Introduction to digital signal processing

- What is a signal?
- Continuous-time and discrete-time signals
- Types of signals
- Signals
- Multichannel signals
- Multidimensional signal
- Digital Signal Processing
- Digital signal processing and analog signal processing
- Digital signal processing – example
- Signals convey information
- Purpose of digital signal processing

Introduction to digital signal processing

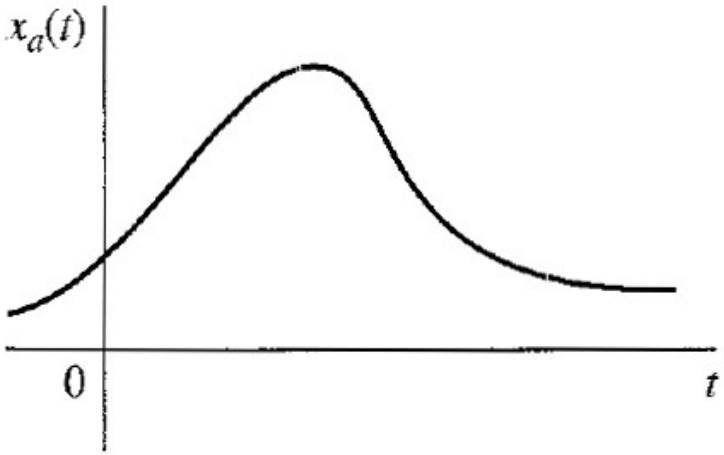
- Signal filtering
- Digital signal processing is everywhere
- Pros and Cons of digital signal processing

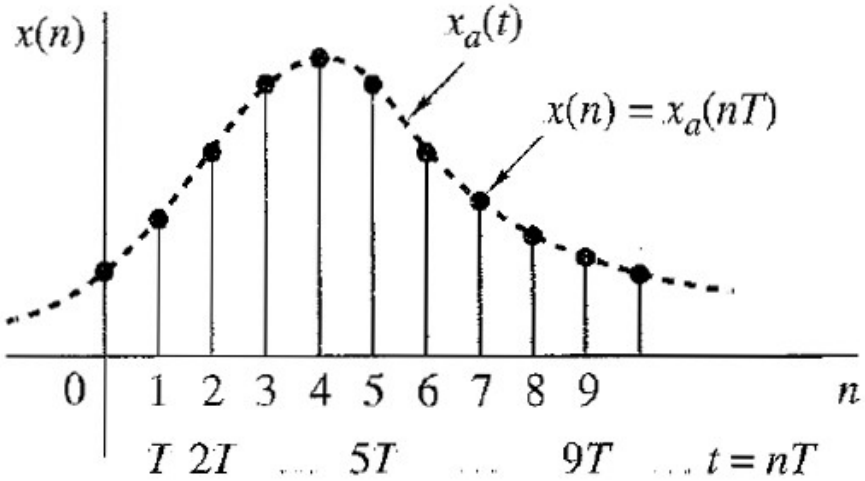
What is a signal?

- What is a signal?
  - A signal is anything you can hear, see, observe, or measure (sound, music, speech, light, radio, TV, radar, sonar, temperature, ECG, EEG, ...)
  - A signal is a function of one (time) or several variables (spatial coordinates) that carries useful information

Continuous-time and discrete-time signals

- Sampling a continuous-time signal, continuous signal, $x_a(t)$
- Discrete-time signal, discrete signal, $x_a(nT) \rightarrow x(n)$
  (also denoted as $x[n]$)





