Section 7

Basics of Signal Processing

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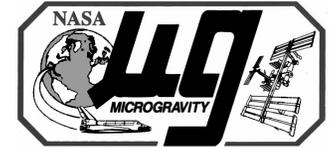
Outline

1. Block Diagram of Data Stream

2. Motivation for Analog-to-Digital Conversion

3. Basic Concepts

- processing depends on and impacts the Principal Investigator

4. Tradeoffs and Summary

Data Stream

decisions impact

Sensor

Real World Signal

Data Acquisition System

Storage, Display, and Analysis

terms & concepts

discussed in later sections

Voltage

Time

Analog Signal

analog signal - a signal defined over all time with infinite precision; a continuous-time, continuous-amplitude signal

Sensor

Data Stream

sequence of numbers from pre-defined set of values

Real World Signal

| **Data Acquisition System** |

Storage, Display, and Analysis

- **Antialias Filtering**
- **Sampling**
- **Quantization**
- **Encoding**
- **Engineering Unit Conversion**

Voltage

Time

Acceleration

Time

motivation before these

Analog Signal

digital signal - a signal defined only at sampling times with finite precision; a discrete-time, discrete-amplitude signal

Digital Signal

Motivation for Analog-to-Digital Conversion

- **Computers**
  - Flexibility. Software does the digital signal processing.
  - Take advantage of the full depth and breadth of processing tools available for this platform.
  - Processing performance does not vary with temperature or time.

- **Reproducibility**
  - No degradation when copying signal.

- **Other factors**

Data Stream

Sensor

Real World Signal

Data Acquisition System

Storage, Display, and Analysis

- **Antialias Filtering** **1st**
- **Sampling** **2nd**
- **Quantization**
- **Encoding**
- **Engineering Unit Conversion**

