OCN 479-001

Sensor communications

(Wired edition)

Today's plan

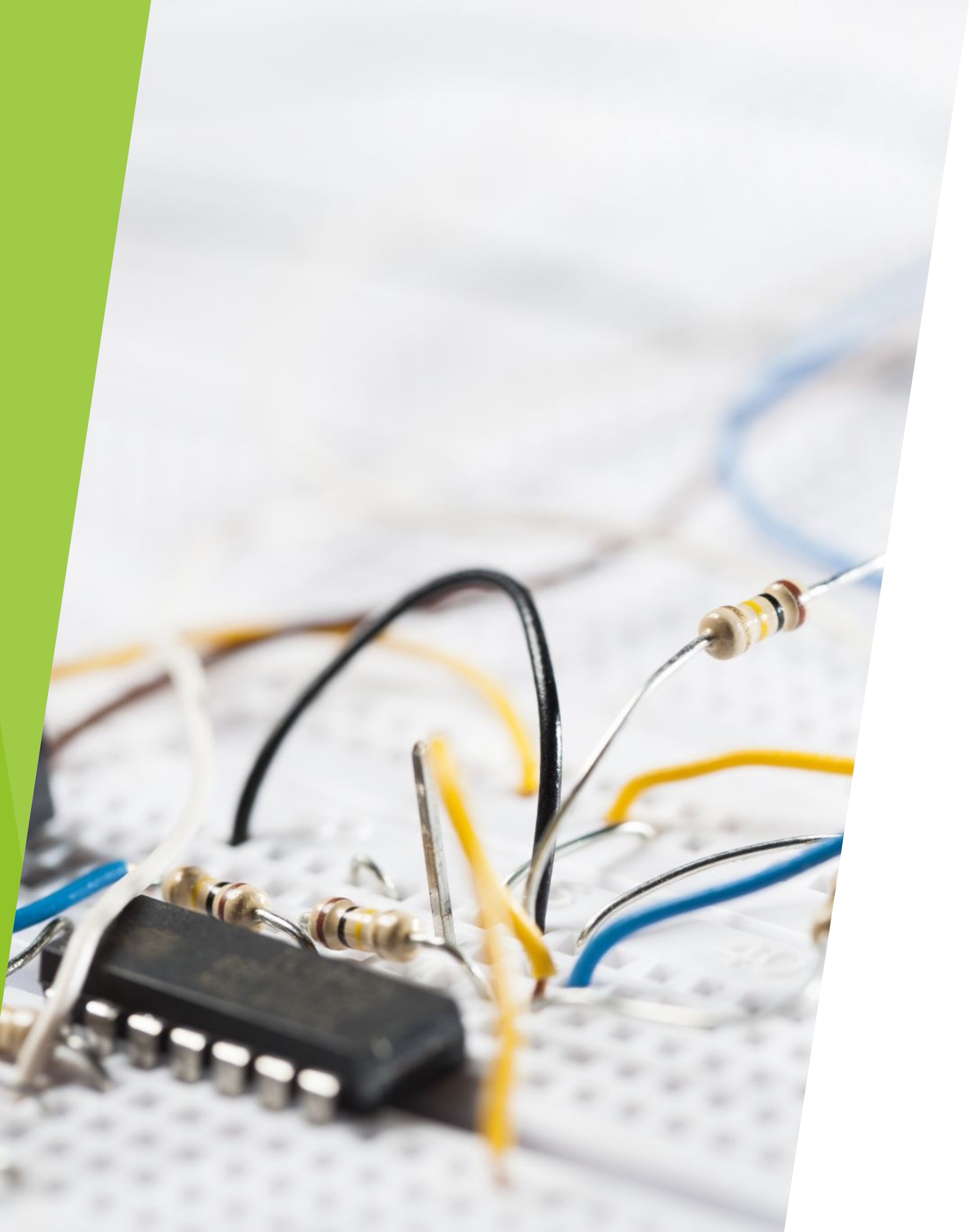
- Lecture
- Finalize teams
- Start building our new sensors in earnest

Assignment (due Sep. 29)
1 per group

- Short presentation on your instrument
  - ~5 minutes, just a couple slides
  - Most critical: methods/principles of operation—how does it work?!
  - Methods: how is it built, what does it do?
  - Principles of operation: how does it convert some physical (chemical, biological) quantity (e.g., conductivity) to a voltage (e.g., it transmits a voltage across the water and measures current flow, enabling the calculation of resistance and therefore conductance)?
  - What accuracy, precision, stability, and response time can we expect?

