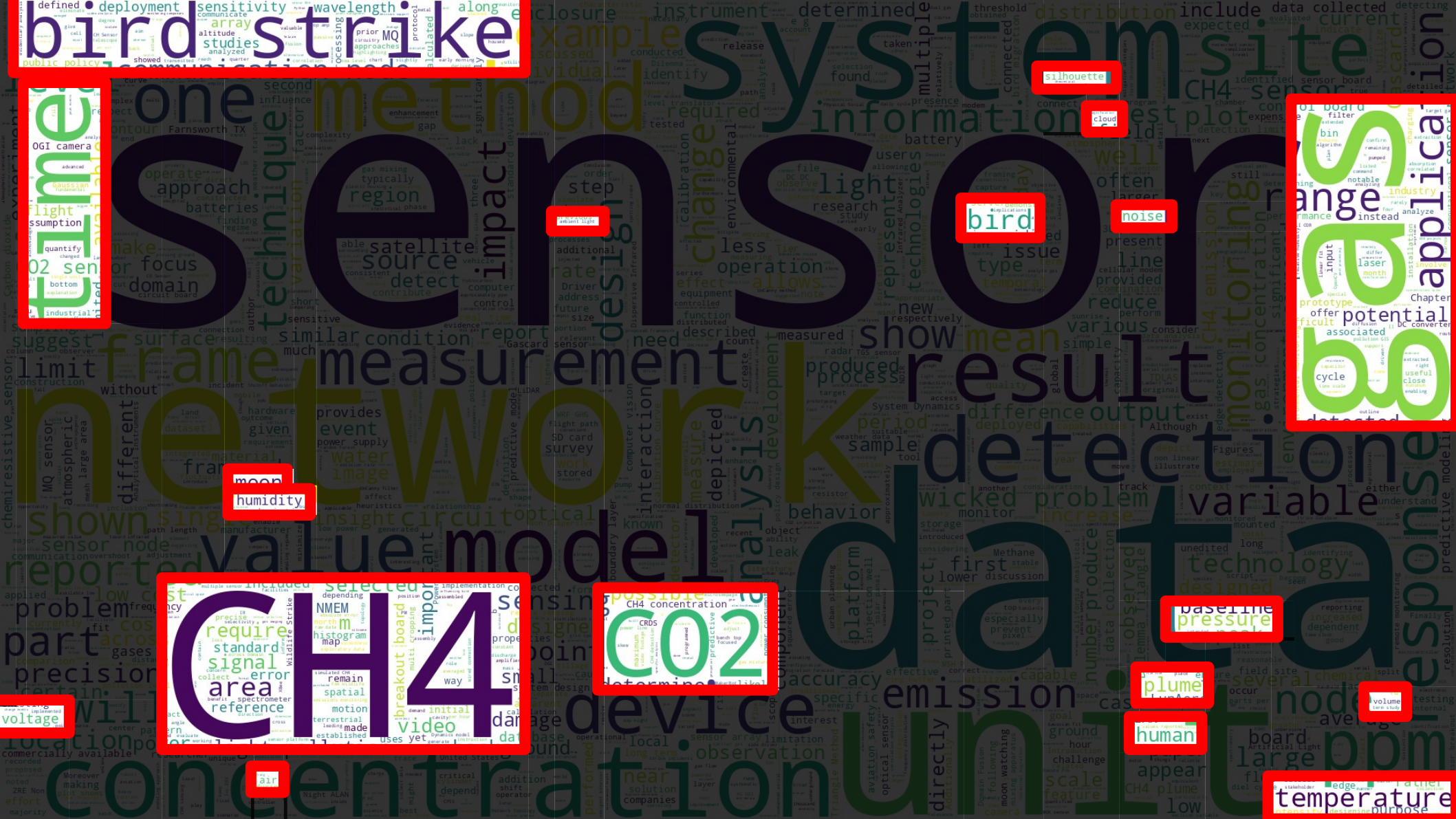
From Signal to Insight: Sensing Fundamentals

Wesley T. Honeycutt
honeycutt@ou.edu


bird strike
sensor
network
data
measurement
result
detection
system
method
concentration
unit
CH4
CO2
bird
noise
silhouette
cloud
gas
application
humidity
moon
temperature
baseline
pressure
plume
human
voltage
air
volume

High Level Definition

- A sensor is anything which outputs a signal to describe part of [physical] reality.
  - A sensor can only detect what is present.
- Sensors respond with a signal that we can interpret elsewhere through the use of a logger, model, analysis, etc., or a combination of these things.
  - A sensor is useless if the signal cannot be interpreted.

✉honeycutt@ou.edu
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What Do You Sense?

Question Time!

?

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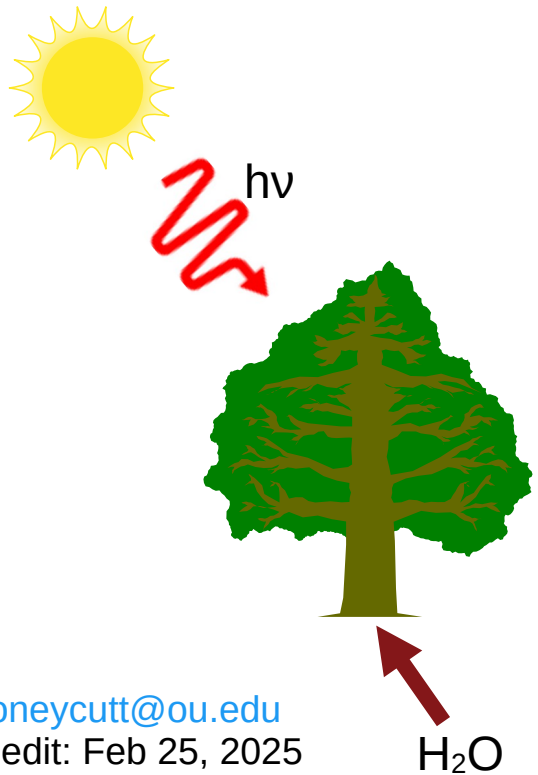
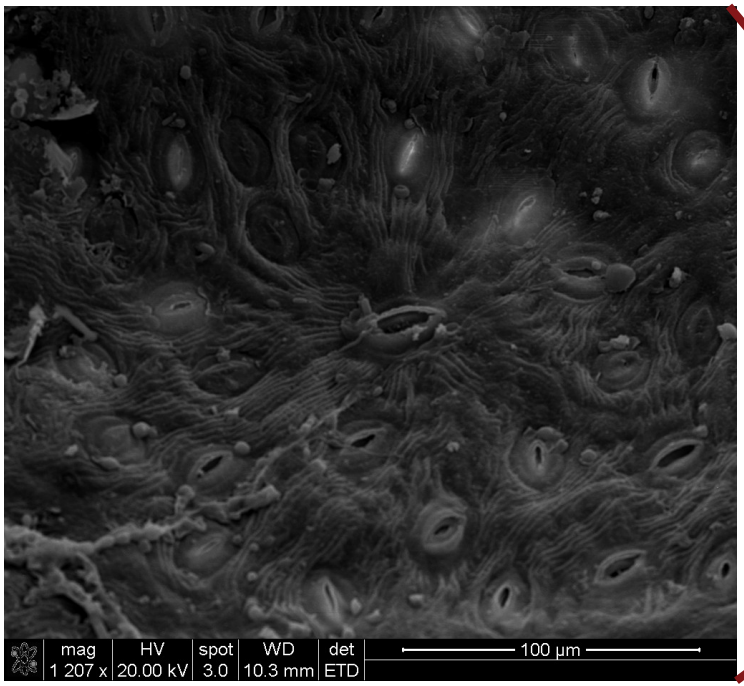
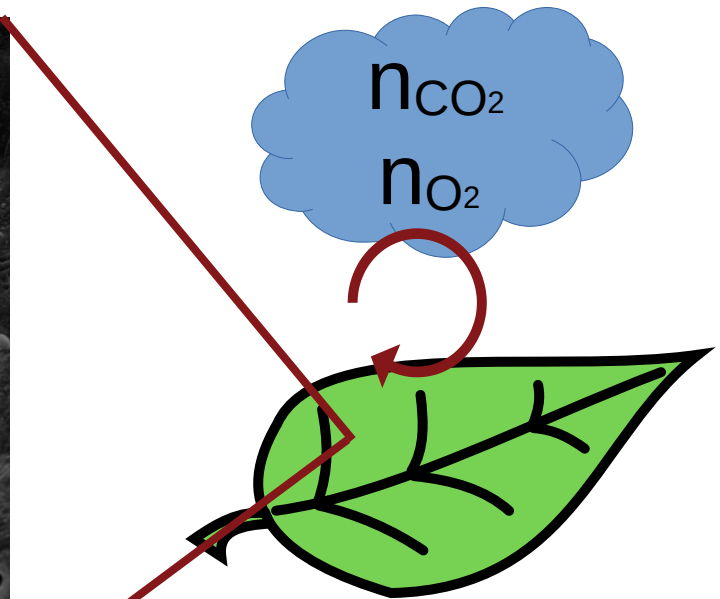
Sensors Describe Environment

$$6CO_2 + 6H_2O \xrightarrow{h\nu} C_6H_{12}O_6 + 6O_2$$







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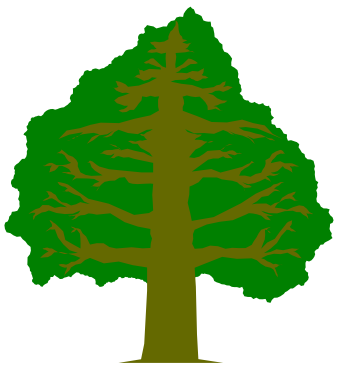
More Than One Tool



Hygrometer, Rain Gauge, Humistor, Conductivity	Pyranometer, Photodiode, CMOS, Colorimeter
Thermocouple Thermometer, Thermistor	Barometer, Piezometer, Flex sensor

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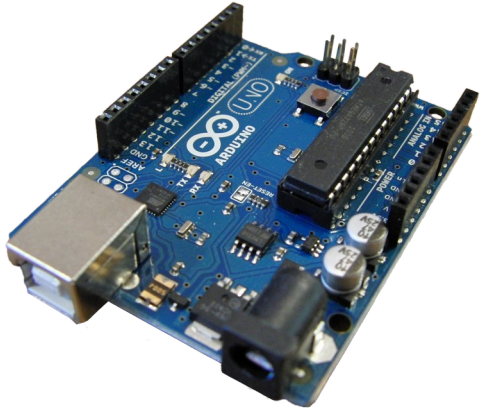
Sensors For Computers

- Most sensors work as modules for a computer.
- Signal processing happens at the computer.
- Model and analysis may happen at a computer, but it may be “dumb.” Consider microcontrollers.



