Digital Signal Processing

EE 453 / CE 352

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What is a Signal?

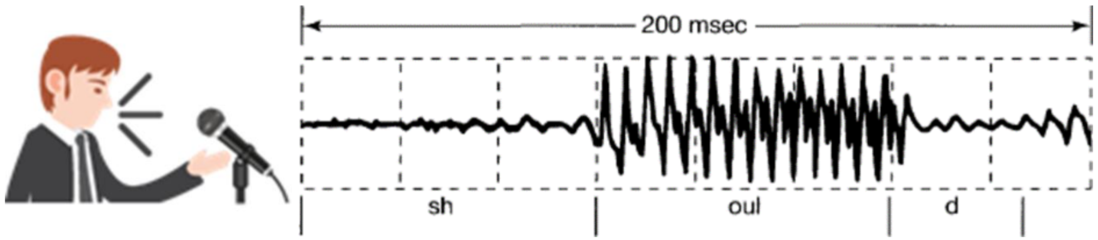
- A function of one or more independent variables.
- Contains information about the behavior/nature of some phenomenon.

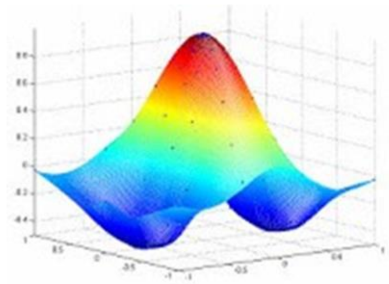
For a function f:

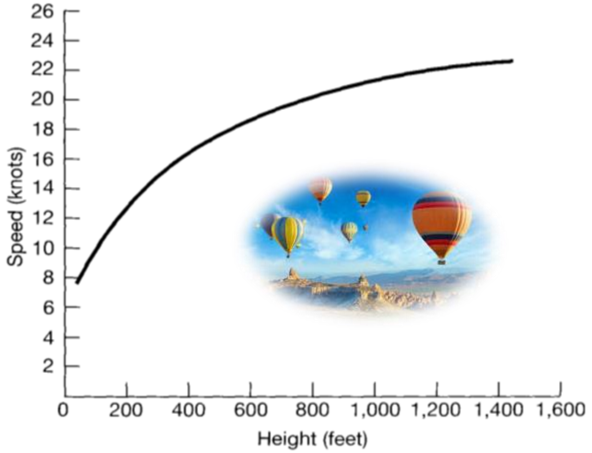
$$y = f(x_1, x_2, \ldots, x_n)$$

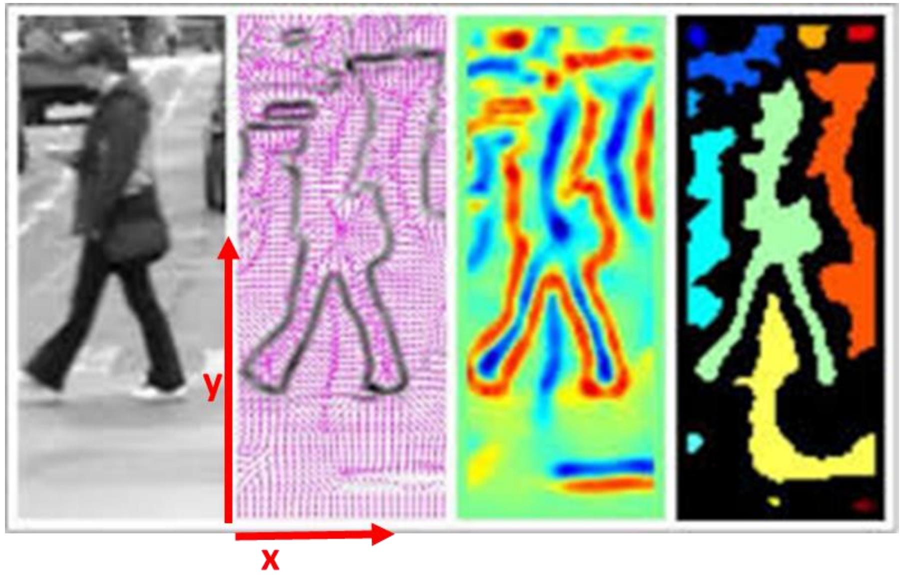
Each of $x_1, x_2, \ldots, x_n$ are called *independent variables*.
y is a *dependent variable.*

What is a Signal?



