Introduction to Intro2BCI

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Introduction to Brain Computer Interfacing, Nijmegen Sept 2011

Outline

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BCI in sci-fi. The hope/hype/future?

What makes a BCI?

- What are the distinguishing characteristics of a sci-fi BCI?

BCI sci-fi

- Firefox (1982) - Brain controlled aircraft. firefox 5:49
- Six Million Dollar Man (1974) - brain controlled limbs 6 million dollar man
- The Ultimate Imposter (1979) - downloadable memories ultimate_imposter
- The Matrix (1999) - brain controlled VR The Matrix Trailer 0:50
- StarTrek borg...
- and many, many, many others, particularly when involving cyborgs...

Characteristics of sci-fi BCI..

- Brain, computer, connection, control, thought
- Fast, accurate
- Psychic, natural, **intuitive** – though directly turned into action
- Feedback, immersive, virtual-reality
- Physical connection to the CNS
- Better than natural/human?
- 2-way communication

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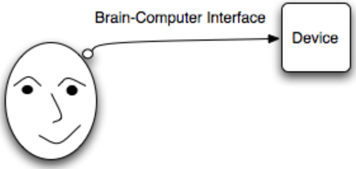
BCI vs. CBI

2 Possible ways to connect computers and brains:

- Brain→Computer (BCI), where the brain puts information into the computer.
- Computer→Brain (CBI), where the computer puts information directly into the brain.



This course is only about Brain to Computer Interfaces (BCIs)

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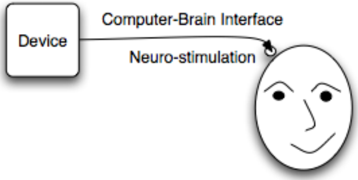

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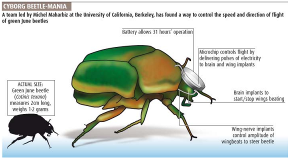
The reality: Computer Brain Interfacing

- Remote Controlled Animals
- Bionic Eyes
- Deep Brain Stimulation
  - To prevent Parkinsons tremors
    STNOFF, STNON, OnOffOnPearson, PBS video
  - To treat depression
    dbs_for_depression 1:16



(New Scientist 06/03/08) robo_moth

remote_controlled_rat_video

Note:

Little generation of virtual sensory signals (... yet?)

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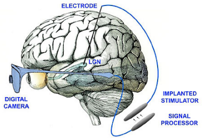

(BBC 18/01/00) movie Discovery Channel Bionic Eye

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The Reality: Brain Computer Interfacing

- BrainGate – 2-d cursor control

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- Graz University, Austria –
  - grasp control

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- Emotive – game system emotive

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Compare the hype to reality

- Much less fine-grained control
- Restricted to a small set of options
- Slow, inaccurate – <<1 char/sec
- Non-intuitive

These differences are mostly due to the low signal-to-noise ratio of brain signals.

Hence, addressing these issues is where most current work is going to improve BCI systems.

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Outline

Aims of the Course

- Understand what a BCI is, how it works and how to build one
- Knowledge of the various types of BCI, in particular the currently most successful systems
- Knowledge of what the current challenges are in BCI and possible approaches to address them

Achieving those aims

1. Lectures
   - No suitable text-book so,
   - lectures will be the main source of information for the course
2. Compulsory Reading
   - Most lectures have associated background reading material
   - provides additional information not possible in the lectures
   - read it before the lecture!
3. Assignment + workshops
   - Assignment brings theory and practice together. You must design;
   - a prototype/novel BCI, and
   - a test to experimentally validate this design
   - Assignment workshops in Thursday 10:45->12:30

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Lecture Schedule

Tues : 13:45-15:30, Rm. Sp A 01.12 / TvA 8.00.13

Date	Lecturer	Title
30/08	Jason Farquhar	Introduction
06/09	Eric Maris	Dection - signals & sensors
13/09	Jason Farquhar	Decoding 1 - Filtering & Artifact rejection
20/09	Jason Farquhar	Decoding 2 - Classification
27/09	Jason Farquhar	Transduction & Output
04/10	Ruud Meulenbroek + Jason Farquhar	Induced Response BCIs
11/10	Jerone Geuze + Marianne Severens	Evoked Response BCIs
28/10	Jason Farquhar + Marianne Severens	Passive BCIs + Rehabilitation
19/10	Jason Farquhar + Linsey Roijendijk	Neurofeedback + Brain-Reading
02/11	Jason Farquhar	Revision Lecture

