IN4MATX 241: Ubiquitous Computing

Class 3:
Signal Processing &
Activity Recognition

Daniel Epstein

Disclaimer

- This is not my area of expertise
- But it underlies many aspects of Ubicomp,
  so I thought it was important to cover
- If you have expertise, feel free to correct me or add supplemental thoughts
- If you don’t, the further along we go, the closer to the “human” we will get
- Many thanks to Jon Froehlich (U Washington) & Alex Mariakakis (U Toronto)
  for materials

https://jonfroehlich.github.io/ https://mariakakis.github.io/

Learning goals

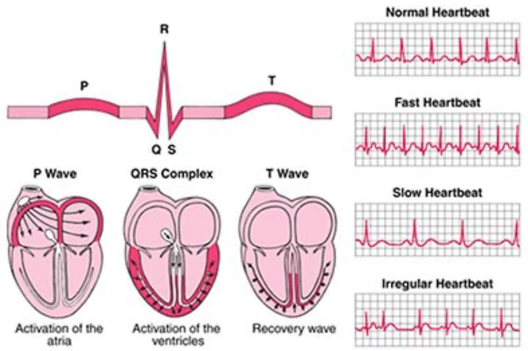
- Understand how sensor data is acquired
- Describe and represent a time-series signal
- Develop strategies for analyzing and processing signals to recognize activities

What are sensors *sensing*?

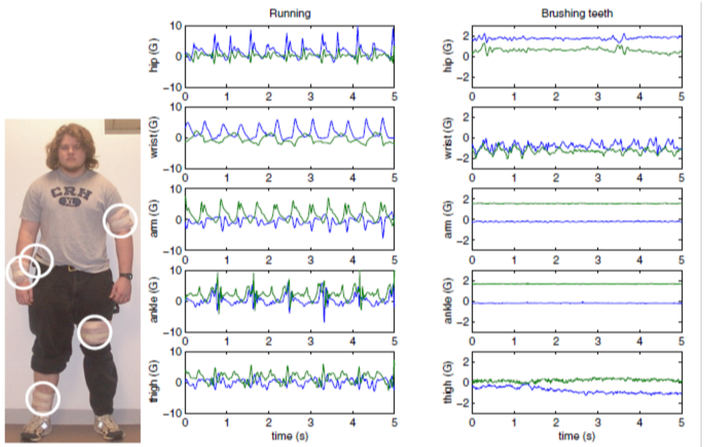
What are sensors *sensing*?

Physical phenomena, digitized, and represented as time series arrays

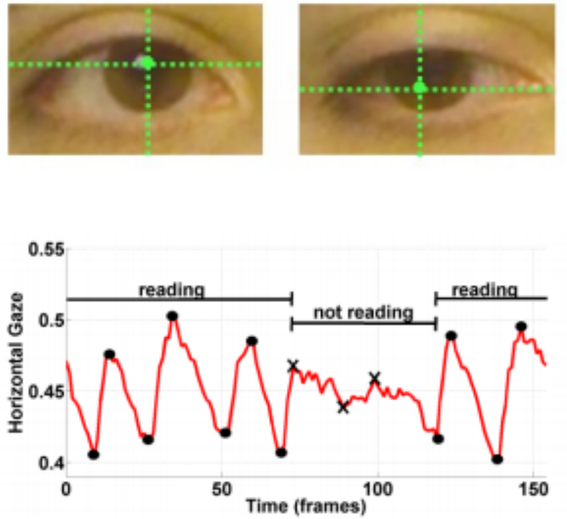
Signals



Electrocardiograms for heartbeat tracking



Accelerometers for activity recognition

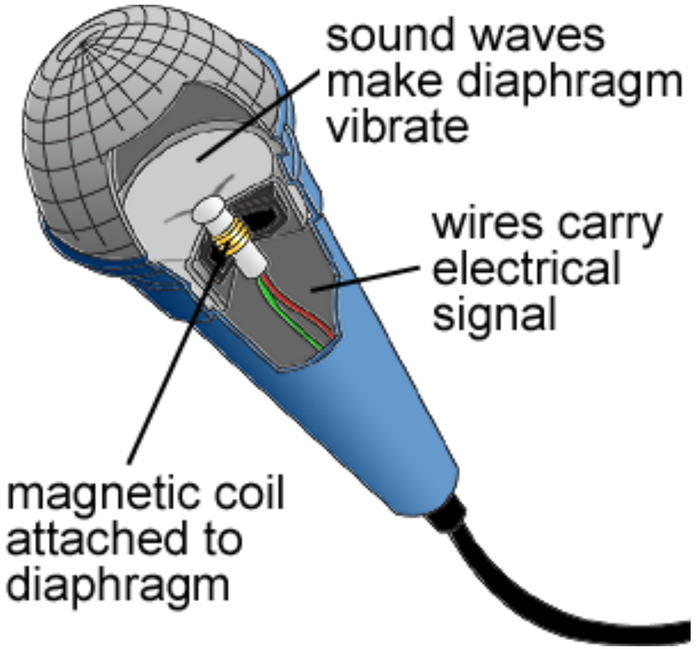


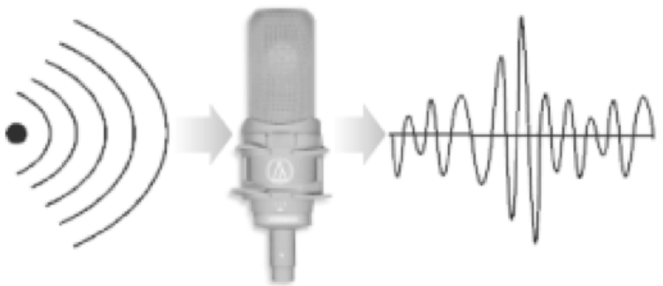
Smartphone camera for gaze tracking

Signals

Example: a microphone

- **Physical stimulus**: when you speak, play an instrument, etc., it vibrates air in a sinusoidal pattern
- **Diaphragm vibration**: Inside a microphone is a small diaphragm that vibrates in response to air movement
- **Electricity generation**: A conductive coil attached to the diaphragm, moves back and forth across a magnet. This generates a current proportional to the sound wave

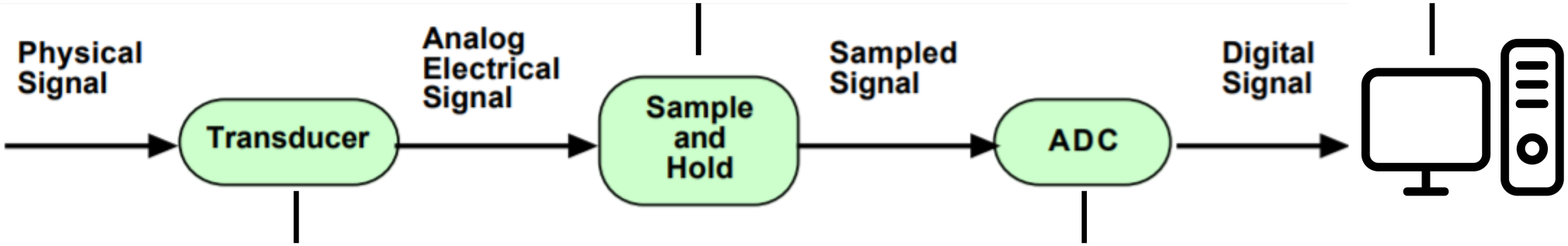




Signals

A sample and hold device *samples* the analog signal (as a voltage) and *holds* it at a fixed level

Once it's on a computer/phone, it can be processed



Converts physical signal into an analog electrical signal

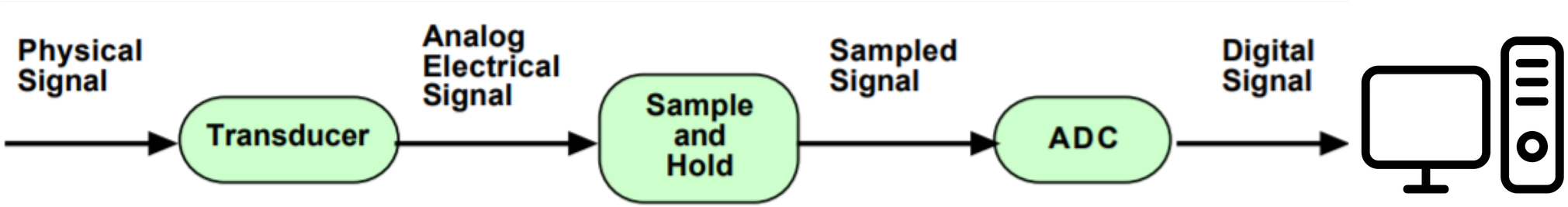
Environmental conditions will introduce noise (humidity, light, etc.)