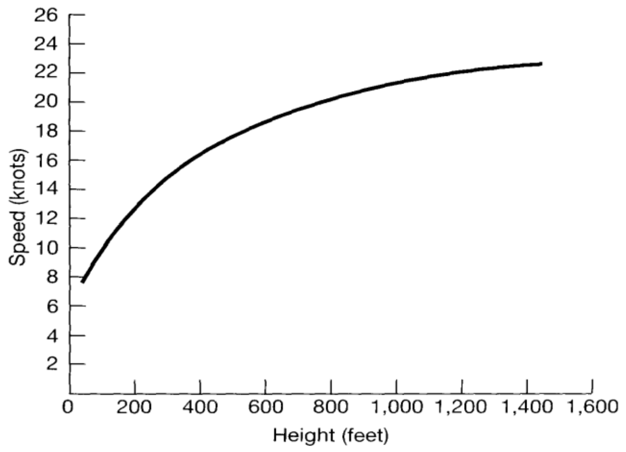




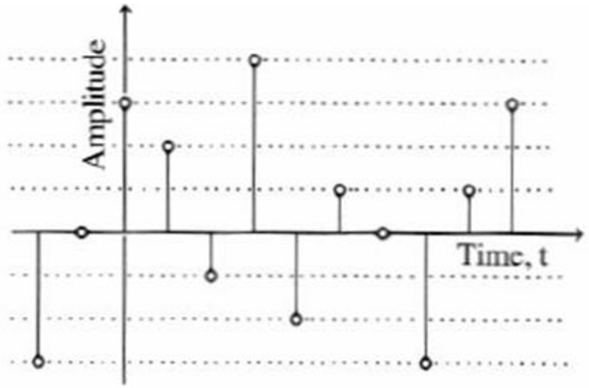


What is a Digital Signal?

