Intro2BCI

Revision Lecture
(27/10/2010)

Outline

- Review of the course
- Example Exam questions
- Questions/Answers

Review of the Course

- 1- Introduction
- 2- Neuro-science Primer
- 3- Detectors
- 4- Decoding
- 5- Transduction & Output
- 6- Induced BCIs
- 7- Evoked BCIs
- 8- Heamodynamic (fMRI) BCI + Passive BCI
- 9- BCI for Rehabilitation + Neurofeedback

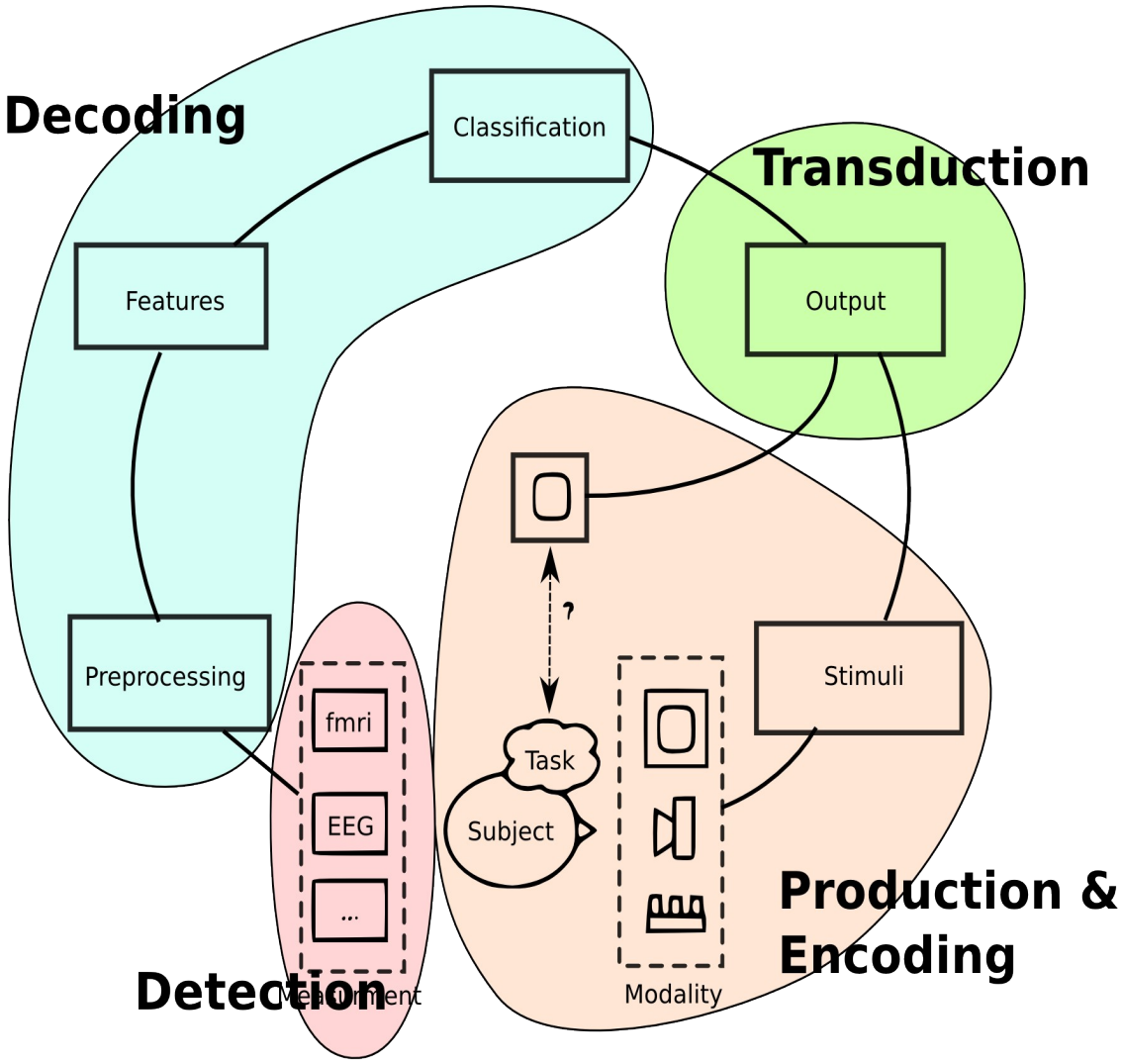
1- Introduction

- What is a BCI?
  - a system which allows someone to communicate information about their mental state without the use of the peripheral nervous system.
  - means detecting (some aspect of) the users mental state from their brain signals
- The BCI-cycle consists of 4 main stages: signal production, detection, decoding and transduction.

1- Introduction

Fundamentally, BCI is a simple(?) engineering problem;

1) Signal Production: Get the person to produce a strong brain signal, either by performing an explicit mental-task, or through normal mental processes
2) Detection: Build a machine able to measure the properties of their brain, e.g. EEG, MEG, fMRI
3) Decoding: Build a machine able to decode the measurements to deduce the users mental state
4) Transduction: Communicate the mental-state to the outside world.



1- Introduction

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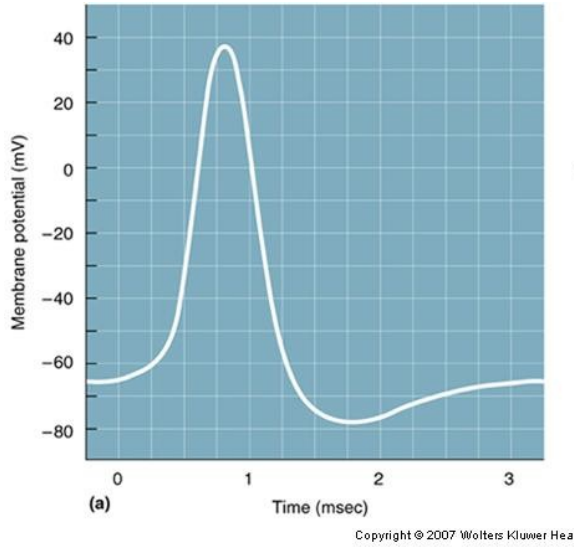
  - means detecting (some aspect of) the users mental state from their brain signals
- The BCI-cycle consists of 4 main stages: signal production, detection, decoding and transduction.
- Why is BCI hard?
  - BCIs must get, faster, more accurate and easier to use to approach the sci-fi ideal.
  - Low s2n, inter-subj var, inter-session var,
- Categorization of BCIs –
  - Active - require the user to encode their intentions in special easy to detect mental tasks
  - Passive – detect the users on-going mental state
  - Dependent – rely on external stimulus
  - Independent – rely on internally generated mental state
  - Hybrid – bit of both

