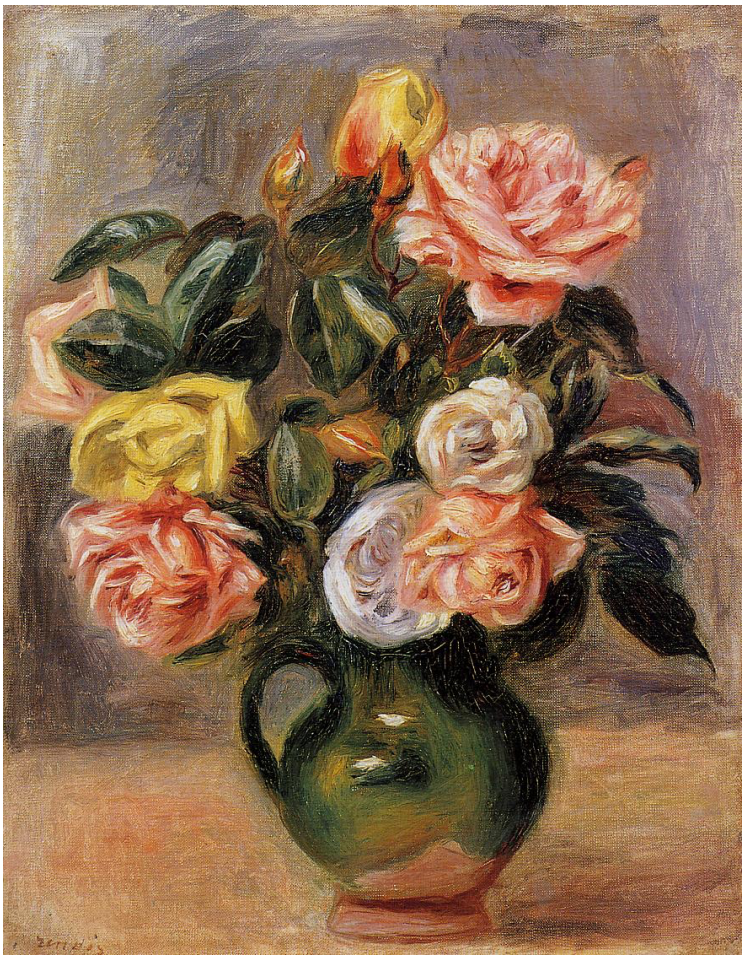

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Physics 524

Survey of Instrumentation and Laboratory Techniques

2023

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University of Illinois at Urbana-Champaign

Unit 1a: Arduino C++ programming environment

Week 1: Organizations, Distributions, and Installations

Goal for this week

- You will assemble a starter circuit on a breadboard and use the Arduino Integrated Developers Environment (IDE) to program and test it.

Notebooks

Please open up your notebook, and add to your account of the afternoon's activities as you work. You'll want to keep track of your work, and your revelations, so you can return to them at a later date. We won't be looking at your notes, but if I ask you something like "where did you go to find that cool piece of demo software?" you should be able to give me an answer based on your notes.

Distribution of stuff!

I have an alarmingly large amount of stuff available for you. Some of the following I've already packed in the parts/tools kits I'll distribute in class. (You'll also use these in Physics 523.)

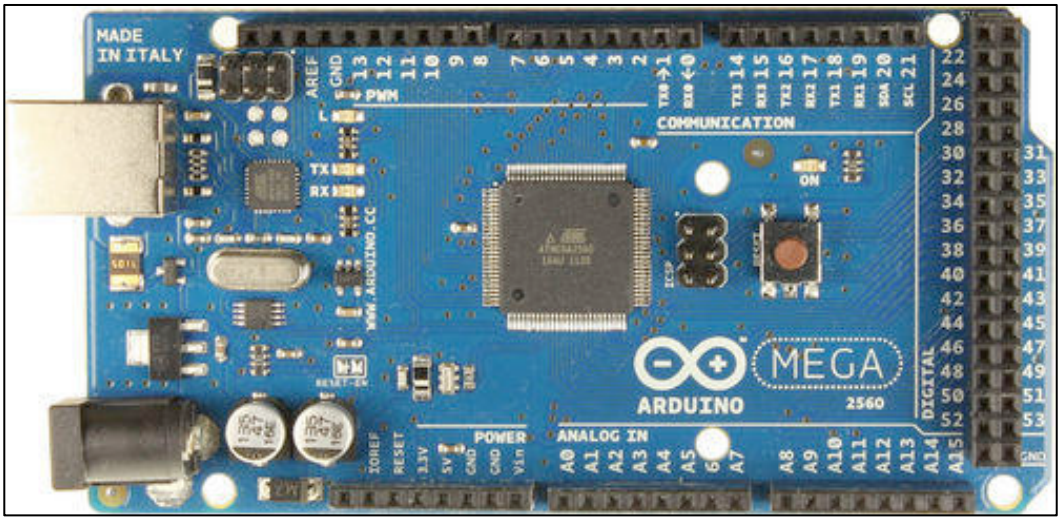
part
16 x 2 LCD CFAH1602B-NGG-JTV
2 x AAA & 1 x AAA battery holders
3 x 4 keypad (#3845)
5 x AA battery holder, Adafruit 3456
74HC137 3-8 decoder/demultiplexer (TTL)
74HC157N quad 2 input (TTL) multiplexer
Adalogger Feather M0, Adafruit 2796, and microUSB – USB A cable
ADXL326 accelerometer (#1018)
ALLPOWERS 2.5W, 5V photovoltaic (solar) cell

Arduino Mega 2560 and USB cable
BME 680 T/RH/P/VOC (#3660)
Diodes: 1N5817 Schottky
DS3231 real time clock (#3013)
electret microphone with amplifier (#1063)
RadioFeather M0 with 900 MHz LoRa radio (#3178)
GPS Antenna - External Active Antenna (#960)
INA219 battery voltage/current sensor (#904)
LSM9DS1 accelerometer/magnetometer/gyroscope 0x1E (#3387)
MCP23008 I2C port expander, Adafruit 593
MCP4725 DAC, 12-bit, I2C (#935)
MicroSD card breakout (#254)
MicroSD memory card 8 GB SDHC (#1294)
Mini Metal Speaker w/ Wires - 8 ohm 0.5W (#1890)
MLX90614 IR sensor. Note that there are distinct 3V and 5V versions!
PAM8302 Audio Amplifier (#2130)
red LEDs (#297)
TCA9548A mux I2C multiplexer
TMP36 analog medium temperature thermometers (#165)
TSL2561 or TSL2591 Digital Luminosity/Lux/Light sensor
ultimate GPS breakout board (#746)
USB DIY connectors

Installing the Arduino programming IDE; running code

Go to the Arduino webpage https://www.arduino.cc/en/software. Download and install the Arduino Desktop IDE (Integrated Development Environment) on your laptop.

The heart of your initial explorations will be an Arduino Mega 2560 microcontroller board, shown here.