- Analog Signal
  - Continuous-Time $\{x(t)\}$
    AND
  - Continuous-Valued

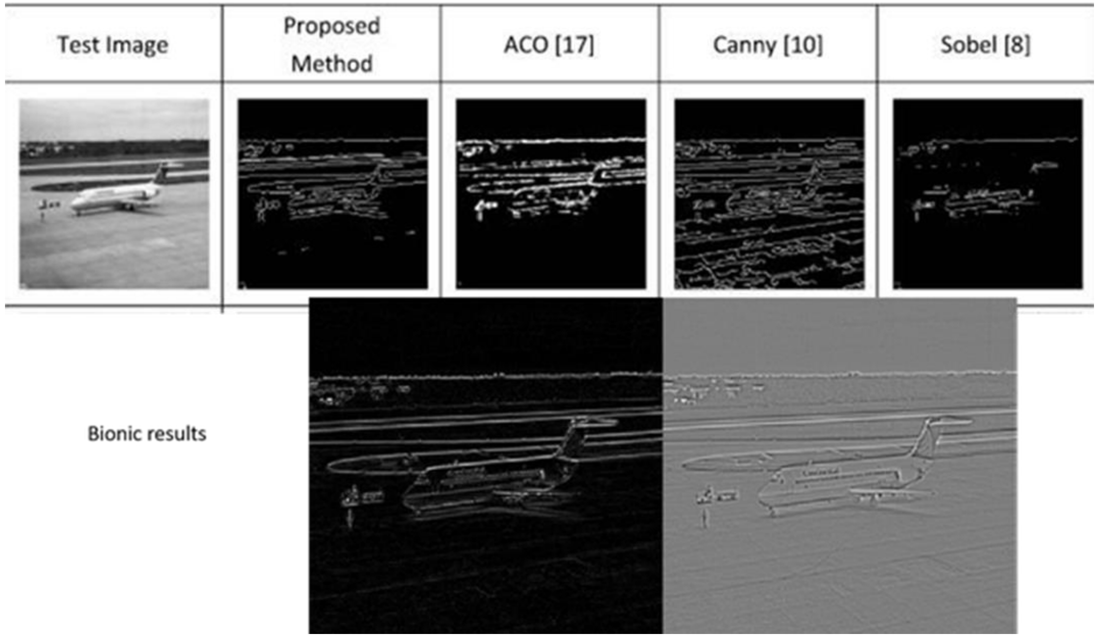


- Digital Signal
  - Discrete-Time $\{x[n]\}$
    AND
  - Discrete Valued



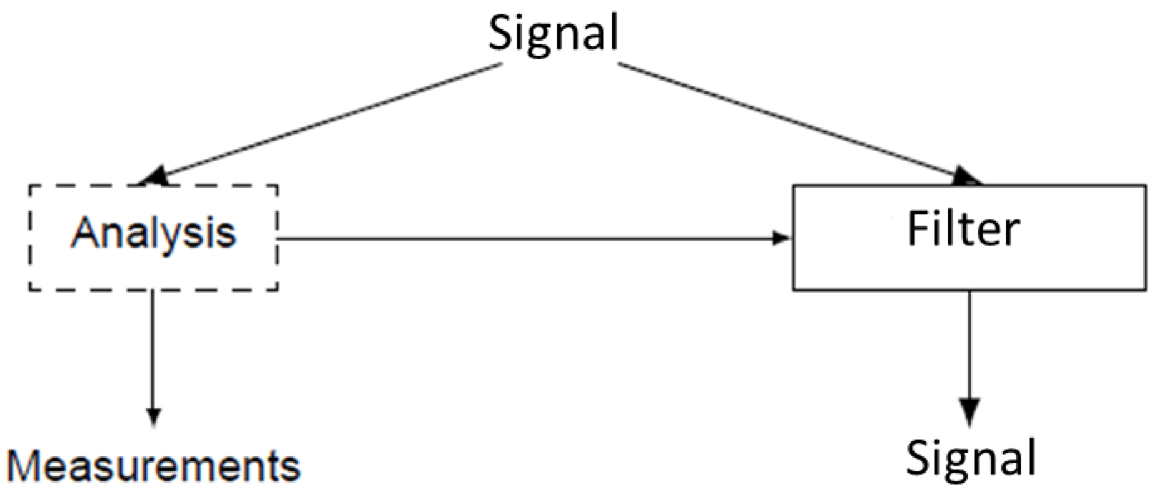
What is Signal Processing?

- Operations designed for:
  - Extracting useful information from a signal.
  - Transforming or enhancing the useful information in a signal.
- Examples
  - Speech recognition.
  - Speaker verification.
  - Target detection.
  - Image enhancement.
  - Noise removal



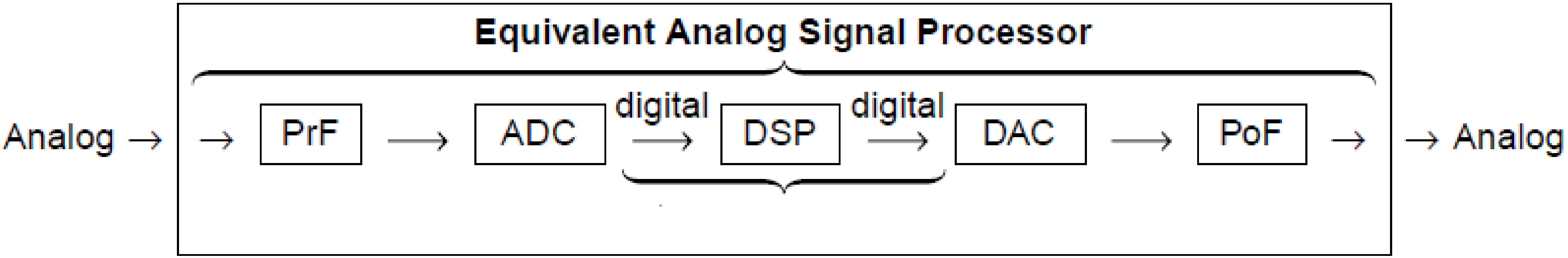
What is Signal Processing?

- Operations on signal that are designed for:
  - Extracting useful information from a signal (Signal Analysis).
  - Transforming or enhancing the useful information in a signal (Signal Filtering).