Today’s topics

Sensor Communications:
(Wired edition)



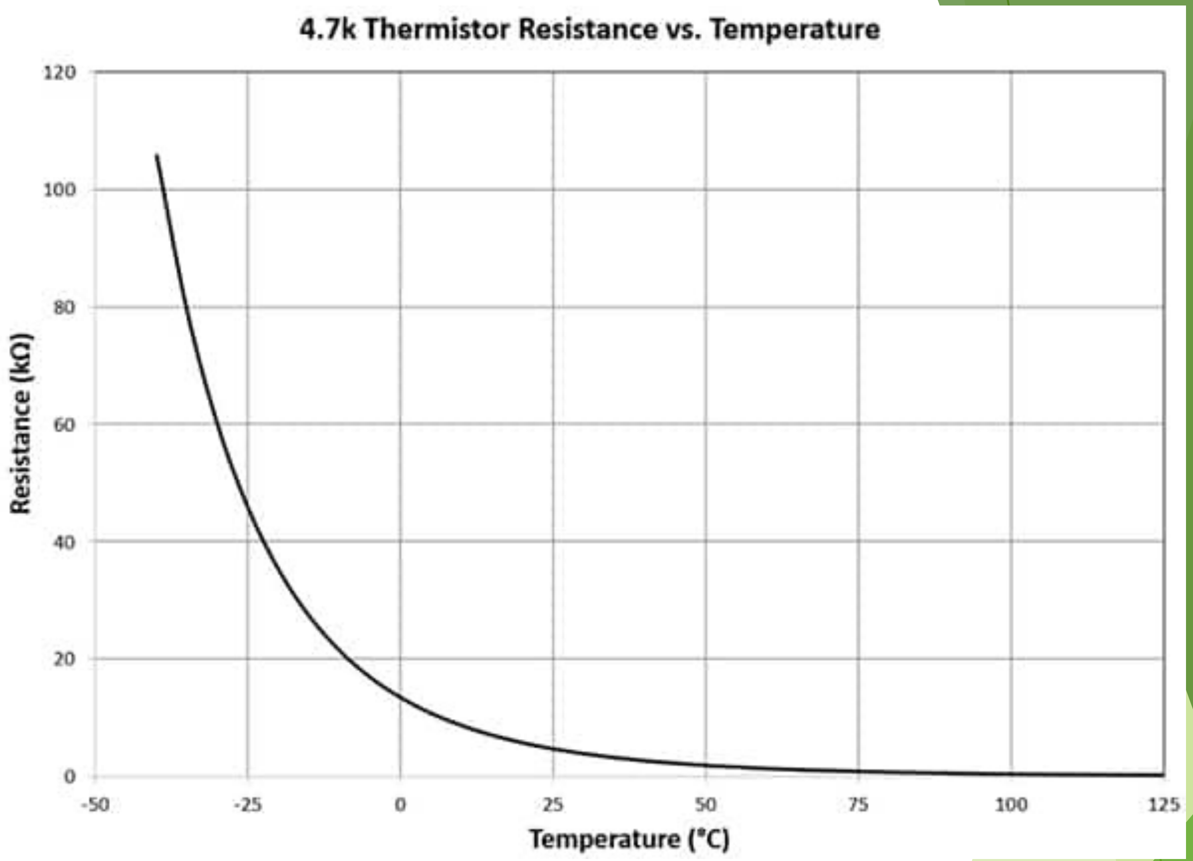
Sensor Communications

How do we transmit information from some device (a peripheral) to the core microcontroller or computer?

Analog vs. Digital

Analog

- Typically a current (4–20 mA) or voltage (0–3.3 V)
- Often proportional to quantity of interest:
  e.g., $T = (100\ ^\circ C/3.3\ V) * Voltage$
- Can be other equations: famous one in oceanography is Steinhart-Hart Equation



https://www.digikey.com/en/articles/quickly-create-an-accurate-thermistor-based-temperature-sensing-circuit

Steinhart–Hart Equation

- A thermistor is a resistor that changes resistance based on temperature
- Have known voltage drop across resistor; measure current; calculate resistance
- Plug resistance into SHE:
  $1/T = A + B[\ln(R)] + C[\ln(R)]^3$

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Digital

- Sending bits (0s and 1s) and bytes (8 consecutive bits) with already translated information
- 01101010 = ???
- Parallel vs. serial communications

