1. Lecture 1.1 – What is a Brain Computer Interface?
   1. The traditional definition of BCI
      1. The goal of BCI was to give significantly paralyzed people another way to communicate, a way that does not depend on muscle control.
   2. New definition
      1. A system which takes a biosignal measured from a person and predicts (in real time / on a single-trial basis) some abstract aspect of the person’s cognitive state.
      2. This definition allows you to take any biosignals and performs state prediction
   3. Three different BCI Subtypes
      1. Active BCI
         1. “An active BCI is a BCI which derived its outputs from brain activity which is directly consciously controlled by the user, independently from external events, for controlling an application.”
         2. The driving force behind the BCI is generated from the user, independently form external events, for controlling an application
         3. E.g., an application
      2. Reactive BCI
         1. “A reactive BCI is a BCI which derives its outputs from brain activity arising in reaction to external stimulation, which is indirectly modulated by the user for controlling an application.”
         2. Driving force is from an external stimulation
         3. E.g. Say you are focusing on a flickering light and monitor the brain for that signal
      3. Passive BCI
         1. “A passive BCI is a BCI which derives its outputs from arbitrary brain activity without the purpose of voluntary control, for enriching a human-computer interaction with implicit information.”
         2. Just sort of monitors the brain
   4. Brain Signals
      1. EEG
         1. All you need is a couple electrodes with EEG
      2. fNIRS
         1. Functional Near-Infrared Spectroscopy
         2. Shines light and deduces what happened
      3. MEG and fMRI
         1. Big and millions of dollars
   5. Non-Brain Signals (used for cleaning up EEG)
      1. SensoMotoric Instruments
      2. Motion Capture and Eye Tracking, super helpful for cleaning up EEG
      3. EMG, ECG, and EOG
      4. Variables in your program
         1. Stimulus presented?
         2. Current vehicle speed
      5. Environmental signals
         1. Line noise
   6. Aspects of Cognitive State
      1. Any aspect of the physical brain state that cn be measured with sufficient single-trial reliability
      2. Tonic State
         1. Degree of “relaxation”, cognitive load, …
         2. Slow changing brain processes
         3. Relaxation state
      3. Phasic State
         1. Switching attention, type of imagining movement
         2. Fast changing state
         3. E.g., the movement that you imagine at any given point
      4. Event-Related State:
         1. These are cognitive process that are linked to a particular event, perhaps an external one.
         2. E.g.,
            1. Surprised/Not Surprised
            2. Committed Error
            3. Event Noticed/Not Noticed
2. 1.2 Application Areas and Examples
   1. Communication and Control for the Severely Disabled
      1. Severe Disabilities:
         1. Tetraplegia
         2. Locked-in syndrome
      2. Speller Programs
      3. Prosthetic Control
      4. Home Automation
   2. Operator Monitoring
      1. Braking Intent
      2. Lane-Change Intent
      3. Workload
      4. Fatigue
      5. Alertness monitoring in Pilots, Air Traffic Controllers, Plant Operators
      6. Now entering an era where BCI is being used for healthy people
   3. Forensics
      1. Lie detection, Brain Fingerprinting, Trust assessment
   4. Entertainment
      1. Mood Assessment, “Thought Control”, Fast Response Detection
   5. Health
      1. Sleep Stage Recognition, Neurorehabilitation
      2. To improve your sleeping or what not
   6. Social
      1. Weird cat ears
   7. Neuroscience
      1. Multivariate Pattern Analysis / Brain Imaging
      2. Study of information content and representations for neurosceientific questions
      3. Also: Closed-loop neuroscience experiments (experiment manipulations depending on brain state)
      4. Using BCI for the development of neuroscience
      5. This is where BCI all started
3. 1.3 Scientific Challenge
   1. Related Areas in Science
      1. **Theory is shared with:** Signal Processing, Machine Learning, Computational Intelligence, Neuroscience, Cognitive Science
      2. **Problems are similar to:** Computer Vision, Speech Recognition, Pattern Recognition, Time-Series Analysis, Control Systems & Robotics
   2. Why is BCI hard
      1. Processing depends on unknown parameters (person-specific, task-specific, otherwise variable), per-sensor weights
         1. Must adapt to the person to do a good job
         2. If you use one model on one person it can give the exact different expected result.
      2. Reasons for variability
         1. Folding of cortex differs between any two person
            1. Even on identical twins
            2. It is like a finger print
         2. Relevant functions map differs across individuals
         3. Sensor locations differ across recording sessions
         4. Brain dynamics are non-stationary at all time scales
   3. Why else is BCI Hard?
      1. Signal-to-noise ratio is very challenging, so *sensitive* measures are hard obtain
         1. Relevant brain activity is small compared to interfering artifacts and compared to brain background activity
         2. Difficult to deal with
      2. *Specific* measures are even harder to obtain (with coarse-grained sensing)
         1. Large collections of neurons are involved in many different activities, not just one
         2. Very hard to be specific with what you are trying to pick up on
      3. Underlying phenomena are also highly diverse and rich and derived measures are still poorly understood – not always clear what to look for.
         1. In some cases we don’t know what to look for or how to look for it
   4. And Furthermore
      1. EEG signals are mathematically complicated to handle since all sensors record almost the same signal (superposition of all brain activity)
      2. Therefore, they need to be computationally (e.g., statistically) disentangled for optimum performance
   5. Consequences
      1. Sophisticated signal processing is required
      2. All approaches are fundamentally statistical
         1. Because there is uncertainty
      3. BCI systems must be calibrated before they can be used
      4. Calibration should entail as much information as available, e.g., example data, prior data, large databases
4. 1.4 Available Tools
   1. BioSig
      1. MATLAB toolbox
      2. Open source
      3. Offline processing
      4. Cross platform
   2. BCI2000
      1. Online processing
      2. Data processing
      3. Signal processing
      4. Helps you just get up and running
      5. Written in C++
      6. Lack of advance signal processing and machine learning algorithms
   3. OpenViBE
      1. Also C++, cross platform
      2. Very user-friendly design
      3. For non-programmers
   4. g.BSanalyze
      1. Commercial system developed by g.Tex
   5. BCILAB
      1. Started in 2010
      2. Purpose is to squeeze out the maximum amount of efficiency
      3. MATLAB
      4. Offline, online analysis
      5. Must be very good to mess with the code