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Alternatives To Computers

- Not every sensor must be an electronic component.
- One example is pH paper.
- Signals are recorded by observer, but it requires a special logger…

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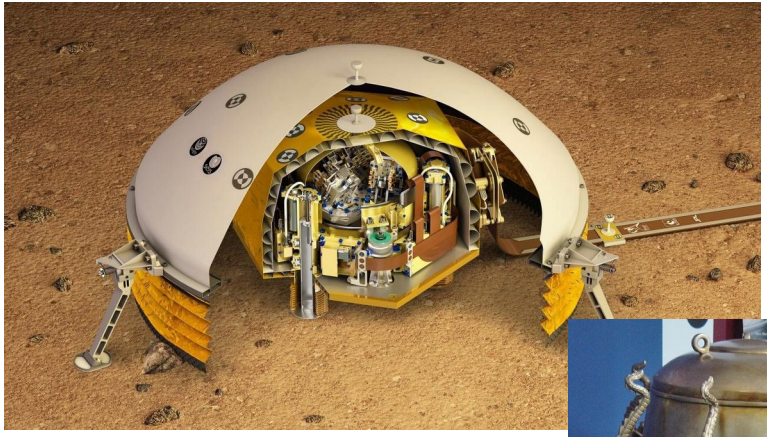
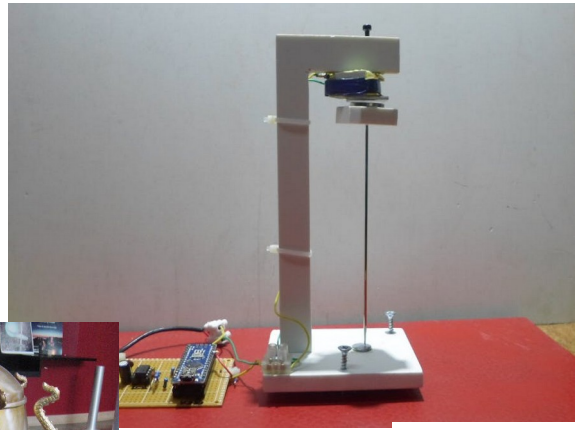
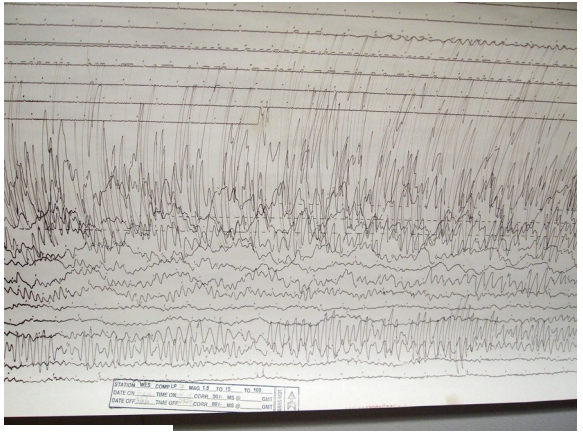
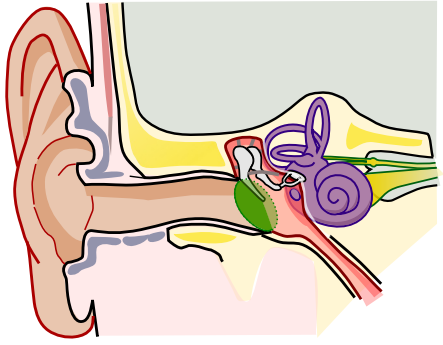
Detect Earthquake

Question Time!









https://science.nasa.gov/resource/cutaway-of-seis/
https://www.hackster.io/mircemk/extremely-sensitive-cheap-homemade-seismometer-175231
https://commons.wikimedia.org/wiki/File:A_seismogram_of_2011_T%C5%8Dhoku_earthquake_and_tsunami.jpg
https://commons.wikimedia.org/wiki/File:EastHanSeismograph.JPG
https://commons.wikimedia.org/wiki/File:Anatomy_of_the_Human_Ear_blank.svg

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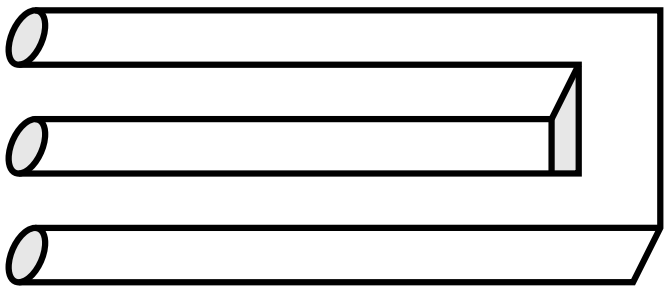
Humans As Sensors

- We are quite good as detectors, if not so great at quantifying.
- Humans can detect “complex” things like patterns.
  - This can be dangerous.
- Simple detection is often driven by evolutionary imperatives.

% Gray?



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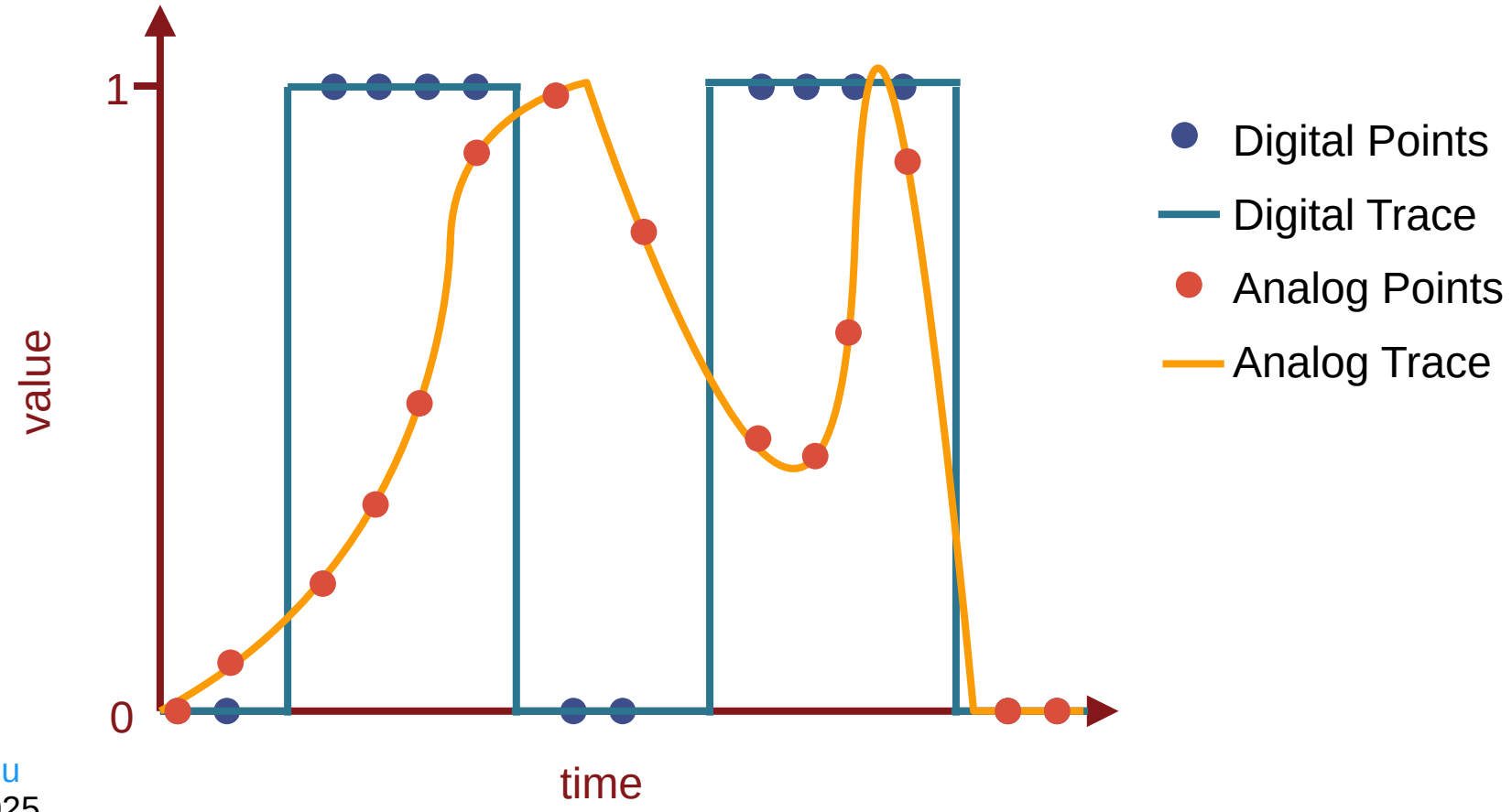
Analog Vs. Digital



