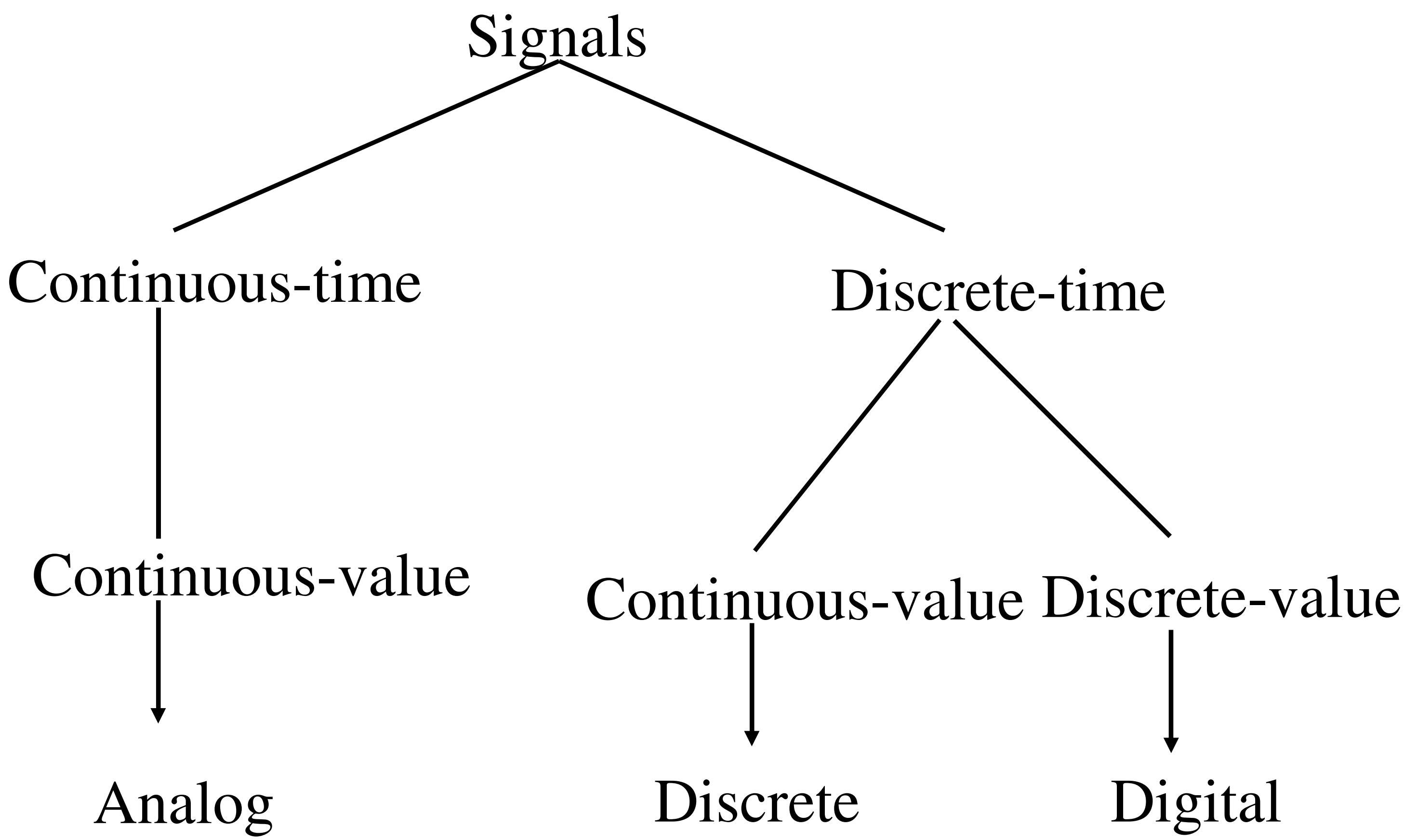
Digital Signal Processing

Introduction to DSP

What is Digital Signal Processing (DSP)?