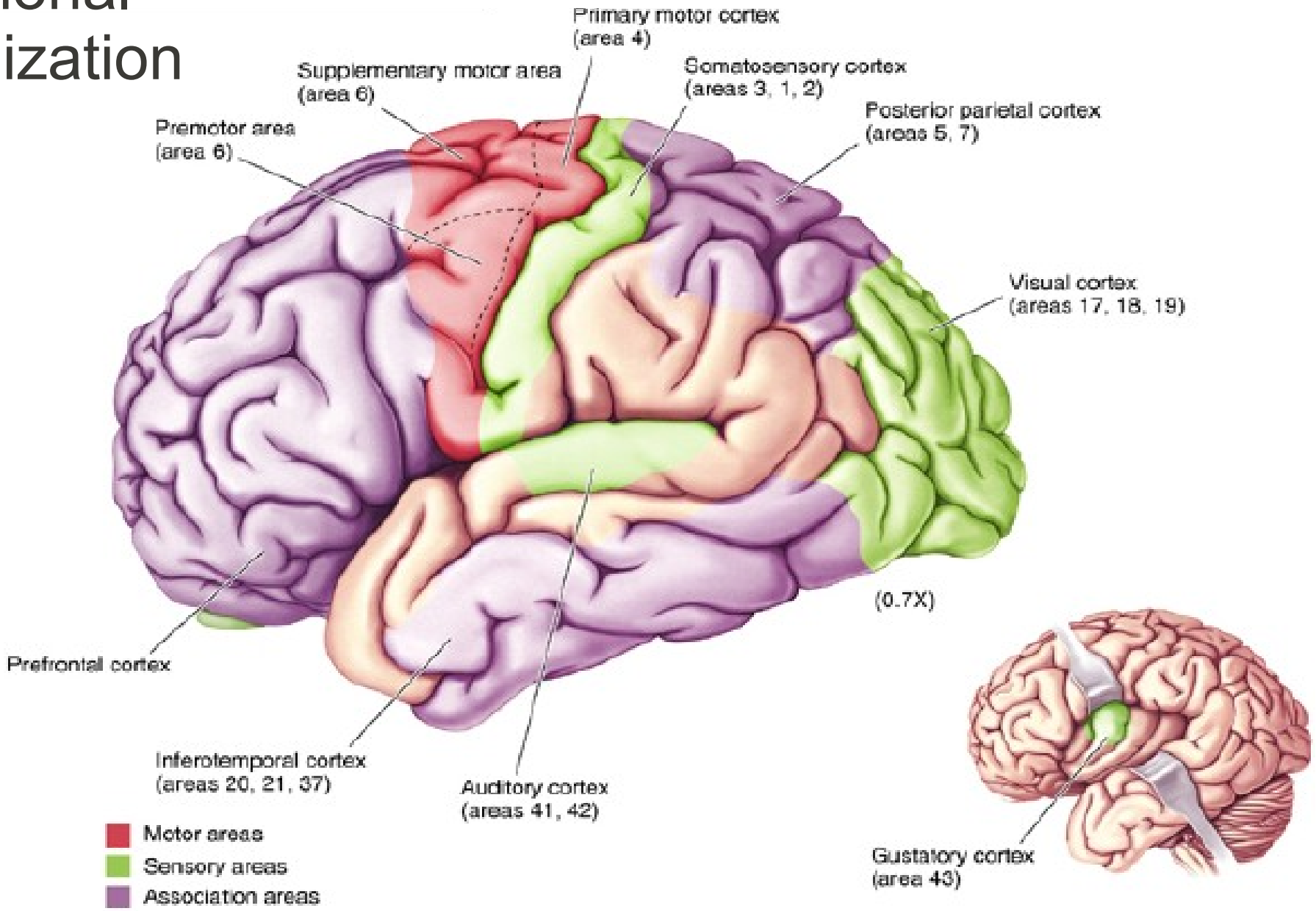
2-Introduction to Neuroscience

- Neurons – basic building blocks of the brain
  - Axons, dendrites, soma, membrane
- Resting potential – maintained by ion pumps
- Action potential –
  - spike caused by membrane depolarization beyond activation threshold
  - Prototypical shape
  - All-or-nothing, long-range communication along axon
- Synapses – communicate information between neurons, using chemical neuro-transmitters
- Integration (spatial/temporal) of EPSPs allows neuron to perform computations