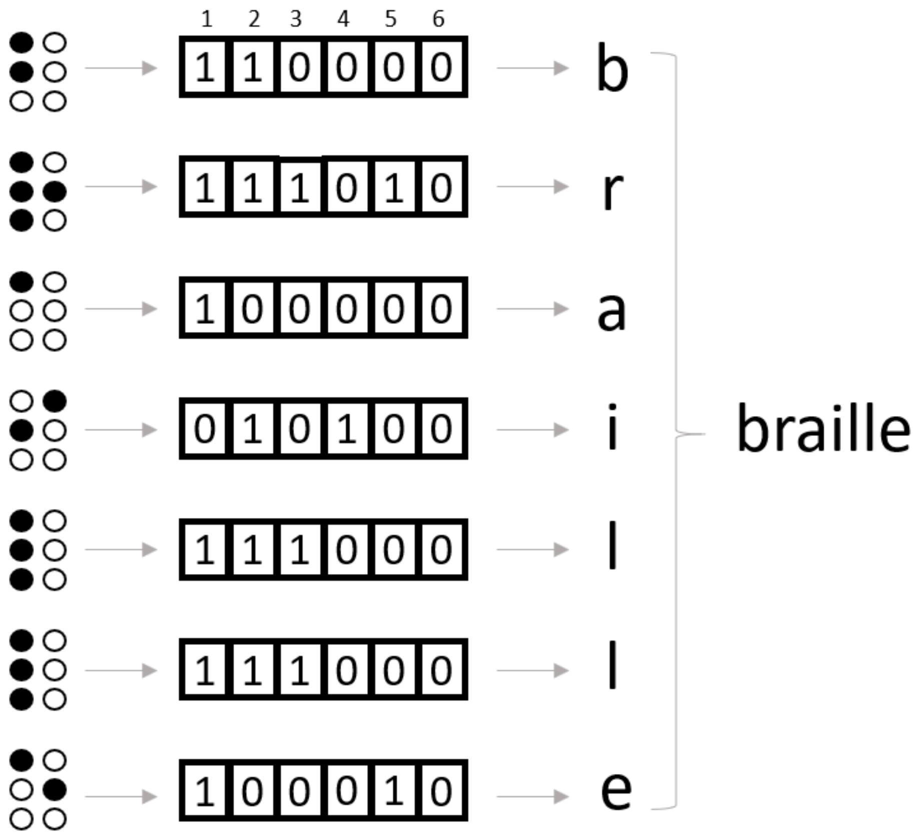
Binary
Two possible values: 0 or 1

- Paul Revere: “One if by land, and two if by sea.”
- How many lanterns lit —> code for possibilities of attack
- Two lanterns means $2^2 = 4$ possibilities
  - 00 = Brits not coming
  - 01 or 10 = coming by land
  - 11 = coming by sea
  - (Sometimes we don’t use all available permutations)

https://chaddsfordhistorical.wordpress.com/2015/07/25/mythbuster-friday-one-if-by-land-two-if-by-sea/

Binary
Two possible values: 0 or 1

- Braille letters use six raised or unraised bumps
- This gives 2^6 = 64 possibilities
- 100000 —> a



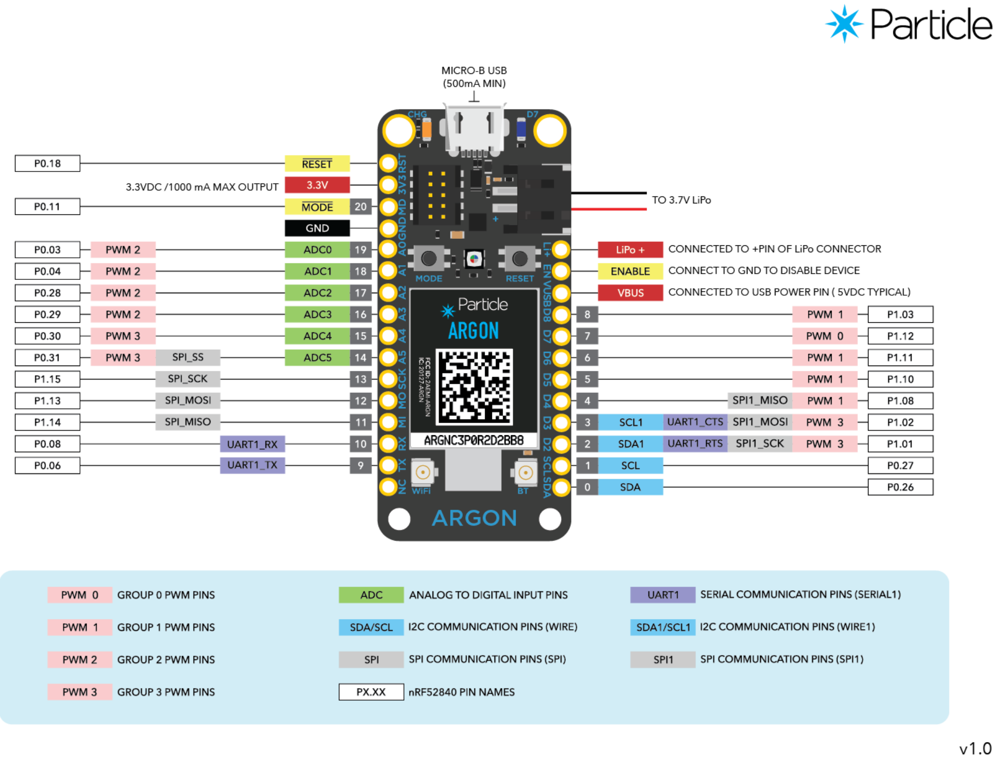
```
// The loop() method is called frequently.
void loop()
{
        // Turn on the LED
        digitalWrite(MY_LED, HIGH);

        // Leave it on for one second
        delay(3s);

        // Turn it off
        digitalWrite(MY_LED, LOW);

        // Wait one more second
        delay(1s);

        // And repeat!
}
```

What if we're using a microcontroller

- HIGH = 1
- LOW = 1
- That's good for one or two bits; what if we want to transmit large numbers?

