Computação Visual e Multimédia

10504: Mestrado em Engenharia Informática

Chap. 1 — Digital Signal Processing: Basics

Module Introduction

What is a signal?

Traditional definition

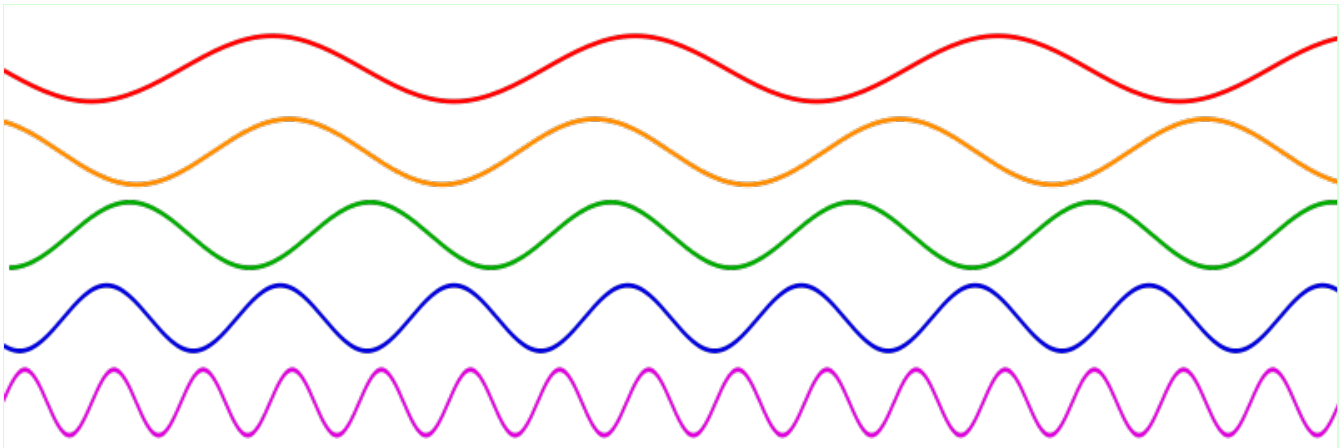
– A signal is a quantity that changes over time and/or in space.

Examples:

– Sound: *f*(t)

– Image: *f*(x,y)

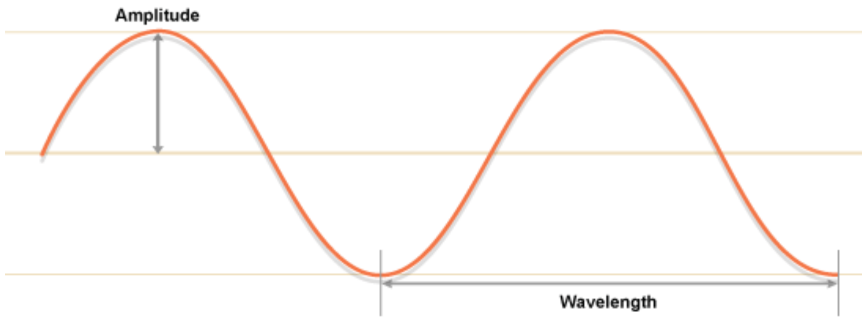
– Video: *f*(x,y,t)



Sinusoidal waves of various frequencies; the bottom waves have higher frequencies than those above. The horizontal axis represents time.

http://en.wikipedia.org/wiki/Frequency

Amplitude, wavelength, frequency, velocity, period

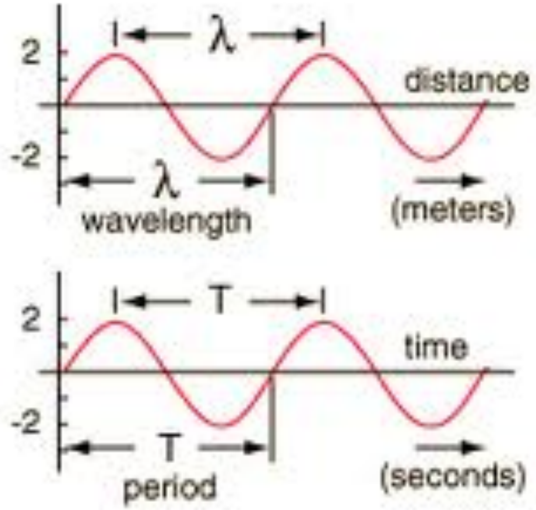


Amplitude

- The amplitude of a wave is its maximum disturbance (height) from its undisturbed position.

Wavelength (λ)

- Distance between homologous points in the adjacent cycles of a waveform signal.