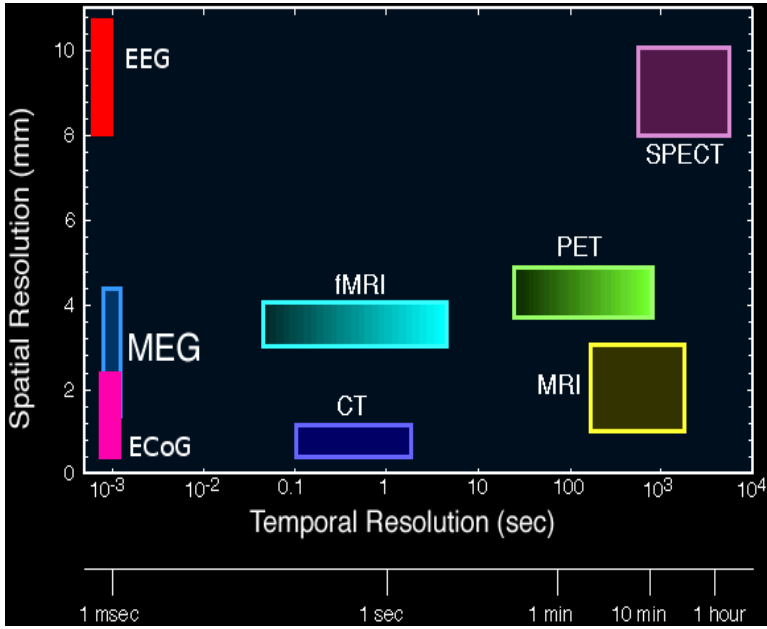
2-Intro to Neuroscience

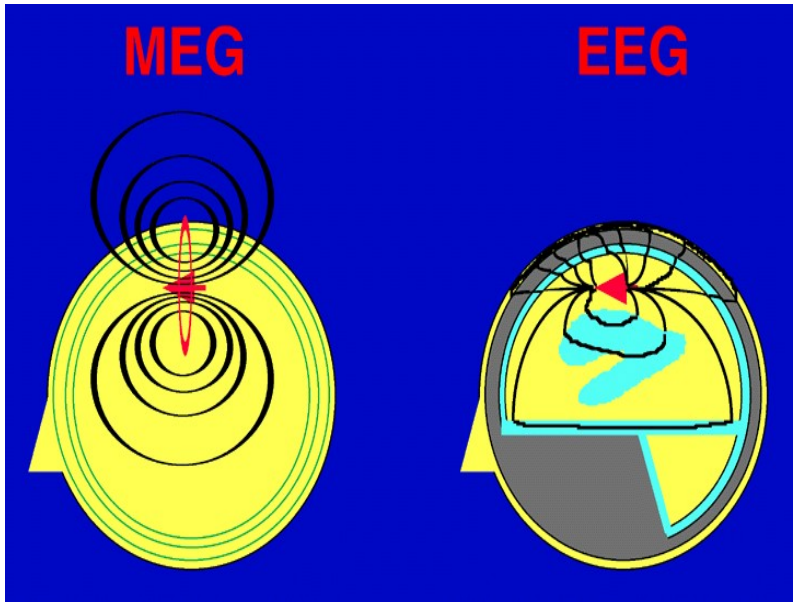
- Functional organization



3-Detectors

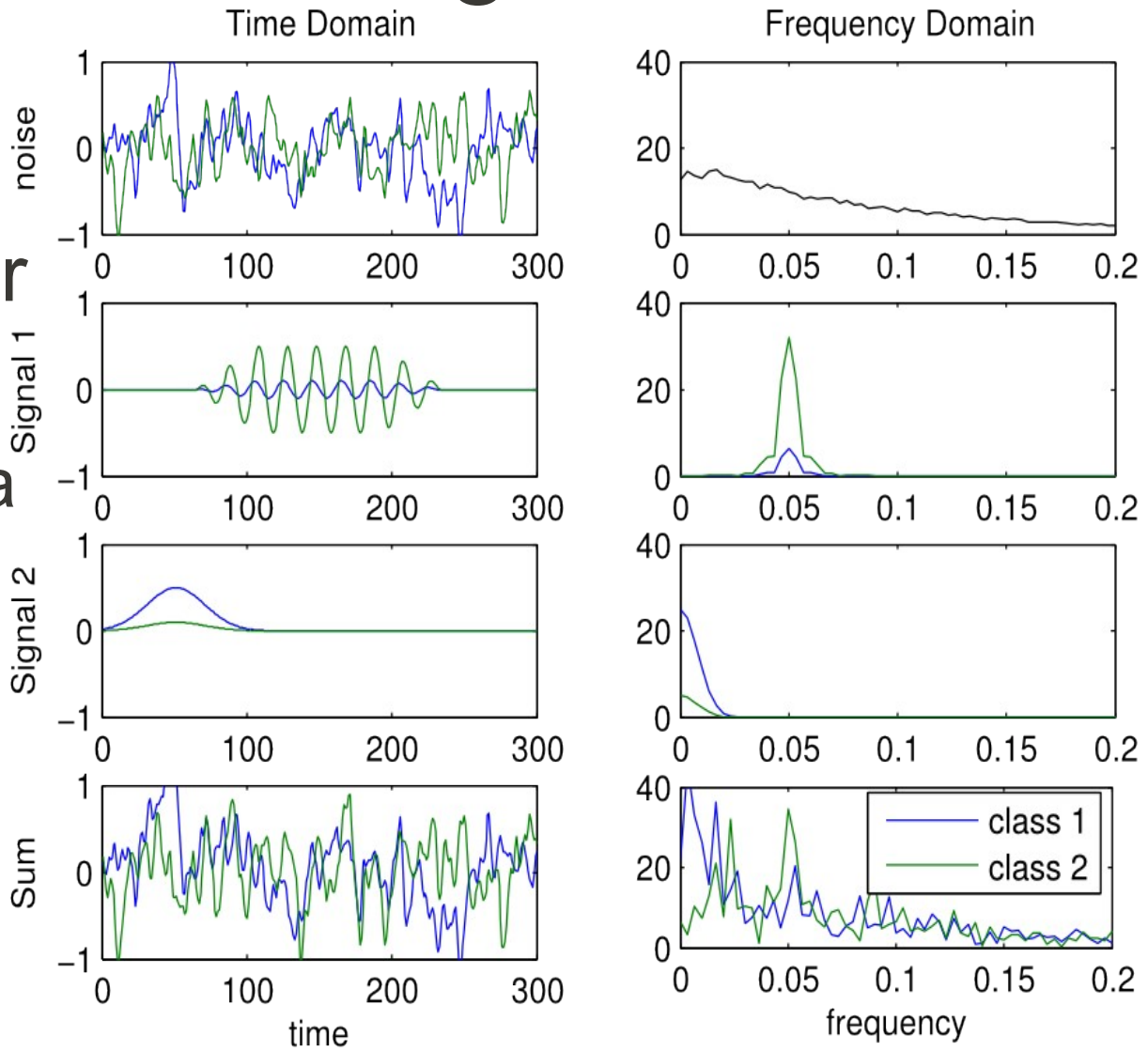
- Types Detector: EEG, MEG, EcoG (iEEG), wire-electrodes, fMRI
- Spatio-temporal structure of measure signals
- Different dececters give different spatio-temporal resolution
- EEG/MEG –
  - measure post-synaptic currents
  - Need synchronised activity of millions pryamidal cells
  - EEG – extra-cellular current only, tangential+radial, spatially smeared by skull
  - MEG – intra+extra-celluar current, tangential only, free-space propogation
- Evoked – time-locked responses
- Induced – non-time-locked, spectral responses





