Voltage,
A2D,
Piece Wise Linear,
Noise

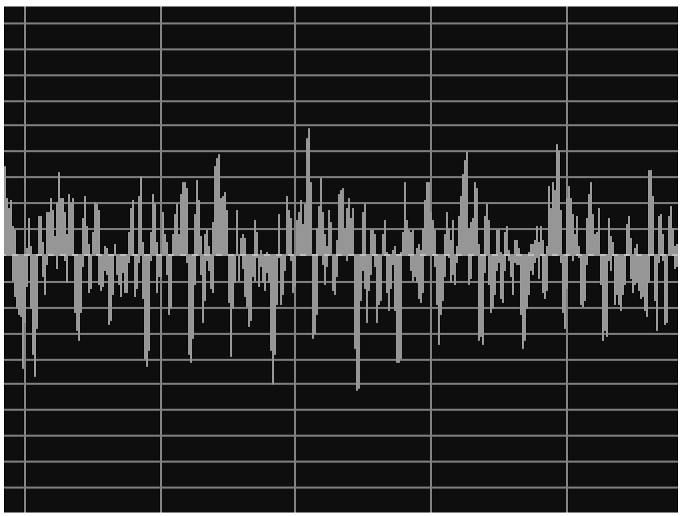
Topics

- What form are real-world signals?
- How can a computer read an analog signal?
- How can we approximate functions?

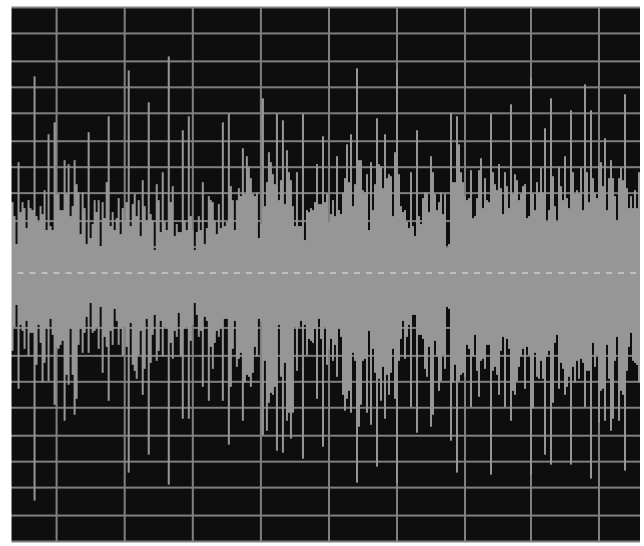
Signals in the “Real World”: Voltage

Voltage

- Real world analog signals are often changes in voltage:
  - Ex: Microphone encodes sound into voltage levels



Audio: Zoomed in

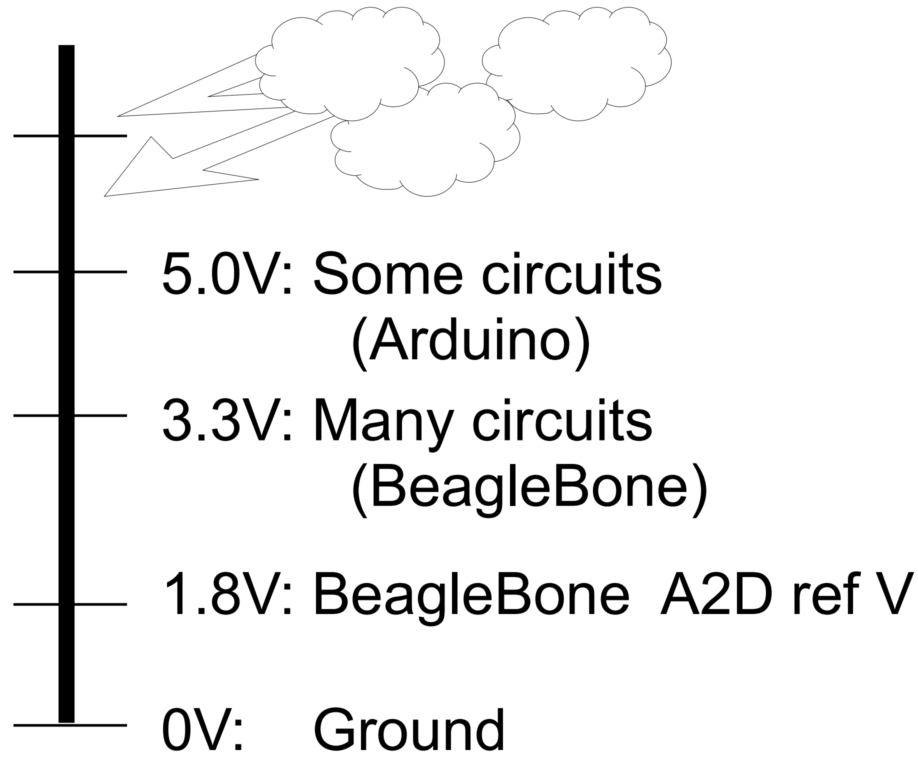


Audio: Zoomed out

Voltage Ranges

These are all DC voltage
(Direct Current)