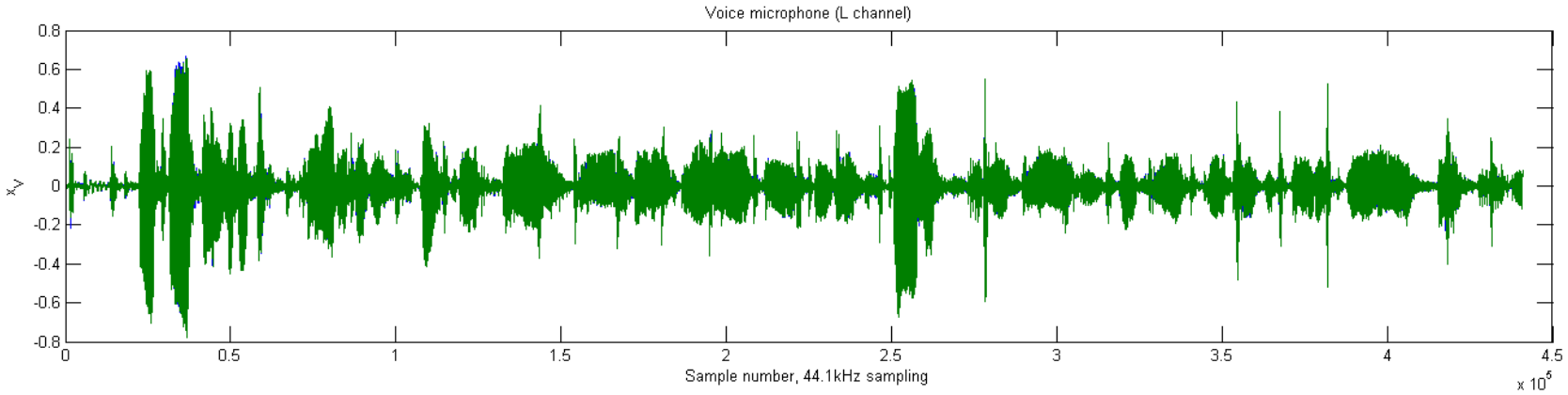
[Proakis, Manolakis]

Types of signals

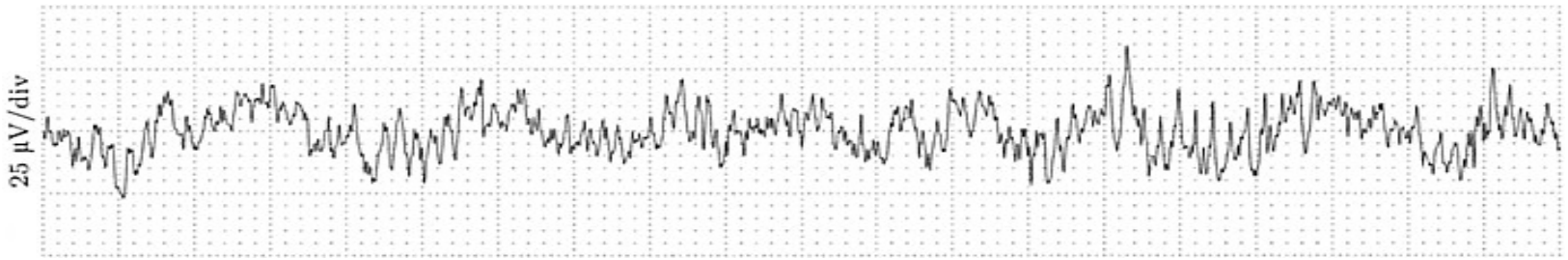
- Types of signals (according to dimensionality)
  - One-dimensional signals depend on a single variable such as *time*
  - Multichannel signals are simultaneous, taken from different points of a system and depend on a single variable such as *time*
  - Multidimensional signals (images) depend on several variables such as *spatial coordinates*, and may depend also on time

Signals

- One-dimensional signals
  - Voice (speech and keystrokes), air pressure variation as a function of time



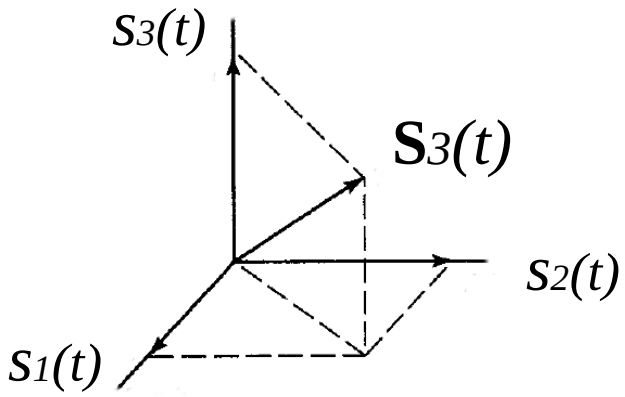
  - An electroencephalogram



Multichannel signals

- Multichannel signals
- Three-channel electrocardiogram

$$\mathbf{s}_3(t) = \begin{bmatrix} s_1(t) \\ s_2(t) \\ s_3(t) \end{bmatrix}$$



Multidimensional signals

- Multidimensional signals
  - Images, 2-D: *f(x, y)* depend on several variables such as spatial coordinates *(x, y)*

