Adapting Modeling Instruction to DIY Arduino (Microcontroller) Lab Equipment Development

A longer version of this talk is online at http://youtu.be/7uYC-EuIFJA

Also, a short paper lives at http://arxiv.org/abs/1407.7613

2014 July 29, 9:50-10am

Tate Lab, 133

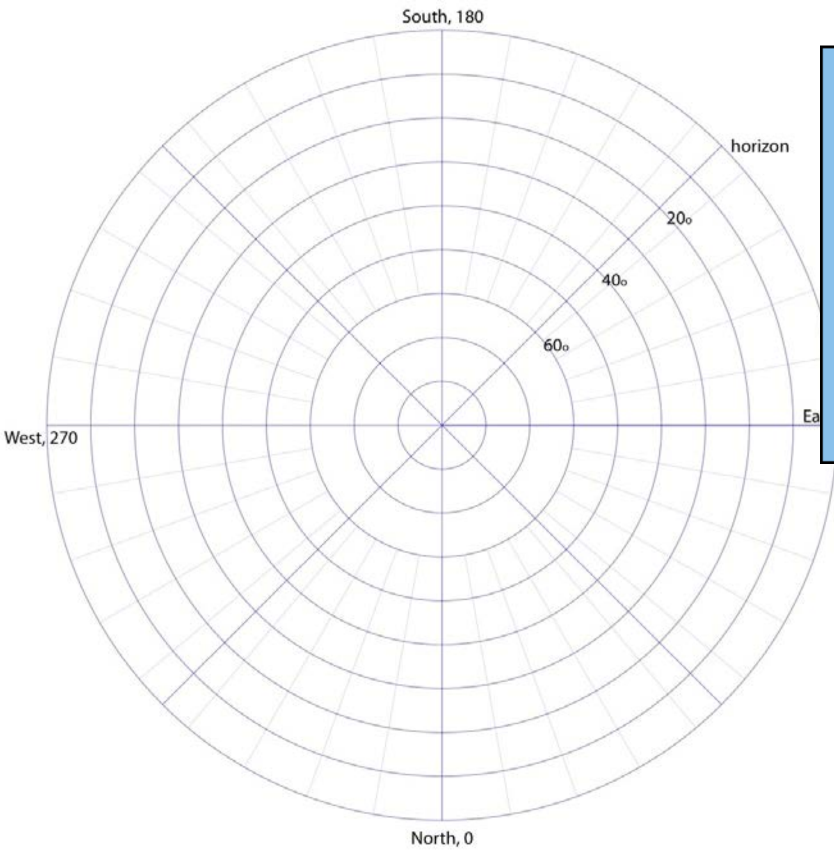
AAPT, Summer 2014

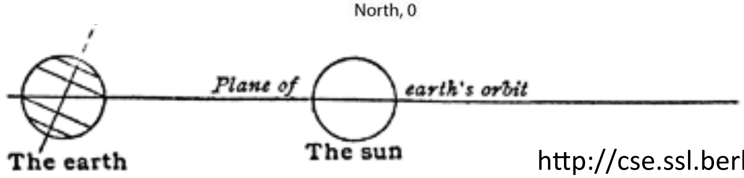
Nathan Moore, Winona State University

Andrew Haugen, Winona State University

Thanks to: Scot Stroh, Tia Troy, Megan Reiner,
Birat Sapkota, WSU Physics 221 classes in Spring 2011 and 2013,
and Paul Lulai

College Physics 1,
What's the rotational speed of the Big Dipper?





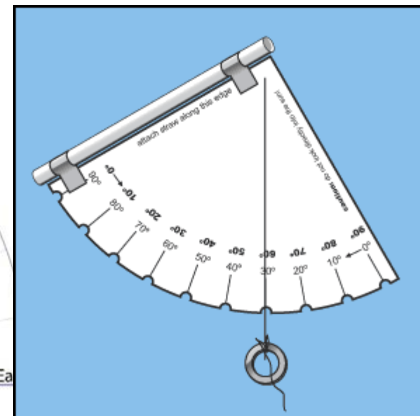
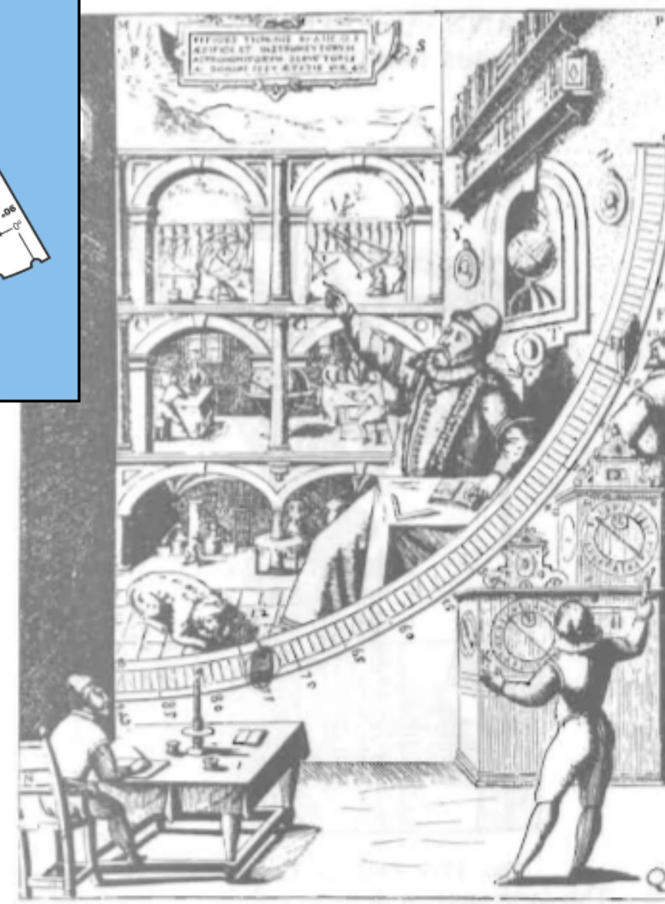


FIG. 17-5. TYCHO'S MURAL QUADRANT
The huge brass arc was firmly fixed in a western wall, with its center at an open window in a southern wall. The empty wall above the arc was decorated by a huge painting showing: Tycho observing; students calculating; Tycho's globe, books, dog; and some of Uraniborg's main instruments. An observer sighted the star (or Sun) by pinholes at F and a marker in the window. The brass arc (radius over 6 ft.) could be read to 1/360 degree. This sketch, from Tycho's own book, shows an observer at F, a recorder, and a timekeeper with several clocks. Good clocks had not been invented, but these were the best Tycho could make.