Arduino Mega 2560

It's a remarkable little gizmo, featuring an Atmel Atmega2560 microcontroller (built by Microchip Technology, Inc.) running at 16MHz. The Atmega2560 has 256kB of flash memory in which your program will reside, along with 8kB of SRAM (static random access memory) in which will live the variables your program modifies as it executes. There are 16 analog inputs that feed an internal multiplexer whose output drives a 10-bit successive approximation analog to digital converter (ADC). See https://store.arduino.cc/arduino-mega-2560-rev3 for more details.

Some of the projects might involve a different processor: I have been developing systems using several Adafruit devices, two of which employ Microchip ATSAMD21G18 microcontrollers. The SAMD21 runs at 48 MHz, features a 12-bit ADC, and has 32 kB of SRAM, four times more than the Atmega2560. It also has a 10-bit digital to analog converter (DAC), which the 2560 does not.

The Adalogger M0 includes a built-in microSD memory holder, while the RadioFeather M0 with RFM95 LoRa radio has a built-in 915 MHz long range radio transceiver. Both are very cool.

The Arduino IDE is quite a bit simpler than Anaconda's iPython IDE. Most of what you will see on your screen is an editor window in which you will create/modify C++ programs that you will compile and upload to the Arduino. See the screen shot, below. You'll write and compile programs using the IDE, then upload them to the Arduino through a USB cable.

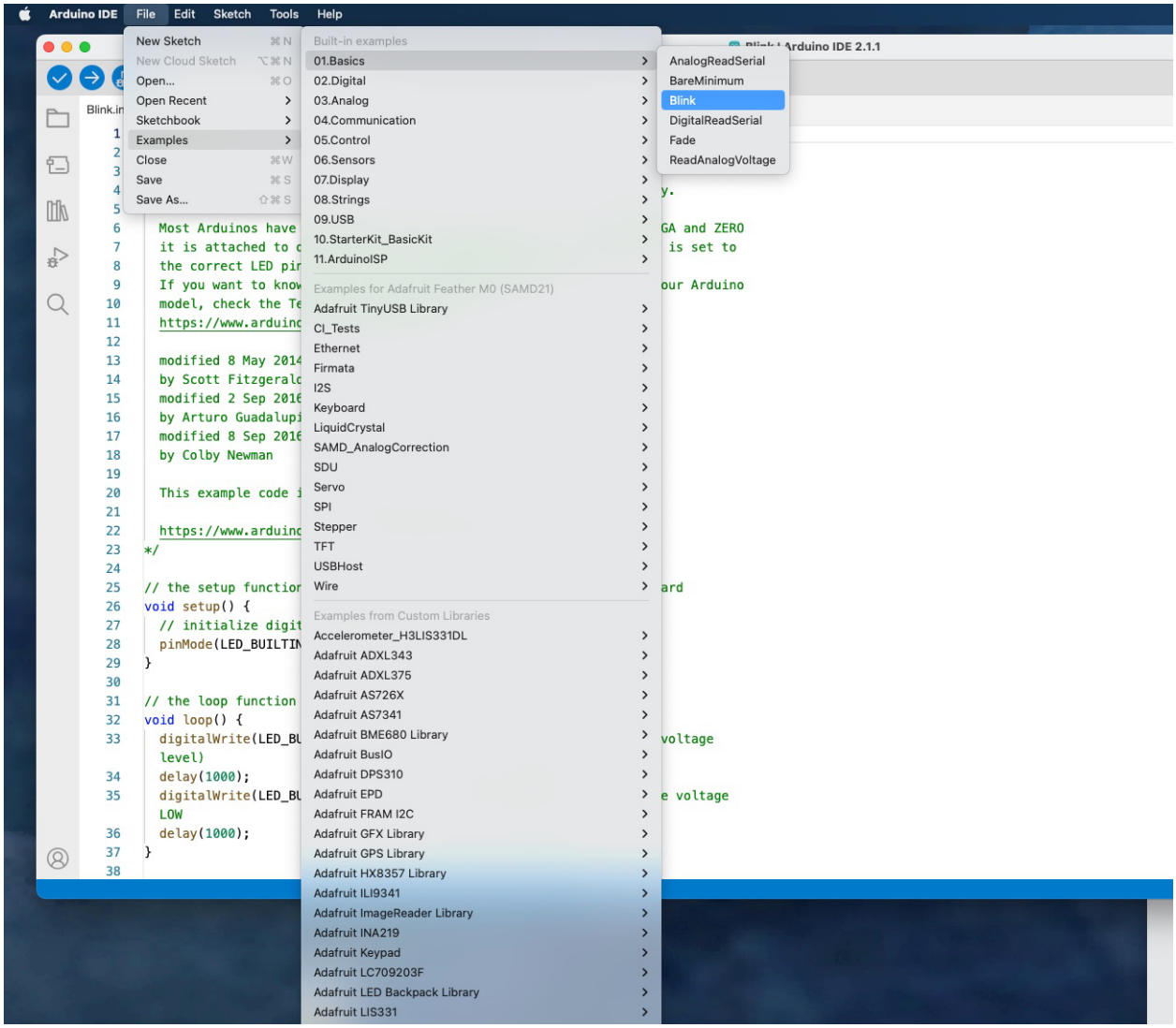
There isn't a debugger, so you'll be forced to print things to a "serial monitor" screen to keep track of what's going on (and going wrong) in the code executed by the Arduino.

Something to keep in mind: the Arduino runs code that is very much like C++, with some minor differences. But the structure of a program is constrained: there are always two specific functions that must be included in a program. The first is called "setup"; it takes no arguments and does not return a value. It is the first routine in a program that executes. The next is called "loop." It too takes no arguments and does not return a value. Upon completion of setup, the