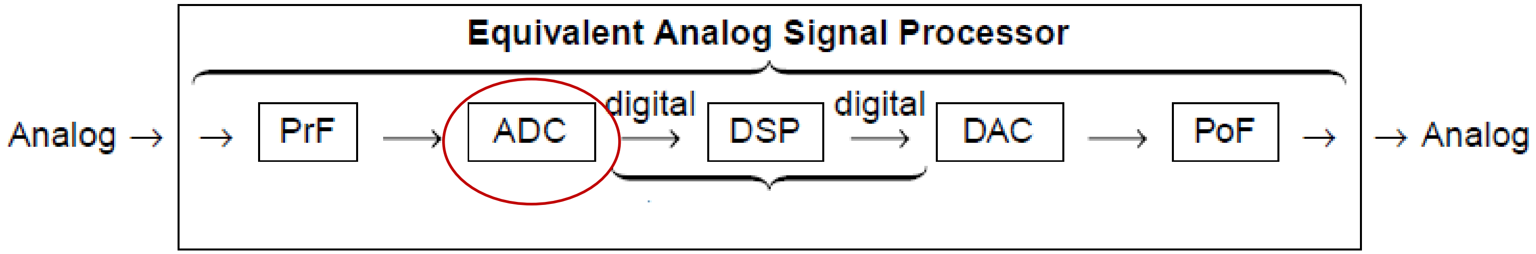


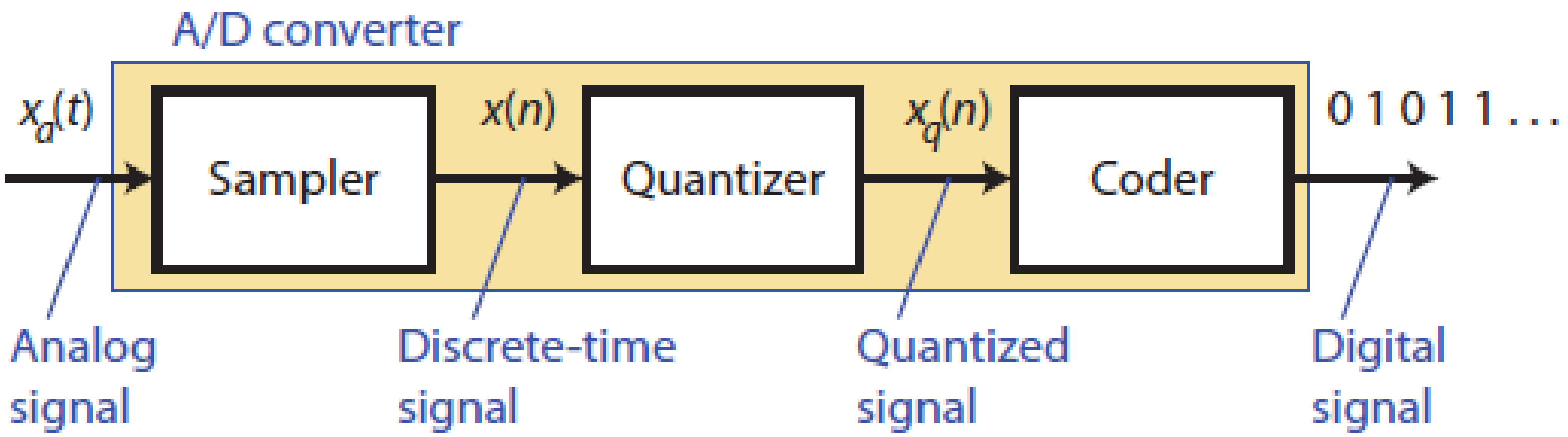
Signal Processing: Analog vs Digital

Analog signal: $x_a(t) \longrightarrow \boxed{\text{Analog signal processor}} \longrightarrow y_a(t)$:Analog signal

