Section 5

Basics of Signal Processing

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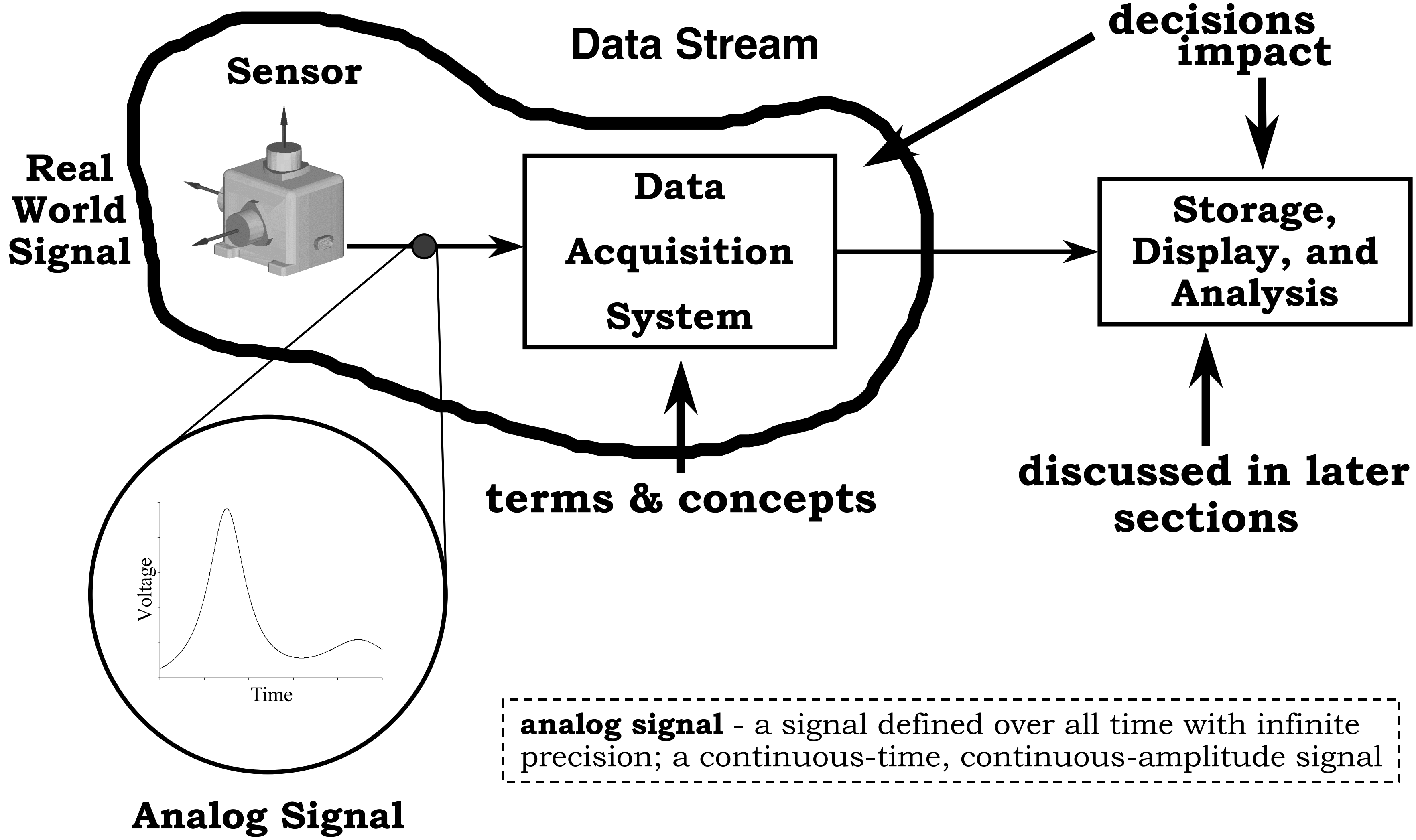
Outline

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

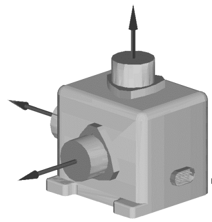


analog signal - a signal defined over all time with infinite precision; a continuous-time, continuous-amplitude signal

