Introduction to Brain Computer Interfaces

BING 8995

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What is BCI?

BMI is a broader name, BCIs refer to interfacing mainly with computers

A BCI systems permits encephalic activity to solely control computers or external devices (such as wheel chairs, robot arm – pneumatic control referred to as BMI)

Benefits – people suffering from neuromuscular diseases, computers help them to perform multiple tasks, such as computer-based videos, games, communication, etc.

Computers can control TVs, DVD and CD players, electric wheel chairs, elevators, doors, lights.

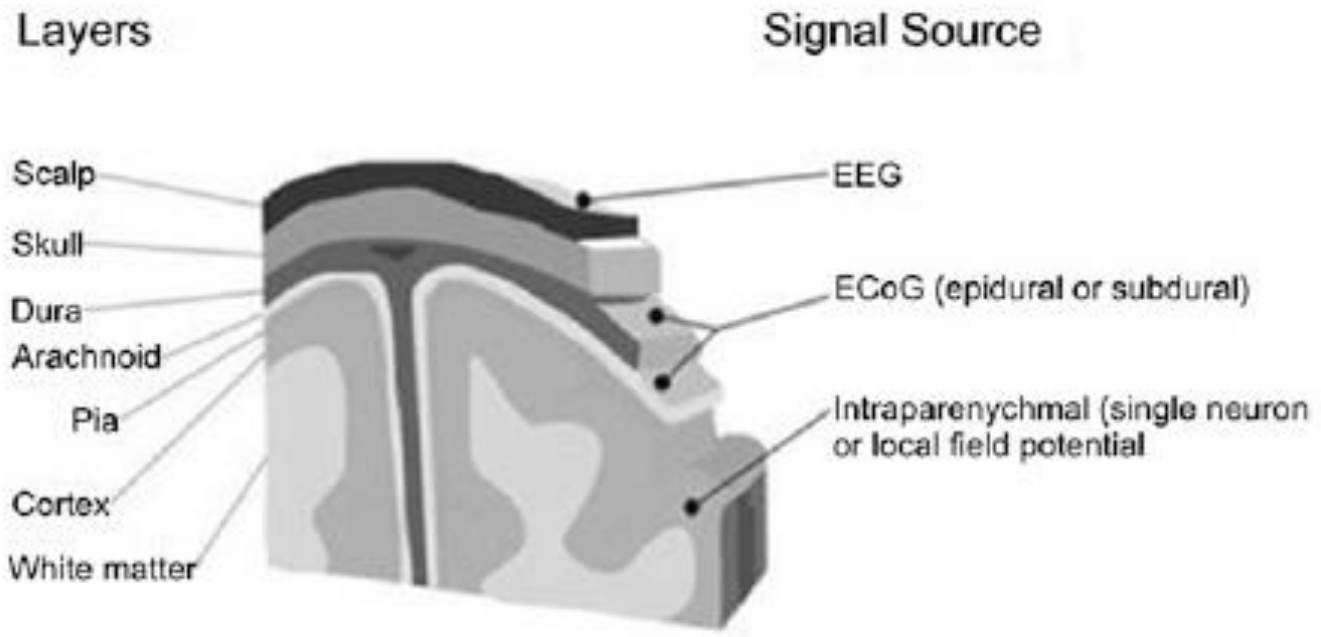
BCIs are muscle free channels of communication to external devices such as computers, speech synthesizers, assistive appliances and neural prostheses.

- BCI is an artificial intelligence based system that recognizes certain set of patterns in brain signals via
  - Signal capturing
  - Preprocessing or signal enhancement
  - Feature extraction
  - Classification
  - Control interface phases for translating the classified signals into meaningful commands for any connected device

Neuroimaging modalities

- Neuroimaging – studies physiological response in the brain, a window to the brain
- It is used to detect damages in brain tissue, skull fractures, injuries, diagnose behavioral problems, metabolic diseases and lesions on a finer scale
- Structural neuroimaging: capture skull bone structure, tissues, blood vessels, tumor
- Functional neuroimaging: detect the electrical impulses, flowing rate of blood within vessel, and change of metabolic activity happened as a response for specific task