Practical/Workshop Schedule

Thurs: 10:45-12:30, Rm. SP A -1.54

Date	Title
01/09	Assignment Description, Group Allocation + Example Assignment
08/09	-
15/09	1st Assignment Workshop
22/09	-
29/09	2nd Assignment Workshop
06/10	Imagined Movement BCI Demo (BCI Lab: B -1.10)
13/10	Event Related Potential BCI Demo (BCI Lab: B -1.10)
20/10	Assignment Group Presentations
27/10	Written Assignment Deadline
03/11	Final Exam

Outline

So what is a Brain computer interface?

Commonly used definition:

a system which allows someone to communicate information about their mental state without the use of the peripheral nervous system.

Note the emphasis:

- without the use of the peripheral nervous system...
- ...this means the signal must come directly from the brain
- that is, no muscles, no eyes, no motor neurons, nothing outside the skull

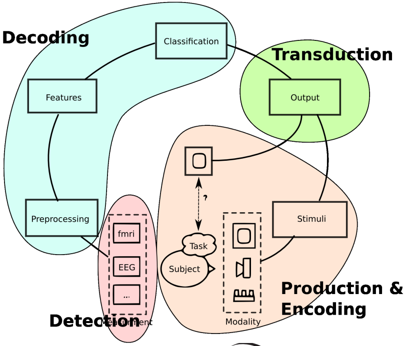
Question?

Is the Emotive system really BCI?

How does a BCI work? (keyslide)

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 (2,6,7,8)
2. Detection: Build a machine able to measure the properties of their brain, e.g. EEG, MEG, fMRI (3)
3. Decoding: Build a machine able to decode the measurements to deduce the users mental state (4)
4. Transduction: Communicate the mental-state to the outside world (5)



BrainGain

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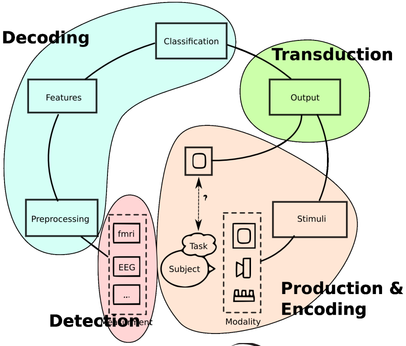

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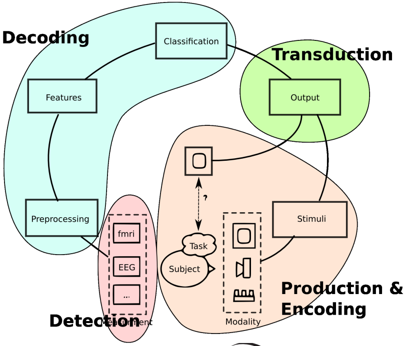

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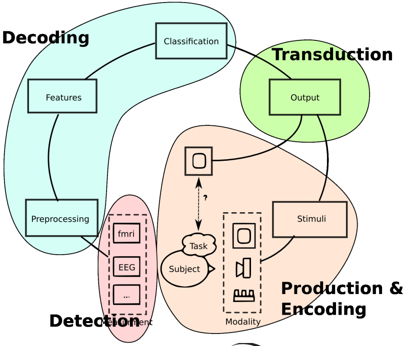


How does a BCI work? (2)

In fact this simple problem was "solved" about 15yr ago:

- [Farwell & Donchin 1988] P300 Visual Speller
- [Birbaurmer N. 1992] Slow Cortical Potential based BCI
- [Pfurtscheller G. et. al. 1992] μ-band Imagined-Movement Event Related De-synchronisation (ERD)

So what have we been doing since then?

Think back to the sci-fi *ideal* BCI... fast, accurate, intuitive

- Building a demo BCI is easy...
- Building a usable BCI is hard!