Frequency (f): $f = v/\lambda$

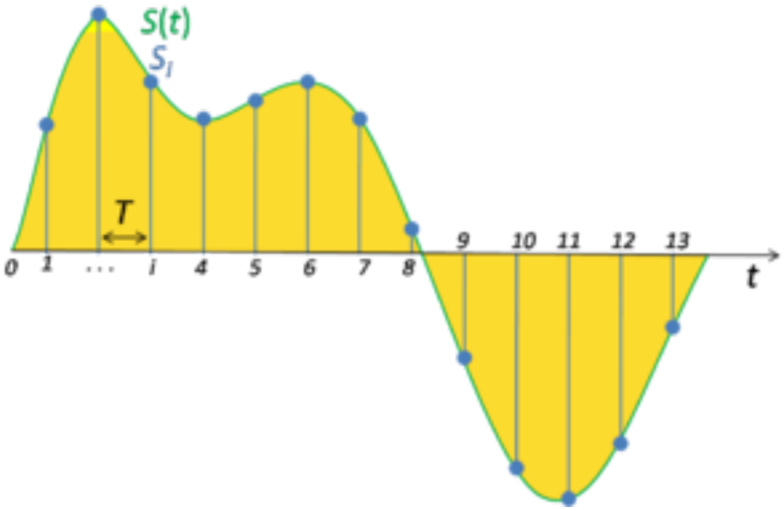
- Number of waves produced by a source per second.
- v stands for the velocity of the wave.

Period (t): $f = 1/t$

- Time taken by a wave to travel a wavelength, i.e., the duration of a cycle.

http://www.bbc.co.uk/schools/gcsebitesize/science/aqa/radiation/anintroductiontowavesrev2.shtml

Analogical vs. Digital Signals



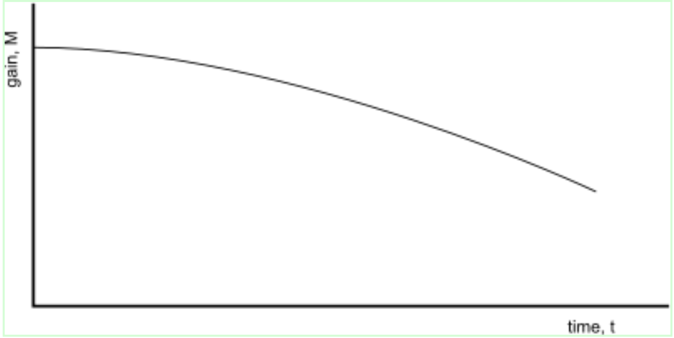
Analogical signal:

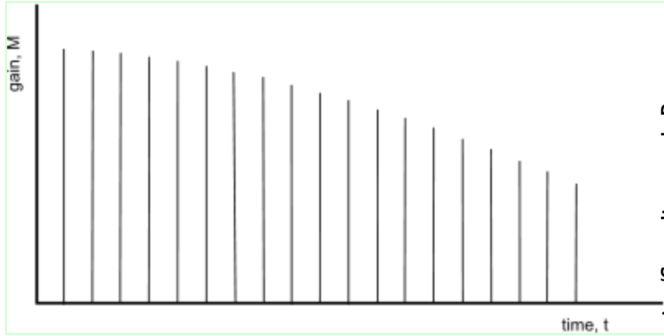
- Continuous in amplitude and in time.
- Examples:
  - Radio sound
  - Velocity of my car
  - TV image broadcasting

Discrete signal:

- Discrete in amplitude and in time.
- Analogical-Digital Conversion (ADC) involves two important operations:
  - Sampling
  - Quantization
- ADC implies loss of information.

Sampling





http://en.wikibooks.org/wiki/Digital_Signal_Processing/Sampling_and_Reconstruction

Definition:

- The process of recording the values (samples) of a signal at given points in time.
- For A/D converters, these points in time are equidistant.

Sampling rate:

- Number of samples per second.

Nyquist sampling rate:

- For lossless digitization, the sampling rate should be at least twice the maximum frequency responses. Indeed many times more the better.

Nyquist's sampling theorem:

- In order for a band-limited signal (band B beyond which the signal power is zero) to be reconstructed fully, it must be sampled at a rate $f \geq 2B$. A signal sampled at $f=2B$ is said to be Nyquist sampled, and is called the **Nyquist frequency**. No information is lost if a signal is sampled at the Nyquist frequency, and no additional information is gained by sampling faster than this rate.