Signals for BCI and their locations relative to the brain layers



Electrocorticography

- ECoG has higher spatial resolution than EEG
- Electrodes are placed under the skull (below the subdural or above the epidural)
- ECoG signals can control computer cursor movement (74-100% accuracy), 7 degrees of arm movement, individual finger movements and natural grasps

Magnetoencephalography

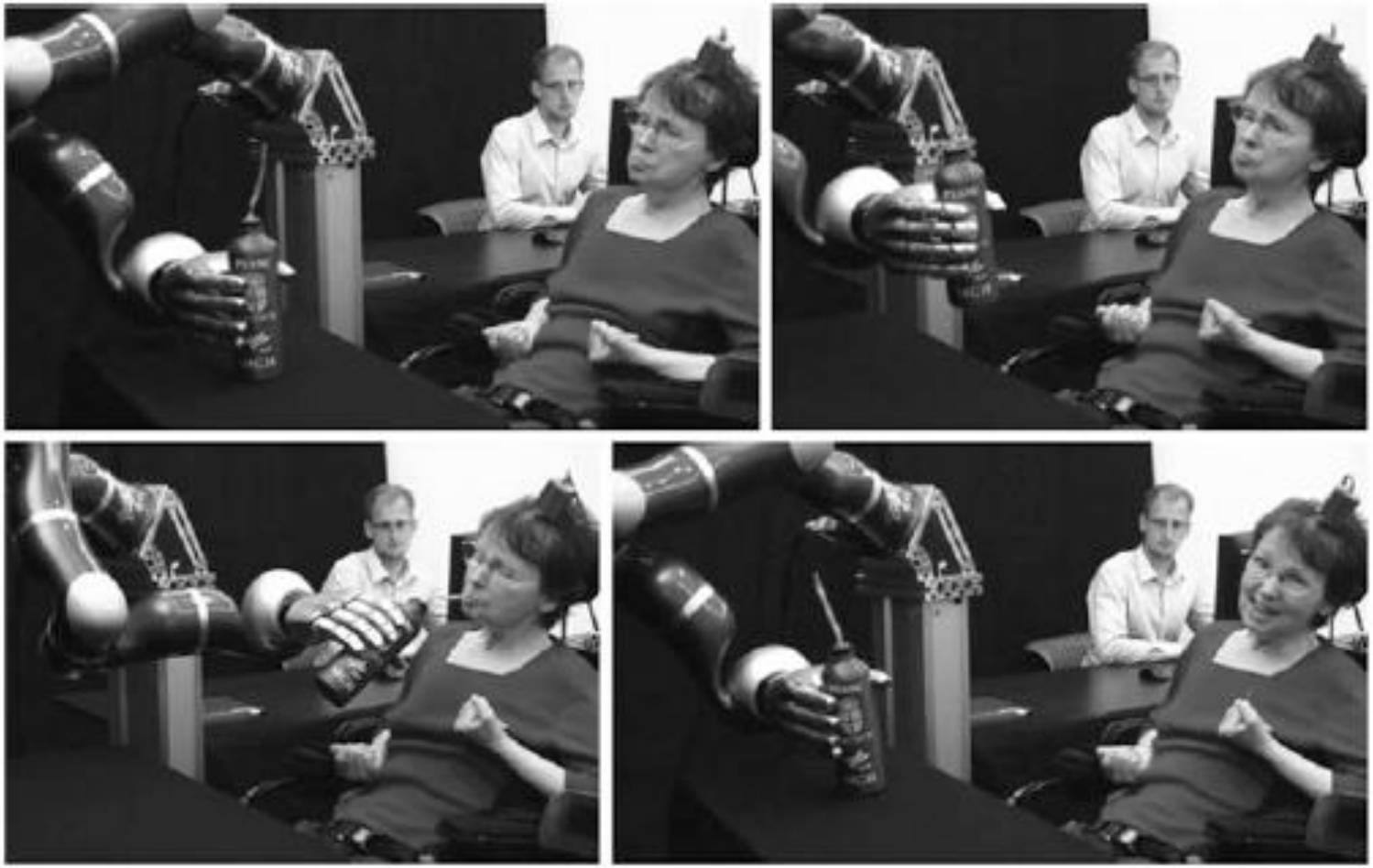
- Measures the magnetic fields generated by charged ions excited within neuron cells
- Has high temporal resolution, resolve time scale to milliseconds
- Superconducting Quantum Interference Device (SQUID) records the signals, should be used in a shielded room to reduce the magnetic field of the Earth (noise)