Particle Argon "pinout"

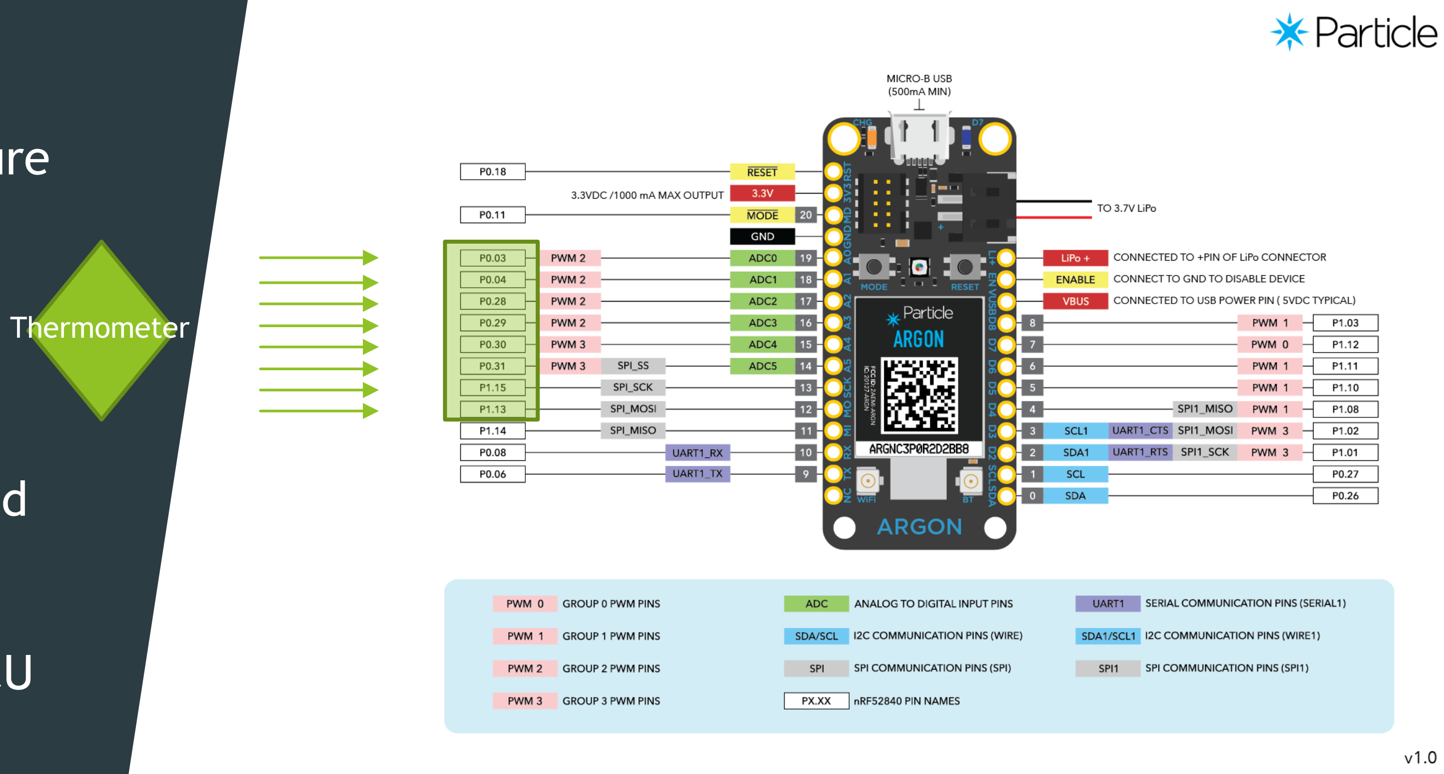
- If we want to transmit an 8-bit value…
- $2^8 = 256$
- Value could range from 0–255 inclusive



What if we want to transmit large numbers?

Option 1: parallel

- Example: we have a temperature sensor and we want to send digital data from it to our microcontroller
- Pick 8 pins
- Simultaneously send your 0s and 1s on each of the 8 pins of the thermometer to each of the corresponding 8 pins on the MCU (microcontroller unit)



