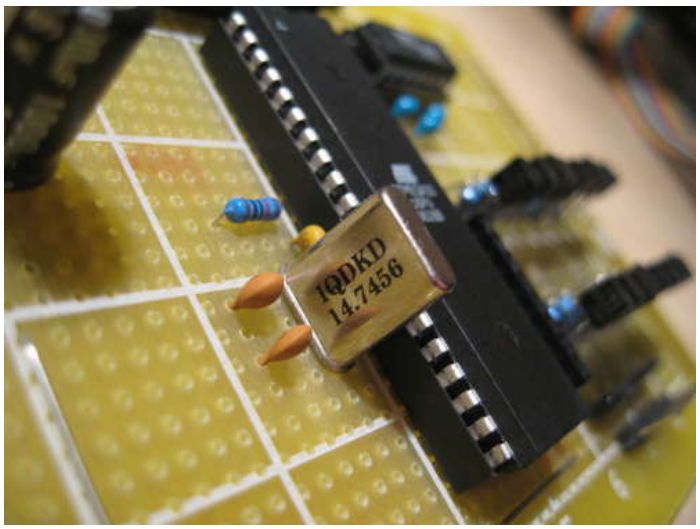


Image Notes
1. This is the frequency of the system clock

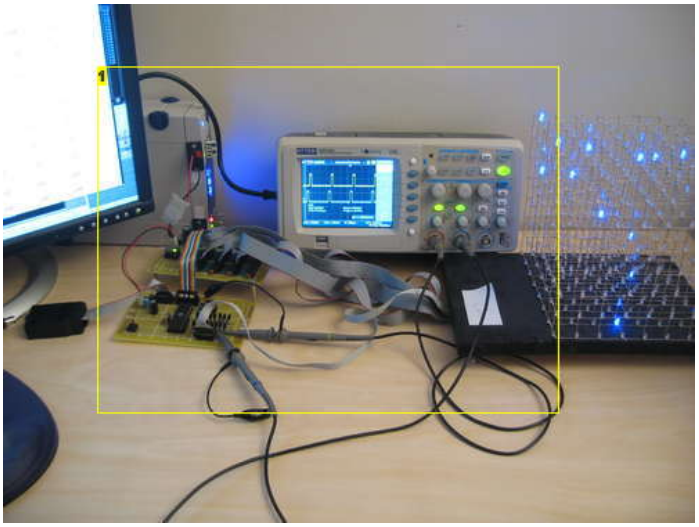


Image Notes
1. I got an oscilloscope for Christmas :D we used it to visualize some of the signals in the LED cube.

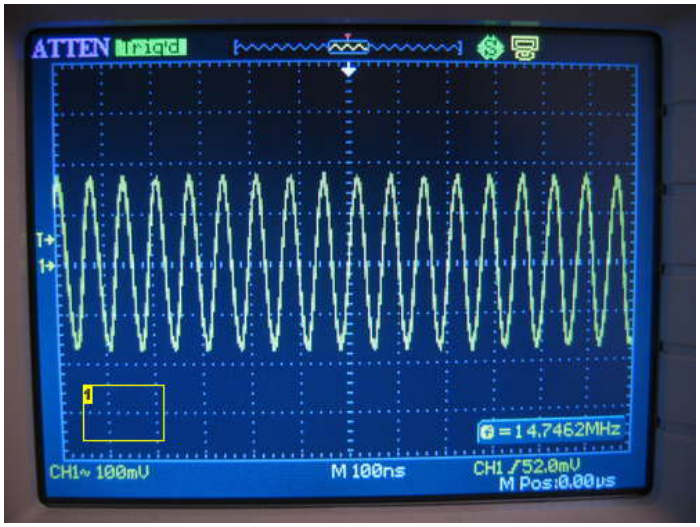


Image Notes
1. This is what the clock signal from a crystal looks like

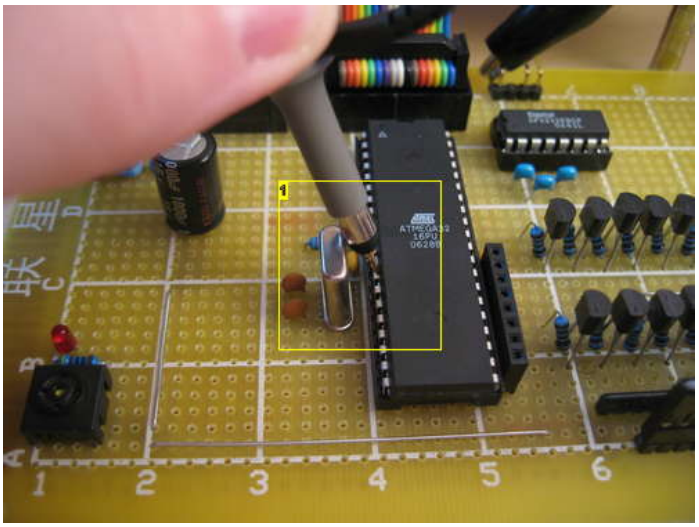


Image Notes
1. Probing the crystal

Step 32: Build the controller: protoboard soldering advice

We see people do a lot of weird stuff when they solder on prototype PCBs. Before you continue, we just want to share with you the process we use to create tracks on prototype PCBs with solder eyes. Once you master this technique, you will probably start using it a lot.

1) Fill each point of the track you want to make with solder.
2) Connect every other points by heating them and adding a little solder.
3) Connect the 2-hole long pieces you now have spanning the desired track.
4) Look how beautiful the result is.

You can see in the video how we do it. We had to touch some of the points twice to join them. It was a bit hard to have the camera in the way when we were soldering ;)

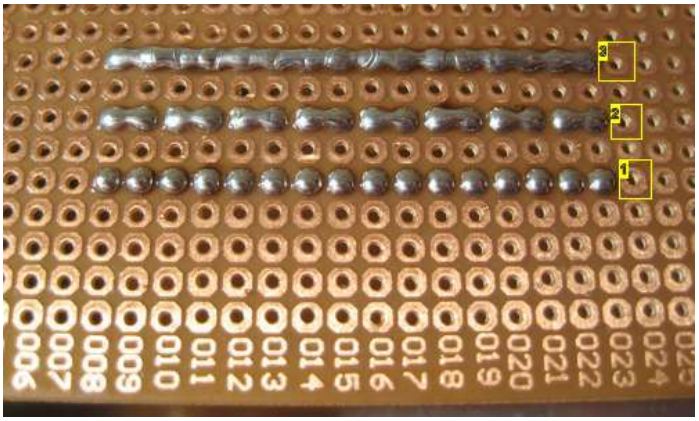


Image Notes
1. 1
2. 2
3. 3

Step 33: Build the controller: Power terminal and filtering capacitors

The cube is complete, now all that remains is a monster circuit to control the thing.

Let's start with the easiest part, the "power supply".

The power supply consists of a screw terminal where you connect the GND and VCC wires, some filtering capacitors, a switch and a an LED to indicate power on.

Initially, we had designed an on-board power supply using an LM7805 step down voltage regulator. However, this turned out to be a big fail.

We used this with a 12V wall wart. But as you may already know, most wall warts output higher voltages than the ones specified on the label. Ours outputted something like 14 volts. The LM7805 isn't a very sophisticated voltage regulator, it just uses resistance to step down the voltage. To get 5 volts output from 14 volts input means that the LM7805 has to drop 9 volts. The excess energy is dispersed as heat. Even with the heat sink that you see in the picture, it became very very hot. Way to hot to touch! In addition to that, the performance wasn't great either. It wasn't able to supply the necessary current to run the cube at full brightness.

The LM7805 was later removed, and a wire was soldered between the input and output pins. Instead we used an external 5V power source, as covered in a previous step.

Why so many capacitors?

The LED cube is going to be switching about 500mA on and off several hundred times per second. The moment the 500mA load is switched on, the voltage is going to drop across the entire circuit. Many things contribute to this. Resistance in the wires leading to the power supply, slowness in the power supply to compensate for the increase in load, and probably some other things that we didn't know about ;)

By adding capacitors, you create a buffer between the circuit and the power supply. When the 500mA load is switched on, the required current can be drawn from the capacitors during the time it takes the power supply to compensate for the increase in load.

Large capacitors can supply larger currents for longer periods of time, whereas smaller capacitors can supply small but quick bursts of energy.

We placed a 1000uF capacitor just after the main power switch. This works as our main power buffer. After that, there is a 100uF capacitor. It is common practice to have a large capacitor at the input pin of an LM7805 and a smaller capacitor at it's output pin. The 100uF capacitor probably isn't necessary, but we think capacitors make your circuit look cooler!

The LED is connected to VCC just after the main power switch, via a resistor.

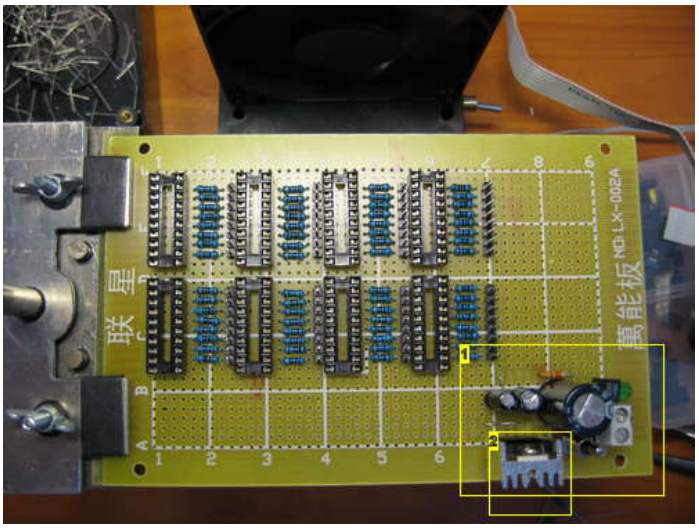


Image Notes
1. Power supply

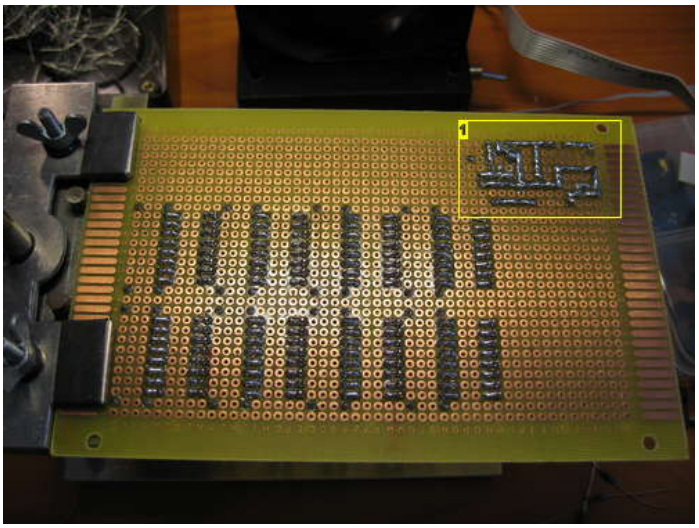


Image Notes
1. Bottom side of power supply. See, only solder traces. No wires.

2. This was removed later, because it couldn't deliver the needed amps.

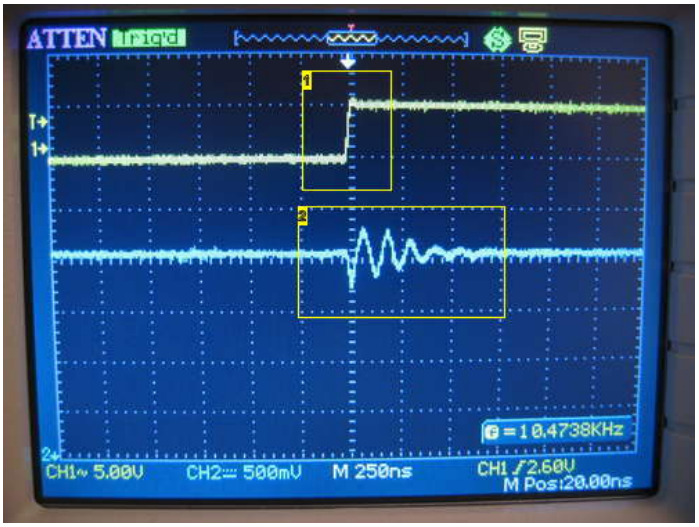


Image Notes
1. A layer in the led cube is switched on.
2. The resulting rise in current draw makes VCC fluctuate a little

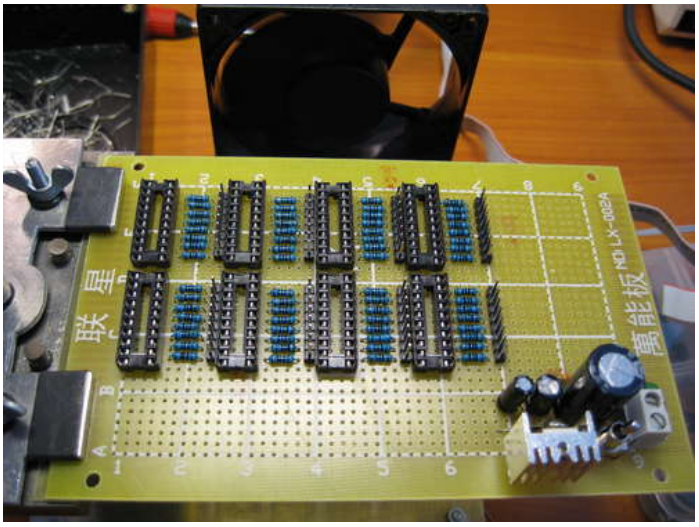
Step 34: Build the controller: IC sockets, resistors and connectors

In this step you will be soldering in the main components of the multiplexer array.

Our main design consideration here was to minimize soldering and wiring. We opted to place the connectors as close to the ICs as possible. On the output-side, there is only two solder joints per LED cube column. IC-resistor, resistor-connector. The outputs of the latches are arranged in order 0-7, so this works out great. If we remember correctly, the latch we are using is available in two versions, one with the inputs and outputs in sequential order, and one with the in- and outputs in seemingly random order. Do not get that one! ;) Don't worry, it has a different 74HC-xxx name, so you'll be good if you stick to our component list.

In the first picture, you can see that we have placed all the IC sockets, resistors and connectors. We squeezed it as tight as possible, to leave room for unforeseen stuff in the future, like buttons or status LEDs.

In the second picture, you can see the solder joints between the resistors and the IC sockets and connectors. Note that the input side of the latch IC sockets haven't been soldered yet in this picture.



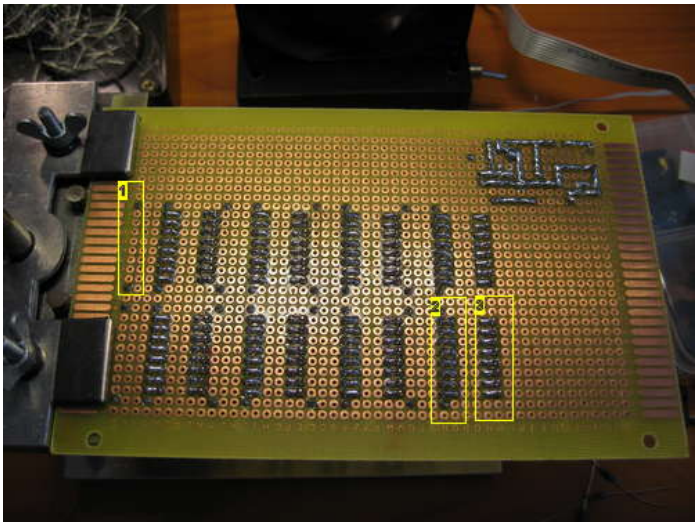


Image Notes
1. Input side not soldered yet.
2. Resistor soldered to IC
3. Resistor soldered to connector

Step 35: Build the controller: Power rails and IC power

Remember that protoboard soldering trick we showed you in a previous step? We told you it would come in handy, and here is where you use it.

Large circuit boards like this one, with lots of wires, can become quite confusing. We always try to avoid lifting the GND and VCC lines off the board. We solder them as continuous solder lines. This makes it very easy to identify what is GND/VCC and what is signal lines.

If the VCC and GND lines needs to cross paths, simply route one of them over the other using a piece of wire on the top side of the PCB.

In the first picture you can see some solder traces in place.

The two horizontal traces is the "main power bus". The lowest one is VCC and the top one is GND. For every row of ICs a GND and VCC line is forked off the main power bus. The GND line runs under the ICs, and the VCC line runs under the resistors.

We went a little overboard when making straight wire for the cube, and had some pieces left over. We used that for the VCC line that runs under the resistors.

In the bottom right corner, you can see that we have started soldering the 8+1bit bus connecting all the latch ICs. Look how easy it is to see what is signal wires and what is power distribution!

In the second picture, you can see the board right-side-up, with some additional components soldered in, just ignore them for the moment.

For every latch IC (74HC574), there is a 100nF (0.1uF) ceramic capacitor. These are noise reduction capacitors. When the current on the output pins are switched on and off, this can cause the voltage to drop enough to mess with the internal workings of the ICs, for a split second. This is unlikely, but it's better to be safe than sorry. Debugging a circuit with noise issues can be very frustrating. Besides, capacitors make the circuit look that much cooler and professional! The 100nF capacitors make sure that there is some current available right next to the IC in case there is a sudden drop in voltage. We read somewhere that it is common engineering practice to place a 100nF capacitor next to every IC, "Use them like candy". We tend to follow that principle.

Below each row of resistors, you can see a tiny piece of wire. This is the VCC line making a little jump to the top side of the board to cross the main GND line.

We also added a capacitor on the far end of the main power bus, for good measure.

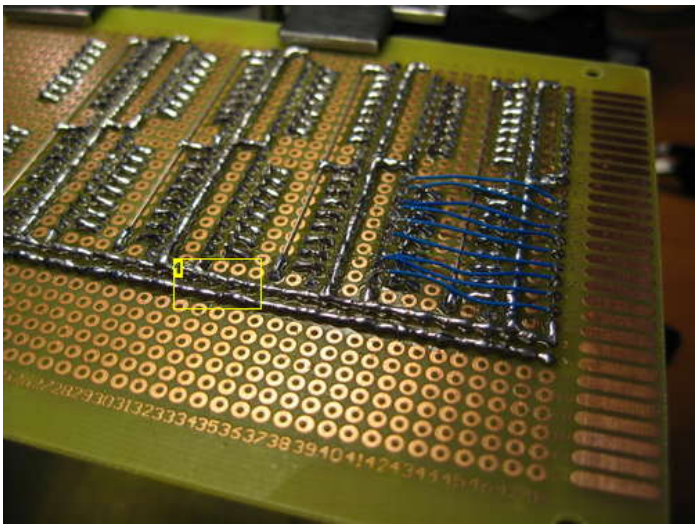


Image Notes
1. GND and VCC runs along the length of the board.

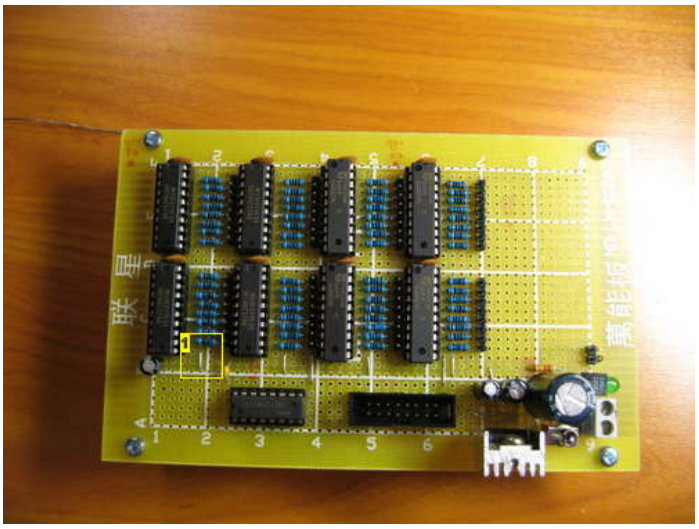


Image Notes
1. VCC crosses GND once for each row of ICs

Step 36: Build the controller: Connect the ICs, 8bit bus + OE

In the picture, you'll notice a lot of wires have come into place.

All the tiny blue wires make up the 8+1bit bus that connects all the latch ICs. 8 bits are for data, and the +1 bit is the output enable line.

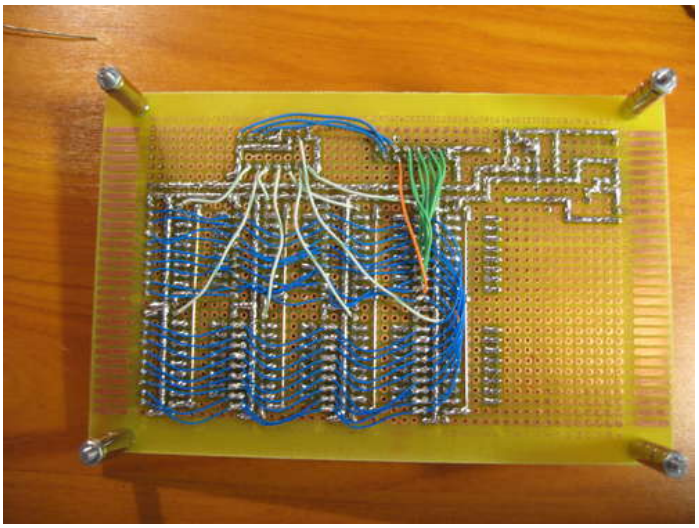
At the top of the board, we have added a 16 pin connector. This connects the latch board to the micro controller board. Next to that, you see the 74HC138.

The tiny blue wires are Kynar wire. This is a 30 or 32 AWG (american wire gauge) wire. Very tiny. We love working with this type of wire. Because it is so thin, it doesn't take up that much space on the circuit board. If we had used thicker wire, you wouldn't be able to see the board through all the wires. Kynar wire is coated with tin, so you can solder directly after stripping it. No need for pre-tinning. The tiny blue wires are connected to the same pin on every latch IC.

From the connector at the top, you can see 8 green wires connected to the bus. This is the 8 bit data bus. We used different colors for different functions to better visualize how the circuit is built.

The orange wire connected to the bus is the output enable (OE) line.

On the right hand side of the connector, the first pin is connected to ground.



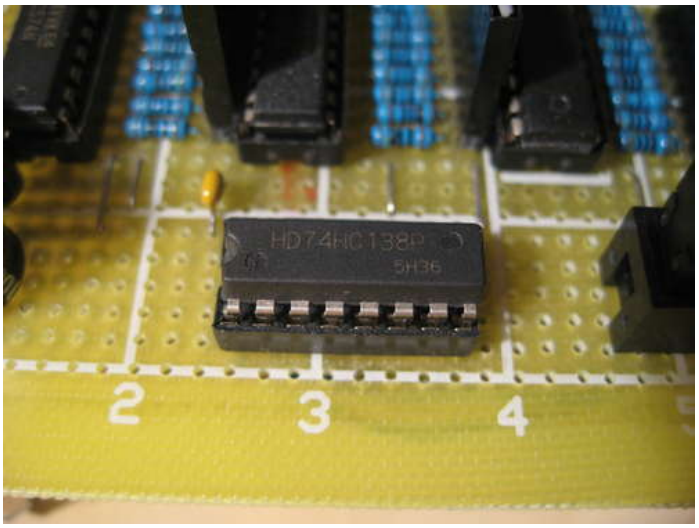
Step 37: Build the controller: Address selector

The 74HC138 is responsible for toggling the clock pin on the 74HC574 latch ICs. We call this an address selector because it selects which one of the 8 bytes in the latch array we want to write data to. The three blue wires running from the connector to the 74HC138 is the 3 bit binary input used to select which of the 8 outputs is pulled low. From each of the outputs on the 74HC138, there is a wire (white) running to the clock pin on the corresponding 74HC574 latch IC.

Start by soldering the GND and VCC connections. If you use the solder trace method to run GND/VCC lines you want to do this before you solder any other wires in place. A 100nF ceramic filtering capacitor is placed close to the VCC and GND pins of the 74HC138.