Data Stream

Sensor

Real World Signal

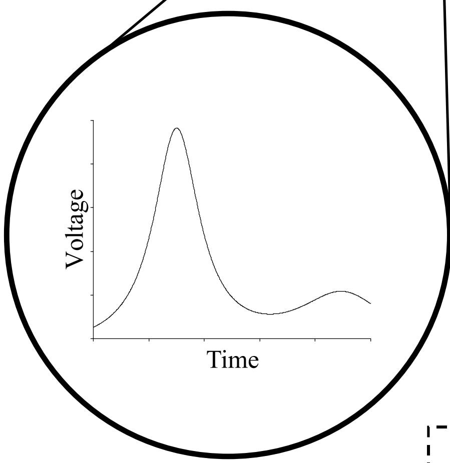


Data Acquisition System

sequence of numbers from pre-defined set of values

Storage, Display, and Analysis

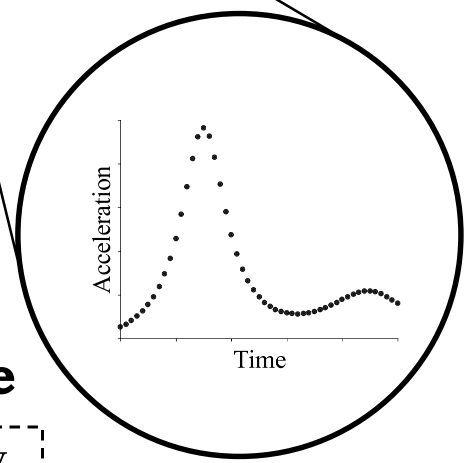
- **Antialias Filtering**
- **Sampling**
- **Quantization**
- **Encoding**
- **Engineering Unit Conversion**