The *analog-to-digital* converter converts the fixed voltage (the sampled signal) to a binary number (quantization)

Signals

Signal acquisition: two key questions

- Sampling rate: how often do I need to sample the “real world”?
- Quantization: How many bits should I use to represent each sample?

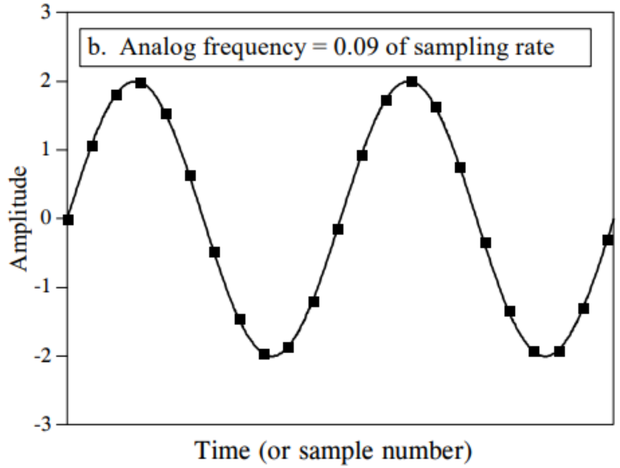


Signals

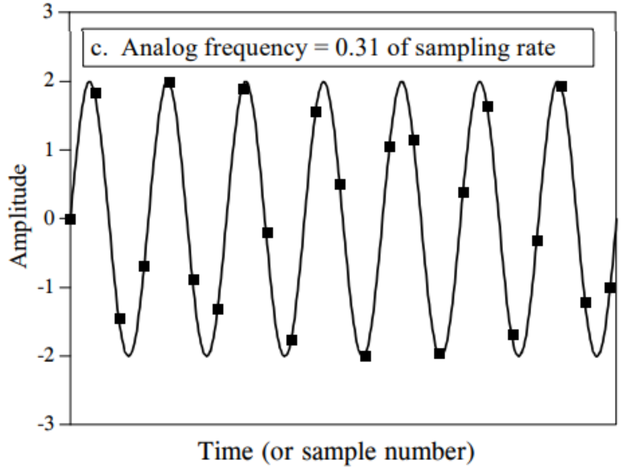
Sampling rate

- You should sample at a rate sufficient to accurately reconstruct the real analog signal

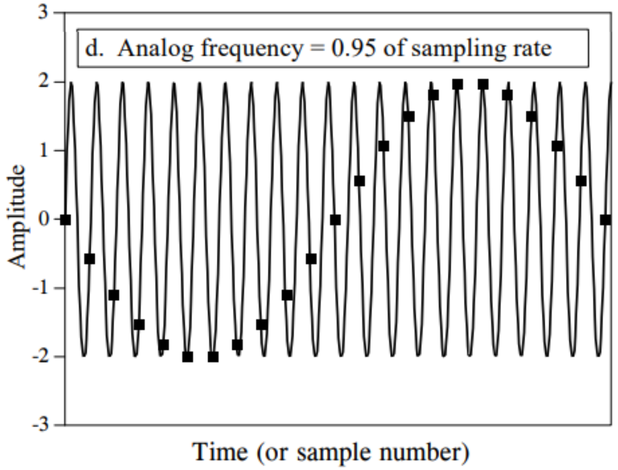
Solid line is the “real world” analog signal, each dot represents a digital sample



This “looks bad”, but there’s enough information (mathematically) to reconstruct the signal



The sampled data now looks like a different signal! This is called *aliasing*.



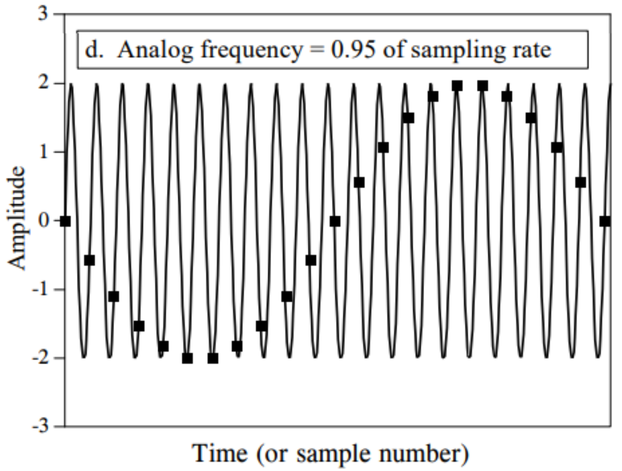
Signals

Sampling rate

- The sampling theorem states that a continuous signal can only be properly sampled if it does not contain frequency components above one-half of the sampling rate

- Sampling rate must be > 2 * max(real world signal frequency)

The sampled data now looks like a different signal! This is called *aliasing*.



http://www.dspguide.com/CH3.PDF

Signals

https://www.youtube.com/watch?v=AYQAKwCxScc

Signals

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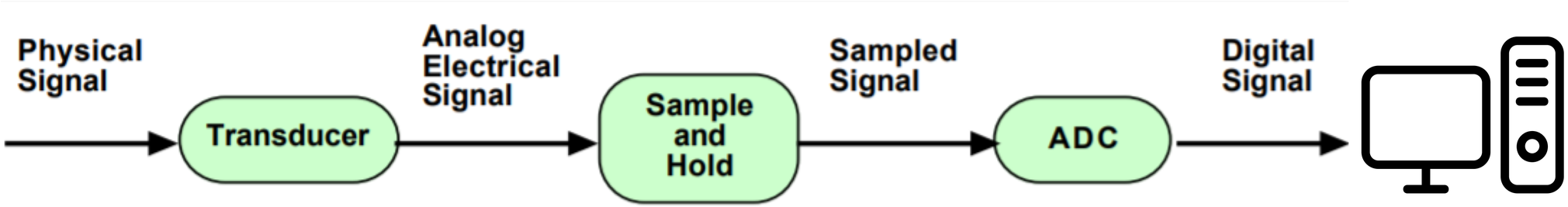
Signals

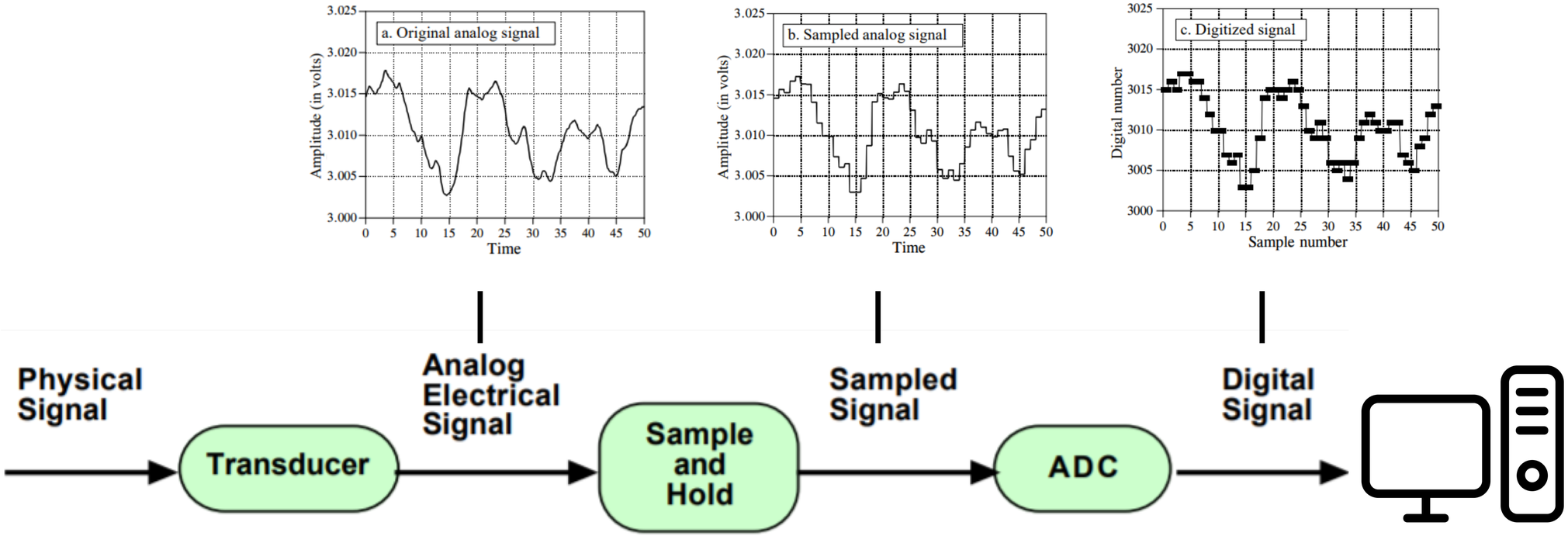
Signal acquisition: two key questions

- Sampling rate: how often do I need to sample the “real world”?
- Quantization: How many bits should I use to represent each sample?