proper sequence

Voltage

Time

Analog Signal

Acceleration

Time

Digital Signal
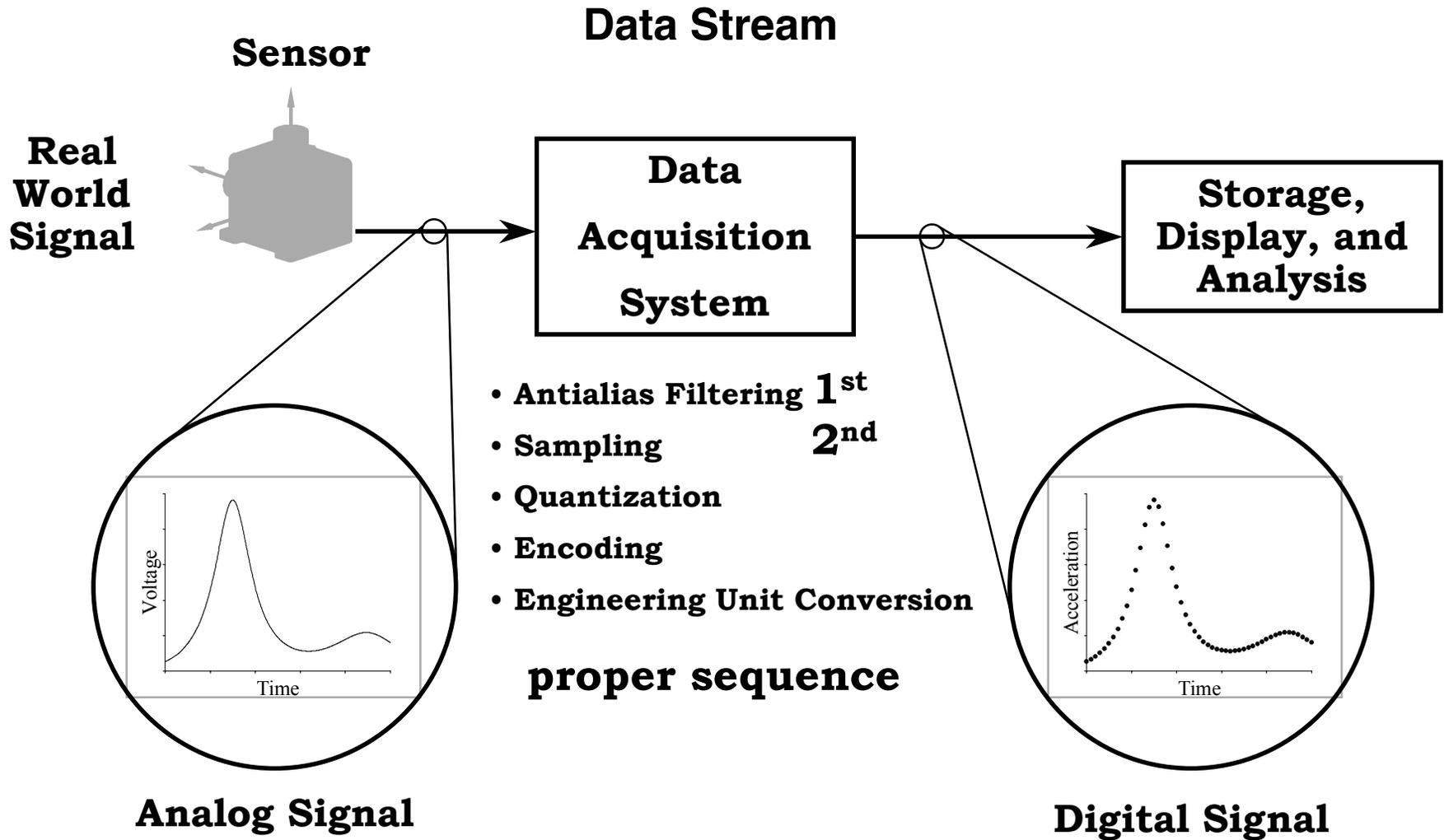
Sampling

has critical implications regarding the information our measurements contain

Analog Signal
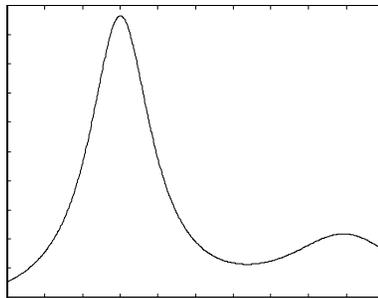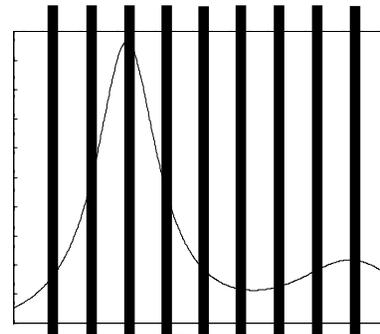
discretization

connect the dots
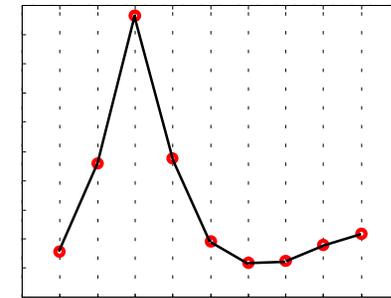
Time
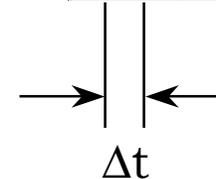
Time

Time

Δt

sampling - converting an analog signal to a discrete-time, continuous-amplitude signal

$$f_s = 1/\Delta t$$

sample rate (f$_s$) - frequency with which analog signal is sampled (samples per second)

