

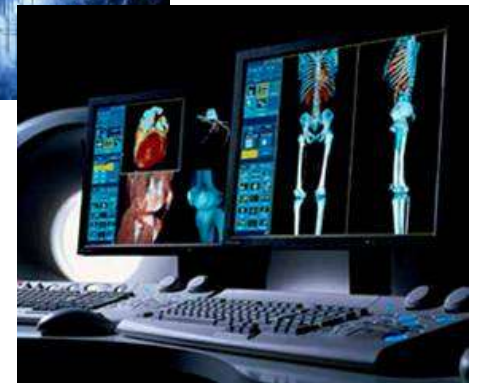
An introduction to Digital Signal Processing

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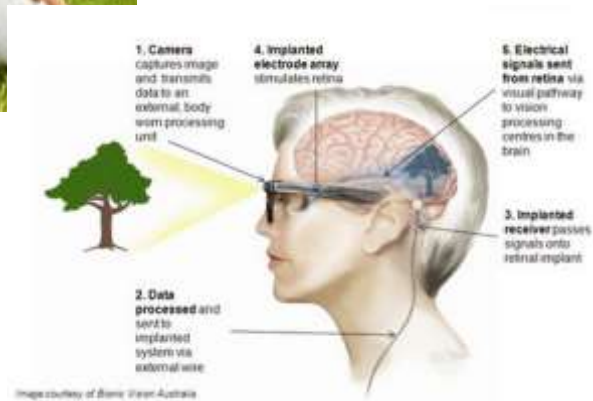
Original material: Rene Cumplido

Introduction

- ▶ DSP is one of the most powerful technologies that will shape science and engineering in the XXI century.
- ▶ Revolutionary changes have already been made in a *broad* range of fields:
 - ▶ Communications, medical imaging, radar & sonar, high fidelity music reproduction, and oil prospecting, to name just a few.
- ▶ Each of these areas has developed a *deep* DSP technology, with its own algorithms, mathematics, and specialized techniques.
- ▶ Learning DSP involves two tasks:
 - ▶ learning general concepts that apply to the field as a whole
 - ▶ learning specialized techniques for your particular area of interest.



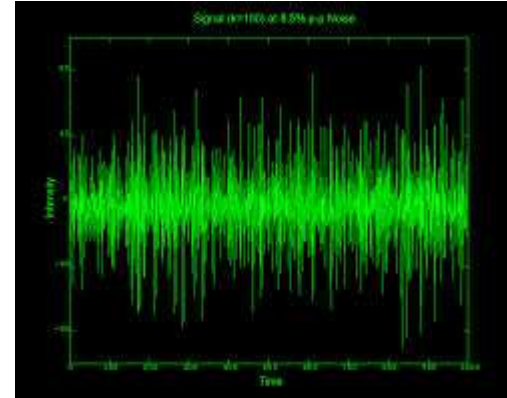
DSP in humans



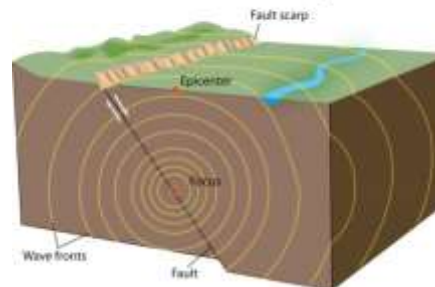
- ▶ We are experts in signal processing
- ▶ We are complex signal processing systems, adaptively processing signals, we:
 - ▶ **input** intricate signals from our environment
 - ▶ **extract** high level representations of information carried by these signals
 - ▶ **make decisions** based on this information
 - ▶ **record** some of the information for later recall and processing
 - ▶ **produce** new signals to change our environment in real time
- ▶ While sleeping, we:
 - ▶ **reintroduce** recent input signals in order to **correlate** them with previously stored signals
 - ▶ decide which signals should be **stored** for long periods of time
 - ▶ **Perfect** our signal processing performance.
- ▶ Due to this signal processing we,
 - ▶ are good at **understanding** speech and immediately reacting based on what has been said
 - ▶ take for granted our ability to recognize faces and proficiency at reading handwriting

Roots of DSP

- ▶ DSP is distinguished from other areas in computer science by the unique type of data it uses: *signals*.
- ▶ Most of these signals originate as sensory data from the real world:
 - ▶ seismic vibrations, visual images, sound waves, etc.
- ▶ **DSP is the mathematics, the algorithms, and the techniques used to manipulate these signals after they have been converted into a digital form.**
- ▶ This includes a wide variety of goals, such as:
 - ▶ **enhancement** of visual images
 - ▶ **recognition and generation** of speech
 - ▶ **compression** of data for storage and transmission



Seismic Waves Radiate from the Focus of an Earthquake



Roots of DSP (2)

- ▶ The roots of DSP are in the 1960s and 1970s when digital computers first became available.