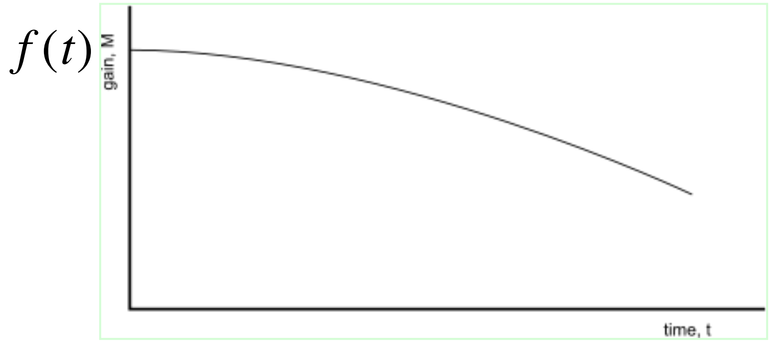
http://mathworld.wolfram.com/SamplingTheorem.html

http://www.cs.cf.ac.uk/Dave/Multimedia/node149.html

Nyquist's sampling theorem

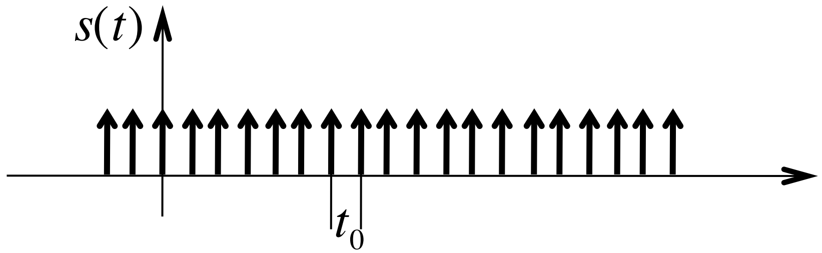
Continuous function/signal:

– $f(t)$



Impulse convoy:

$$s(t) = \sum_{n=-\infty}^{\infty} \delta(t - nt_0)$$



Sampled function/signal:

– $f_s(t) = f(t)s(t) = f(t)\sum_{n=-\infty}^{\infty} \delta(t - nt_0)$

http://www.cs.cf.ac.uk/Dave/Multimedia/node149.html

Example: playing piano on telephone?

Telephone's sampling rate:

- It is 8kHz (8000 samples per second)

Sound's maximum frequency?:

- According to Nyquist, it is 8kHz / 2 = 4kHz

Sound:

- Low frequencies: grave sounds
- High frequencies: acute sounds

Playing piano on telephone:

- Only grave sounds are heard.

Humans hear frequencies from 20Hz up to 20kHz.

http://www.cs.cf.ac.uk/Dave/Multimedia/node149.html

Example: more about aliasing in music…

Sampling rate for music:

- If a piece of music is sampled at 32000 samples per second (sps), any frequency components above 16000 Hz (the Nyquist frequency) will cause aliasing when the music is reproduced by a digital to analog converter (DAC).

Solution:

- A possible solution to this aliasing problem is to choose a higher Nyquist frequency by sampling faster, typically:
  - 44100 sps (CD),
  - 48000 (professional audio), or
  - 96000 (high definition audio).

http://www.cs.cf.ac.uk/Dave/Multimedia/node149.html

Aliasing

Temporal aliasing:

- In signal processing and related disciplines, aliasing refers to an effect that causes different signals to become indistinguishable (or aliases of one another) when sampled.
- It also refers to the distortion or artifact that results when the signal reconstructed from samples is different from the original continuous signal.
- Thus, Nyquist theorem can guarantee an anti-aliased reconstruction of the signal.

Spatial aliasing:

- This happens in imaging when an image is reproduced by a monitor (or a printer) with lower resolution than the original image resolution.

Aliasing example of the A letter in Times New Roman. Left: aliased image, right: antialiased image.

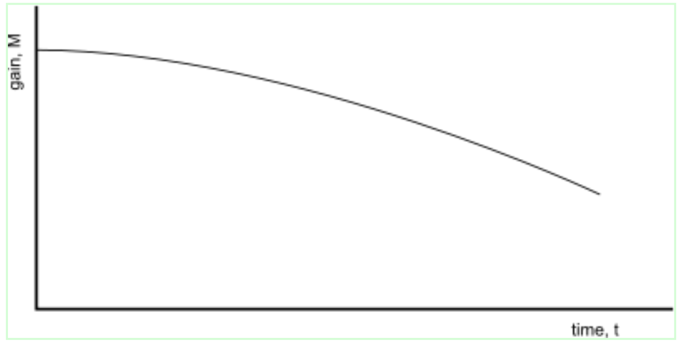
http://en.wikipedia.org/wiki/Aliasing#Folding

Quantization

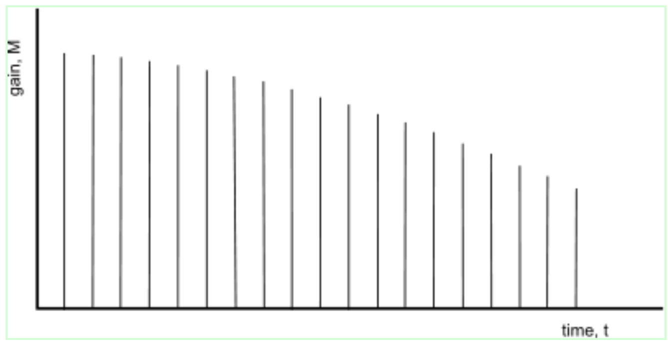
Definition:

- It is the process of constraining something from a relatively large or continuous set of values (such as the real numbers) to a relatively small discrete set (such as the integers).
- The input analog signal is compared to a set of pre-defined signal levels. Each of the levels is represented by a unique binary number, and it is chosen the binary number that corresponds to the level that is closest to the analog signal value.
- Thus, quantization is the process of representing an analog signal from a fixed number of bits.