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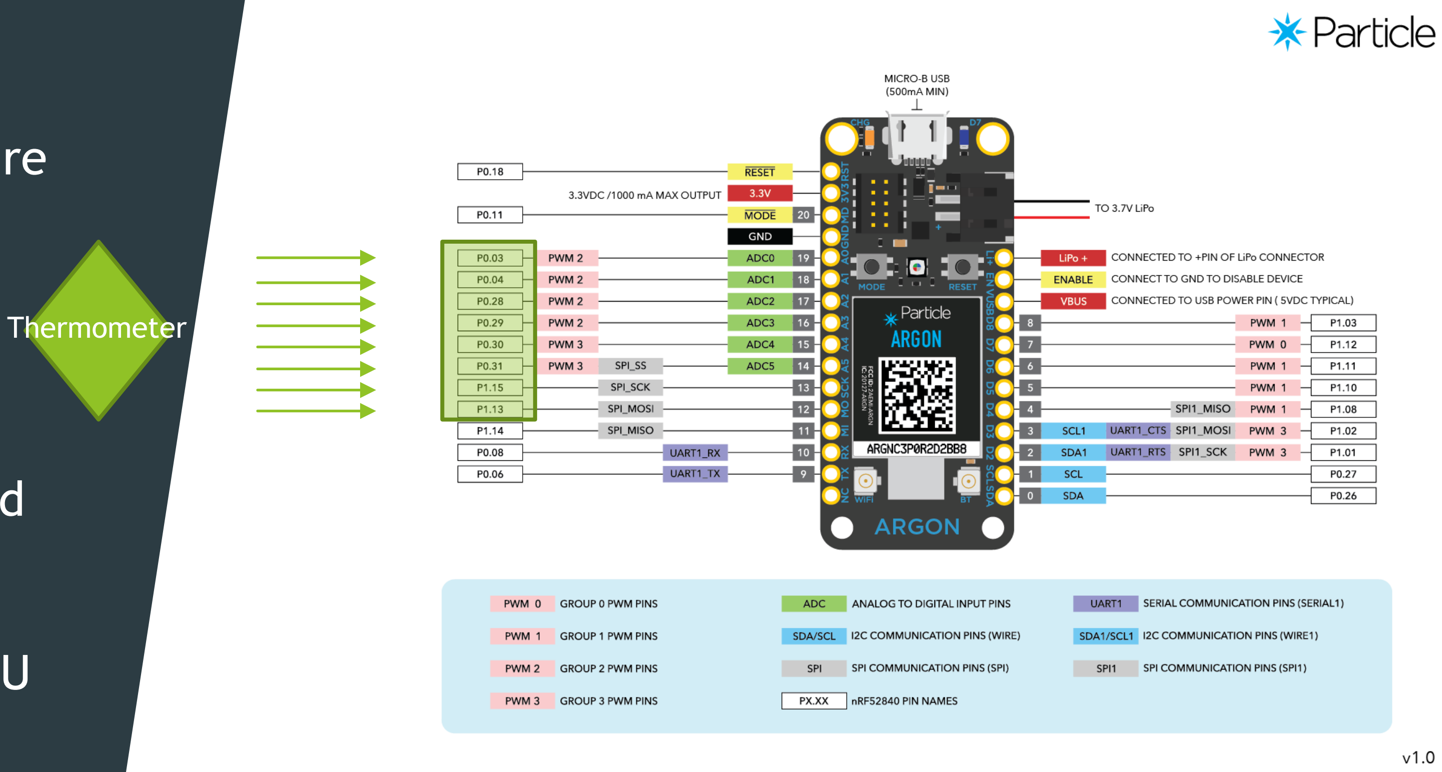
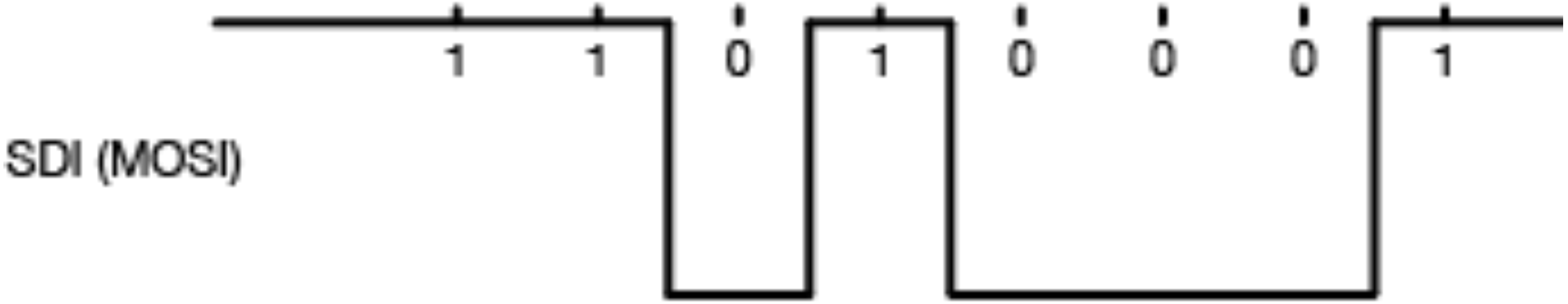
Option 1: parallel

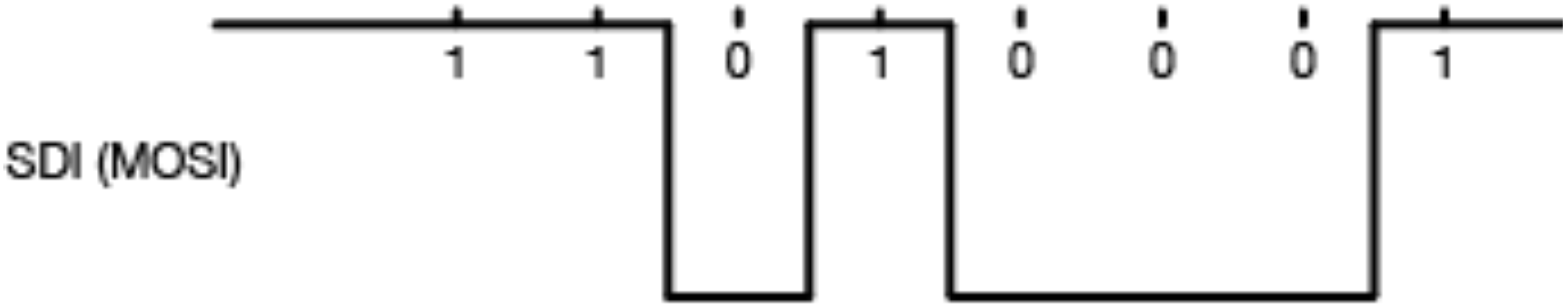
- Example: we have a temperature sensor and we want to send digital data from it to our microcontroller
- Pick 8 pins
- Simultaneously send your 0s and 1s on each of the 8 pins of the thermometer to each of the corresponding 8 pins on the MCU (microcontroller unit)
- Very inconvenient: lots of wires, lots of parallel processing