- ▶ DSP was limited to only a few critical applications. Pioneering efforts were made in four key areas:
 - ▶ *radar & sonar*
 - ▶ *oil exploration*
 - ▶ *space exploration*
 - ▶ *medical imaging*

- ▶ Personal Computer revolution of the 1980s and 1990s caused DSP to explode with new applications.

- ▶ Civil use

- ▶ DSP was then driven by the commercial marketplace.

- ▶ DSP reached the public in such products as: mobile telephones, compact disc players, and electronic voice mail.

DSP Applications

- Space
- Medical
- Commercial
- Telephone
- Military
- Industrial
- Scientific

-Space photograph enhancement
 -Data compression
 -Intelligent sensory analysis by remote space probes

-Diagnostic imaging (CT, MRI, ultrasound, and others)
 -Electrocardiogram analysis
 -Medical image storage/retrieval

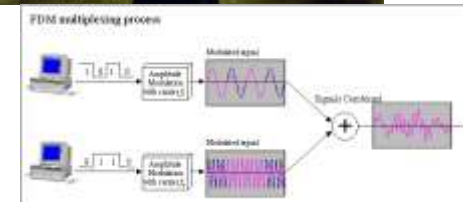
-Image and sound compression for multimedia presentation
 -Movie special effects
 -Video conference calling

-Voice and data compression
 -Echo reduction
 -Signal multiplexing
 -Filtering

-Radar
 -Sonar
 -Ordnance guidance
 -Secure communication

-Oil and mineral prospecting
 -Process monitoring & control
 -Nondestructive testing
 -CAD and design tools

-Earthquake recording & analysis
 -Data acquisition
 -Spectral analysis
 -Simulation and modeling