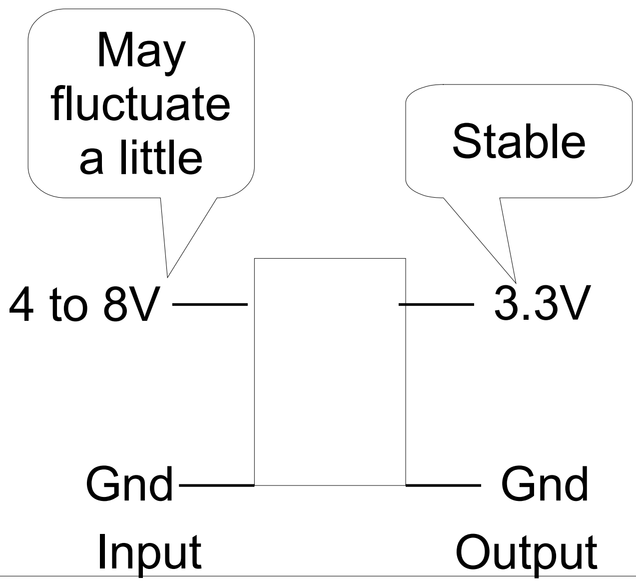
Out of the wall comes AC Voltage
(Alternating Current)



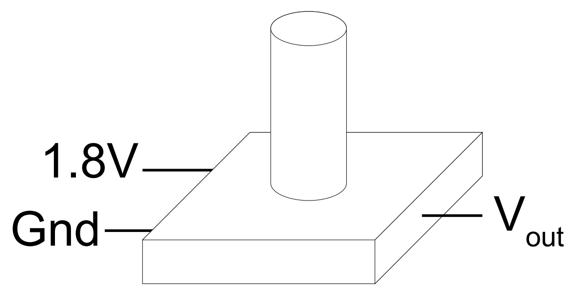
Electronics Components ("Parts")

- Many electronics components run on, manage, and work with voltages.

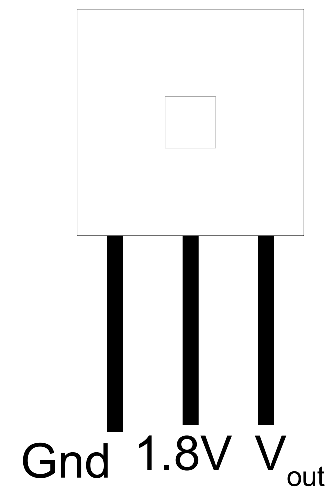
Voltage Regulator:
Converts input voltage to stable output voltage.



Potentiometer:
Turning the knob adjusts the output voltage on V_{out}.



Light Sensor:
The more light, the lower the voltage on V_{out}



Reading a Voltage

- How can we read a signal into the computer?
  - Real world is analog voltages; computer are digital.
  - We need an analog to digital converter (ADC)
    - Also called an A2D (Analog “to” Digital)
- BeagleBone has a 12 bit A2D:
  - It reads a voltage and gives a number between 0 and 2^{12}-1 (=4095)
  - It can sample voltages between 0V and 1.8V
    - It is easily damaged by higher voltages!

Quantization & Sampling

- Quantization:
  Since it has 4096 samples over 1.8V
  - Resolution of a single bit is:
    1.8V / 4096 = 0.00044V = 0.44 mV

    This is pretty good for most applications!
- Sample Rate:
  How fast the A2D can read samples
  - Need 44100 Hz (44.1kHz) for CD audio
  - BeagleBone can sample at 1.6MHz (1600kHz)
  - Some applications (reading a POT for volume) may need low sample rates (~10Hz)

BBB A2D Demo for POT

- A2D is enabled by default
  - Done for us by UBoot via /boot/uEnv.txt

- Change to sys file system folder:

```
(bbg)$ cd /sys/bus/iio/devices/iio\:device0
```