Analog Signal

motivation before these

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

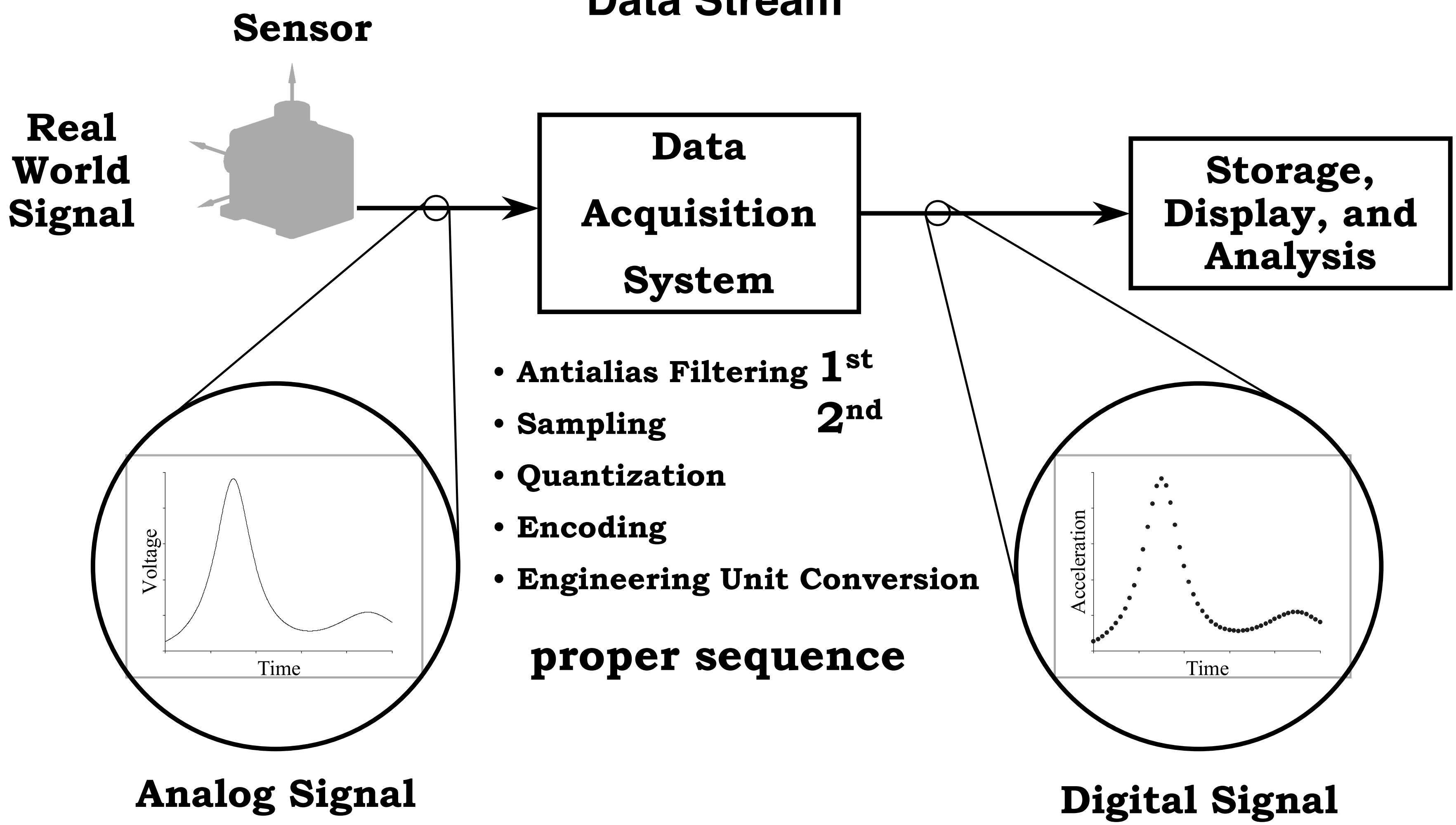


Digital Signal

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**

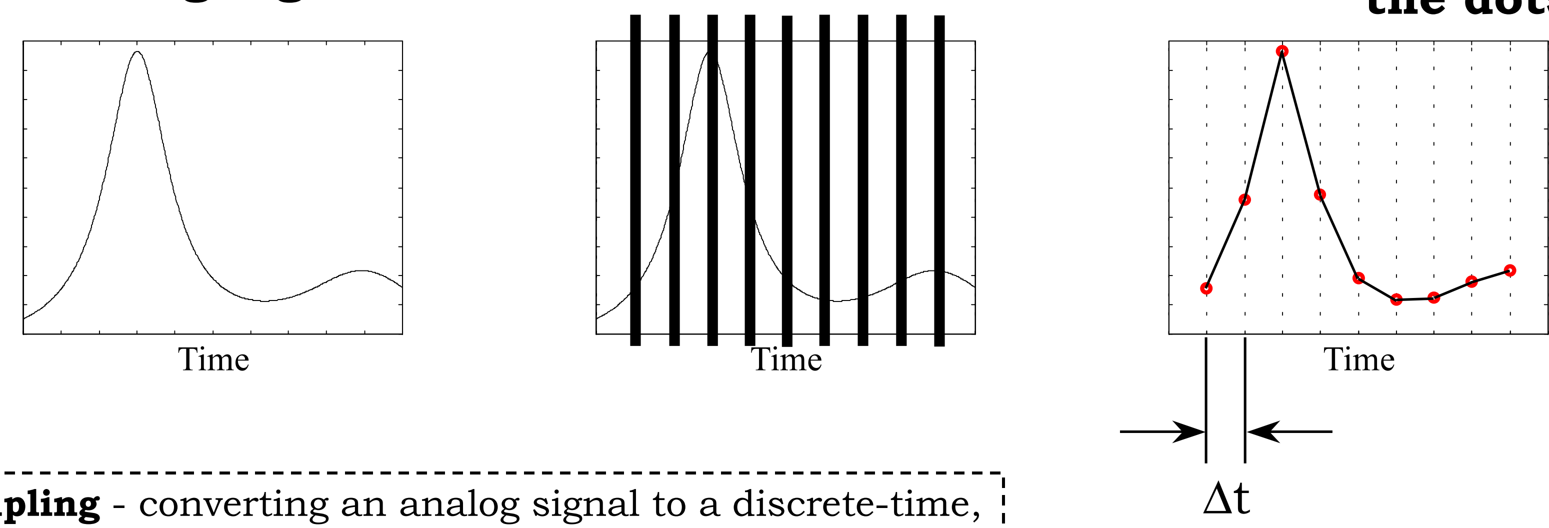
Data Stream


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
Acceleration
Time
Analog Signal
Digital Signal