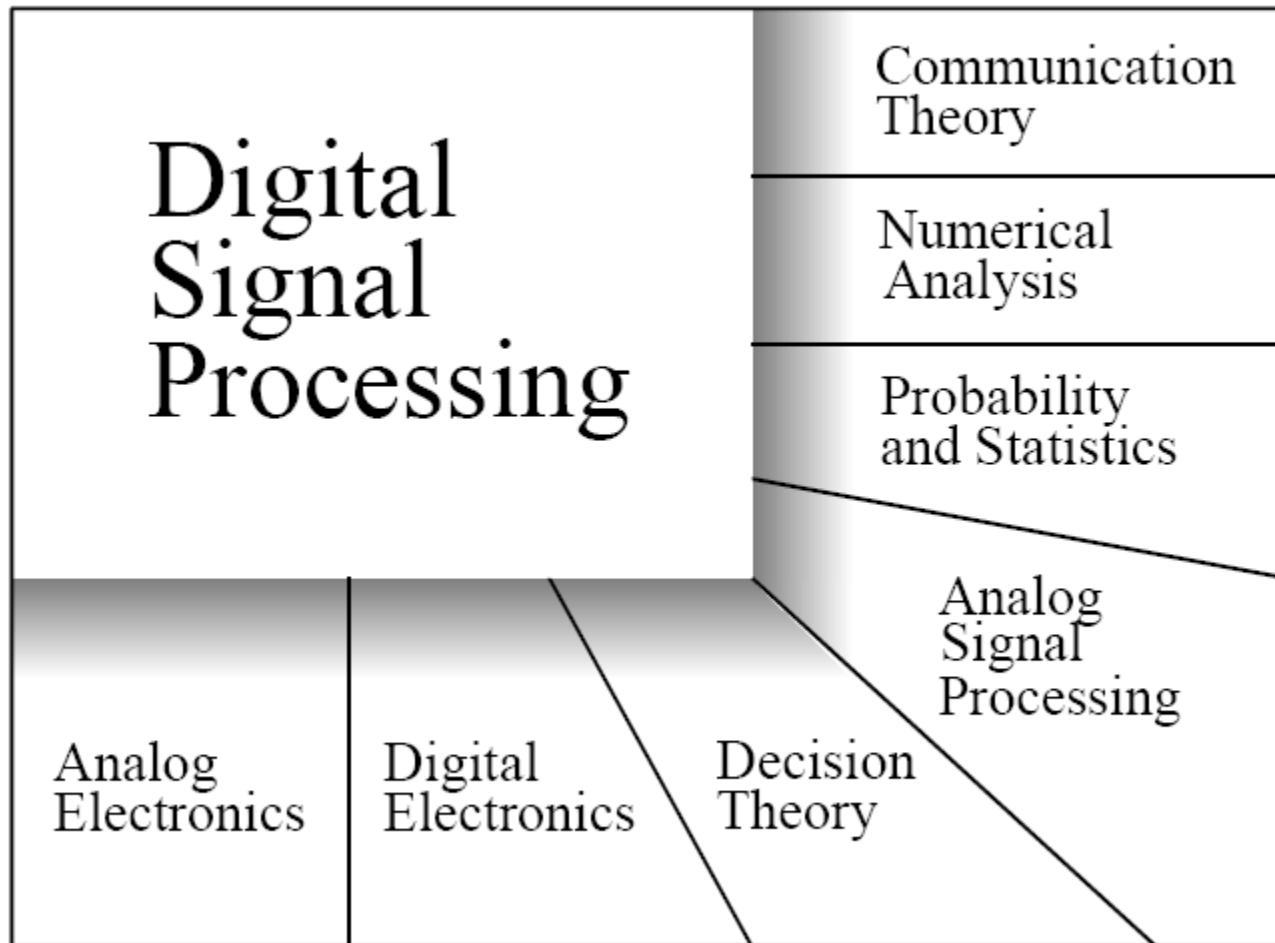
DSP Teaching

- ▶ In the early 1980s, DSP was taught as a *graduate* level course in electrical engineering.
- ▶ In the 1990s DSP became a standard part of the *undergraduate* curriculum.
- ▶ Today, DSP is a *basic skill* needed by scientists and engineers in many fields.

About this course

- ▶ It aims to introduce DSP techniques without the traditional barriers of detailed mathematics and theory.
- ▶ The idea is to *learn DSP as a tool*.

DSP is highly interdisciplinary

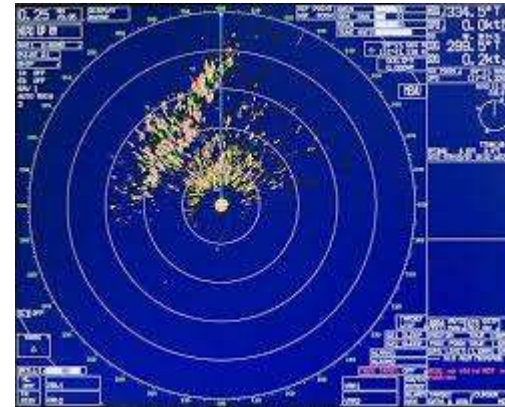


DSP in main areas

▶ Telecommunications



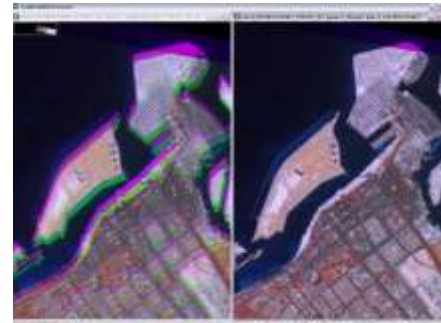
▶ Echo location



▶ Audio processing



▶ Image processing



DSP in Telecommunications

- ▶ Telecommunications is about transferring information from one location to another.
- ▶ Telecommunications companies receive *payment* for transferring information.
- ▶ Includes many forms of information:
 - ▶ telephone conversations, television signals, computer files, and other types of data.
- ▶ The idea is simple, the more information they can pass through a single channel, the more money they make.
- ▶ To transfer the information, you need a *channel* between the two locations.
- ▶ DSP has revolutionized the telecommunications industry in many areas:
 - ▶ signaling tone generation and detection, frequency band shifting, filtering to remove power line hum, etc.
- ▶ This may be a wire pair, radio signal, optical fiber, etc.