Like with speech recognition to be usable a BCI must be:

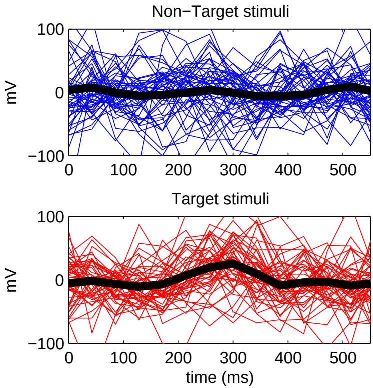
- Fast – <3s per binary decision
- Accurate – >90% correct decisions

Further (to a lesser extent) it should be:

- Easy to use – no expert knowledge or human intervention to use, no need to learn a special language
- fast to setup – no long training times (for the user or the decoder)
- generally applicable – should work for everyone

Outline

Why is it so hard to make usable BCIs?



(source: p300-visual speller data, elect. Cz)

- Low signal to noise ratio (≈1:5)
  - external noise sources
  - other neural sources
  - Muscle artifacts – eye, neck, tongue (5-10x stronger than EEG)
  - 50Hz line noise
- Inverse frequency ($1/f$) spectrum
- High spatial correlation between electrodes
- High levels of inter-subject variability – BCI Illiterates
- High levels of inter-session variability – and user learning

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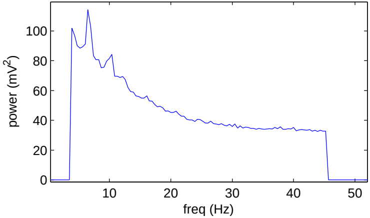

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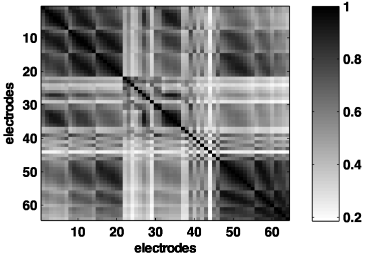

(source: p300-visual speller data, 64ch)

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- High spatial correlation between electrodes
  - due to signal propagation effects – volume conduction
  - $1/s$ spatial spectrum?
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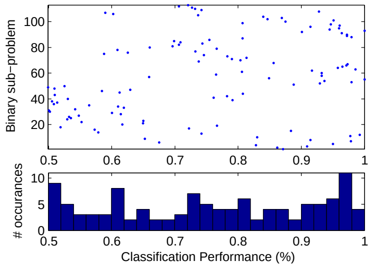

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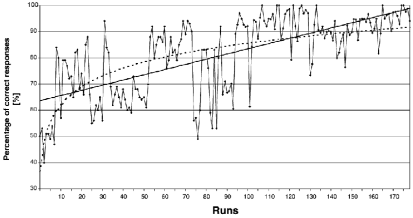

(source: Birbaurmer et. all, Slow cortical potential (SCP) data)

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2 approaches to addressing these challenges

- The basic problem of BCI is to improve the detection and decoding of the users mental states.
- To understand how to do this, first need to understand what makes a signal easily detectable.

Note: Easily Detectable Signals

- Easily detectable signals are those which differ strongly from the background noise.
- does not necessarily mean they have high amplitude (though this always helps)
- Signal may have other features allow it to be detected,
  - it may have a particular time structure which makes it detectable, e.g. p300, noise-tagging
  - or a particular spatial distribution in th brain,
  - or particular frequency characteristics, e.g. FM-radio, change in stimulation frequency power in SSEP
  - or some combination of the above..

Note:

Detectability is heavily dependent on knowledge of the characteristics of the signal and the noise and the decoding algorithm used.

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2 approaches to addressing these challenges

As a BCI is a co-operative system of 2 components, there are 2 ways to improve the system.

1. Brain-based: Make the brain-signals easier to detect using new mental tasks,e.g.
   - selective attention to new types of stimuli, such as noise-tags
   - new types of hybrid BCI, particularly auditory/musical
   - time-locked imagination tasks

2. Computer-based: Make the decoding methods more sensitive or easier to use, e.g.
   - new, more sensitive detectors
   - specialised machine learning techniques to reduce over-fitting on multi-channel time-series
   - learning across subjects & sessions
   - continuous learning systems which adapt to signal variability

Outline

Active vs. Passive BCIs

BCIs can be broadly categorised based on the type of mental signal used:

Active BCI

- User actively attempts to communicate by intentionally controlling their mental processing, e.g. imaging moving, attending to a particular stimulus

Passive BCI

- User takes no special measures to use the BCI, but just operates normally.
- System observes this operation to identify mental-states of interest, e.g. drowsiness
- may use detected mental-states to control devices.