Sampling

has critical implications regarding the information our measurements contain

Analog Signal *discretization* **connect the dots**

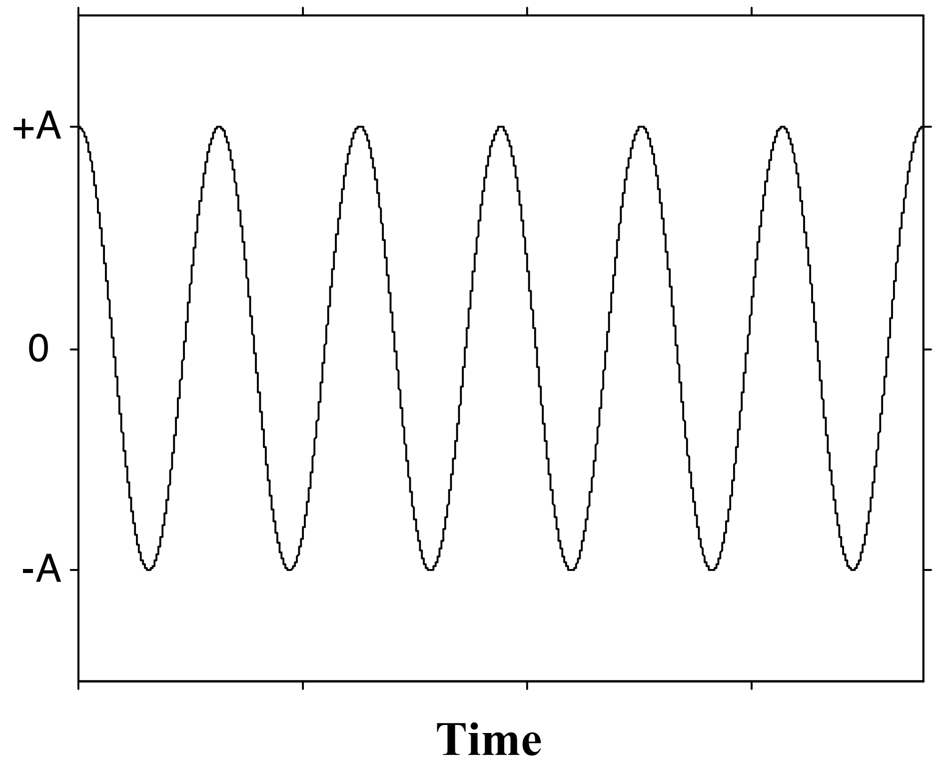


$f_s = 1/\Delta t$

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

sample rate (f_s) - frequency with which analog signal is sampled (samples per second)