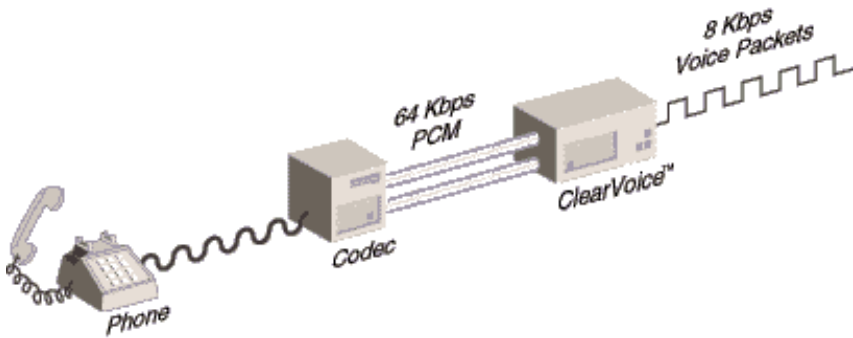
Multiplexing

- ▶ *One billion* telephones in the world.
- ▶ Switching networks allow any one of these to be connected to any other in only a few seconds.
- ▶ Until the 1960s, a connection between two telephones required passing the analog voice signals through mechanical switches and amplifiers. One connection required one pair of wires.
- ▶ In comparison, DSP converts audio signals into a stream of serial digital data.
 - ▶ Bits can be intertwined and later separated
 - ▶ Thus many telephone conversations can be transmitted on a single channel.
- ▶ A telephone standard known as the *T-carrier system* can simultaneously transmit 24 voice signals.
 - ▶ Each voice signal is sampled 8000 times per second using an 8 bit companded ADC, i.e. 64,000 bits/sec.
 - ▶ 24 channels > 1.544 megabits/sec.
 - ▶ Signal is Tx about 6000 feet using ordinary telephone lines of 22 copper wire.
- ▶ Wire and analog switches are expensive; digital logic gates are cheap.



Data Compression - Voice

- ▶ A digitized voice signal at 8000 samples/sec, most digital information is *redundant*.
 - ▶ I.e. information carried by any one sample is largely duplicated by the neighboring samples.
- ▶ Algorithms vary in the compression achieved and resulting sound quality.
 - ▶ Reducing a data rate from 64 kilobits/sec to 32 kilobits/sec results in no loss of sound quality
 - ▶ When compressed to 8 kilobits/sec, the sound is noticeably affected, but still usable
 - ▶ The highest achievable compression is about 2 kilobits/sec
 - ▶ Sound highly distorted
 - ▶ Usable for some applications such as: military and undersea communications.
 - ▶ Play sample
- ▶ DSP algorithms convert digitized voice signals into data streams that require fewer bits/sec.



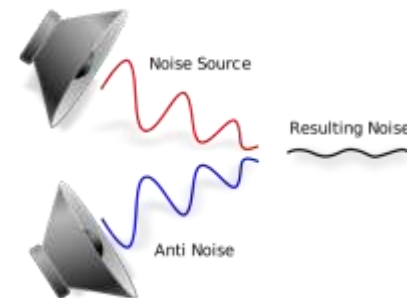
Echo control

- ▶ Echoes are a serious problem in long distance telephone connections.



- ▶ A signal representing your voice travels to the connecting receiver, a portion of it returns as an echo.
- ▶ Delays can be of several hundred milliseconds for intercontinental communications, and is particularly annoying.

- ▶ DSP measures the returned signal and generates an appropriate *anti-signal* to cancel the echo
- ▶ This technique allows speakerphone users to hear and speak at the same time without fighting audio feedback (squealing)
- ▶ It can also be used to reduce environmental noise by canceling with digitally generated *anti-noise*.



DSP in audio Processing - Music

- ▶ Digital data representation is important to prevent degradation commonly associated to analog storage and manipulation.



- ▶ A musical piece is recorded in a sound studio on multiple channels or tracks.
 - ▶ This involves recording individual instruments and singers separately.
 - ▶ This gives greater flexibility in creating the final product.