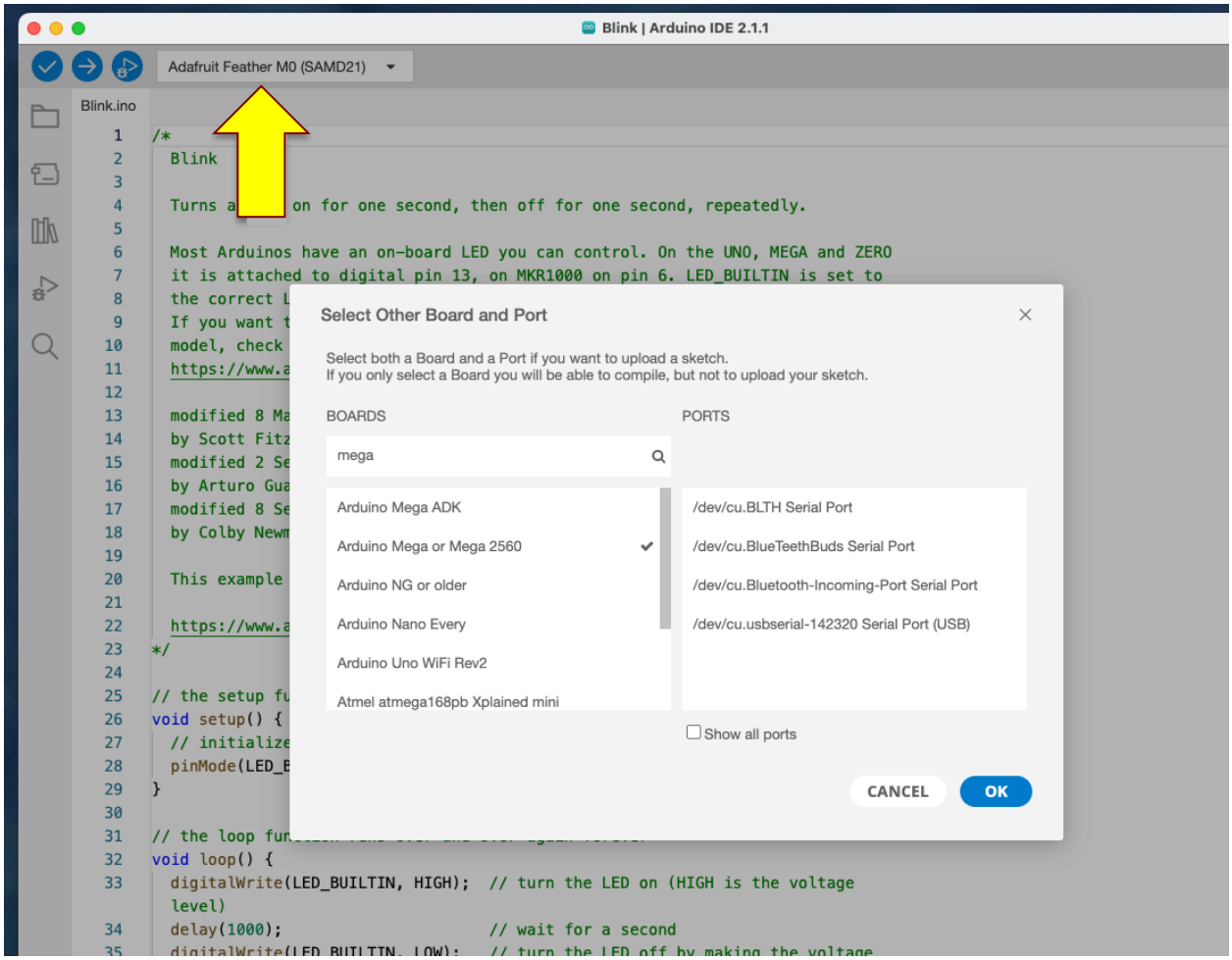
Arduino goes straight into the loop function. It executes loop over and over, jumping back into it each time the function completes.

Do this: plug the Arduino into a USB port on your laptop, then fire up the IDE. Open the Blink example, compile and upload it, and see if your processor will talk to you. You'll need to make sure the IDE knows what kind of processor you are using: a Mega 2560. (Select this from the pull-down menu which, in my screen shot, below, initially says "Adafruit Feather M0 (SAMD21)."

Here are some screen shots:

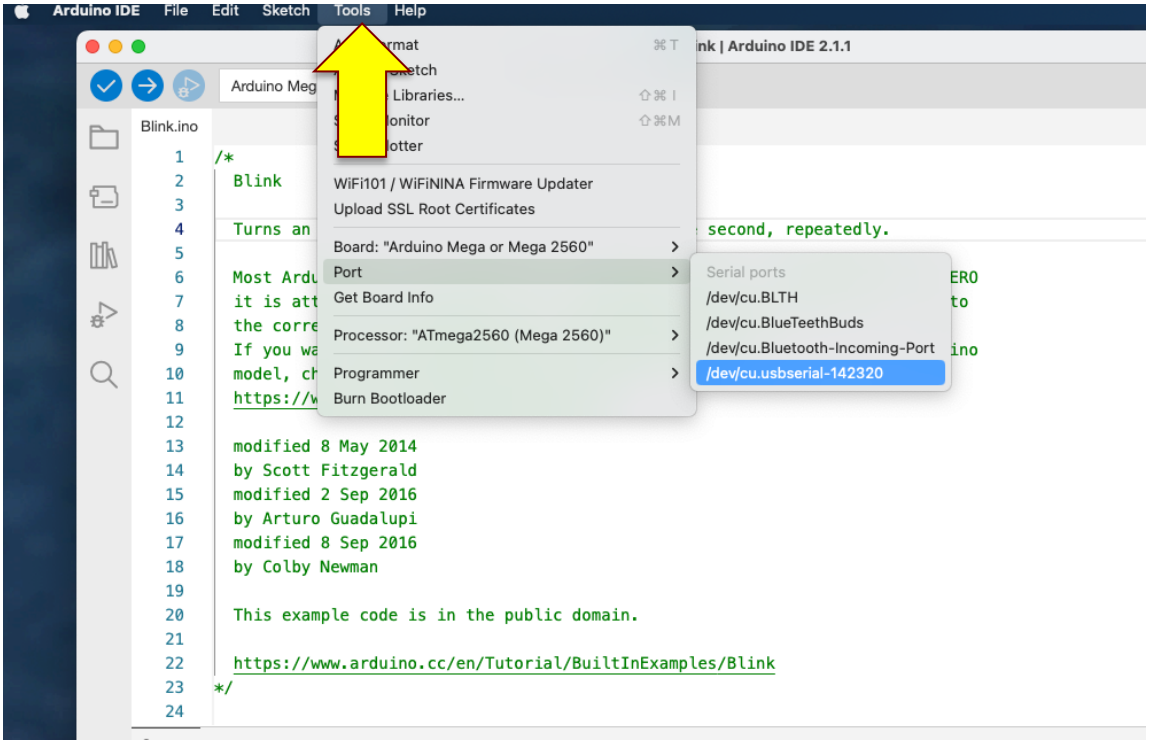


Opening the "blink" example.



Identifying the processor to be used.

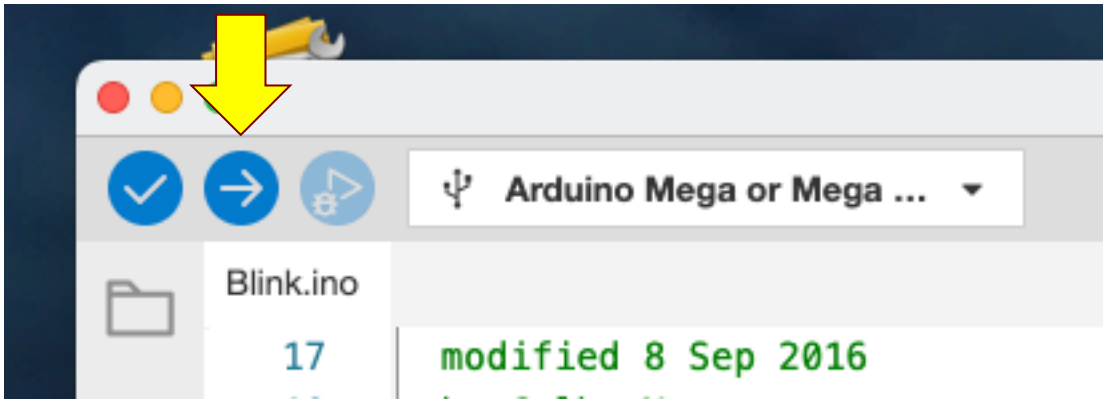
You'll need to tell the IDE which port to use:



Specifying the USB port to use.