$$f(x, y) = \begin{bmatrix} f(0,0) & f(0,1) & \cdots & f(0, N-1) \\ f(1,0) & f(1,1) & \cdots & f(1, N-1) \\ \vdots & \vdots & & \vdots \\ f(M-1,0) & f(M-1,1) & \cdots & f(M-1, N-1) \end{bmatrix}$$

Multidimensional signals

- Multidimensional signals

  - Color images, 3 X 2-D: $\{r(x, y), g(x, y), b(x,y)\}$

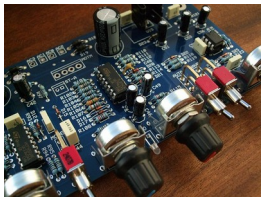
  - Video, 3 X 3-D: $\{r(x, y, t), g(x, y, t), b(x, y, t)\}$

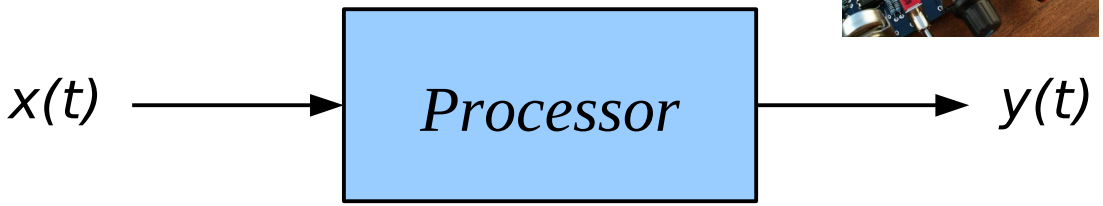
Digital Signal Processing

- Digital Signal Processing (DSP) - processing of discrete (Digital) Signals (sequences of numbers) using different procedures and algorithms

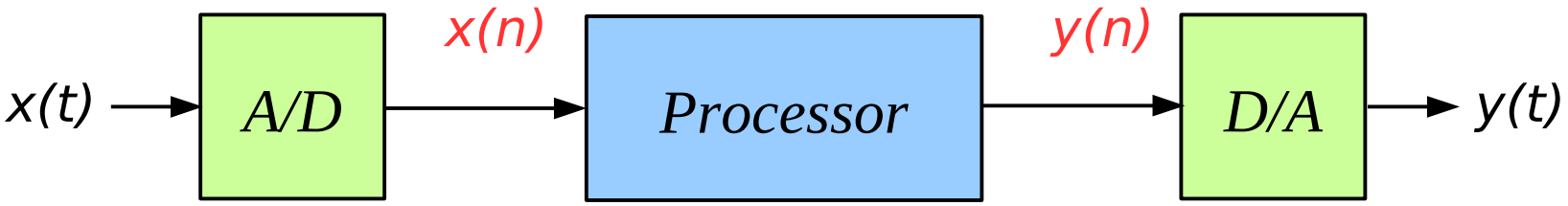
Digital signal processing and analog signal processing

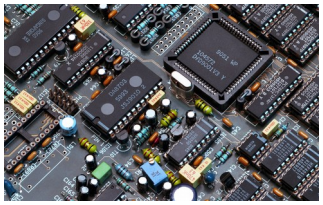
- Conventional analog signal processing:





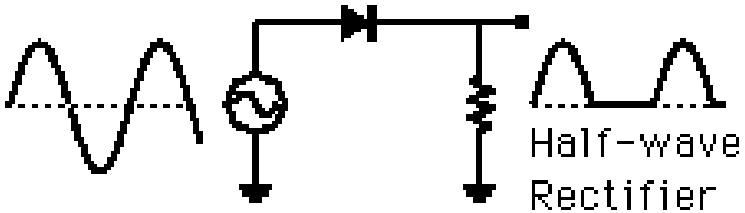
- Digital signal processing system:





Digital signal processing and analog signal processing

- Conventional analog signal processing (diode):



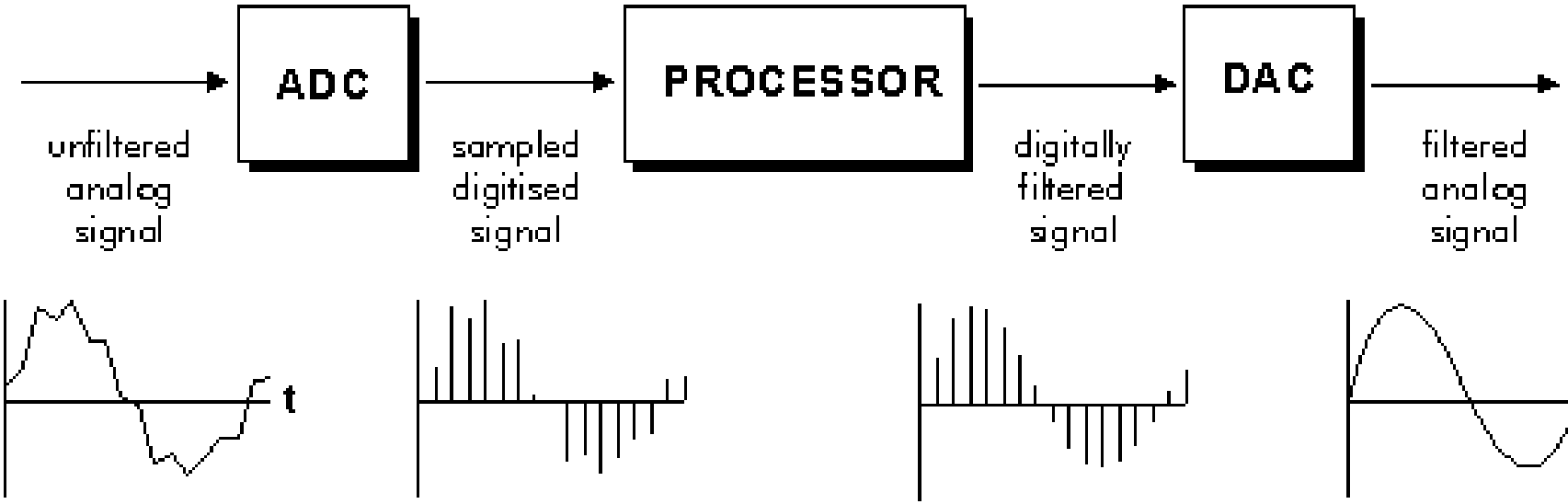
- Digital signal processing (A/D, DSP program, D/A):

```
If (input > 0) then
    output = input;
else
    output = 0;
```

(*input* = *x(n)*, *output* = *y(n)*)

Digital signal processing - example

- Example, rejecting high-frequency noise



Signals convey information

- A signal conveys the information of interest as well as irrelevant information (noise, artifacts) which need to be rejected
- What constitutes information of interest depends on the specific application
  - Voice contains information about what is spoken and who is speaking (speech and speaker recognition)
  - ECG contains information about sickness (diagnosis)
  - Radar signal contains information about the object (navigation, defend from attack)
  - Biometric images contain information about authentication (face images, finger prints, iris recognition)
- It is not possible to add information to a given signal, only to eliminate it