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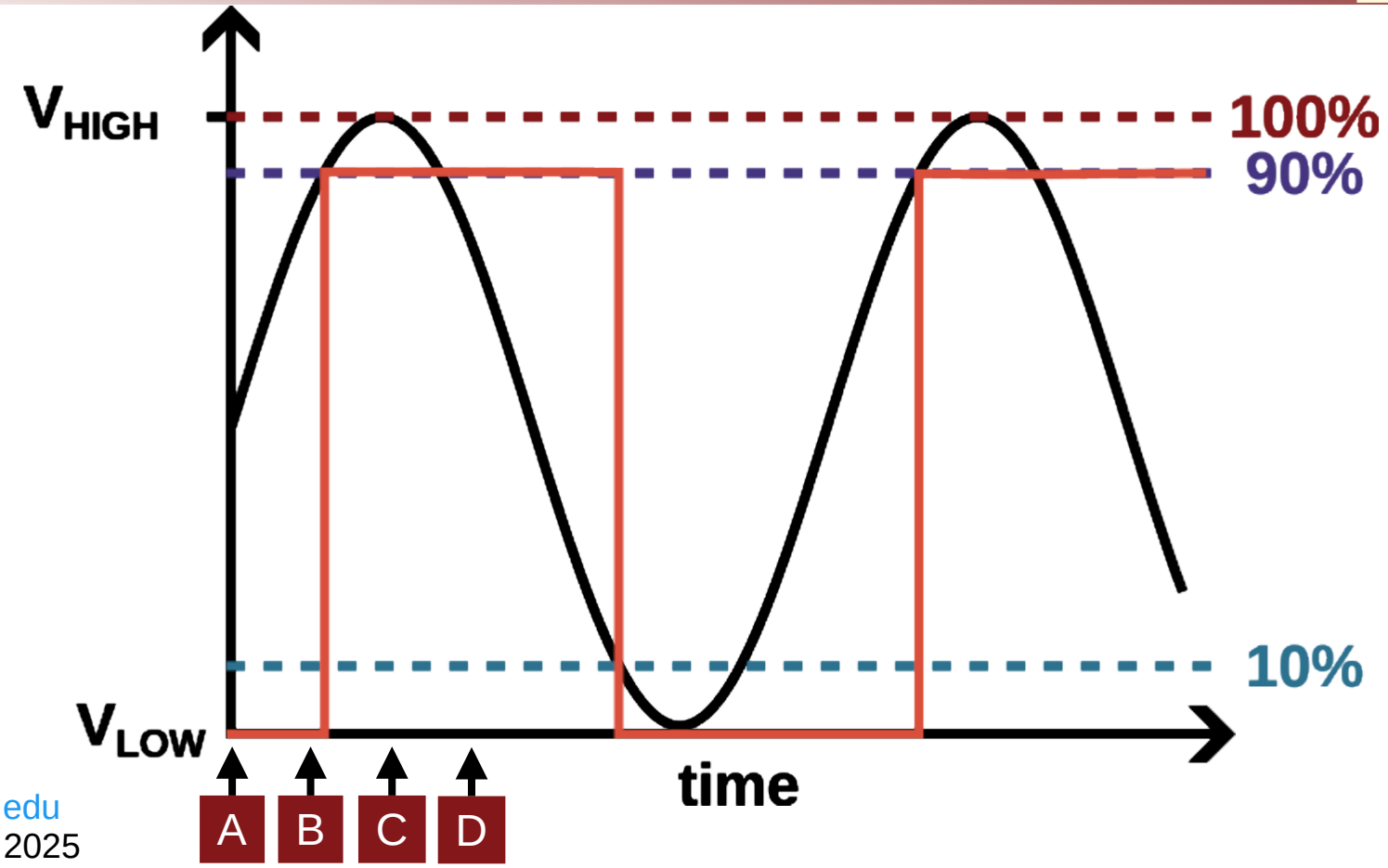
Analog-Digital Conversion

Question Time!



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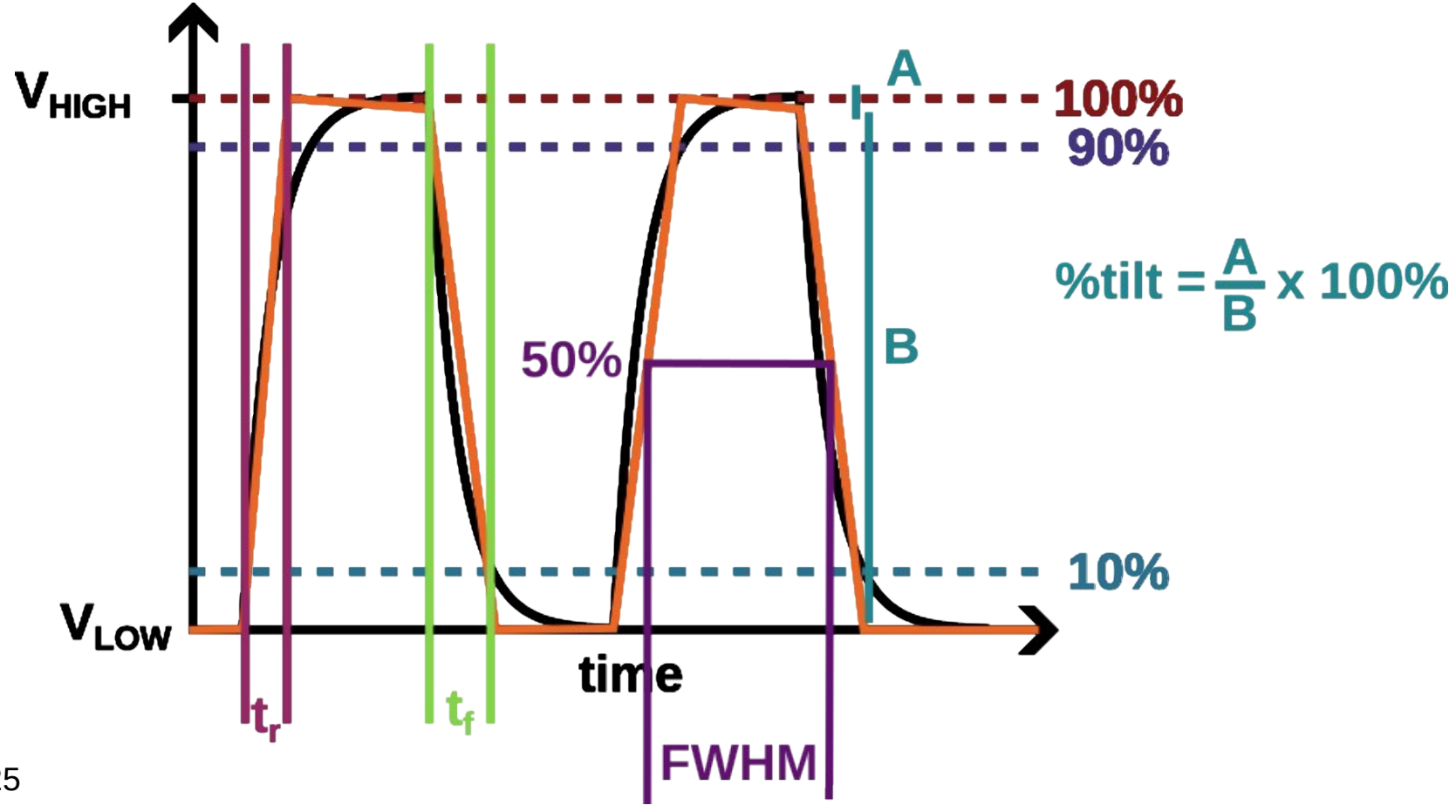
The Shape Of A Signal



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Time Hertz

- How fast do you need to measure?
- Can you average over a time period?
- How fast can your equipment run?