Signals

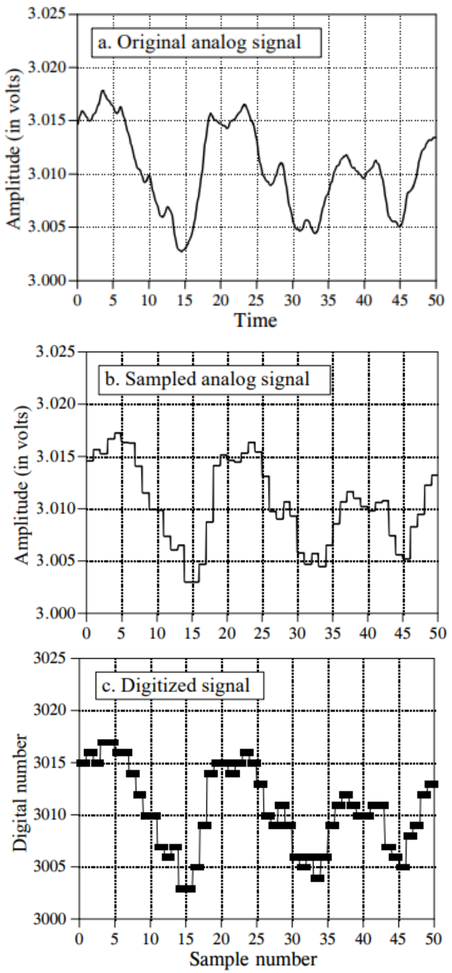
Quantization



Signals

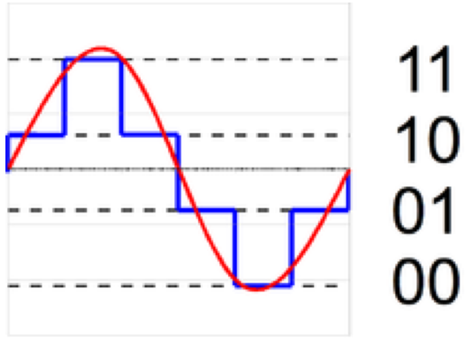
Quantization

- Why must we quantize signals?
  - Input is typically continuous,
    thus not possible to represent digitally
  - If we're sampling with high frequency,
    there's a *lot* of data to store
  - Quantization is the basis for
    basically all compression algorithms