Option 2: Serial

Use one wire and pulse it up (1) and down (0)

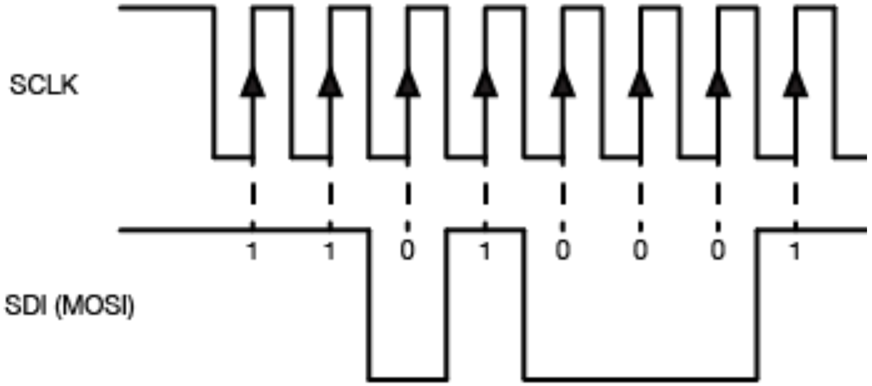


Option 2: Serial

MAJOR (POTENTIAL) PROBLEM: how do we know how many consecutive 0s or 1s we have?

I.e., the code above is 11010001. But how do we know it's not 1111001100000011?

Option 2: Serial



SOLUTION: use a second wire to send a clock (just regularly alternating 0s and 1s)

https://itp.nyu.edu/physcomp/lessons/synchronous-serial-communication-the-basics/

Serial wins, but different flavors

- SPI: Serial peripheral interface
- I2C: Inter-inter communications
- UART: Universal asynchronous receive/transmit

Serial wins, but different flavors

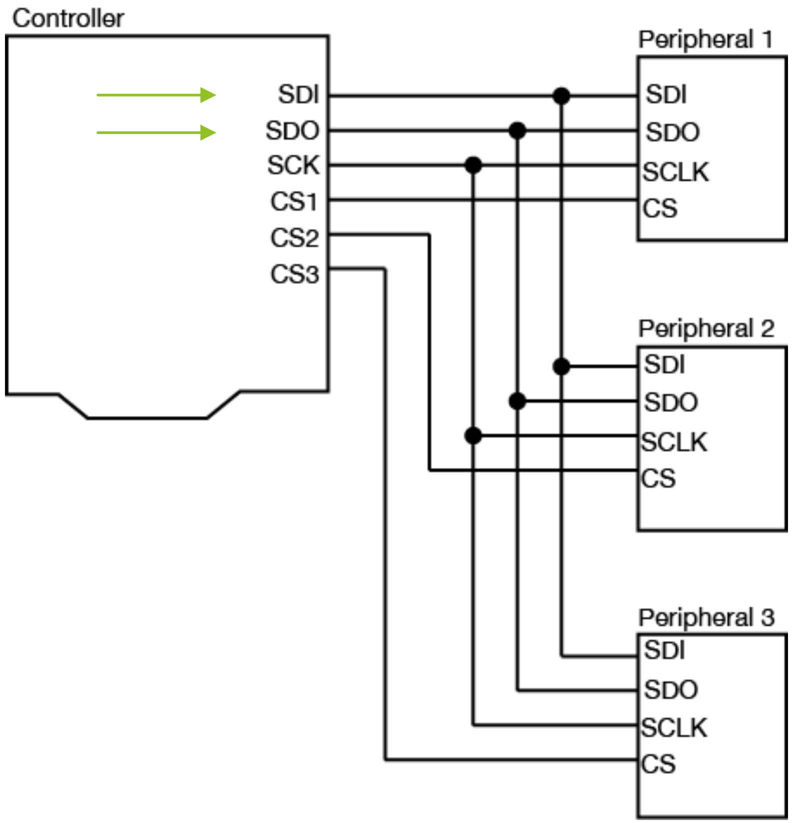
- SPI: Serial peripheral interface
- I2C: Inter-inter communications
- UART: Universal asynchronous receive/transmit

- 99% of people you work with in sensor applications will just refer to all of this (and more) as serial comms

- In our work, we'll use soldered/breadboarded wires
- Could also use an RS-232 cable, RS-485 cable, Ethernet cable, …
- These protocols have additional details that we won't cover this semester, but look up if you need them for your device (or interest or job)!