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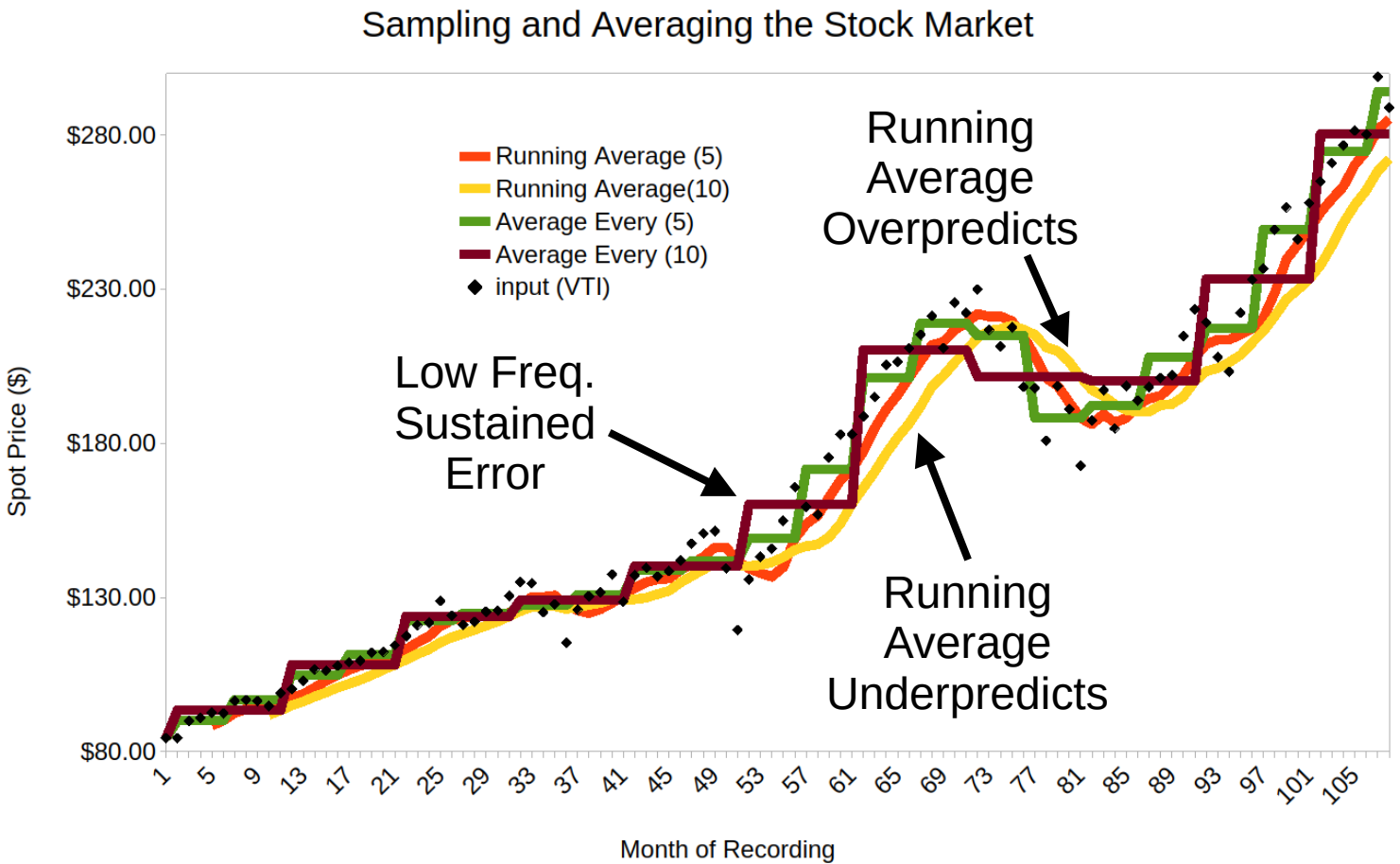
Windowing Time



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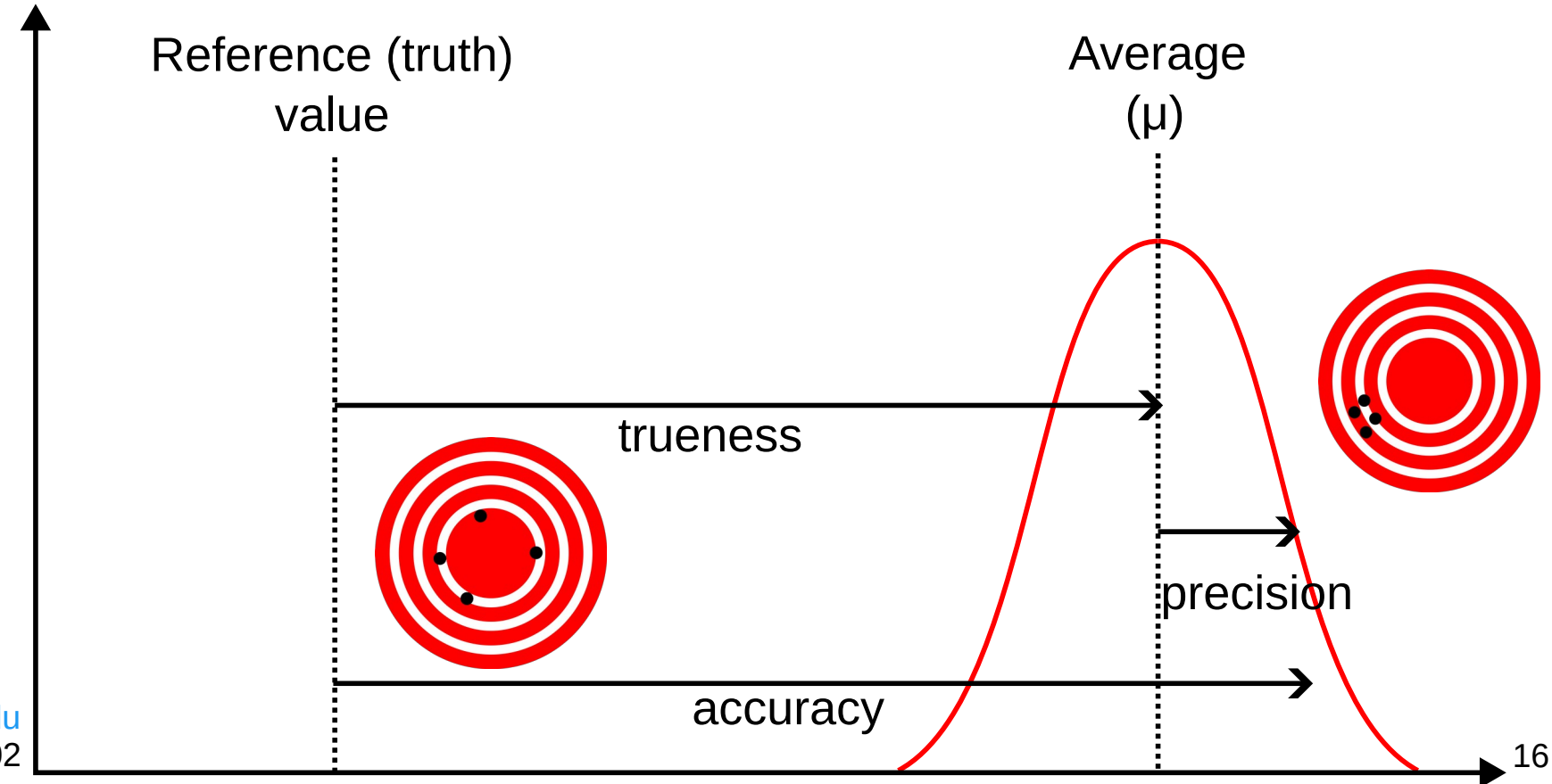
Characterization: Basics



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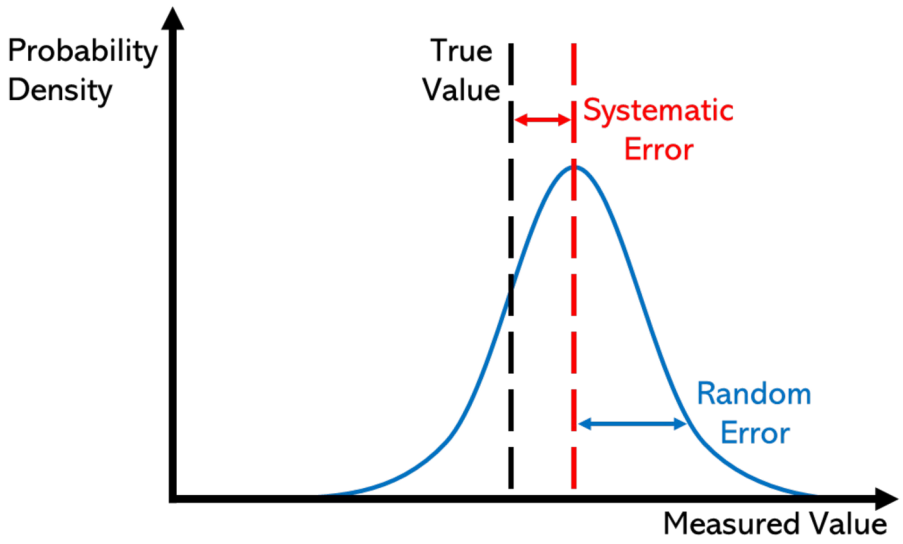
Error

- Systematic Error – Predictable deviations based on the system which acquires data.
- Random Error – Unpredictable deviations.