Then connect the address lines and the 8 clock lines.

If you look carefully at the connector, you can see two pins that are not used. These will be used for a button and debug LED later.



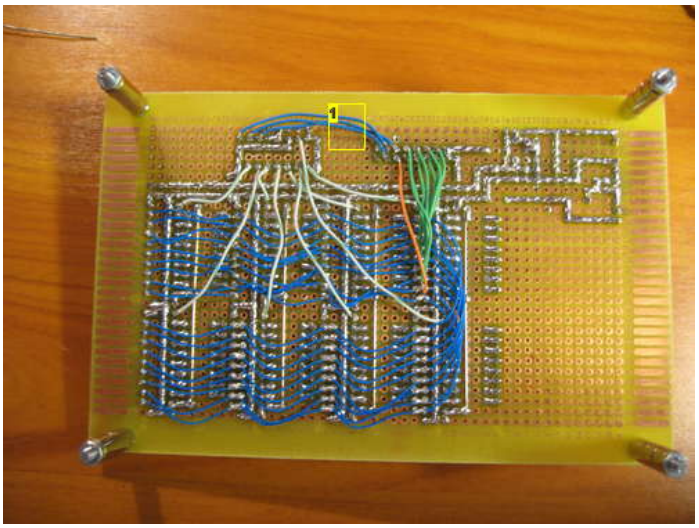


Image Notes
1. 3 bit address select bus

Step 38: Build the controller: AVR board

Braaaaainzz!!!

This board is the brain of the LED cube. The main component is an Atmel AVR ATmega32.

This is an 8 bit microcontroller with 32 KB of program memory and 2 KB RAM. The ATmega32 has 32 GPIO (General Purpose IO) pins. Two of these will be used for serial communication (TX+RX). Three IO pins are used for ISP (In-circuit Serial Programming). This leaves us with 27 GPIO to drive the LED cube, buttons and status LEDs.

A group of 8 GPIO (8 bits, one byte) is called a port. The ATmega32 has 4 ports. PORTA, PORTB, PORTC and PORTD. On PORTC and PORTD some of the pins are used for TX/RX and ISP. On PORTA and PORTB, all the pins are available. We use these ports to drive the data bus of the latch array and layer select transistor array.

PORTA is connected to the data bus on the latch array.

Each pin on PORTC is connected to a pair of transistors that drive a ground layer.

The address selector on the latch array (74HC138) is connected to bit 0-2 on PORTB. Output enable (OE) is connected to PORTB bit 3.

In the first image, you see the AVR board right-side-up.

The large 40 pin PDIP (Plastic Dual Inline Package) chip in the center of the board is the ATmega32, the brainz! Just to the left of the ATmega, you see the crystal

oscillator and it's two capacitors. On either side of the ATmega there is a 100nF filtering capacitor. One for GND/VCC and one for AVCC/GND.

In the top left corner, there is a two pin connectors and two filtering capacitors. One 10uF and one 100nF. The LED is just connected to VCC via a resistor, and indicates power on.

The large 16 pin connector directly above the ATmega connects to the latch array board via a ribbon cable. The pinout on this corresponds to the pinout on the other board.

The smaller 10 pin connector to the left, is a standard AVR ISP programming header. It has GND, VCC, RESET, SCK, MISO and MOSI, which are used for programming. Next to it, there is a jumper. When this is in place, the board can be powered from the programmer.

Caution: DO NOT power the board from the programmer when the actual LED cube is connected to the controller. This could possibly blow the programmer and even the USB port the programmer is connected to!

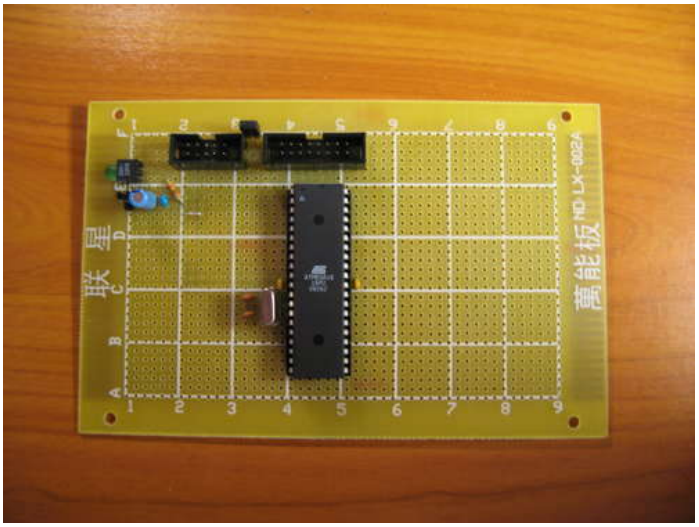
The second image shows the underside. Again all GND and VCC lines are soldered as traces on the protoboard or bare wire. We had some more left over straight metal wire, so we used this.

The orange wires connect the ATmega's RESET, SCK, MOSI and MISO pins to the ISP programming header.

The Green wires connect PORTA to the data bus.

The blue wires are the address select lines for the 74HC138 and output enable (OE) for the latch array.

1) Start by placing the 40 pin IC socket, the 10 pin ISP connector with a jumper next to it and the 16 pin data bus connector.
2) Solder in place the power connector, capacitors and power indicator LED.
3) Connect all the GND and VCC lines using solder traces or wire. Place a 100nF capacitor between each pair of GND/VCC pins on the ATmega.
4) Solder in the crystal and the two 22pF capacitors. Each capacitor is connected to a pin on the crystal and GND.
5) Run all the data bus, address select and OE wires, and the ISP wires.
Transistors, buttons and RS232 will be added in later steps.
At this time, the AVR board can be connected to an ISP programmer and the ATmega should be recognized.



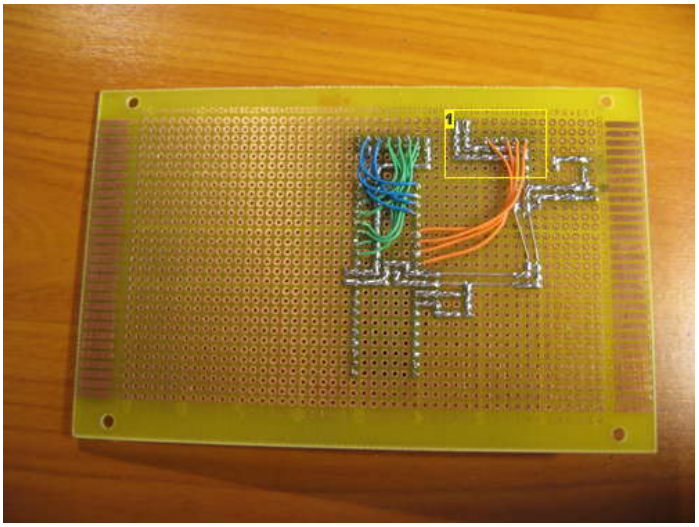
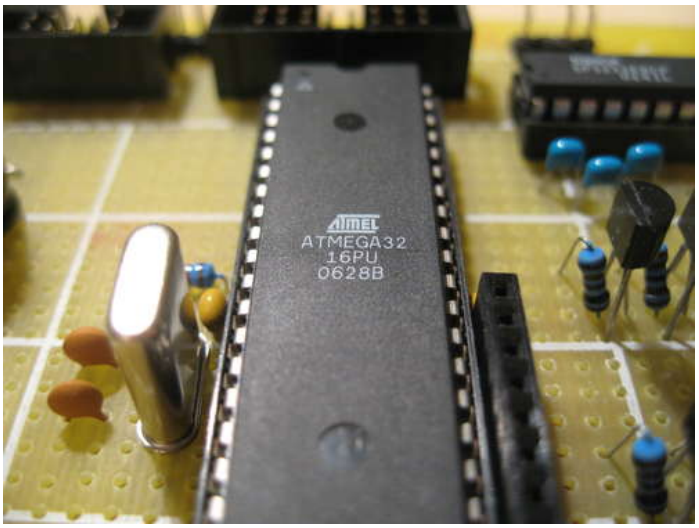
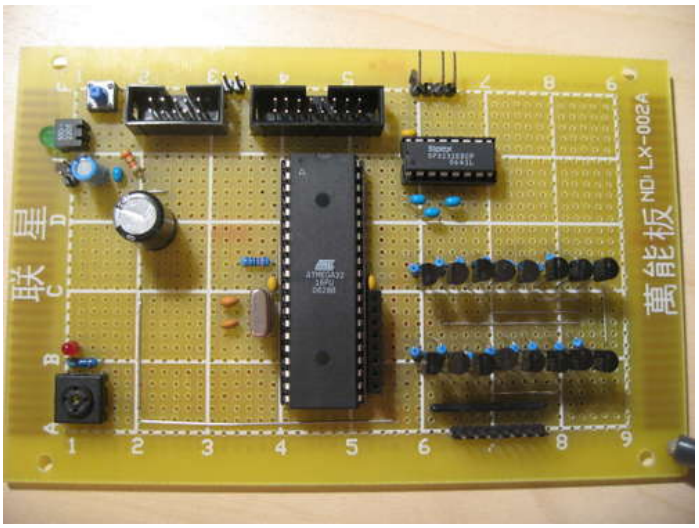


Image Notes
1. In circuit serial programming header.





Step 39: Build the controller: Transistor array

The transistor array is responsible for switching on and off GND for each layer in the LED cube.

Our first attempt at this was an epic fail. We bought some transistors rated for over 500mA, thinking that would be plenty of juice. We don't remember the model number.

The LED cube worked, but it wasn't very bright, and the brightness was inversely proportional to the number of LEDs switched on in any given layer. In addition to that, there was some ghosting. Layers didn't switch completely off when they were supposed to be off.

Needless to say, we were kind of disappointed, and started debugging. The first thing we did was to add pull-up resistors to try to combat the ghosting. This removed almost all the ghosting, yay! But the cube was still very dim, bah!

We didn't have any powerful transistors or MOSFETs lying around, so we had to come up with another solution.

We posted a thread in the electronics section of the AVRFreaks.net forum, asking if it was possible to use two smaller transistors in parallel. This is the only option available to us using the parts we had on hand. The general response was, this will never work so don't even bother trying. They even had valid theories and stuff, but that didn't deter us from trying. It was our only solution that didn't involve waiting for new parts to arrive in the mail.

We ended up trying PN2222A, NPN general purpose amplifier. Ideally, you'd want a switching transistor for this kind of application, but we needed 16 transistors of the same type. This transistor was rated at 1000mA current, so we decided to give it a try.

For each layer, we used two PN2222As in parallel. The collectors connected together to GND. The emitters connected together, then connected to a ground layer. The base of each transistors was connected to it's own resistor, and the two resistors connected to an output pin on the ATmega.

We soldered in all the transistors and turned the thing on again, and it worked, perfectly!

If you know what you are doing, you should probably do some research and find a more suitable transistor or MOSFET. But our solution is tried and tested and also does the trick!

1) Start by placing all 8 all transistors on the PBC and soldering each of their pins.

2) Run a solder trace between the the emitters of all 16 transistors. Connect this solder trace to GND.

3) Solder in a resistor for each transistor, the solder the resistors together in pairs of two.

4) Run kynar wire from the output pins on the ATmega to each of the 8 resistor pairs.

5) Solder together the collectors of the transistors in pairs of two and run solder trace or wire from the collector pairs to an 8 pin header.

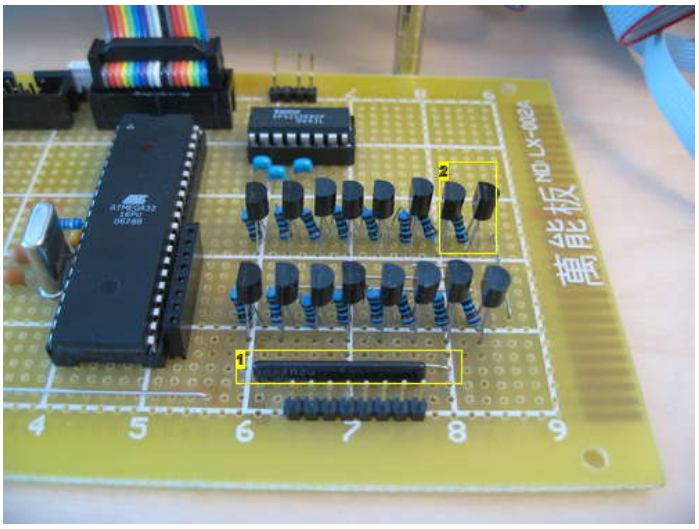


Image Notes
1. Pull up resistors. This type of resistor is called a resistor network. It just has a bunch of resistors connected to a common pin.
2. Two and two resistors work together.

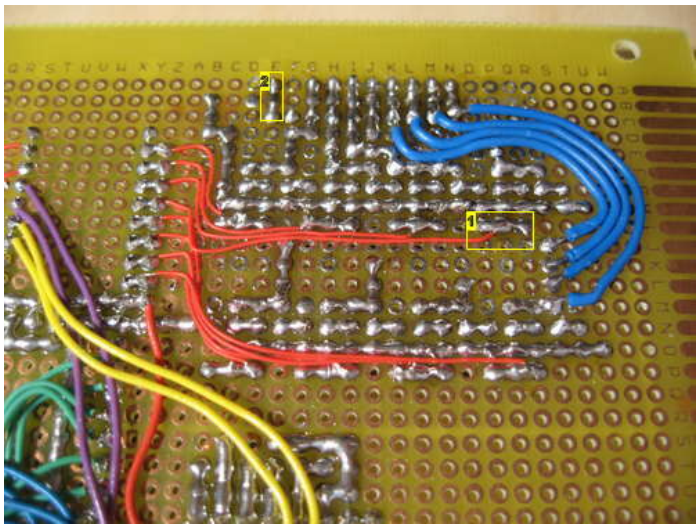
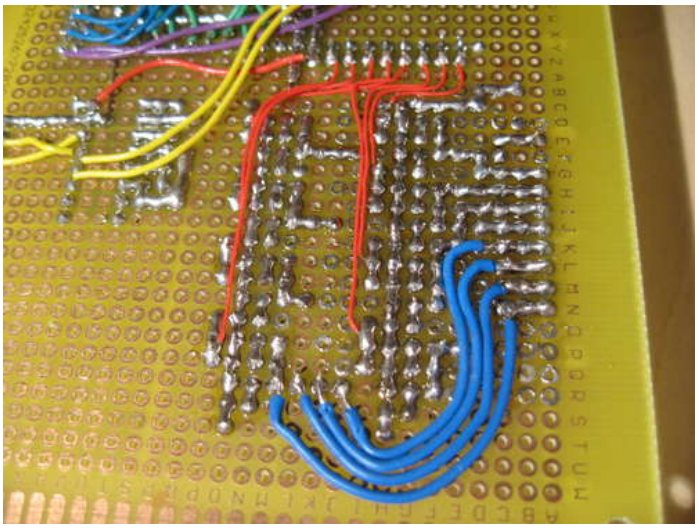


Image Notes
1. Signal goes to two transistors.
2. This point was connected to VCC after this picture was taken.



Step 40: Build the controller: Buttons and status LEDs

You can make a LED cube without any buttons at all, but it's nice to have at least one button and some status LEDs for debugging.

We added one awesome looking button with two built in LEDs, and one regular button with an LED.

The first button is mounted on the latch array PCB, since this will sit on top of the AVR board, and we want the button easily accessible. The wires are routed through the ribbon cable. The second button and LED sits on the AVR board and was mostly used for debugging during construction.

The buttons are connected between GND and the IO pin on the ATmega. An internal pull-up resistor inside the ATmega is used to pull the pin high when the button is not pressed. When the button is pressed, the IO pin is pulled low. A logic 0 indicates that a button has been pressed.

The LEDs are also connected between GND and the IO pin via a resistor of appropriate size. Don't connect an LED to a micro controller IO pin without having a resistor connected in series. The resistor is there to limit the current, and skipping it can blow the IO port on your micro controller.

To find the appropriate resistor, just plug the led into a breadboard and test different resistors with a 5v power supply. Choose the resistors that make the LED light up with the brightness you want. If you use LEDs with different colors, you should test them side by side. Different color LEDs usually require different resistors to reach the same level of brightness.

We will leave it up to you to decide the placement of your status LEDs, but you can see in the pictures below how we did it:

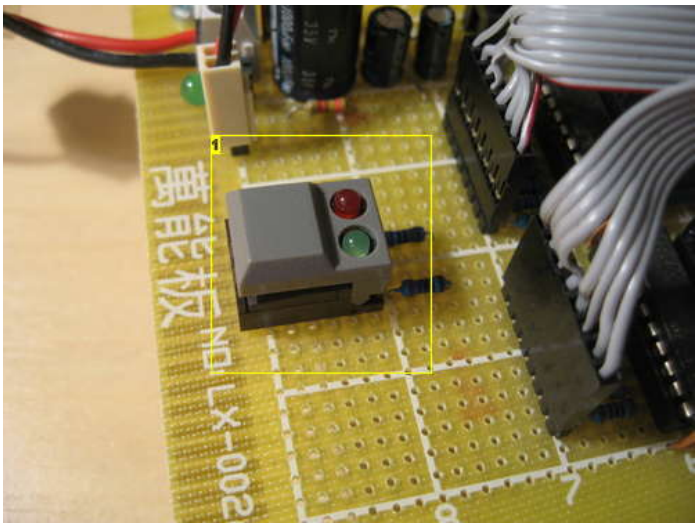


Image Notes
1. Start the cube in autonomous mode

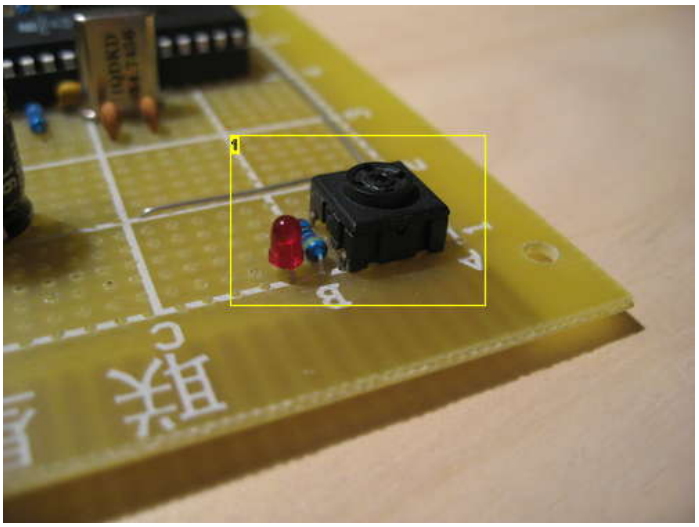


Image Notes
1. Start the cube in rs232-mode

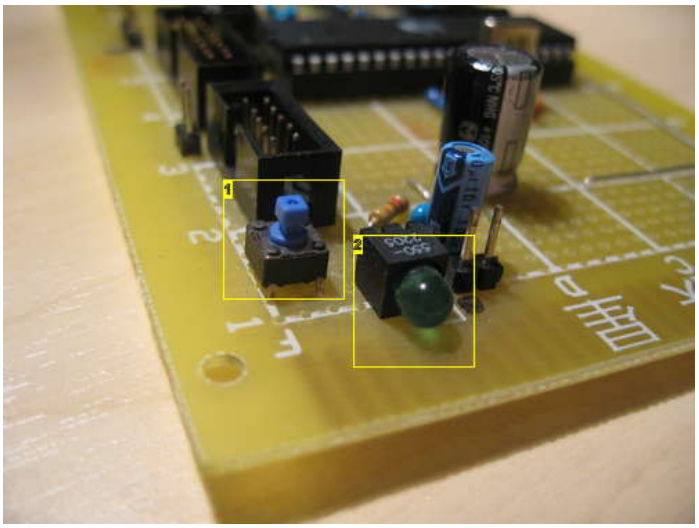


Image Notes
1. Reset
2. Power on

Step 41: Build the controller: RS-232

To get the truly amazing animations, we need to connect the LED cube to a PC. The PC can do floating point calculations that would have the AVR working in slow motion.

The ATmega has a built in serial interface called USART (Universal Synchronous and Asynchronous serial Receiver and Transmitter).

The USART communicates using TTL levels (0/5 volts). The computer talks serial using RS232. The signal levels for RS232 are anywhere from +/- 5 volts to +/- 15 volts.

To convert the serial signals from the micro controller to something the RS232 port on a PC can understand, and vice versa, we use the Maxim MAX232 IC. Actually, the chip we are using isn't from Maxim, but it is a pin-compatible clone.

There are some 100nF ceramic capacitors surrounding the MAX232. The MAX232 uses internal charge-pumps and the external capacitors to step up the voltage to appropriate RS232 levels. One of the 100nF capacitors is a filter capacitor.

The RS232 connector is at a 90 degree angle for easy access when the latch array board is mounted on top of the AVR board. We used a 4 pin connector and cut one of the pins out to make a polarized connector. This removes any confusion as to which way to plug in the RS232 cable.

In the second picture you can see two yellow wires running from the ATmega to the MAX232. These are the TTL level TX and RX lines.

1) Connect the GND and VCC pins using solder trace or wire. Place a 100nF capacitor close to the GND and VCC pins.

2) Solder in place the rest of the 100nF capacitors. You can solder these with solder traces, so its best to do this before you connect the tx/rx wires.

3) Solder in place a 4 pin 0.1" header with one pin removed. Connect the pin next to the one that was removed to GND.

4) Connect the tx/rx input lines to the micro controller, and the tx/rx output lines to the 4 pin header.

The wires going to the 4 pin header are crossed because the first serial cable we used had this pinout.

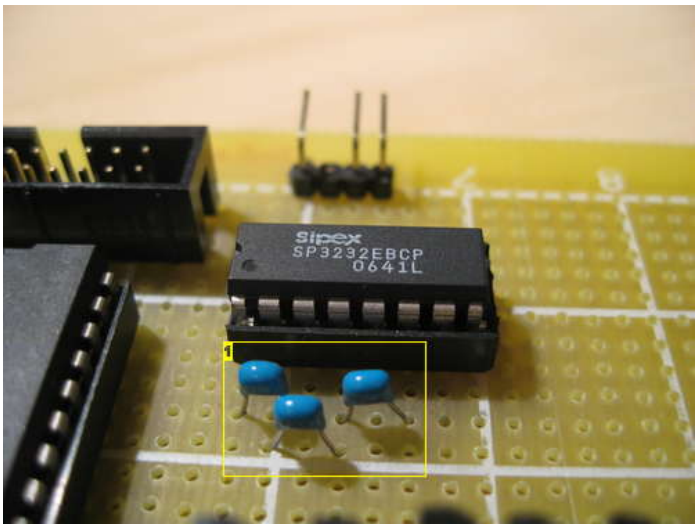


Image Notes
1. These capacitors helps the max232 bump the voltage up to rs232 levels.

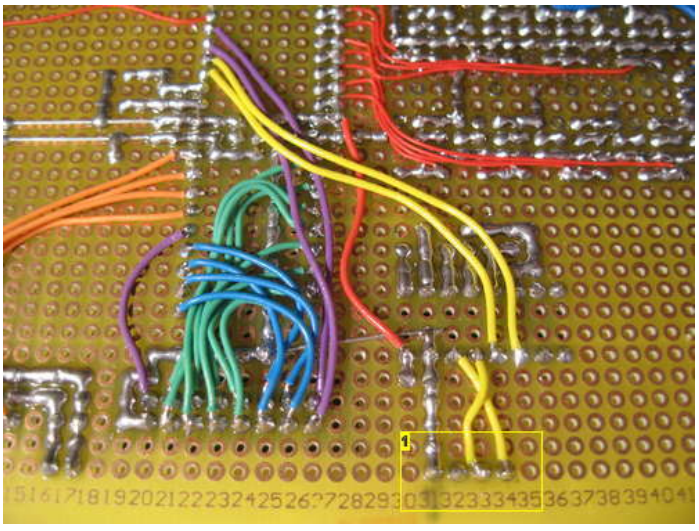


Image Notes
1. RS232 connector

Step 42: Build the controller: Make an RS-232 cable

To connect the LED cube to a serial port on your computer, you need to make a serial cable with a female D-Sub 9 pin connector.