MEG system

Intracortical neural recording

- Use for imaging grey matter using microelectrode arrays implanted in the brain
- The electrode components vary in shape (cylindrical, planar), size (15, 50 and 75 mm), 3 days and 12 week time points for electrophysiological analyses

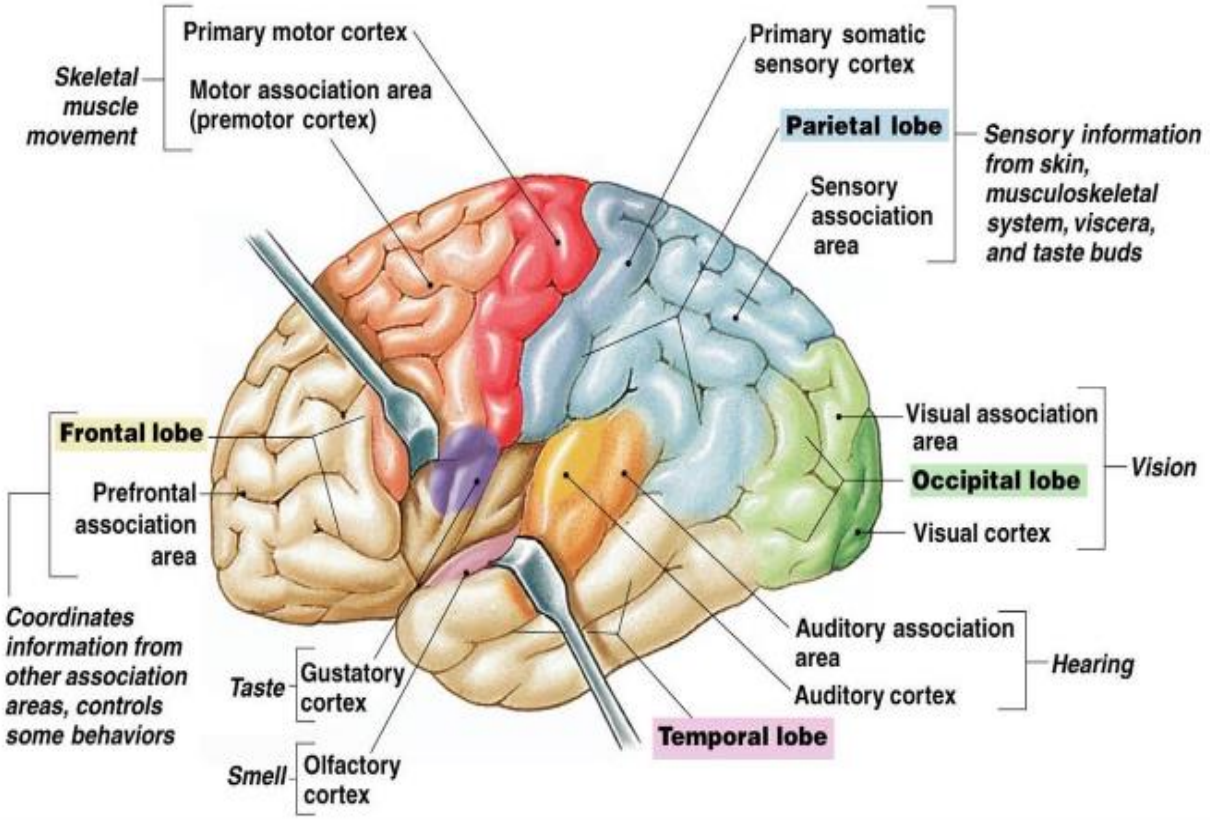
Neuronal control of robotic arm to reach and grasp a thermos