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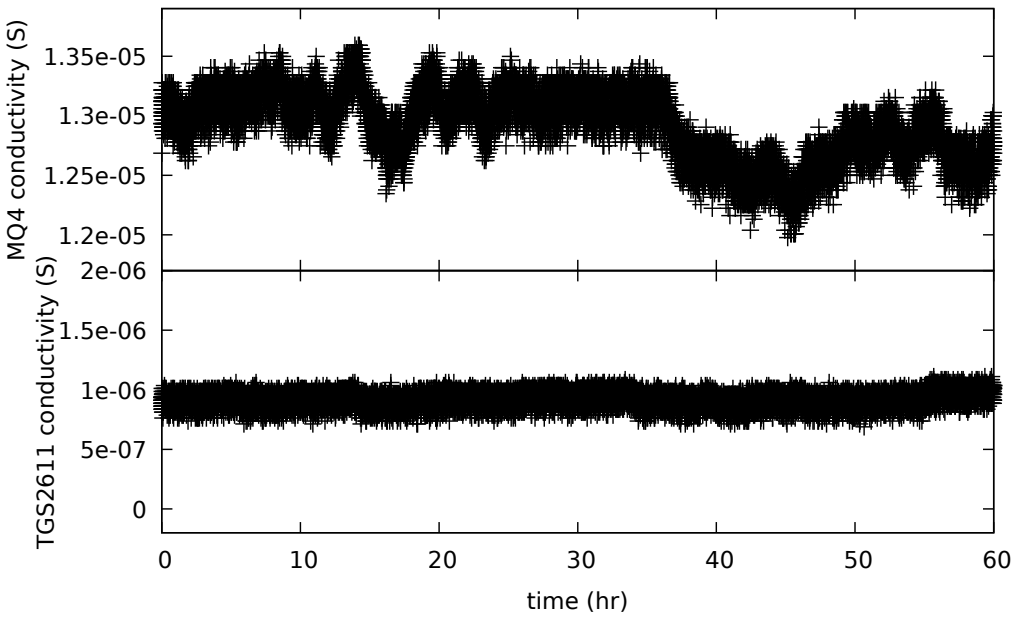
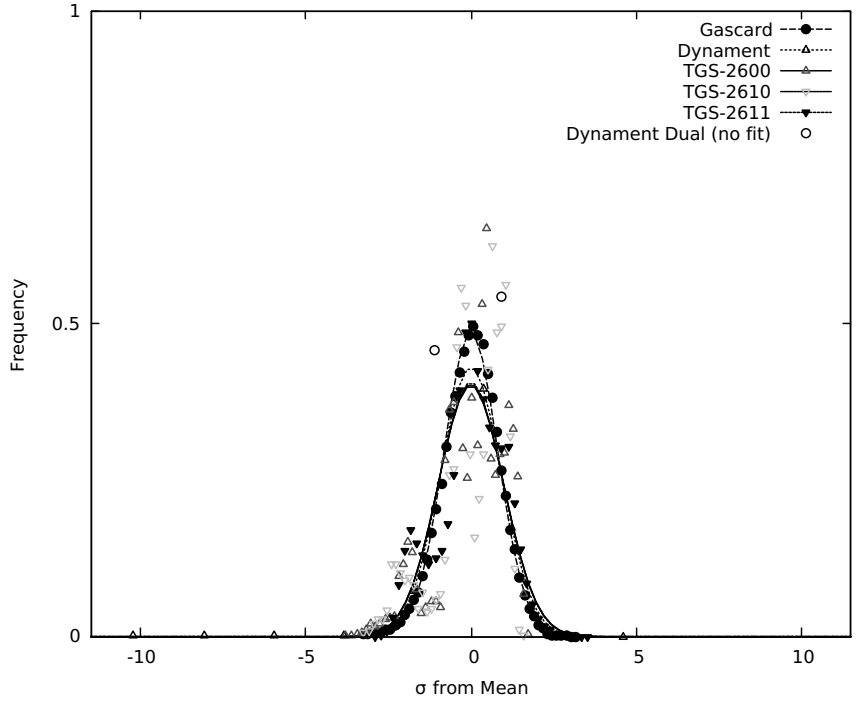
Noise





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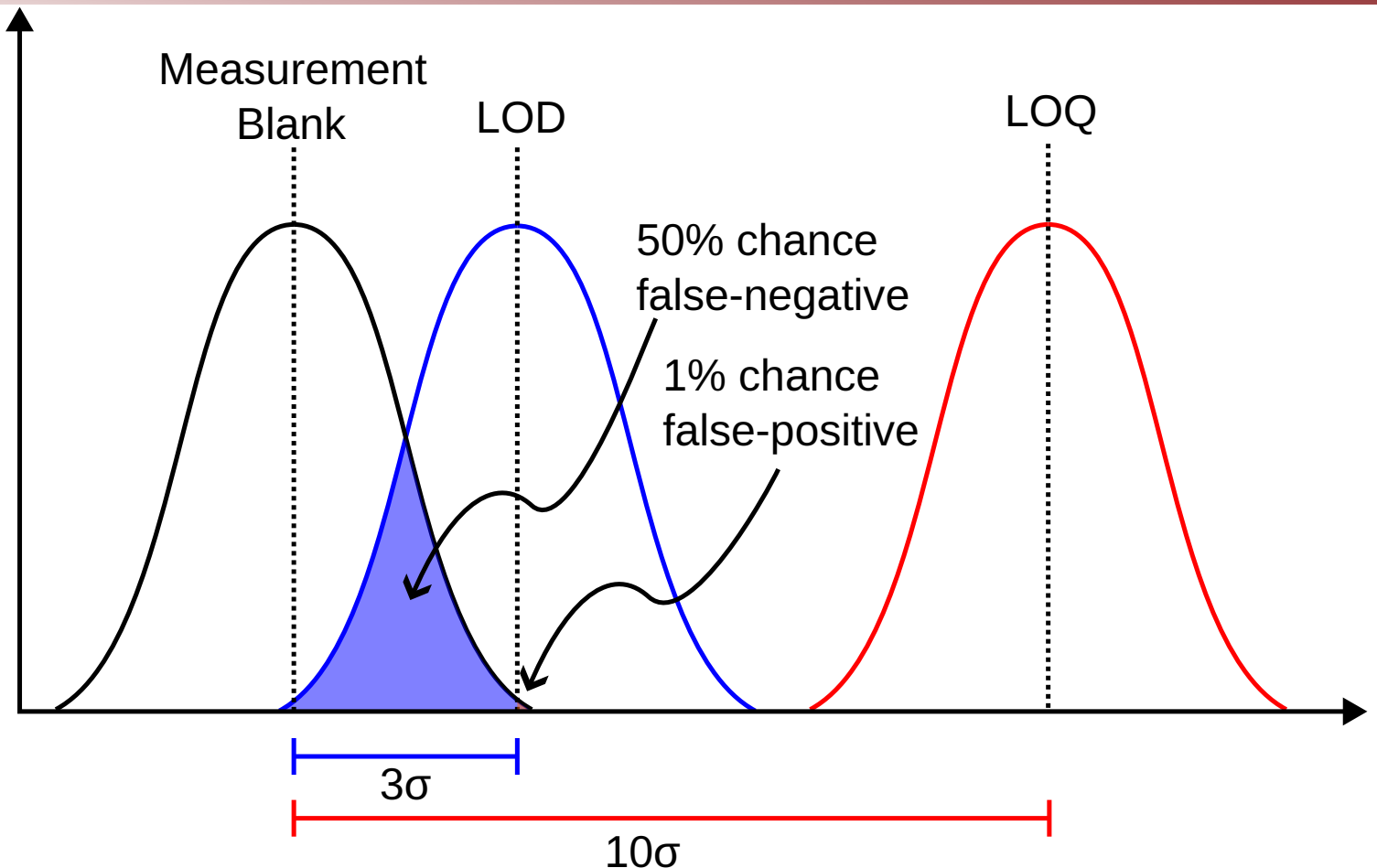
Detection And Quantification



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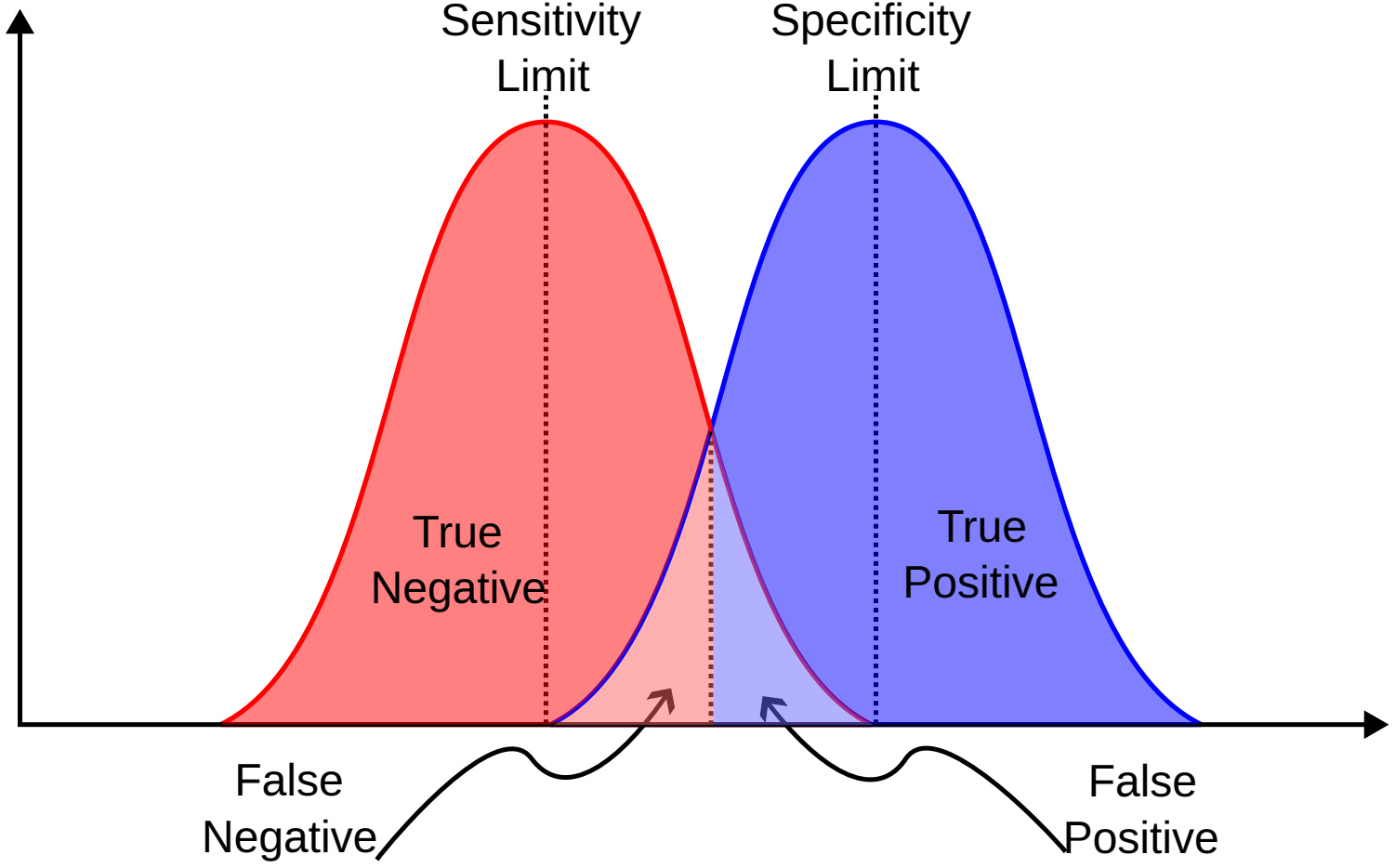
Sensitive And Specific