Serial: two more challenges

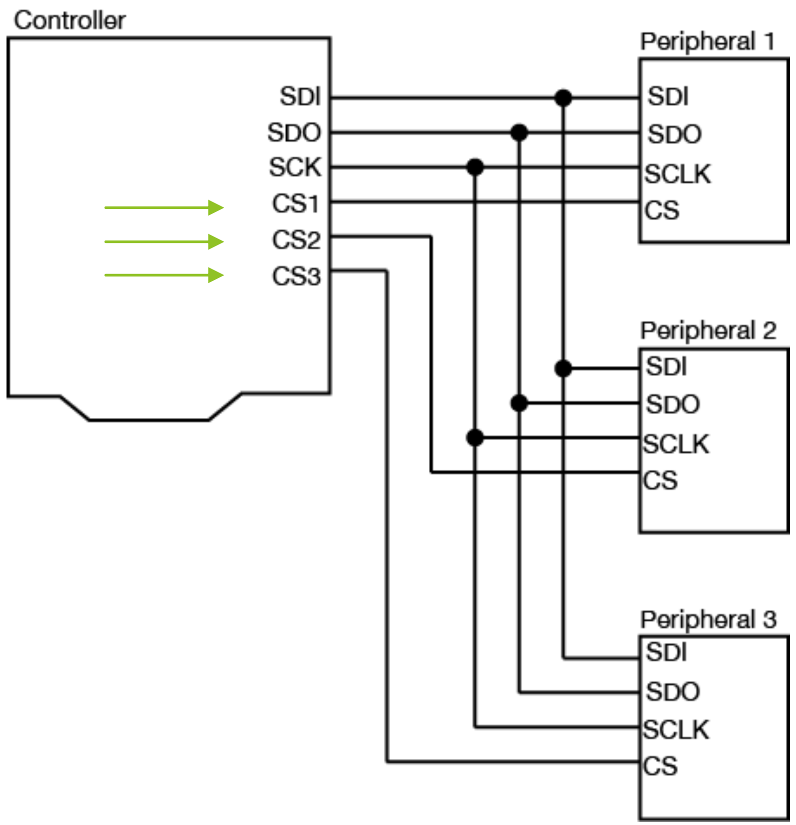
1. What if we want two-way comms?



- Use one serial data in (SDI) wire
- One serial data out (SDO) wire

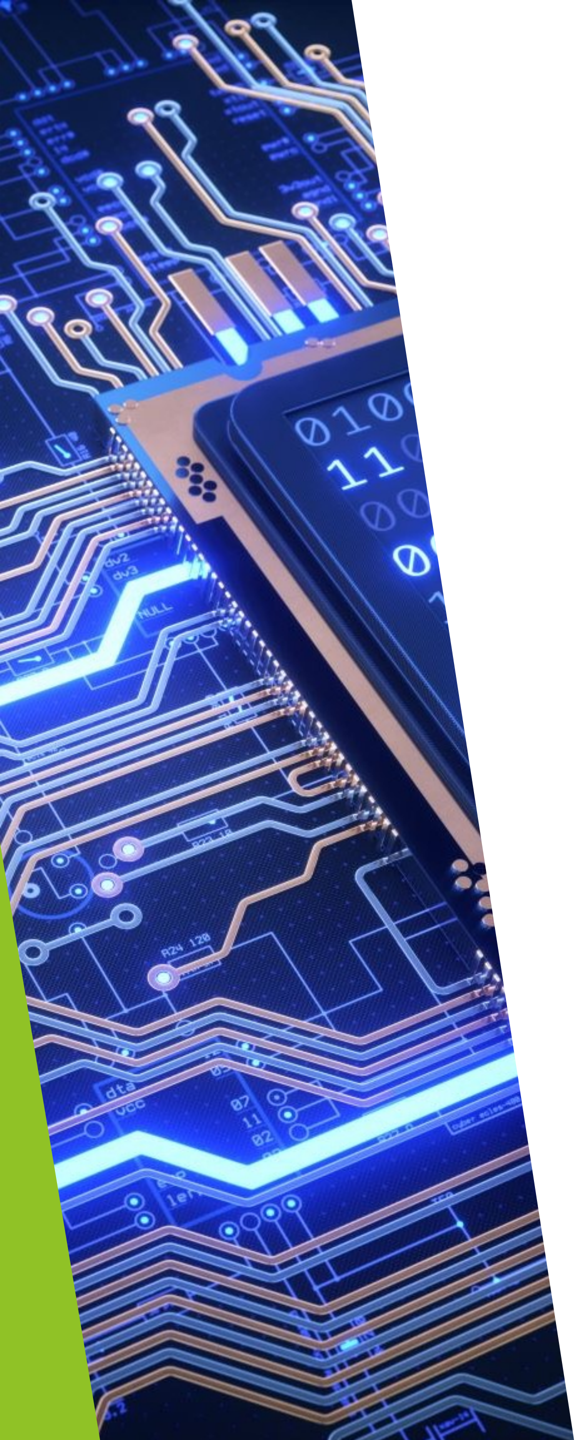
Serial: two more challenges

2. What if we want multiple sensors connected?



- Use multiple “chip select” (“CS”) wires but same data in/data
- Note that same SDO and SDI lines go to all three peripherals

https://itp.nyu.edu/physcomp/lessons/synchronous-serial-communication-the-basics/