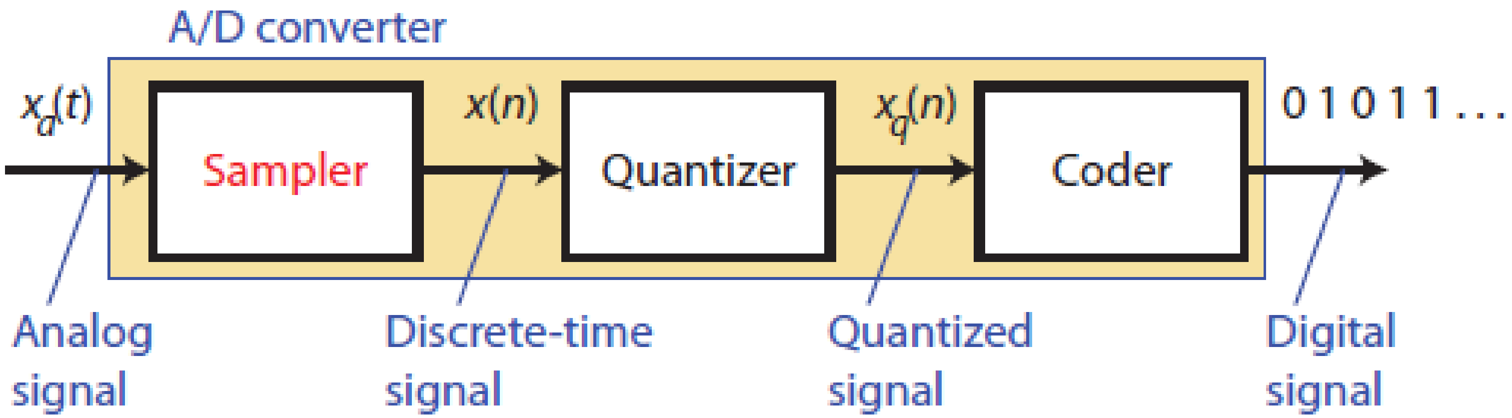


Digital Signal Processing



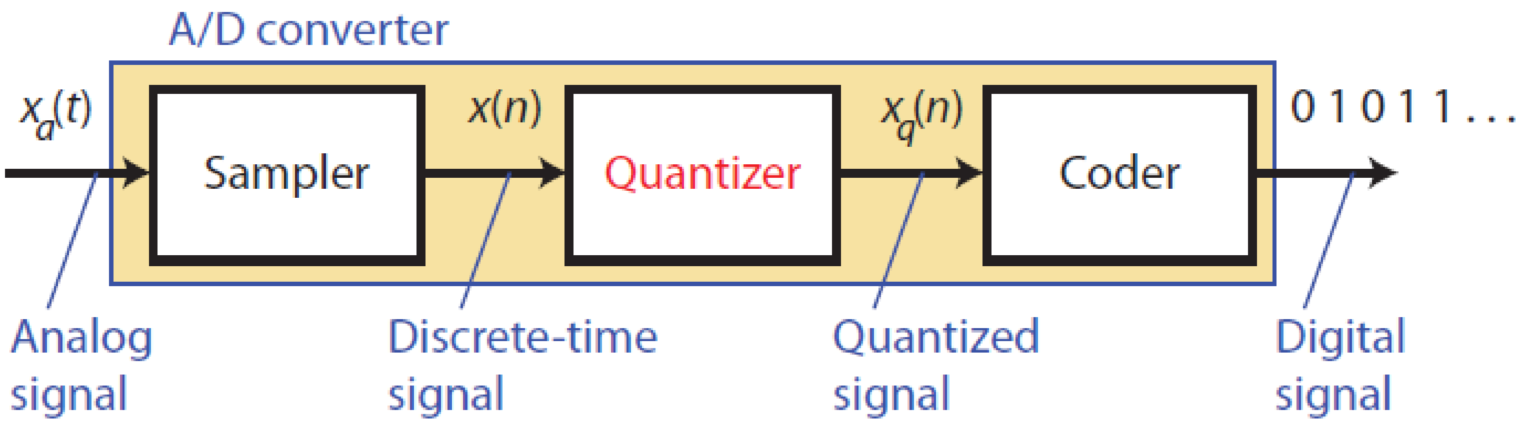


Analog-to-Digital Conversion



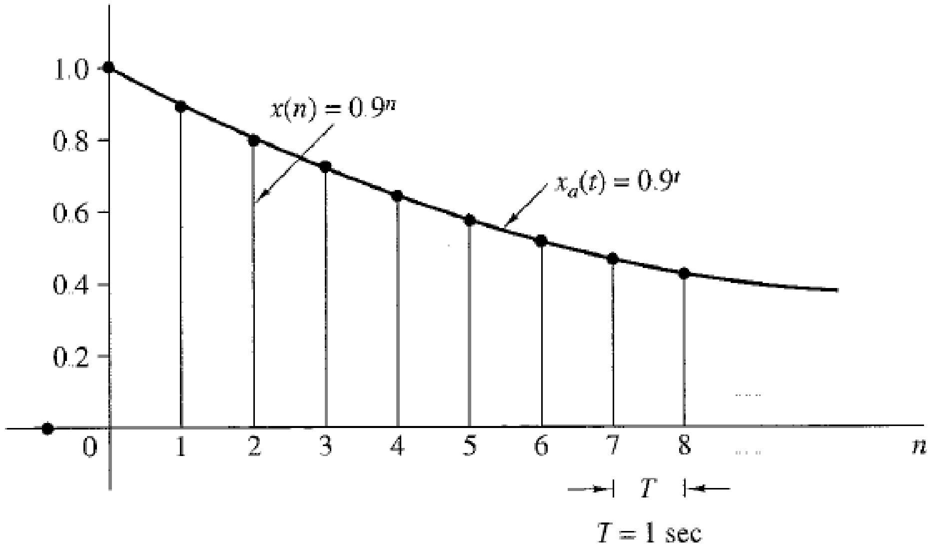
- Sampling
  - Conversion from continuous-time to discrete-time by taking "samples" at discrete time instants.
  - E.g., uniform sampling: $x(n) = x_a(n\mathrm{T})$
    - Where T is the sampling period and n ∈ Z