Our employer deployed 70 Ethernet switches with management last year. With each switch comes an RS232 cable that is never used. We literally had a big pile of RS232 cable, so we decided to modify one of those.

On the LED cube, a 0.1" pin header is used, so the RS232 cable needs a new connector on the cube side.

We didn't have a 4 pin female 0.1" connector, so we used a 4 pin female PCB header instead.

The connector on the LED cube PCB has one pin removed, to visualize the directionality of the connector. The pin numbers goes from right to left.

Pinout of the RS232 connector:

1) GND (DSub9 pin 5)
2) Not connected
3) RX (DSub9 pin 3)
4) TX (DSub9 pin 2)

Follow these steps to make your own RS232 cable:

1) Cut of the connector at one end of the cable. If your cable has a female and a male connector, make sure to remove the male connector!

2) Strip away the outer sheath on the end where you removed the connector.

3) Strip all the wires inside.

4) Set your multimeter to continuity test mode. This makes the multimeter beep when the probes are connected. If your multimeter doesn't have this option, use the resistance mode. It should get close to 0 ohm when you connect the probes.

5) Connect one multimeter probe to the DSub9's pin 5, then probe all the wires until you the multimeter beeps. You have now identified the color of GND in your cable. Repeat for pin 2 and 3 (TX and RX).

6) Write down the colors you identified, then cut off the other wires.

7) Cut the three wires down to size, 30mm should do.

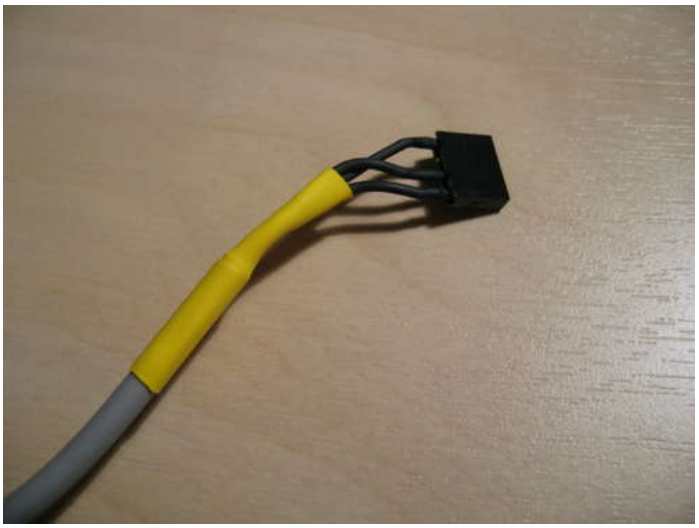
8) Pre-tin the wires to make soldering easier. Just apply heat and solder to the stripped wires.

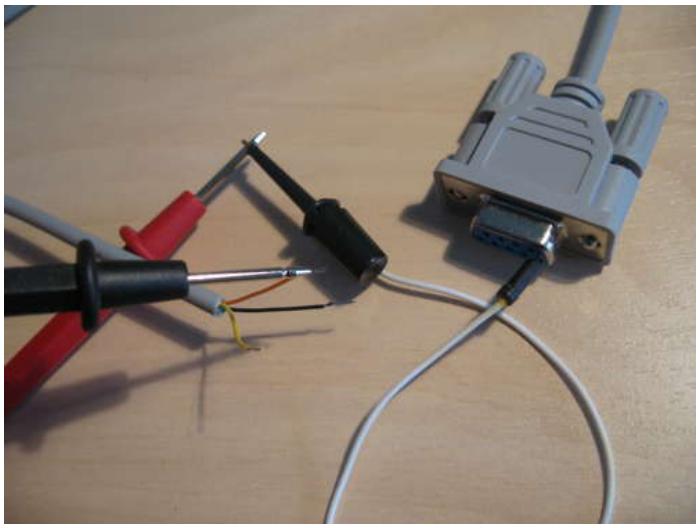
9) Slide a shrink tube over the cable. Slide three smaller shrink tubes over the individual wires.

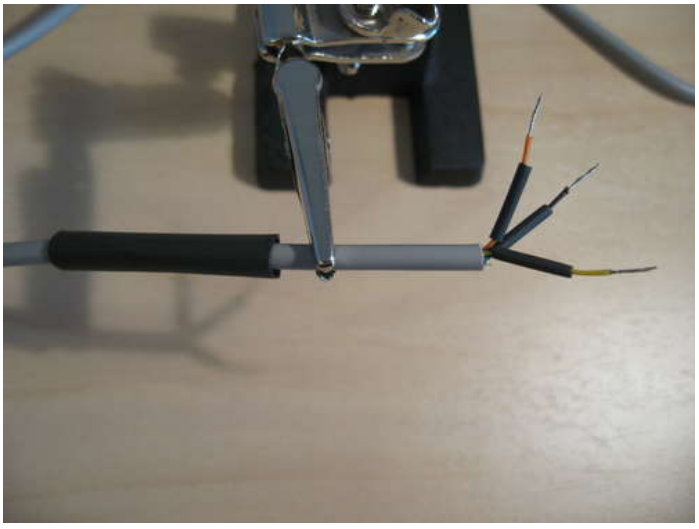
10) Solder the wires to the connector.

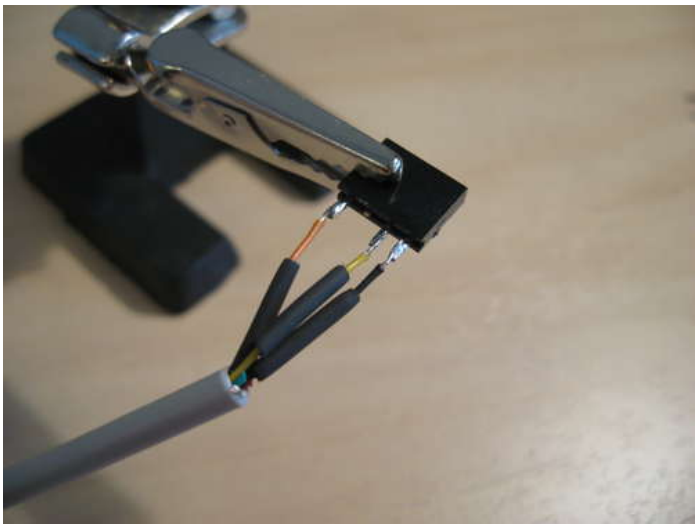
11) Shrink the smaller tubes first, then the large one. If you use a lighter, don't hold the shrink tube above the flame, just hold it close to the side of the flame.

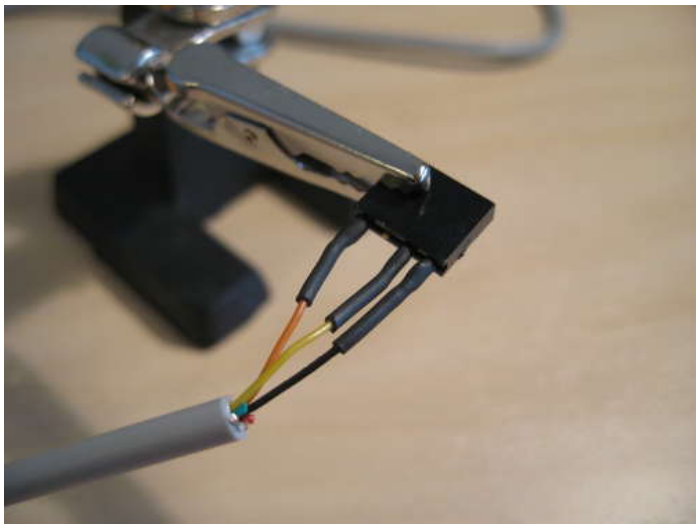
Don't make your cable based on the colors we used. Test the cable to find the correct colors.











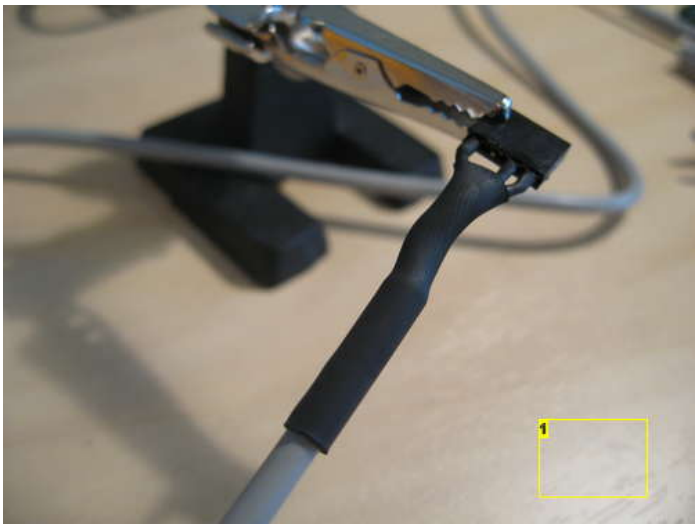


Image Notes
1. We managed to get the colors wrong on the first try. That's why the cable in the first picture has a yellow shrink tube ;)

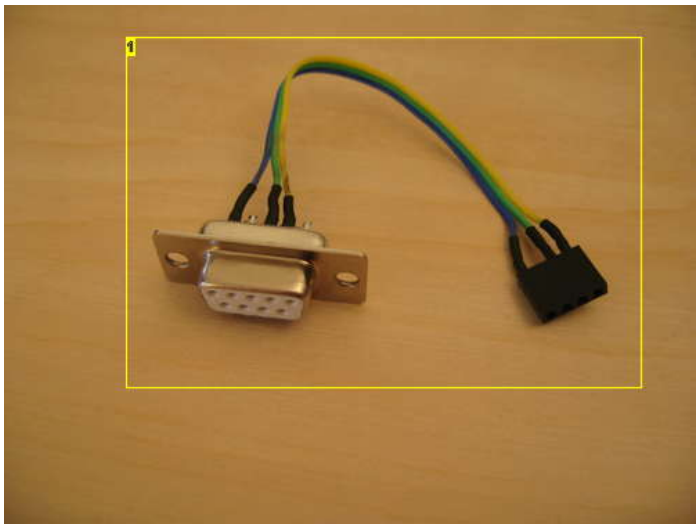


Image Notes
1. This is another way of doing it..

Step 43: Build the controller: Connect the boards

The two boards are connected by two cables:

- A ribbon cable for the DATA and Address BUS.
- A 2 wire cable for GND and VCC.

After connecting these two cables, your board is complete.

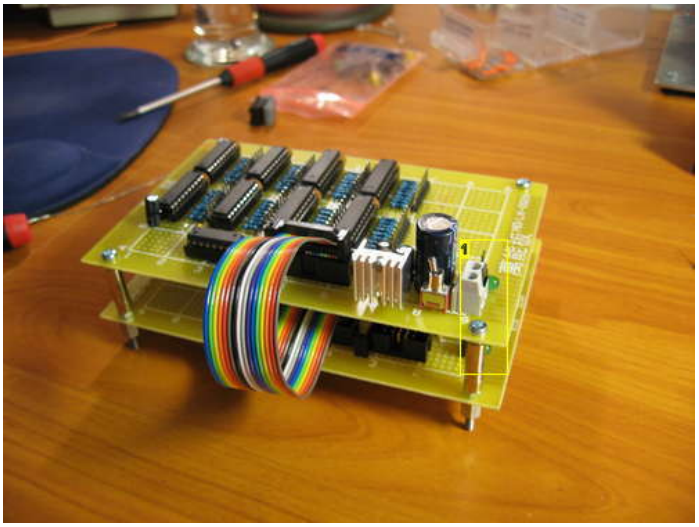
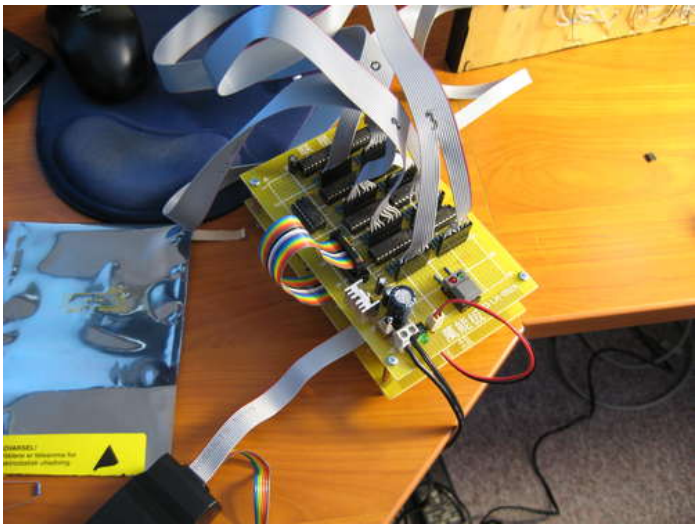
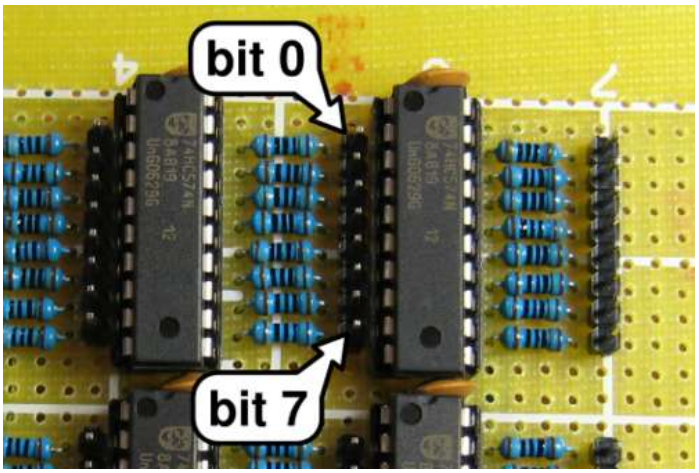


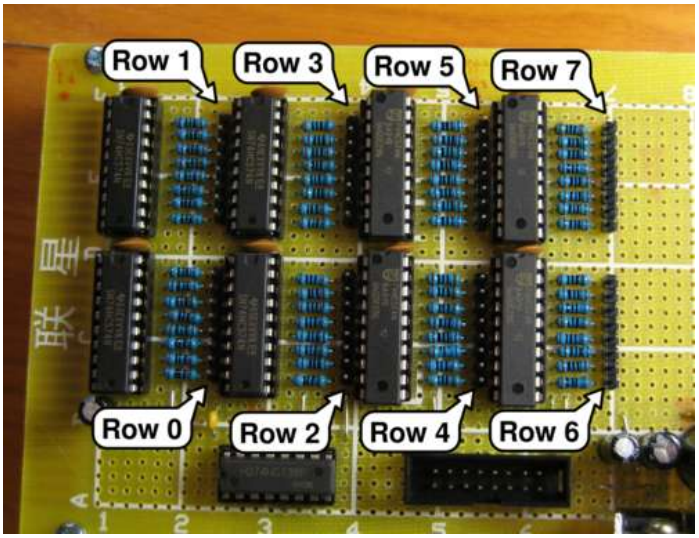
Image Notes
1. The GND/VCC cable connects between the two 2pin headers here.

Step 44: Build the controller: Connect the cube

Connect the ribbon cables according to the pin-outs shown in picture 2 and 3.
The ground layer ribbon cable connects to the pin header near the transistor array. If the cube is upside-down, just plug it in the other way.







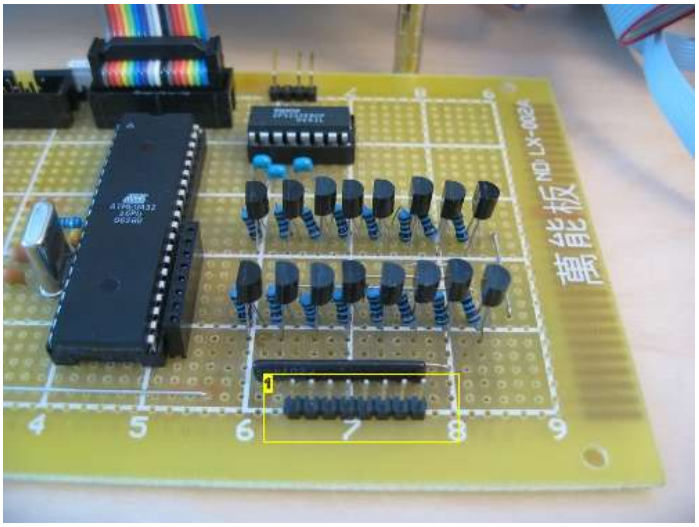


Image Notes
1. The ground layer ribbon cable connects here. Just connect it the other way if your LED cube is upside-down ;)

Step 45: Program the AVR: Set the fuse bits

The ATmega32 has two fuse bytes. These contain settings that have to be loaded before the CPU can start, like clock source and other stuff. You have to program your ATmega to use an external high speed crystal oscillator and disable JTAG.

We set the lower fuse byte (lfuse) to 0b11101111, and the high fuse byte to 0b11001001. (0b means that everything after the b is in binary).

We used avrdude and USBtinyISP (http://www.ladyada.net/make/usbtinyisp/) to program our ATmega.

In all the following examples, we will be using an Ubuntu Linux computer. The commands should be identical if you run avrdude on Windows.

- avrdude -c usbtiny -p m32 -U lfuse:w:0b11101111:m
- avrdude -c usbtiny -p m32 -U hfuse:w:0b11001001:m

Warning: If you get this wrong, you could easily brick your ATmega! If you for example disable the reset button, you won't be able to re-program it. If you select the wrong clock source, it might not boot at all.


```
chr@wrk:~/dev/tg10/dev/cube_test$ cat fuses.txt

lfuse: 0b11101111
hfuse: 0b11001001


chr@wrk:~/dev/tg10/dev/cube_test$ avrdude -c usbtiny -p m32 -U hfuse:w:0b1100100
1:m
```

Image Notes
1. USBtinyISP

```
Reading | ################################################## | 100% 0.01s

avrdude: Device signature = 0x1e9502
avrdude: reading input file "0b11001001"
avrdude: writing hfuse (1 bytes):

Writing | ################################################## | 100% 0.00s

avrdude: 1 bytes of hfuse written
avrdude: verifying hfuse memory against 0b11001001:
avrdude: load data hfuse data from input file 0b11001001:
avrdude: input file 0b11001001 contains 1 bytes
avrdude: reading on-chip hfuse data:

Reading | ################################################## | 100% 0.00s

avrdude: verifying ...
avrdude: 1 bytes of hfuse verified

avrdude: safemode: Fuses OK

avrdude done.  Thank you.

chr@wrk:~/dev/tg10/dev/cube_test$
```

```
chr@wrk:~/dev/tg10/dev/cube_test$ cat fuses.txt

lfuse: 0b11101111
hfuse: 0b11001001



chr@wrk:~/dev/tg10/dev/cube_test$ avrdude -c usbtiny -p m32 -U lfuse:w:0b1110111
1:m
```

```
Reading | ################################################## | 100% 0.01s

avrdude: Device signature = 0x1e9502
avrdude: reading input file "0b11101111"
avrdude: writing lfuse (1 bytes):

Writing | ################################################## | 100% 0.00s

avrdude: 1 bytes of lfuse written
avrdude: verifying lfuse memory against 0b11101111:
avrdude: load data lfuse data from input file 0b11101111:
avrdude: input file 0b11101111 contains 1 bytes
avrdude: reading on-chip lfuse data:

Reading | ################################################## | 100% 0.00s

avrdude: verifying ...
avrdude: 1 bytes of lfuse verified

avrdude: safemode: Fuses OK

avrdude done.  Thank you.

chr@wrk:~/dev/tg10/dev/cube_test$
```

Step 46: Program the AVR with test code

Time to test if your brand new LED cube actually works!

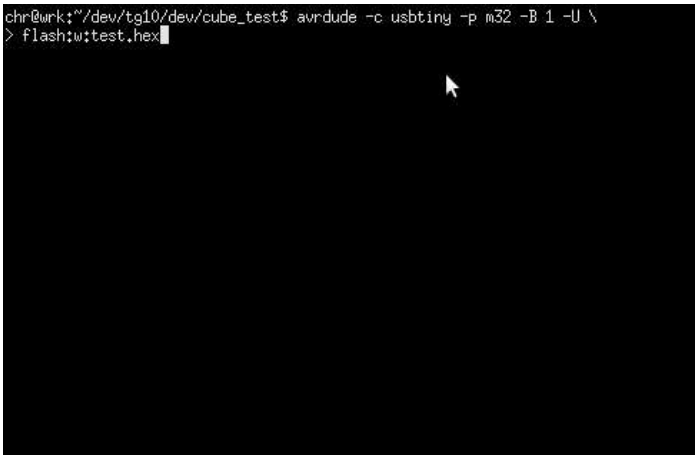
We have prepared a simple test program to check if all the LEDs work and if they are wired correctly.

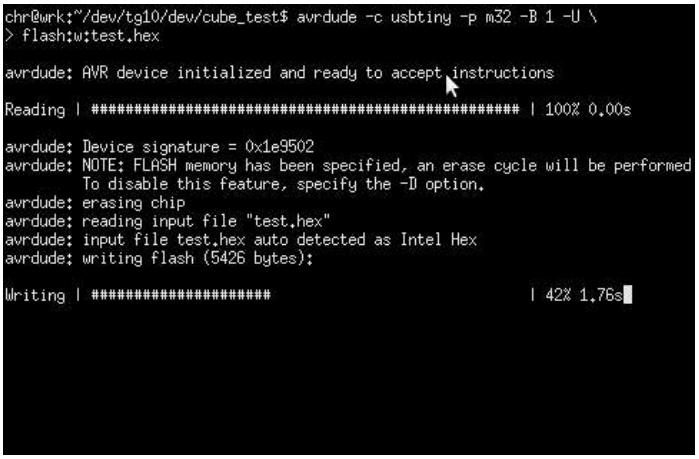
You can download the firmware test.hex in this step, or download the source code and compile it yourself.

As in the previous step, we use avrdude for programming:

- avrdude -c usbtiny -p m32 -B 1 -U flash:w:test.hex

-c usbtiny specifies that we are using the USBtinyISP from Ladyada -p m32 specifies that the device is an ATmega32 -B 1 tells avrdude to work at a higher than default speed. -U flash:w:test.hex specifies that we are working on flash memory, in write mode, with the file test.hex.





File Downloads

test.hex (14 KB)
[NOTE: When saving, if you see .tmp as the file ext, rename it to 'test.hex']

Step 47: Test the cube

The test code you programmed in the previous step will let you confirm that everything is wired up correctly.

It will start by drawing a plane along one axis, then moving it along all 8 positions of that axis. (by plane we mean a flat surface, not an airplane :p) The test code will traverse a plane through all three axis.

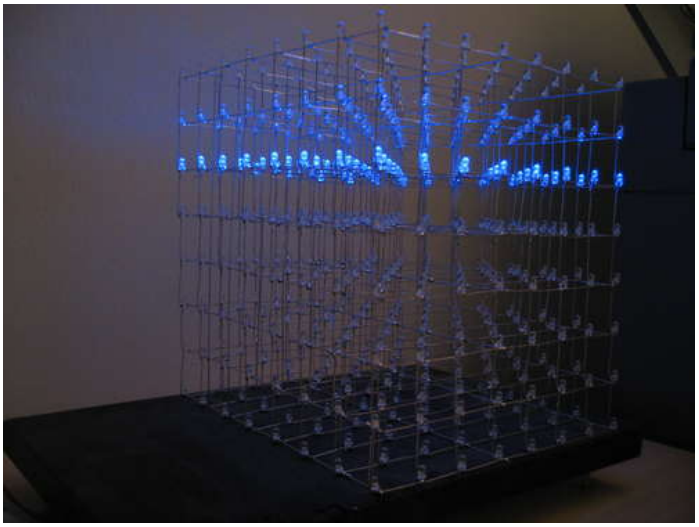
After that, it will light the LEDs in a layer one by one, starting at the bottom layer.