What the program does is pretty obvious. Good coding references are on the Arduino site: see https://www.arduino.cc/reference/en/ and https://www.arduino.cc/en/reference/libraries.

You can compile the program upload it to your Arduino by clicking the right-arrow button near the top of the window:



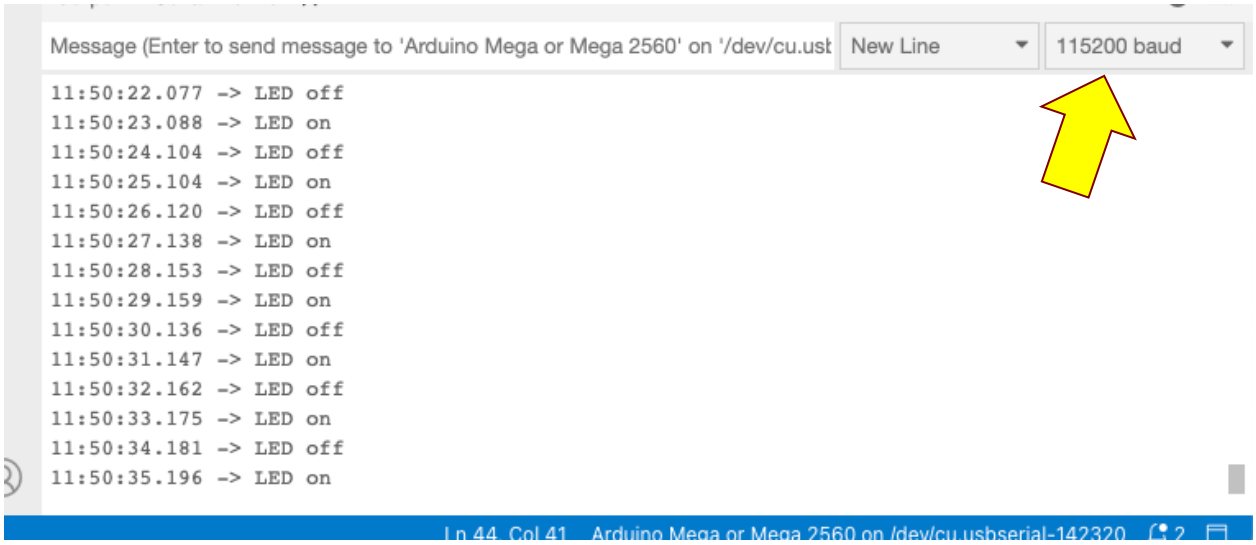
Note the presence of the setup and loop functions.

Some more technical commentary: many of the Arduino's "pins" are configurable: they can be defined to be digital inputs, or outputs, or analog inputs. The pinMode instruction defines the pin driving the red LED to be a (digital) output.

Here's what you can do to view program output in a "serial monitor" window. First add some code to write to it:

```
*/

// the setup function runs once when you press reset or power the board
void setup() {
  // initialize digital pin LED_BUILTIN as an output.
  pinMode(LED_BUILTIN, OUTPUT);

  // light up the serial monitor and wait for it to be ready, but include a
  // timeout in case there are problems.
  // define a 32 bit, unsigned integer and load it with the number of
  // milliseconds since the program began executing.
  uint32_t t1234 = millis();

  // Light up the serial mnonitor at 115,200 baud (bits per second)
  Serial.begin(115200);

  // wait for the serial line to be ready: it'll return "true" when it's up.
  while (!Serial && millis() - t1234 < 5000) {/* do nothing */}

  // let's assume everything went OK, so we'll write stuff to the
  // serial monitor.
  Serial.println("Blink program is starting up!");
}

// the loop function runs over and over again forever
void loop() {
  // turn the LED on (HIGH is the voltage level)
  digitalWrite(LED_BUILTIN, HIGH);
  // let the user know
  Serial.println("LED on");
  // wait for a second
  delay(1000);
  // turn the LED off
  digitalWrite(LED_BUILTIN, LOW);
  Serial.println("LED off");
  // wait for a second
  delay(1000);
```

Then set the baud rate:



In-class exercise: blink code

Modify the blink program so that it blinks the initials (of your English/American name) in Morse code.

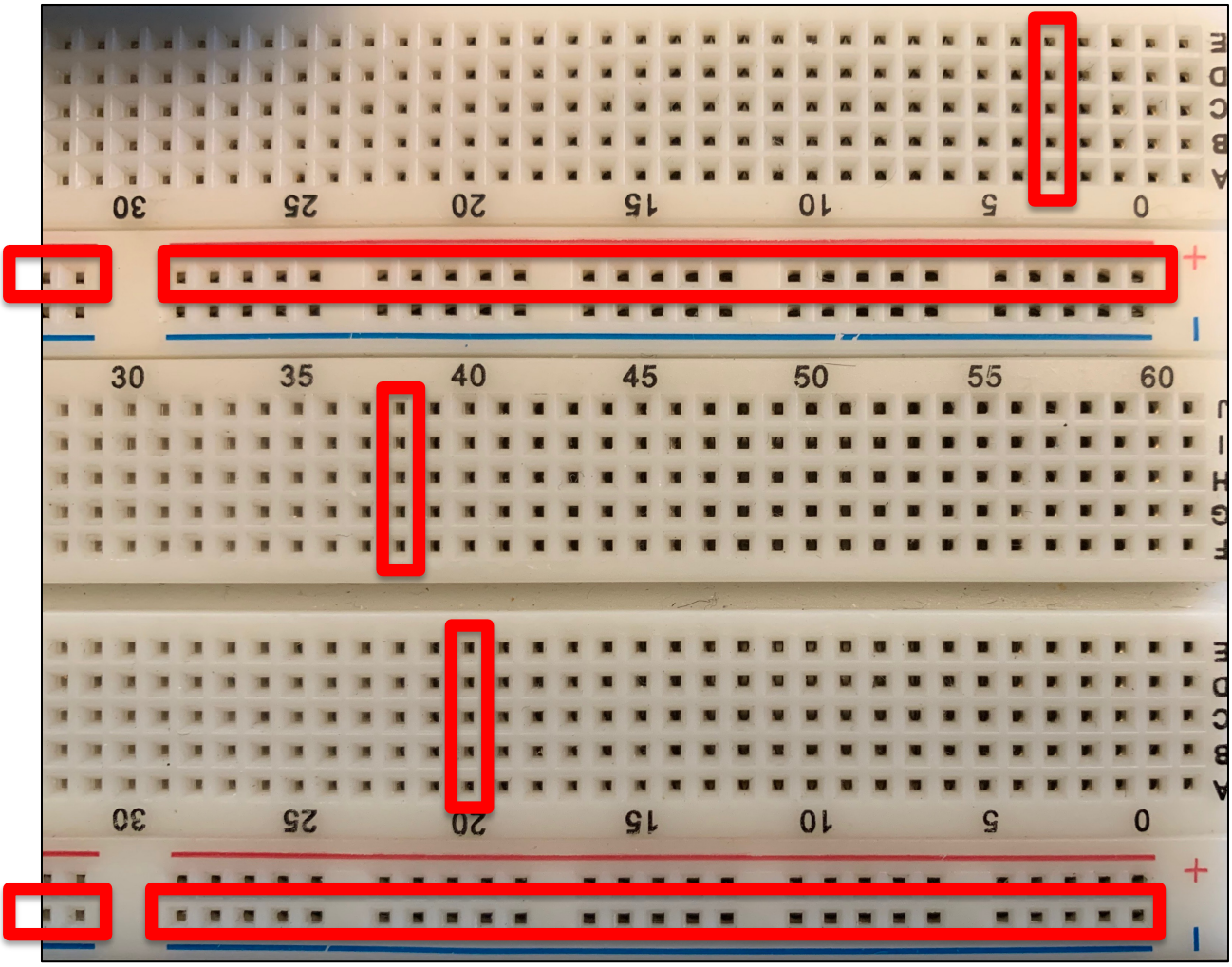
Breadboarding!