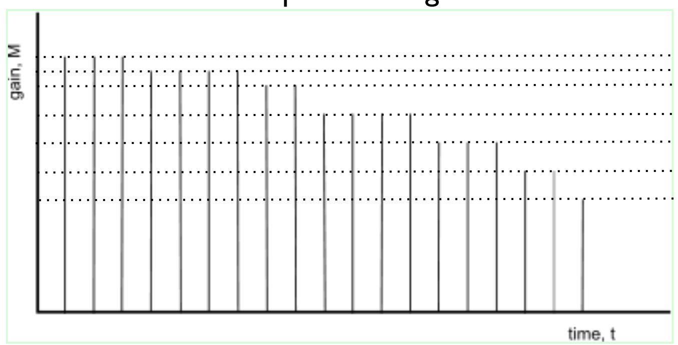
analog signal



sampled signal



quantized signal



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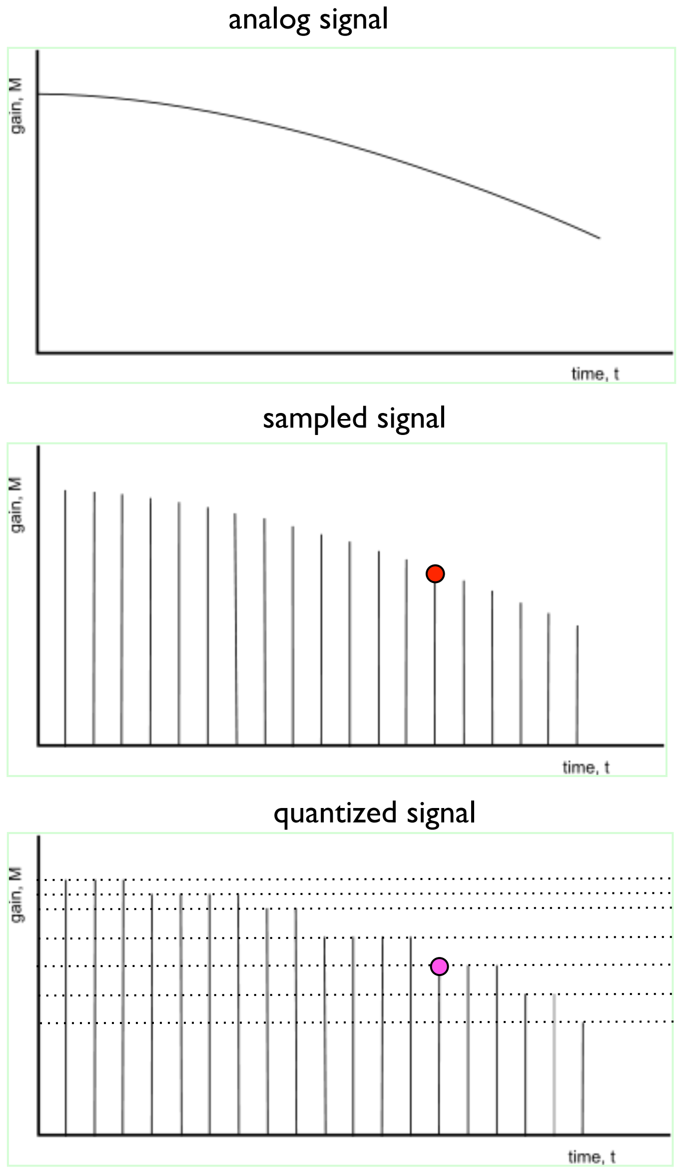
Quantization levels



Number of levels:

– $L=2^n$, where n is the number of storage bits

Sampling to quantization:

– Each sample value is rounded to the closest quantization level.

http://en.wikipedia.org/wiki/Aliasing#Folding

Noise

Definition:

- Any degradation of a signal.