- Consists of three words:
  Digital **,** ***Signal*** and ***Processing***
- ***Signal***: any (physical or non-physical) quantity that varies with time, space, or other independent variable(s)
- ***Digital***: a discrete-time and discrete-valued signal, i.e. digitization involves both *sampling* and *quantization*
- ***Processing***: operations on the signal

Signal Types



Examples of Signals

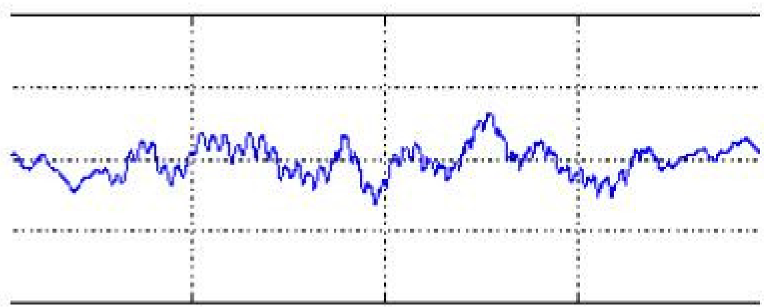
- Signals are everywhere and may reflect countless measurements of some physical quantity such as:
  - electric voltages
  - brain signals
  - heart rates
  - temperatures
  - image luminance
  - investment prices
  - vehicle speeds
  - seismic activity
  - human speech

Signal Acquisition

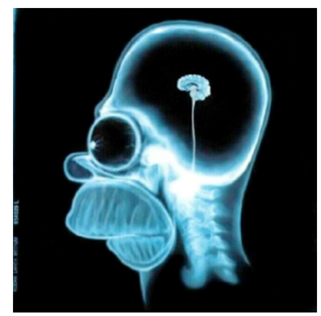
- Various apparatus could be used to acquire signals, including:
  - Digital camera → Image
  - MRI scanner → Activity of the brain
  - EEG/EMG/EOG electrodes → Physiological signals
  - Voice recorder → Audio signal

Signal Dimensions

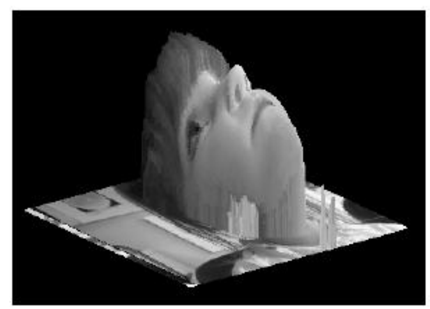
- 1D (e.g. dependent on time)



- 2D (e.g. images dependent
  on two coordinates in a plane)

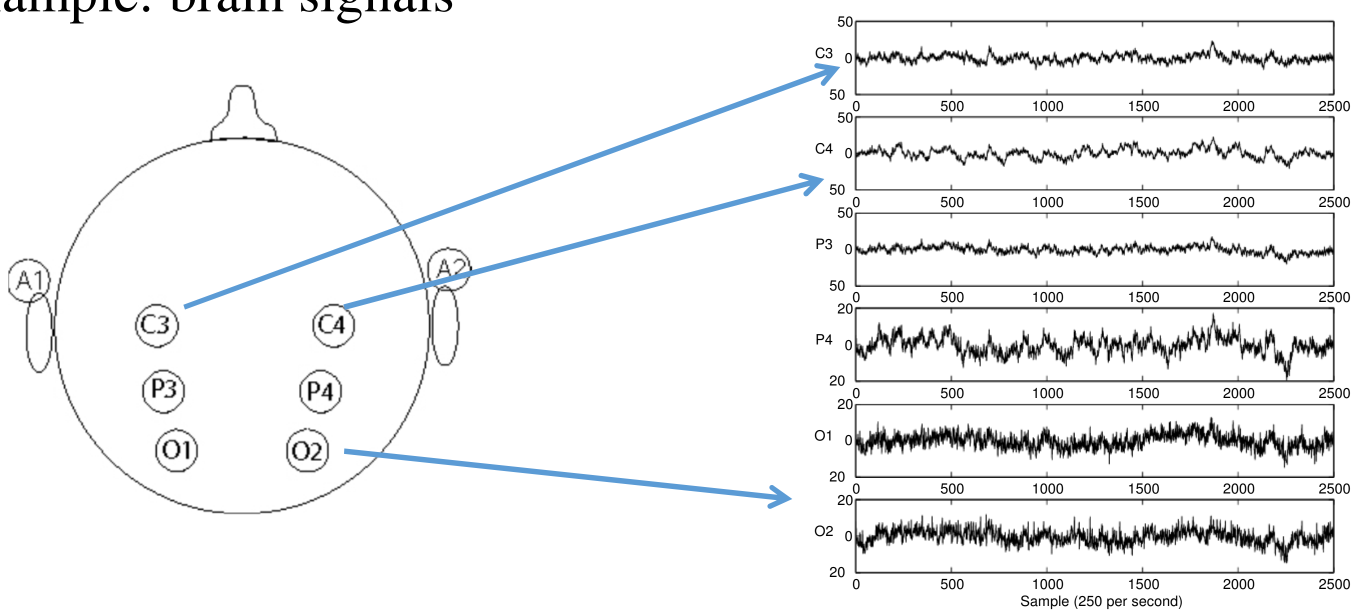


- 3D (e.g. describing an object in space)