Analog-to-Digital Conversion

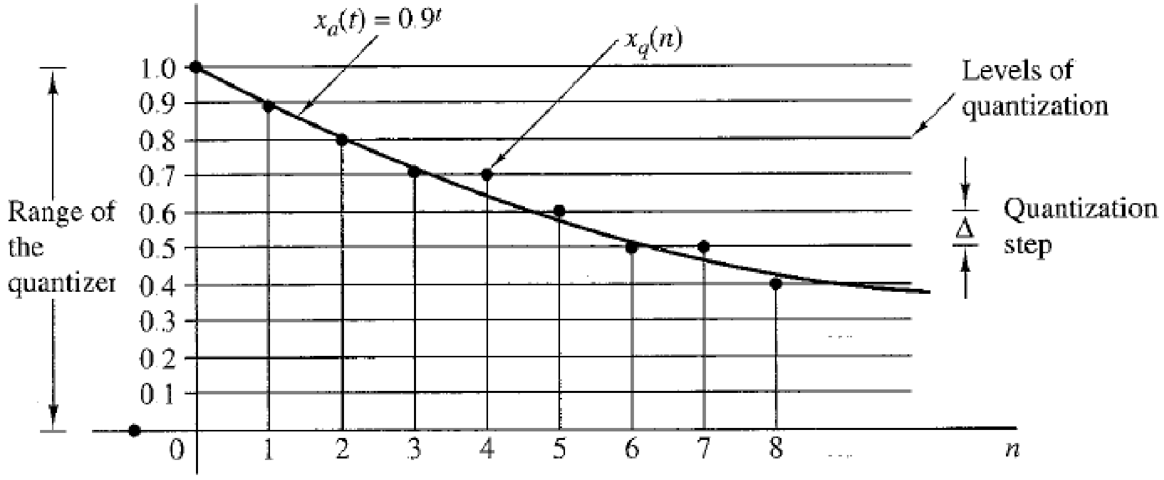


- Quantization
  - Conversion from discrete-time, continuous-valued signal to discrete-time, discrete-valued signal by taking "samples" at discrete time instants.
  - Quantization error: $e_q(n) = x_q(n) - x(n)$ for all n ∈ Z

Analog-to-Digital Conversion



(a)

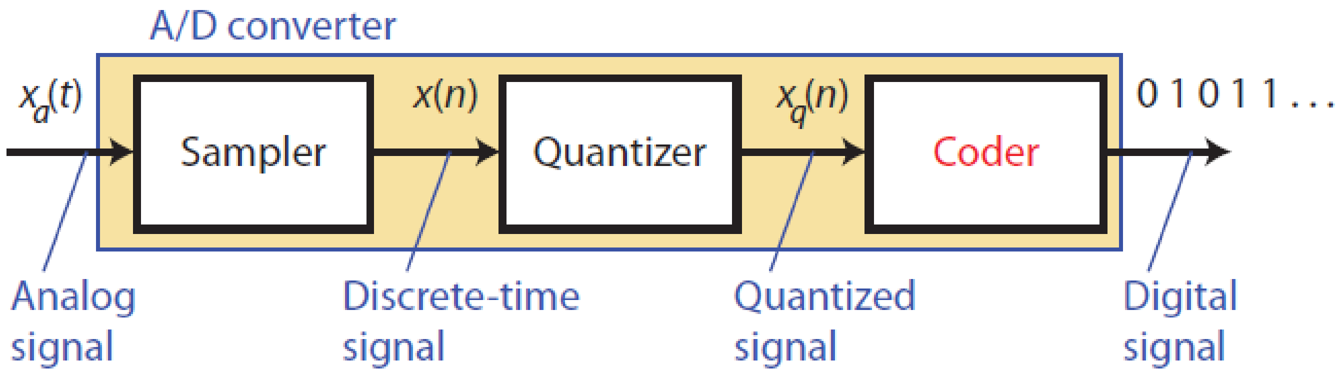


(b)