QVADRANS MVRALIS
SIVE TICHONICUS



http://cse.ssl.berkeley.edu/AtHomeAstronomy/activity_07.html

What would it be like if every student had their own motion detector in their dorm room? What would they do?

See the editor of Make on Colbert,
http://www.colbertnation.com/the-colbert-report-videos/311944/june-08-2010/mark-frauenfelder

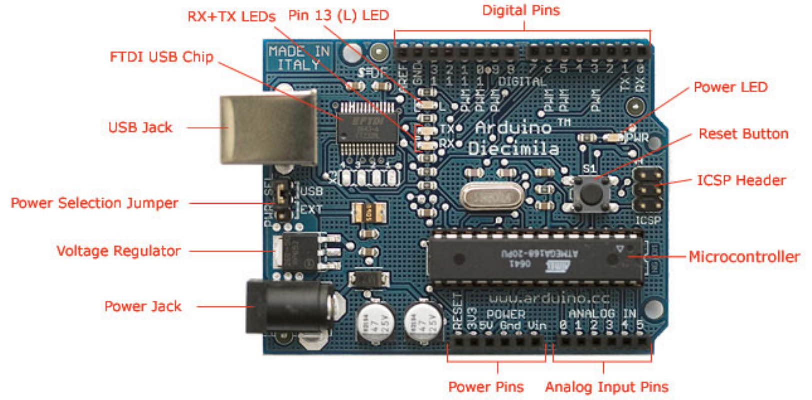
“Makerspace in the Clasroom”
http://makezine.com/2014/01/10/makerspace-in-the-classroom/

Hey, isn't this talk about Arduinos?

ATMega328 microcontroller, 8bit, 16MHz, 2k RAM
14 Digital I/O pins
6 Analog inputs (10+ bit ADC)
Pre-built sensor arrays, "shields"
"open hardware"
Open-source programmer (IDE)
Program in "C-tran"

3-Axis Accelerometer
$20

Ultrasonic
Distance $30



Photograph by SparkFun Electronics. Used under the Creative Commons Attribution Share

IR Distance

We can all be
Eratosthenes.

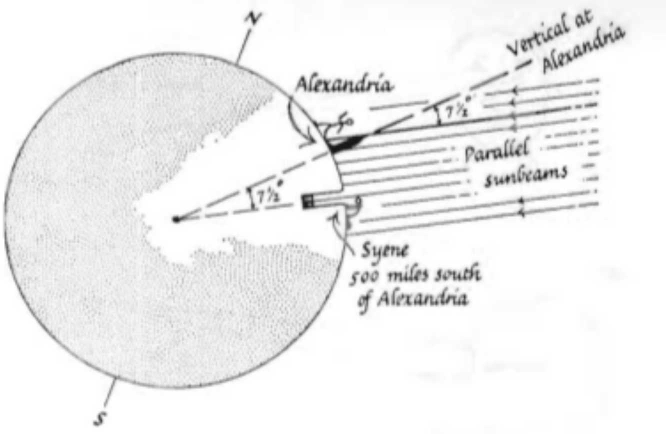
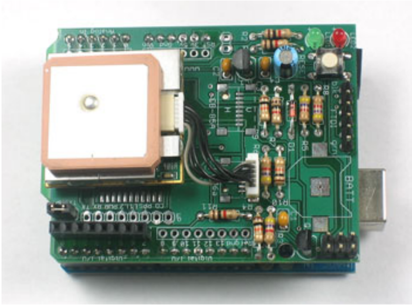
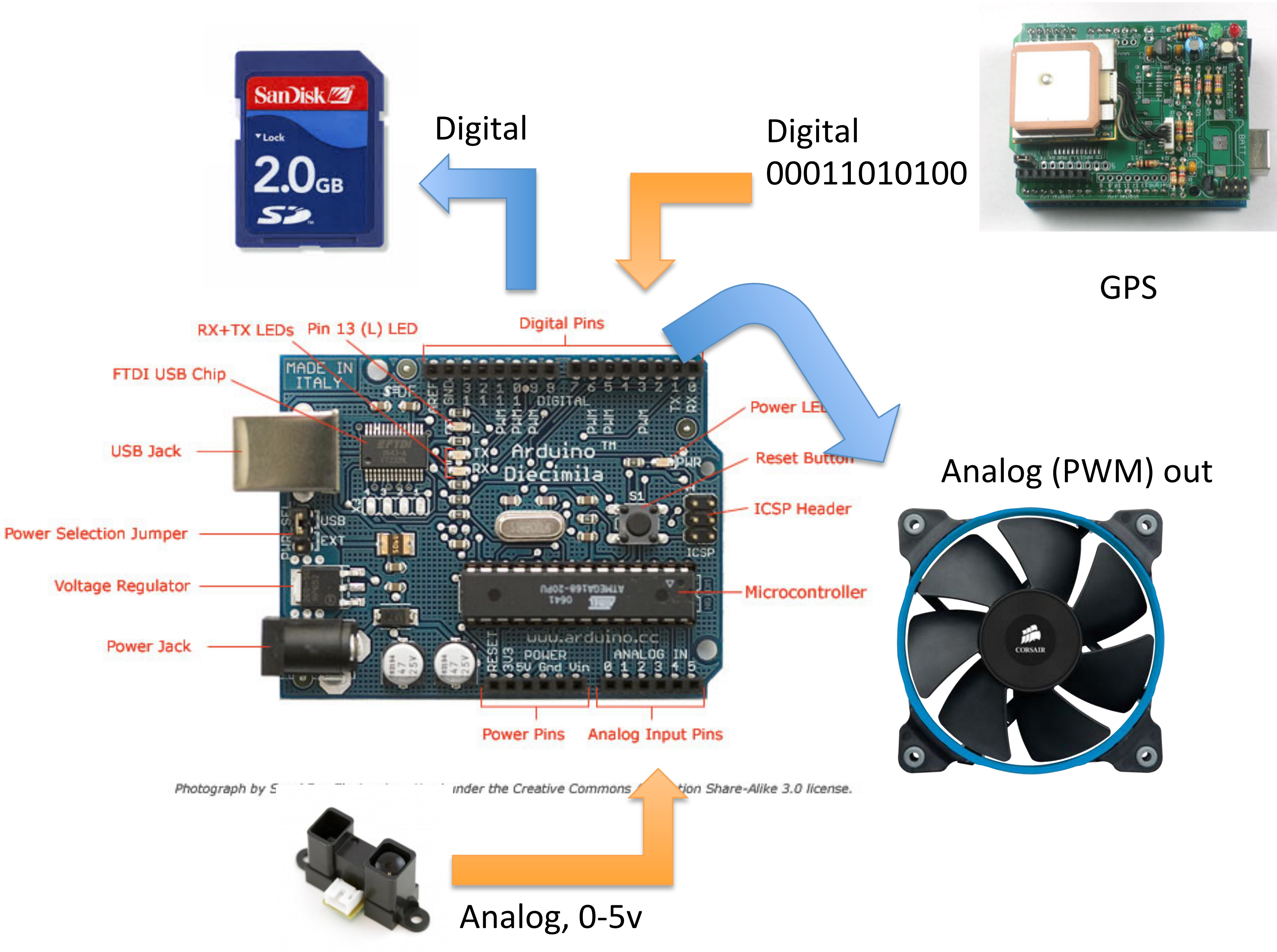