Sampling
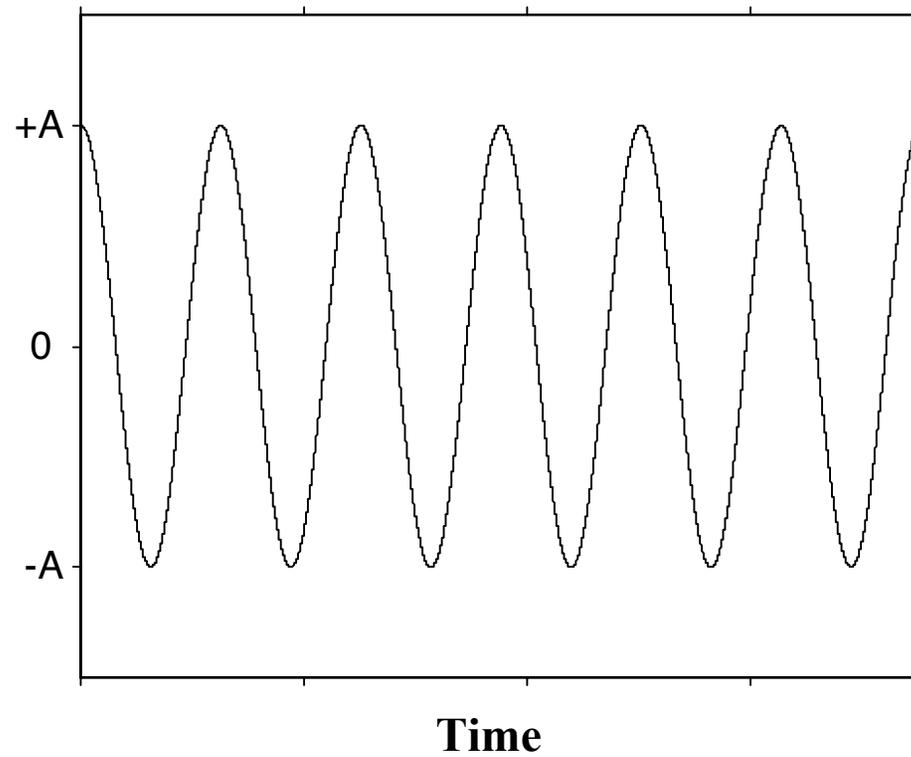
harmless-looking sinusoid

Time

Real World (Analog) Signal of Interest

Sampling

problem?