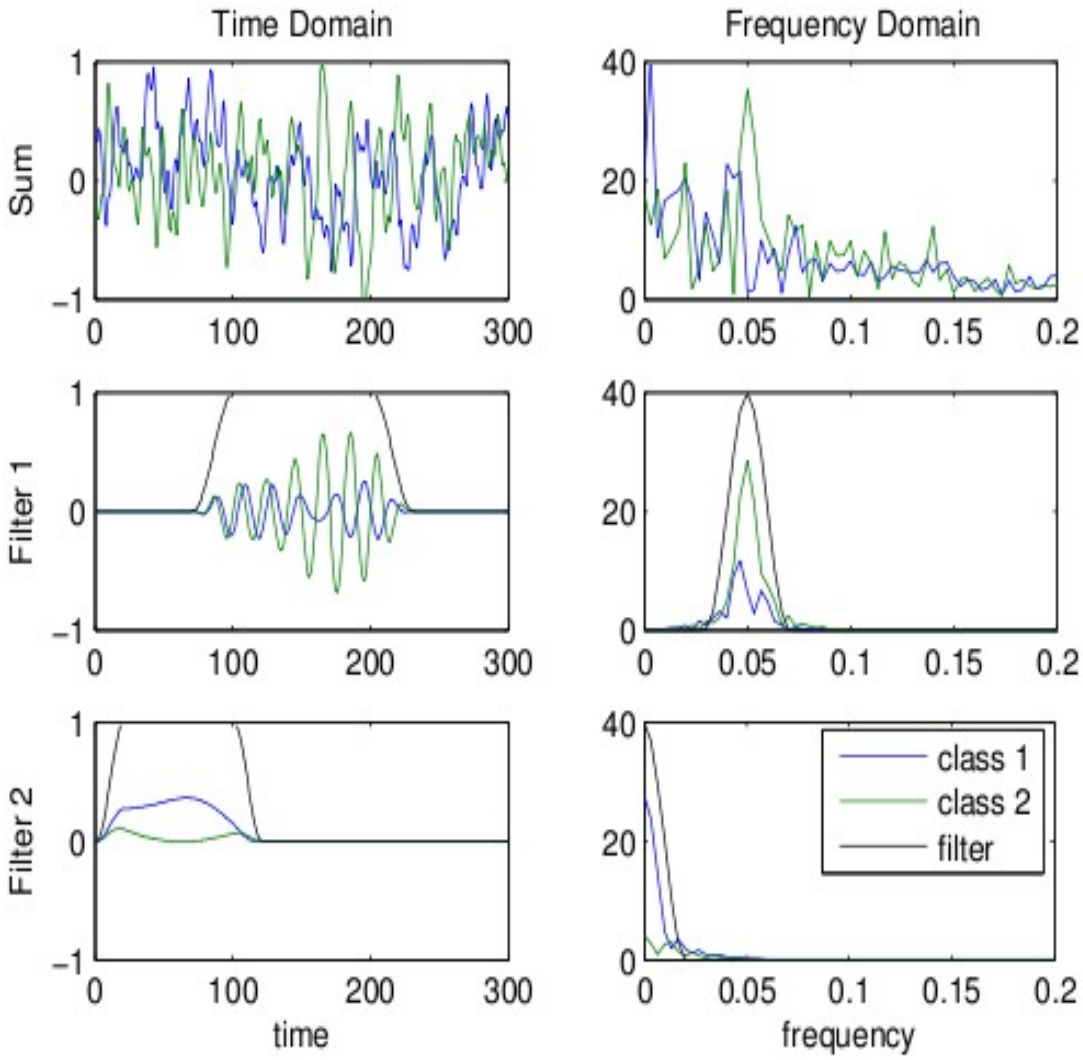
4 - Decoding

- Signals can be represented in; time, frequency or time+frequency
  - (though there is a limit to the TF resolution)
- Different representations make different characteristics of the data apparent