Examples:

- Measure noise
- Thermal noise (Johnson noise)
- Audio noise
- Visual noise
- Etc.

http://en.wikipedia.org/wiki/Aliasing#Folding

Signal-to-noise ratio (SNR)

http://en.wikipedia.org/wiki/Signal-to-noise_ratio

Definition:

- SNR is a measure that compares the level of a desired signal to the level of background noise.
- It measures the effect of noise in the degradation of the signal.

$$SNR = \frac{P_{signal}}{P_{noise}} = \left(\frac{A_{signal}}{A_{noise}}\right)^2$$

http://en.wikipedia.org/wiki/Aliasing#Folding

P_{signal} – *power of signal*
P_{noise} – *power of noise*

Noise models

Models:

- Gaussian, Raylegh, Erlang, Exponential, etc.

Typical modeling:

- Degradation function d(x,y) that acts on the signal f(x,y) together with an additive term of noise n(x,y):

$$h(x,y) = d(x,y) \otimes f(x,y) + n(x,y)$$

↑

convolution

http://en.wikipedia.org/wiki/Aliasing#Folding

Noise types

White:

– Approximately constant.

Pink:

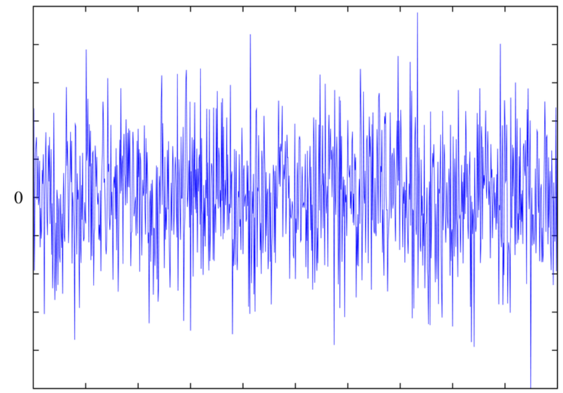
– 1/f

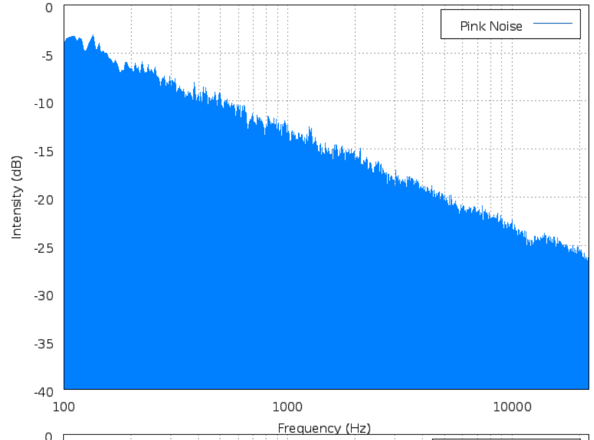
Brown(ian):

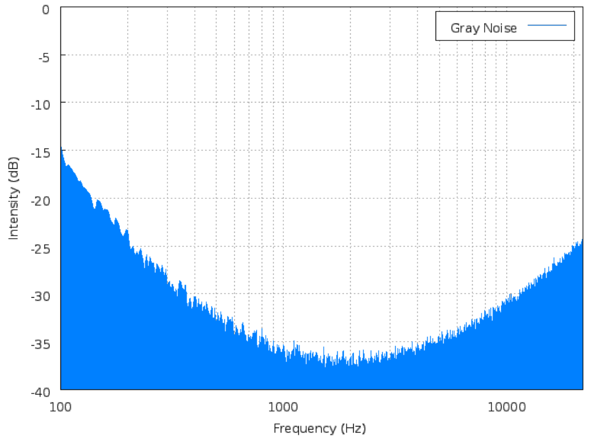
– $1/f^2$

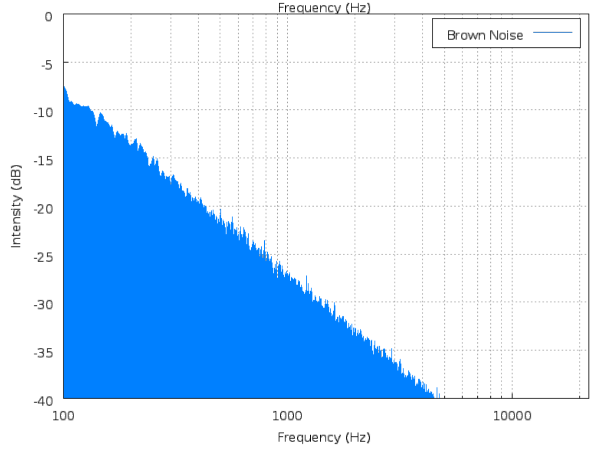
Grey:

– 1/f









http://en.wikipedia.org/wiki/White_noise

http://en.wikipedia.org/wiki/Aliasing#Folding

What is DSP?
Digital Signal Processing

Digital

– The use of discrete signals to represent data by means of numbers

Signal

– A parameter (electrical quantity or effect) that can be varied in such a way as to convey information

Processing

– A series of operations performed according to programmed instructions

Analysing and changing information which is measured as discrete sequences of numbers

DSP Implementation

The DSP pipeline:

- To implement DSP we must be able to perform both A/D and D/A conversions.