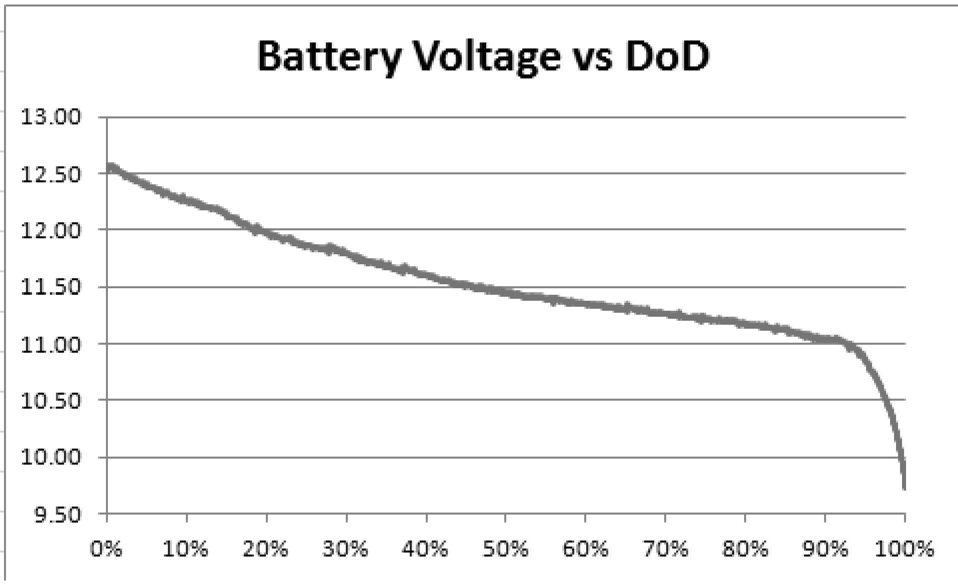
- Read voltage 0 (for POT):

```
(bbg)$ cat in_voltage0_raw
```

Approximating Functions:
Piece Wise Linear

Function Approximations

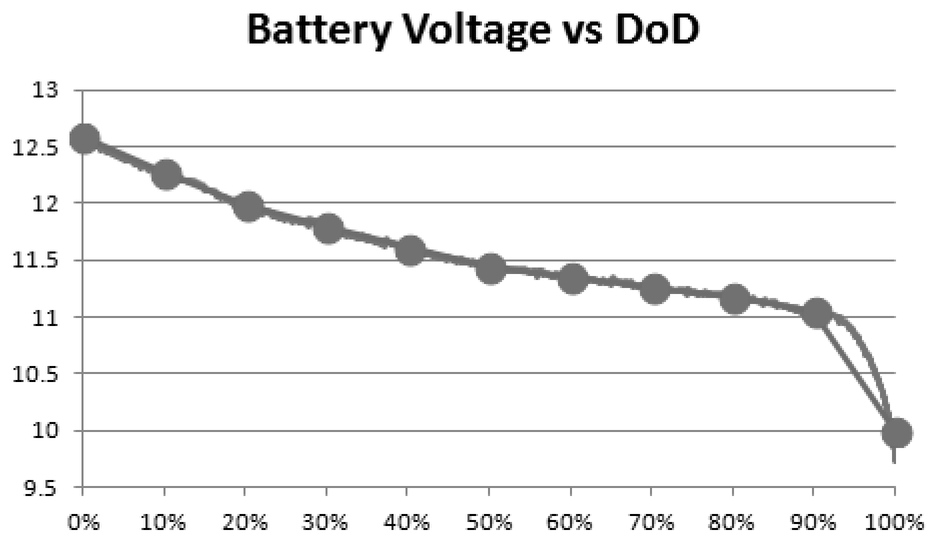
- Real world functions can be hard to approximate.
  - Some approximations are computationally expensive (high-order polynomials, cubic-spline, ..)
  - Piecewise Linear (PWL)
    Approximate a function with a series of lines.



As you discharge a battery, its voltage drops. (DoD is Depth of Discharge)