FIG. 14-14. HOW ERATOSTHENES ESTIMATED THE SIZE OF THE EARTH

GPS Shield + Antenna ($50)



Gas (ethanol, CO, etc)



Data/Control Flow

Implementation at WSU

Physics 221, Calculus-based Intro mechanics

- Engineering, Chemistry, Math, Physics majors
- Students buy a “labkit” consisting of Arduino+sensors
- Standard lecture
- Lab consists of making DAQ equipment and then using it (2 week cycle)
- Trial 1, Programming via Arduino code editor (2011)
- Trial 2, Programming via Labview (2013)

Outcomes

- One student gets an internshop at SpaceX
- Some senior engineering design projects include Arduino programming
- Some students take the Labview certification exam (beginner)
- One student solves numerical integration (MS Excel) program w/ Arduino
- MPEX results are unremarkable
- Student attitudes are mixed
- Students love soldering

http://www.physics.umd.edu/perg/expects/

How do you program a dishwasher?

(That's what the micro inside an arduino is used for…)

~~Assembly~~

"Arduino" language

(subset of C/C++)

Avoid fancy function calls,
Floating point math,
Pointers, C++ etc

2000 bytes of memory means:

500 long ints

or

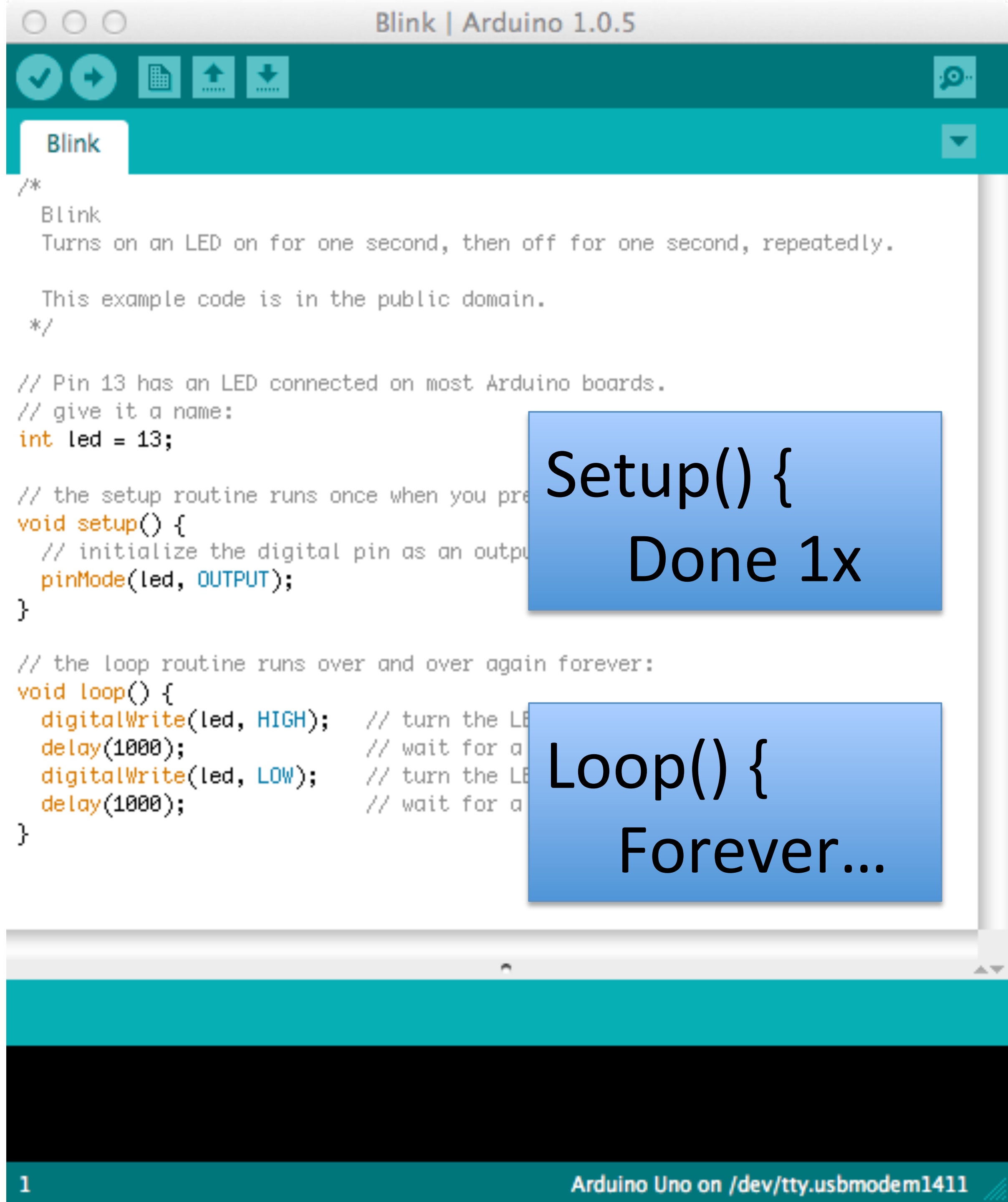
1000 ints (0-64k)