Multi-Channel Signals

- In some applications, signals are generated by multiple sources or multiple sensors→ represented by a vector
- Such a vector is called a *multi-channel* signal.
- Example: brain signals



Continuous-time vs. Discrete-time

- Continuous-time signals are signals defined at each value of independent variable(s).
- They have values in a continuous interval (a,b) that could extend from $-\infty$ to ∞.
- Discrete-time signals are defined only at specific values of independent variable(s).
- Discrete-time signals are represented mathematically by a sequence of real or complex numbers.

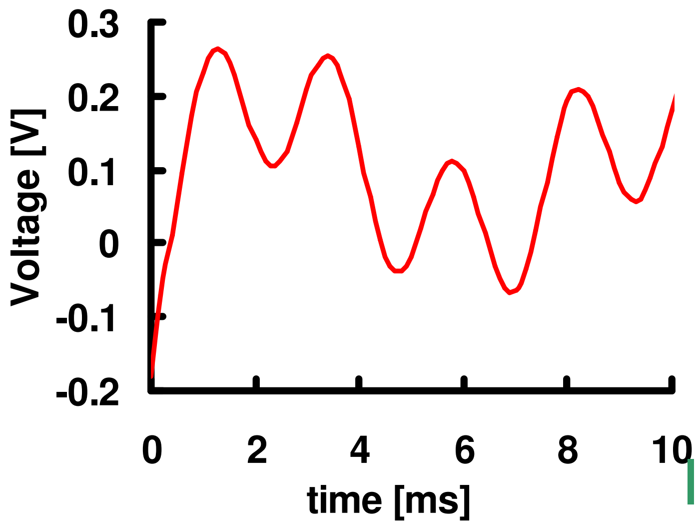
Continuous-time vs. Discrete-time

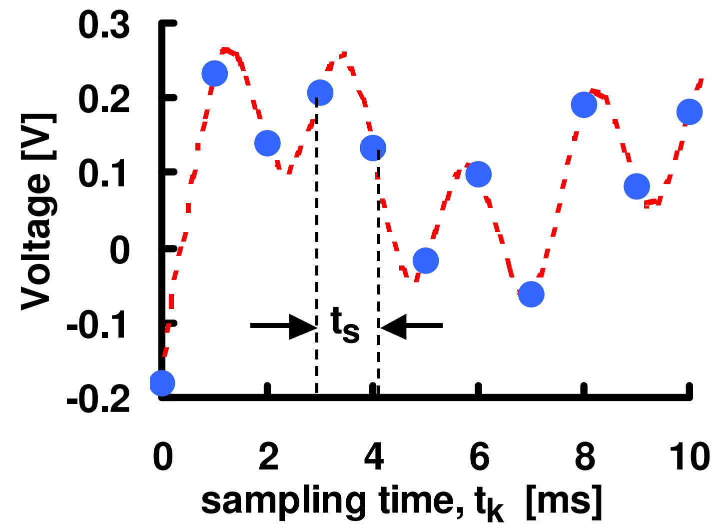
CT

Continuous function V of *continuous* variable t (time, space etc) : V(t).

DT

Discrete function V_k of *discrete* sampling variable t_k, with k = integer: $V_k = V(t_k)$.