+A

0

-A

Δt

Time

span of 1 second

Discretized Signal
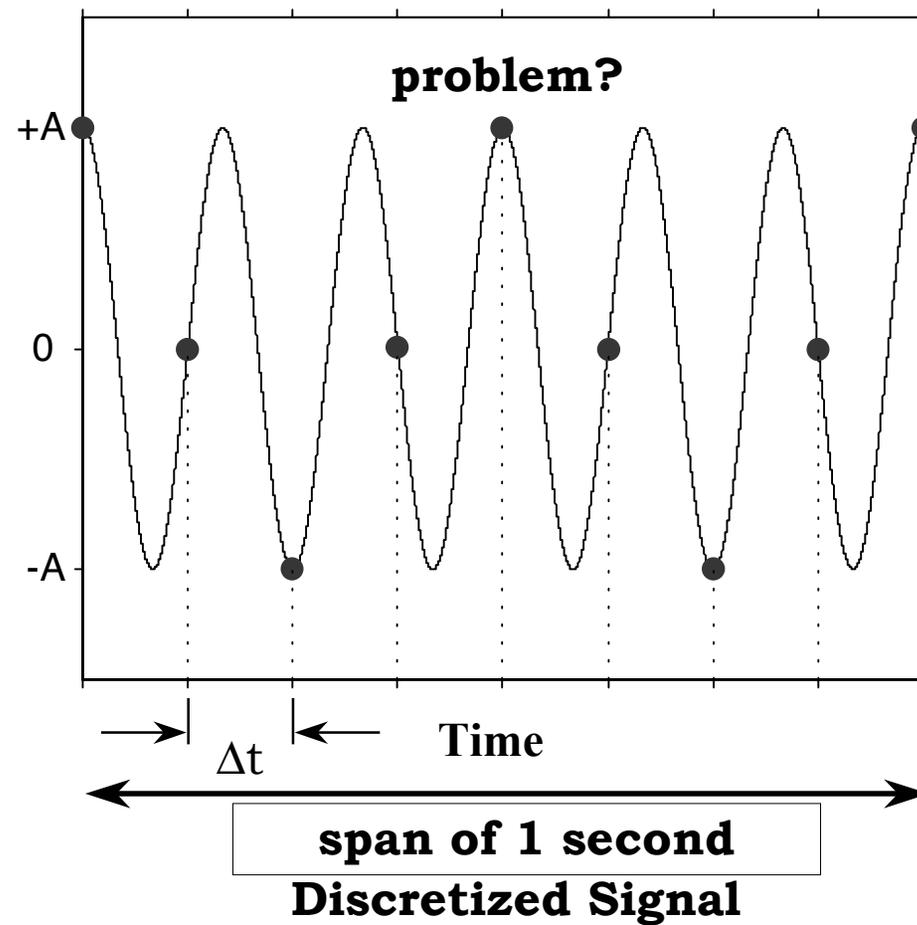
sample it

$f_s = 8$
samples/sec

Sampling

6 cycles/sec.

Analog Signal

Alias

2 cycles/sec.

+A

0

-A
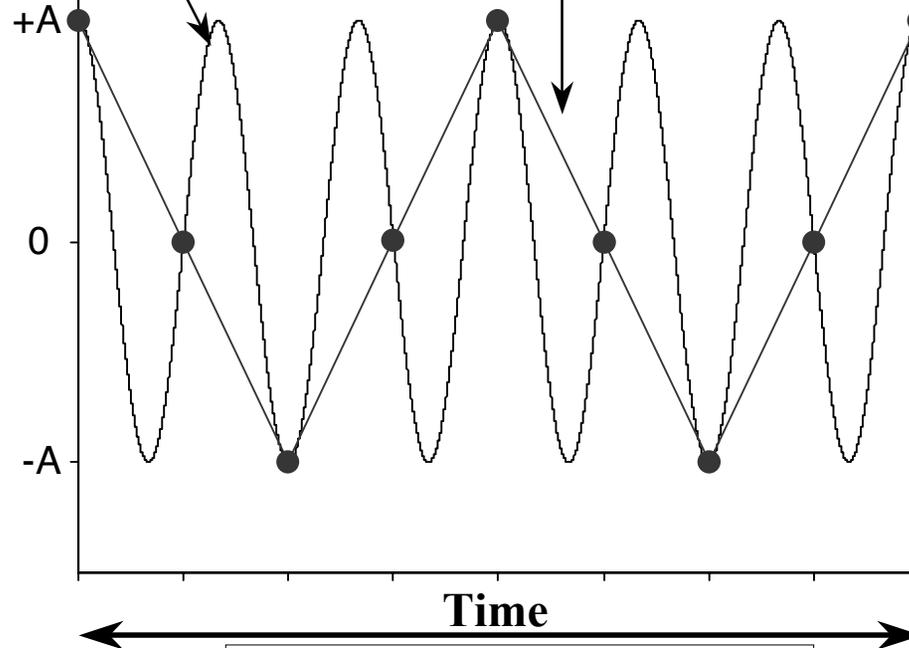
How do we enforce this if we are taking measurements of real world signals and do not know the exact nature of their content or behavior?

How do we avoid aliasing?

Time

span of 1 second

aliasing - high frequency signals manifested as low frequency signals

Nyquist criteria - sample rate at least twice highest frequency contained in the signal of interest

Antialias Filtering

pass without attenuation or amplification below cutoff frequency

total attenuation above cutoff frequency

Why does cutoff, f_c, matter?
• For acceleration data, besides sensor location, the cutoff frequency (f_c) is one of most important decisions you make. It should be greater than the highest frequency that is of interest or concern to you.