Outline

Active BCI Design

Core Problem

The core problem of Active BCIs is to get the users brain to generate an easily detectable signal which is intentionally controllable.

Note:

- Generally, the natural task – such as thinking "Yes" for yes – does not produce a strong signal
- Thus, the user must encode their intention by performing a special mental task which generates a stronger signal.

Note: Intentionally Controllable Signals

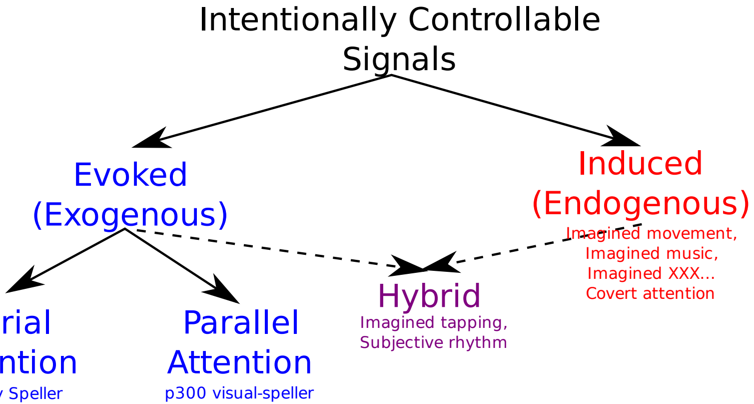
Brain produces many types of detectable signals;

- low-level perceptual responses to external stimulation, e.g. sounds, touch, visual changes, etc.
- higher-level responses to stimulus characteristics, e.g. p300 odd-ball response, N400 response to semantic violations
- increased α-power with reduced concentration or illumination
- changed spectral power in response to imagined tasks, such as limb-movement, spatial navigation, mental arithmetic, colors etc.

However, only those signals which can be changed by conscious intention are useful for Active BCI.

- low-level perceptual responses are usually very strong but not directly useful for BCI (many are present in unconscious subjects)
- however, top-down effects may mean low-level response can be modulated by intention, e.g. perceptual response to a particular stimulus can be increased by focusing attention on it.

Types of Active BCI



Evoked Response Active BCIs

Evoked Response or Exogenous or dependent

BCI signal is a direct response to external stimulus. However, this response is modified by the subject to encode their intentions, by selectively attending to a subset of the stimulus events.

Advantages

- precise control of stimulus properties, and hence the evoked response, makes signal detection easier
- lot of literature on evoked responses to different stimuli which can be exploited to make BCIs
- user-friendly – make the stimuli compatible with the output

Dis-advantages

- reliance on subject perceiving stimuli – intact and available sensory system
- stimuli must be present – no self-paced control
- high risk of becoming a 'Stimulus-CI' (Brain-reading) or Artifact-CI

Evoked Response BCIs (2)

Can be sub-categorised by type of mental-task:

- Serial – where only a single stimulus stream is presented at one time, and the user selectively attends to events within this stream.
- Parallel – where multiple stimuli are presented at the same time, and the user selectively attends to only one of these stimulus streams.

Or by type of stimulus response:

- Steady State responses – where the stimuli happen so rapidly that they are perceived by the subject as a continuous stream of stimulation and generate a constant response
- Event Related or transient responses – where the stimulus events are perceived independently and produce individual responses

Evoked Response BCIs (3)

Example Evoked Response BCIs:

- Event Related:
  - P300-visual speller – (Parallel) letters presented on a visual grid and all flash together in sequence, user attends to the intended letter
  - P300-auditory speller – (Serial) letters are pronounced sequentially, user attends to the intended letter.
- Steady State:
  - Tactile/Auditory/Visual Frequency Tagging – (Parallel), multiple stimuli are presented at different frequencies (and locations), user attends to selected stimuli to communicate their intention

movie

Induced Response Active BCI

Induced Response or Endogenous

BCI signal is a response to internally performing some mental-task. User intention encoded by selecting the mental task to perform.