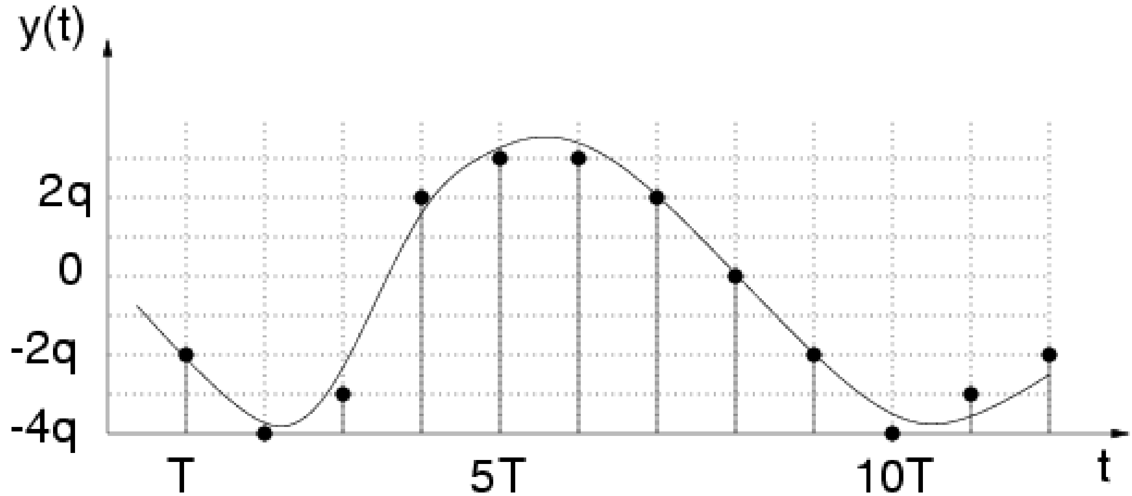




Periodic sampling

Continuous-valued vs. Discrete-valued

- Both continuous and discrete-time signals can take a finite (discrete) or infinite (continuous) *range.*
- For a signal to be called *digital,* it must be *discrete-time* and *discrete-range*, i.e. digitization involves both *sampling and quantization.*

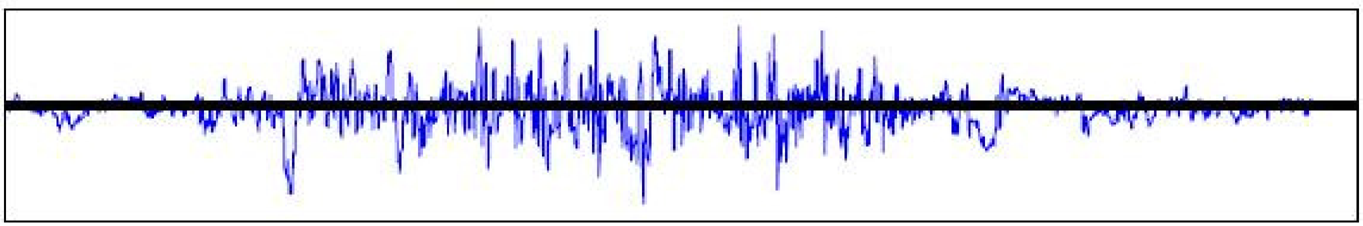


Deterministic vs. Random Signals

- Signals could be *deterministic,* with an explicit mathematical description, a table or a well-defined rule.
- All past, present, and future signal values are precisely known with *no uncertainty:*

  $s_1(t) = at$ $\qquad\qquad$ $S_2(x,y)=ax+bxy+cy^2$

- In contrast, for *random* signals the functional relationship is unknown.



- → *statistical analysis techniques*

Signal Processing System

- A **system** that performs some kind of task on a signal which depends on the application, e.g.
  - *Communications*: modulation/demodulation, multiplexing/de-multiplexing, data compression
  - *Speech Recognition*: speech to text transformation
  - *Security*: signal encryption/decryption
  - *Filtering*: signal denoising/noise reduction
  - *Enhancement*: audio signal processing, equalization
  - *Data manipulation*: watermarking, reconstruction, feature extraction
  - *Signal generation*: music synthesis

Digital vs. Analog Processing

Digital Signal Processing

Advantages

- More flexible
- Data easily stored
- Better control over accuracy requirements
- Reproducibility
- Cheaper

Limitations

- A/D & signal processors' speed
- Finite word-length effect:

  (round-off: Error caused by rounding math calculation result to nearest quantization level)