Analog-to-Digital Conversion

n	$x(n)$ Discrete-time signal	$x_q(n)$ (Truncation)	$x_q(n)$ (Rounding)	$e_q(n) = x_q(n) - x(n)$ (Rounding)
0	1	1.0	1.0	0.0
1	0.9	0.9	0.9	0.0
2	0.81	0.8	0.8	−0.01
3	0.729	0.7	0.7	−0.029
4	0.6561	0.6	0.7	0.0439
5	0.59049	0.5	0.6	0.00951
6	0.531441	0.5	0.5	−0.031441
7	0.4782969	0.4	0.5	0.0217031
8	0.43046721	0.4	0.4	−0.03046721
9	0.387420489	0.3	0.4	0.012579511

Analog-to-Digital Conversion

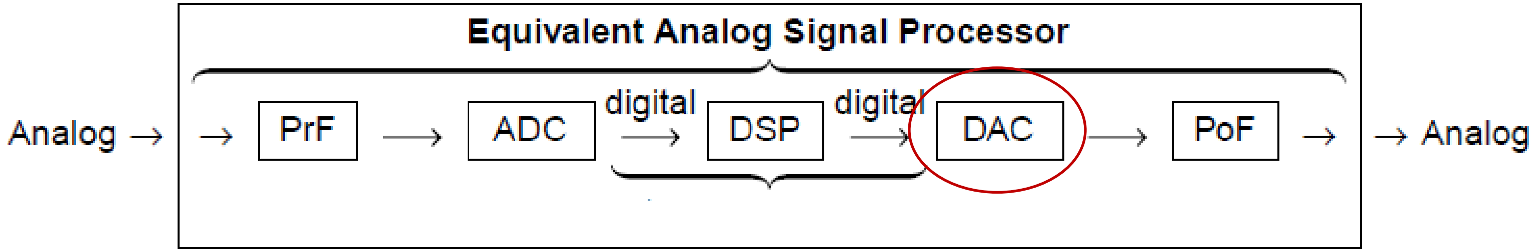


- Coding:
  - Representation of each discrete-value $x_q(n)$ by a *b*-bit binary sequence
  - If for any n, $x_q(n) \in \{0, 1, \ldots, 6, 7\}$, then the coder may use the following mapping to code the quantized amplitude:

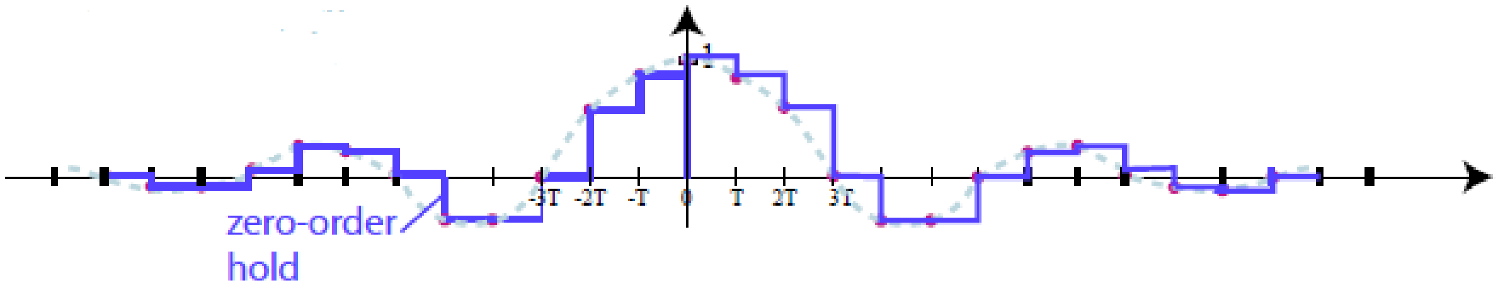
Example coder:

0	000	4	100
1	001	5	101
2	010	6	110
3	011	7	111

Digital-to-Analog Conversion



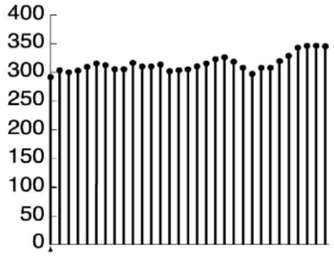
- Common Interpolation Approaches:
  - Zero-order hold, linear interpolation, higher-order interpolation.
  - In practice, “cheap” interpolation along with a smoothing filter is employed.



DSP: Without A/D Conversion

- Digital signal processing is not always applied in conjunction with A/D conversion.