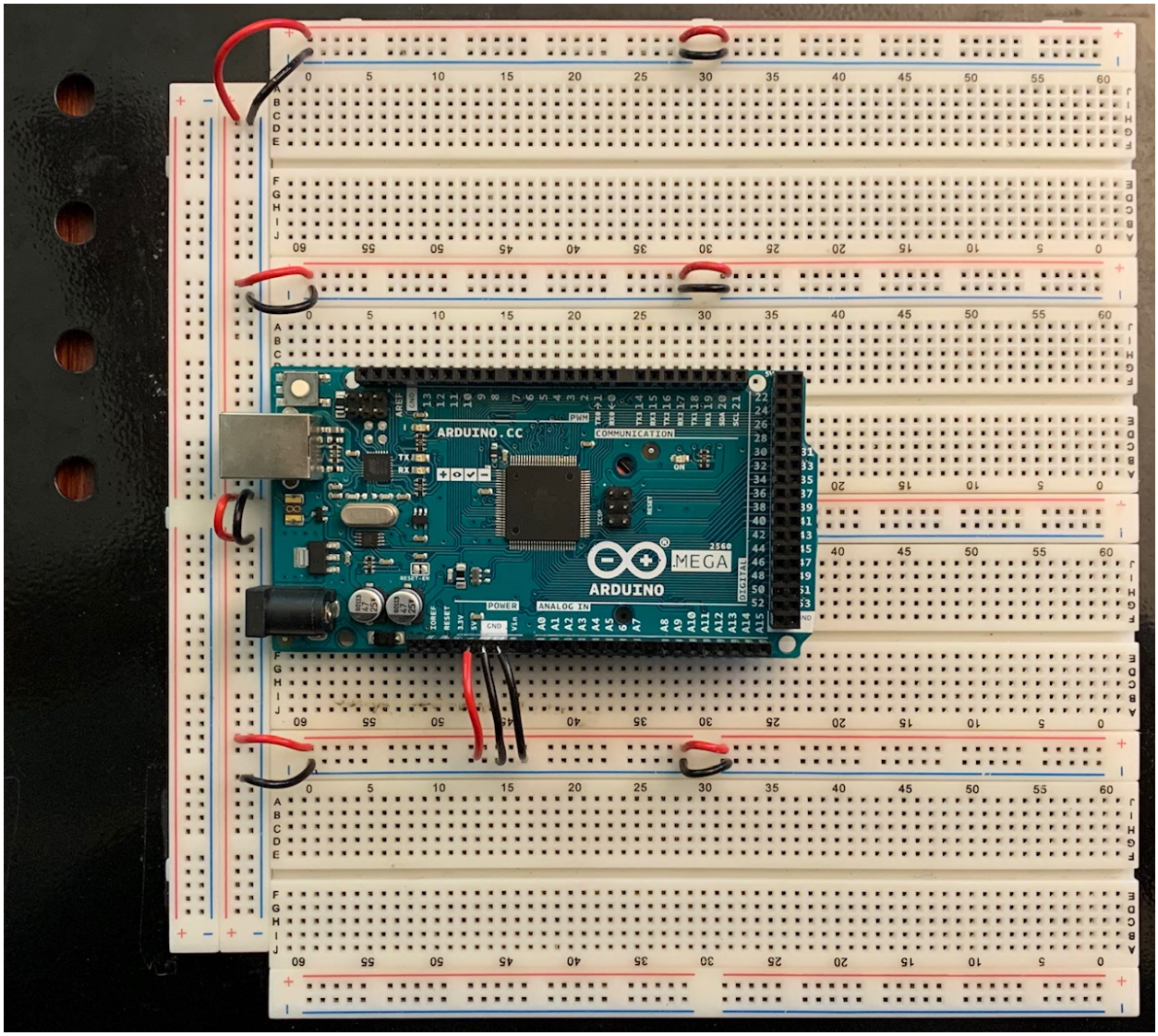
Let's prep our breadboards. Please fasten an Arduino to your breadboard. I recommend duct tape (the baby sitter's friend!); position the device to that it doesn't cover any of the breadboard's plastic structures that are used to hold components.

Here's how the holes are interconnected, underneath the plastic surface. The five holes in a column are connected, as shown in a few spots in the picture below. The 25 holes in a horizontal row are also connected.

In the photo after the close up I show a breadboard with an Arduino and connections between the Arduino's 5V and grounds to the breadboard. The doubled connection of the Arduino grounds is not electrically necessary, but it does provide redundancy in case one of the ground wires falls out.

Be sensible in your choices of wire colors: always use red for 5V and black for ground. You'll want to strip about 5 mm of insulation from each end of a wire when establishing your connections.