If any of the layers or columns seem to light up in the wrong order, you have probably soldered the wrong wire to the wrong layer or column. We had one mistake in our cube ;)

If you find anything that is out of order, just de-solder the wires and solder them back in the right order. You could of course make a workaround in software, but that would eat CPU cycles every time the interrupt routine runs.

You can compare your cube to the test video below:

CLICK TO PLAY VIDEO



Step 48: Program the AVR with real code

So everything checked out in the test. It's time to program the ATmega with the real firmware!

For the most part, the process is the same as in the previous programming step. But in addition you have to program the EEPROM memory. The LED cube has a basic bitmap font stored in EEPROM, along with some other data.

Firmware is programmed using the same procedure as with the test code.

Firmware:

- avrdude -c usbtiny -p m32 -B 1 -U flash:w:main.hex

EEPROM:

- avrdude -c usbtiny -p m32 -B 1 -U eeprom:w:main.eep

-U eeprom:w:main.eep specifies that we are accessing EEPROM memory, in write mode. Avr-gcc puts all the EEPROM data in main.eep.

If you don't want to play around with the code, your LED cube is finished at this point. But we recommend that you spend some time on the software side of things as well. That's at least as much fun as the hardware!

If you download the binary files, you have to change the filenames in the commands to the name of the files you downloaded. If you compile from source the name is main.hex and main.eep.

```
chr@wrk:~/dev/tg10/dev/cube8$ avrdude -c usbtiny -p m32 -B 1 \
> -U eeprom:w:main.eep

avrdude: AVR device initialized and ready to accept instructions

Reading | ################################################## | 100% 0.00s

avrdude: Device signature = 0x1e9502
avrdude: reading input file "main.eep"
avrdude: input file main.eep auto detected as Intel Hex
avrdude: writing eeprom (503 bytes):

Writing | ########################                           | 50% 2.29s
```

```
section            size      addr
.text             16582         0
.data                56   8388704
.bss                130   8388760
.eeprom             503   8454144
.stab             11460         0
.stabstr           2282         0
.debug_aranges      192         0
.debug_pubnames    1498         0
.debug_info        9577         0
.debug_abbrev      2158         0
.debug_line        8951         0
.debug_frame       1200         0
.debug_str         1482         0
.debug_loc        10361         0
.debug_ranges       160         0
Total             66592


-------- end --------

chr@wrk:~/dev/tg10/dev/cube8$ avrdude -c usbtiny -p m32 -B 1 -U flash:w:main.hex
```

```
-------- end --------

chr@wrk:~/dev/tg10/dev/cube8$ avrdude -c usbtiny -p m32 -B 1 -U flash:w:main.hex
avrdude: Error: Could not find USBtiny device (0x1781/0xc9f)

avrdude done.  Thank you.

chr@wrk:~/dev/tg10/dev/cube8$ avrdude -c usbtiny -p m32 -B 1 -U flash:w:main.hex

avrdude: AVR device initialized and ready to accept instructions

Reading | ################################################## | 100% 0.00s

avrdude: Device signature = 0x1e9502
avrdude: NOTE: FLASH memory has been specified, an erase cycle will be performed
         To disable this feature, specify the -D option.
avrdude: erasing chip
avrdude: reading input file "main.hex"
avrdude: input file main.hex auto detected as Intel Hex
avrdude: writing flash (16638 bytes):

Writing | ########                                           | 15% 1.95s
```

```
-------- end --------

chr@wrk:~/dev/tg10/dev/cube8$ avrdude -c usbtiny -p m32 -B 1 -U flash:w:main.hex
avrdude: Error: Could not find USBtiny device (0x1781/0xc9f)

avrdude done.  Thank you.

chr@wrk:~/dev/tg10/dev/cube8$ avrdude -c usbtiny -p m32 -B 1 -U flash:w:main.hex

avrdude: AVR device initialized and ready to accept instructions

Reading | ################################################## | 100% 0.00s

avrdude: Device signature = 0x1e9502
avrdude: NOTE: FLASH memory has been specified, an erase cycle will be performed
         To disable this feature, specify the -D option.
avrdude: erasing chip
avrdude: reading input file "main.hex"
avrdude: input file main.hex auto detected as Intel Hex
avrdude: writing flash (16638 bytes):

Writing | ##########################                         | 54% 6.89s
```

```
Writing | ################################################## | 100% 12.60s



avrdude: 16638 bytes of flash written
avrdude: verifying flash memory against main.hex:
avrdude: load data flash data from input file main.hex:
avrdude: input file main.hex auto detected as Intel Hex
avrdude: input file main.hex contains 16638 bytes
avrdude: reading on-chip flash data:

Reading | ################################################## | 100% 8.17s



avrdude: verifying ...
avrdude: 16638 bytes of flash verified

avrdude: safemode: Fuses OK

avrdude done.  Thank you.

chr@wrk:~/dev/tg10/dev/cube8$
```

File Downloads

ledcube_8x8x8_eeprom.eep (1 KB)
[NOTE: When saving, if you see .tmp as the file ext, rename it to 'ledcube_8x8x8_eeprom.eep']

ledcube_8x8x8.hex (46 KB)
[NOTE: When saving, if you see .tmp as the file ext, rename it to 'ledcube_8x8x8.hex']

Step 49: Software: Introduction

The software is written in C and compiled with the open source compiler avr-gcc. This is the main reason we use Atmel AVR micro controllers. The PIC series from Microchip is also a nice choice, but most of the C compilers cost money, and the free versions have limitations on code size.

The AVR route is much more hassle free. Just apt-get install the avr-gcc compiler, and you're in business.

The software on the AVR consists of two main components, the cube interrupt routine and effect code for making fancy animations.

When we finally finished soldering, we thought this would be the easy part. But it turns out that making animations in monochrome at low resolutions is harder than it sounds.

If the display had a higher resolution and more colors, we could have used sin() and cos() functions and all that to make fancy eye candy. With two colors (on and off) and low resolution, we have to use a lot of if() and for() to make anything meaningful.

In the next few steps, we will take you on a tour of some of the animations we made and how they work. Our goal is to give you an understanding of how you can make animations, and inspire you to create your own! If you do, please post a video in the comments!

File Downloads

ledcube_8x8x8-v0.1.2.tar.gz (20 KB)
[NOTE: When saving, if you see .tmp as the file ext, rename it to 'ledcube_8x8x8-v0.1.2.tar.gz']

Step 50: Software: How it works

As mentioned in the previous step, the software consists of two pars. The interrupt routine and the effect code.

Communication between these two happens via a voxel array. This array has a bit for every LED in the LED cube. We will refer to this as the cube array or cube buffer from now on.

The cube array is made of 8x8 bytes. Since each byte is 8 bits, this gives us a buffer that is 8 voxels wide, 8 woxels high and 8 voxels deep (1 byte deep).

volatile unsigned char cube[8][8];

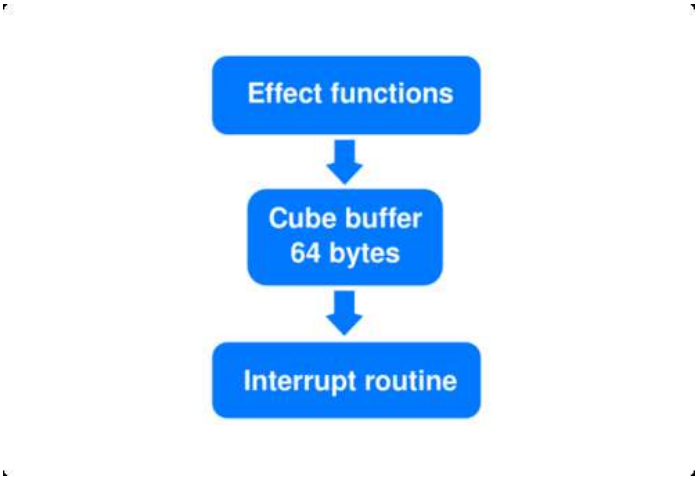
The interrupt routine reads from the cube array at given intervals and displays the information on the LED cube.

The effect functions writes the desired LED statuses to this array.

We did not use any synchronization or double buffering, since there is only one producer (either the effects currently running, or input from RS232) and one consumer (the interrupt-code that updates the cube). This means that some voxels could be from the next or previous "frame", but this is not a problem, since the frame rate is so high.

When working with micro controllers, code size is critical. To save code size and programming work, and to make the code easier to read, we have tried to write re-usable code as often as possible.

The LED cube code has a base of low level drawing functions that are used by the higher level effect functions. The draw functions can be found in draw.c. Draw functions include everything from setting or clearing a single voxel to drawing lines and wireframe boxes.



Step 51: Software: IO initialization

The first thing the ATmega does after boot, is to call the ioinit() function.

This function sets up IO ports, timers, interrupts and serial communications.
All IO ports on the ATmega are bi-directional. They can be used either as an input or an output. We configure everything as outputs, except the IO pins where the two buttons are connected. The RX pin for the serial line automatically becomes an input when USART RX is enabled.

1) DDRx sets the data direction of the IO pins. (Data Direction Register). 1 means output, 0 means input.

2) After directionality has been configured, we set all outputs to 0 to avid any blinking LEDs etc before the interrupt has started.

3) For pins configured as inputs, the PORTx bit changes its function. Setting a 1 in the PORTx register bit enables an internal pull up resistor. The port is pulled up to VCC. The buttons are connected between the port and GND. When a button is pressed the corresponding PINx bit reads a logic 0.

4) Timer 2 is configured and a timer interrupt enabled. This is covered in a separate step.

5) Serial communications is configured and enabled. This is also covered in a separate step.

```
void ioinit (void)
{
    DDRA = 0xff;    // DATA bus output
    DDRB = 0xef;    // Button on B4
    DDRC = 0xff;    // Layer select output
    DDRD = 0xdf;    // Button on D5


    PORTA = 0x00; // Set data bus off
    PORTC = 0x00; // Set layer select off
    PORTB = 0x10; // Enable pull up on button.
    PORTD = 0x20; // Enable pull up on button.


    // Timer 2
    // Frame buffer interrupt
    // 14745600/128/11 = 10472.72 interrupts per second
    // 10472.72/8 = 1309 frames per second
    OCR2 = 10;  // interrupt at counter = 10
    TCCR2 |= (1 << CS20) | (1 << CS22); // Prescaler = 128.
    TCCR2 |= (1 << WGM21); // CTC mode. Reset counter when OCR2 is reached.
    TCNT2 = 0x00;   // initial counter value = 0;
    TIMSK |= (1 << OCIE2); // Enable CTC interrupt
                                                          132,0-1       41%
```

```
#include "main.h"
#include "effect.h"
#include "launch_effect.h"
#include "draw.h"

// Main loop
// the AVR enters this function at boot time
int main (void)
{

    // This function initiates IO ports, timers, interrupts and
    // serial communications
    ioinit();

    // This variable specifies which layer is currently being drawn by the
    // cube interrupt routine. We assign a value to it to make sure it's not >7.
    current_layer = 1;

    int i;

    // Boot wait
    // This function serves 3 purposes
    // 1) We delay starting up any interrupts, as drawing the cube causes a lot
    //    noise that can confuse the ISP programmer.
-- INSERT --                                          29,5-8        1%
```

Step 52: Software: Mode selection and random seed

When we first started writing effects and debugging them, we noticed that the functions using random numbers displayed the exact same animations every time. It was random alright, but the same random sequence every time. Turns out the random number generator in the ATmega needs to be seeded with a random number to create true random numbers.

We wrote a small function called bootwait(). This function serves two purposes.

1) Create a random seed. 2) Listen for button presses to select mode of operation.

It does the following:

1) Set counter x to 0.

2) Start an infinite loop, while(1).

3) Increment counter x by one.

4) Use x as a random seed.

5) Delay for a while and set red status led on.

6) Check for button presses. If the main button is pressed, the function returns 1. If the PGM button is pressed it returnes 2. The return statements exits the function thus ending the infinite loop.

7) Delay again and set green led on.

8) Check for button presses again.

9) Loop forever until a button is pressed.

The loop loops very fast, so the probability that you will stop it at the same value of x two times in a row is very remote. This is a very simple but effective way to get a good random seed.

Bootwait() is called from the main() function and its return value assigned to the variable i.

If i == 1, the main loop starts a loop that displays effects generated by the ATmega. If i == 2, it enters into RS232 mode and waits for data from a computer.

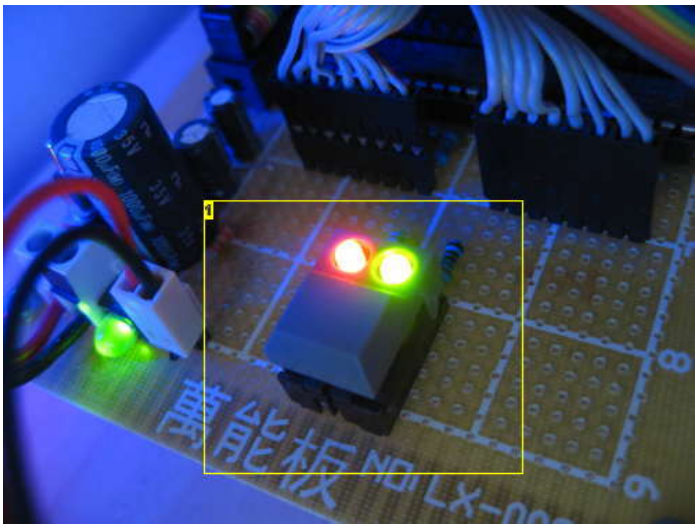


Image Notes
1. blink blink blink

Step 53: Software: Interrupt routine

The heart of the LED cube code is the interrupt routine.

Every time this interrupt runs, the cube is cleared, data for the new layer is loaded onto the latch array, and the new layer is switched on. This remains on until the next time the interrupt runs, where the cube is cleared again, data for the next layer is loaded onto the latch array, and the next layer is switched on.

The ATmega32 has 3 timer/counters. These can be set to count continuously and trigger an interrupt routine every time they reach a certain number. The counter is reset when the interrupt routine is called.

We use Timer2 with a prescaler of 128 and an Output Compare value of 10. This means that the counter is incremented by 1 for every 128th cpu cycle. When Timer2 reaches 10, it is reset to 0 and the interrupt routine is called. With a cpu frequency of 14745600 Hz, 128 prescaler and output compare of 10, the interrupt routine is called every 1408th CPU cycle (128*11) or 10472.7 times per second. It displays one layer at a time, so it takes 8 runs of the interrupt to draw the entire cube once. This gives us a refresh rate of 1309 FPS (10472.7/8). At this refresh rate, the LED cube is 100% flicker free. Some might say that 1300 FPS is overkill, but the interrupt routine is quite efficient. At this high refresh rate, it only uses about 21% of the CPU time. We can measure this by attaching an oscilloscope to the output enable line (OE). This is pulled high at the start of each interrupt and low at the end, so it gives a pretty good indication of the time spent inside the interrupt routine.

Before any timed interrupts can start, we have to set up the Timer 2. This is done in the ioinit() function.

TCCR2 (Timer Counter Control Register 2) is an 8 bit register that contains settings for the timer clock source and mode of operation. We select a clock source with a 1/128 prescaler. This means that Timer/counter 2 is incrementet by 1 every 128th CPU cycle.

We set it to CTC mode. (Clear on Timer Compare). In this mode, the counter value TCNT2 is continuously compared to OCR2 (Output Compare Register 2). Every time TCNT2 reaches the value stored in OCR2, it is reset to 0 and starts counting from from 0. At the same time, an interrupt is triggered and the interrupt routine is called.

For every run of the interrupt, the following takes place:

1) All the layer transistors are switched off.

2) Output enable (OE) is pulled high to disable output from the latch array.

3) A loop runs through i = 0-7. For every pass a byte is outputed on the DATA bus and the i+1 is outputed on the address bus. We add the +1 because the 74HC138 has active low outputs and the 74HC574 clock line is triggered on the rising edge (transition from low to high).

4) Output enable is pulled low to enable output fro the latch array again.

5) The transistor for the current layer is switched on.

6) current_layer is incremented or reset to 0 if it moves beyond 7.

That's it. The interrupt routine is quite simple. I'm sure there are some optimizations we could have used, but not without compromising human readability of the code. For the purpose of this instructable, we think readability is a reasonable trade-off for a slight increase in performance.

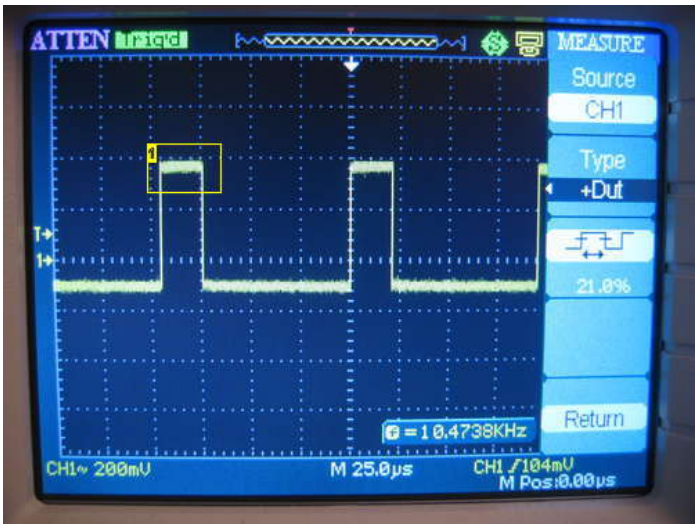


Image Notes
1. The interrupt routine pulls Output Enable high while running to disable the output of the latch array.

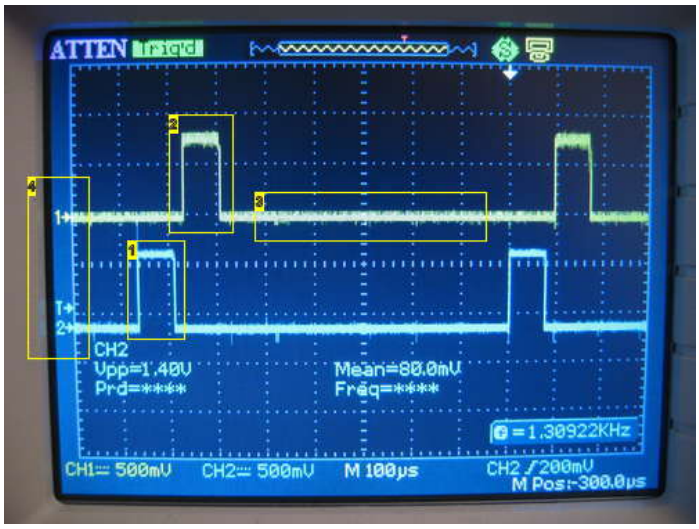


Image Notes
1. Layer 0 is on
2. Layer 1 is on
3. My oscilloscope doesn't have 8 channels, so I can only show the first two layers.
4. Output from the layer transistor lines.

Image Notes
1. The interrupt routine runs roughly 21% of the time. This leaves the remaining 79% for effect code!

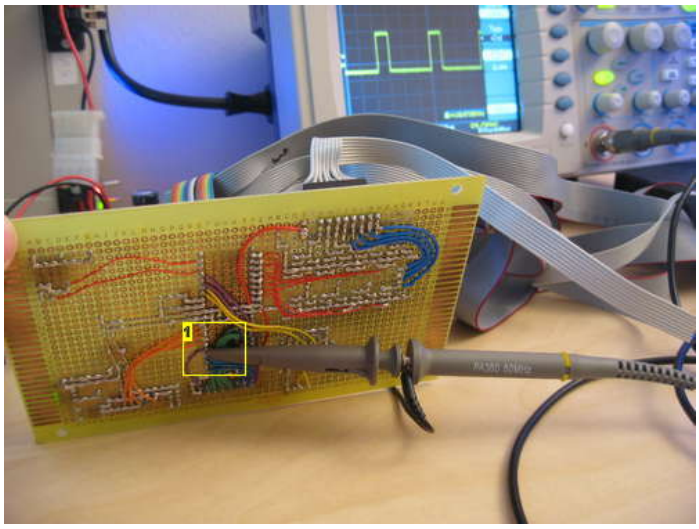
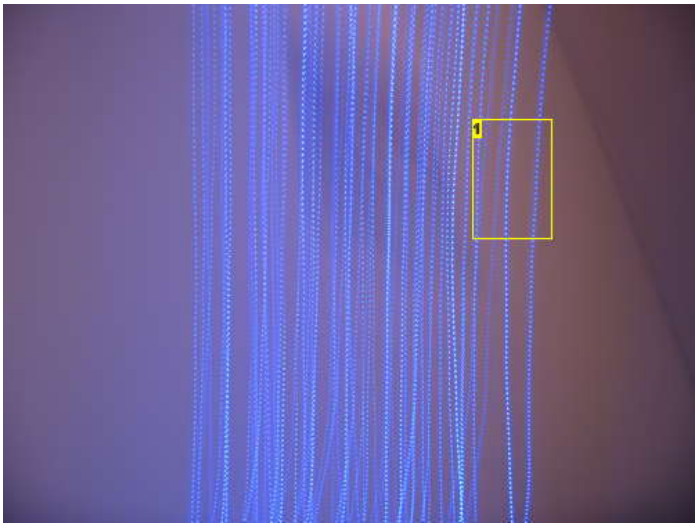


Image Notes
1. Probing output enable



```
ISR(TIMER2_COMP_vect)
{
    int i;

    LAYER_SELECT = 0x00; // Turn all cathode layers off. (all transistors off)
    OE_PORT |= OE_MASK; // Set OE high, disabling all outputs on latch array

    // Loop through all 8 bytes of data in the current layer
    // and latch it onto the cube.
    for (i = 0; i < 8; i++)
    {
        // Set the data on the data-bus of the latch array.
        PORTA = cube[current_layer][i];
        // Increment the latch address chip, 74HC138, to create
        // a rising edge (LOW to HIGH) on the current latch.
        LATCH_ADDR = (LATCH_ADDR & LATCH_MASK_INV) | (LATCH_MASK & (i+1));
    }

    OE_PORT &= ~OE_MASK; // Set OE low, enabling outputs on the latch array
    LAYER_SELECT = (0x01 << current_layer); // Transistor ON for current layer

    // Increment the curren_layer counter so that the next layer is
    // drawn the next time this function runs.
    current_layer++;
"main.c" 285L, 7753C written                          103,17-20     30%
```

Image Notes
1. If you move the camera when taking a picture of any POV gadget, you can see the POV action. I moved the camera very fast in this picture. Yet you can barely see the effect. With a lower refresh rate, the dots and spaces would be longer

```
void ioinit (void)
{
    DDRA = 0xff;    // DATA bus output
    DDRB = 0xef;    // Button on B4
    DDRC = 0xff;    // Layer select output
    DDRD = 0xdf;    // Button on D5


    PORTA = 0x00; // Set data bus off
    PORTC = 0x00; // Set layer select off
    PORTB = 0x10; // Enable pull up on button.
    PORTD = 0x20; // Enable pull up on button.


    // Timer 2
    // Frame buffer interrupt
    // 14745600/128/11 = 10472.72 interrupts per second
    // 10472.72/8 = 1309 frames per second
    OCR2 = 10;  // interrupt at counter = 10
    TCCR2 |= (1 << CS20) | (1 << CS22); // Prescaler = 128.
    TCCR2 |= (1 << WGM21); // CTC mode. Reset counter when OCR2 is reached.
    TCNT2 = 0x00;   // initial counter value = 0;
    TIMSK |= (1 << OCIE2); // Enable CTC interrupt
                                                    111,1         41%
```

Step 54: Software: Low level functions

We have made a small library of low level graphic functions.
There are three main reasons for doing this.

Memory footprint

The easiest way to address each voxel would be through a three dimensional buffer array. Like this:

unsigned char cube[x][y][z]; (char means an 8 bit number, unsigned means that it's range is from 0 to 255. signed is -128 to +127)

Within this array each voxel would be represented by an integer, where 0 is off and 1 is on. In fact, you could use the entire integer and have 256 different brightness levels. We actually tried this first, but it turned out that our eBay LEDs had very little change in brightness in relation to duty cycle. The effect wasn't noticeable enough to be worth the trouble. We went for a monochrome solution. On and off.