Purpose of digital signal processing

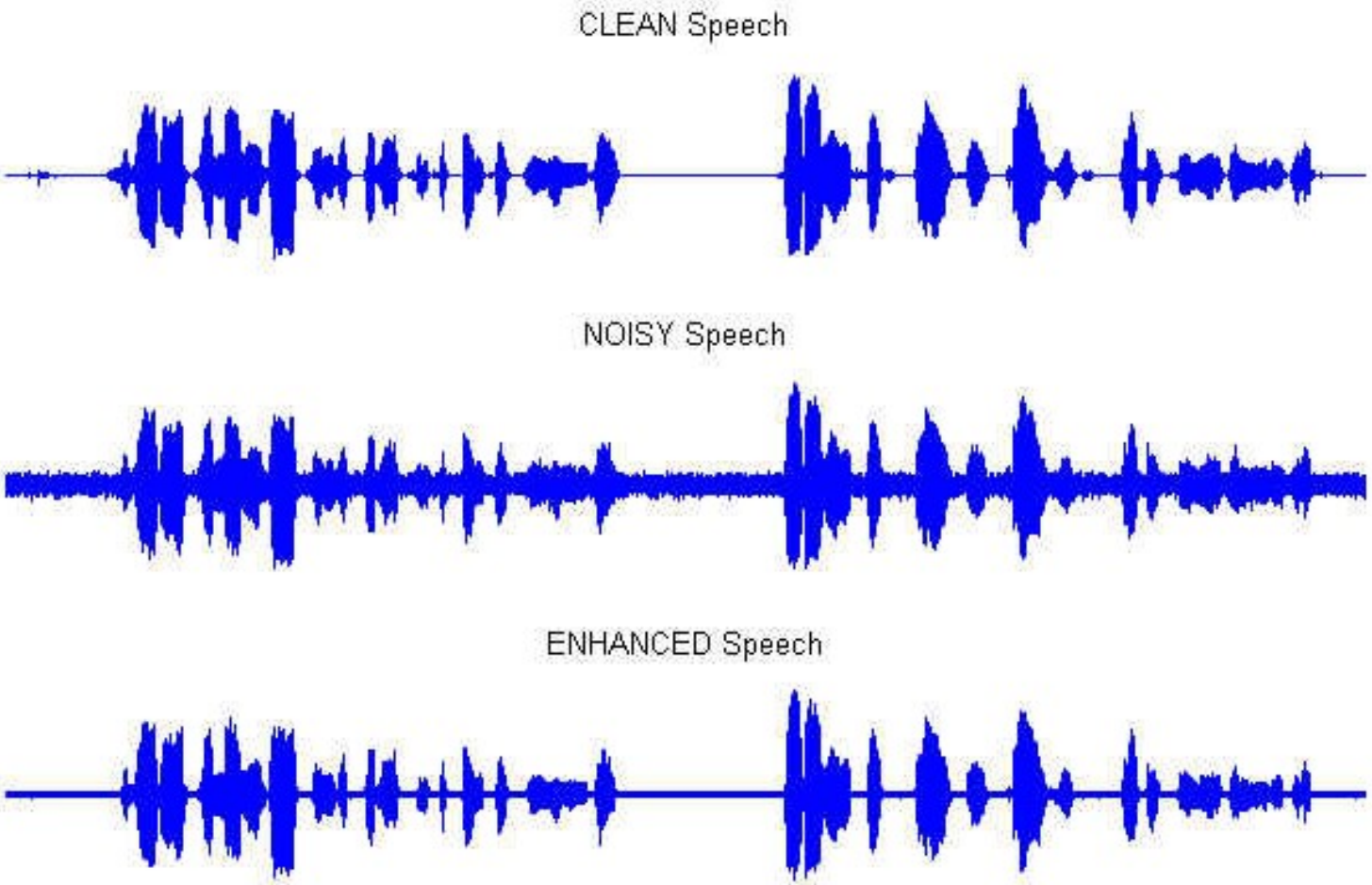
- The purpose of *digital signal processing* (*signal filtering*) is to selectively eliminate irrelevant information from a signal, or, to make the information of interest within a signal more easily accessible to a computer system or a human observer

Purpose of digital signal processing

- Signal filtering – to improve the signal (to eliminate unwanted noise; to separate frequency bands – sound, music, ECG, EEG)
- Signal filtering – to extract properties or features of signal (time domain analysis - extraction of events: ECG, EEG; spectral analysis – sound, music, EEG; detection – radar, echo; pattern recognition – text, voice, images, video)
- Modes
  - Real-time analysis (*simultaneously receive samples of input signal and instantaneously calculate samples of output signal*)
  - Off-line analysis (*previously stored signal, no time limitations*)