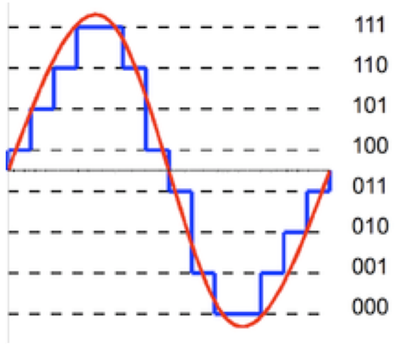


Signals

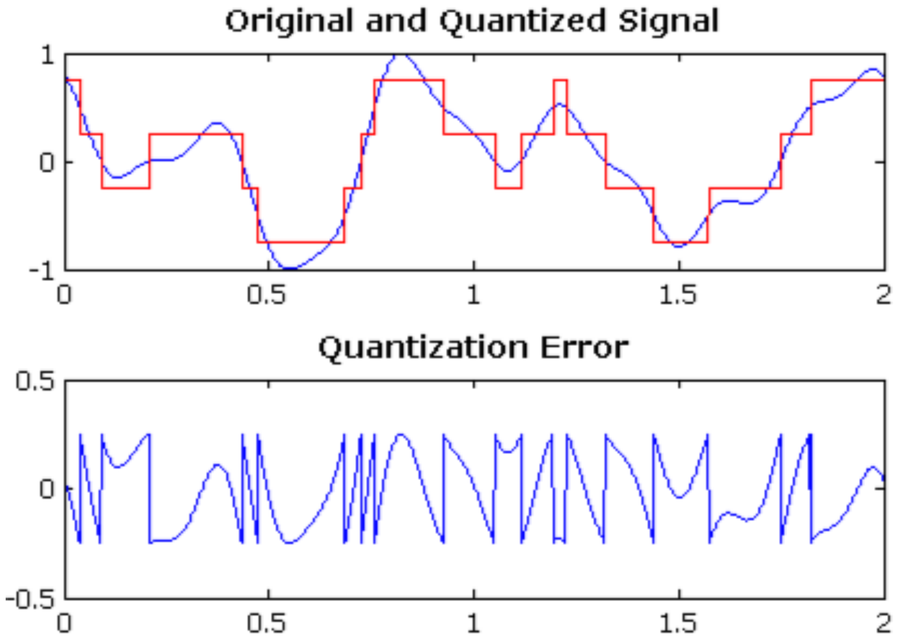
Quantization



2-bit resolution allows for four discretization levels of an analog signal

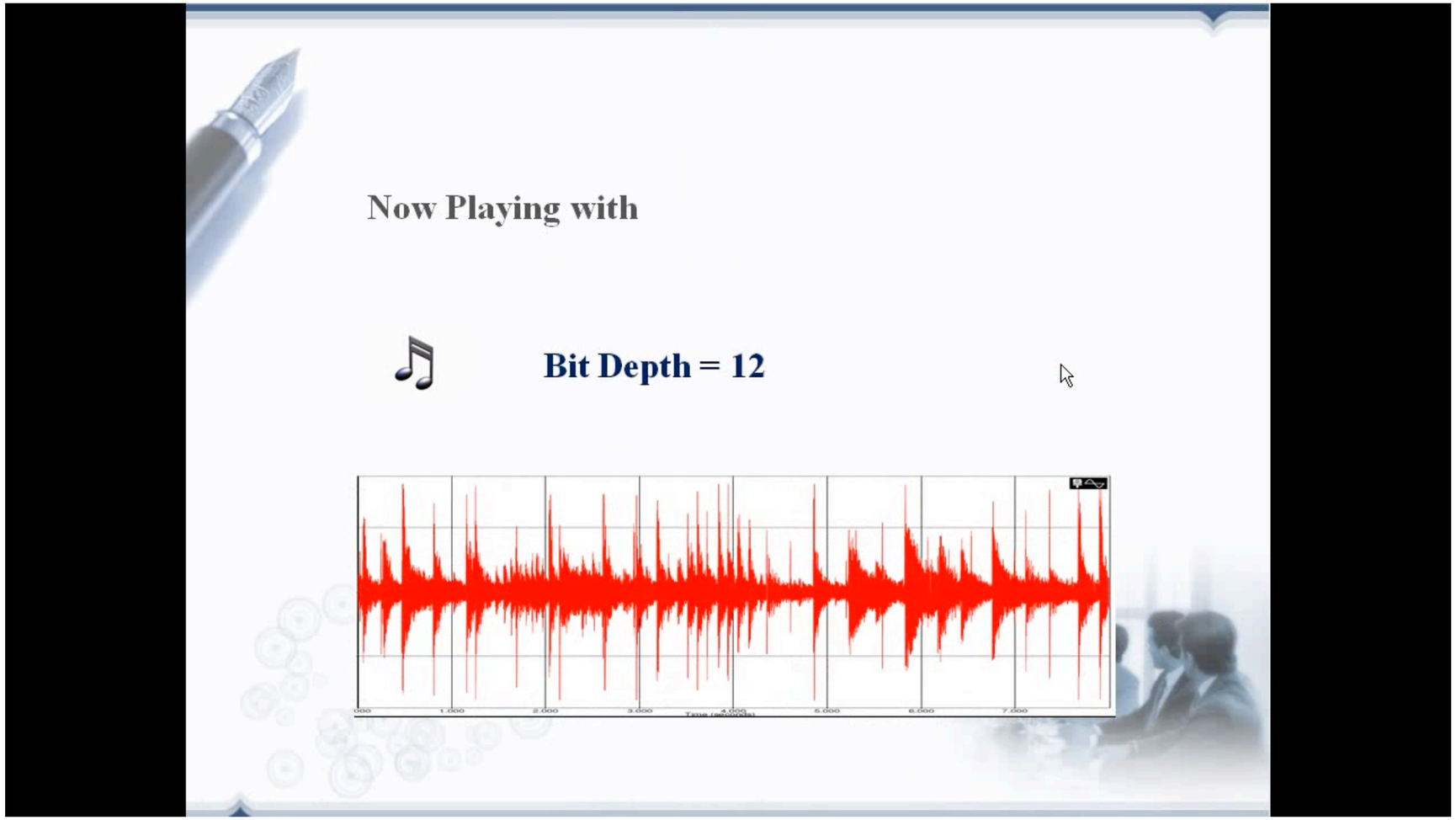


3-bit resolution allows for eight discretization levels of an analog signal

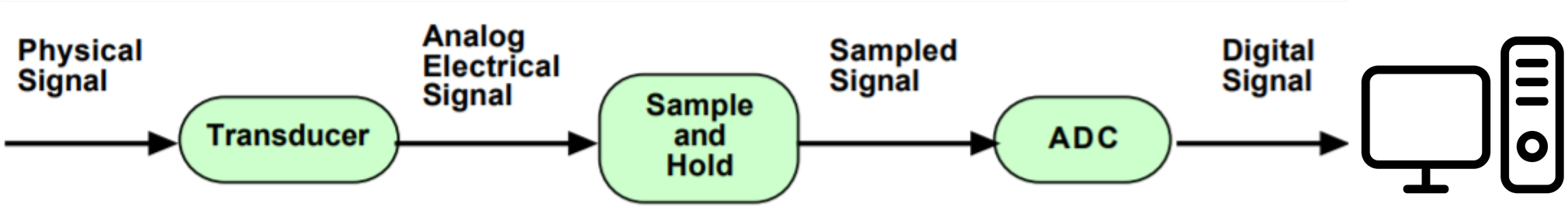


The quantization error is the difference between an input value and its quantized value

Signals



https://www.youtube.com/watch?v=_cRFBBnUFug

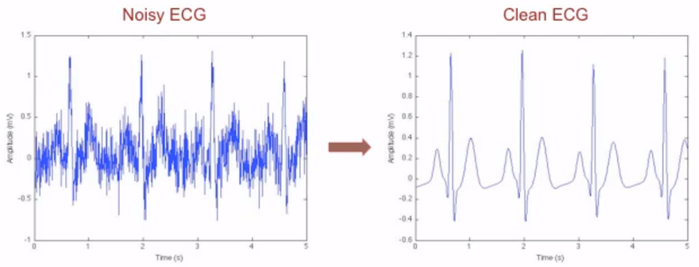

Physical Signal
Transducer
Analog Electrical Signal
Sample and Hold
Sampled Signal
ADC
Digital Signal

What is *signal processing*?

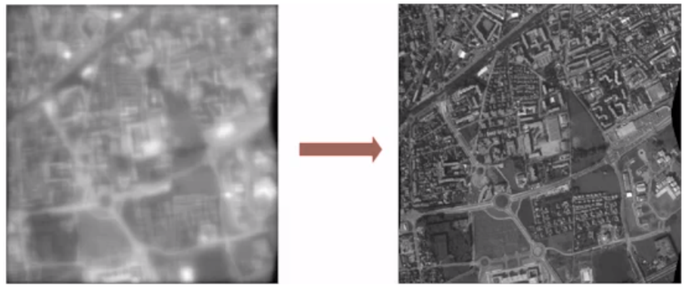
What is *signal processing*?

Manipulating a signal to change its characteristics or extract information

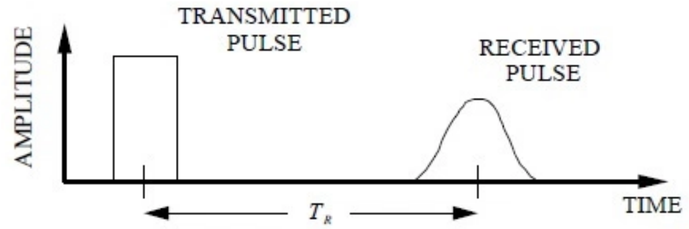
Signal processing



Eliminating noise
(e.g., smoothing ECG)



Correcting distortion
(e.g., Hubble lens)



Extracting information
(e.g., distance & velocity
from radar pulse)

Signal processing

- With a lot of math, you can break a signal down into component signals, which can be useful for recognition
- But we'll stop here :-)

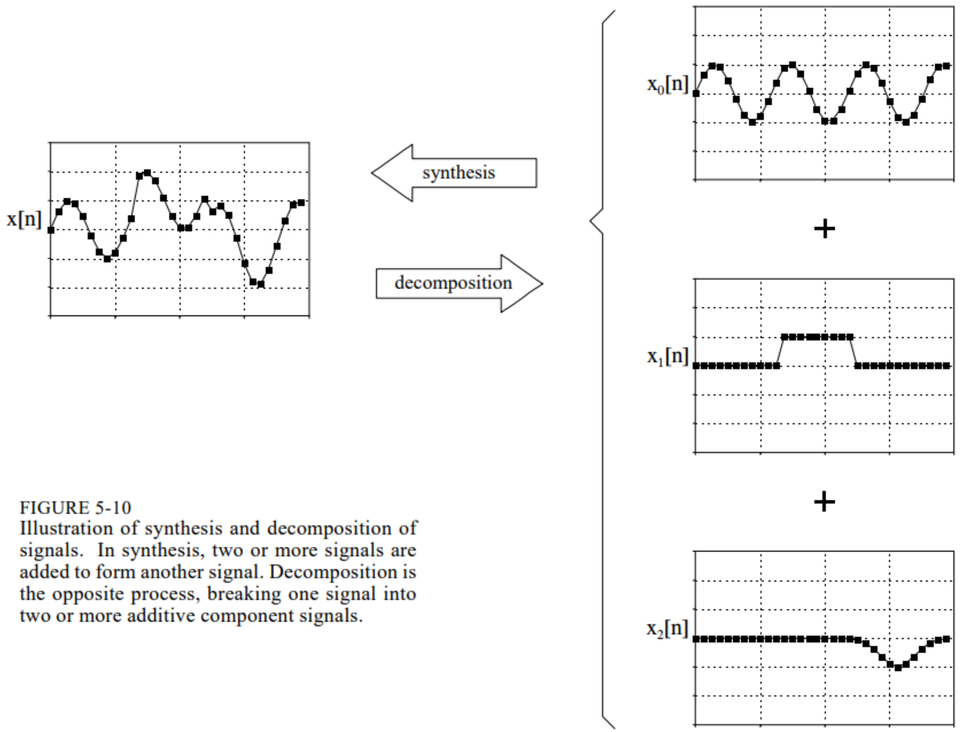


FIGURE 5-10
Illustration of synthesis and decomposition of signals. In synthesis, two or more signals are added to form another signal. Decomposition is the opposite process, breaking one signal into two or more additive component signals.