Signal Processing

- Theoretical vs. Applied

Applicable to any field

Easier to comprehend

- Algorithm development vs. implementation

e.g., C++-code,
Matlab code

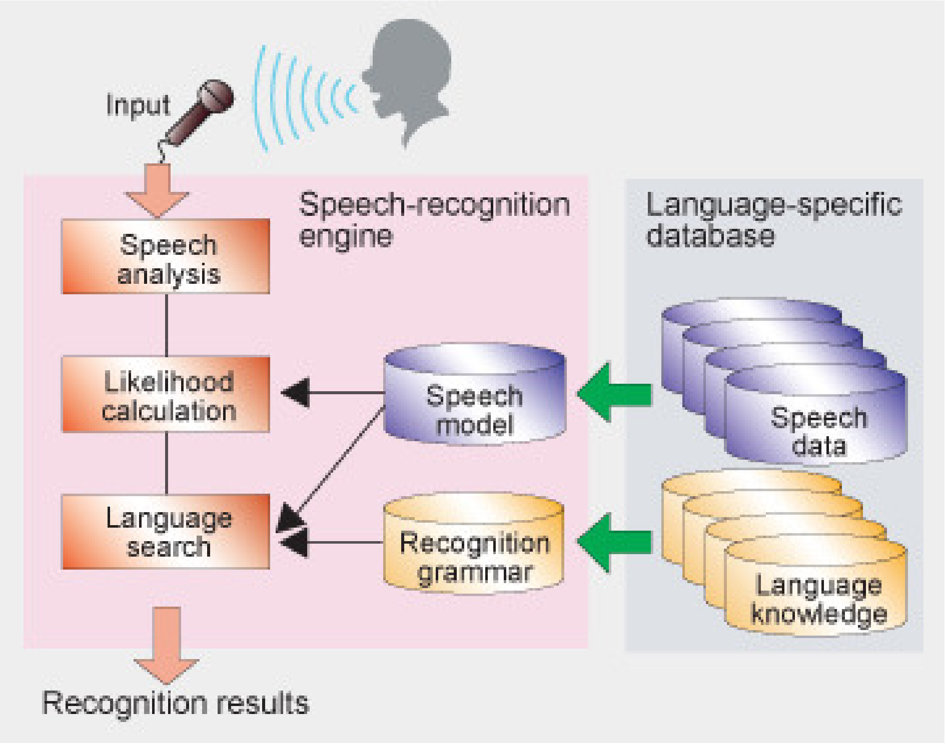
Easier to adapt

e.g., ASIC, DSP chip

Much faster

Example Application: Audio Processing

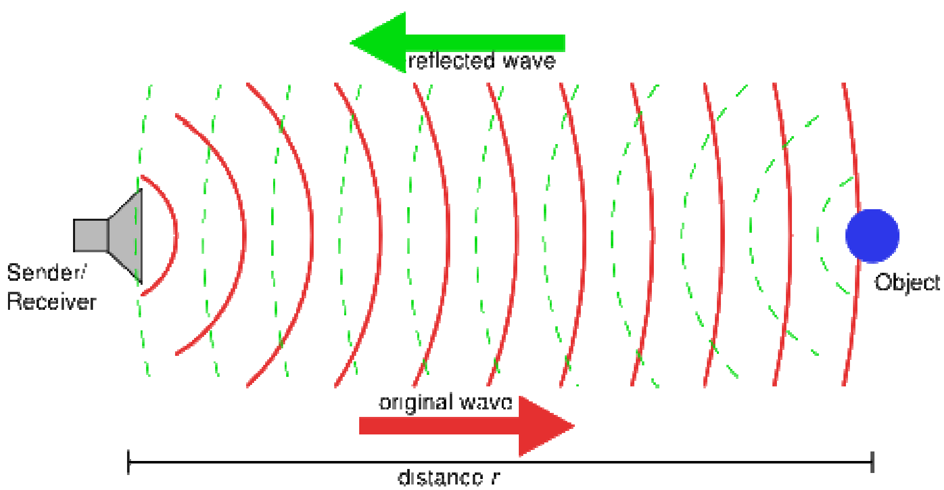
- Applications include speech generation / speech recognition
- ***Speech recognition***: DSP generally approaches the problem of voice recognition in two steps: *feature extraction* followed by *feature matching*.