or

500 floats

or

2000 characters



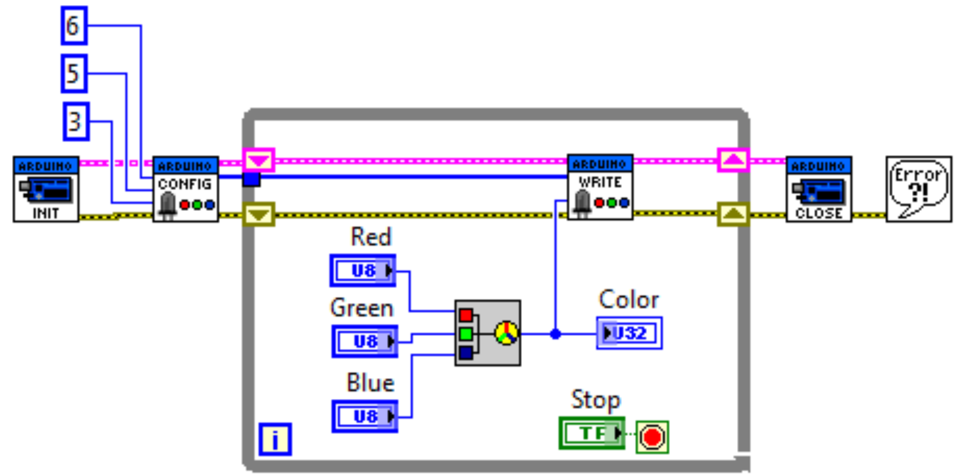
Or, how do you program a Steelmill?

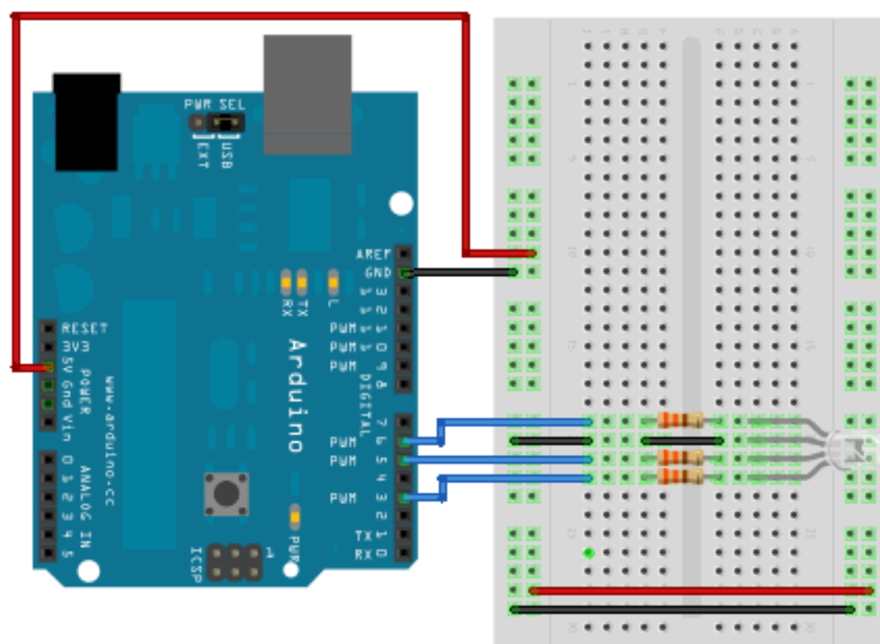
National Instruments "Labview"
(Programming "by cartoon")

Widely used in Engineering Test Industry, DSP

Arduino+Student Edition for ~$50

Similar to Lego NXT programming



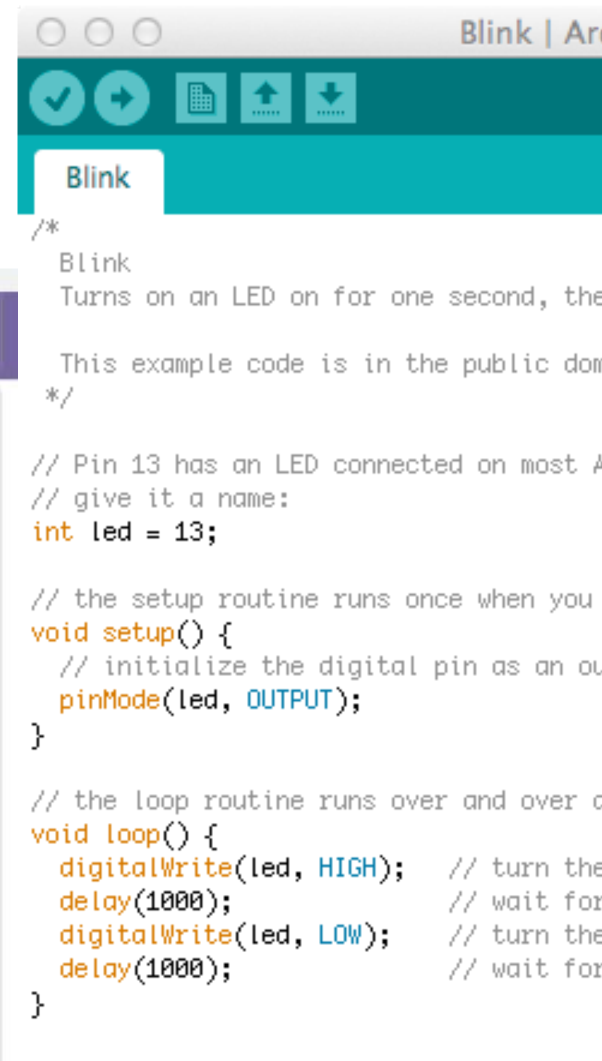


https://www.sparkfun.com/products/11225

How do you teach a (physics) student to program (in physics)?

