Lecture 12

Building an LED Display
By the End of Lecture, You Should Be Able To:

• Use LEDs in simple circuits

• Use time division multiplexing to control LEDs
  – Control $n^2$ lights using only $2n$ wires
  – By turning $n$ lights on in $n$ different time slices

• Create a 2-D plane of LEDs that can be multiplexed
  – And be able to stack planes to create a cube
LED Cube

- You are building a 4 x 4 x 4 cube of LEDs

- You can choose
  - Red, Green, Blue, White
  - Or can mix it up

- Two challenges
  - How to control 64 lights?
  - How to build something
    - With 64 elements
      - That is a lot of soldering
      - A little planning will go a long way

- Friday’s lecture will discuss building the cube strategies.
The Control Problem

- Our cube has 64 lights
  - We would like to allow any combinations of lights to be on
    - So you can create any light pattern that you would like
  - If every light is independent
    - Need at least one bit per light (on, off)
    - State of lights is 64 bits (4x4x4 array)

- Our computer only has around 20 digital output pins
  - And 20 is less than 64.
  - Need to communicate 64 bits over 20 pins.

- How are we going to do this?
Optical Persistence

- We can take advantage of the fact that our eyes are “slow”

- If we turn an LED ON and OFF faster than our eyes can “see” then we will perceive a constant light intensity.
  - The flicker fusion rate is around 30Hz
  - Your eye averages the signal

- Electronics takes advantage of the fact that your eyes are slow
  - Creates more outputs than wires
  - Creates analog light output values on digital pins
Basic Approach

• If I have many lights, I don’t need to turn them all on at once
  – I can create different slots in each time period
    • Say I created 8 slots
  – Then I only need to light 64 / 8 lights in each slot

• But how do I get the right lights to light up at the right time?
  – Leverage the diode nature of the LED
LED Wiring Diagram
Where To Put The Resistor?
LED Array Wiring Diagram
Testing Our Understanding

- If we use time division multiplexing to drive the LED array
  - How do you light up the red LEDs?
  - How many time slots?
Driving the LED Cube
BUILDING THE LED CUBE

Watch Mark Horowitz build an LED cube: Tutorial 4 on class website
https://www.youtube.com/watch?v=4u4eAnd1yEk&feature=youtu.be
The Numbers

- You have 64 LEDs
  - Each has 2 wires, generally are soldering two wires together
  - End up with 64+ solder joints

- This is not a huge amount
  - But it is larger than a few
  - And there are not to a well defined structure
    - They are not going to be fixed on a printed wiring board

- You should be thinking about
  - How to minimize the work you need to do
  - How to catch your mistakes early
    - When they are easier to fix, and so you don’t repeat them
Making the Soldering Easier

• Since we need to do the same thing multiple times
  – Need to build each plane
    • And each plane consists of a set of rows

• What can we do to make the task easier?
  – Think about how the lights will connect to each other
    • Is there a way to make the connections easier to solder
  – Before building the cube, test out your ideas
    • Try before committing to a method
    • Optimizing your technique might save you time in the long run
    • If things are not working, think about what is going wrong
      – Why isn’t it working, and what can you do to fix that problem
Repetition Is Good

• While doing the same thing multiple times gets boring
  – That is not all bad

• Boring means you don’t need to think very much to do the job
  – At Stanford, that can be relaxing ;-)  

• It also means that your design will be modular
  – You are building the same part multiple times
    • So you can use one jig to test all the modules
  – Can even build a jig to help you do the soldering
    • Soldering things hanging in space is hard
      – You don’t have enough hands
For the LED Array

- Want the ‘+’ to run horizontally
  - And the ‘-’ to run vertically

- Bend the leads of each LED $90^\circ$ to each other
  - And make them different heights!
Building a Row
Adding Next Row
Final Array
Cube is a Little More Complex

• But actually is it not much worse

• Start with the LED plane and build 4, 4x4 planes
  − Each plane would be straight forward to make

• Now the question is how to connect them together?
Currently You Have This

- 4, 4x4 planes

- Would like to create an 8x8 array

- Create 2, 4x8 arrays by connecting the anodes of 1\textsuperscript{st} & 2\textsuperscript{nd} planes together and the 3\textsuperscript{rd} and 4\textsuperscript{th} anodes together
Connecting Anodes of Planes

• To connect the 4 anode wires of the two planes
  – On the top plane bend the 4 LED + leads on the left down
    • But leave a little room to bypass the LED
  – On the 2nd plane, bend the 4 LED + leads on the left up
    • But leave a little room to bypass the LED and miss the – wire
  – Solder these 4 wires to each other

• Your two planes will be floppy
  – Solder two wires on the left, for mechanical support
Place 1\textsuperscript{st} Plane in Pliers to Hold
Add 2\textsuperscript{nd} Plane
2 Plane Module
Now You Have This

- 2, 4x8 planes that are folded around the y axis

- Create an 8x8 array by connecting the – wires of 1\textsuperscript{st} & 2\textsuperscript{nd} planes to the – wires of the 4\textsuperscript{th} and 3\textsuperscript{rd} planes
Final Cube
Completed Cube
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LED Cube Driver
So We Soldered Our Cube …

- We have an 8 x 8 array
  - Logically looks like:
  - Physically it is different

- Need to drive it
  - To light up the lights

- For independent light control
  - Either only one + wire high
  - Or only one - wire low
  - Max of 8 LEDs on at once
The LED Driver Current Requirements

• Look at current requirements
  – - wires drive 8 LEDs; + wires drive 8 LEDs
  – But we decided to drive only + wire high at a time

• So each - wire can drive only one LED that is on at any time
  – But each + wire can drive 8 LEDs that are on at on time

• How much current will each LED take?
  – Series resistance is about 100Ω total
    • 82Ω from explicit resistor, 20-30Ω from pin
  – Voltage drop across this resistance is 2-3V
  – Current is approximately 20-30mA (for green/blue or red)
Arduino Current Limitations

- If you read Arduino specs
  - Each pin can drive 40mA
  - Whole chip should drive less than 200mA

- Pin current is limited by MOS devices on the chip
  - Have measured 20 ohm
    - If you measure the current it is less ~60mA
    - This makes sense. If the spec is 40mA
      - That is the guaranteed value. Nominally it will be higher
Max Chip Current

- Why is there a max total chip current?
  - When current flows out of pin
    - It must flow in from somewhere
      - \( \sum i = 0 \)
    - Somewhere is the Gnd pin
      - Or Vdd
- The current must flow through some small wires
  - Called bonding wires, which connect chip to package
  - Too much current and these wires become fuses
    - Poof, and it is gone
  - Very conservatively spec’d. Probably 400mA is ok
    - But remember Poof is possible and permanent
How to Drive Your LEDs

• Arduino can drive the - wires directly
  – Use 82Ω series resistor to limit current
  – Current will be 20mA for blue/green LEDs, 30mA for red

• Total Arduino current will be around 240mA max
  – Above spec, but will be ok

• + wire driver will need to supply 160-240mA
  – Arduino can’t drive that current
  – Will need an external driver for that
  – What type or driver do we need?
Driving the + Wires of the Cube

• Want to build as little as possible
  – Need to build 8 of them

• What do we need?
  – Need to connect to Vdd
  – Need to disconnect from Vdd
  – Don’t need to drive it to Gnd
Where To Put The Resistor and Transistor?