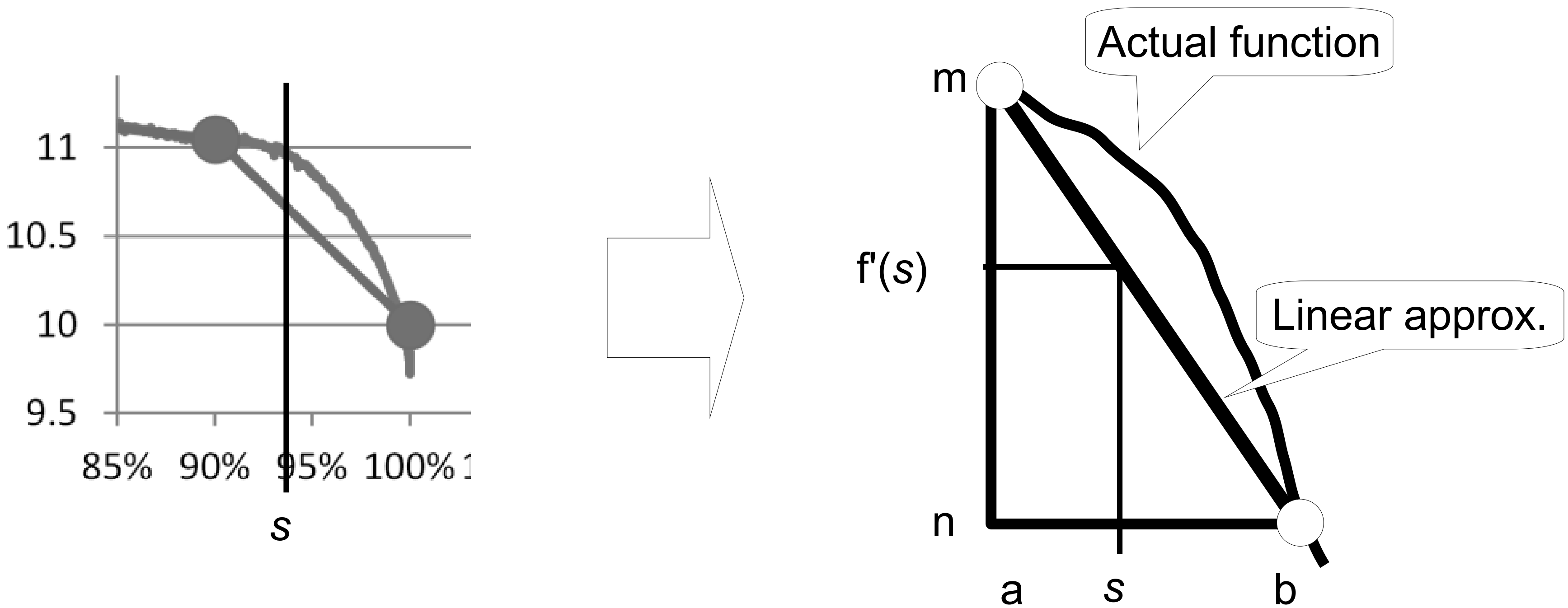
Piece Wise Linear

- Pick good points on the function f(x) to capture its shape
  - can be evenly spaced, or
  - can be specially selected points
- Between adjacent points, draw a straight line.
- The approximation f'(x) is the straight lines.



Computing Piecewise Linear

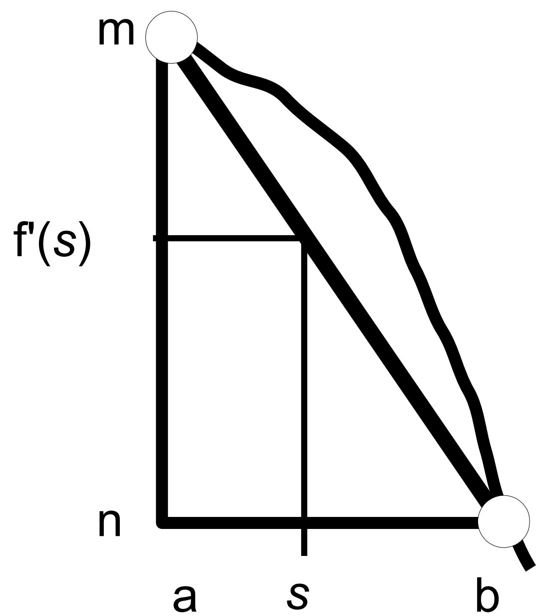
- Given an input value *s*, use points on either side
- Compute f'(s) by solving the point on the line