• Higher f_c means higher f_s, but limitations on the transmission bandwidth, storage, and processing resources put a limit on f_s.

actual

ideal
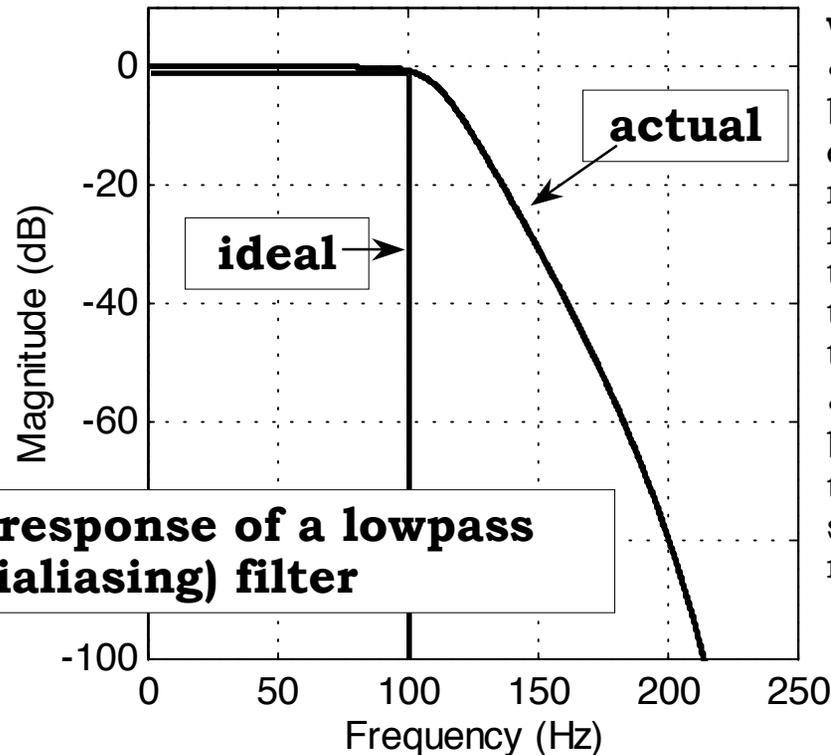
Frequency response of a lowpass (antialiasing) filter

Magnitude (dB) vs Frequency (Hz)

antialias filtering - lowpass (bandlimit) analog signal to reduce effects of aliasing

cutoff frequency (f_c) - highest frequency of interest

Data Stream

Sensor

Real World Signal

Data Acquisition System

Storage, Display, and Analysis

- **Antialias Filtering**
- **Sampling**
- **Quantization**
- **Encoding**
- **Engineering Unit Conversion**

Voltage

Time

Analog Signal

Acceleration

Time

Digital Signal

Quantization

Analog Signal

Time

Time

discretized signal
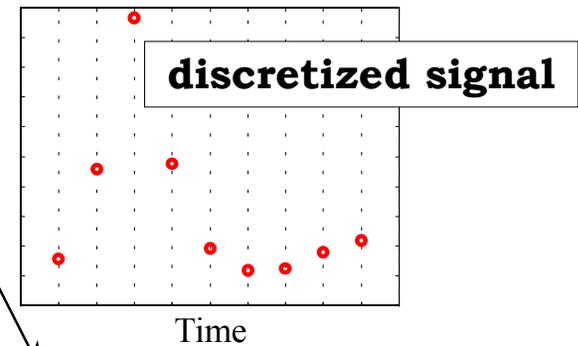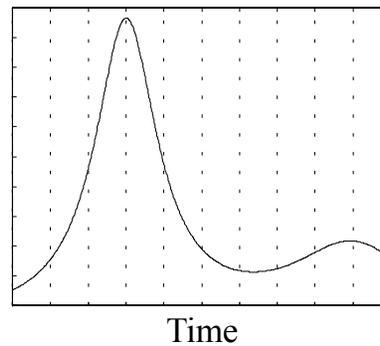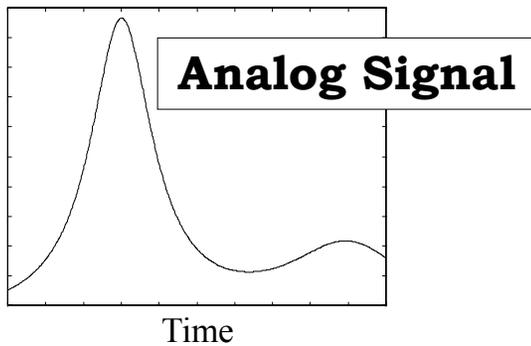
Time