With a monochrome cube and a three dimensional buffer, we would be wasting 7/8 of the memory used. The smallest amount of memory you can allocate is one byte (8 bits), and you only need 1 bit to represent on and off. 7 bits for each voxel would be wasted. 512*(7/8) = 448 bytes of wasted memory. Memory is scarce on micro controllers, so this is a sub-optimal solution.

Instead, we created a buffer that looks like this:

unsigned char cube[z][y];

In this buffer the X axis is represented within each of the bytes in the buffer array. This can be quite confusing to work with, which brings us to the second reason for making a library of low level drawing functions:

Code readability

Setting a voxel with the coordinates x=4, y=3, z=5 will require the following code:

cube[5][3] |= (0x01 << 4);

You can see how this could lead to some serious head scratching when trying to debug your effect code ;)

In draw.c we have made a bunch of functions that takes x,y,z as arguments and does this magic for you.

Setting the same voxel as in the example above is done with setvoxel(4,3,5), which is _a lot_ easier to read!

draw.c contains many more functions like this. Line drawing, plane drawing, box drawing, filling etc. Have a look in draw.c and familiarize yourself with the different functions.

Reusable code and code size

As you can see in draw.c, some of the functions are quite large. Writing that code over and over again inside effect functions would take up a lot of program memory. We only have 32 KB to work with. Its also boring to write the same code over and over again ;)

```
#include "draw.h"
#include "string.h"

// Set a single voxel to ON
void setvoxel(int x, int y, int z)
{
    if (inrange(x,y,z))
        cube[z][y] |= (1 << x);
}

// Set a single voxel in the temporary cube buffer to ON
void tmpsetvoxel(int x, int y, int z)
{
    if (inrange(x,y,z))
        fb[z][y] |= (1 << x);
}

// Set a single voxel to OFF
void clrvoxel(int x, int y, int z)
{
    if (inrange(x,y,z))
        cube[z][y] &= ~(1 << x);
}

"draw.c" 558L, 9655C written                          1,1           Top
```

Step 55: Software: Cube virtual space

Now that we have a cube buffer and a nice little collection of low level draw functions to populate it, we need to agree on which ways is what, and what is up and what is down ;)

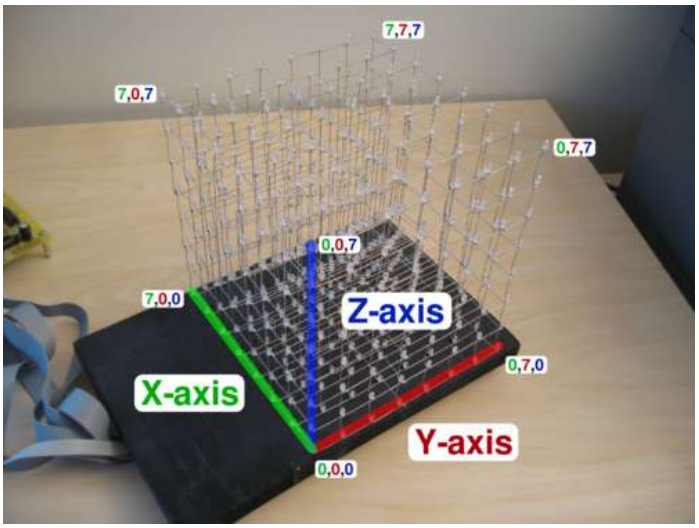
From now on, the native position of the LED cube will be with the cables coming out to the left.

In this orientation, the Y axis goes from left to right. The X axis goes from front to back. The Z axis goes from bottom to top.

Coordinates in this instructable is always represented as x,y,z.

Position 0,0,0 is the bottom left front corner. Position 7,7,7 is the top right back corner.

Why did we use the Y axis for left/right and X for back/front? Shouldn't it be the other way around? Yes, we think so too. We designed the the LED cube to be viewed from the "front" with the cables coming out the back. However, this was quite impractical when having the LED cube on the desk, it was more practical to have the cables coming out the side, and having cube and controller side by side. All the effect functions are designed to be viewed from this orientation.



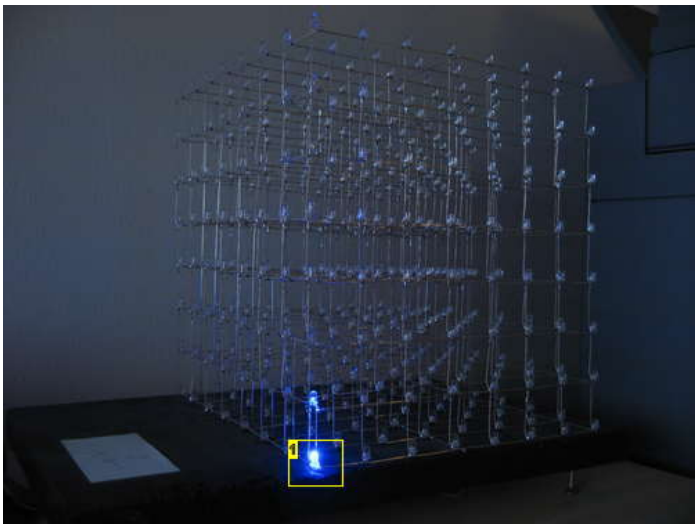


Image Notes
1. 0,0,0

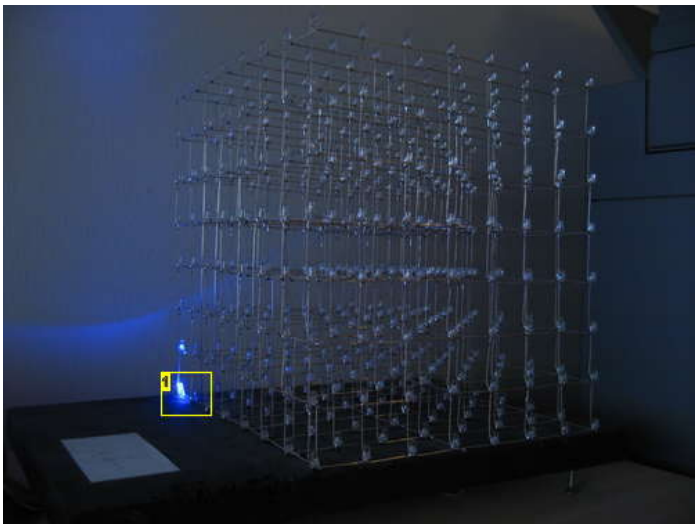


Image Notes
1. 7,0,0

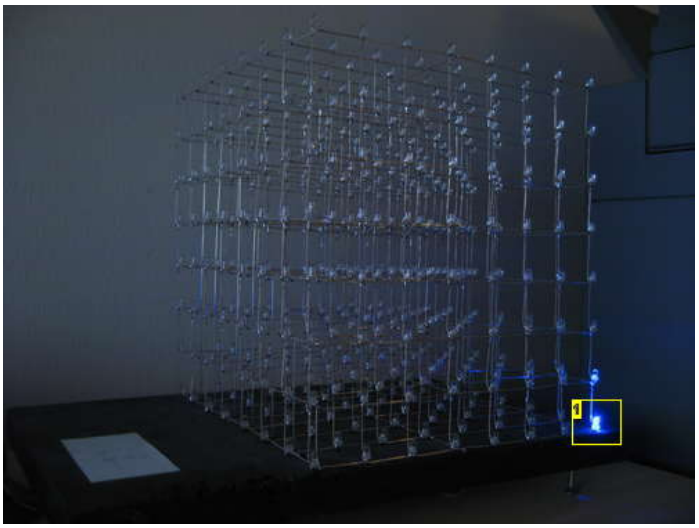


Image Notes
1. 0,7,0

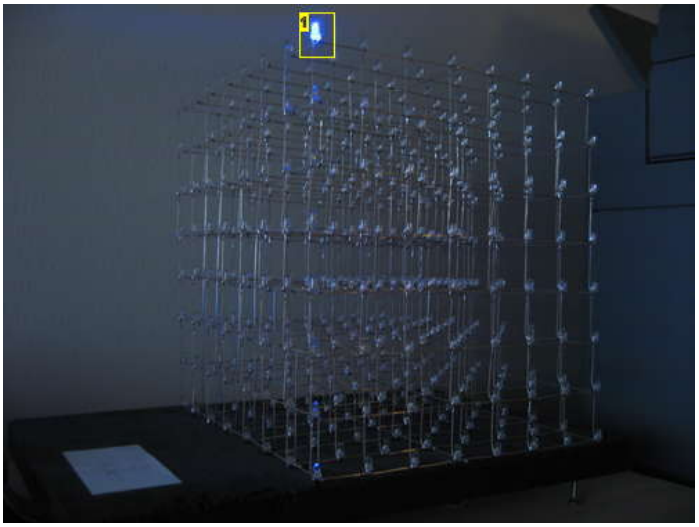


Image Notes
1. 0,0,7

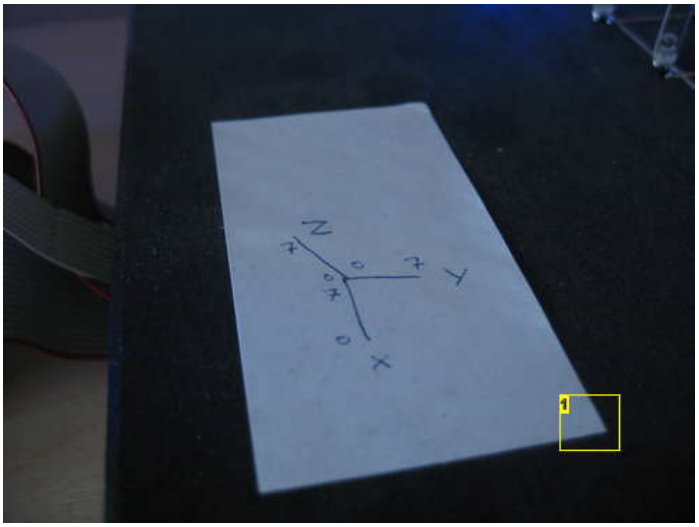


Image Notes
1. Made a little cheat note while programming ;)

Step 56: Software: Effect launcher

We wanted an easy way to run the effects in a fixed order or a random order. The solution was to create an effect launcher function.

launch_effect.c contains the function launch_effect (int effect).

Inside the function there is a switch() statement which calls the appropriate effect functions based on the number launch_effect() was called with.

In launch_effect.h EFFECTS_TOTAL is defined. We set it one number higher than the highest number inside the switch() statement.

Launching the effects one by one is now a simple matter of just looping through the numbers and calling launch_effect(), like this:

```
while(1)
	for (i=0; i < EFFECTS_TOTAL; i++)
	{

		launch_effect(i);

	}
}
```

This code will loop through all the effects in incremental order forever.
If you want the cube to display effects in a random order, just use the following code:

```
while (1)
{
	launch_effect(rand()%EFFECTS_TOTAL);

}
```

The %EFFECTS_TOTAL after rand() keeps the random value between 0 and EFFECTS_TOTAL-1.

```
void launch_effect (int effect)
{
    int i;
    unsigned char ii;

    fill(0x00);

    switch (effect)
    {
        case 0x00:
            effect_rain(100);
            break;


        case 1:
            sendvoxels_rand_z(20,220,2000);
            break;

        case 2:
            effect_random_filler(5,1);
            effect_random_filler(5,0);
            effect_random_filler(5,1);
            effect_random_filler(5,0);
            break;
                                                    29,1-4        3%
```

```
#ifndef LAUNCH_H
#define LAUNCH_H

#include "cube.h"

// Total number of effects
// Used in the main loop to loop through all the effects one by bone.
// Set this number one higher than the highest number inside switch()
// in launch_effect() in launch_effect.c
#define EFFECTS_TOTAL 27

void launch_effect (int effect);

#endif
~
~
~
~
~
~
~
~
~
"launch_effect.h" 15L, 330C                           1,1           All
```

```
    // Go to rs232 mode. this function loops forever.
    if (i == 2)
    {
        rs232();
    }

    // Result of bootwait() is something other than 2:
    // Do awesome effects. Loop forever.
    while (1)
    {
        // Show the effects in a predefined order
        for (i=0; i<EFFECTS_TOTAL; i++)
            launch_effect(i);

        // Show the effects in a random order.
        // Comment the two lines above and uncomment this
        // if you want the effects in a random order.
        //launch_effect(rand()%EFFECTS_TOTAL);
    }

}

/*
 * Multiplexer/framebuffer routine
                                                    64,1          16%
```

Step 57: Software: Effect 1, rain

Lets start with one of the simplest effects.

In effect.c you will find the function effect_rain(int iterations).

This effect adds raindrops to the top layer of the cube, then lets them fall down to the bottom layer.

Most of the effects have a main for() loop that loops from i=0 to i < iterations.
effect_rain(int iterations) only takes one argument, which is the number of iterations.

Inside the iteration loop, the function does the following:

1) Create a random number between 0 and 3, lets call it n here.

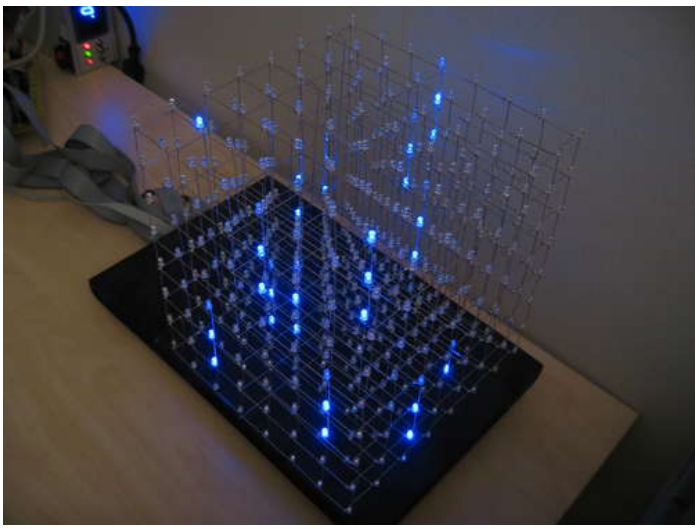
2) Loop a for() loop n number of times.

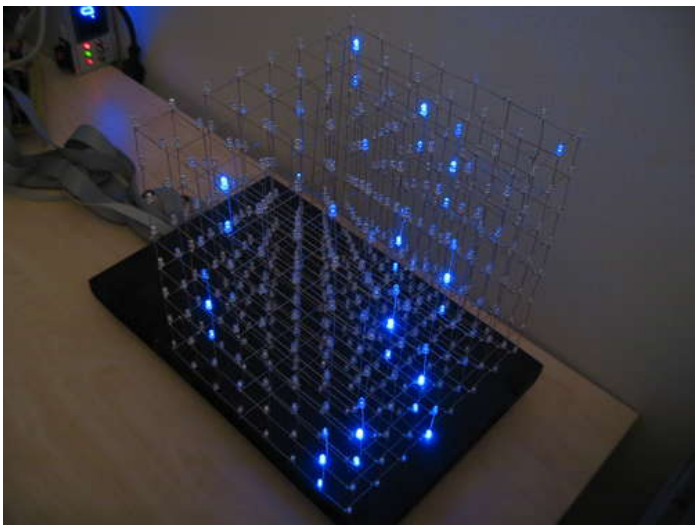
3) For each iteration of this loop, place a pixel on layer 7 (z=7) at random x and y coordinates.

4) Delay for a while

5) Shift the contents of the entire cube along the Z axis by -1 positions. This shifts everything down one level.

This is a pretty simple effect, but it works!





```
void effect_rain (int iterations)
{
    int i, ii;
    int rnd_x;
    int rnd_y;
    int rnd_num;

    for (ii=0;ii<iterations;ii++)
    {
        rnd_num = rand()%4;

        for (i=0; i < rnd_num;i++)
        {
            rnd_x = rand()%8;
            rnd_y = rand()%8;
            setvoxel(rnd_x,rnd_y,7);
        }

        delay_ms(1000);
        shift(AXIS_Z,-1);
    }
}
"effect.c" 1331L, 21045C written                    672,0-1       49%
```

Step 58: Software: Effect 2, plane boing

Another simple effect, effect_planboing(int plane, int speed).

This effect draws a plane along the specified axis then moves it from position 0 to 7 on the axis and back again. This is very simple, but it really brings out the depth of the 3d LED cube :)

This function doesn't have an iteration loop. Instead it is called twice for each axis in launch_effect().

Here is what it does:

1) For()-loop i from 0 to 7.

2) Clear the cube with fill(0x00);

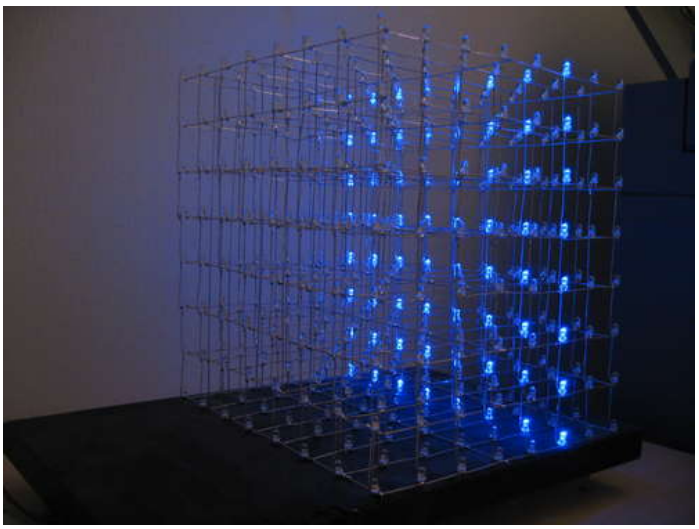
3) Call setplane() to draw a plane along the desired axis at position i. The plane isn't actually drawn on the axis specified, it is drawn on the other two axis. If you specify AXIS_Z, a plane is drawn on axis X and Y. It's just easier to think of it that way. Instead of having constants named PLANE_XY, PLANE_YZ etc.

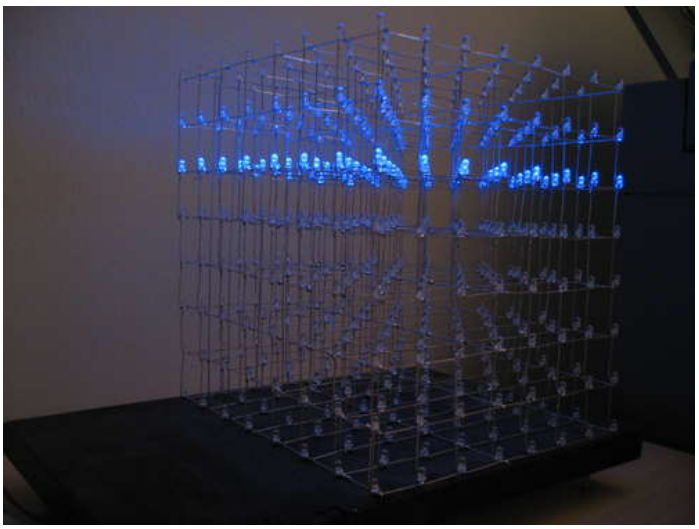
4) Delay for a while.

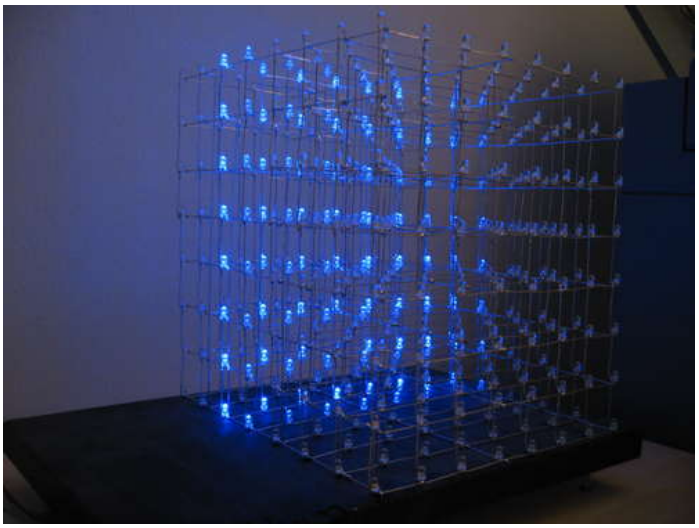
5) Repeat the same loop with i going from 7 to 0.

Very simple, but a very cool effect!

CLICK TO PLAY VIDEO







```
            effect_box_woopwoop(800,0);
            effect_box_woopwoop(800,1);
            effect_box_woopwoop(800,0);
            effect_box_woopwoop(800,1);
            break;

        case 7:
            effect_planboing (AXIS_Z, 400);
            effect_planboing (AXIS_X, 400);
            effect_planboing (AXIS_Y, 400);
            effect_planboing (AXIS_Z, 400);
            effect_planboing (AXIS_X, 400);
            effect_planboing (AXIS_Y, 400);
            fill(0x00);
            break;

        case 8:
            fill(0x00);
            effect_telcstairs(0,800,0xff);
            effect_telcstairs(0,800,0x00);
            effect_telcstairs(1,800,0xff);
            effect_telcstairs(1,800,0xff);
            break;

"launch_effect.c" 182L, 3489C written                    52,30-39      30%
```

```
}

// Draw a plane on one axis and send it back and forth once.
void effect_planboing (int plane, int speed)
{
    int i;
    for (i=0;i<8;i++)
    {
        fill(0x00);
        setplane(plane, i);
        delay_ms(speed);
    }

    for (i=7;i>=0;i--)
    {
        fill(0x00);
        setplane(plane,i);
        delay_ms(speed);
    }
}

void effect_blinky2()
{
    int i,r;
"effect.c" 1331L, 21045C written                          83,1          4%
```

Step 59: Software: Effect 3, sendvoxels random Z

This effect sends voxels up and down the Z axis, as the implies.

void sendvoxels_rand_z() takes three arguments. Iterations is the number of times a voxel is sent up or down. Delay is the speed of the movement (higher delay means lower speed). Wait is the delay between each voxel that is sent.

This is how it works:

1) The cube is cleared with fill(0x00);

2) Loop through all 64 positions along X/Y and randomly set a voxel at either Z=0 or Z=7.

3) Enter the main iteration loop

4) Select random coordinates for X and Y between 0 and 7. If the X and Y coordinates are identical to the previous coordinates, this iteration is skipped.

5) Check if the voxel at this X/Y coordinate is at Z=0 or Z=7, and send it to the opposite side using sendvoxel_z().

6) Delay for a while and save the coordinates of this iteration so we can check them against the random coordinates in the next iteration. It looked weird to move the same voxel twice in a row.

The actual movement of the voxels is done by another function, sendvoxel_z. The reason for this, is that a couple of other effects does the same thing only in different ways.

The function sendvoxel_z() takes four argument. X and Y coordinates. Z coordinate, this is the destination and can either be 0 or 7. Delay which controls the speed.

This is how it works:

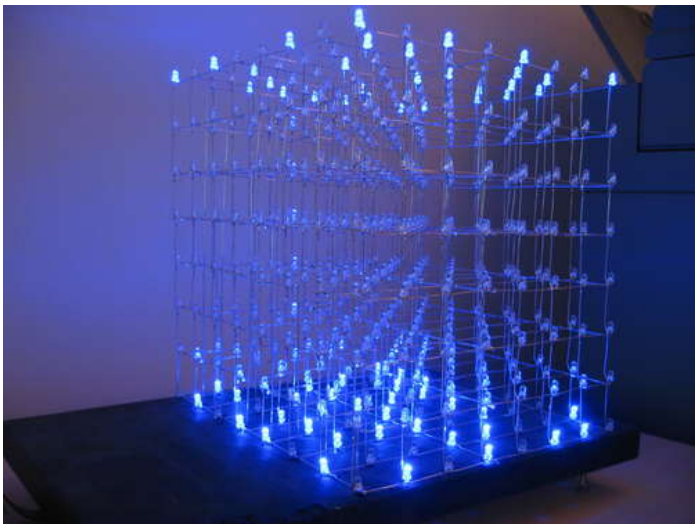
1) For()-loop i from 0 to 7.