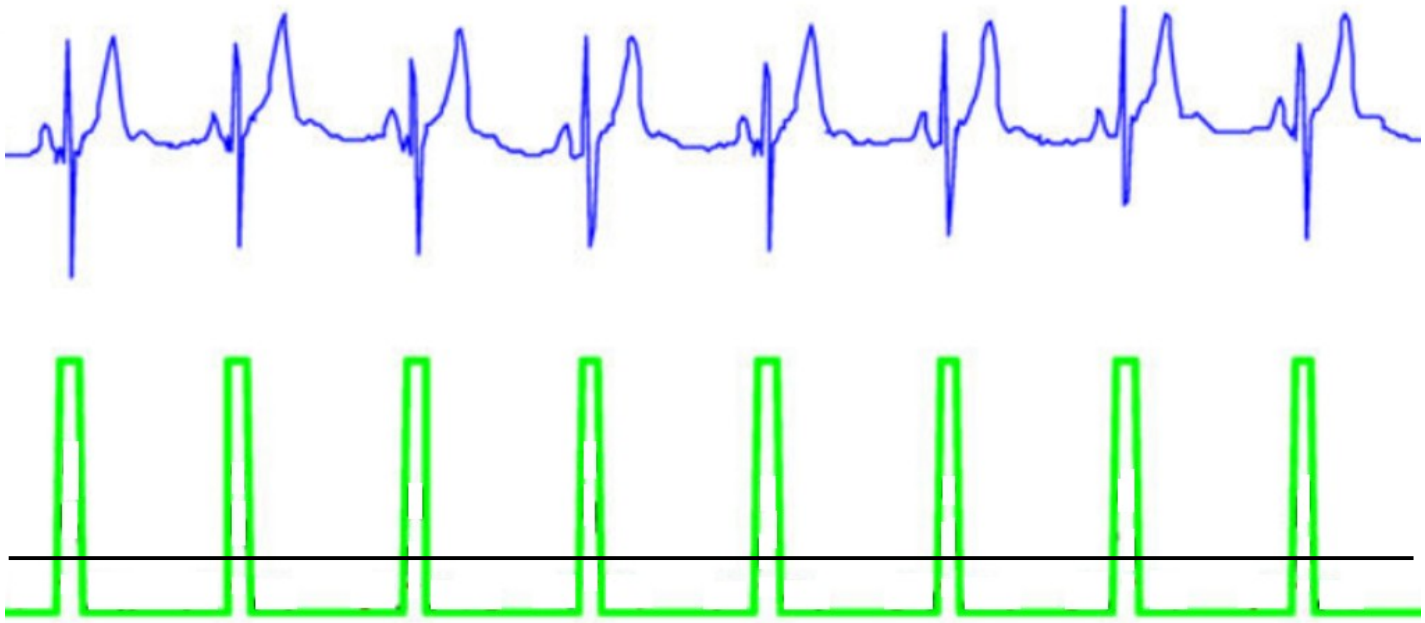
Signal filtering

- Improving signals (eliminate noise)



Signal filtering

- Extracting properties or features of signals (extract events)



Digital signal processing is everywhere

- Sound (synthesis, special effects, recognition, compression, enhancement, dictation, text-to-speech, cell phones, MP3 players, ...)
- Image/Video (JPEG, special effects, video conferencing, ...)
- Brain computer interface (Electroencephalogram, ...)
- Automotive (ABS, GPS, cruise control, parking, motor control, ...)
- Medical (MRI, CT, Electrocardiogram, Electromyogram, ...)
- Mechanical (process control, ...)
- Communication (modulation, coding, detection, dial-up modem, DSL modem, satellite receiver, ...)
- Military (radar, sonar, space photographs, remote sensing, remote control, ...)

Pros and Cons of digital signal processing

- Pros
  - Accuracy can be controlled by choosing word length
  - Duplicability (repeatability)
  - Stability
  - Use of a general computer (flexibility, software implementations)
  - Non-linear and time-varying operations are easier to implement
  - Digital storage is cheap
  - Digital information can be encrypted for security
  - Low ratio price/performance

Pros and Cons of digital signal processing

- Cons
  - Sampling causes loss of information
  - Limitations of A/D and D/A (speed, price)
  - Quantization and round-off errors (length of word)
  - Delay