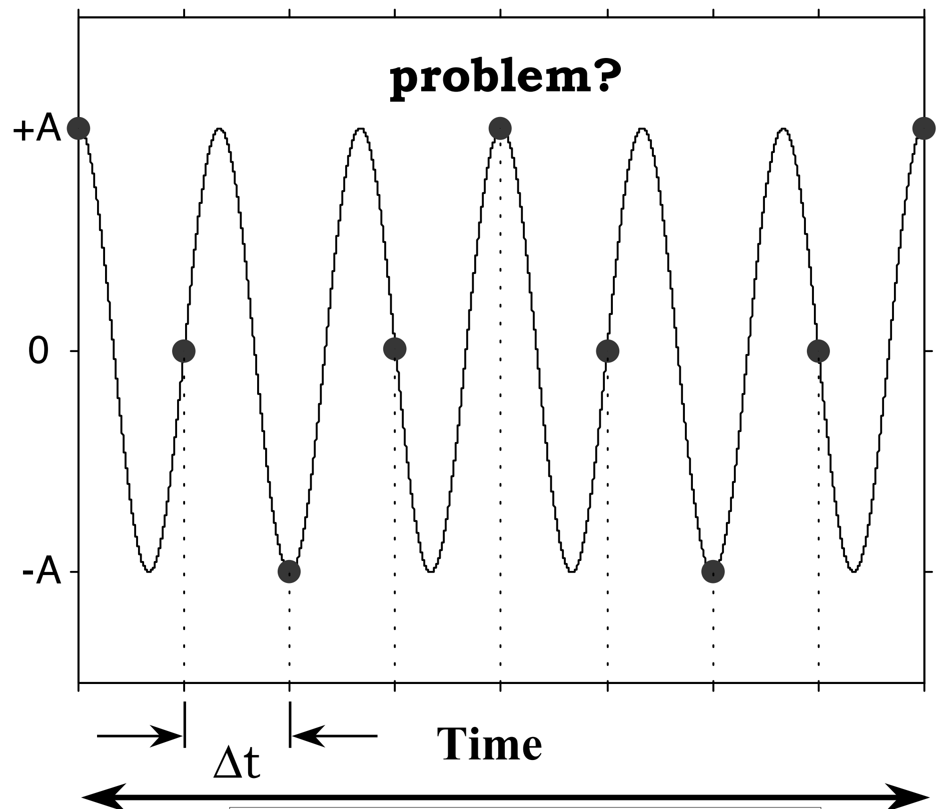
Sampling



harmless-looking sinusoid

Real World (Analog) Signal of Interest

Sampling



sample it

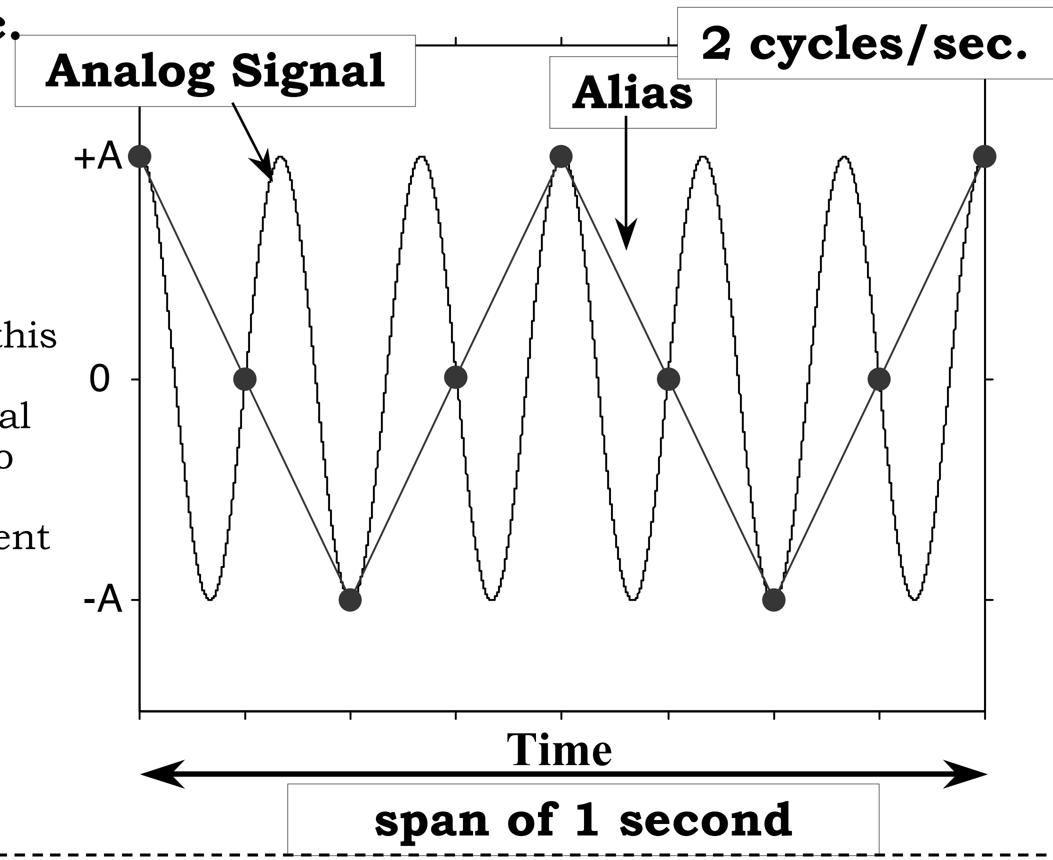
f_s = 8 samples/sec

span of 1 second

Discretized Signal

Sampling

6 cycles/sec.



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?

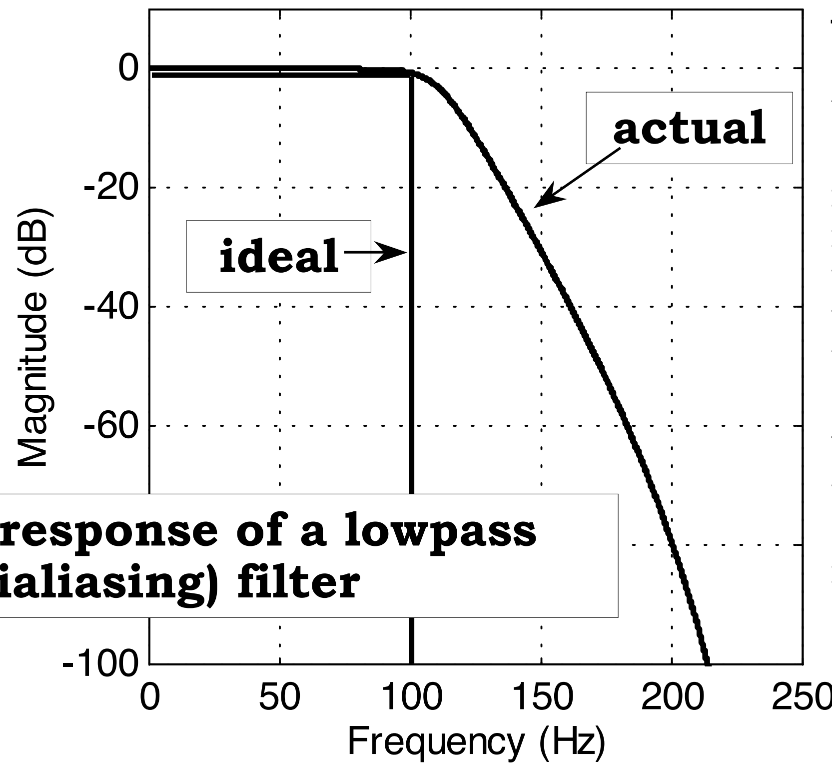
aliasing - high frequency signals manifested as low frequency signals