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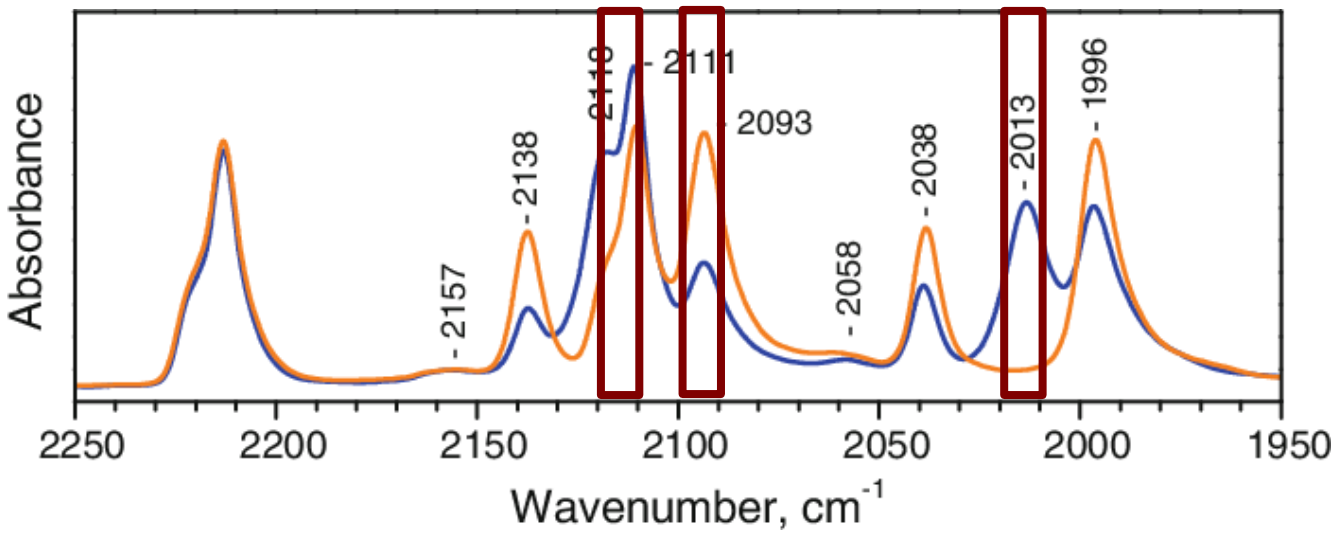
Another Look At Selectivity

Question Time!



If your sensor can only measure this much in one sample...

Where do you measure the BLUE?

The ORANGE?

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Adapted from: Mihaylov, Mihail & Lagunov, Oleg & Ivanova, Elena & Hadjiivanov, Konstantin. (2011). Determination of Polycarbonyl Species on Nickel-Containing Catalysts by Adsorption of CO Isotopic Mixtures. Topics in Catalysis. 54. 308-317. 10.1007/s11244-011-9661-6.

Reporting Sensitivity

666

420

8675.309

10000

10000

0.0067

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Sensor Precision

1.0 ± 0.5

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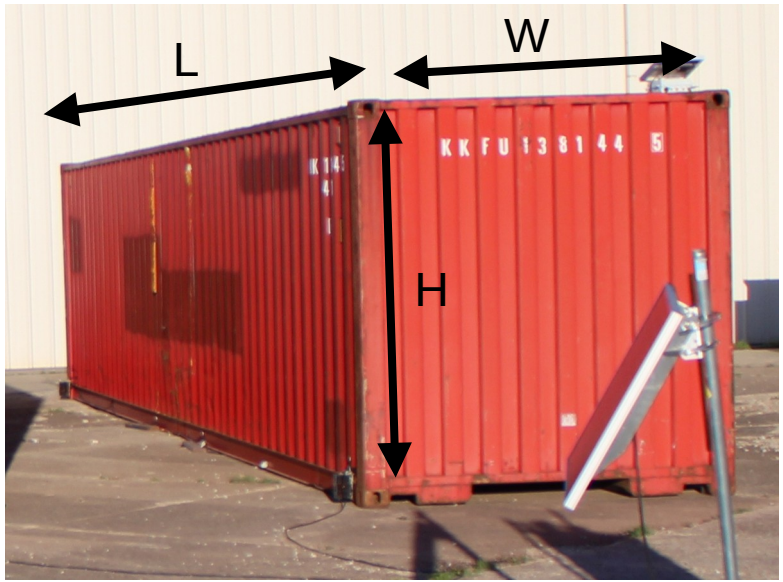
Uncertainty Propagates



L: 6.058 m
W: 2.438 m
H: 2.591 m

V = L×W×H

~~38.27 m³~~

CLASS II: ±2.30 mm

~~38.27 ± .0023~~ m³

L: 6.058 ± .0023 m
W: 2.438 ± .0023 m
H: 2.591 ± .0023 m

$$\sigma_x^2 = V \times \sum \sigma_i^2 \left(\frac{\delta x}{\delta i}\right)^2$$

$$\sigma = V \times \sqrt{\left(\frac{0.0023^2}{6.058^2}\right)+\left(\frac{0.0023^2}{2.438^2}\right)+\left(\frac{0.0023^2}{2.591^2}\right)}$$

38.27 ± .05 m³

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Sensor Precision Matters

5.5 Electrical Characteristics: V_{DD} = 2 V for TLC555C, V_{DD} = 3 V for TLC555I

over operating free-air temperature range (unless otherwise noted)

PARAMETER		TEST CONDITIONS[1]		MIN	TYP	MAX	UNIT
V_{IT}	Threshold voltage	25°C	TLC555C	0.95	1.33	1.65	V
			TLC555I	1.6		2.4	
		Full range	TLC555C	0.85		1.75	
			TLC555I	1.5		2.5	

5 Specifications

5.1 Absolute Maximum Ratings

V = 1.3±2.0

over operating free-air temperature range (unless otherwise noted)[1]

			MIN	MAX	UNIT
Voltage		Supply, V_{DD} [2]	–0.3	18	V
		Input, any input	–0.3	V_{DD}	
		Discharge	–0.3	18	

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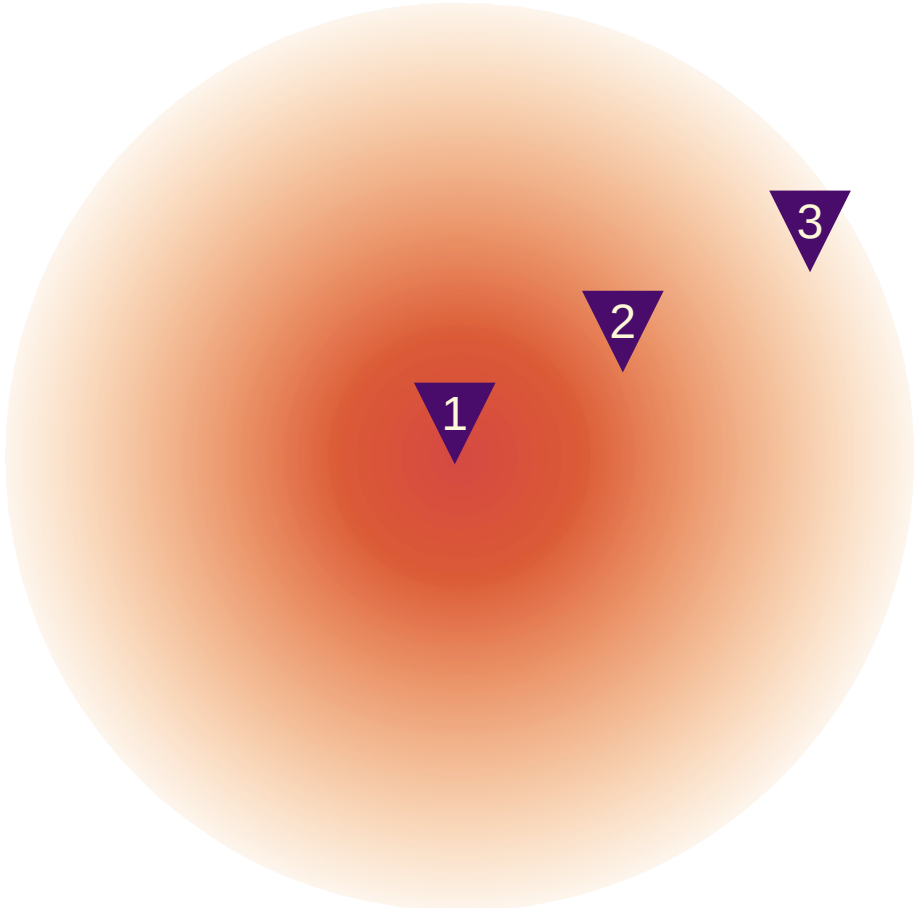
https://www.ti.com/lit/ds/symlink/tlc555.pdf