Example:

- Digital recording and playback of music (signal is sensed by microphones, amplified, converted to digital, processed, and converted back to analog to be played).

http://en.wikipedia.org/wiki/Aliasing#Folding

Main limitations of DSP

Sampling signals that are analog in nature leads to …

Alias:

- Sampling analog signals at intervals so that we don't know what happens in between.
- Alias phenomenon: Cannot distinguish between lower and higher frequencies
- Solution: to avoid aliasing, sampling rate must be at least twice the maximum frequency component (`bandwidth') of the signal.

Quantization Error:

- Limited (by the number of bits available) precision in data storage and arithmetic
- Quantization Error: smoothly varying signal represented by "stepped" waveform.

Loss of Information!

http://en.wikipedia.org/wiki/Aliasing#Folding

Advantages of Digital over Analog Signal Processing

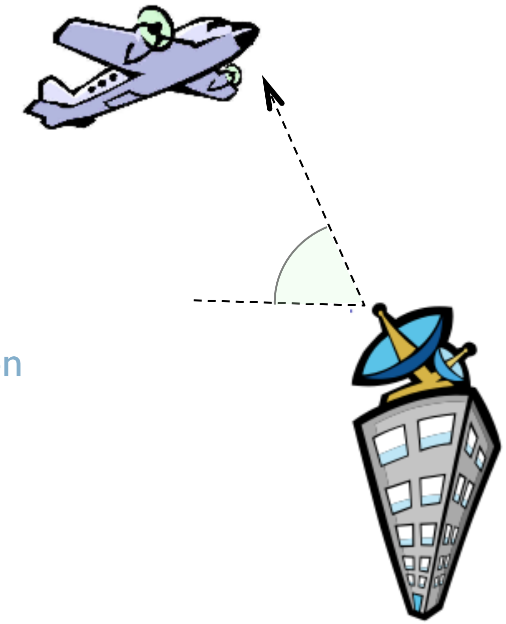
Why still do it?:

- Digital system can be simply reprogrammed for other applications / ported to different hardware / duplicated
  - Reconfiguring analog system means hardware redesign, testing, verification.
- DSP provides better control of accuracy requirements
  - Analog system depends on strict components tolerance, response may drift with temperature
- Digital signals can be easily stored without deterioration
  - Analog signals are not easily transportable and often can't be processed off-line
- More sophisticated signal processing algorithms can be implemented
  - Difficult to perform precise mathematical operations in analog form

http://en.wikipedia.org/wiki/Aliasing#Folding

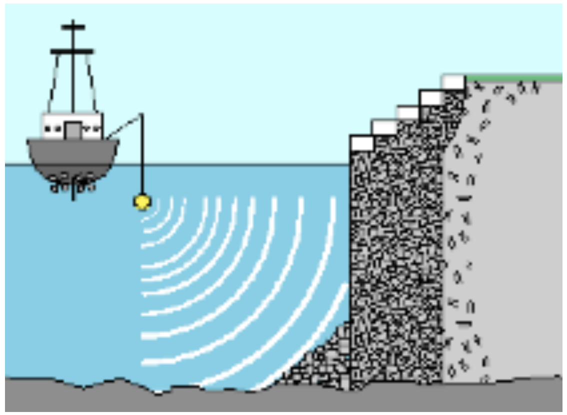
http://www-sigproc.eng.cam.ac.uk/~op205/3F3_1_Introduction_to_DSP.pdf

DSP Applications: Radar and Sonar



Examples

- Radar
  - target detection: position and velocity estimation
- Sonar
  - tracking



DSP Applications: Biomedical Devices

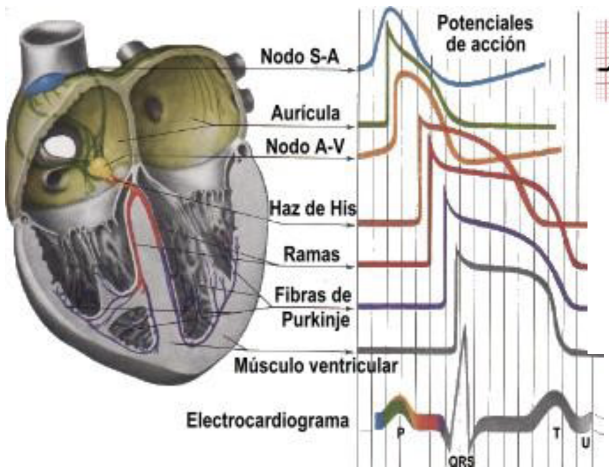
Biomedical Engineering

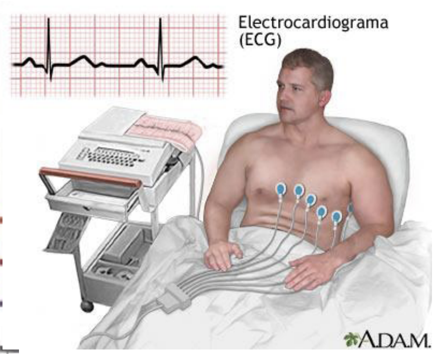
– analysis of biomedical signals, diagnosis, patient monitoring, preventive health care, artificial organs

Examples

– electrocardiogram (ECG) signal – provides doctor with information about the condition of the patient's heart (electrical activity of heart).