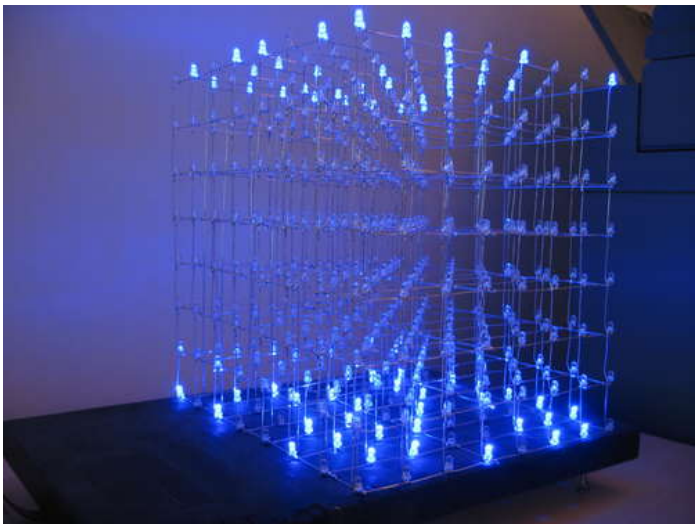
2) If the destination is 7, we set ii to 7-1, thus making ii the reverse of i. Clear the voxel at Z = ii+1. When moving down, ii+1 is the previous voxel.

3) If the destination is 0, let ii be equal to i. Clear ii-1. When moving upwards, -1 is the previous voxel.

4) Set the voxel at z=ii.

5) Wait for a while.





```
void sendvoxels_rand_z (int iterations, int delay, int wait)
{
    unsigned char x, y, last_x = 0, last_y = 0, i;

    fill(0x00);

    // Loop through all the X and Y coordinates
    for (x=0;x<8;x++)
    {
        for (y=0;y<8;y++)
        {
            // Then set a voxel either at the top or at the bottom
            // rand()%2 returns either 0 or 1, multiplying by 7 gives either 0 or
7.
            setvoxel(x,y,((rand()%2)*7));
        }
    }

    for (i=0;i<iterations;i++)
    {
        // Pick a random x,y position
        x = rand()%8;
        y = rand()%8;
        // but not the sameone twice in a row
"effect.c" 1331L, 21045C written                          235,0-1       16%
```

```
    for (i=0;i<iterations;i++)
    {
        // Pick a random x,y position
        x = rand()%8;
        y = rand()%8;
        // but not the sameone twice in a row
        if (y != last_y && x != last_x)
        {
            // If the voxel at this x,y is at the bottom
            if (getvoxel(x,y,0))
            {
                // send it to the top
                sendvoxel_z(x,y,0,delay);
            } else
            {
                // if its at the top, send it to the bottom
                sendvoxel_z(x,y,7,delay);
            }
            delay_ms(wait);

            // Remember the last move
            last_y = y;
            last_x = x;
    }
                                                          259,1-4       17%
```

```

// Send a voxel flying from one side of the cube to the other
// If its at the bottom, send it to the top..
void sendvoxel_z (unsigned char x, unsigned char y, unsigned char z, int delay)
{
    int i, ii;
    for (i=0; i<8; i++)
    {
        if (z == 7)
        {
            ii = 7-i;
            clrvoxel(x,y,ii+1);
        } else
        {
            ii = i;
            clrvoxel(x,y,ii-1);
        }
        setvoxel(x,y,ii);
        delay_ms(delay);
    }
}

// Send all the voxels from one side of the cube to the other
                                                          168,0-1       12%
```

Step 60: Software: Effect 4, box shrinkgrow and woopwoop

A wireframe box is a good geometric shape to show in a monochrome 8x8x8 LED cube. It gives a very nice 3d effect.

We made two box animation functions for the LED cube. Effect_box_shrink_grow() draws a wireframe box filling the entire cube, then shrinks it down to one voxel in one of 8 corners. We call this function one time for each of the 8 corners to create a nice effect. Effect_box_woopwoop() draws a box that starts as a 8x8x8 wireframe box filling the entire cube. It then shrinks down to a 2x2x2 box at the center of the cube. Or in reverse if grow is specified.

Here is how effect_box_shrink_grow() works.

It takes four arguments, number of iterations, rotation, flip and delay. Rotation specifies rotation around the Z axis at 90 degree intervals. Flip > 0 flips the cube upside-down.

To make the function as simple as possible, it just draws a box from 0,0,0 to any point along the diagonal between 0,0,0 and 7,7,7 then uses axis mirror functions from draw.c to rotate it.

1) Enter main iteration loop.

2) Enter a for() loop going from 0 to 15.

3) Set xyz to 7-i. This makes xyz the reverse of i. We want to shrink the box first, then grow. xyz is the point along the diagonal. We just used one variable since x, y and z are all equal along this diagonal.

4) When i = 7, the box has shrunk to a 1x1x1 box, and we can't shrink it any more. If i is greater than 7, xyz is set to i-8, which makes xyz travel from 0 to 7 when i travels from 8 to 15. We did this trick to avoid having two for loops, whith one going from 7-0 and one from 0-7.

5) Blank the cube and delay a little bit to make sure the blanking is rendered on the cube. Disable the interrupt routine. We do this because the mirror functions takes a little time. Without disabling interrupts, the wireframe box would flash briefly in the original rotation before being displayed rotated.

6) Draw the wireframe box in its original rotation. side of the box is always at 0,0,0 while the other travels along the diagonal.

7) Do the rotations. If flip is greather than 0, the cube is turned upside-down. rot takes a number from 0 to 3 where 0 is 0 degrees of rotation around Z and 3 is 270 degrees. To get 270 degrees we simply mirror around X and Y.

8) Enable interrupts to display the now rotated cube.

9) Delay for a while then clear the cube.

The other function involved in the wireframe box effect is effect_box_woopwoop(). The name woopwoop just sounded natural when we first saw the effect rendered on the cube ;)

The woopwoop function only does one iteration and takes two arguments, delay and grow. If grow is greater than 0, the box starts as a 2x2x2 box and grow to a 8x8x8 box.

Here is how it works:

1) Clear the cube by filling the buffer with 0x00;

2) For()-loop from 0 to 3.

4) Set ii to i. If grow is specified we set it to 3-i to reverse it.

5) Draw a wireframe box centered along the diagonal between 0,0,0 and 7,7,7. One corner of the box uses the coordinates 4+ii on all axes, moving from 4-7. The other corner uses 3-ii on all axes, moving from 3-0.

6) Delay for a while, then clear the cube.

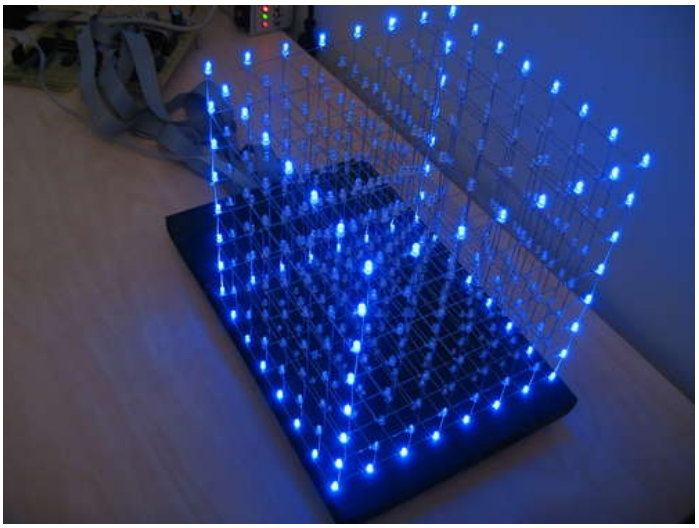
These two functions are used as one single effect in the effect launcher. First the shrink grow effect is called 8 times, one for each corner, then woopwoop is called four times, two shrink and grow cycles.

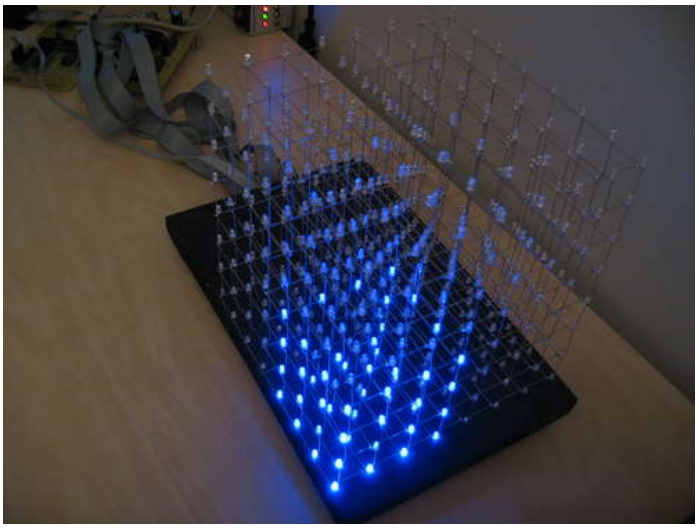
To launch the shrink grow function, we used a for loop with some neat bit manipulation tricks inside to avoid writing 8 lines of code.

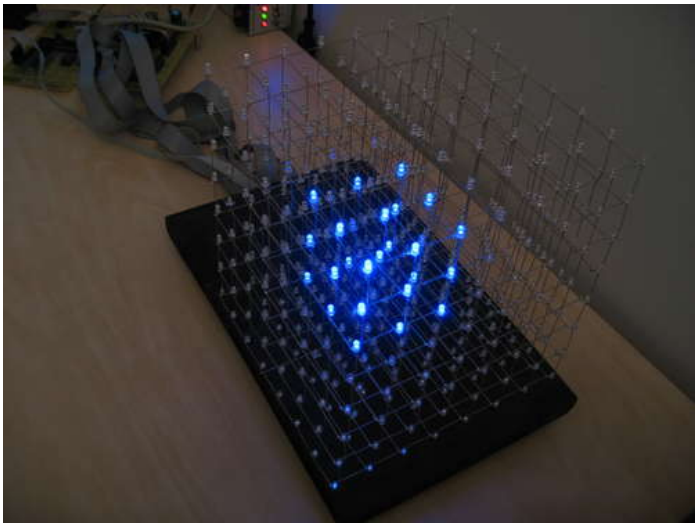
The second argument of the shrink grow functions is the rotation, in 4 steps. We are counting from 0 to 7, so we can't simply feed i into the function. We use the modulo operator % to keep the number inside a range of 0-4. The modulo operator divides by the number specifies and returns the remainder.

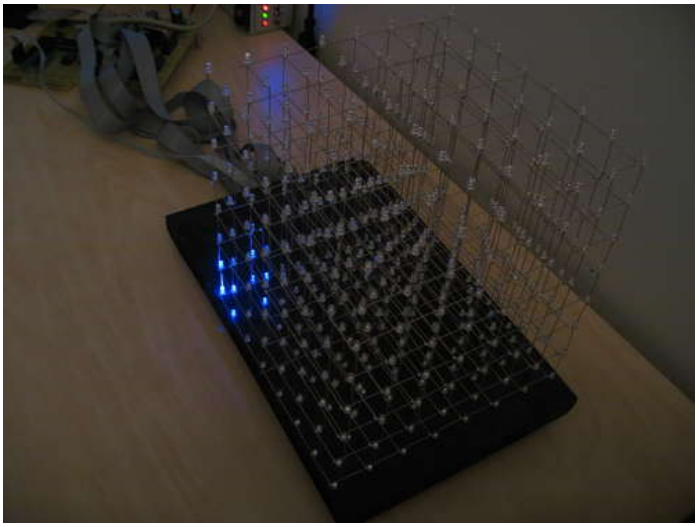
The third argument is the flip. When flip = 0, the cube is not flipped. > 0 flips. We use the bitwise AND operator to only read bit 3 of i.

Bitwise operators are an absolute must to know about when working with micro controllers, but that is outside the scope of this instructable. The guys over at AVR Freaks have posted some great information about this topic. You can read more at http://www.avrfreaks.net/index.php?name=PNphpBB2&file=viewtopic&t=37871









```
}

// Creates a wireframe box that shrinks or grows out from the center of the cube.
void effect_box_woopwoop (int delay, int grow)
{
    int i,ii;

    fill(0x00);
    for (i=0;i<4;i++)
    {
        ii = i;
        if (grow > 0)
            ii = 3-i;

        box_wireframe(4+ii,4+ii,4+ii,3-ii,3-ii,3-ii);
        delay_ms(delay);
        fill(0x00);
    }
}


// Send a voxel flying from one side of the cube to the other
// If its at the bottom, send it to the top..
void sendvoxel_z (unsigned char x, unsigned char y, unsigned char z, int delay)
                                                          148,1         11%
```

```
}

// Flip the cube 180 degrees along the x axis
void mirror_x (void)
{
    unsigned char buffer[8][8];
    unsigned char y,z;

    memcpy(buffer, cube, 64); // copy the current cube into a buffer.

    fill(0x00);

    for (z=0; z<8; z++)
    {
        for (y=0; y<8; y++)
        {
            cube[z][y] = flipbyte(buffer[z][y]);
        }
    }
}

// flip the cube 180 degrees along the z axis
void mirror_z (void)
{
                                                          544,1         97%
```

```
void effect_box_shrink_grow (int iterations, int rot, int flip, uint16_t delay)
{
    int x, i, xyz;
    for (x=0;x<iterations;x++)
    {
        for (i=0;i<16;i++)
        {
            xyz = 7-i; // This reverses counter i between 0 and 7.
            if (i > 7)
                xyz = i-8; // at i > 7, i 8-15 becomes xyz 0-7.

            fill(0x00); delay_ms(1);
            cli(); // disable interrupts while the cube is being rotated
            box_wireframe(0,0,0,xyz,xyz,xyz);

            if (flip > 0) // upside-down
                mirror_z();

            if (rot == 1 || rot == 3)
                mirror_y();

            if (rot == 2 || rot == 3)
                mirror_x();
            
                                                    142,12        9%
```

```
        case 5:
            effect_blinky2();
            break;

        case 6:
            for (ii=0;ii<8;ii++)
            {
                effect_box_shrink_grow (1, ii%4, ii & 0x04, 450);
            }

            effect_box_woopwoop(800,0);
            effect_box_woopwoop(800,1);
            effect_box_woopwoop(800,0);
            effect_box_woopwoop(800,1);
            break;

        case 7:
            effect_planboing (AXIS_Z, 400);
            effect_planboing (AXIS_X, 400);
            effect_planboing (AXIS_Y, 400);
            effect_planboing (AXIS_Z, 400);
            effect_planboing (AXIS_X, 400);
            effect_planboing (AXIS_Y, 400);
            fill(0x00);
                                                    41,4-13       24%
```

Step 61: Software: Effect 5, axis updown randsuspend

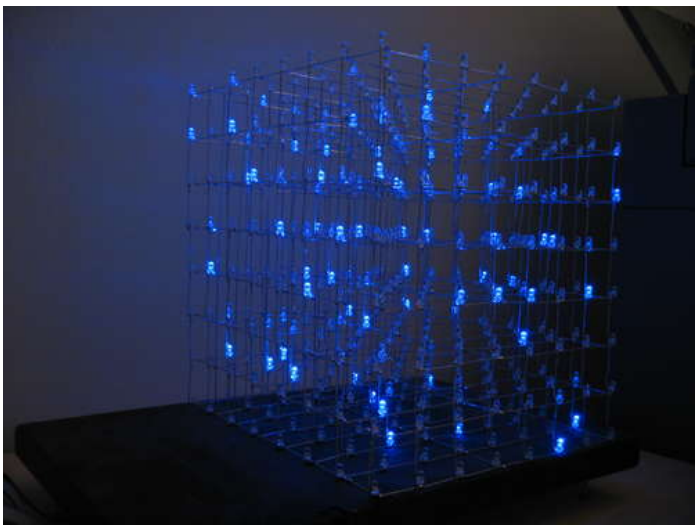
This is one of our favorite effects. The voxels randomly suspended in the cube gives a nice 3d depth, especially if you move your head while viewing the effect.

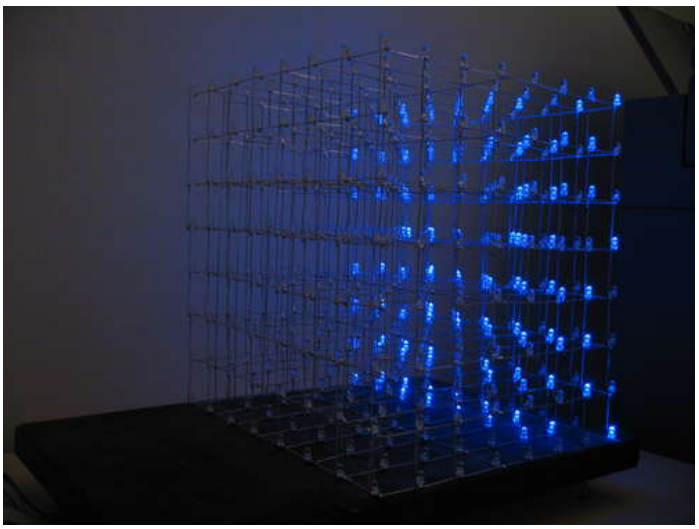
64 voxels start out on one of the side walls. Then they all get assigned a random midway destination between the side wall they started at and the wall on the opposite side.

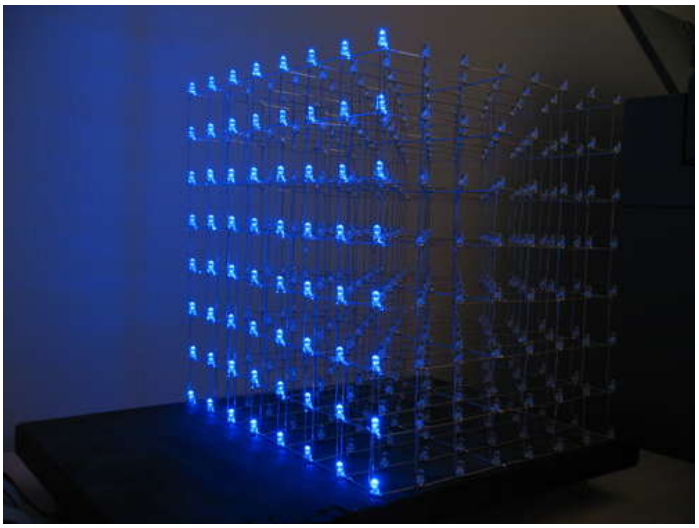
The function then loops 8 times moving each voxel closer to its midway destination. After 8 iterations, the voxels are suspended at different distances from where they started. The function then pauses for a while, thus the name axis_updown_randsuspend ;). It then loops 8 times again moving the voxels one step closer to their final destination on the opposite wall each time.

The actual voxel drawing is done in a separate function, draw_positions_axis() so it can be used in different effects. For example, the voxels could be suspended midway in a non-random pattern. We will leave it up to you to create that effect function! :D

You may have noticed that the description for this effect was less specific. We encourage you to download the source code and read through the functions yourself. Keep the text above in mind when reading the code, and try to figure out what everything does.







```
void effect_axis_updown_randsuspend (char axis, int delay, int sleep, int invert)
{
    unsigned char positions[64];
    unsigned char destinations[64];

    int i,px;

    // Set 64 random positions
    for (i=0; i<64; i++)
    {
        positions[i] = 0; // Set all starting positions to 0
        destinations[i] = rand()%8;
    }

    // Loop 8 times to allow destination 7 to reach all the way
    for (i=0; i<8; i++)
    {
        // For every iteration, move all position one step closer to their destina
tion
        for (px=0; px<64; px++)
        {
            if (positions[px]<destinations[px])
            {
                positions[px]++;
                                                              752,1-4       55%
```

```
            {
                positions[px]++;
            }
        }
        // Draw the positions and take a nap
        draw_positions_axis (axis, positions,invert);
        delay_ms(delay);
    }

    // Set all destinations to 7 (opposite from the side they started out)
    for (i=0; i<64; i++)
    {
        destinations[i] = 7;
    }

    // Suspend the positions in mid-air for a while
    delay_ms(sleep);

    // Then do the same thing one more time
    for (i=0; i<8; i++)
    {
        for (px=0; px<64; px++)
        {
            if (positions[px]<destinations[px])
                                                              774,1-4       57%
```

```
    // Suspend the positions in mid-air for a while
    delay_ms(sleep);

    // Then do the same thing one more time
    for (i=0; i<8; i++)
    {
        for (px=0; px<64; px++)
        {
            if (positions[px]<destinations[px])
            {
                positions[px]++;
            }
            if (positions[px]>destinations[px])
            {
                positions[px]--;
            }
        }
        draw_positions_axis (axis, positions,invert);
        delay_ms(delay);
    }
}
void draw_positions_axis (char axis, unsigned char positions[64], int invert)
                                                              787,0-1       58%
```

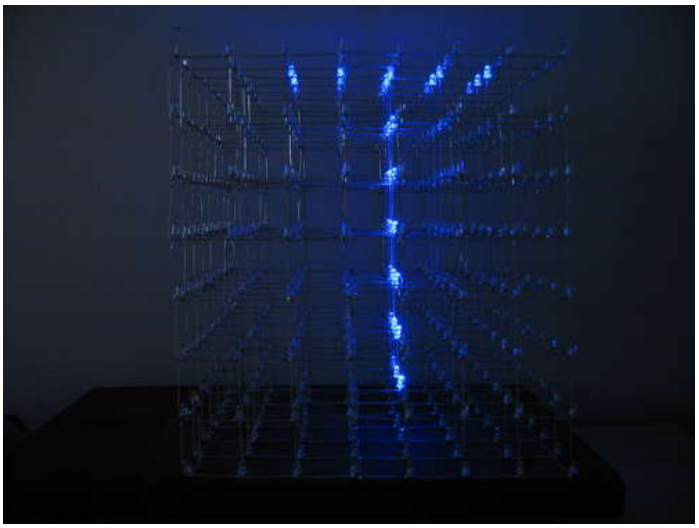
Step 62: Software: Effect 6, stringfly

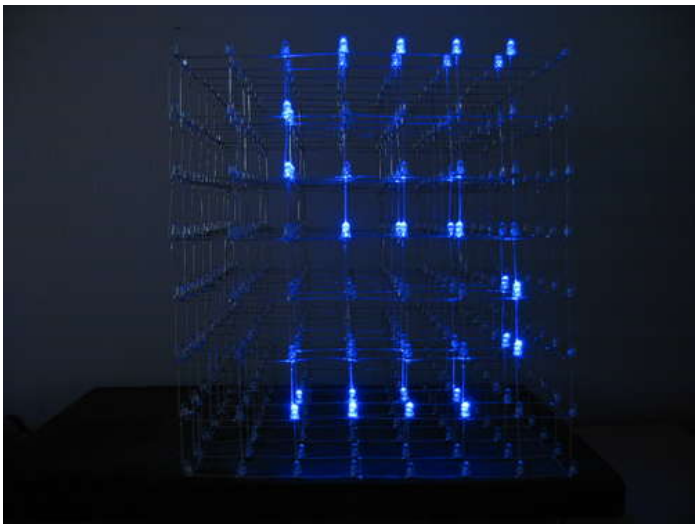
8x8 is about the smallest size required to render a meaningful text font, so we just had to do just that!

We loaded a 8x5 bitmap font that we had previously used with a graphical LCD display into EEPROM memory, and created some functions that took an ASCII char as an argument and returned a bitmap of the character.

The function stringfly2 takes any ASCII string and displays it as characters flying through the cube.