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



Frequency response of a lowpass (antialiasing) filter

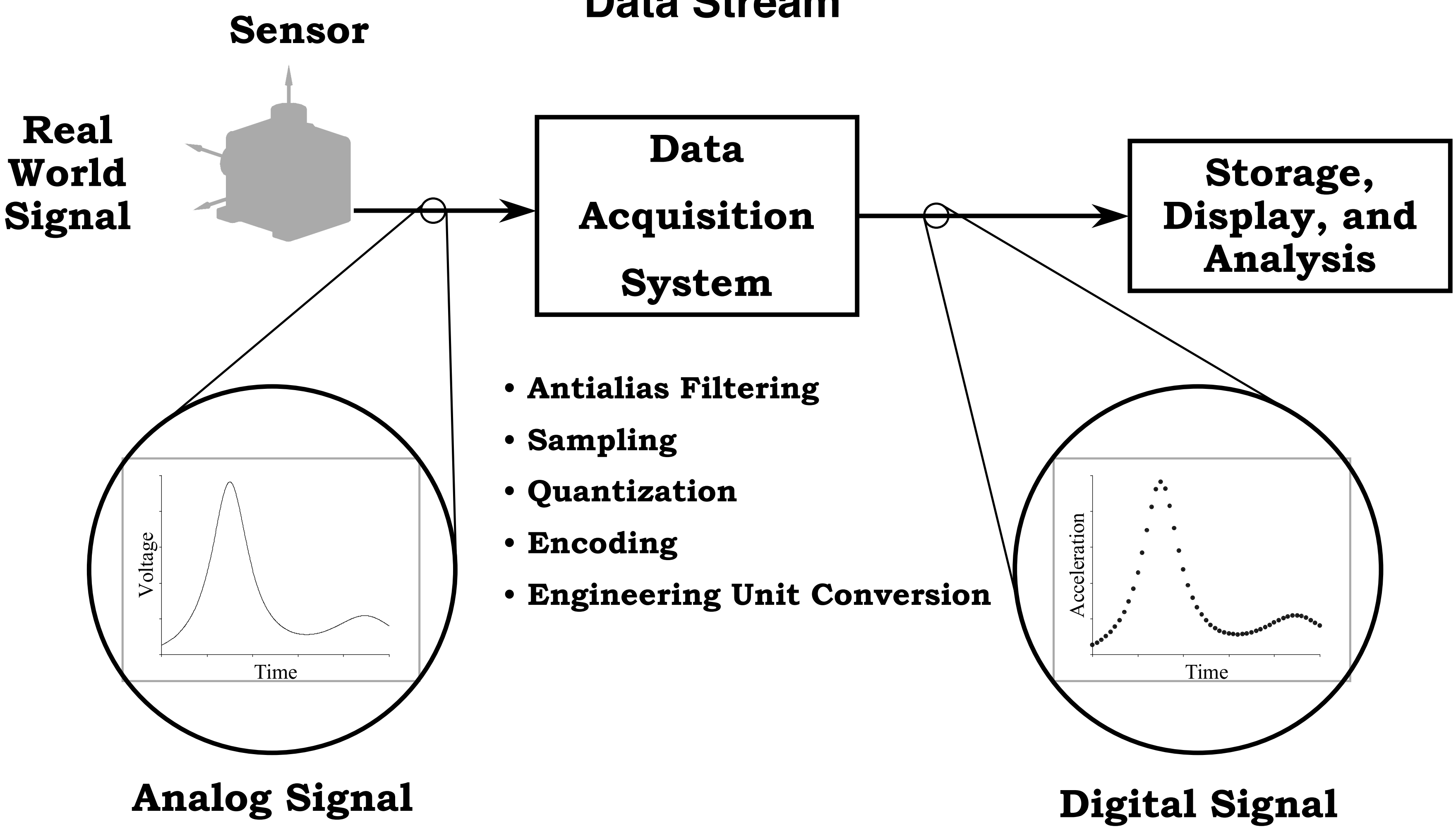
Why does cutoff, f_c, matter?