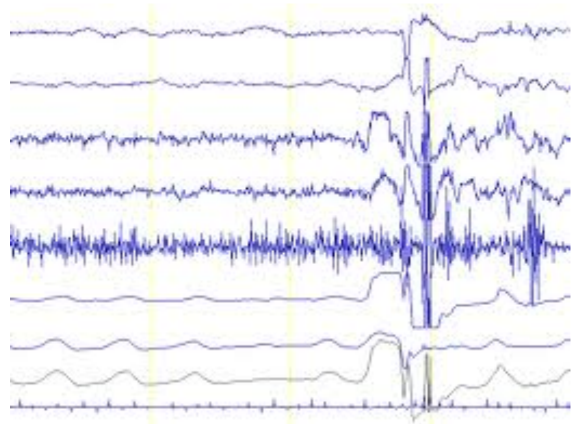
– electroencephalogram (EEG) signal – provides Information about the electrical activity of the brain





Person wearing electrodes for ECG

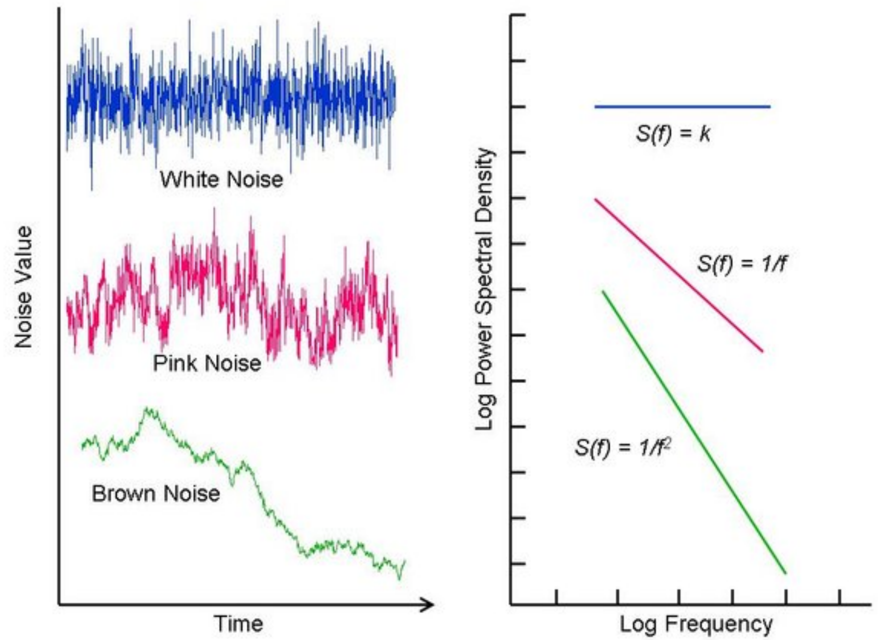
Person wearing electrodes for EEG



DSP Applications: Speech

Examples

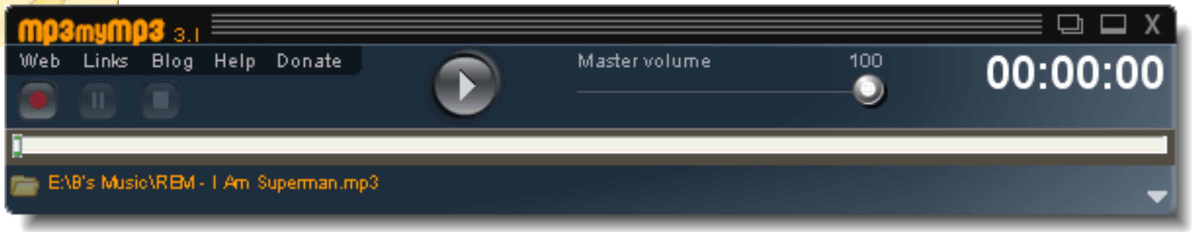
- noise reduction – reducing background noise in the sequence produced by a sensing device (microphone)
- speech recognition – differentiating between various speech sounds
- synthesis of artificial speech – text to speech systems for blind