Signal processing

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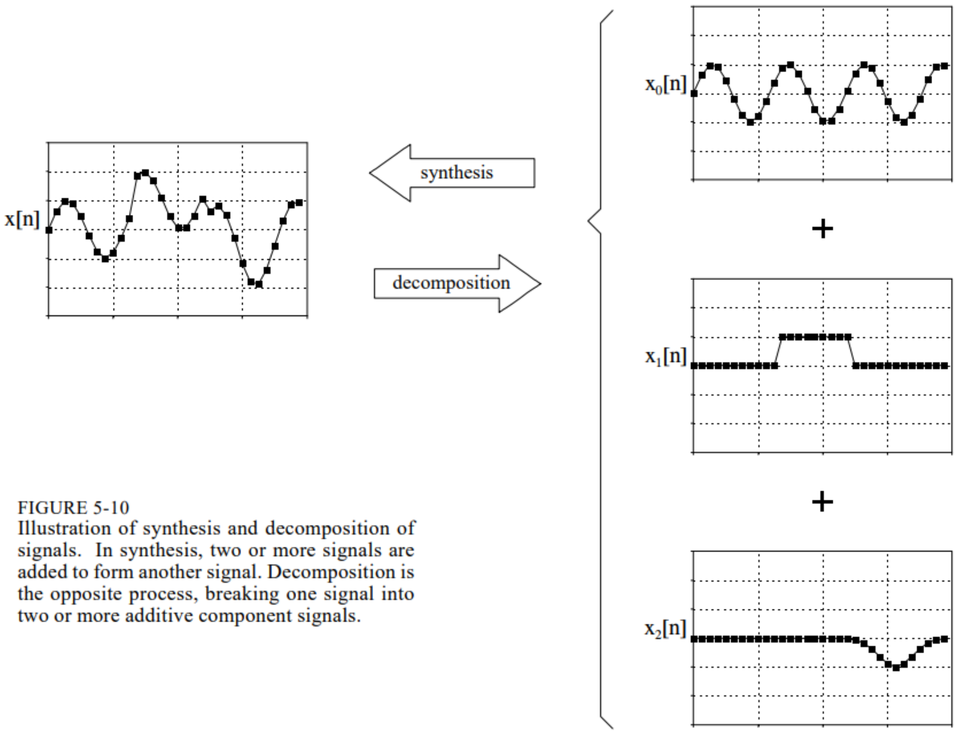


FIGURE 5-10
Illustration of synthesis and decomposition of signals. In synthesis, two or more signals are added to form another signal. Decomposition is the opposite process, breaking one signal into two or more additive component signals.

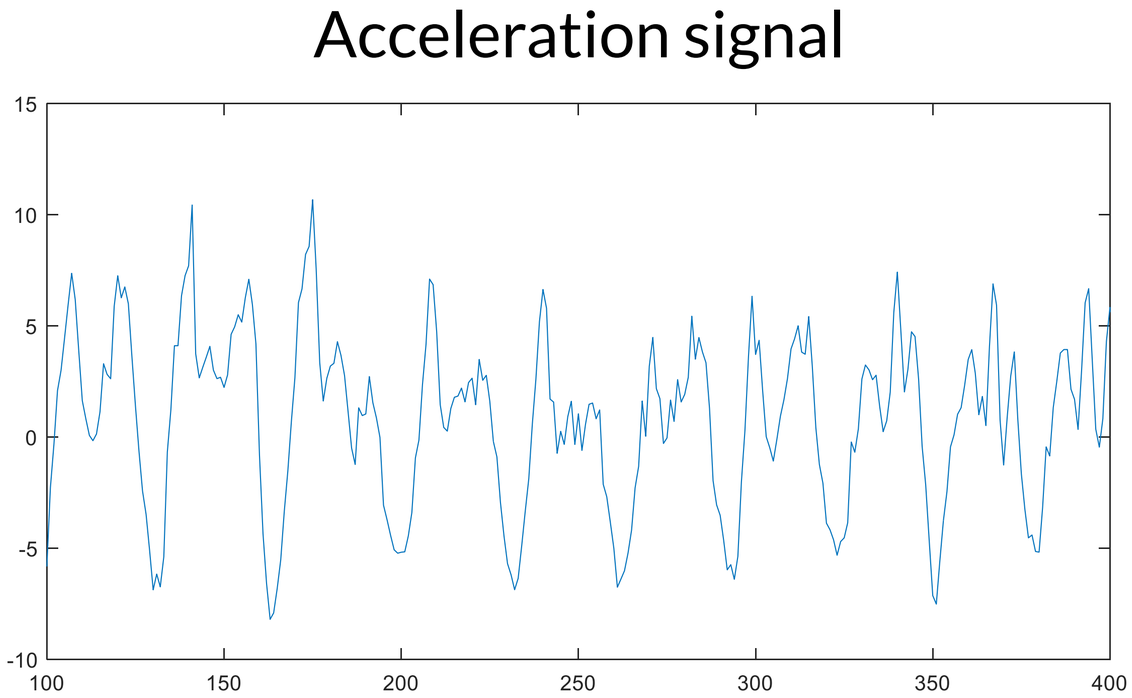
How do we translate these theoretical approaches to the applied nature of Ubicomp?

Signal Processing in Ubicomp

- **Capture signals under controlled conditions** with “ground truth” (e.g., walk ten steps, wait, walk ten steps, wait). Collect easy & hard samples.
- **Use tools to visualize, study, & process the signal**. Identify patterns, brainstorm potential approaches. Calculate descriptive stats (mean, median)
- **Search for previous solutions** to comparable problems (e.g., Google Scholar). What can be re-appropriated for your problem?
- **Generate** and **test approaches offline** using test data. Iterate.
- When offline works well, **adapt approach to perform in real-time**. If approach is not as effective as desired, collect more naturalistic samples & repeat

Example: Step Counting

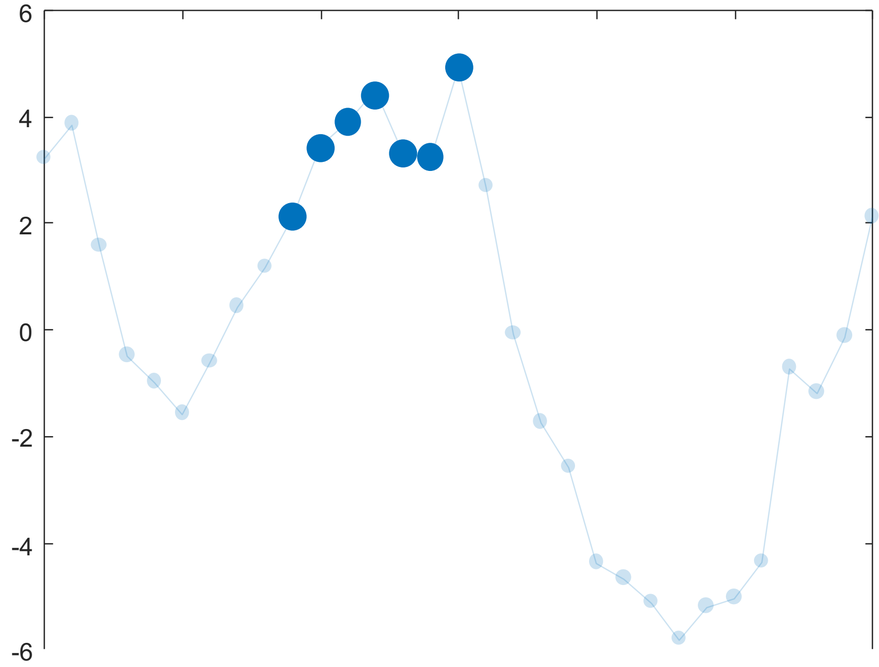
Step counting



Step counting

Sliding Window

- As your signal gets longer, it does not make sense to analyze all of that data at once
  - Infeasible for memory/performance
  - Older information is usually less useful
- When a new value comes, add it to your list and get rid of the oldest
- How large of a window? It depends!

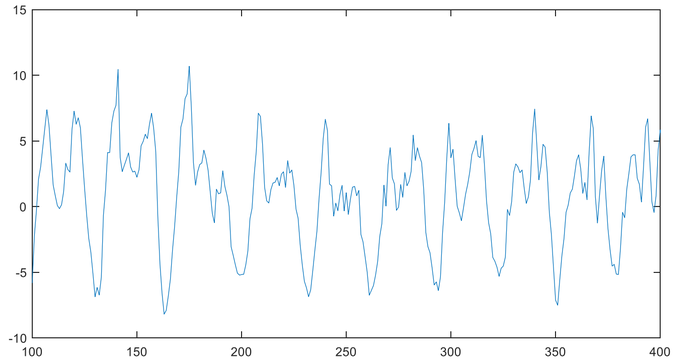


Window size: 5

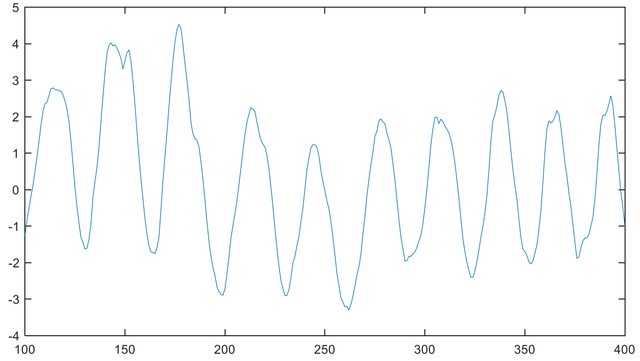
Step counting

Filtering

- As previously discussed, signals will almost never look as clean as you want them to be
- Sensors will have noise that break assumptions you make in your algorithm