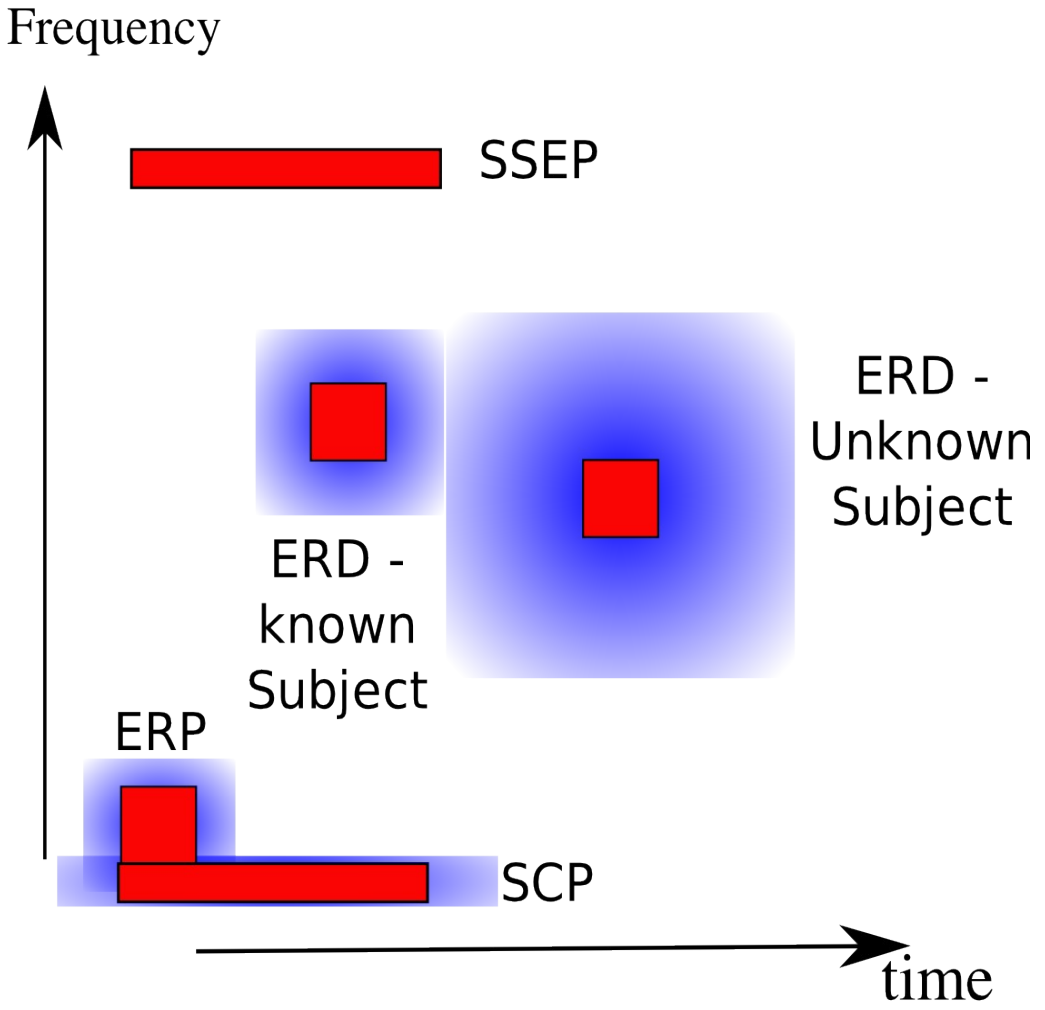


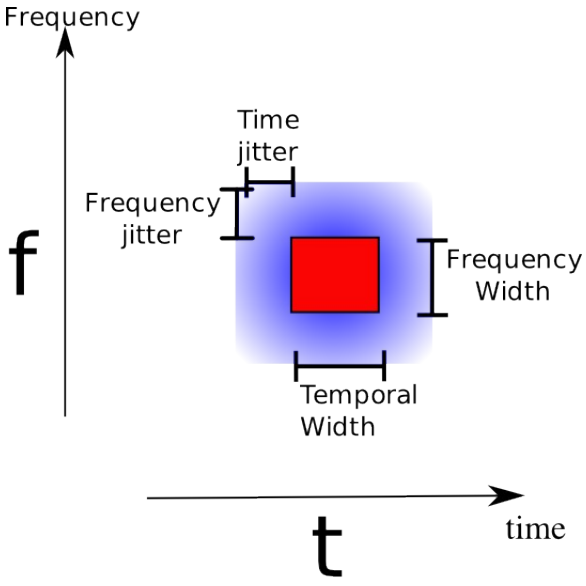
4-Decoding

- Averaging –
  - Used in time/frequency domain to suppress the non-time/frequency locked components
- Filtering
  - Used in time/ frequency/ spatial/ (time+frequency) domains to remove non-signal suppress/remove known noise signals



4-Decoding





- Characteristics of common BCI signals – used to design filters

5-Transduction+Output

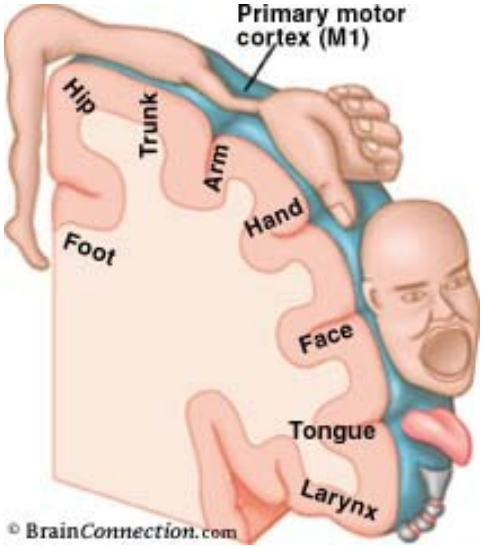
- The output stage of the BCI is primarily concerned with HCI issues, e.g. Ease of use, ease of learning, stimulus compatibility
- The unreliable, low-bit-rate, high-latency, nature of BCI mean the system must be designed for these properties
- Contextual information can be used to reduce the number of decision needed to transmit a message
- BCI designs used for spelling include; p300-visual-speller, TTD, Graz-virtual-keyboard, Dasher, Hex-o-spell, etc.
- Information Transfer Rate (ITR) gives a better idea of a BCIs usefulness than classification rate alone

$$B = VR$$

$$R = \log_2(N) + P\log_2(P) + (1-P)\log_2\left(\frac{1-P}{N-1}\right)$$

6- Movement Based BCIs

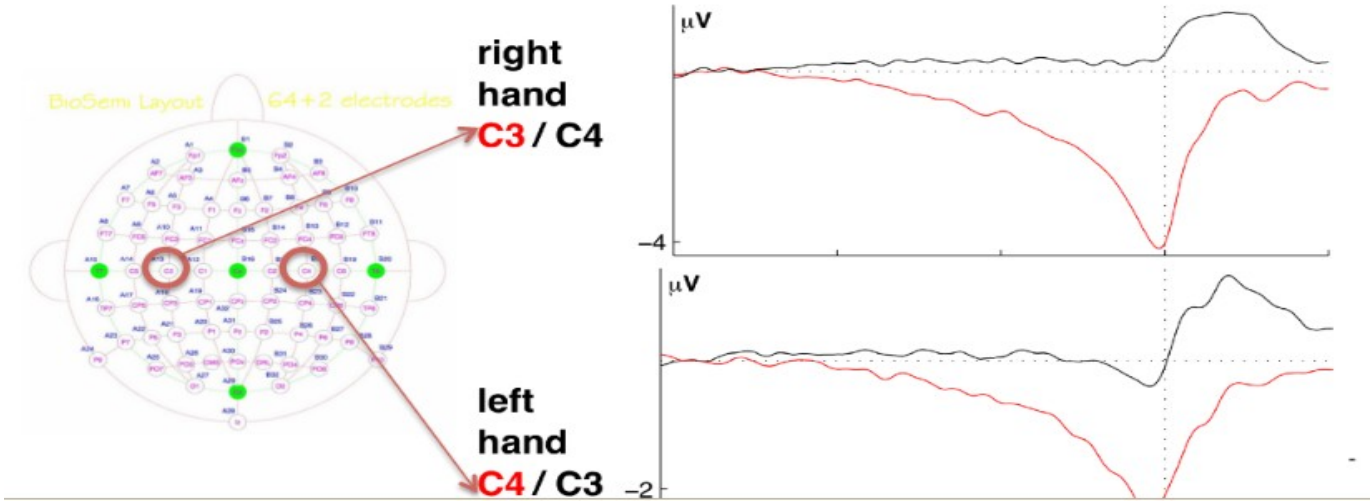
- There are many ways an intention (e.g. write a letter) can be transformed into motor commands
- Further, there are many motor commands which can achieve the same goal – many neural structures support motor planning/execution
- There is a functional-equivalence between motor-execution and imagined movement
  - Motor Imagery can improve actual performance
- 3 types imagined movement: visual 1st vs. 3rd person, and kinesthetic
- Motor observation can activate similar pathways as imagination
- Subjects posture influences easy of motor imagery