It starts by placing the character at the back of the cube, then uses the shift() function to shift the cube contents towards you, making the text fly.





```
#include "font.h"
#include <avr/eeprom.h>

volatile const unsigned char font[455] EEMEM = {
    0x00,0x00,0x00,0x00,0x00,0x00,0x5f,0x5f,0x00,0x00,  // !
    0x00,0x03,0x00,0x03,0x00,0x14,0x7f,0x14,0x7f,0x14,  // "#
    0x24,0x2a,0x7f,0x2a,0x12,0x23,0x13,0x08,0x64,0x62,  // $%
    0x36,0x49,0x55,0x22,0x50,0x00,0x05,0x03,0x00,0x00,  // &'
    0x00,0x1c,0x22,0x41,0x00,0x00,0x41,0x22,0x1c,0x00,  // ()
    0x14,0x08,0x3e,0x08,0x14,0x08,0x08,0x3e,0x08,0x08,  // *+
    0x00,0x50,0x30,0x00,0x00,0x08,0x08,0x08,0x08,0x08,  // ,-
    0x00,0x60,0x60,0x00,0x00,0x20,0x10,0x08,0x04,0x02,  // ./
    0x3e,0x51,0x49,0x45,0x3e,0x00,0x42,0x7f,0x40,0x00,  // 01
    0x42,0x61,0x51,0x49,0x46,0x21,0x41,0x45,0x4b,0x31,  // 23
    0x18,0x14,0x12,0x7f,0x10,0x27,0x45,0x45,0x45,0x39,  // 45
    0x3c,0x4a,0x49,0x49,0x30,0x01,0x71,0x09,0x05,0x03,  // 67
    0x36,0x49,0x49,0x49,0x36,0x06,0x49,0x49,0x29,0x1e,  // 89
    0x00,0x36,0x36,0x00,0x00,0x00,0x56,0x36,0x00,0x00,  // :;
    0x08,0x14,0x22,0x41,0x00,0x14,0x14,0x14,0x14,0x14,  // <=
    0x00,0x41,0x22,0x14,0x08,0x02,0x01,0x51,0x09,0x06,  // >?
    0x32,0x49,0x79,0x41,0x3e,0x7e,0x11,0x11,0x11,0x7e,  // @A
    0x7f,0x49,0x49,0x49,0x36,0x3e,0x41,0x41,0x41,0x22,  // BC
    0x7f,0x41,0x41,0x22,0x1c,0x7f,0x49,0x49,0x49,0x41,  // DE
    0x7f,0x09,0x09,0x09,0x01,0x3e,0x41,0x49,0x49,0x7a,  // FG
"font.c" 104L, 4142C                                    1,1           Top
```

Image Notes
1. Font stored in EEPROM memory.

```
    for (i = 0; i < length; i++)
        destination[i] = pgm_read_byte(&paths[i+offset]);
}

void font_getchar (char chr, unsigned char dst[5])
{
    int i;
    chr -= 32; // our bitmap font starts at ascii char 32.

    for (i = 0; i < 5; i++)
        dst[i] = eeprom_read_byte(&font[(chr*5)+i]);
}

void font_getbitmap (char bitmap, unsigned char dst[8])
{
    int i;

    for (i = 0; i < 8; i++)
        dst[i] = eeprom_read_byte(&bitmaps[bitmap][i]);

}

unsigned char font_getbitmappixel ( char bitmap, char x, char y)
                                                        76,1          90%
```

Image Notes
1. Takes an ASCII character as input and returns a bitmap of the character.

```
void effect_stringfly2(char * str)
{
    int x,y,i;
    unsigned char chr[5];

    while (*str)
    {
        font_getchar(*str++, chr);

        // Put a character on the back of the cube
        for (x = 0; x < 5; x++)
        {
            for (y = 0; y < 8; y++)
            {
                if ((chr[x] & (0x80>>y)))
                {
                    setvoxel(7,x+2,y);
                }
            }
        }

        // Shift the entire contents of the cube forward by 6 steps
        // before placing the next character
        for (i = 0; i<6; i++)
                                                        49,1-4        1%
```

Step 63: Software: RS-232 input

To generate the most awesome effects, we use a desktop computer. Computers can do floating point calculations and stuff like that much quicker than a micro controller. And you don't have to re-program the micro controller for every effect you make, or every time you want to test or debug something.

The USART interface in the ATmega is configured to work at 38400 baud with one stop bit and no parity. Each byte that is sent down the line has a start bit and a stop bit, so 10 bits is sent to transmit 8 bits. This gives us a bandwidth of 3840 bytes per second. The cube buffer is 64 bytes. Syncing bytes make up 2 bytes per cube frame. At 38400 baud we are able to send about 58 frames per second. More than enough for smooth animations.

0xff is used as an escape character, and puts the rs232 function into escape mode. If the next byte is 0x00, the coordinates for the buffer are restored to 0,0. If the next byte is 0xff, it is added to the buffer. To send 0xff, you simply send it twice.

The rs232 function just loops forever. A reset is needed to enter the cube's autonomous mode again.

```
// Take input from a computer and load it onto the cube buffer
void rs232(void)
{
    int tempval;
    int x = 0;
    int y = 0;
    int escape = 0;

    while (1)
    {
        // Switch state on red LED for debugging
        // Should switch state every time the code
        // is waiting for a byte to be received.
        LED_PORT ^= LED_RED;

        // Wait until a byte has been received
        while ( !(UCSRA & (1<<RXC)) );

        // Load the received byte from rs232 into a buffer.
        tempval = UDR;

        // Uncomment this to echo data back to the computer
        // for debugging purposes.
        //UDR = tempval;
                                                    200,1         75%
```

```
    TCCR2 |= (1 << WGM21); // CTC mode. Reset counter when OCR2 is reached.
    TCNT2 = 0x00;  // initial counter value = 0;
    TIMSK |= (1 << OCIE2); // Enable CTC interrupt



    // Initiate RS232
    // USART Baud rate is defined in MYUBRR
    UBRRH = MYUBRR >> 8;
    UBRRL = MYUBRR;
    // UCSRC - USART control register
    // bit 7-6      sync/ascyn 00 = async,  01 = sync
    // bit 5-4      parity 00 = disabled
    // bit 3        stop bits 0 = 1 bit  1 = 2 bits
    // bit 2-1      frame length 11 = 8
    // bit 0        clock polarity = 0
    UCSRC  = 0b10000110;
    // Enable RS232, tx and rx
    UCSRB = (1<<RXEN)|(1<<TXEN);
    UDR = 0x00; // send an empty byte to indicate powerup.


}
                                                    153,0-1       49%
```

Step 64: PC Software: Introduction

The cube just receives binary data via RS232. This data could easily be generated by a number of different programming languages, like python, perl or even php.

We chose to use C for the PC software, since the micro controller software is written in C. This way effects from the micro controller code can just be copy-pasted into the PC software.

Just like in the micro controller code, this code also does two things. Where the micro controller has an interrupt routine that draws the contents of cube[][] onto the LED cube, the PC software has a thread that continually sends data to the LED cube.

```
// Display a sine wave running out from the center of the cube.
void ripples (int iterations, int delay)
{
    float origin_x, origin_y, distance, height, ripple_interval;
    int x,y,i;

    fill(0x00);

    for (i=0;i<iterations;i++)
    {
        for (x=0;x<8;x++)
        {
            for (y=0;y<8;y++)
            {
                distance = distance2d(3.5,3.5,x,y)/9.899495*8;
                //distance = distance2d(3.5,3.5,x,y);
                ripple_interval =1.3;
                height = 4+sin(distance/ripple_interval+(float) i/50)*4;

                setvoxel(x,y,(int) height);
            }
        }
        delay_ms(delay);
        fill(0x00);
                                                    428,2-8       63%
```

File Downloads

cube_pc-v0.1.tar.gz (82 KB)
[NOTE: When saving, if you see .tmp as the file ext, rename it to 'cube_pc-v0.1.tar.gz']

Step 65: PC Software: Cube updater thread

In cube.c we have a function called cube_push(). This takes the 64 byte array and sends it down the serial line to the LED cube.

It also handles the formatting, sending every 0xff byte twice because 0xff is our escape character. 0xff and 0x00 is sent first to reset the LED cubes internal x and y counters.

In main.c we have the function cube_updater(). This function is launched as a separate thread using pthread_create(). The main thread and the cube updater thread shares the memory area rs232_cube[8][8]. The cube updater thread is just a while true loop that calls cube_push() over and over.

The first attempt at an updater thread turned out to create some flickering in the animations. After some debugging, we found out that frames were being transmitted before they were fully drawn by the effect functions. We generally do a fill(0x00), then some code to draw new pixels. If a frame is transmitted right after a fill(0x00), the cube will flash an empty frame for 1/60th ish of a second.

This wasn't a problem in the code running on the LED cube, since it has a refresh rate of over 1000 FPS, but at 60 FPS you can notice it.

To overcome this we create a double buffer and sync the two buffers at a point in time where the effect function has finished drawing the frame. Luckily all the effect functions use the delay_ms() function to pause between finished frames. We just put a memcpy() inside there to copy the cube buffer to the rs232 buffer. This works beautifully. No more flickering!

```
void cube_push (unsigned char data[8][8])
{
    int x,y,i;

    i= 0;

    unsigned char buffer[200];

    buffer[i++] = 0xff; // escape
    buffer[i++] = 0x00; // reset to 0,0

    for (x=0;x<8;x++)
    {
        for (y=0;y<8;y++)
        {
            buffer[i++] = data[x][y];
            if (data[x][y] == 0xff)
            {
                buffer[i++] = data[x][y];
            }
        }
    }

    write(tty,&buffer,i);
                                                    31,2-5        13%
```

Step 66: PC Software: Effect 1, ripples

This is the first effect we made for the PC software, and we think it turned out very nice.

While this may seem like a complicated effect, it's really not!

All the effect functions running on the micro controller mostly use if() statements to create effects. The effects on the PC software are built a little different. We use a lot of sin(), cos() and other math functions here. Most coordinates are calculated as floating point coordinates then typecast into integers before being drawn on the cube.

The effect you see in the video is actually just a sine wave eminating from the center of the cube, x=3.5, y=3.5.

Here is how it works:

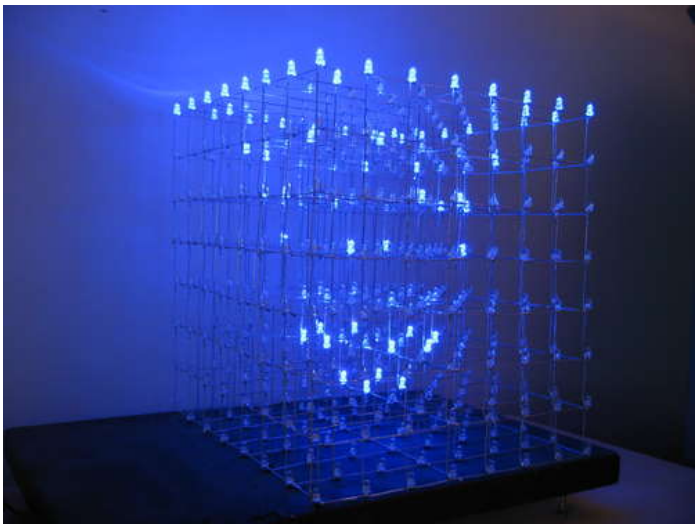
1) Loop through the iteration counter.

2) Loop through all 64 x and y coordinates.

3) Calculate the distance between the center of the cube and the x/y coordinate.

4) The z coordinate is calculated with sin() based on the distance from the center + the iteration counter. The result is that the sine wave moves out from the center as the iteration counter increases.

Look how easy that was!



Step 67: PC Software: Effect 2, sidewaves

This is basically the exact same function as the ripple function.

The only difference is the coordinates of the point used to calculate the distance to each x/y coordinate. We call this point the origin, since the wave emanates from this point.

The origin coordinate is calculated like this:

x = sin(iteration counter) y = cos(iteration counter)

The result is that these x and y coordinates moves around in a circle, resulting in a sin wave that comes in from the side.

We just wanted to show you how easy it is to completely alter an effect by tweaking some variables when working with math based effects!

CLICK TO PLAY VIDEO

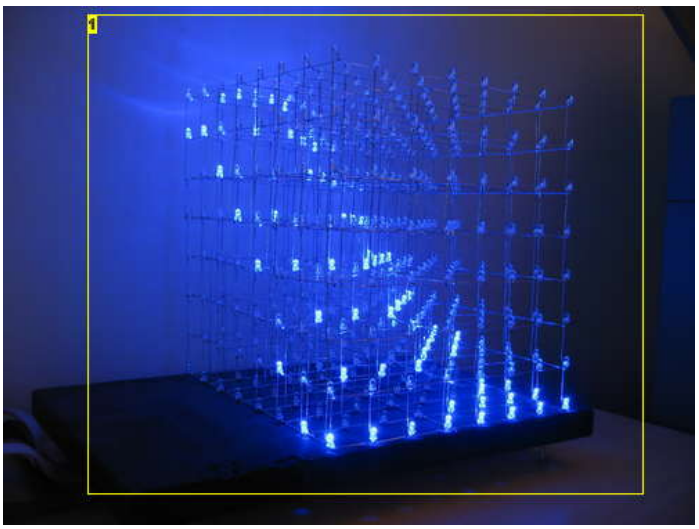


Image Notes
1. Beautiful math!

Step 68: PC Software: Effect 3, fireworks

This effect was quite fun to make.
To make this effect, we really had to sit down and think about how fireworks work, and which forces influence the firework particles.

We came up with a theoretical model of how fireworks work:

1) A rocket is shot up to a random position, origin_x, origin_y, origin_z.

2) The rocket explodes and throws burning particles out in random directions at random velocities.

3) The particles are slowed down by air resistance and pulled towards the ground by gravity.

With this model in mind we created a fireworks effect with a pretty convincing result. Here is how it works:

1) A random origin position is chosen. (within certain limits, x and y between 2 and 5 to keep the fireworks more or less in the center of the cube. z between 5 and 6. Fireworks exploding near the ground can be dangerous! :p)

2) The rocket, in this case a single voxel is moved up the Z axis at the x and y coordinates until it reaches origin_z.

3) An array of n particles is created. Each particle has an x, y and z coordinate as well as a velocity for each axis, dx, dy and dz.

4) We for() loop through 25 particle animation steps:

5) A slowrate is calculated, this is the air resistance. The slowrate is calculated using tan() which will return an exponentially increasing number, slowing the particles faster and faster.

6) A gravity variable is calculated. Also using tan(). The effect of gravity is also exponential. This probably isn't the mathematically correct way of calculating gravity's effect on an object, but it looks good.

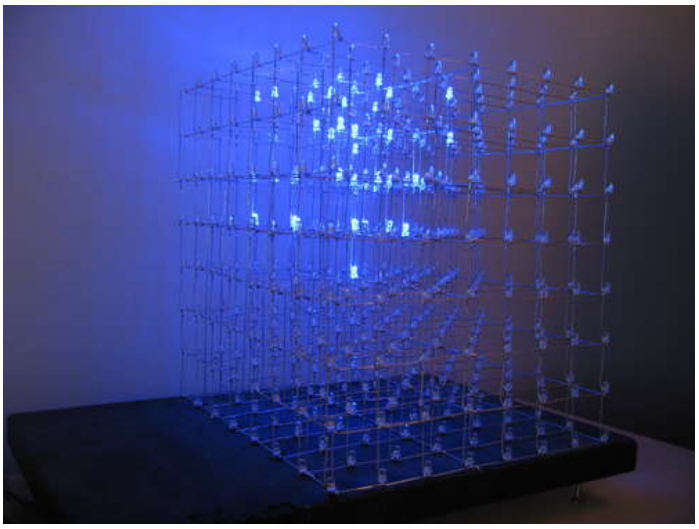
7) For each particle, the x y and z coordinates are incremented by their dx, dy and dz velocities divided by the slowrate. This will make the particles move slower and slower.

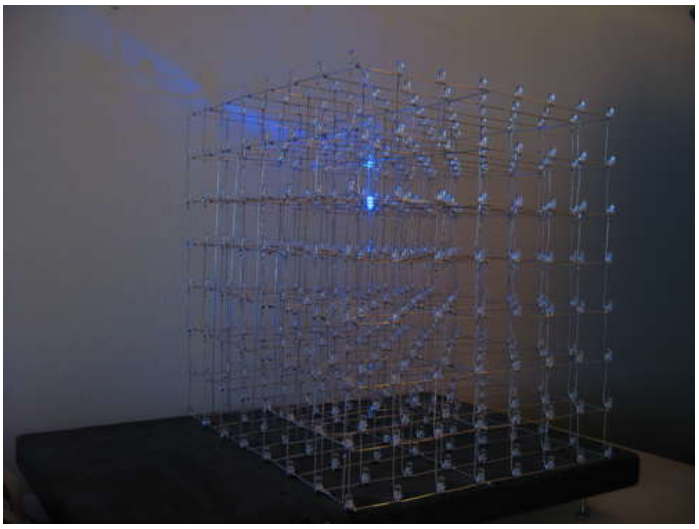
8) The z coordinate is decreased by the gravity variable.

9) The particle is drawn on the cube.

10) Delay for a while, then do the next iteration of the explosion animation.

We are quite pleased with the result.





Step 69: PC Software: Effect 4, Conway's Game of Life 3D

The Game of Life, also known simply as Life, is a cellular automaton devised by the British mathematician John Horton Conway. You can read more about this on Wikipedia, if you haven't heard about it before.

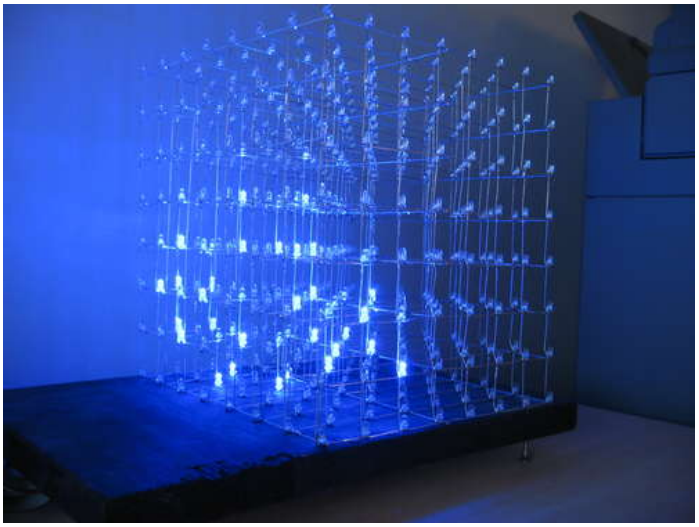
By popular demand, we have implemented Game of Life in 3D on the LED cube.
To make it work in 3d the rules have to be tweaked a little:

- A dead cell becomes alive if it has exactly 4 neighbors
- A live cell with 4 neighbors live
- A live cell with 3 or fewer neighbors die
- A live cell with 5 or more neighbors die

The program starts by placing 10 random voxels in one corner of the cube, then the game of life rules are applied and the iterations started.

In the second video, we run the animation faster and seed with 20 voxels.

CLICK TO PLAY VIDEO



Step 70: Run the cube on an Arduino

Since we published our last LED Cube instructable, we have gotten a lot of questions from people wondering if they could use an Arduino to control the cube.

This time, we are one step ahead of you on the "Can i use an arduino?" front :D

The IO requirements for an 8x8x8 LED cube is:

- Layer select: 8
- Data bus for latches: 8
- Address bus for latches: 3
- Output enable (OE) for latches: 1

Total: 21

The Arduino has 13 GPIO pins and 8 analog inputs, which can also be used as GPIO. This gives you a total of 21 IO lines, exactly the amount of IO needed to run the LED cube!

But why write about it when we could just show you?

We hooked the cube up to an Arduino and ported some of the software.

Since the multiplexer array and AVR board are separated by a ribbon cable, connecting the IO lines to an Arduino is a simple matter of connecting some breadboard wires. Luckily, we soldered in a female 0.1" pin header for the transistor lines when we were debugging the first set of transistors. Just remove the ATmega and connect wires from the Arduino to these pin headers.

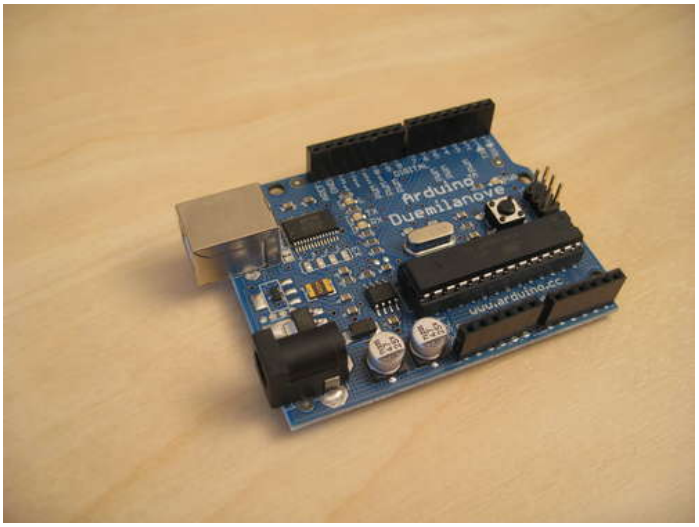
We connected the cube like this: DATA bus: Digital pins 0-7. This corresponds to PORTD on the ATmega328 on the Arduino board, so we can use direct port access instead of Arduinos digitalWrite (which is slow). Address bus: Digital pins 8-10. This corresponds to PORTB bit 0-2. On this we HAVE to use direct port access. Arduinos digitalWrite wouldn't work with this, because you can't set multiple pins simultaneously. If the address pins are not set at the exact same time, the output of the 74HC138 would trigger the wrong latches. Output Enable: Digital pin 11. Layer transistors: Analog pins 0-5 and digital pins 12 and 13.

We had to go a bit outside the scope of the Arduino platform. The intention of Arduino is to use digitalWrite() for IO port access, to make the code portable and some other reasons. We had to sidestep that and access the ports directly. In addition to that, we had to use one of the timers for the interrupt routine.

The registers for the interrupt and timers are different on different AVR models, so the code may not be portable between different versions of the Arduino board.

The code for our quick Arduino hack is attached.

CLICK TO PLAY VIDEO



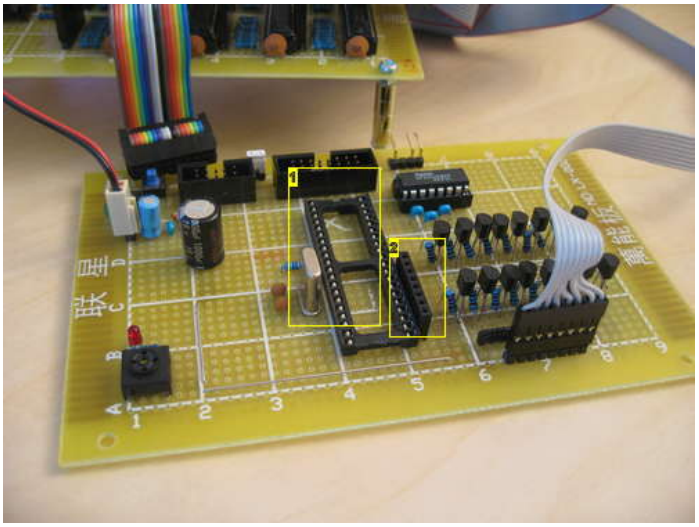
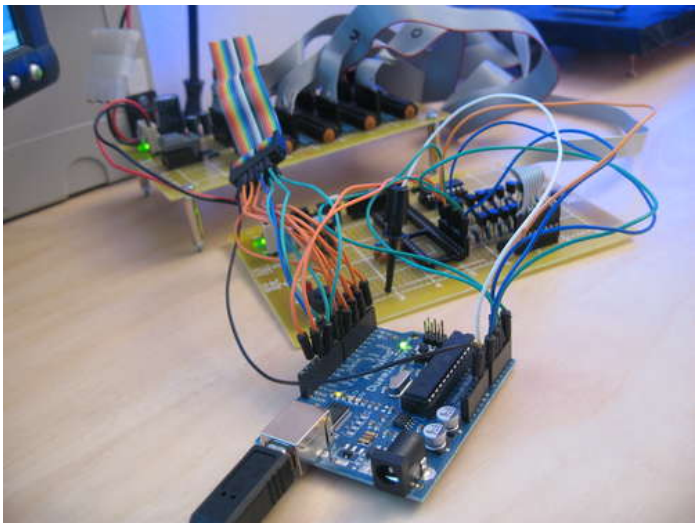
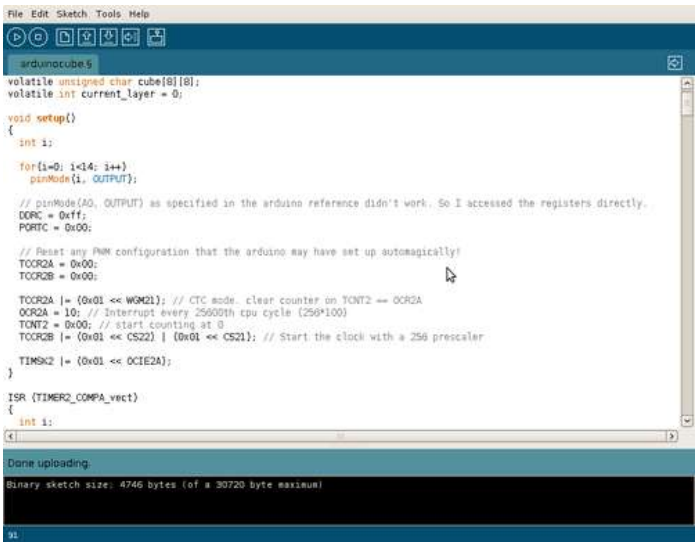


Image Notes
1. ATmega temporarily removed
2. Layer select lines can be connected to this header, without the ATmega interfering.