- ▶ *Mix down* is a complex process of combining individual tracks into a single final track.
- ▶ DSP provides several functions during mix down, including:
 - ▶ filtering, signal addition and subtraction, signal editing, etc.

Speech generation and recognition

- ▶ Speech generation and recognition are used to communicate humans and machines.
 - ▶ Rather than using your hands and eyes, you use your mouth and ears.



- ▶ This is very convenient when your hands and eyes should be doing something else:
 - ▶ driving a car, performing surgery, or firing your weapons at the enemy.
 - ▶ two approaches are used for computer generated speech:
 - ▶ *Digital recording and vocal tract simulation.*

- ▶ Digital recording:
 - ▶ a speaker's voice is digitized and stored, usually compressed
 - ▶ during playback, the stored data are uncompressed and converted back into an analog signal
- ▶ An hour of recorded speech requires only about three megabytes of storage
- ▶ this is the most common method of digital speech generation used today

Speech generation (2)

- ▶ Vocal tract simulators mimic the physical mechanisms by which we create speech
- ▶ The human vocal tract is an acoustic cavity with resonate frequencies determined by the size and shape of the chambers
- ▶ Sound originates in the vocal tract in one of two basic ways, called *voiced and fricative sounds*
- ▶ Vocal tract simulators operate by generating digital signals that resemble these two types of excitation
- ▶ The characteristics of the resonate chamber are simulated by passing the excitation signal through a digital filter with similar resonances
- ▶ *Play video sample*

Speech recognition

- ▶ Automated recognition of human speech is more difficult than speech generation.
- ▶ Speech recognition is a classic example of things that the human brain does well, but digital computers do poorly.
- ▶ Digital computers can:
 - ▶ store and recall vast amounts of data
 - ▶ perform fast mathematical calculations
 - ▶ do repetitive tasks efficiently
- ▶ Unfortunately, present day computers perform very poorly when faced with raw sensory data.

DSP in Image Processing

- ▶ **Images are signals with special characteristics.**
 - ▶ They are a measure of a parameter over *space* (distance), while most signals are a measure of a parameter over *time*.
 - ▶ They contain a great deal of information.
 - ▶ For example, more than 10 megabytes can be required to store one second of television video.
 - ▶ The final judge of quality is often a subjective human evaluation
- ▶ **Image processing is a distinct subgroup within DSP.**

Medical Imaging

- ▶ In 1895, Wilhelm Conrad Röntgen discovered that x-rays could pass through substantial amounts of matter.
- ▶ Medical x-ray systems spread throughout the world in only a few years.
- ▶ Medical x-ray imaging was limited by four problems until DSP techniques were available the 1970s.
 - ▶ Overlapping structures in the body can hide behind each other.
 - ▶ It is not always possible to distinguish between similar tissues.
 - ▶ x-ray images show *anatomy*, the body's structure, and not *physiology*, the body's operation.
 - ▶ x-ray exposure can cause cancer



Medical Imaging (2)

- ▶ Computed tomography (1971) deals with overlapping structures
- ▶ X-rays from many directions are passed through a section of the patient's body being examined
 - ▶ Instead of forming images, produced signals are converted to digital data and stored in a computer.
- ▶ DSP techniques processes stored digital data to generate images of body's slices
- ▶ These images show much greater detail than conventional techniques, allowing significantly better diagnosis and treatment



- ▶ CT's impact was nearly as large as the original introduction of x-ray imaging itself
- ▶ *See video sample*

Medical Imaging (3)