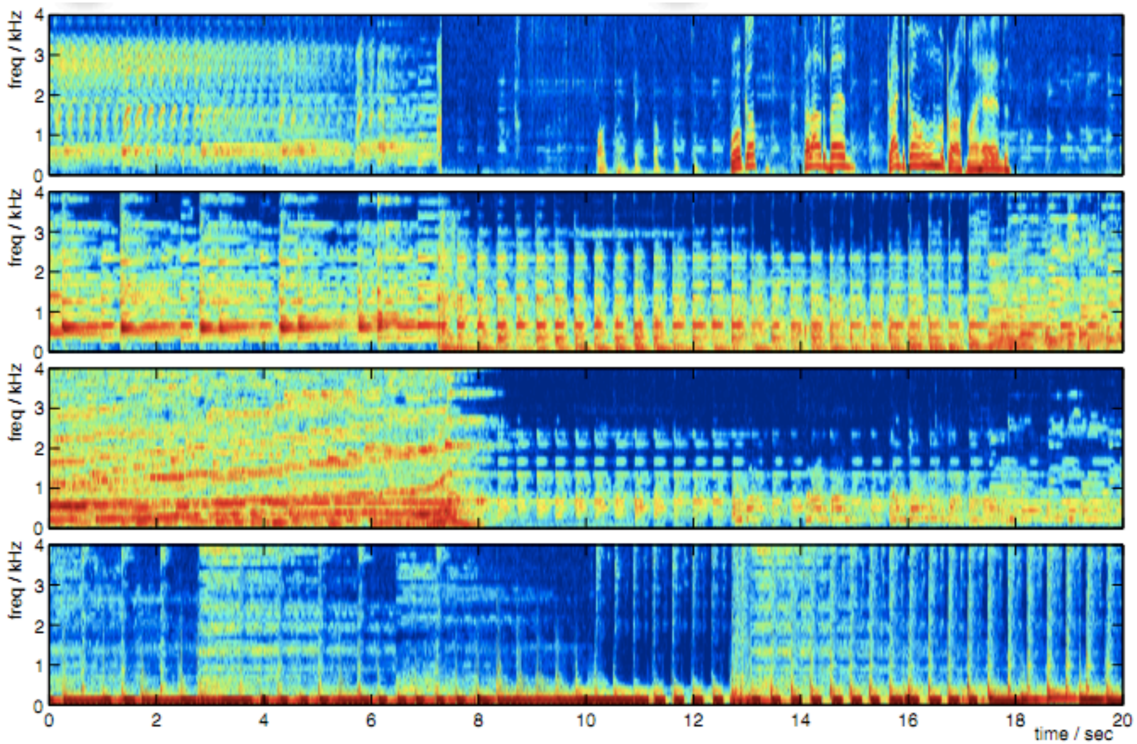


DSP Applications: Music

Examples

- Recording
- Playback
- Manipulation (mixing, special effects)

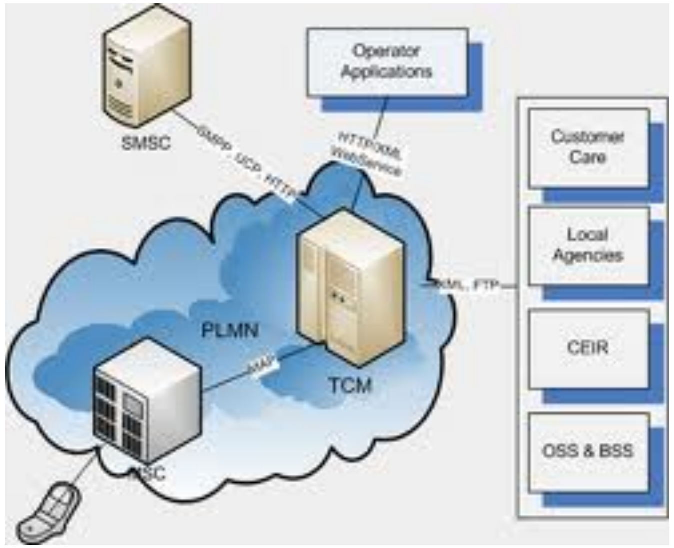




DSP Applications: Communications

Examples

- Telephony: transmission of information in digital form via telephone lines, modem technology, mobile phones
- Encoding and decoding of the information sent over a physical channel (to optimise transmission or to detect or correct errors in transmission)



DSP Applications: Image Processing

Examples

- Content based image retrieval: browsing, searching and retrieving images from databases
- image enhancement
- compression - reducing the redundancy in the image data to optimise transmission / storage

Summary

What is a signal?

Signal parameters: amplitude, wavelength, frequency, velocity, period

Analog vs. Digital Signals

Sampling

Nyquist's sampling theorem

Aliasing

Quantization

DSP pipeline

Limitations and advantages of DSP

Applications