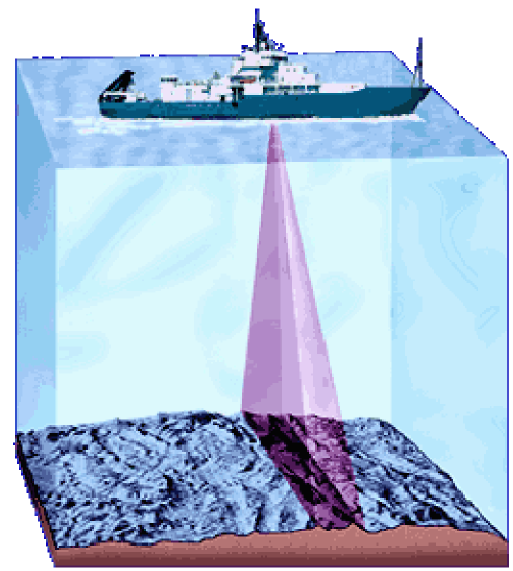
Source: Canon

Example Application: Echo Location

- A common method of obtaining information about a remote object is to bounce a *wave* off of it.
- Applications include radar and sonar.
- DSP can be used for filtering and compressing the data.



Source:
CCTT.org



Source:
WHIO

Pattern Recognition

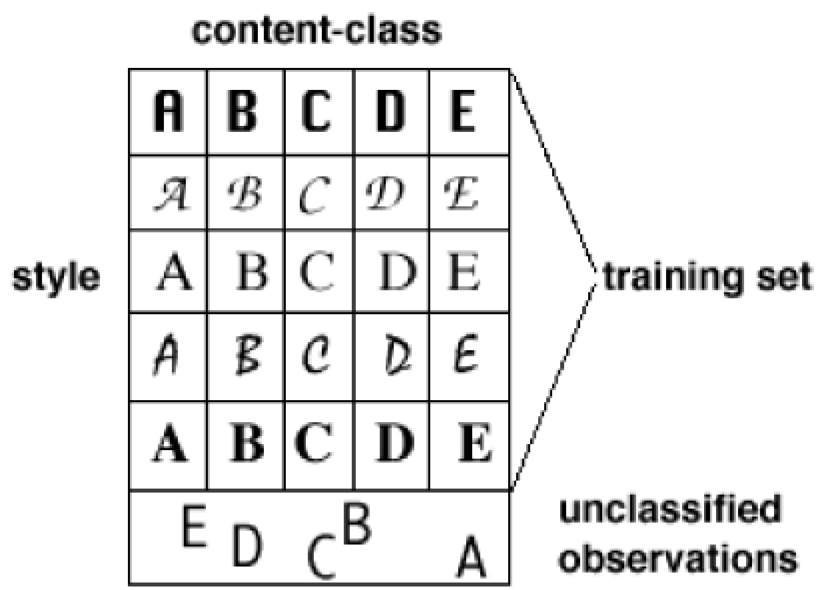
- Pattern recognition is a research area that is closely related to digital signal processing.
- Definition: "*the act of taking in raw data and taking an action based on the category of the data*".
- Pattern recognition

classifies data based on

either *a priori knowledge*

or on *statistical information*

extracted from the patterns.



Source: merl.com

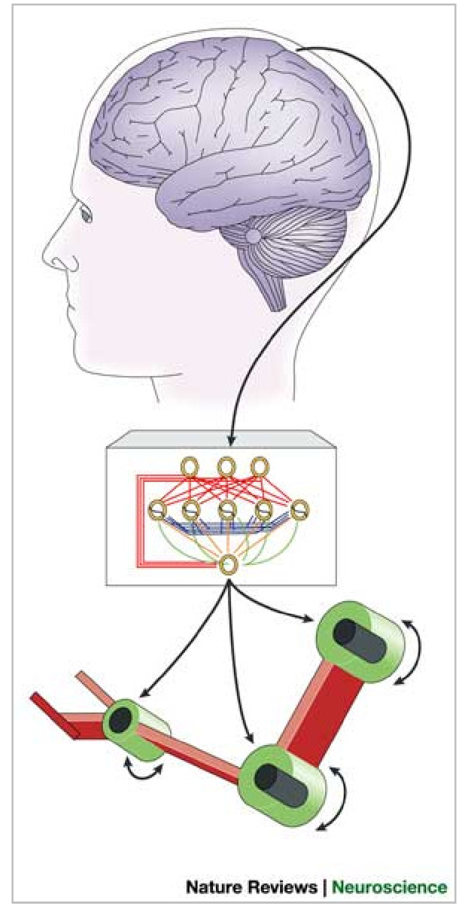
Application: Biometrics

- The "Biometrics" field focuses on methods for uniquely identifying humans using one or more of their intrinsic physical or behavioural traits.
- Examples include using face, voice, fingerprints, iris, handwriting or the method of walking.