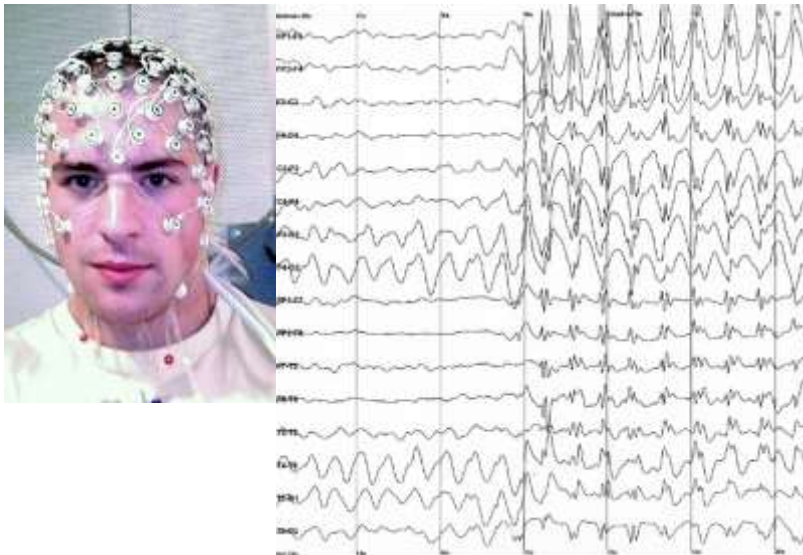
- ▶ Overlapping, tissue similarity, body's operation
 - ▶ Penetrating energy: radio and sound waves
- ▶ Magnetic Resonance Imaging (MRI) uses magnetic fields in conjunction with radio waves to form images of the body
 - ▶ Anatomy and physiology of the body
- ▶ MRI provides discrimination between different types of soft tissue
- ▶ MRI also provides information about physiology, such as blood flow through arteries.
- ▶ *See video sample*



"MRI-Philips" by Jan Ainali - Own work. Licensed under CC BY 3.0 via Commons - <https://commons.wikimedia.org/wiki/File:MRI-Philips.JPG#/media/File:MRI-Philips.JPG>

Biomedical engineering

- ▶ The human brain is a massively parallel computer containing about 10^{10} processing units called neurons.
- ▶ These neurons fire electric impulses that are observable by placing electrodes at various positions on the scalp
 - ▶ Voltages that represent sums of many neurons are detectable.
- ▶ These recordings are known as electroencephalograms (EEG) and after processing they can be used for diagnosis of sleep disorders, epilepsy, and brain disease.
- ▶ The electric activity of the heart can also be monitored, using the electrocardiogram (ECG)
- ▶ Processing this signal aids the physician in diagnosing potential problems.



Radar and sonar processing (1)

- ▶ Purpose: to locate bodies in space and optionally to determine their speeds.
- ▶ **RA**dio **D**etection **A**nd **R**anging
- ▶ Radar signals usually have very high bandwidths, thus require very fast processing rates

- ▶ Radar applications include
 - ▶ air traffic control
 - ▶ aircraft radar
 - ▶ smart-missiles
 - ▶ weather satellite radar
 - ▶ police speed traps.
- ▶ Distance determination relies on the sensitive detection and accurate timing of return signals
 - ▶ Electromagnetic signals for radar

Band Designation	Frequency Range	Typical Usage
VHF	50-330 MHz.	Very long-range surveillance
UHF	300-1,000 MHz.	Very long-range surveillance
L	1-2 GHz.	Long range surveillance, enroute traffic control

www.aewa.org/Library/fc_bands.html

Radar and sonar processing (2)

- ▶ **SOund NAVigation and Ranging**
- ▶ **Active**
 - ▶ 2-40 kHz sound pulses are transmitted into water, echoes are detected and analyzed
 - ▶ Range 10-100 km
 - ▶ Detection & localization of undersea bodies
 - ▶ Navigation
 - ▶ Communication
 - ▶ Sea floor mapping
- ▶ **Passive**
 - ▶ Senses underwater sounds including natural turbulence, marine life, mechanical sounds from submarines or surface vessels
 - ▶ Military surveillance
 - ▶ Range x1000 km
- ▶ **DSP in Radar and Sonar**
 - ▶ Pulse generation
 - ▶ Pulse compression
 - ▶ Filtering of detected signals

Seismology

- ▶ Seismic signal analysis is used by:
 - ▶ Oil and gas industries in the exploration of subsurface hydrocarbon reserves
 - ▶ Government agencies for nuclear detonation detection
 - ▶ Authorities for investigation of subsurface geological formations and their significance to architecture and urban development.
- ▶ Signals passively collected during seismic events (earthquakes and volcanic eruptions) aid in their detection, epicenter location, and prediction.
- ▶ During active exploration such seismic disturbances must be initiated by setting off high-energy charges.
 - ▶ Seismic waves are scattered by interfaces between different geological strata, and collected at the earth's surface by an array of seismometers.
 - ▶ Multiple seismic signals must be digitized and processed to lead to source location or mapping of the geological strata.