$$f'(s)=\left(\frac{s-a}{b-a}\right)\cdot(n-m)+m$$

Understanding Piecewise Linear

$$f'(s) = \left(\frac{s-a}{b-a}\right) \cdot (n-m) + m$$

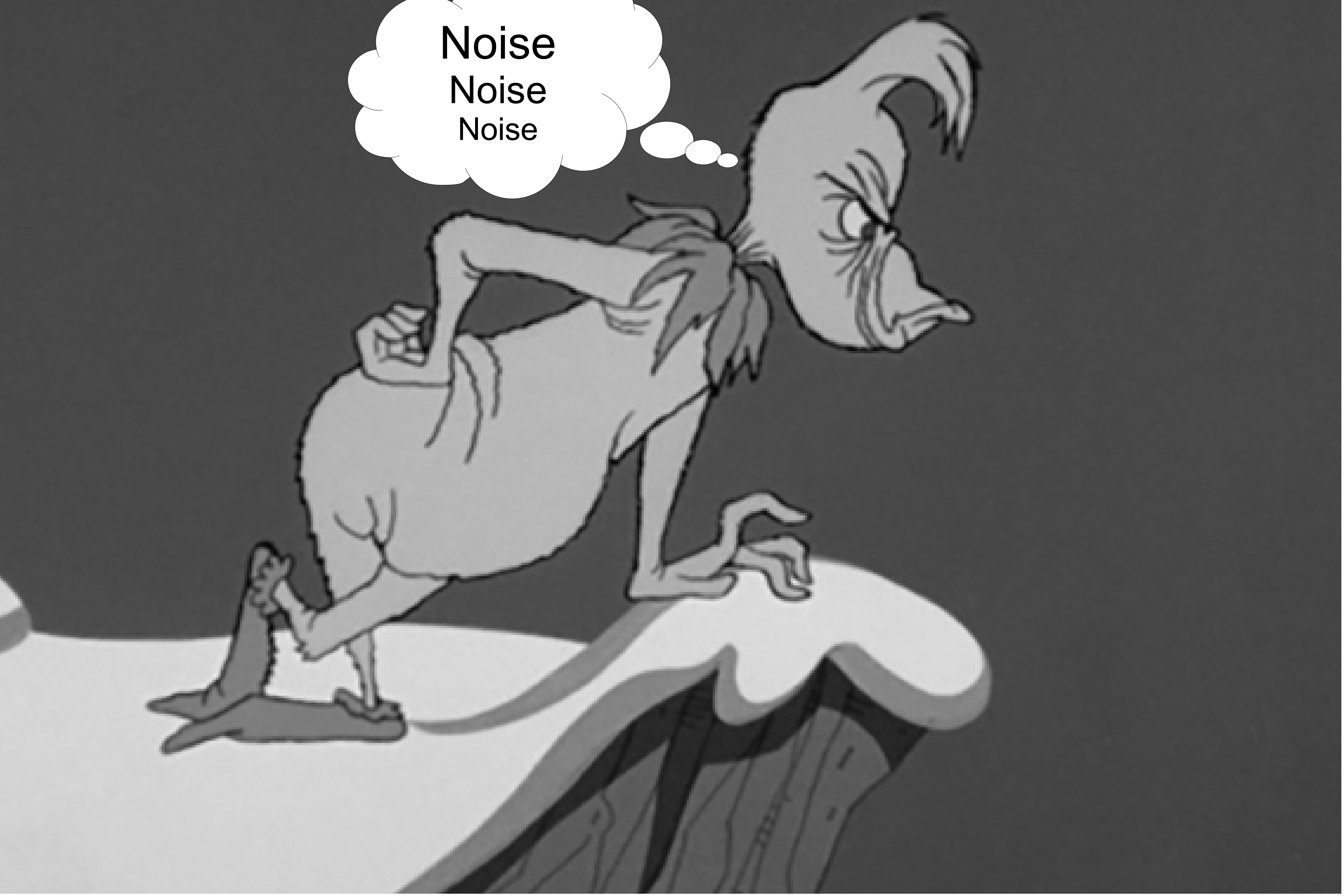


Piecewise Linear Details

- Some extra notes:
  - If a reading is < min or > max data point, clip it to min & max.
  - Enter the points into a program as two arrays:

```
#define PIECEWISE_NUM_POINTS 11
const float PIECEWISE_DoD[] ={  .0,    .1, ...   .8,   .9,  1};
const float PIECEWISE_V[]   ={12.6,  12.3, ... 11.2, 11.1, 10};
```

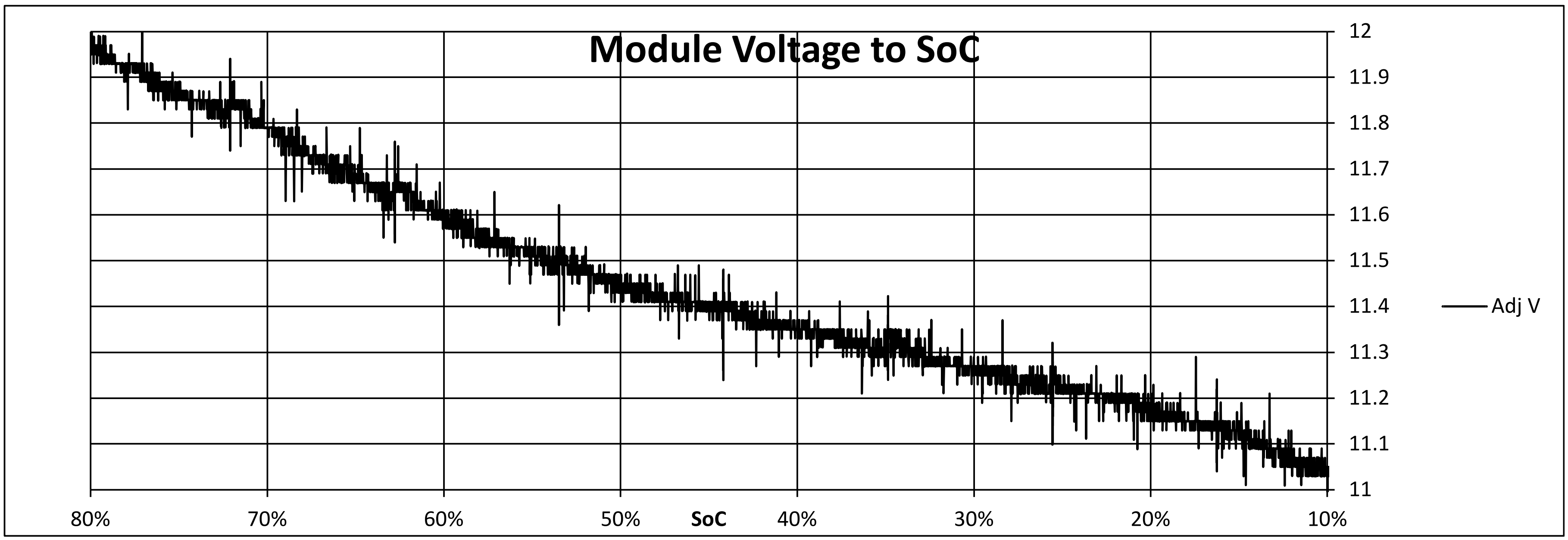
  - Make sure to use the correct data types for your calculation (possibly floating point).
  - Watch for array out of bounds!