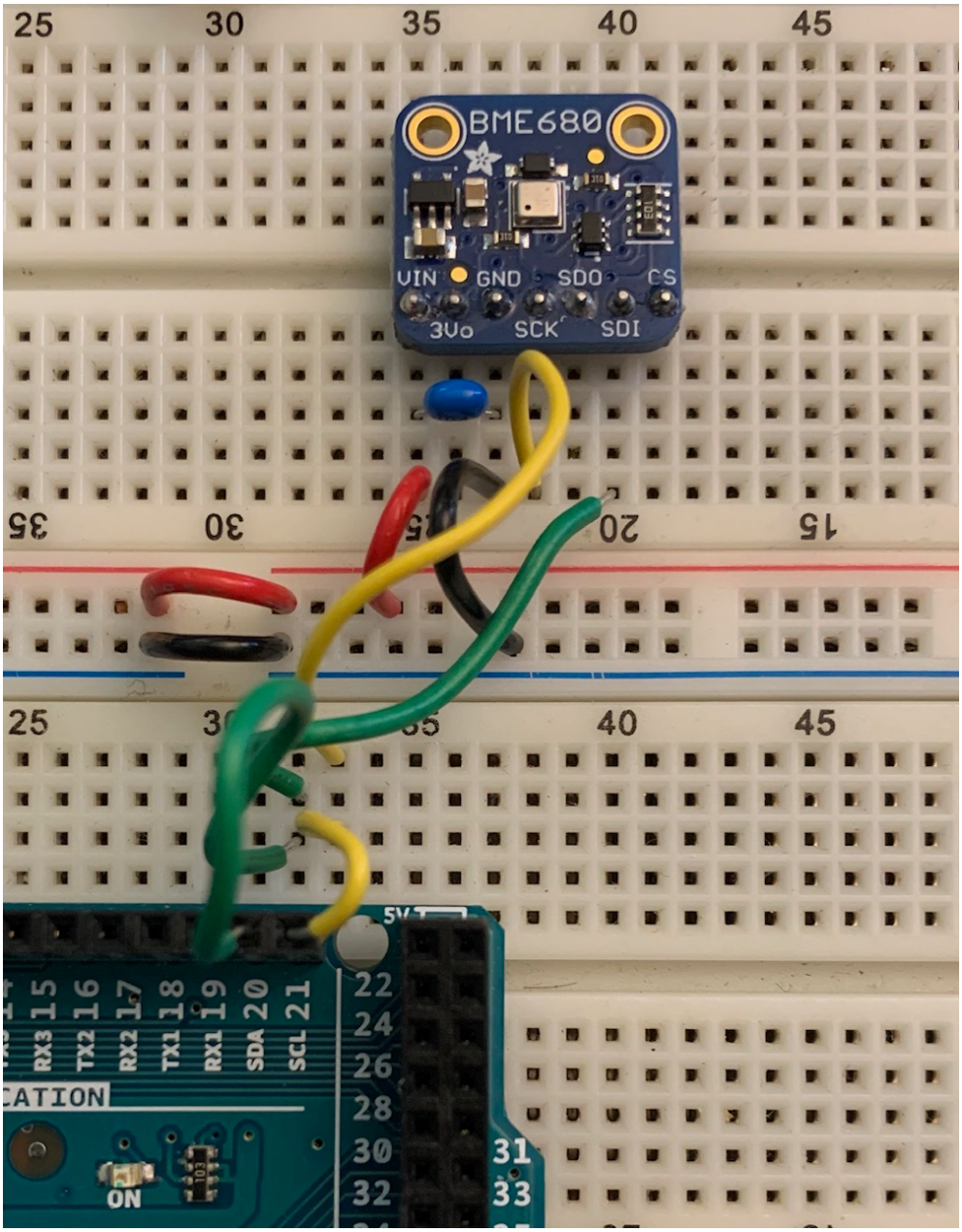




In-class exercise/milestone 1b: BME680

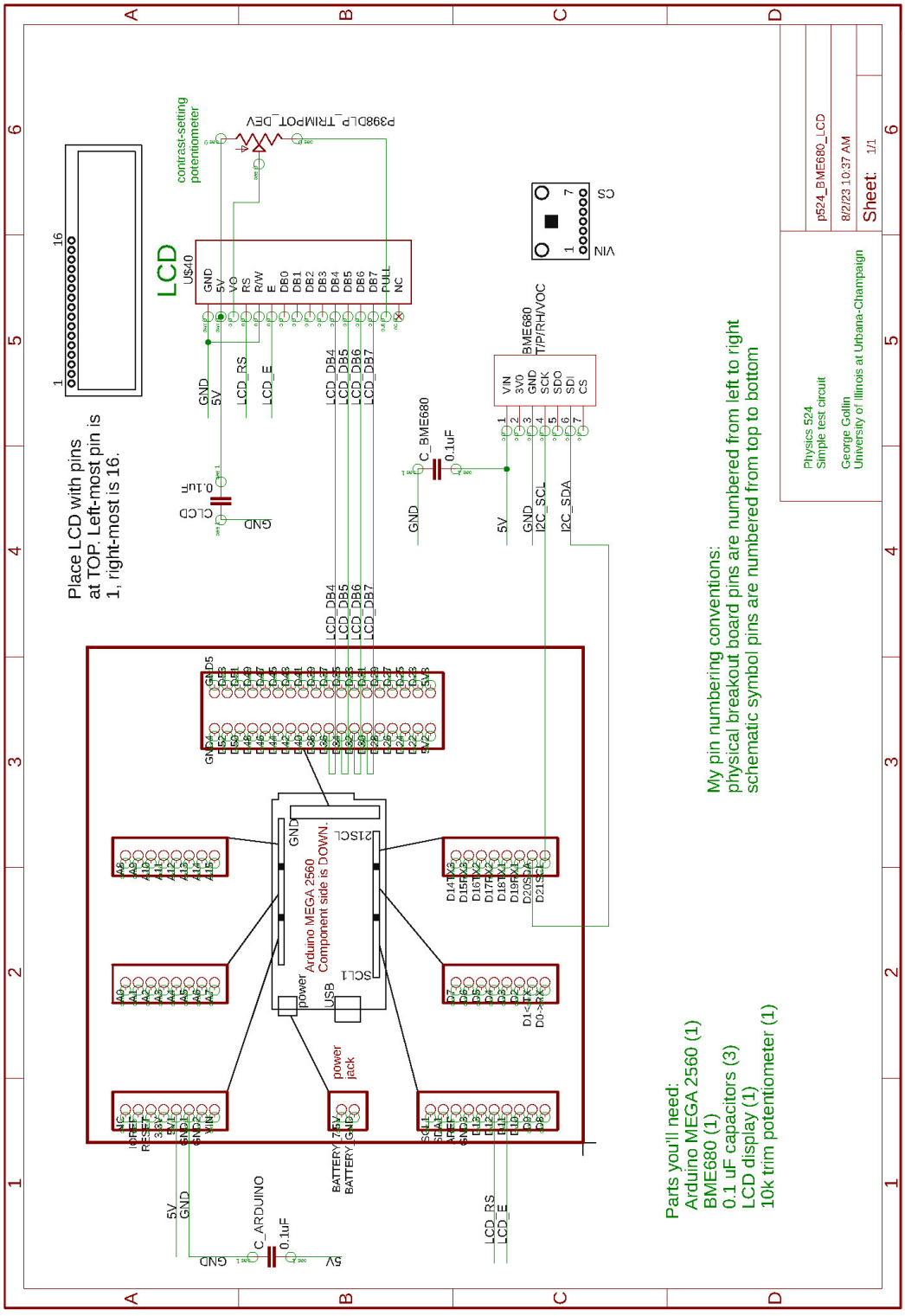
Most of our breakout boards were built by Adafruit Industries, a wonderful provider of small electronic packages intended largely for the hobbyist market. Go to the Adafruit site https://www.adafruit.com/ and find the BME680 page that mentions some of the supporting infrastructure available for you.

Install the BME680 onto your breadboard. (See https://www.adafruit.com/product/3660 and links therein.) You should power it using the Arduino's +5V and GND lines. Using sensible colors (red for +5V, black for ground, other colors for signal lines), connect GND to one of the Arduino's GND lines and VIN to one of the Arduino's 5V lines. Also connect the leads of a 0.1μF capacitor to the BME680's power and ground inputs.