Functional Magnetic Resonance Imaging (fMRI)

- Measures changes in blood oxygenation and flow that occur in response to neural activity
- Diagnose psychological diseases such as dyslexia, autism
- NIRS: Near Infrared Spectroscopy used in agriculture, chemistry, environmental analysis
- Measures hemodynamic alterations: oxygenated hemoglobin and deoxygenated hemoglobin
- Cheap, portable, good temporal resolution
- Limitation: vascular changes occur a certain number of seconds after neural activity

Basic functional mapping



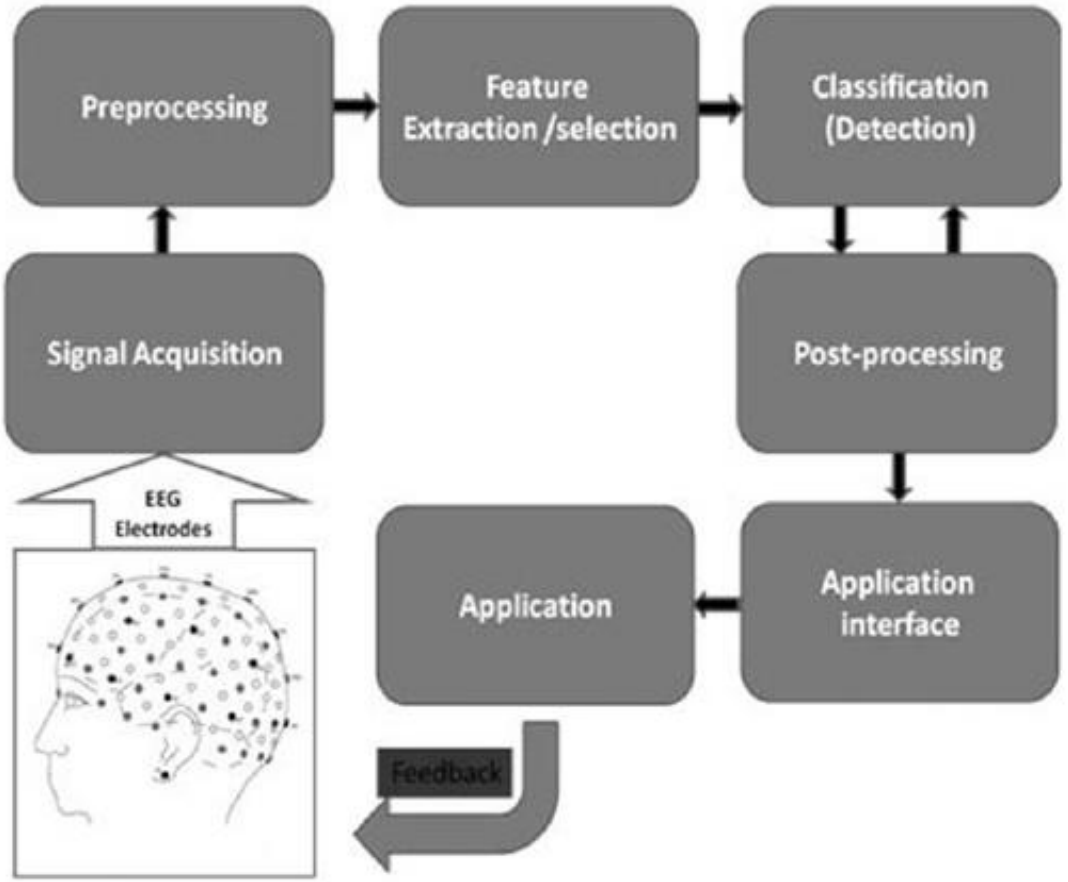
Control signals in BCI systems

- EEG is a noninvasive method that records brain electrical activity. EEG rhythms are classified as
- Delta waves: 0.5 – 4 Hz: found in infants and in deep sleep stage in adults. Normally appearing in the deeper stages of sleep. Any anomaly is indicative of neurological diseases, in adults in an awake state
- Theta waves: 4 – 7 Hz: Amplitude of 20 µV: seen during drowsiness and light sleep stages, but may be present in wakefulness. Theta band has been associated with meditative concentration and a wide range of cognitive processes such as mental calculation