Noise
Noise
Noise

Noise

- Real world data is often 'noisy'
  - each sample has..
    causing it to differ from the correct real-world value.

    A2D Sample = (precise real-world value) + (noise)



Problem with Noise

- A noisy signal's fluctuations may be:
  - changes in the real signal
  - noise
- Ex: Turn off phone when battery is empty (3V)

```
static void powerDownIfBatteryDead() {
    if (batteryVoltage < 3.0) {
        powerDown();
    }
}
```

What could go wrong?

  - What happens when noise spike gives you 2.99V reading when battery actually at 3.10V?

Tolerating Noise:
N Samples Past Threshold

- An idea to tolerate some noise:..

- Ex: Power off if 5 consecutive samples are less than 3V:

```
static double batteryVHistory[5];
static void powerDownIfBatteryDead() {
    for (int i = 0; i < 5; i++) {
        if (batteryVHistory[i] >= 3.0) {
            return;
        }
    }
    powerDown();
}
```

Tolerating Noise: Hysteresis

- State machine should be stable:..
  - Problematic Example:
    Battery-saver when State of Charge < 30%

```
static bool inLowPower = false;
static void manageLowPowerState() {
    if (batterySoC < 30) {
        inLowPower = true;
    } else {                                ..
        inLowPower = false;
    }
}
```

- Problem?

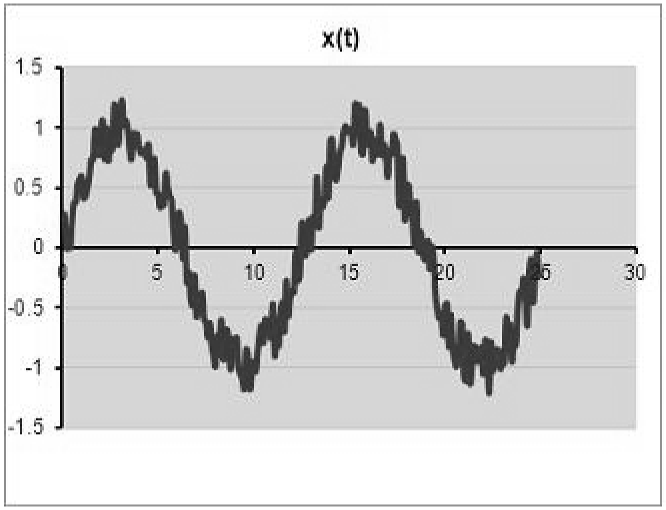
..

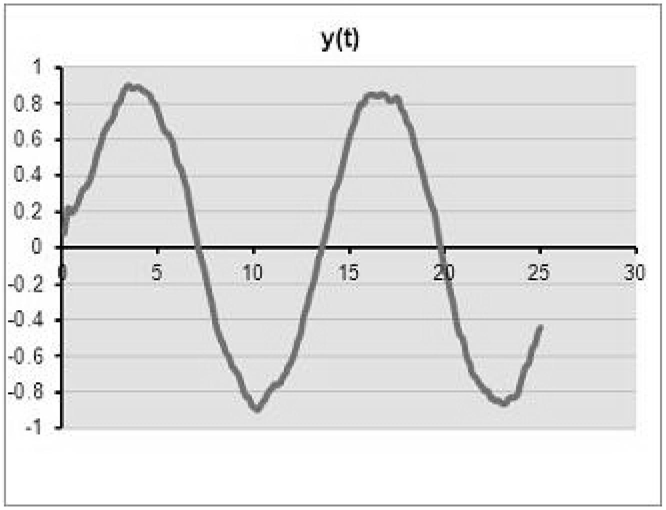
Hysteresis Solution

- A solution:

  ..

```
static bool inLowPower = false;
static void manageLowPowerState() {
    // Enter
    if (batterySoC < 30) {
        inLowPower = true;
    }
    // Exit (5% SoC Hysteresis)
    if (batterySoC > 35) {
        inLowPower = false;
    }
}
```