Sensing Spatially



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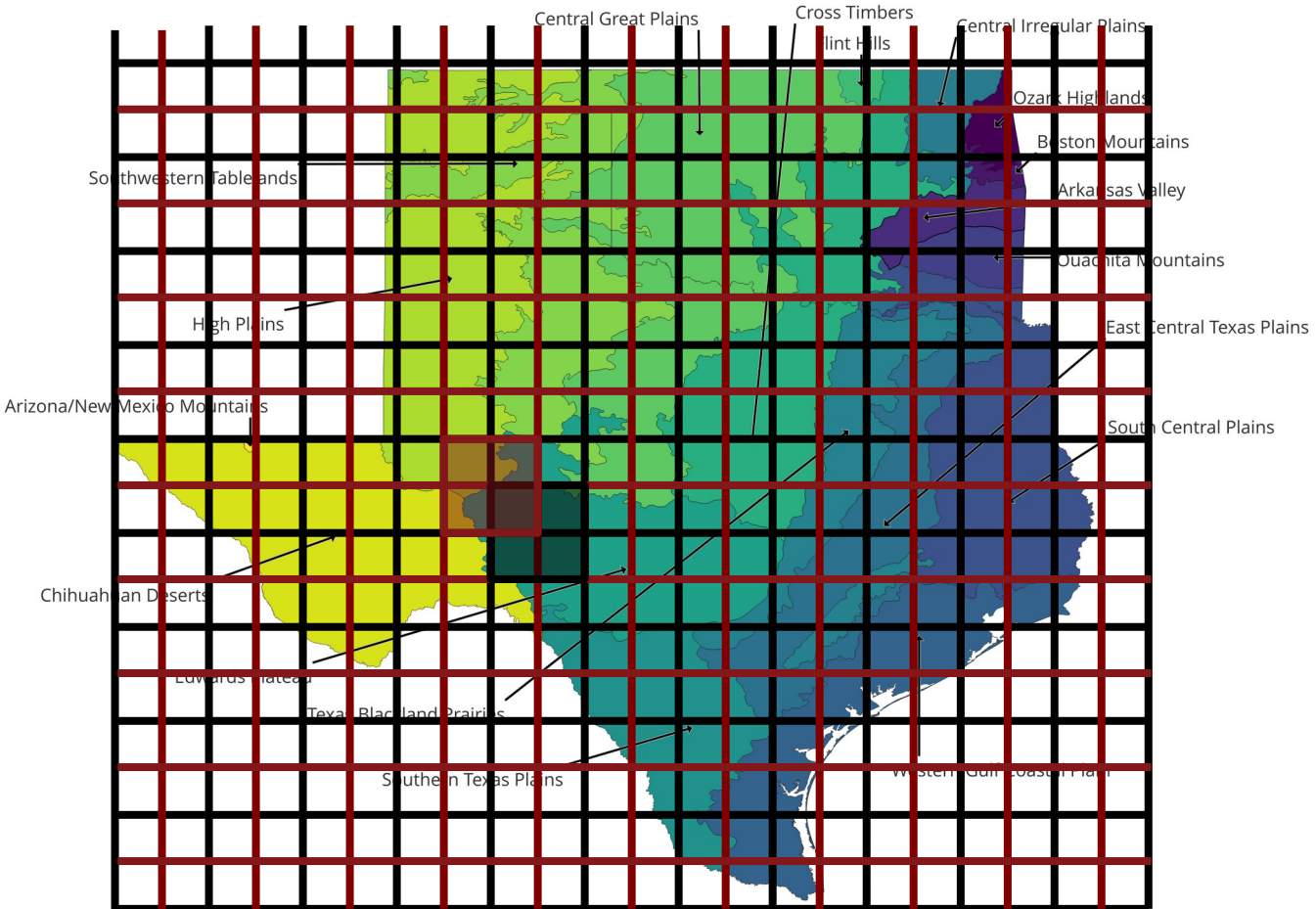
Modifiable Aerial Unit Problem



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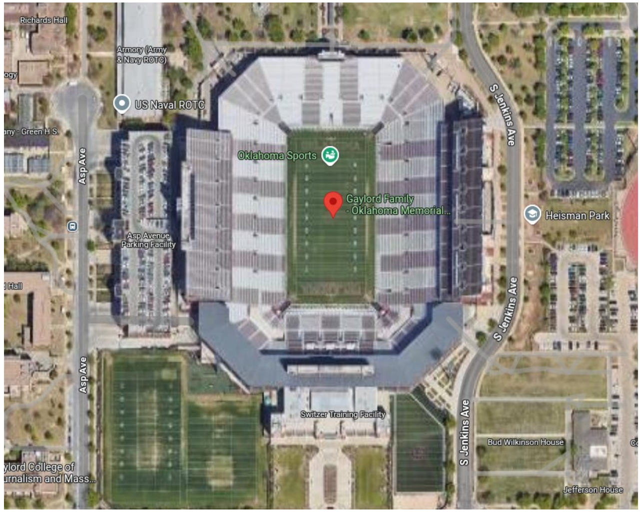
GPS And Precision



- ← N/S, E/W hemisphere
_ ← Only exists for longitude
9 ← 1000 km (continent)
7. ← 111 km (country/state)
4 ← 11.1 km (big city)
4 ← 1.1 km (town)
2 ← 110 m (farm)
3 ← 11 m (parcel)
0 ← 11 cm
2 ← 1.1 cm (limit of GPS)
9 ← 1.1 mm
2 ← 110 microns
2 ← aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
8
0
3
3

Just because the computer prints out all those decimals does not mean you should use them!

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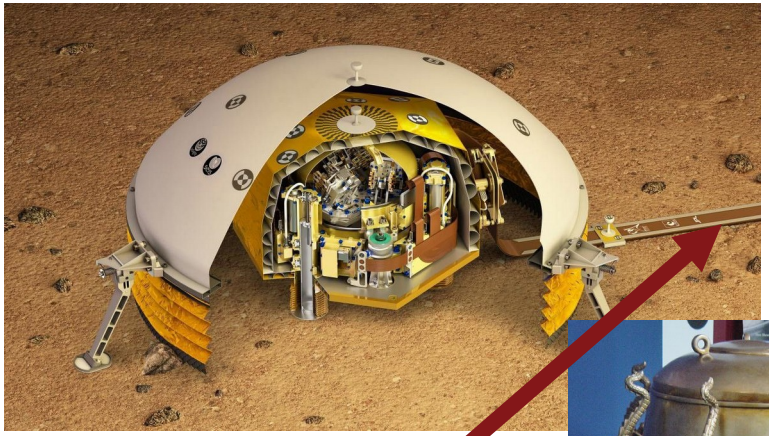
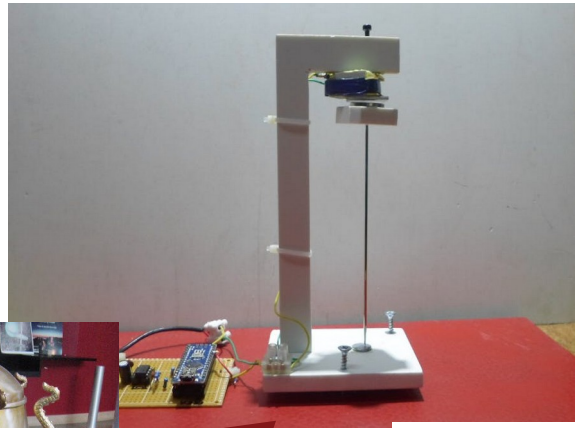
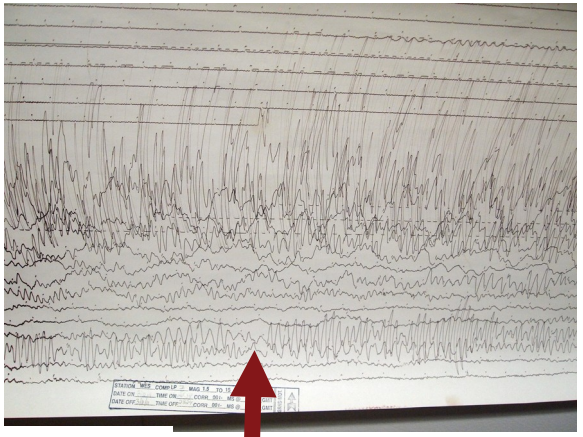
Collection And Storage



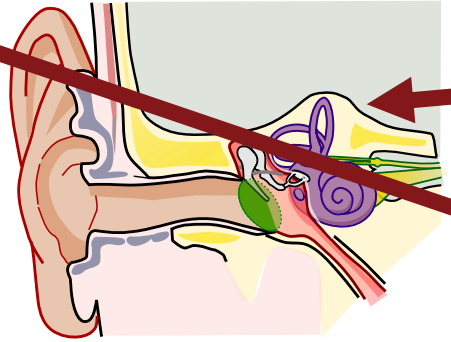
Transmission to computer





Paper

Bells



Arduino

https://science.nasa.gov/resource/cutaway-of-seis/
https://www.hackster.io/mircemk/extremely-sensitive-cheap-homemade-seismometer-175231
https://commons.wikimedia.org/wiki/File:A_seismogram_of_2011_T%C5%8Dhoku_earthquake_and_tsunami.jpg
https://commons.wikimedia.org/wiki/File:EastHanSeismograph.JPG
https://commons.wikimedia.org/wiki/File:Anatomy_of_the_Human_Ear_blank.svg

✉honeycutt@ou.edu
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Seismometer Ring Buffer