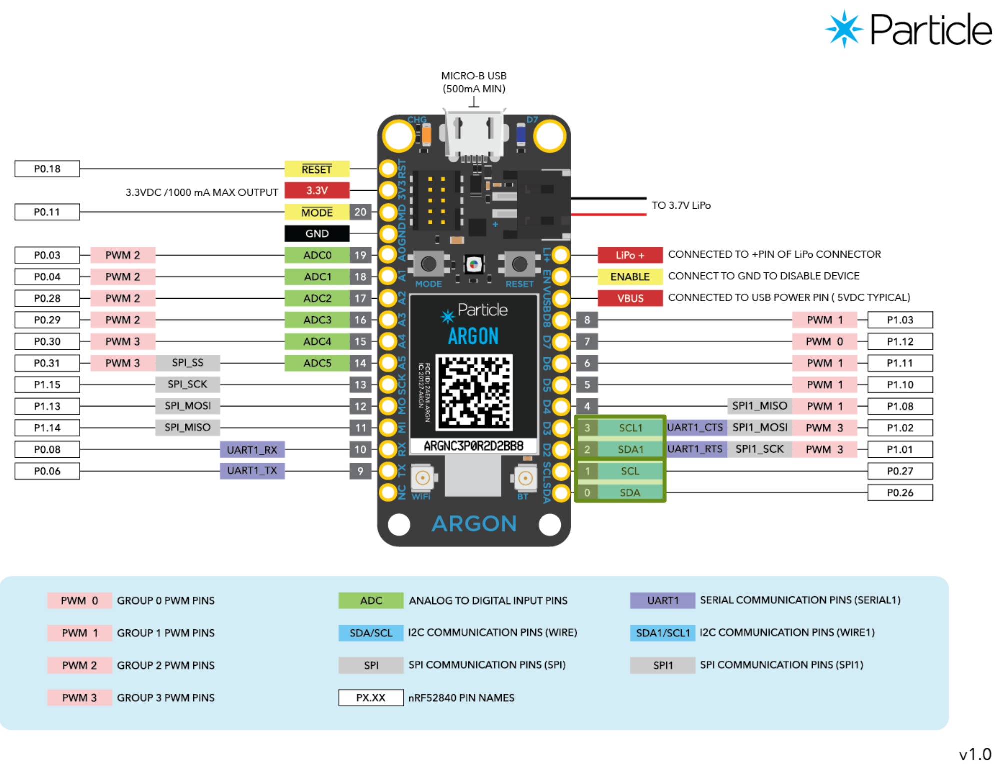


Digital (serial) comms gives us a bunch of 0s and 1s: what next?

- Datasheet for chip will tell us how to interpret the bits and bytes
- Computer/electrical engineers and people with lots of patience can write code to interpret these values
- In this class, we’ll use “drivers”—prepackaged code chunks—to do the interpretation

Particle Argon "pinout"

- Tells us what pins can be used for what functions
- Sometimes multiples of a single function
  - SCL/SDA vs. SCL1/SDA1 means there are two I2C ports
- Sometimes one pin can have multiple functions (we tell microcontroller what to use in firmware)



Analog vs. Digital

Analog

- Typically a current (4–20 mA) or voltage (0–3.3 V)
- Often proportional to quantity of interest:
  e.g., T = (100 °C/3.3 V)*Voltage
- Can be other equations: famous one in oceanography is Steinhart-Hart Equation
- **Good for sending "raw" voltages, instantly usable**
- **Bad if noise could mess up reading**

Digital

- Sending bits (0s and 1s) and bytes (8 consecutive bits) with already translated information
- 01101010 = ???
- Parallel vs. serial communications
- **Good for preventing data loss**
- **Challenging because needs additional wires and (slightly) more complicated code/drivers**

Combining the two: analog + digital

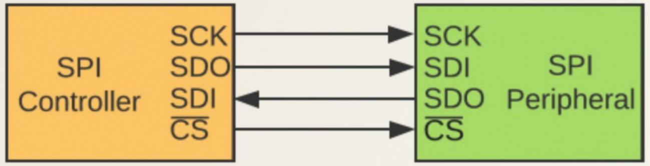
ADC: Analog-to-Digital Converter

- Takes an analog voltage referenced to something and converts it to a digital number that can be recorded by the microcontroller
- Recorded in ADC “counts” based on resolution of microcontroller
- E.g., 12-bit ADC —> 2^{12} = 4096 possible values
- We have to convert this back to the actual voltage!
- Scales proportionately: $V = V_{ref}/4096*ADC_{counts}$
- V_{ref} is fixed property of your microcontroller (3.3 V for us)
- ADC_{counts} is what your microcontroller recorded

A REDEFINTION OF SPI SIGNAL NAMES

With the help of a few good friends, we've authored a resolution to rename the SPI signal names.

SEE FULL RESOLUTION



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SPI is short for Serial Peripheral Interface. It's a great protocol and interface mechanism between multiple devices on a bus. It's used all the time in the electronics world - it's what makes your displays, SD cards, sensors and programmers work. The problem is that since its inception in the 1980s, the terms **Master** and **Slave** have been used to describe the controller and the peripheral (MOSI = Master Output Slave Input, and vice versa). **The technology world can do better than this**.

A final plea

Until recently, it was extremely common to see SPI wires described as MISO and MOSI. Now **PICO and POCI** are catching on; **use these terms**. See more here: https://www.sparkfun.com/spi_signal_names

Today’s lab

1. Create groups based on interest, strengths, number of students
2. Begin work on project of interest
3. Don’t just dive in: map out what you’ll need:
   1. Circuitry?
   2. Code?
   3. Housing design?
   4. ?
4. START. TAKING. NOTES. Your main deliverables at end of semester are presentation on your sensor and a continuity report (where would someone get started if following your example?).
   1. How will sensor(s) communicate with microcontroller?
   2. How many sensors are involved?
   3. How will you log data?
   4. What peripherals will you need for other functions (e.g., GPS)?

Kayaking plans