File Downloads

arduinocube.pde (12 KB)
[NOTE: When saving, if you see .tmp as the file ext, rename it to 'arduinocube.pde']

Step 71: Hardware debugging: Broken LEDs

Disaster strikes. A LED inside the cube is broken!

We had a couple of LEDs break actually. Luckily the hardest one to get to was only one layer inside the cube.

To remove the LED, just take a small pair of needle nose pliers and put some pressure on the legs, then give it a light touch with the soldering iron. The leg should pop right out. Do this for both legs, and it's out.

Inserting a new LED is the tricky part. It needs to be as symmetrical and nice as the rest of the LEDs. We used a helping hand to hold it in place while soldering. It went surprisingly well, and we can't even see which LEDs have been replaced.

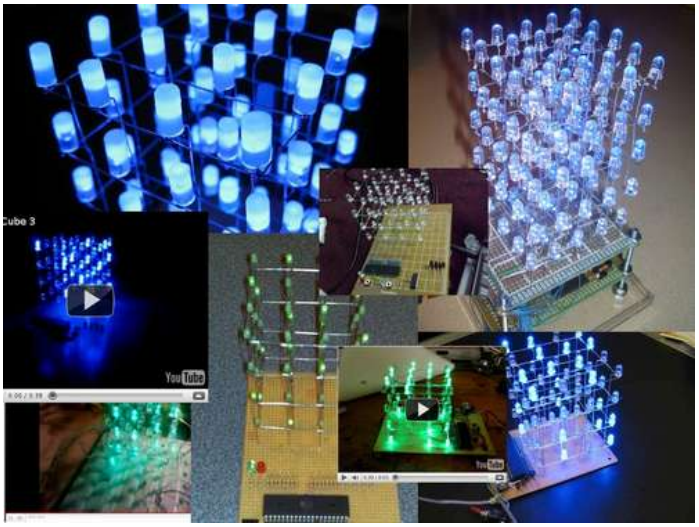
Step 72: Feedback

We love getting feedback on our projects! The 4x4x4 LED cube has received a ton of feedback, and many users have posted pictures and videos of their LED cubes.

If you follow this Instructable and make your own LED cube, please post pictures and video!

Oh, and don't forget to rate this Instructable if you liked it :)

As a token of gratitude for all the great feedback, here is a collage of some of the feedback on our 4x4x4 LED cube instructable:



Related Instructables

Memory led cube by Radobot

LED Cube 4x4x4 by chr

Led Cube 4x4x4 (video) by bajgik

LED Cube 3x3x3 with ATMEGA8 by G7Electronica.NET

4x4x4 LED Cube! by joewp

Road Following Robot"Tweety BOT" by techaaibee

Comments

50 comments **Add Comment** **view all 396 comments**

Archy says: Mar 18, 2011. 3:30 PM **REPLY**

Question:
I'm pretty handy, (a decent level of geek) and I feel confident that I can build this.
However, as having never needed to read a circuit board before, the schematics for the board are a serious headache to try to piece together. I intend to try to do it from the pictures, but I think that is likely to be very prone to error.
Is there any simpler way to show the board? I tried the board converter in eagle, but try for yourself, it's a doozy.
I appreciate the help, if possible.

bakerlogan says: Mar 18, 2011. 3:20 PM **REPLY**

where do you save the .hex file?

bernutu says: Mar 18, 2011. 3:24 AM **REPLY**

Hi there!
Me and a friend of mine made this led cube 8x8x8 but following another instructable, because we're italian (this one: http://www.instructables.com/id/Come-costruire-un-led-cube-8x8x8/)
Anyway we have finished it it works but we have a small problem. We notice that when we turn on a layer a underneath layer it turns on too. Not with the same intensity but it's pretty visible. To be sincerely the intensity of light of each led sucks. We used npn transistors 2n3904 and shift register m74hc164b1. I think there's a problem with the transistor. Wich type of transistor should I use?
Thanks for your time!

dombeef says: Mar 17, 2011. 11:03 AM **REPLY**

Next, 16x16x16! and make it smaller, plus multicolor!

lol

Geethal says: Mar 15, 2011. 8:03 AM **REPLY**

Can I use PIC16F877A by replacing ATmega32 microcontroller

Ken R says: Mar 15, 2011. 8:35 AM **REPLY**

In general you could use any uC you like. However, realize that by doing so, you have to carefully evaluate all schematics/drawings, as they may no longer be valid (uC pin out changes,voltage levels etc).

Also this circuit is designed to run at a certain clock speed (to avoid timing issues with RS232), make sure your uC can do the same. Lastly; source code/compiler issues - different devices = different code.

Simply put, if you want to follow/use this specific design I would get an ATMega. If you don't mind redesigning, reading up on datasheets, compilers, code and other stuff change the uC (you'll probably learn more in the process).

Geethal says: Mar 16, 2011. 8:07 AM **REPLY**

Thanks for the information,I am new with PIC microcontrollers,I want to use PIC16F877A IC for this process,can you suggest me a design(circuit diagram and Code) for that IC? if you can i kindly appreciate that.....

Ken R says: Mar 16, 2011. 11:00 AM **REPLY**

If you're bent on using the PIC16 you have two options:
-Do what I said in my previous post; compare datasheets, pinout, etc
-Google "PIC16 led cube" and see if you can find a similar project where they use that uC.

I have never built a 8x8x8 led cube with the PIC16 uC, so I can not help you with schematics / drawings or code.

Realize that electronics is not like LEGO brick building; one electronic component can not simply be exchanged with a different one without making sure it's characteristics are identical.

Geethal says: Mar 16, 2011. 7:00 PM **REPLY**
Thanks for the info

MrGentlemen says: Mar 16, 2011. 4:36 PM **REPLY**
what is the Value of R2 in the AVR-Shematic?

flunk2003 says: Mar 16, 2011. 3:53 PM **REPLY**
Hey, I have built a cube following your fantastic instructable. I loaded the test file and everyting works fine (after an afternoon of adjusting). But when I load the main.hex and main.eeprom file you have provided I run into a problem. The cube won't start any animations, pressing the RS232-button doesn't light up the linked led and the upper reset button doesn't work either. But when I change the code you provided in main to not start the bootwait program (so immediately start with the programmed effects) the cube doesn't do anything for 40 seconds, and start suddenly to play the effects, starting with effect box shrink grow (case 6). After some effects (about 2-3 minutes) the cube suddenly stops and I have to reset it to replay the effects. Does anyone have an idea what could be wrong. I guess it's a hardware problem but I've checked and don't find any problems. Where should I look?

altered code: int main (void) { ioinit(); current_layer = 1; int i; for (i=0; i<EFFECTS_TOTAL; i++)
launch_effect(i);

LINOLARIOS says: Mar 16, 2011. 11:42 AM **REPLY**
WHERE CAN I FIND MOST OF THE PARTS I NEED ??? I WAN TO START THE PROJECT, ITS OK IF I USE THE ARDUINO UNO ???

guusberens says: Feb 26, 2011. 4:47 AM **REPLY**
hello,

Can anyone help me?
I have a question about the schedule multiplexerboard.sch.
It's about the thick blue line that goes to all 74HC574N. How should I connect?
For example, can I connect pin 14 of SV1 to all 74HC574N pin 2? or how do I do this?

Thanks!!!

Ken R says: Mar 15, 2011. 4:30 PM **REPLY**
Yes, that would be the way to do it - SV1:14 to every 2, SV1:13 to every 3 etc.

Ken R says: Mar 15, 2011. 2:31 PM **REPLY**
Is there a reason why you did not connect VCC and GND on the schematic in step 30?
Also, could someone please explain why V+ and V- are connected through a cap? I've seen several different designs;
V+ connected to VDC though cap, V- connected to GND through cap.
V+ connected to GND through cap, V- connected to GND through cap.
V+ and V- connected through cap.
(Also seen on http://www.sparkfun.com/tutorials/104)
Why was this specific design chosen ?

MÃ¶hiÃ¶Ã¶ says: Feb 5, 2011. 2:58 AM **REPLY**
Hi!

Nice word and thanks for the good project guide. I will also try to make one with shift registers and darlington transistor array for the layer enabling and with arduino.

Btw, the leds you ordered and not received.. I ordered the same, because I like the look of your project, and I got the diffused! Jei.. but wait a minute, my leds legs are 10mm shorter than yours :D That means that its going to be 15mm frame and the whole cube is going to be 120x120mm wide. Oh well, I'll try anyway..

And also, the led seller should thank you. I bet his sales have increased after this project release.

macnomad84 says: Mar 14, 2011. 9:05 PM **REPLY**
Please let me know. Im working at controlling 8x8 RG bicolor matrix (8x16) with 1x uln2803 and 2x 74hc595s. Seems basic but my arduino cuts out when supply rails go to ICs... gah im doing something wrong

Croy9000 says: Feb 18, 2011. 11:07 AM **REPLY**
I had the same problem! My cube was going to be way smaller and visually denser, something I didnt want. So I ended up buying about 100' of copper wire, and straightening it to create cathode rails (plus the anode rails). This let me space the LEDs out how I wanted, then i just laid a copper rail down over the cathodes and soldered into place. Worked very well, and created a very rigid structure. Was way more work, but worth it imo.

mstoetz1 says: Feb 22, 2011. 6:17 AM **REPLY**
Hey Croy... what AWG of copper wire did you use?

I have been keeping my eyes open for a wire that can be kept very straight... even something that is spring steel but solderable and around 18awg.

All I've found so far was piano wire, which isn't solderable. The cube I did was pretty good, but my next one I want to be perfectly straight.

rclay701 says: Feb 24, 2011. 10:12 AM **REPLY**

I've been looking too - finally stumbled on 'stem wire' - used in flower arrangements - available in pre-cut lengths and in several gauges. Some are painted (not good), but you can find unpainted types too. Nice and straight. I am still experimenting - the copper solution is also in the running.

Croy9000 says: Feb 22, 2011. 7:40 AM **REPLY**

I think it was 18 gauge. It was this stuff from Lowes http://bit.ly/gOxU12. I used the method in the instructable of putting one end of a piece into a vice, then pulling with pliers till I felt it stretch. It resulted in a perfectly straight wire.

In hindsight it would I might have used one size smaller wire, and bought in bulk (like from McMaster-Carr) to potentially save money. Also a silver colored wire might have been nice as well.

StarGazerBob says: Feb 23, 2011. 5:44 PM **REPLY**

I'd be interested to see some photos of your completed cube; how did you space your leds?

mstoetz1 says: Feb 23, 2011. 8:18 PM **REPLY**

Hi Stargazer... I used gerber files from Andrew who made the instructable. Therefore the board is identical to his. He has many pics that show how he made his cube... and used a template which is what I did (1" centers). One thing I learned, is the holes for the LEDs have to be close to perfect. While the cube itself isn't perfect once it was all soldered it really is pretty close. My issue was that I had a hard time getting wire really straight and I'm working on that as I build the next cube.

StarGazerBob says: Feb 25, 2011. 2:53 PM **REPLY**

Thanks. I'm still soldering layers together (4 down, 4 to go.) We'll see how "perfect" it is once I start to assemble them. My spacing is only 15mm (I ddin't check lead length before buying my LEDs) so I fear that imperfections will be more noticable. Thanks for the tips.

mstoetz1 says: Feb 25, 2011. 3:26 PM **REPLY**

you're doing the 8x8? I'd do the 8x8 if I had a pcb rather that using a prototype board.

On the 5x5 cube I cut all the leads short, so the length wouldn't have mattered much. For each LED, I made a closed loop on both the anode and cathode, but had them turned so they'd fit both a vertical and horizontal wire frame. I didn't like just placing the leads flat on the wire frame and soldering.

I have to admit.. the first cube anyone does is probably a big learning experience.

The first bunch of leds I got were green clearn straw hat leds. They were nice and bright... so when you do the random pattern, it actually looks like fireworks.

The next set of LEDs I ordered are difused and I also ordered some "wide angle" just to see if there is much of a difference.

StarGazerBob says: Feb 26, 2011. 6:49 AM **REPLY**

Yes, I'm doing the 8x8x8. I hope I don't regret not starting with the 5x5x5.
I like your loops idea!

mstoetz1 says: Feb 23, 2011. 8:19 PM **REPLY**

sorry.. the cube I did was this one:

http://www.instructables.com/id/LED-Cube-with-Arduino-and-custom-PCB/

Its 5x5... although I do want to do an 8x8 too.

stergios1107 says: Feb 27, 2011. 2:47 PM **REPLY**

On the shematics at step you said that we have to put 2 capacitors between VCC and GND and on the image and description you said that you put only one. Why?

macnomad84 says: Mar 14, 2011. 8:59 PM **REPLY**

Those chips are switching pretty fast and the caps filter any high frequency noise introduced into the power supply as a result of said switching. Boosts performance/probability of errors, but may work without stilll... would have to try to know for sure.

cfudala says: Feb 27, 2011. 11:36 PM **REPLY**

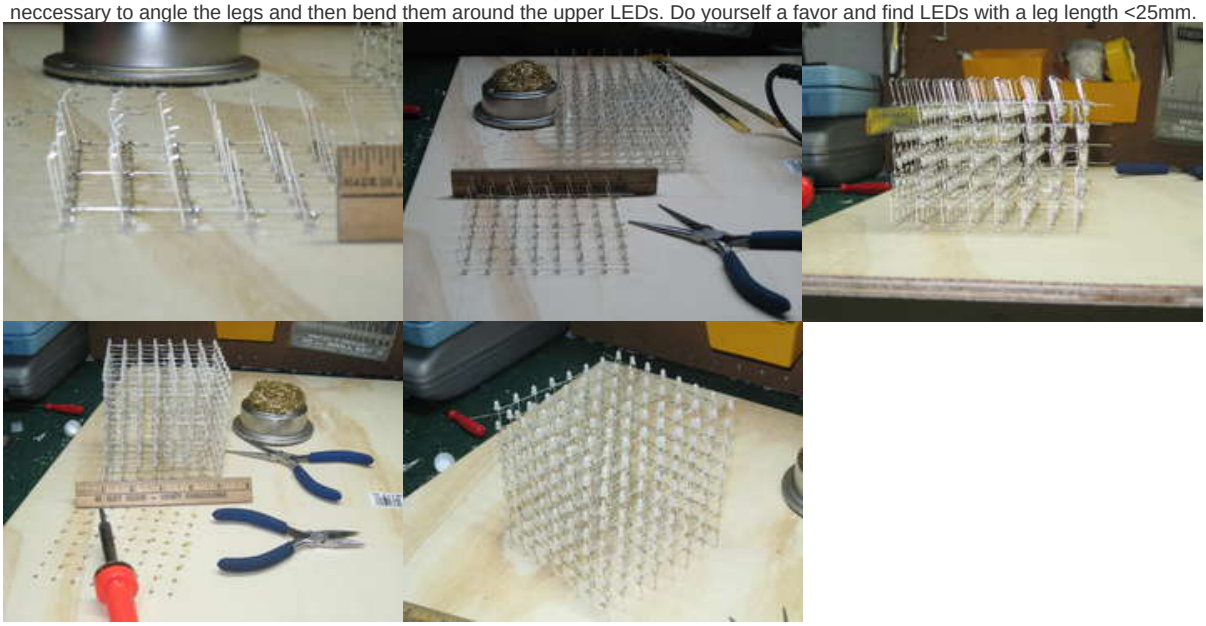
Hmmm, would using copper rods to connect the LEDs work just as well? I'm not terribly familiar with properties of metals so I don't know if it will affect anything.

macnomad84 says: Mar 14, 2011. 8:57 PM **REPLY**

copper excellent conductor. clean soldering surface with fine fine scotch wool before .

StarGazerBob says: Mar 14, 2011. 7:03 PM **REPLY**

I just finished my minicube. Making the layers was easy enough, but putting the layers together was a challenge. The shorter LED leg length made it neccessary to angle the legs and then bend them around the upper LEDs. Do yourself a favor and find LEDs with a leg length <25mm.



Ken R says: Mar 14, 2011. 5:42 PM **REPLY**

I believe "10x smallest available" means that the 10x is the least amount you can buy @ futurlec. They will not sell smaller quantities.

Also, looking at the schematics and browsing through data sheets I noticed the following: for the MAX232 converter, the charge pump cap. value is set to 0.1uF witch is OK for the MAX232A. However for the MAX232CPE, 1uF should be used. Take note when ordering either!

on a slightly technical note, you can safely use larger charge pump caps, but understand that the bigger the cap. the longer the charge time - which could adversely affect your transfer speeds/ baud rate.

...or you could just get the MAX233, which has all caps. built in

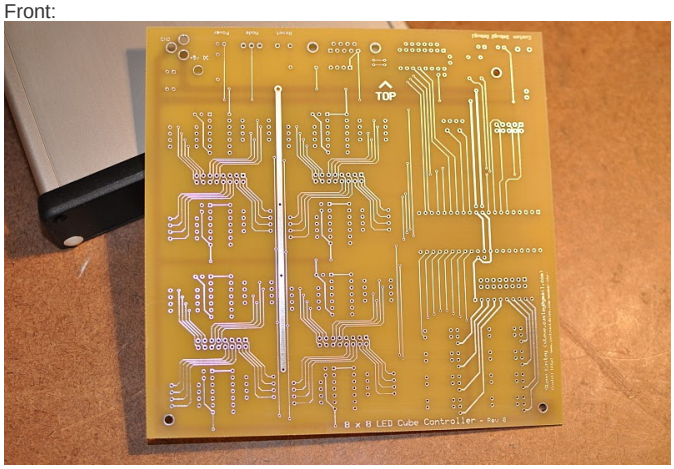
Please correct me if I'm wrong ;)

Croy9000 says: Mar 6, 2011. 12:52 PM **REPLY**

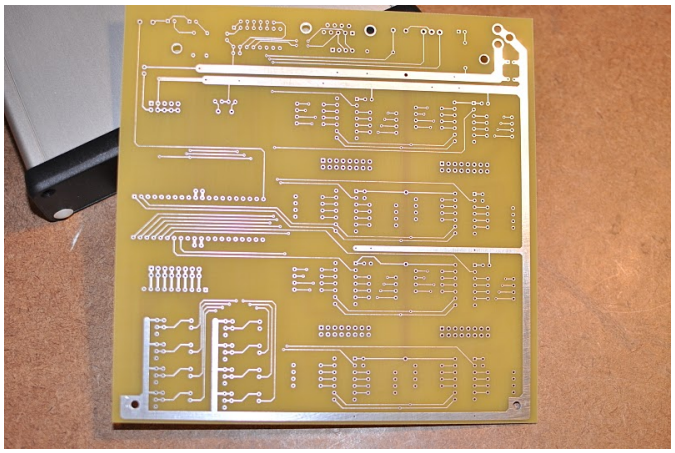
Finally completed my cube! For the controller board I used an ExpressPCB board I designed. Using a PCB board instead of a proto board saved tons of time.

And here are some pictures of the PCB board:

Front:



Back:



Here are some pictures of the enclosure and board together https://picasaweb.google.com/steve.easley/LEDCube?authkey=Gv1sRgCK3EjJ65sbacrgE#

I have three extra PCB boards made if anyone is interested in buying one. The board features places for:

- DB9 serial jack female for interfacing to a computer for advanced animations (I did include a place for the 4 pin header if preferred though).
- High power Mosfets as layer drivers
- Shift registers as column drivers
- 16-pin ribbon cable headers (male plugs) for interfacing to the controller to the cube
- DC power jack 2.1mm
- Slide switch for selecting the mode (autonomous vs RS232)
- 2 custom LEDs and 1 pushbutton assigned to IO ports that you can use for your own debugging/feature purposes.

The PCB board is $50. You will need your own components, but I will supply you a spreadsheet of exactly what to buy. Send me a PM if interested.

coppertopneo says: Mar 14, 2011. 3:53 PM **REPLY**
i would like to buy one of the pcb.

navyaj says: Mar 13, 2011. 6:30 PM **REPLY**
I would like to buy one.

StarGazerBob says: Mar 9, 2011. 6:18 PM **REPLY**
Nicely done!! Thanks for the follow up; I'm still assembling my cube and I keep coming back to the comments for advice.

arsenala5 says: Mar 14, 2011. 12:25 PM **REPLY**
How is this type of pull up resistor called and what value is it (5k?) ?

PrivatHost says: Mar 9, 2011. 5:52 AM **REPLY**
I have a question!
For what is the 8 Pin Connector belong the ATMEGA at the Pins: 22-29?

Sorry for my bad English!

Dheed says: Jan 13, 2011. 3:37 AM **REPLY**
This is my first time that i see something about electronics and i don't know anything about it...so Could you post an image of the backside of this controler at the end?
Thanks.

sbrown7792 says: Mar 8, 2011. 6:43 PM **REPLY**
I second this. I have been looking at the pictures and schematics side by side, and sometimes they don't match perfectly. It'd be great if we could get a couple high-res front, back, and maybe some angle shots of both of the completely finished boards. Some of the boards in the current pictures aren't quite completed, so I feel like they may not have been the final version.
Thanks!

Croy9000 says: Feb 24, 2011. 7:19 AM
(removed by author or community request)

justn says: Mar 7, 2011. 1:08 PM **REPLY**
i would be interested in one.

Croy9000 says: Mar 7, 2011. 6:59 PM **REPLY**
I removed my original post like a numnut. See my newer post (Mar 6th) for the latest info on the PCB board.

rclay701 says: Feb 24, 2011. 10:28 AM **REPLY**
Not sure what kind of responses you are getting - I would be interested in one of the boards - do you have a component list? Let me know - respond to me at rclay701@gmail.com

Croy9000 says: Feb 24, 2011. 10:52 AM **REPLY**
Yes, I would provide a complete component list with part numbers. If I get enough interest in the next few days I will do a bulk order. Express PCB requires a two boards min order, so at the very least I will have one extra. Its just a matter of how many extra im comfortable with ordering. The more I order, the cheaper for everyone.

cupo says: Mar 3, 2011. 2:26 PM **REPLY**
we finished our cube just a week ago.
We made it as a school project
Check it out in RED

http://www.youtube.com/watch?v=dkAg6EdLWIo

I hope you like it :)
Thank you guys from Instructables ;)

cupo says: Mar 7, 2011. 3:49 PM **REPLY**
Video with thubnail....actual it is brighter, ,,,,but I dont want to see reflections from light :)

cupo says: Mar 7, 2011. 3:46 PM **REPLY**
Video with thubnail.....actualy it is brighter, but i dont want to see reflections from light :)

Croy9000 says: Mar 7, 2011. 7:07 PM **REPLY**
Looks great! Awesome job. Did you make any changes from the chr's circuit? What would you do differently next time?

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