EEG classification and crossvalidation using the BCILAB toolbox: intro

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Toolbox download link: ftp://sccn.ucsd.edu/pub/bcilab/

Outline

- Definition
- Motivation
- Operational basis
- Model structure
- Model learning
- Toolbox overview

What is a Brain-Computer Interface?

All-inclusive definition: A BCI is a system which takes a biosignal measured from a person, and predicts (in real time) some aspect of the person's cognitive state.



What is a Brain-Computer Interface?



Schmidt, 2003

Areas of Research

- **Clinical**: Communication and control devices for the severely disabled (e.g., spelling devices in late-stage ALS)
- **HCI**: User-state monitoring for intelligent assistive systems, complex/demanding operational environments, etc.
- Entertainment: Computer game controllers (e.g., Emotiv, NeuroSky)
- **Neuroscience**: Pattern recognition and machine learning on brain signals, computational expert knowledge?







 \leftarrow Sensors

← Sensor State

Time

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Abstract user state of interest \rightarrow (e.g., surprised/not surprised)



- We postulate the existence of a certain aspect of the user's state (e.g., likelihood of being surprised, #items in working memory, type of imagined movement)
- To be able to estimate it from sensor readings, we require that a relationship between the two exists
- Physics provides some level of justification



- The task is to find a mathematical mapping between sensor signals and user state of interest that is accurate, robust, and computationally tractable
- Usually, many such mappings could be defined for any given question about cognitive state, depending on assumptions made
- Example: Spectral properties for oscillatory processes, time averages for slow-wave phenomena, partial directed coherence for information flow aspects



Defining a BCI approach Example intermediate abstraction And the second of the second s and and the standard and the states and the states and **X(t) S**(t) **y(t)** administration of the second second second and a subsection of the second second second http://www.hute-http://www.hute

Time



Defining a BCI approach, ct'd

- Problem: The mapping involves parameters (here: A⁻¹, w, b) that need to be obtained
- Optimal values for many such parameters vary drastically over people (and/or sessions, tasks, etc.)
- Thus, in many cases they need to be learned on the basis of source data
- Sometimes easy, but frequently hard

The problem of variability

 Spatial filters across 4 persons for predicting imagined movements (Left hand vs. Foot):



Blankertz et al., 2007

The problem of variability

- Many data sources can in principle help (e.g., MR images)
- Best known type of data source:
 Example data
 - Dedicated "training" / "calibration" session
 - Recording of both bio-signals X and target variables y across multiple trials
 - y known by construction of the experimental paradigm (e.g., via instructions, stimuli, ...)

 Typical calibration data contains segments (trials) for which there is information on the cognitive state of interest (e.g., via stimuli)

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• A sequence of filters (e.g., spatial, spectral) is applied and each trial is extracted from the processed data





'(t)

Stimulus presented (y=1)

 $X(t) \quad \rightarrow \mathsf{Filtering...} \rightarrow \ S(t)$



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• For each resulting processed trial segment, a group of features that is assumed to carry information about the cognitive state at the given time interval is extracted

- Feature extraction translates a processed trial into a feature vector, reducing the data dimensionality
- This is a very powerful approach to simplify the learning problem
- In this example, each trial is reduced to three parameters: peak latency, peak amplitude, peak width
- This implements the (very strong) assumption that a peak is the distinctive feature of each trial

- This gives a feature vector for every trial, which can be interpreted as the coordinates of a point in some space
- As the experimental condition for every trial is known, we learn the distribution of conditions in this feature space

- The task is to find a parametric mapping from locations in this space to final outputs
- The equation for a plane as below gives parameters w,b

 In some cases, complex assumptions are required, as the data can be high-dimensional, overlapping, and can have complicated spatial structure

- The result of this learning procedure is a predictive model (structure + parameters)
- This model can subsequently be
 - Applied in real time or "offline"
 - Evaluated on recorded data with known conditions
 - Inspected

Typical BCI approach

- An adaptive, learned, multi-stage parametric mapping (using signal processing and machine learning)
 - Preprocessing
 - Feature Extraction
 - Inference

Other possible approaches

• Solve all parameters as a joint optimization problem (can guarantee stronger optimality)

Other possible approaches

 Solve all parameters as a joint probabilistic inference problem (generalizes well to complex settings)

Other possible approaches

 Solve all parameters as a joint probabilistic inference problem (generalizes well to complex settings)

BCILAB

- BCI research is now supported by an EEGLAB plugin: the BCILAB toolbox
- It is a framework for the design, calibration, evaluation and application of Brain-Computer Interfaces
- The main goal is to offer the best achievable predictive performance, using state-of-the-art methods
- At the same time, it shall be accessible to nonexperts, without restricting efficient use by experts

Toolbox Interfaces

Toolbox Structure

| Standard BCI Paradigms | | | | | | | | | | | |
|------------------------|---|----|--|-----|--|--|--|--|--|--|--|
| CS | > | BP | | DAL | | | | | | | |

| Paradigm Components (Methods) | | | | | | | | | | | |
|-------------------------------|--|-----------------------|--|--------------------------|--|--------|--|--|--|--|--|
| Signal Processors | | Feature Extractors | | Learners / Predictors | | Others | | | | | |

| Infrastructure | | | | | | | | | | | |
|----------------|--------------|-------------------|----|---------|-----------|-----|--|--|--|--|--|
| | Optimization | Statistics | ΙΟ | Network | GUI tools | etc | | | | | |

Thanks!

Questions? (Next: practicum)