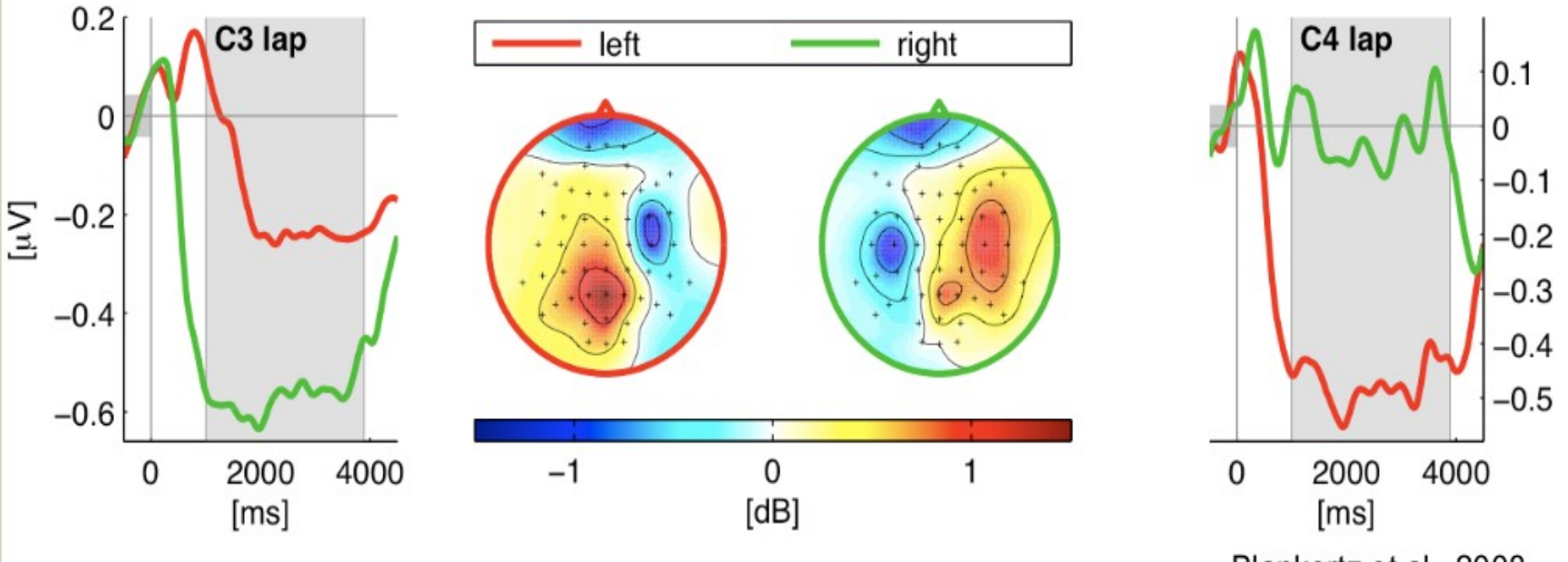


6-Movement Based BCIs

- Brain signatures of motor imagery

Lateralised Readiness Potential (LRP)





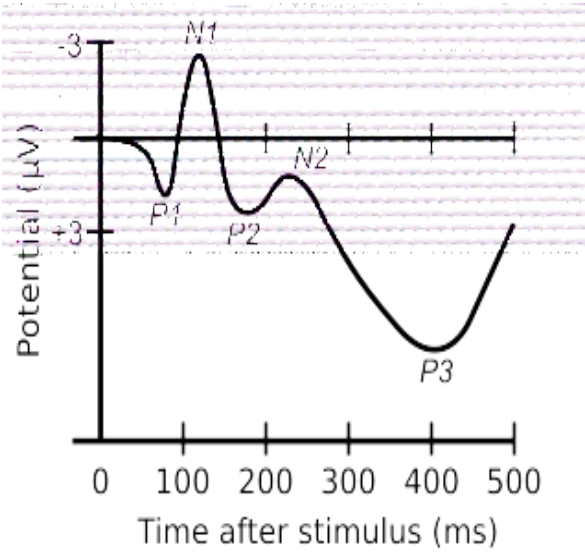
ERD/ ERS

6-Movement Based BCIs

- BCI performance influenced by:
  - Type of imagination (kinsethetic/visual), speed of imagined movement, duration of movement, but **not** type of movement
- IM used for: brain-switch, 2/3-d cursor control (with user training), spelling (hex-o-spell)
- Mu-peak height → predictor of IM BCI performance

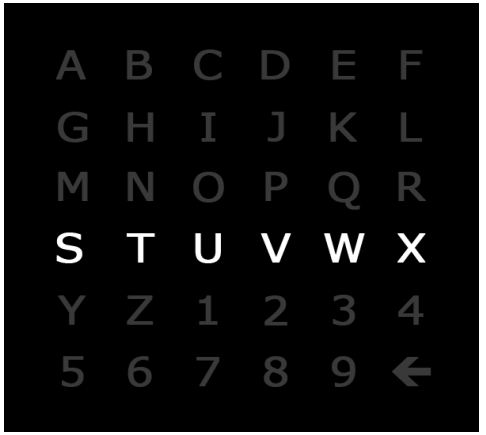
7 – Evoked BCIs

- ERP – time-locked signal generated in response to stimulus
- Can depend on more than raw stimulus properties, e.g.
  - Syntatic processing, semantic processing, semantic updating, error-processing, surprise, etc.
- P300 – 'oddball' response
  - Evoked by: unusual stimulus, absence of stimulus
  - Influenced by: uncertainty resolved by event, importance of the stimulus
  - P300a – stimulus response
  - P300b – cognitive response



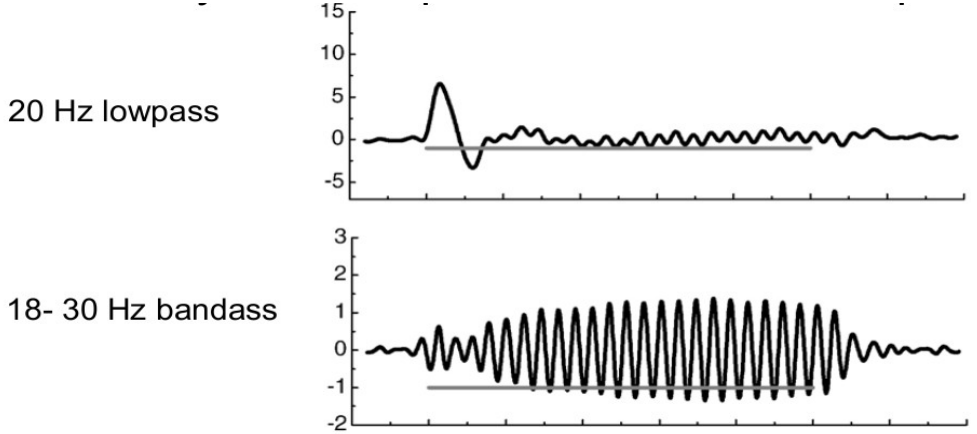
7-Evoked BCIs

- P300 - ERP applications
  - Cortically Coupled Computer Vision (CCCV/RSVP), Brain-fingerprinting
- BCI spelling (Farwell&Donchin) matrix speller
  - Parallel selective attention task
  - Each symbol has unique sequence of 'odd-ball' events
- Overt vs. covert attention
  - Most matrix speller performance based on eye-pointing **but** still works without it..