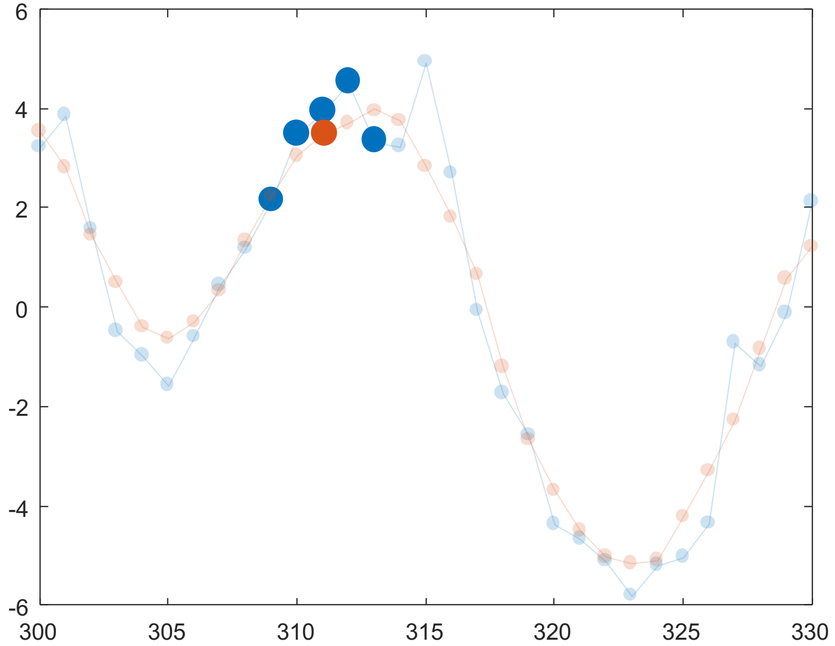
Unfiltered



Filtered

Step counting

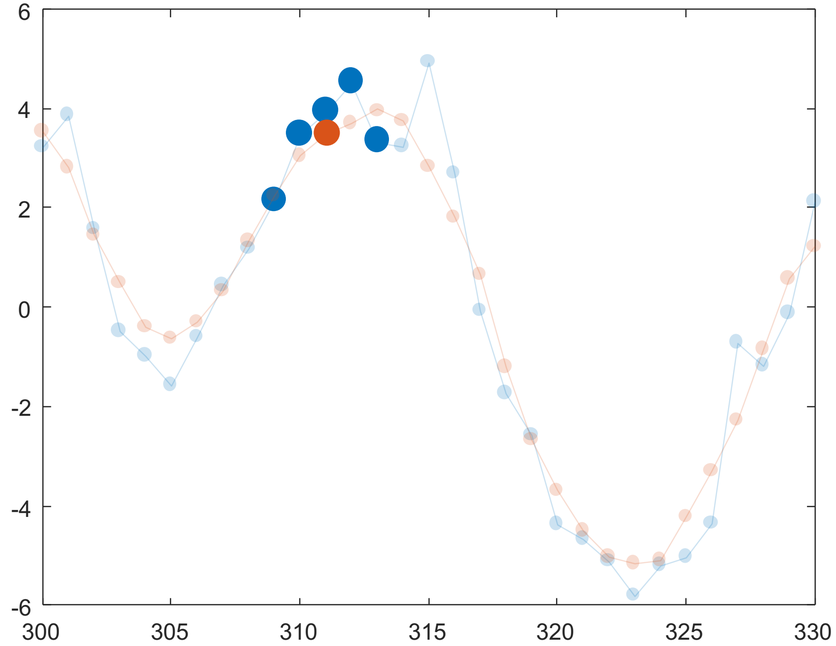
Filtering



Filter Length [n] = 5

Input = [2.4, 4, 4.5, 5, 3.5]

Output= (2.4, 4, 4.5, 5, 3.5)/5 = 3.9



Filter Length [n] = 5

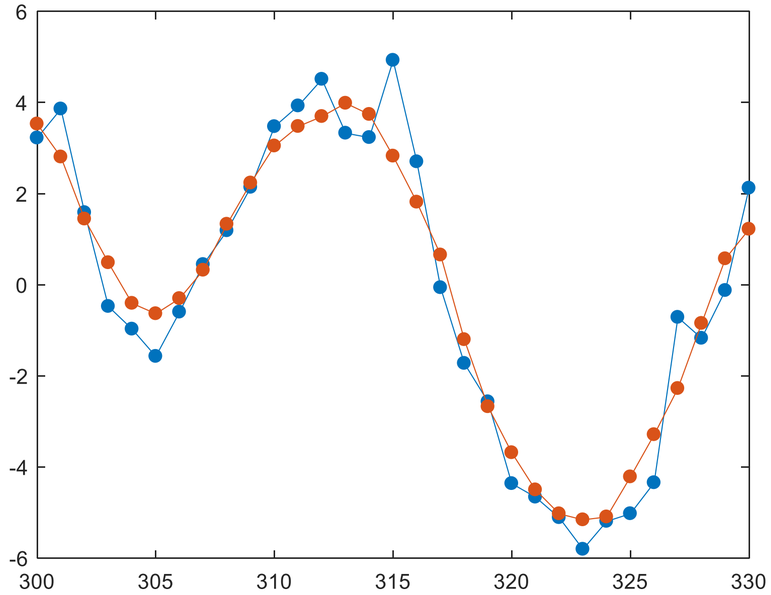
Input = [4, 4.5, 5, 3.5, 3.2]

Output= (4, 4.5, 5, 3.5+3.2)/5 = 4.0

Step counting

Filtering

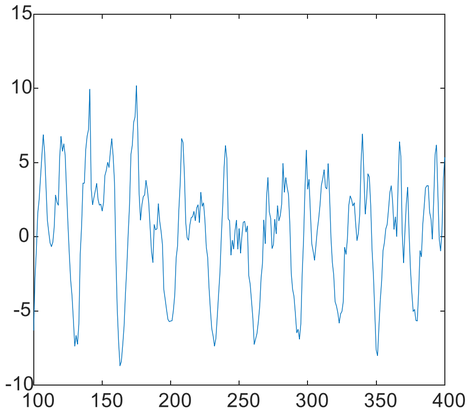
- Filter length [N] = 5
- Does not have future information
- *Delay* of filter length