- For Example: Stock analysis computer program



Advantages of Digital Signal Processing?

- Flexibility in reconfiguration
- Accuracy
  - Tolerances in analog circuit components
  - A digital system provides much better control of accuracy requirements by choosing appropriate A/D converter and the digital signal processor.
- More sophisticated signal processing algorithms
  - Difficult to perform precise mathematical operations in analog form (through active and passive circuit components).
- Cost
- Size/Weight

Limitations of Digital Signal Processing?

- Signals having extremely wide bandwidth require fast sampling-rate A/D converters and digital signal processors.
  - Example: Terahertz communication and sensing

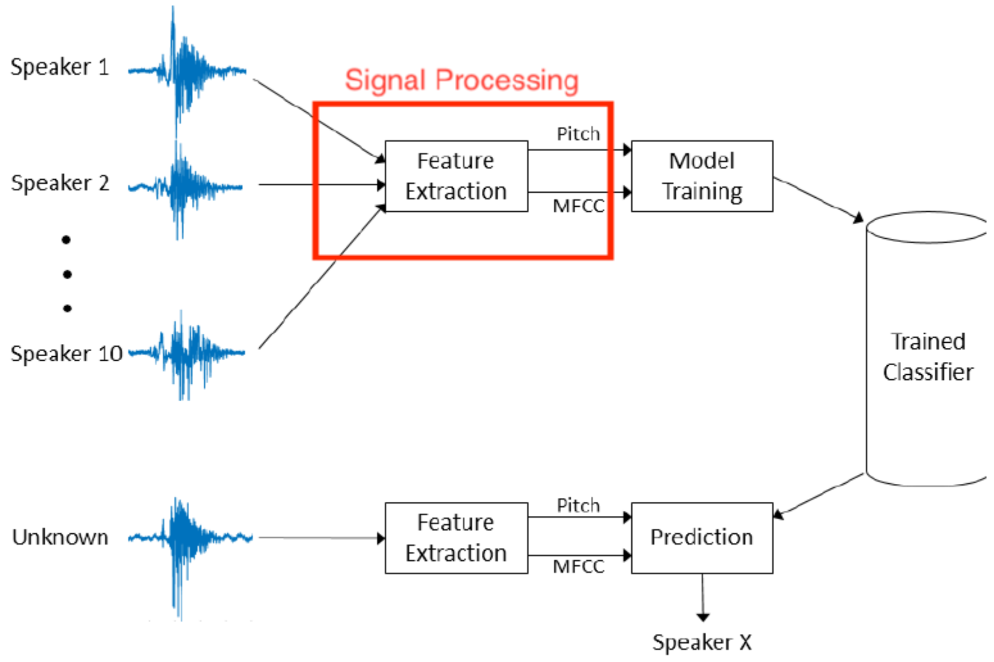
- Digital signals take on values from a finite set of possible values, dictated by the word length (8, 16, 32 bit) of a digital computer, which causes complications in the analysis.
  - Finite-precision arithmetic effect
  - To avoid these complications, we initially neglect the quantized nature of digital signals and consider them as discrete time, continuous valued signals.

Application Domains of DSP

- Speech Processing
- Image and Video Processing
- Telecommunication
- Biomedical Signal Processing
- Financial Signal Processing

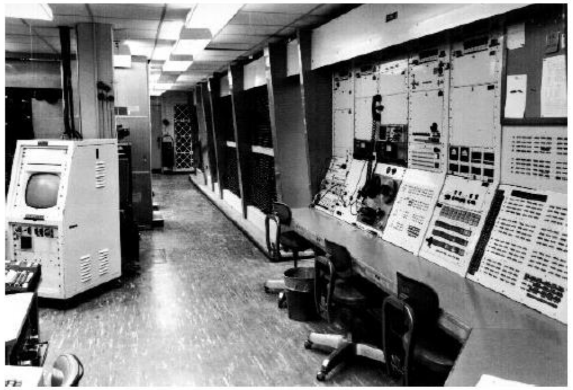
DSP and Machine Learning

- Signal processing and machine learning techniques work together in many applications.
  - Example: Speaker Identification



DSP Landscape: Three “Axes”

- Theory/algorithms
  - Fourier Analysis
  - Z-Transform
  - Filter Design
- Application domains
  - Speech processing
  - Image/video processing
  - Financial signal processing
- Implementation platforms
  - General purpose computers
  - Microcontrollers
  - Digital signal processors
  - FPGAs



The TX-2 Computer, Circa 1967