What is an algorithm?

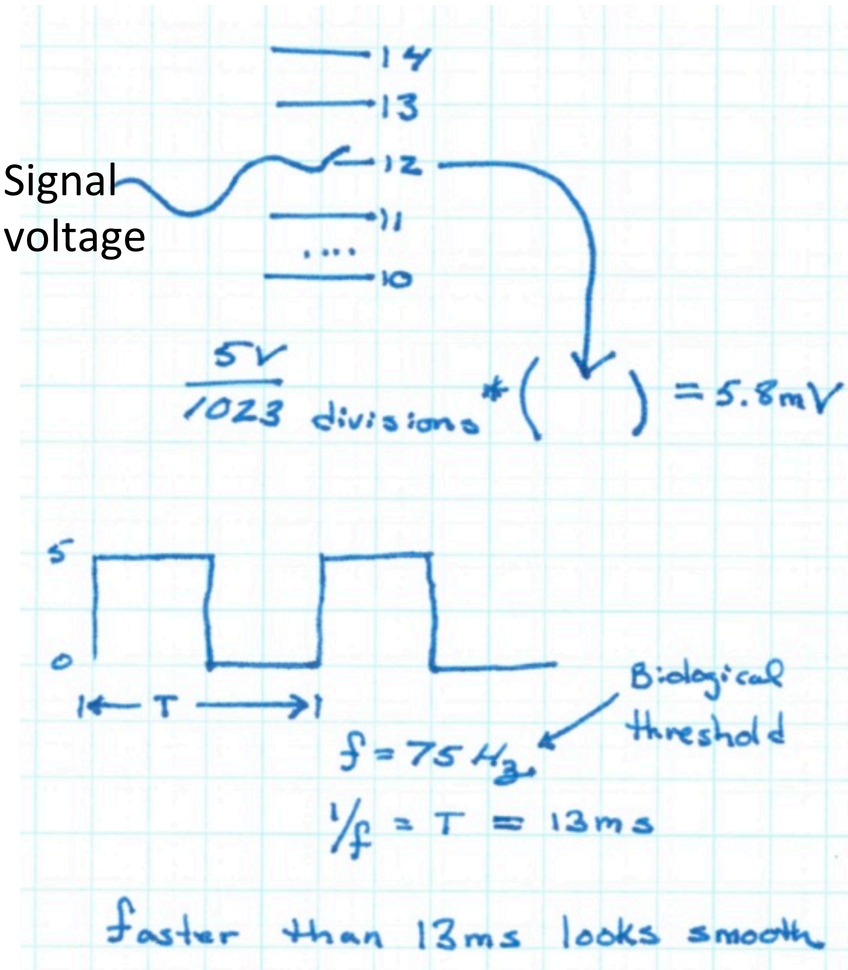
See “Math from 3 to 7,”
A. Zvonkin, MRSI/AMS, or



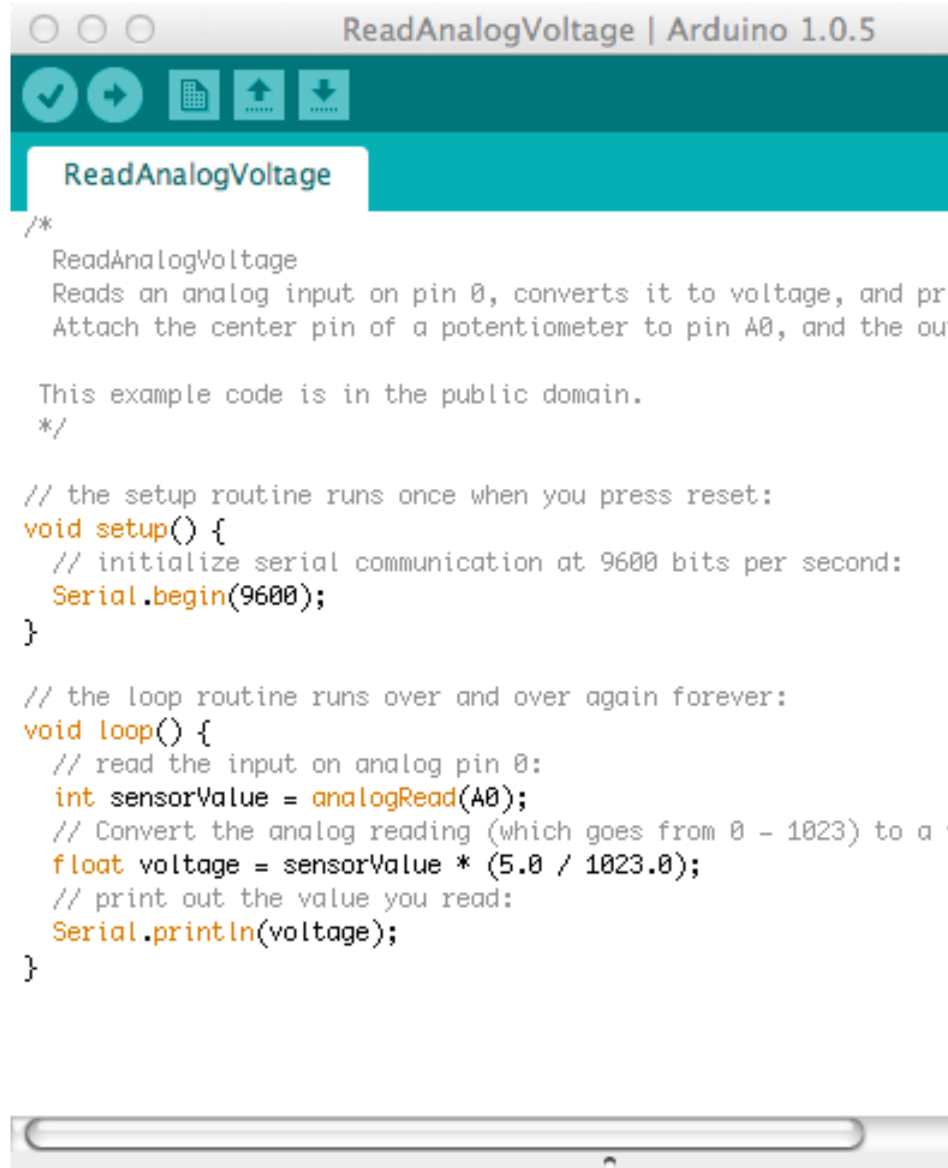
How do you teach a (physics) student to interface a microcontroller (in physics)?