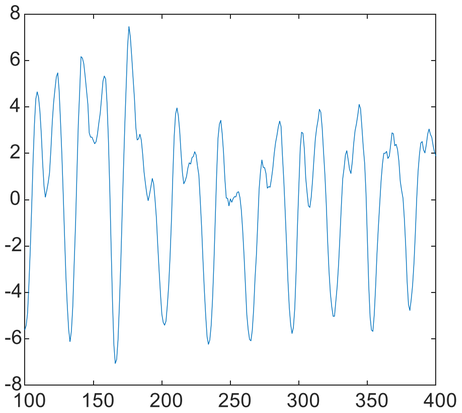
Noisy signal
Filtered signal

Step counting

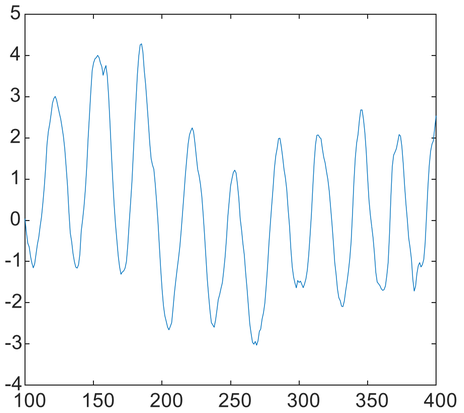
Filtering



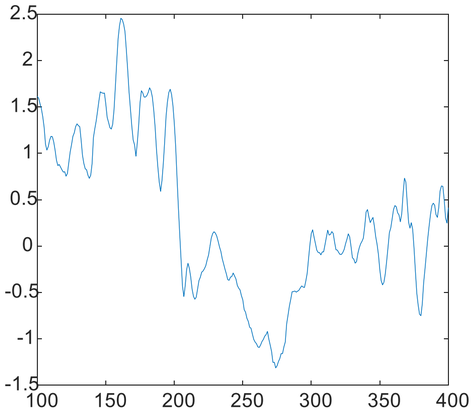
N=1



N=5



N=15

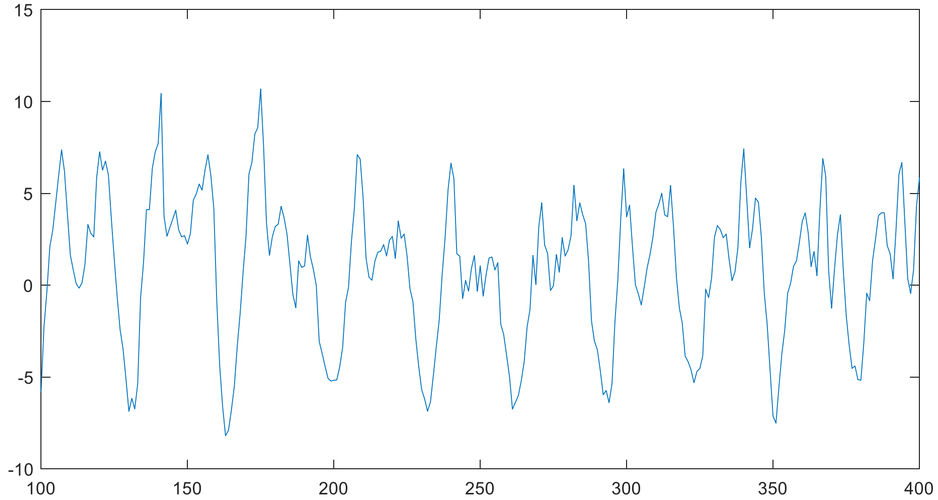


N=30

Step counting

Two potential strategies

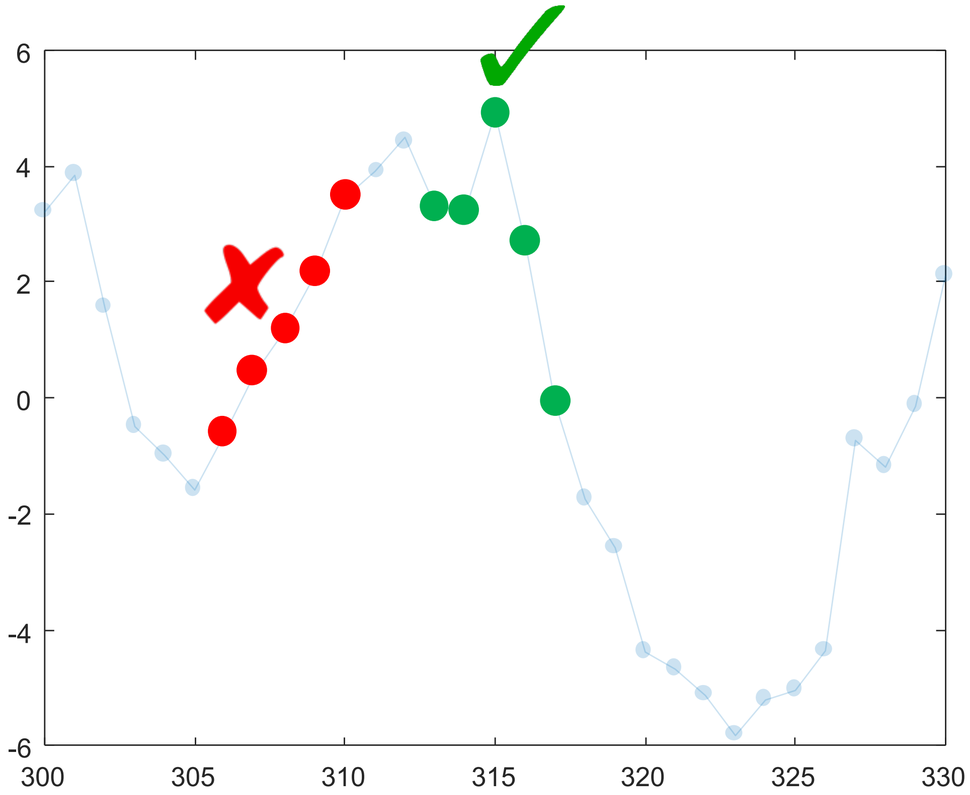
- Peak finding
- Zero crossing



Step counting

Peak finding

- Is the value in the middle of the sliding window a peak?



Step counting

Peak finding

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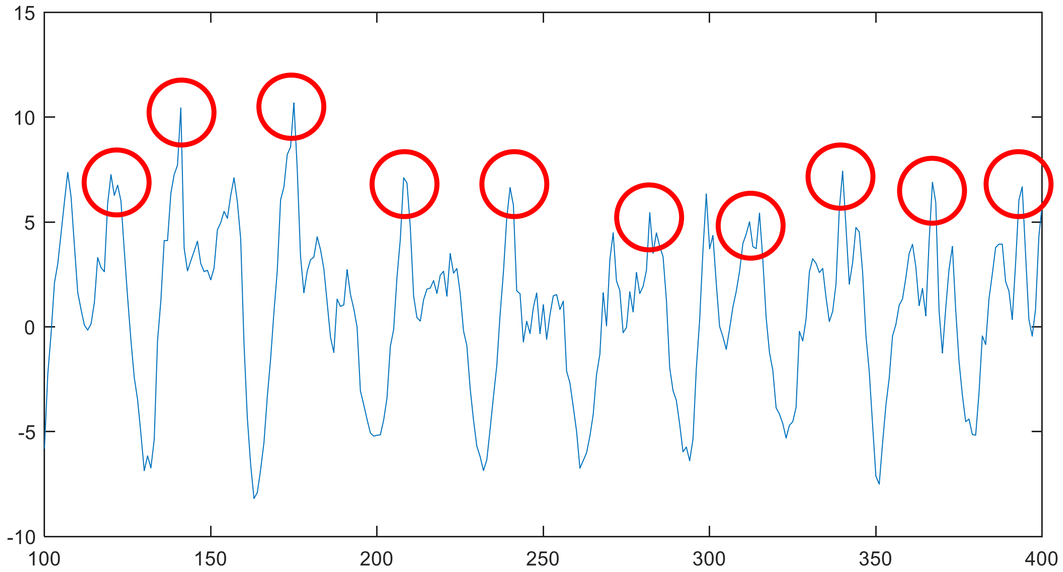
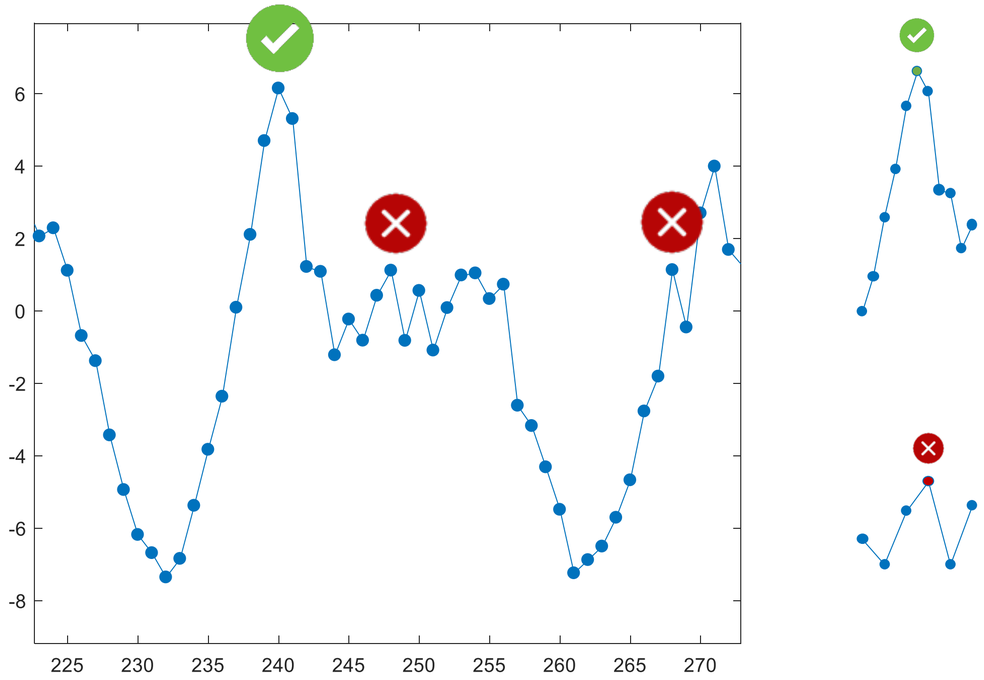