Advantages

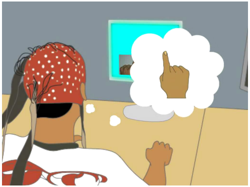
- internally generated – potential for self-paced operation
- potential for continuous output, by controlling the "strength" of the mental execution
- possible user learning to improve performance over time

Dis-advantages

- poor control of signal properties, such as timing, more difficult to detect
- intention encoding tends to be un-natural – though there is some evidence that over time this it becomes internalised

Example Induced Response BCIs

- Imagined Movement – subject imagines moving different parts of their body
- Imagined Navigation – subject imagines moving from place to place in the world
- Imagined XXX – pretty much any imagined something BCI
- Spatial Rotation – subject imagines rotating 3-d objects
- Covert Attention – subject covertly attends (i.e. without eye movement) to part of the visual field



movie

Evoked+Induced Hybrid BCI

Hybrid systems

External stimulus is used to instruct the subject when to perform an internally generated task and the user encodes their intention in the choice of which task to perform.

Advantages

- better control of signal properties – improved signal detection
- stimulus can make the task simpler by providing a queue for the user
- all the advantages of induced-response and evoked-response BCIs

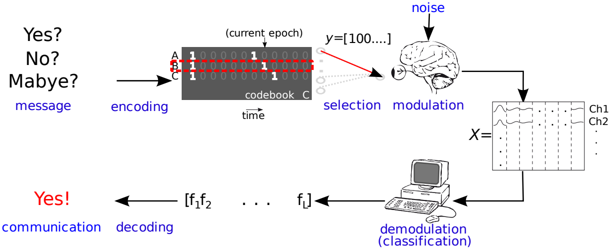
Dis-advantages

- all the disadvantages of stimulus reliance

Example Evoked+Induced Hybrid systems

- imagined tapping – auditory metronome is used to time-lock imagined movements
- subjective-rhythm – evoked response to auditory metronome has superimposed accents which encode intentions, i.e. tick-tock vs. tock-tick.

Example Good Active BCI Design – P300 visual Speller



1. parallel-selective attention event related response task
2. strong (SNR=.1) high-level effect – the P300 odd-ball response
3. simple user interface – just concentrate (look?) at the target letter
4. precise timing information makes the signature easier to detect
5. multiple response events & clever stimulus sequence design – makes detection robust to missing a few stimulus events

Video : from the g.Tec web-site, a spin-off of TU-Graz, Austria.

Outline

Core Problem

The core problem of Passive BCIs is to decode the signal which the users brain is generating anyway.

Note:

- no control over the types of signal generated
- more-fundamental (and much harder) problem of decoding what the brain is doing
- generally, limited to mental-states which are known to generate strong well-understood signals, e.g. perceptual responses

Types Passive BCI

1. dependent or Exogenous – signal is direct response to external stimulus
2. independent or Endogenous – signal is internally generated

Dependent passive BCIs

Brain-reading

- Detect which stimulus the user is experiencing, e.g. sound, word, picture
- easy(?) problem is to select perceived stimulus from a set of possible stimuli
- harder problem to to re-construct perceived stimulus from brain signals
- Examples: music-detection, word-detection, image-re-construction

Cognitive Response-detection

- Detect the users more abstract response to some stimulus
- Examples: lie-detection, error-detection, image-recognition

Independent Passive BCIs

The holy grail of BCI research! Direct access to the users internal world!

- Unique modality, not accessible in any other way.
- In general really hard, but possible for some high level states,
- Alertness monitoring, level-of anaesthesia detection, consciousness detection
- Emotion detection, workload detection

Note:

- Probably the 1st commercial application of BCI research
- M$ applied for patent on the use of BCI for user monitoring in HCI design (New Scientist 15/10/07)

Summary

Welcome to the course, start the assignment early!

- BCI, 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.
- Low signal-to-noise and high signal variability makes building usable BCIs very difficult
- BCIs must get, faster, more accurate and easier to use to approach the sci-fi ideal.
- Current Active BCIs require the user to encode their intentions in special easy to detect mental tasks
- Current Passive BCIs are limited to detecting mental-states with known strong brain signals, such as perceptual responses or mental effort.

Final Thoughts

Much like Artificial Intelligence, building a BCI is a very hard problem which has been over-hyped over the last 20years. However, is still an exciting area to work in with a potential of massive societial impact.