Analog to Digital Conversion (ADC)

Signal voltage



Pulse Width Modulation (PWM)




```
/*
  ReadAnalogVoltage
  Reads an analog input on pin 0, converts it to voltage, and pr
  Attach the center pin of a potentiometer to pin A0, and the ou

 This example code is in the public domain.
 */

// the setup routine runs once when you press reset:
void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);
}

// the loop routine runs over and over again forever:
void loop() {
  // read the input on analog pin 0:
  int sensorValue = analogRead(A0);
  // Convert the analog reading (which goes from 0 - 1023) to a
  float voltage = sensorValue * (5.0 / 1023.0);
  // print out the value you read:
  Serial.println(voltage);
}
```

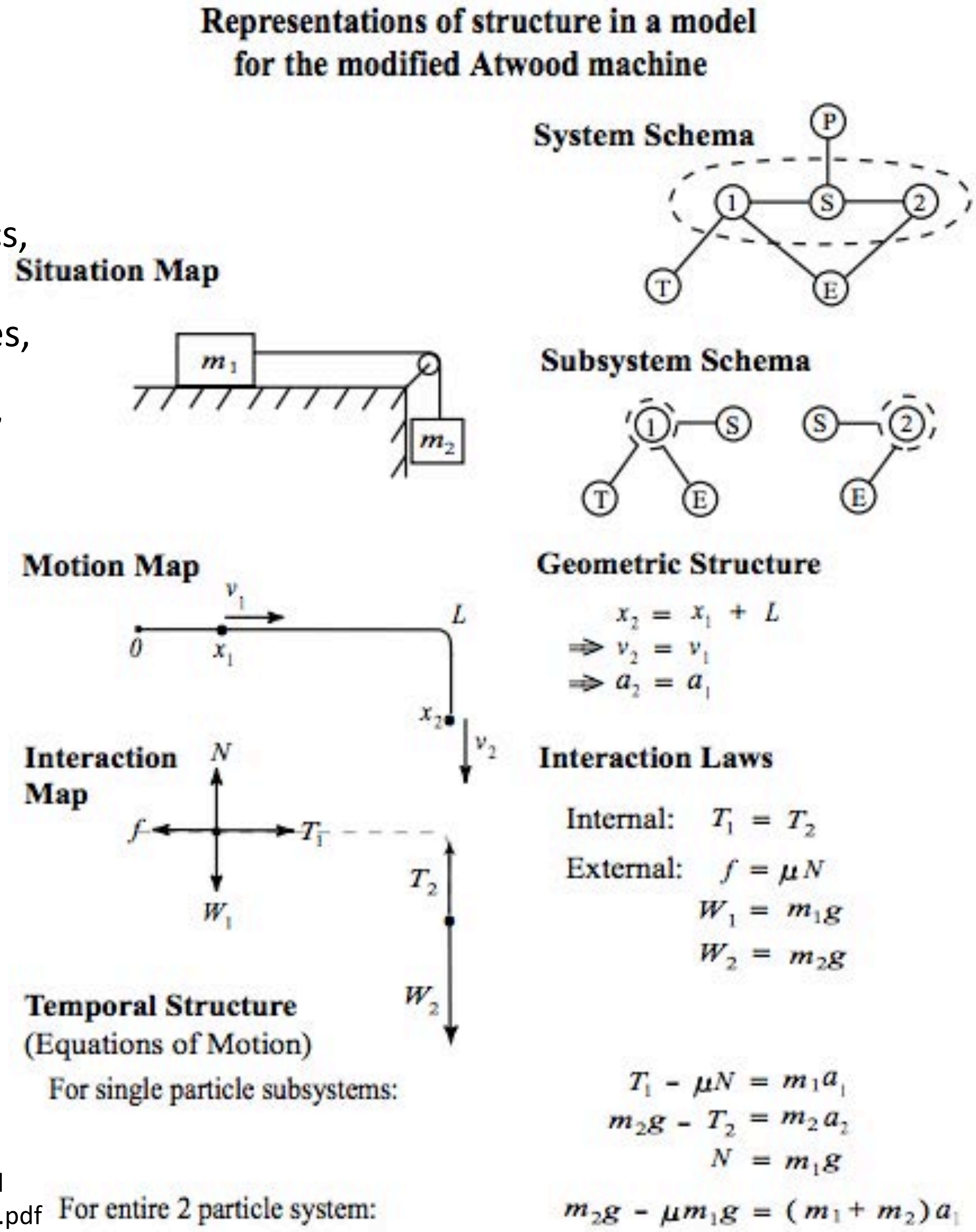
How does Modeling come into play?

- 3wk workshops, ASU
- Physics (Physical Science, Mechanics, E&M), Chemistry, Biology
- Incredibly high FCI gains, PISA scores, student maturity
- Students are “prepared for college”
- True Vygotskian social construction

Model Development

↓

Model Deployment



For more, see:

http://modelinginstruction.org/
http://youtu.be/3GkY-ZXnx4w
http://modeling.asu.edu/modeling/mod_cycle.html
http://modeling.asu.edu/R&E/ModelingMeth-jul98.pdf

Modeling “Model“ for DIY Sensors

Model Development

1. Context-rich Concrete preparation
2. Sensor Data Collection
3. Mathematical Model-Building
4. Algorithmic Model-Building

Model Deployment

5. (Engineering) Applications

Model Development

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Context-Rich Concrete Preparation

Over the summer you have a job working for a medical technology start-up in Rochester, MN. The company is working on a high-precision infra-red incubator to be used in the maternity ward of hospitals for newborn babies, and you're excited to be able to help on the project.