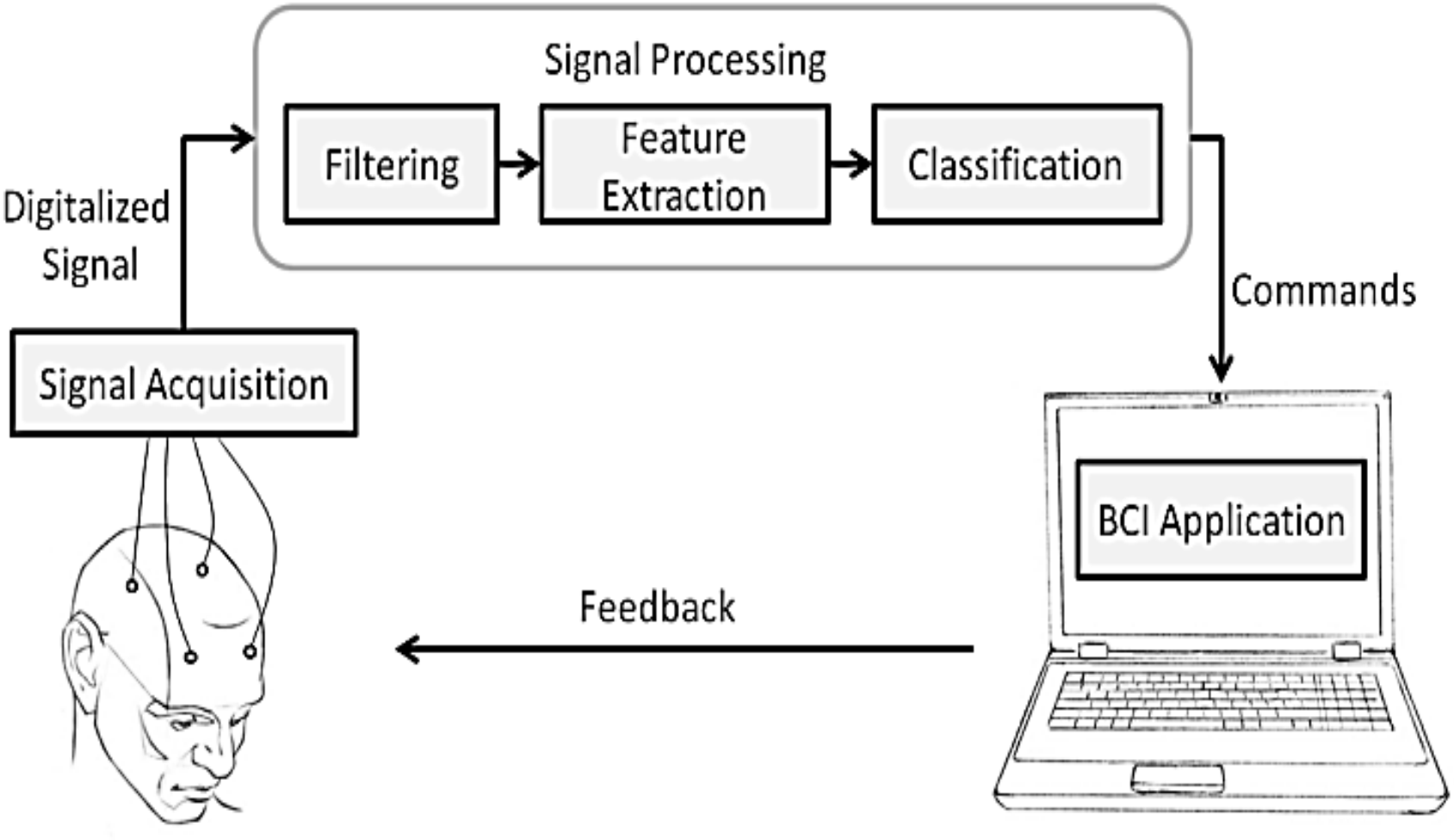
Brainwave

- Alpha waves: 8 – 13 Hz: Amplitude of 30 to 50 µV: seen best when eyes are closed and most pronounced over the occipital regions. The amplitude of the alpha rhythm is attenuated by eye opening, attention, and mental effort. The *mu*-rhythm (7-11 Hz) appears in the alpha band that occurs in the central and centro-parietal regions in wakefulness. The mu-rhythm is not attenuated by eye-opening but by contraction of muscles on the collateral side of the body. This will be the main focus frequency range for motor imagery classification.
- Beta waves: 13 – 30 Hz, Amplitude of 5 to 30 µV: evidently seen in the frontal and central lobe area and are associated with mental engagement such as activity, busy and anxious thinking
- Gamma waves: 35 Hz and up: Have very sharp waves, spikes and other non-sinusoidal activity, related to certain motor functions or perceptions, such as visual and auditory stimuli and high information transfer rate it offers higher spatial specificity.

Fig 1.10 Different stages of EEG signal processing



EEG based BCI



Data collection through electrodes

- Electrodes are placed on the scalp using a gel as a conducting material
- Number of electrodes: 10 to 20, 32, 64, 128 or 256, 500
- BrainAmp has both passive and active (actiCAP) electrode systems
- BCIs can directly control robot or prosthesis without employing a personal computer

Pre-processing methods in BCI designs

- Sources of noise in EEG signals
- Brain signals have small SNR
- Two types of noise: from external, environmental sources of noise, AC power lines, lighting and a large array of electronic equipments
- Electro-magnetic noise, direct current lighting (insulate recording room from EM noise by use of a Faraday cage)
- Physiological artifacts: Electrooculargraphic activity (EOG, eye), electromyographic activity (EMG, muscle), electrocardiographic activity (ECG, heart), balistocardiographic (heart-related pulsatile motion) and respiration
- Additional EEG signal attenuation by intervening veins and skull

Preprocessing techniques