We'll let the device and the Arduino communicate using an I2C ("I Two C": Inter Integrated Circuit) interface; set this up by connecting the BME680's SCK (serial clock) pin to the Arduino's SCL output (pin 21). Also connect the BME680's SDI (serial data) to the Arduino's SDA input (pin 20). You should leave unconnected the BME680's 3Vo, SDO, and CS pins.

Here's a schematic for the circuit that also includes a liquid crystal display. We'll discuss briefly how to read the schematic. (Don't bother with the LCD for the moment, though you are free to wire it up, if you'd like.)



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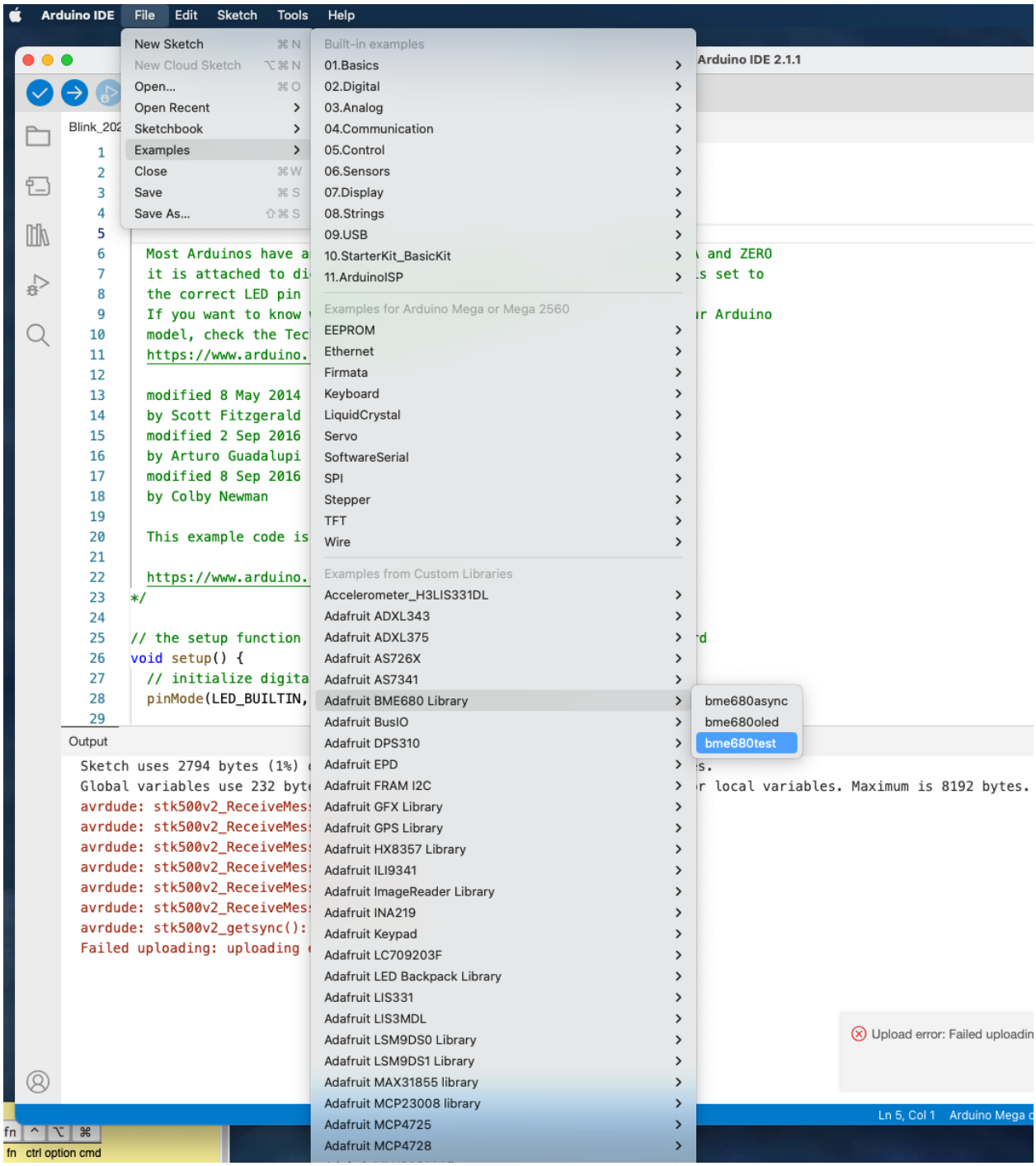
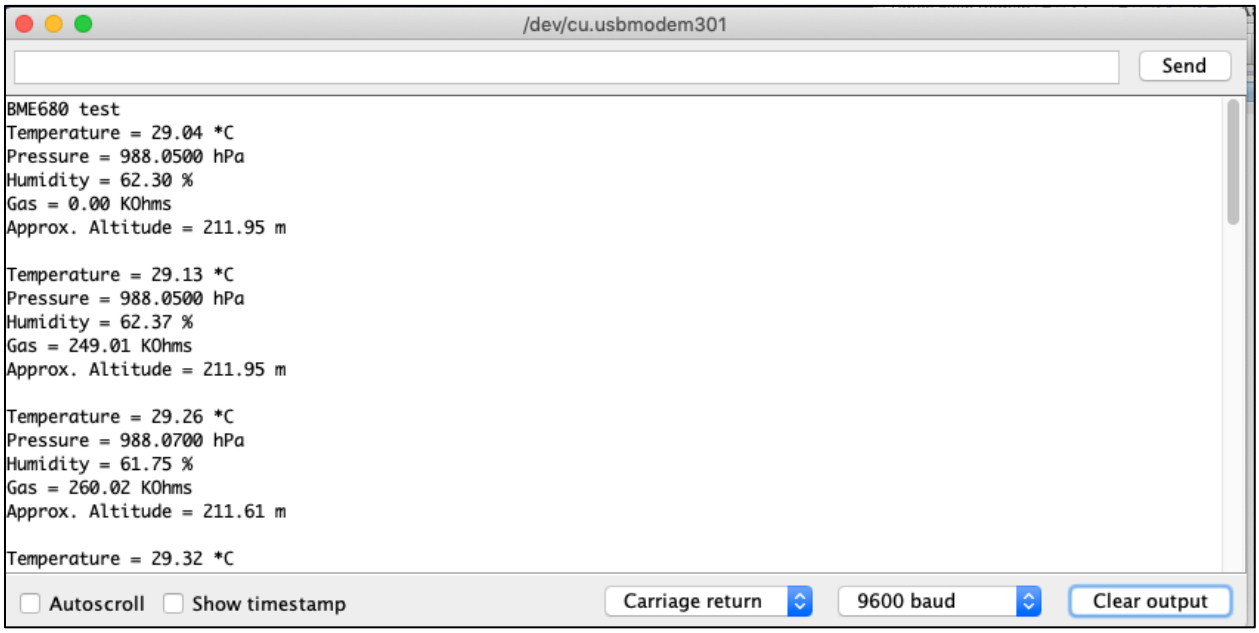
You'll need to install one of Adafruit's libraries to drive the BME680. See https://learn.adafruit.com/adafruit-bme680-humidity-temperature-barometic-pressure-voc-gas/arduino-wiring-test and scroll down to the section titled "Install Adafruit_BME680 library." Follow the directions to install the library and upload to the Arduino the demonstration software. Then open, compile, and run the example program BME680test.