Noise Filters

Simple Moving Average

- Rather than tolerating noise,..
- Maintain buffer of *previous* N samples

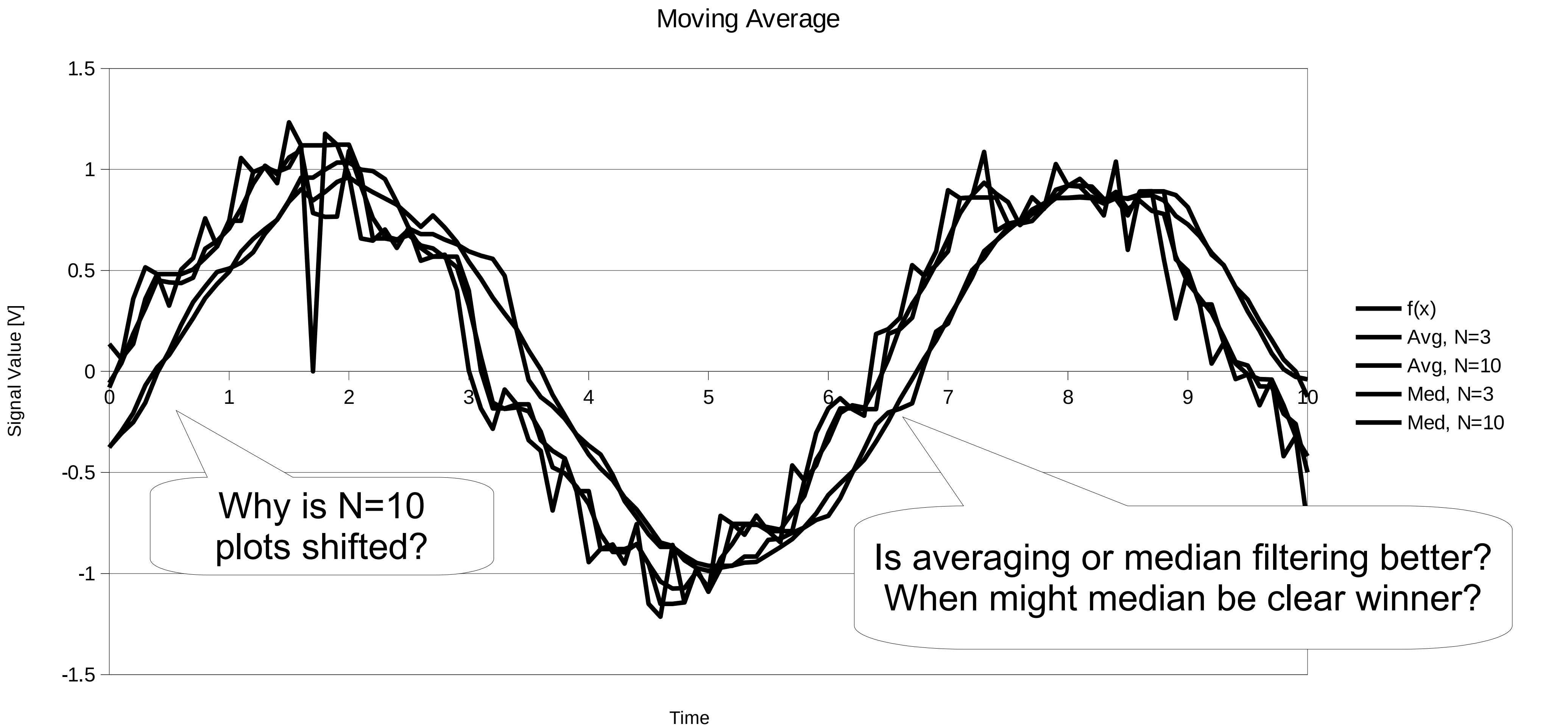
```
static double batteryVFiltered = 0;
static double samples[10];
static int nextIdx = 0;
static void getNewBatetryV() {
    // Sample
    samples[nextIdx] = readA2DVoltage();
    nextIdx = (nextIdx + 1) % 10;

    // Filter
    batteryVFiltered = average(samples, 10);
    //batteryVFiltered = median(samples, 10);
}
static double average(double *data, int numValues) {...}
```

- Note: Must also handle non-full buffer.

Noise Example

Simple Moving Average Effectiveness



Exponential Smoothing

- Simple moving average equally weights all samples, ..