In your first week, your boss asks you to familiarize yourself with temperature measuring equipment (obviously, the incubator can't allow the baby to be chilled or overheat, and the control circuitry has to be designed accordingly). The specific device she wants you to work with is an LM34 temperate probe, which is made by National Semiconductor (among others). A data sheet for the LM34 is available (attached). Please read through the datasheet.

The specific wiring diagram for the LM34 is given in figure ??. From reading through the datasheet, you should be able to determine appropriate values for V_S and the numerical conversion from V_{OUT} to a sensor temperature, measured in degrees Fahrenheit.

You should be able to supply V_S and GND from your Arduino, and V_{OUT} can be read either with a voltmeter or one of the analog-to-digital (A2D) pins on your Arduino.

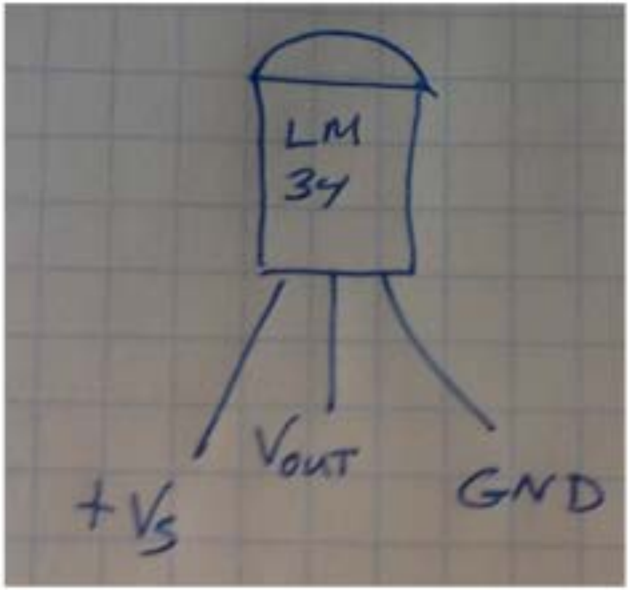
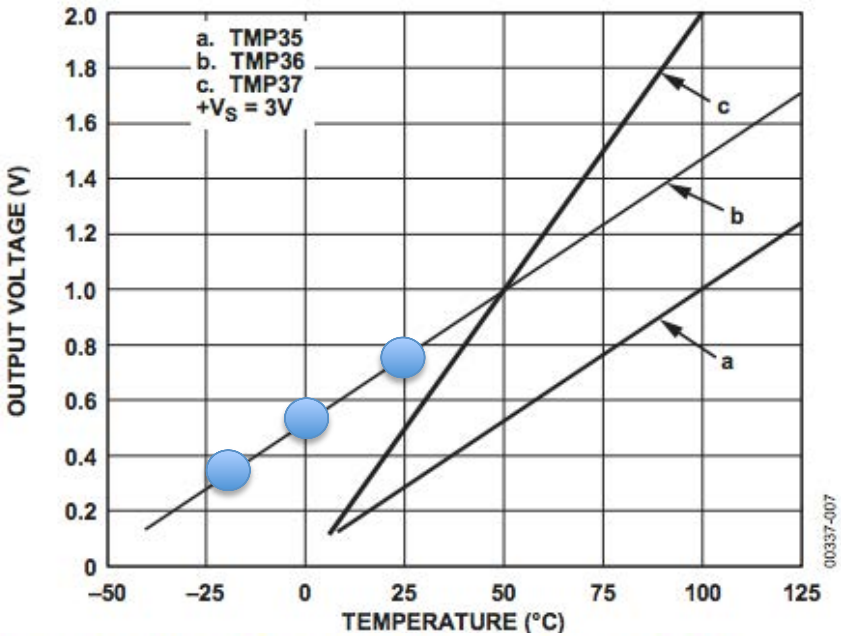


Figure 2: Wiring pin-out for an LM-34 Temperature probe.

Sensor Data Collection/Calibration



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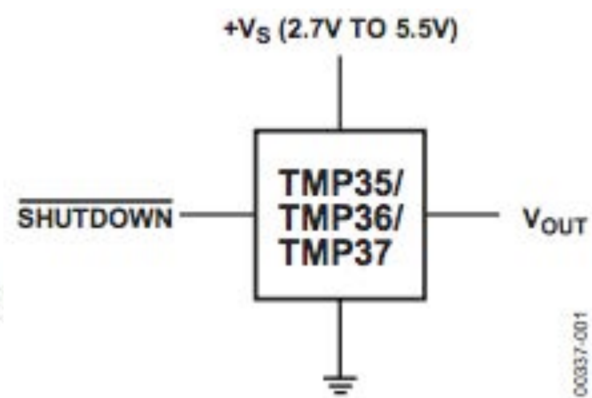
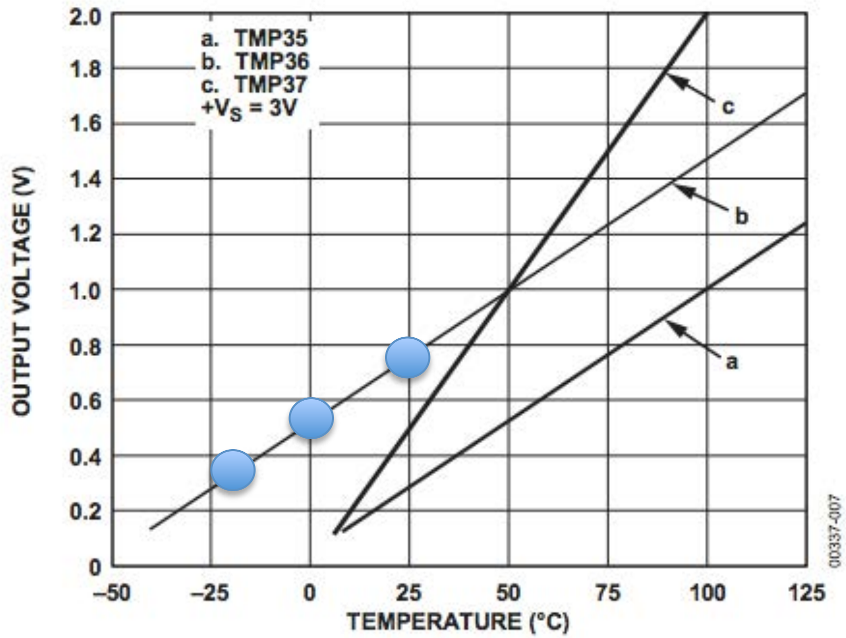
After wiring up your LM34 sensor, please take data (using a glass thermometer as a control), which characterizes the behavior of the sensor. Please make sure your data allows you to answer the following questions:

1. What pin, and in what way do you measure sensor voltage?
2. How do you convert the sensor voltage into a sensor temperature?
3. How long does it take the sensor to equilibrate with its surroundings?
4. What's the min/max surface temperature of your body? (be modest!)
5. How does the value read from the LM34 compare (in accuracy) to a reading glass thermometer?
6. Is the calibration formula given in the datasheet reliable?
7. To what accuracy does the sensor allow you to measure temperature?



Mathematical Model-Building



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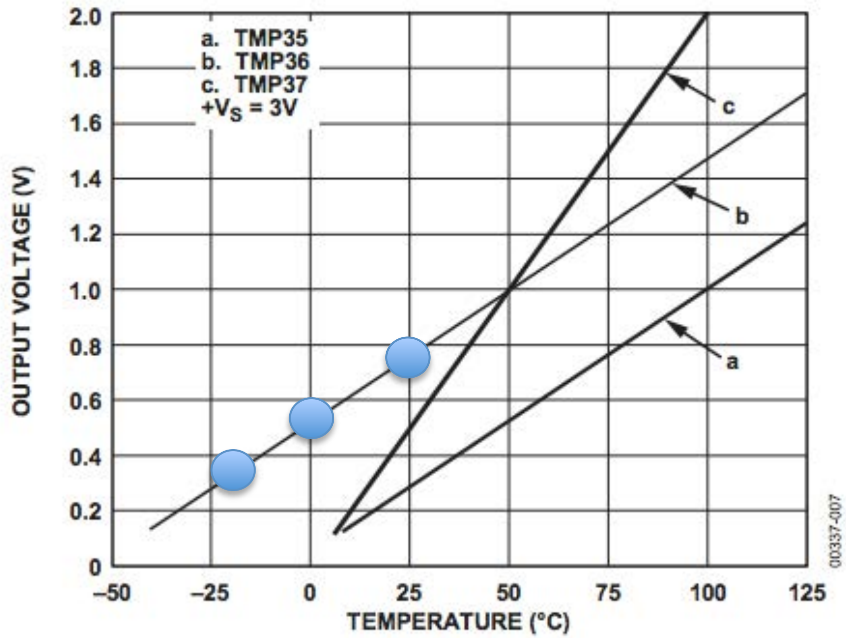
With data collected, pleas build a mathematical model which allows you to predict sensor temperature based on the voltage the sensor reports. To create this model, you should first produce a graph of sensor temperature as a function of output voltage. A mathematical model should be accessible from the data you plot.

Voltage = a (Temperature) + b

Algorithmic Model-Building



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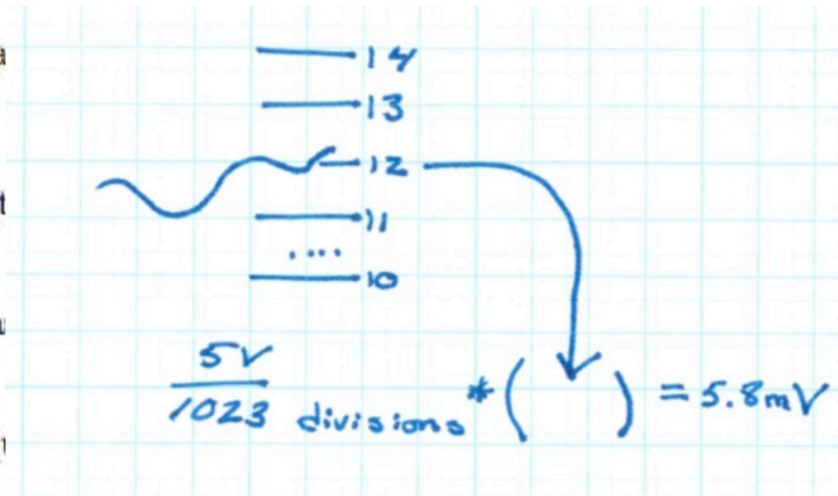
Voltage = a (Temperature) + b

Temperature = …

From what you already know about Arduinos, please create an algorithm which illustrates the following procedure.

1. The sensor is in contact with an object whose temperature we wish to measure.
2. The sensor outputs a voltage which corresponds to a tempera
3. The Arduino reads this voltage via an A2D pin.
4. The Arduino converts the integer A2D value into a temperat model, above).
5. The Arduino sends the temperature reading and a time mea (e.g., your laptop).
6. The Arduino waits a specified time, and then repeats the seq



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Model Deployment, Applications

1. In the infant incubator, the IR heating lab should turn on if the sensor reads an infant finger temperature lower than $T_1 = 98.0°F$, and further, the heating lamp should turn off when the temperature exceeds $T_2 = 100.0°F$. Using your model and initial algorithm, create and implement a new algorithm which executes this temperature-control procedure. You can represent the heater's function via an LED, which would be driven by the Arduino. In an actual design, the Arduino would drive a relay, which controls the heater.

2. Children are precious, and it won't do to trust the life of a child to a single $0.76 component. For greater safety and reliability, consider an improved design which would read in values from two LM34 sensors and actuate a heater if and only if both sensors agree. Create and implement such an algorithm.

3. A rice cooker has two heater settings, the first to get the rice+water up to boiling, and a second heater setting to keep the rice warm once it has fully cooked. Design and implement an algorithm to model the function of a rice-cooker. You can use LED's to represent the function of the two heaters.

4. Whenever you open a refrigerator door, cold air leaks out and the compressor has to run to cool down your food. Create and implement a data collection algorithm that would allow you to capture this data to see how much time it takes to cool the fridge down to proper temperature after the door has been opened.