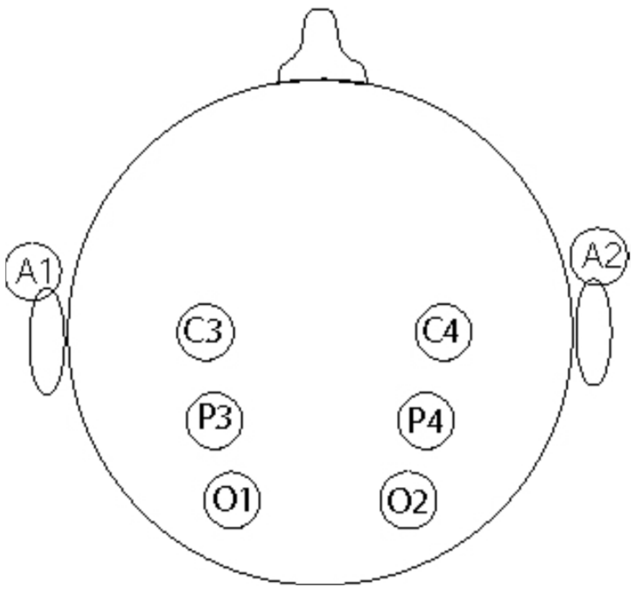
Source: BBC

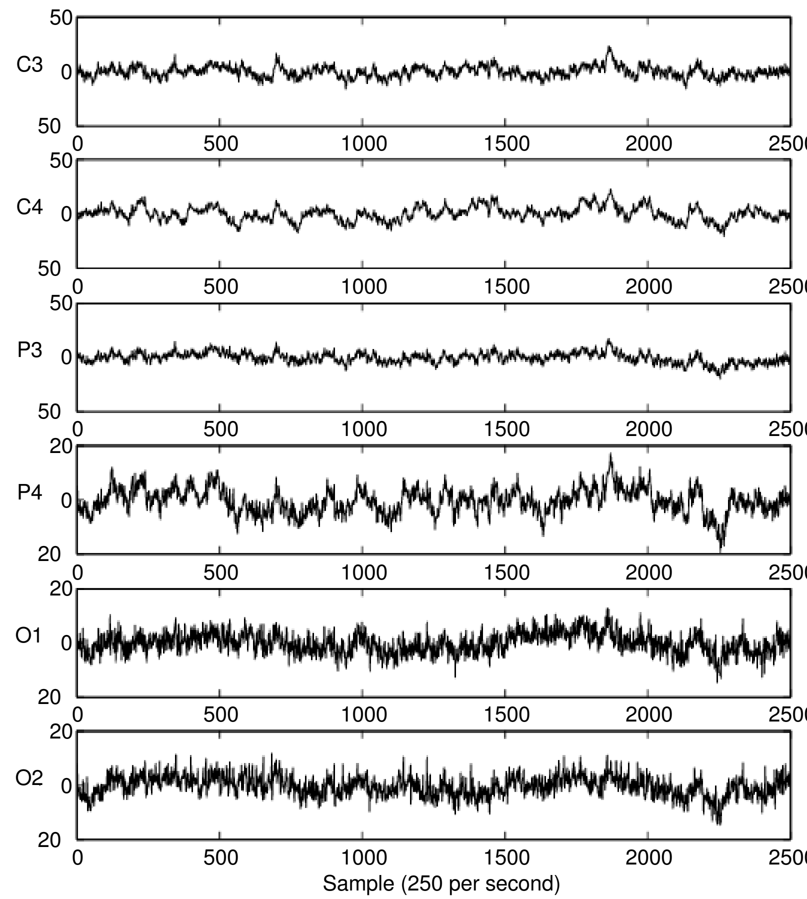
Biomedical Application: Brain computer interface

- A means for communication between a brain and a computer via measurements associated with brain activity.
- No muscle motion is involved (e.g., eye movement).



Electrode Placement and Sample Data





Pfurtscheller et al, 2003

Graz-BCI: State of the Art and Clinical Applications

IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING, VOL. 11, NO. 2, JUNE 2003

In a pilot project with a tetraplegic patient, a mechanical-hand orthosis was controlled by ongoing EEG activity based on a synchronous BCI design and two types of motor imagery. After a number of training sessions with varying types of motor imagery strategies over a period of several months, motor imagery of foot movement versus right hand movement achieved a classification accuracy of close to 100%.

BCI Application- Neuroprosthesis