- Exponential Smoothing Details
  - Let s_n be the Nth sample from the A2D
    Let v_n be the Nth filtered value
    Let *a* be a weighting value between 0 and 1
- Smoothed Data Points (v_n)

$$v_0 = s_0$$

$$v_n = a * s_n \quad + \quad (1 - a) * v_{(n-1)}$$

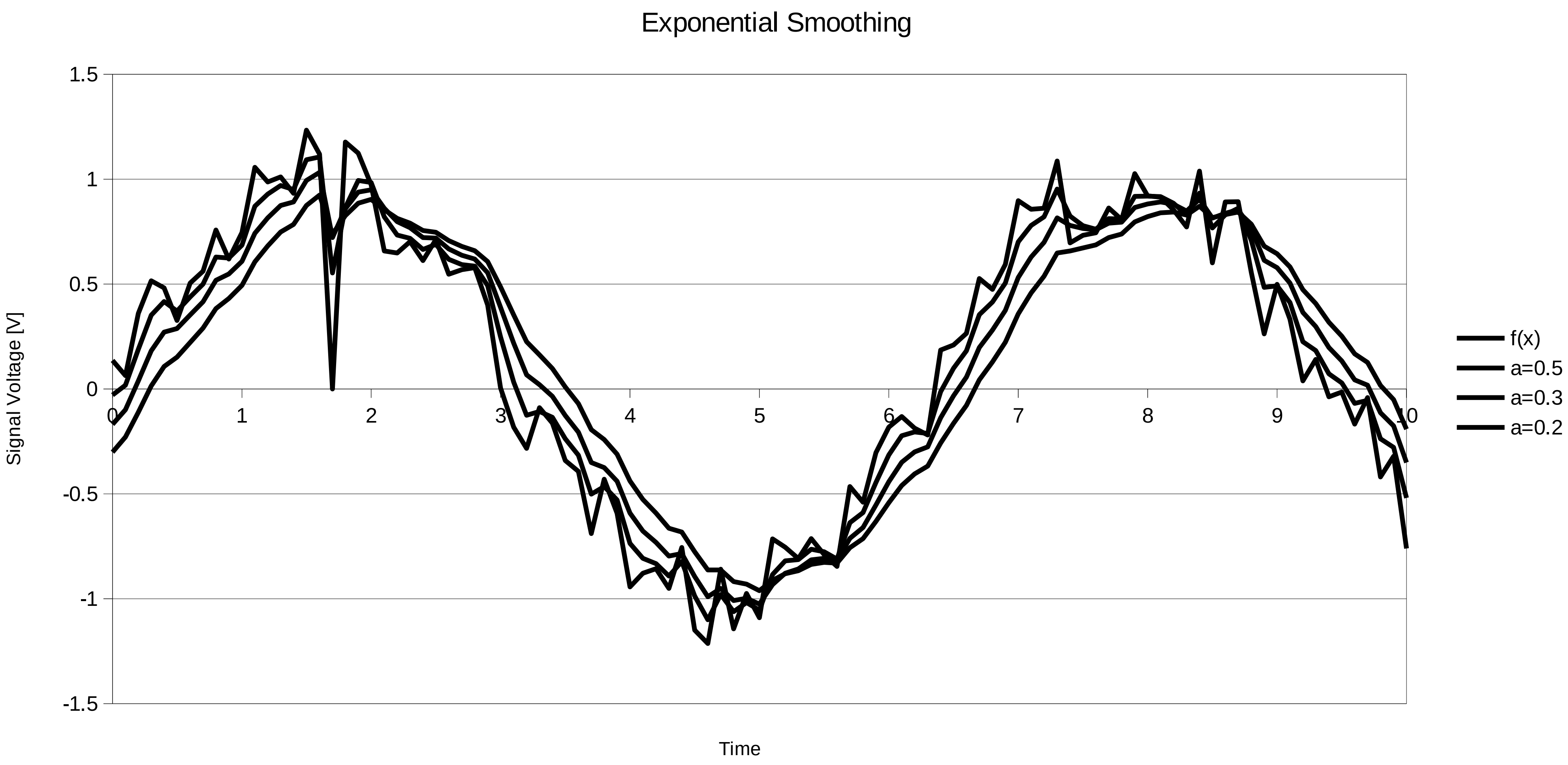
Exponential Smoothing Intuition

- s_n is the Nth sample from the A2D
  v_n is the Nth filtered value
  `a` is a weighting value between 0 and 1
- Smoothed Data Points (v_n)

  $v_0 = s_0$

  $v_n = a * s_n + (1 - a) * v_{(n-1)}$
- Intuition
  - a = 1: 100% weight on instantaneous ‘now’ sample (filtering disabled)
  - a = 0.1: Very heavy weight on old data, not much on new data (average over very long time frame)

Exponential Smoothing Effectiveness



Summary

- Many sensor generate analog voltage signals.
  - Be careful that signal is in correct voltage range!
- BBB can sample voltages between 0 and 1.8V
  - 12-bit A2D: digital values between 0 and 4095
- Piecewise Linear approximates functions
  - Given a reading (on the X axis),
    use the selected points and straight lines to
    approximate desired value (on the Y axis)
- Noise adds errors to samples
  - Tolerate nose with hysteresis and filter thresholds
  - Filter with simple moving average or exponential smoothing.