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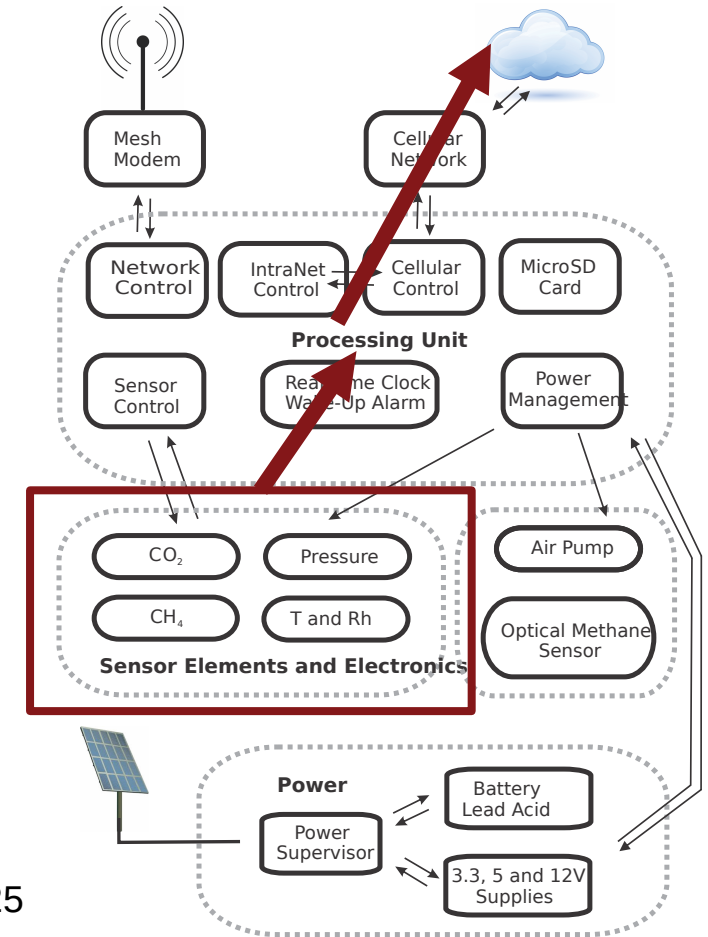
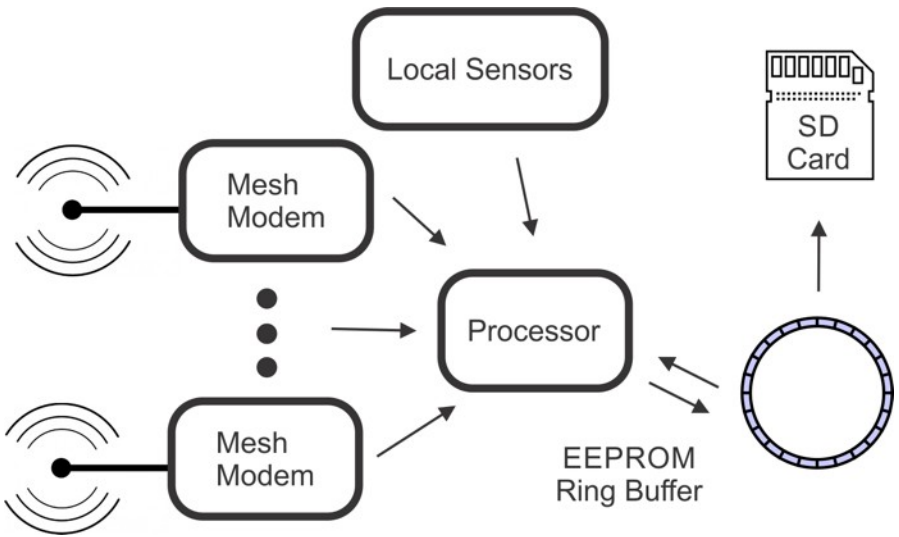
https://commons.wikimedia.org/wiki/File:Seismograph_recording.jpg

Data Storage, Loops





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Simple Ring Buffer

```
buffer = []
for i in range(0, 100, 1):
    buffer.append(i)
    if len(buffer) == 10:
        print(buffer)
        buffer = []
print(done)
```

```
$ python3 ring_buffer.py
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
[10, 11, 12, 13, 14, 15, 16, 17, 18, 19]
[20, 21, 22, 23, 24, 25, 26, 27, 28, 29]
[30, 31, 32, 33, 34, 35, 36, 37, 38, 39]
[40, 41, 42, 43, 44, 45, 46, 47, 48, 49]
[50, 51, 52, 53, 54, 55, 56, 57, 58, 59]
[60, 61, 62, 63, 64, 65, 66, 67, 68, 69]
[70, 71, 72, 73, 74, 75, 76, 77, 78, 79]
[80, 81, 82, 83, 84, 85, 86, 87, 88, 89]
[90, 91, 92, 93, 94, 95, 96, 97, 98, 99]
done
```

How you do this can impact the time series data collection. Remember the running averages?

✉honeycutt@ou.edu

Analysis

We won’t discuss how to analyze your data in this discussion. It must follow everything we discussed here.

- A well-framed problem;
- Appropriate sensor choice;
- Recording which logs faithfully;
- Near truth, with little noise;
- Sensitive and selective;
- Spatially and temporally meaningful;
- Represents a meaningful sample of the logs.

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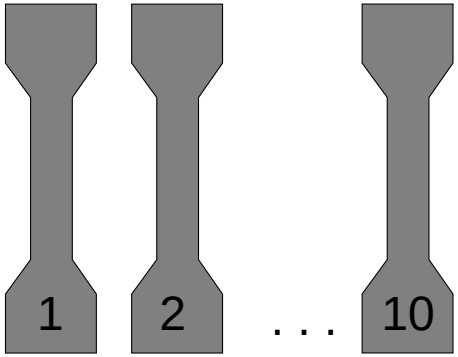
Summarize This Experiment

Question Time!



Al Alloy

Aluminum Elasticity	
Sample	Elasticity (ksi)
1	10600
2	10600
3	10400
4	10300
5	10500
6	10700
7	10000
8	10100
9	10000
10	10700

These are measured elasticity values for a cast aluminum alloy. How would you use the data to describe this alloy?

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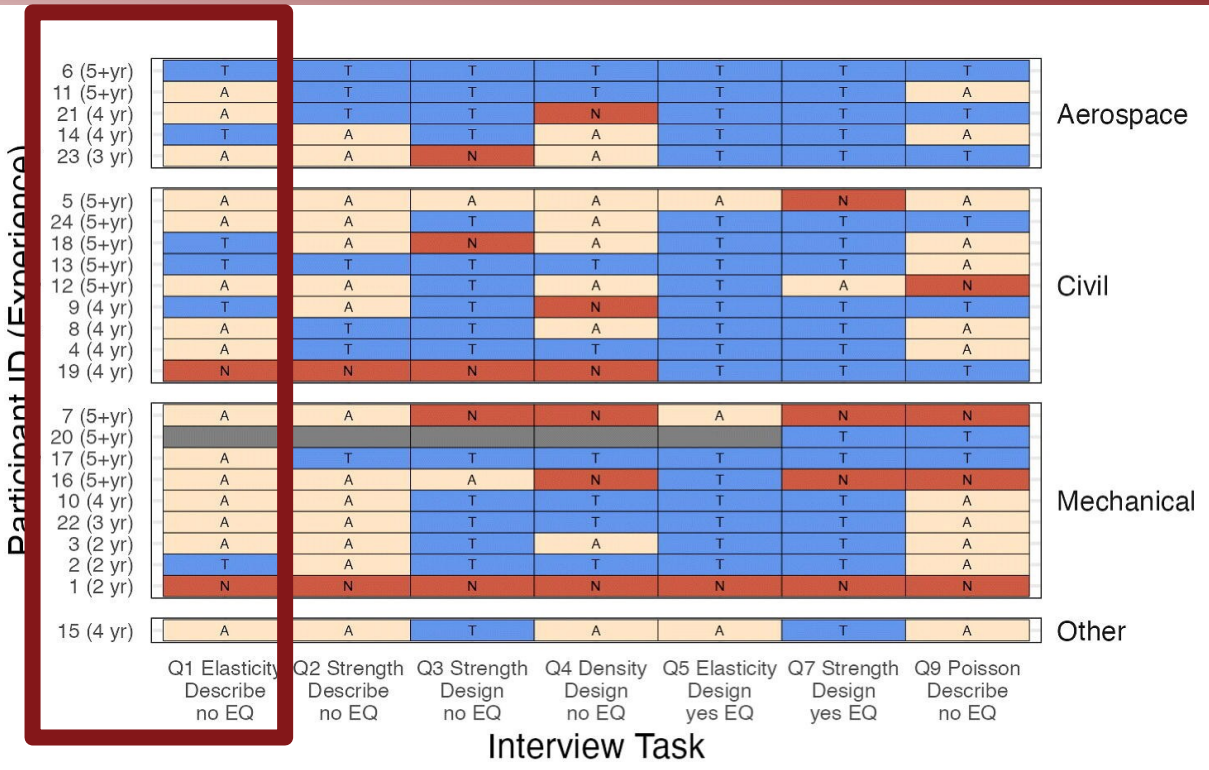
[1]Shalaby, H. A., Soliman, N. K., and Al-Saudi, K. W., 2024, “Antibacterial and Preventive Effects of Newly Developed Modified Nano-Chitosan/Glass-Ionomer Restoration on Simulated Initial Enamel Caries Lesions: An in Vitro Study,” Dental and Medical Problems, 61(3), pp. 353–362. https://doi.org/10.17219/dmp/158835.

How Did You Do?

- A well-framed problem;
- Appropriate sensor choice;
- Recording which logs faithfully;
- Near truth, with little noise;
- Sensitive and selective;
- Spatially and temporally meaningful;
- Represents a meaningful sample of the logs.



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[1]del Rosario, Z., 2024, "Neglected, Acknowledged, or Targeted: A Conceptual Framing of Variability, Data Analysis, and Domain Consequences," Journal of Statistics and Data Science Education, 32(4), pp. 432–443. https://doi.org/10.1080/26939169.2024.2308119.

Wrap Up

- A well-framed problem;
- Appropriate sensor choice;
- Recording which logs faithfully;
- Near truth, with little noise;
- Sensitive and selective;
- Spatially and temporally meaningful;
- Represents a meaningful sample of the logs.

✉honeycutt@ou.edu

Let’s Chat

honeycutt@ou.edu

http://wesleythoneycutt.com