7-Evoked BCIs - SSEPs

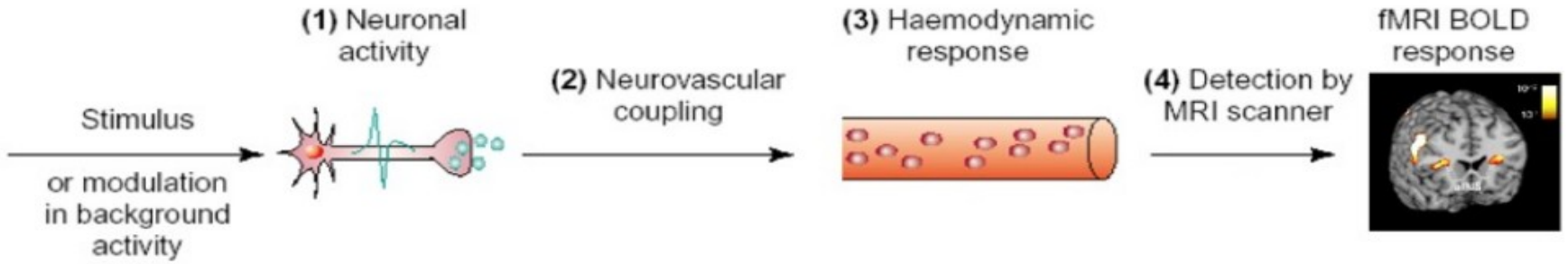
- Steady State Response
  - response to long-term periodic stimulus



- Modality dependent optimal frequency
  - Visual (VSSEP)– 16-20Hz, occiptial cortex
  - Auditory (ASSR) – AM modulation ~40Hz, auditory cortex
  - Tactile (SSSEP) – AM ~21Hz, contralatorial somatosensory cortex
  - Used to diagonise correct operation of the sensory system
- Response amplitude influenced by selective attention
  - Used for parallel/serial selective attention BCI

8 – fMRI BCI

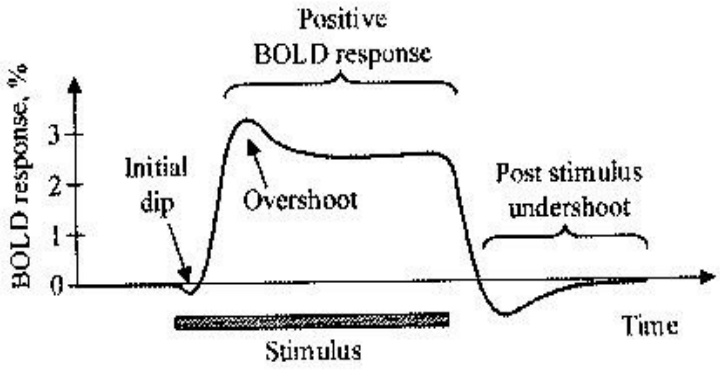
- fMRI – measures the haemodynamic response caused by neural activity



Source: Arthurs & Boniface, 2002

TRENDS in Neurosciences

- Output is 3d matrix of activation ~3mm voxels every 2s
- BOLD response lags activity by ~6s
- rtFMRI used for: BCI, lie-detection, training to up-regulate activity, etc.



8 – fMRI BCI

- fMRI also used for brainreading (passive-BCI)
  - decoding brains response to **natural** stimuli
  - 3 types decoding: classification, identification, re-construction
- This works because;
  - 1) functional organization means different brain regions process different stimulus features, e.g. retinotopic organization, V1, V2, V3, etc. objects, semantics
  - 2) biased sampling means large-scale voxels have a bias towards certain small-scale spatially distributed features
- Combining information from multiple feature levels can be used to improve the reconstruction performance

8- Passive BCIs

- Passive BCI – just observes the users ongoing mental state
- Dependent Passive BCI
  - Brainreading - decode the stimulus the user is experiencing; 3 sub-problems; classification, identification, re-construction
  - Cognitive response detection – decode the users subject experience of the stimulus, e.g. emotion, error, recogination
- Independent Passive BCI
  - Assess users current mental-state: e.g. workload, emotion, alertness

8-Passive BCIs

- Example Applications
  - Error detection/correction
  - Brain fingerprinting
  - Rapid-serial visual presentation
  - Auditory brainreading – EEG ERP based classification of the heard musical fragments

9-Rehabilation

- Clinical applications of BCI
  - Communication – CLIS/LIS patients
  - Neuroprosthesis – bypass spinal-cord-injury
  - Rehabilitation of movement – stroke recovery
- Rehabilitation relies on plasticity
  - Changing of neurons, organization of their networks and their functions via new experiences
  - Recruitment – heavily used functions enlarge as they recruit adjacent underused areas
    - e.g. finger region, occipital recruitment in braille readers, increased auditory-cortex size in deaf, phantom-limb syndrome in amputees

9-Rehabilitation

- Plasticity in BCI
  - Allows users to 'internalize' BCI control so user no-longer thinks of the mental task
  - Updated body-schema to include the prosthetic: monkey example
- Neuroprosthesis
  - Reinnervation - via. chest muscels
  - BCI controlled robotic limbs
  - BCI controlled function electrical stimulation of the users limbs
- BCI for movement restoration
  - BCI used to **force** subject to continue using damaged/disconnected areas
  - Prevents decay
  - may promote recruitment of near-by undamaged areas

Example Exam Questions

- Format:
  - 2hr closed-book exam
  - 9 questions (1 per lecture topic)
  - Answer 7 questions for full-marks (~15min/question)
  - Mostly short essay style questions (should need no more than 2 paragraphs per question section)

Q1: Introduction (10 marks)

a) What is the definition of Brain Computer Interfacing (BCI) used in the lectures. What are its' important distinguishing characteristics compared to other human-computer interfaces.

b) Draw a labeled diagram of the (simplified) 4-stage BCI cycle used in the lectures, and *briefly* (in 1-2 sentences) explain the purpose of each stage in the cycle.

c) BCIs demos have existed since the early 1990s however transitioning from a demo to a usable system has been slow. List the main (at least 2) objectives in making a useable BCI and (at least 2) the possible reasons which make achieving this objective difficult.