- 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.

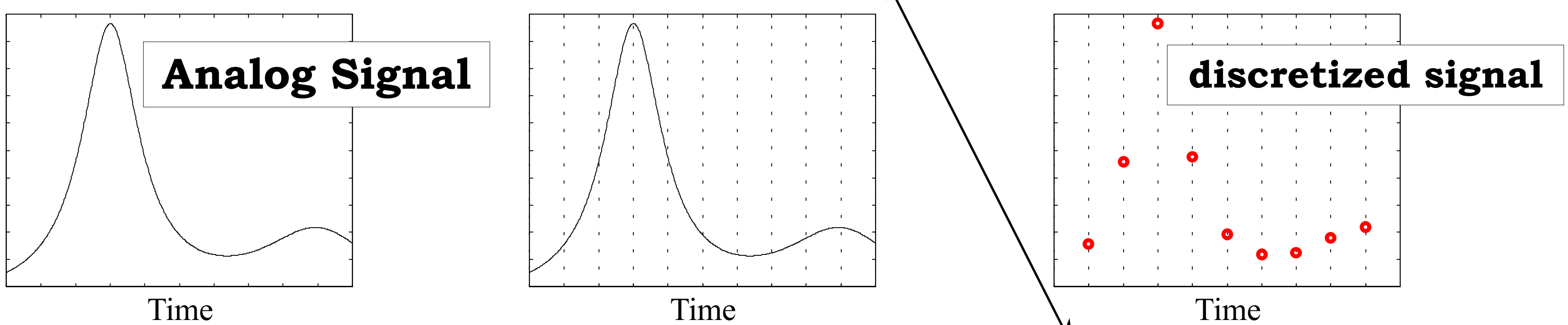
antialias filtering - lowpass (bandlimit) analog signal to reduce effects of aliasing

cutoff frequency (f_c) - highest frequency of interest

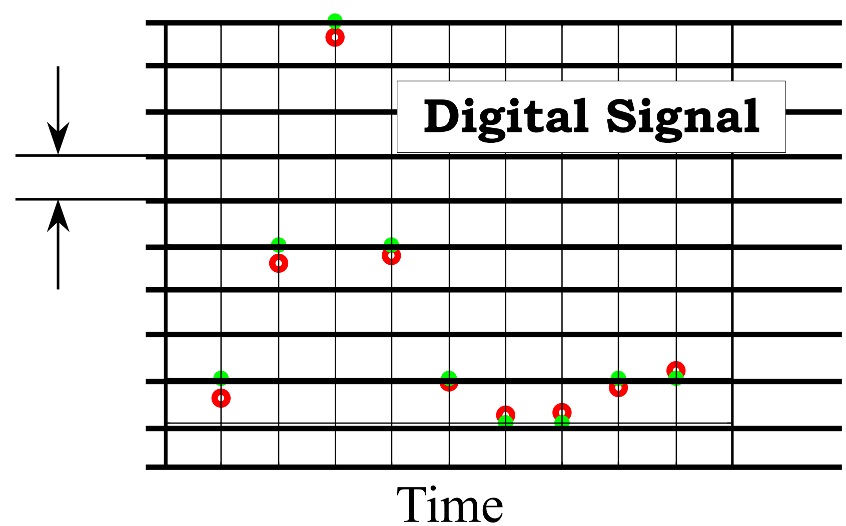
Data Stream


Sensor
Real World Signal
Data Acquisition System
Storage, Display, and Analysis
• Antialias Filtering
• Sampling
• Quantization
• Encoding
• Engineering Unit Conversion
Voltage
Time
Acceleration
Time
Analog Signal
Digital Signal