Step counting

Peak finding

- Distinguishing actual peaks from local maxima
- When is a peak significant enough to indicate a step?
- How long should the window be?
- Could use derivatives in place of pure peak finding



Step counting

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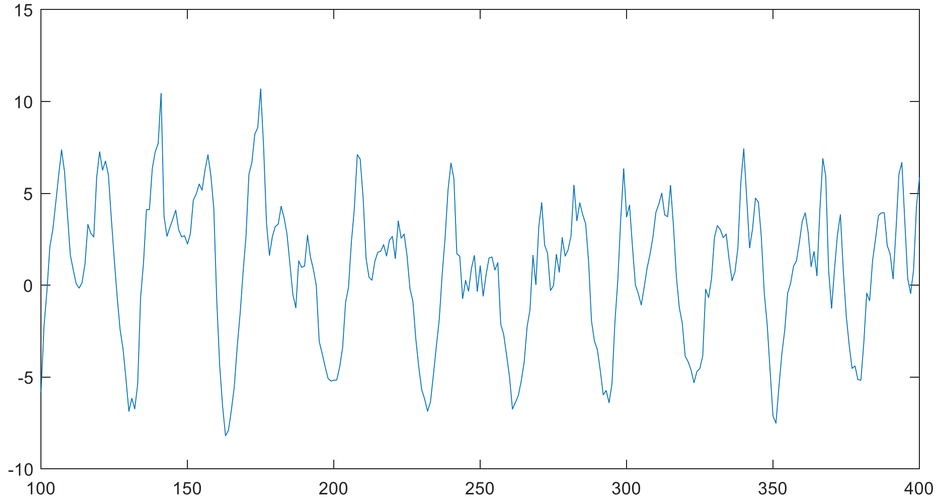
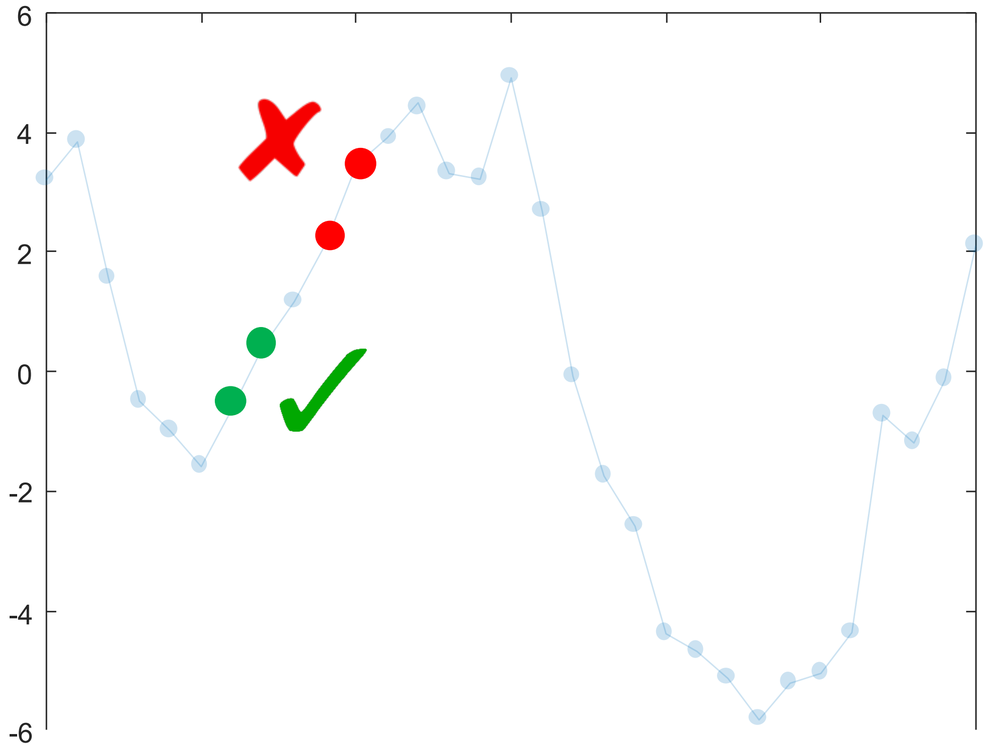


Step counting

Zero crossing

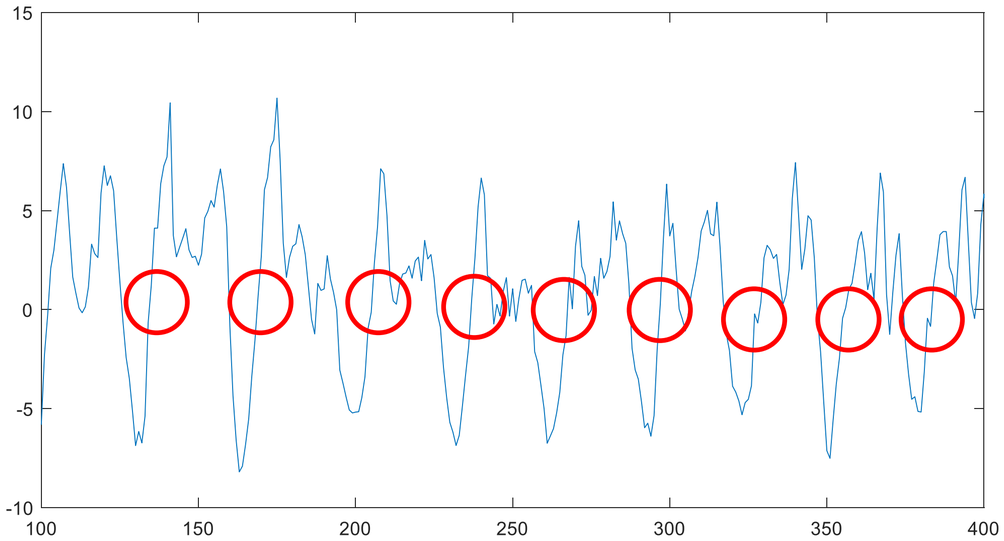
- Does the signal cross the x-axis? (Note: pick increasing or decreasing)



Step counting

Zero crossing

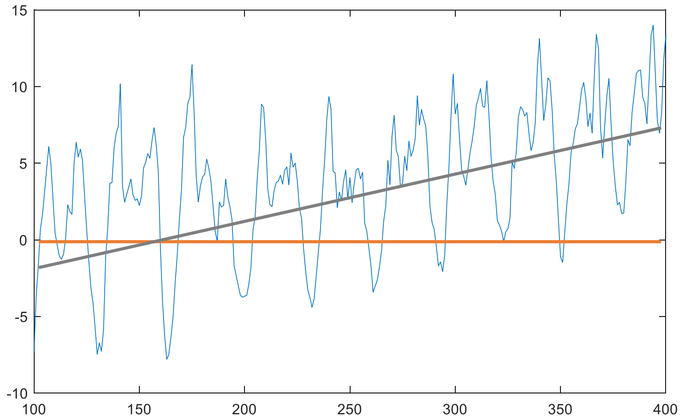
- Does the signal cross the x-axis? (Note: pick increasing or decreasing)



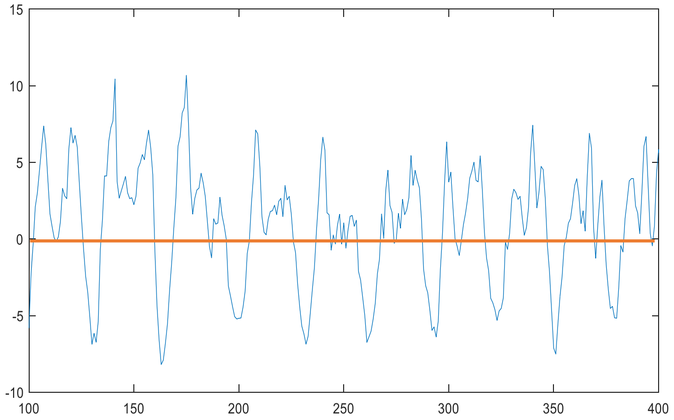
Step counting

Zero crossing

- Signal isn’t always centered around zero
- False positive if there are perturbations in the middle
  - Smoothing can help with this



De-mean (subtract average)



Signal Processing in Ubicomp

- Capture signals under controlled conditions
- Use tools to visualize, study, & process the signal
- Search for previous solutions to comparable problems
- Generate and test approaches offline using test data
- When offline works well, adapt approach to perform in real-time

IN4MATX 241: Ubiquitous Computing

Class 3:
Signal Processing &
Activity Recognition

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