- Avoid blinking and body movement
- Artifact removal: Filtering and higher-order statistical separation
- Blind Source Separation (BSS): higher-order statistical difference between artifacts and cerebral components
- Independent Component Analysis (ICA) to remove blinks, EMG and line interferences. It is superior to PCA, regressive methods

Feature extraction for BCI designs

- Features can be binary, categorical or continuous
- Amplitude values of EEG signals, Band Powers (BP), Power Spectral Density (PSD) values, Auto regressive (AR) and Adaptive AutoRegressive (AAR) parameters, Time-frequency features and inverse model-based features

Feature dimension reduction techniques

- Dimension of raw EEG signals: 102 – 103 features
- Feature selection or subspace learning
- Goal: find a feature subset of size n (n<<M) that maximizes the system's ability to classify object instances
- Fisher criterion (Fisher score), Linear Discriminant Analysis (LDA), Principal Component Analysis (PCA) – uses first and second moments of the measured data-relies on Gaussian data, and Independent Component Analysis (ICA) -8 independent sources, only 2 sources are used in P300
- Genetic Algorithm (GA): evaluates a set of solutions simultaneously, does not get stuck at local minima, does not require assumptions about interactions between features

Classification methods and post processing
Properties of classifiers

- Generative/Discriminative: Bayes learns class models. Generative classifiers compute likelihood of each class and choose the most likely. Discriminative- Support Vector Machines (SVM)
- Static/dynamic: multilayer perceptron (static), Hidden Markov Model (HMM) is a dynamic classifier-catches temporal dynamics
- Stable/unstabe: LDA, unstable: multilayer perceptron
- Regularized: carefully control complexity to prevent overtraining , has good generalization performance and is more robust to outliers

Classifiers used in BCI research

- Linear classifiers
- Neural networks
- Nonlinear Bayesian classifiers
- Nearest neighbor classifiers
- Combinations of classifiers
- Classification performance metrics