digitization

quantization - conversion of discrete-time, continuous-amplitude signal to discrete-time, discrete-amplitude signal

$$q = V_{fs}/(2^b-1)$$

$$b = \text{\# of bits}$$

V_{fs} = full scale voltage

q = quantization level

q

Digital Signal
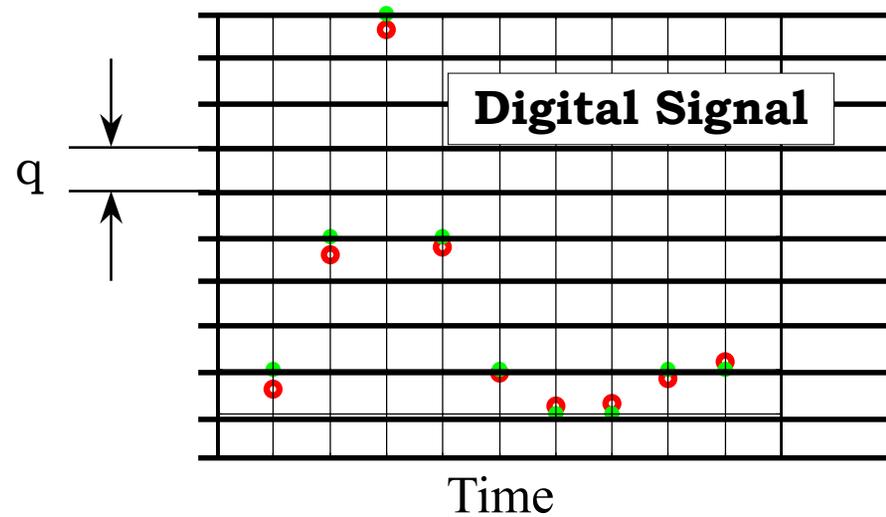
Time

Quantization

Analog Signal
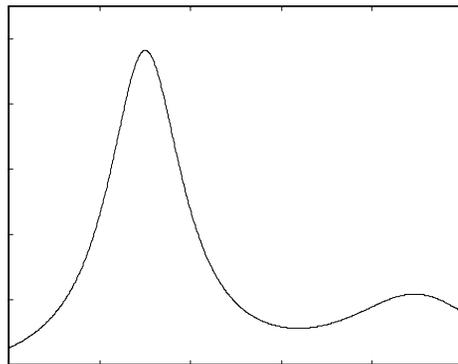
"Noticeable" Quantization Error