Quantization



digitization



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

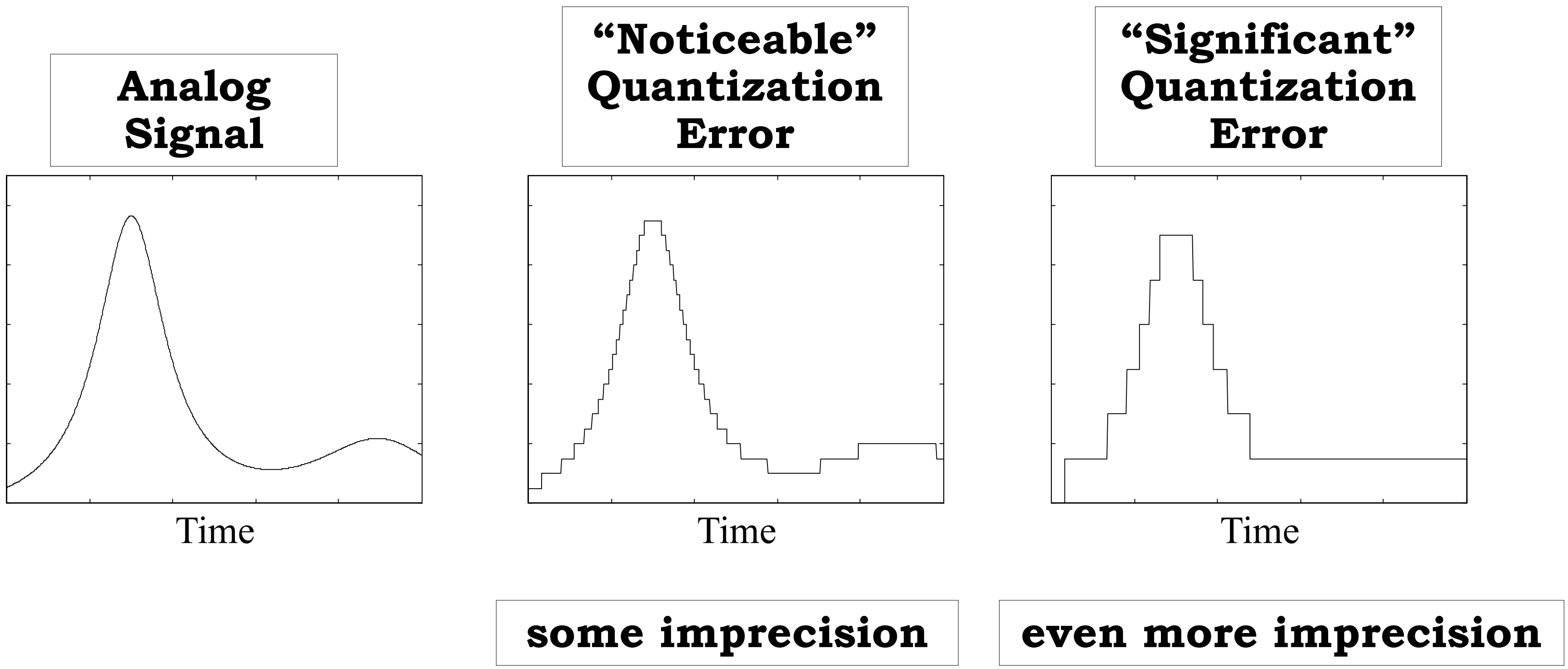
$$q = V_{fs}/(2^b-1)$$

b = # of bits

V_{fs} = full scale voltage

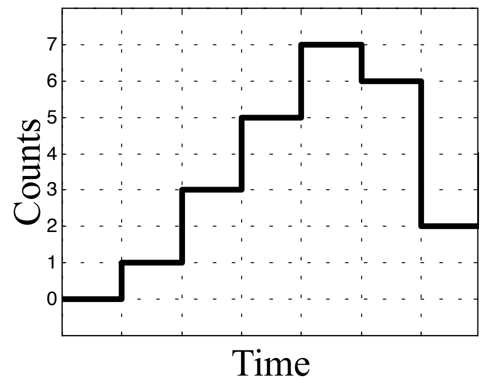
q = quantization level

Quantization



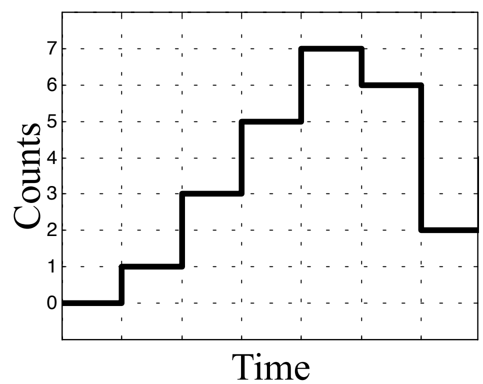
Encoding & Engineering Unit Conversion

- **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 $\longrightarrow$ leads to loss of high frequency information
2. Sampling
   - sample rate $\longleftarrow$ transmission, storage, and processing
   - discretization in time $\longrightarrow$ aliasing
3. Quantization
   - digitization of amplitude $\longrightarrow$ precision limited by number of bits
4. Encoding
5. Engineering Unit Conversion