Q2: Tasks + Signatures + NeuroImaging

a) Define the following terms;

Resting Potential

Action Potential

Synapse

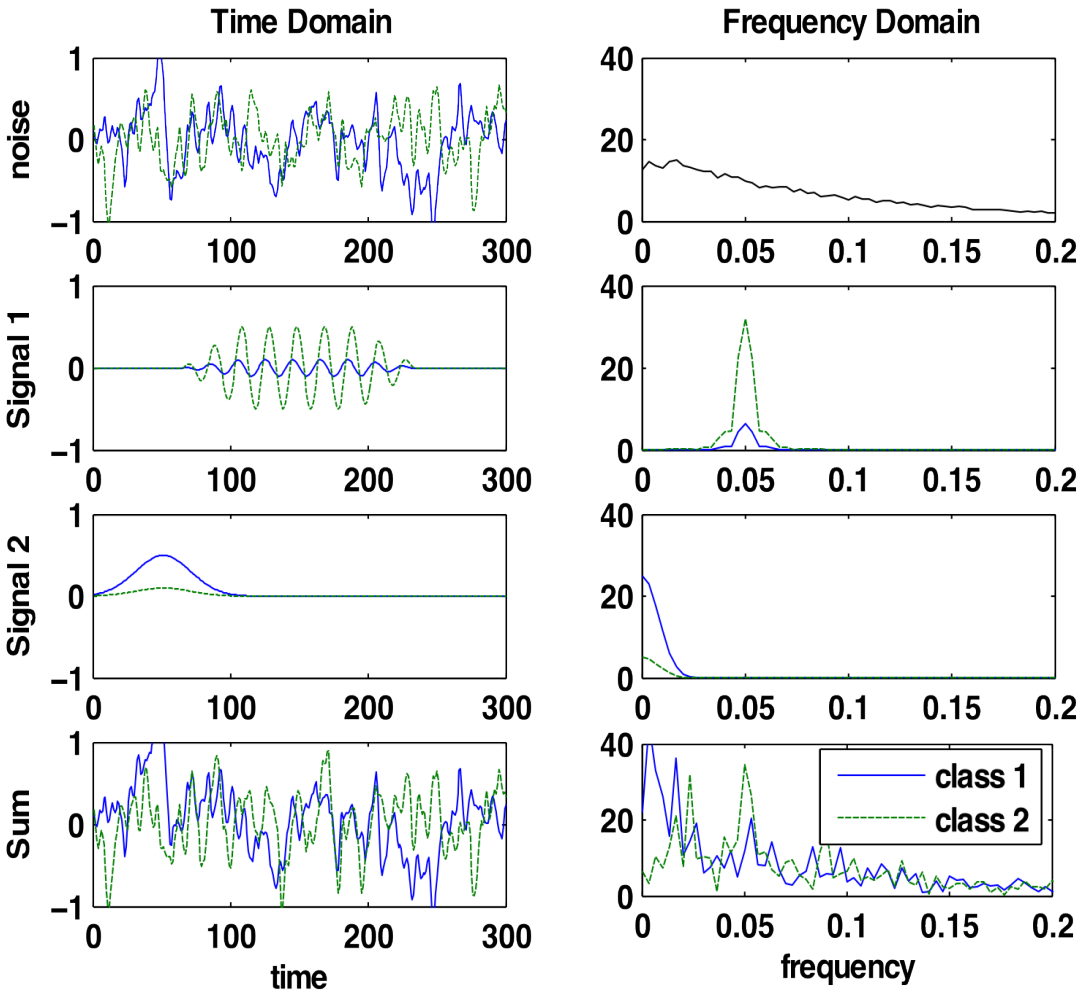
b) Neurons can act as a simple type of analogue computer by integrating their incoming Excitatory Postsynaptic Potentials (EPSP) over time and/or space. Explain how this **integration** is achieved. Draw a diagram showing a single EPSP and then how the neuron combines multiple EPSPs when generated at multiple locations or times to exceed the Spike threshold. (Note: you do not need to explain how the EPSPs are integrated by the neuron, **not** how they are generated or propogated).

c) Four (4) types of electrofysiological brain signal detectors were discussed in the lecture. Name each and give a short description of their characteristics and how they differ from the others. You should particularly mention the spatial and temporal resolution of each detector type and its sensitivity to artifacts.

Q3: Decoding (10 marks)

a) The figure below shows the time domain and frequency domain characteristics of two signals and the background noise. Explain what a time-frequency representation (TFR) is, and for the 2 signals below (signal 1 and signal 2) sketch what you would expect their TFR to look like.

b) Averaging can be a powerful and widely used technique for making signals embedded in noise more apparent. Explain how you would use averaging to enhance time-locked and frequency-locked (but not time-locked) signals.



Q4: Transduction and Output (5marks)

a) Contextual information can be used to improve the performance of many BCI systems.

Describe what is meant by contextual information, and describe a BCI application area where contextual information is particularly useful and how it can be used.

Q5: Imagined Movements (10 marks)

a) Explain the meaning of the following terms, in the context of Imagined movement BCIs

Readiness Potential (RP)

Event-Related De-synchronization (ERD)

Event-Related Synchronization (ERS)

b) One can imagine movements in many different ways. Two such ways are Kinesthetic and Visual. Explain the difference between these 2 types of imagination and mention the relevance of this distinction for BCI purposes.

c) Quasi-movements are a further type of imagined movement. Explain what this term means, and how it's relevant for BCI – particularly for certain patient groups.

Q6: Evoked Responses (10 marks)

a) The p300-style visual speller is one of the most popular BCIs. Explain how it works, in particular how the flashes evoke responses in the brain which can be used to identify the attended letter.

b) Give at least 3 examples of different event-related potentials (ERP), and the ways they can be used (or might possibly be used) in brain-computer interfacing applications.

Q7: Passive BCI (10 marks)

a) Define the terms Active BCI and Passive BCI with an emphasis on the differences between these 2 types of BCI.

b) Pick 1 (**one**) of the following Passive BCI systems and describe how it works.

Brain-Fingerprinting

Cortically Coupled Computer Vision (also called Rapid-Serial Visual Presentation)

Alertness Monitoring

N.B. Your description should include the type of stimulus used (if any), the task the user performs and the type of neural signal generated by the task, and how the neural signal is used in the application.

b) In the paper: '*Visual Image Reconstruction from Human Brain Activity using a Combination of Multiscale Local Image Decoders',* fMRI is used to reconstruct images. fMRI has very different properties than EEG. Describe one positive property and one negative property of using fMRI **specifically** for the problem of decoding of images.

Q8: Rehabilitation (10 marks)

a) Describe how BCI could be used for re-habilitation purposes in spinal-cord-lesion bypass.

b) Further describe (2) two possible ways in which **plasticity** can be used in rehabilitation applications to improve the patients ability to use the BCI system and/or long term recovery. (Hint: tool-use, cortical representation, efferent signals)

b) Neurofeedback has received a lot of publicity in recent years as a solution to many cognitive problems. Describe how neurofeedback is supposed to work in the treatment of cognitive dysfunctions (such as ADHD). Further, name at least 3 methodological limitations of previous neurofeedback research which prevent them rigorously demonstrating its clinical effectiveness