"Significant" Quantization Error
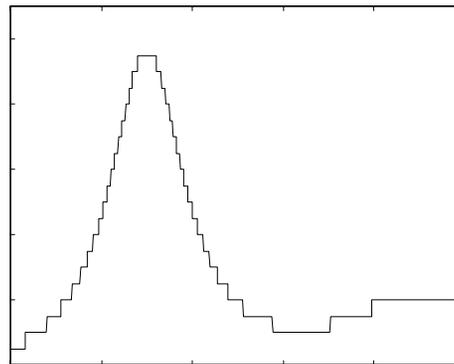
Time

Time
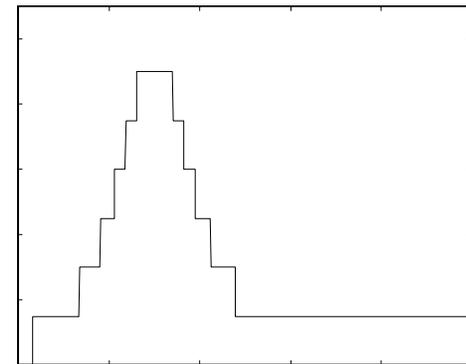
Time

some imprecision

even more imprecision

Encoding & Engineering Unit Conversion

- **Encoding** - assigning unique codes to the quantized samples

codes	
0	000
1	001
2	010
3	011
4	100
5	101
6	110
7	111
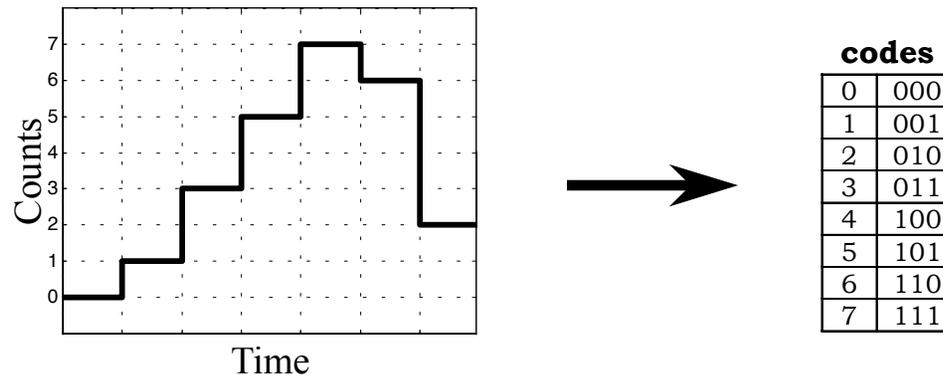
- **Engineering Unit Conversion** - translation of encoded values to desired "final" representation

codes		µg
0	000	0
1	001	5
2	010	10
3	011	15
4	100	20
5	101	25
6	110	30
7	111	35
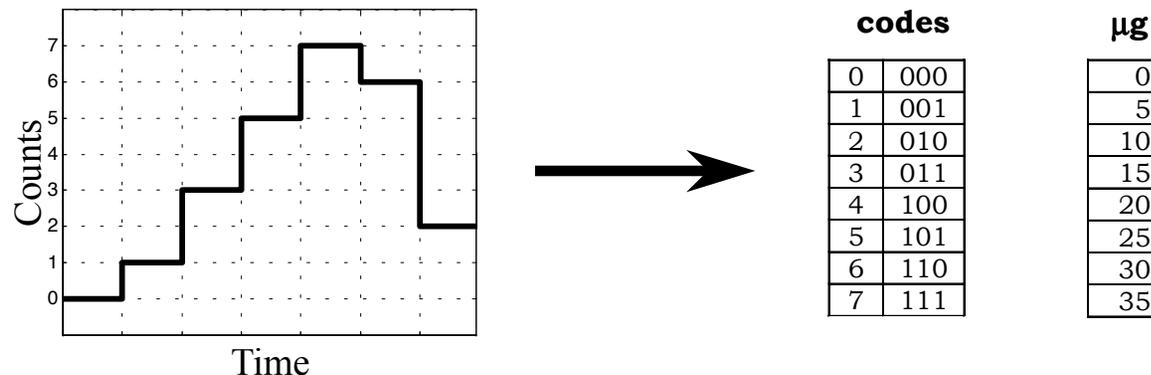
Tradeoffs and Summary

Analog-to-Digital Conversion - computer processing is the motivation

   1. Antialias Filtering

      - lowpass filter $\rightarrow$ leads to loss of high frequency information

   2. Sampling

      - sample rate $\leftarrow$ transmission, storage, and processing

      - discretization in time $\rightarrow$ aliasing

   3. Quantization

      - digitization of amplitude $\rightarrow$ precision limited by number of bits

   4. Encoding

   5. Engineering Unit Conversion