You should find that the pressure transducer is so sensitive that it can tell that you've lifted the board up from your worktable by a couple of feet just from the change in atmospheric pressure.



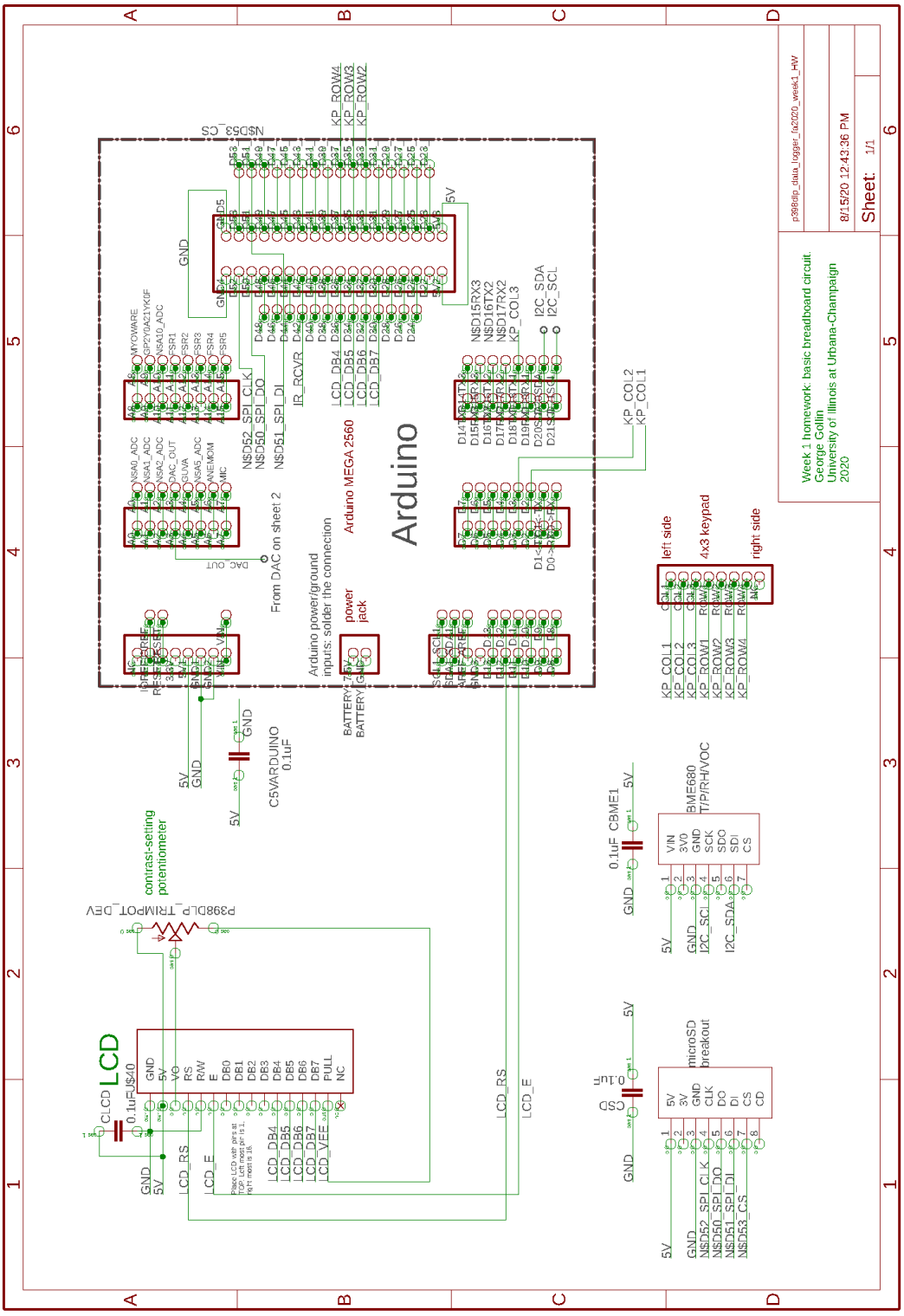
In-class (due at the first class meeting next week)

On your breadboard, install the following devices (in addition to the BME680 and Arduino): LCD (including 10kΩ trimpot), keypad, and microSD breakout. See the schematic, below.

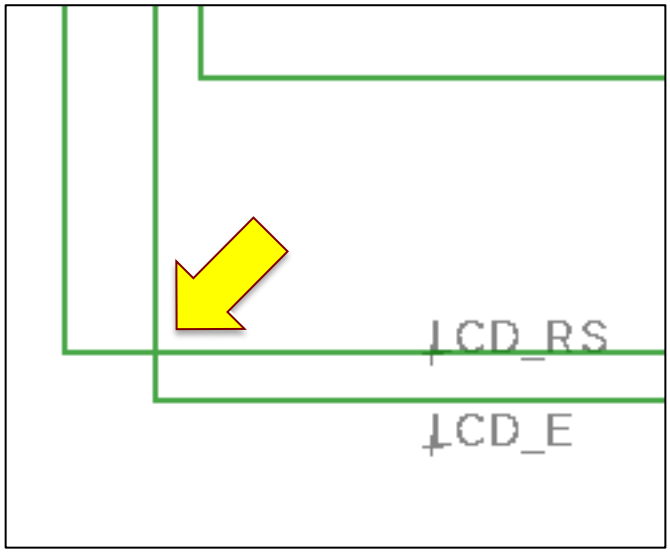
For each device find a demo program (perhaps on the Adafruit site, or from a library that you might install, or from the course's "Code & design resources repository") and confirm that it functions properly. You'll need to fool around with the 10k trimpot to adjust the LCD contrast properly.

How to read a schematic

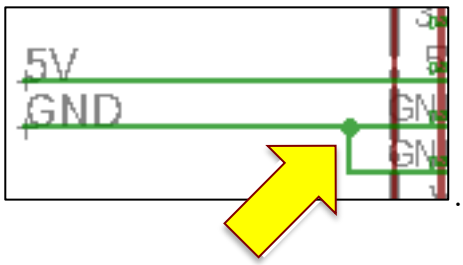
A schematic holds a topological representation of an electronic circuit. The two most important things on it are symbols for the various components—resistors, capacitors, integrated circuits and so forth—and (named) nets, which define the electrical connections between components. For example, the BME680 symbol on the schematic shows seven pins, with pins 1, 3, 4, and 6 connected to the nets named 5V, GND, I2C_SCL, and I2C_SDA, respectively. (Pins 2, 5, and 7 are not connected to anything.) Anything tied to the 5V net is electrically connected to everything else on the 5V net.



When lines representing nets cross each other the point of crossing does ***not*** represent a connection between the nets! For example, the LCD_RS and LCD_E nets are not connected to each other here:



We indicate a point at which two lines (which are on the ***same*** net) are electrically connected with a dot as follows:



This week's homework assignment (due at the first class meeting next week)

Finish all of the in-class exercises in this unit, and be prepared to show your results to the course staff during class.