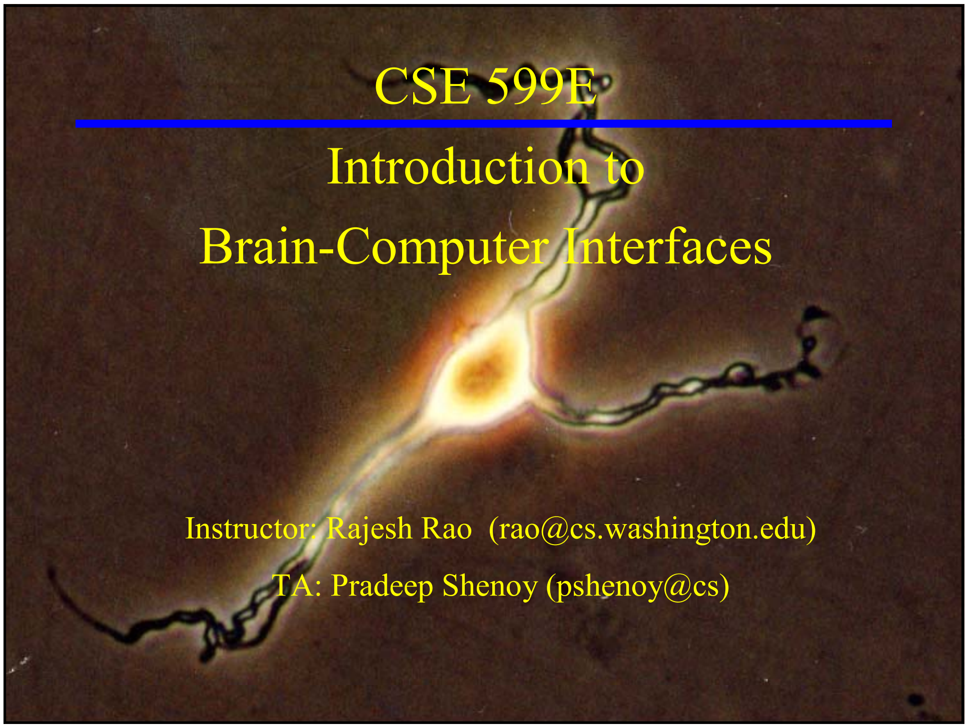


CSE 599E

Introduction to Brain-Computer Interfaces

Instructor: Rajesh Rao (rao@cs.washington.edu)

TA: Pradeep Shenoy (pshenoy@cs)

Today's Agenda

- Introduction: Who's in this class?
- Course Info and Logistics
- Motivation
  - What are Brain-Computer Interfaces (BCIs)?
- Introduction to BCIs

Course Information

- The course will include:
  - Lectures (by Raj and Pradeep)
  - Invited speakers:
    - Eb Fetz (PBIO) on neural control and BCIs
    - Dieter Fox (CSE) on Particle/Kalman Filtering
    - Kai Miller (MD/PhD program) on Electrocorticography
  - Student-led Discussion of Research Papers
- Browse class web page for syllabus and schedule:
  - http://www.cs.washington.edu/education/courses/599e/06sp
- Lecture slides will be made available on the website
- Add yourself to the mailing list→ see class web page

Workload and Grading

- Course grade will be Credit/No Credit (CR/NC) only.
- Grade will be based on:
  - Paper presentations – see list of papers on class website
  - Final group project – literature survey or data analysis
  - Participation in on-line & in-class discussions
    - On-line blog (discussion board) for discussing assigned papers, posting/answering questions, etc.
- Group Project: Group of 1-3 persons
  - Survey other BCI topics not covered in course, or
  - Perform analysis of existing BCI data
  - Each group will submit a report and give a presentation in the last class

Okay, enough logistics – let's begin…

What are Brain-Computer Interfaces?

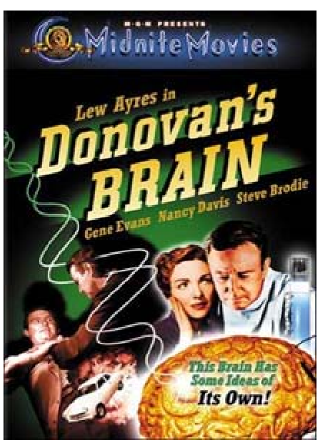
What is a Brain-Computer Interface (BCI)?

- **Current Human-Computer Interaction (HCI)**: Human controls virtual or physical objects using muscular activity. Examples:
  - *Mouse* (hand/finger movements)
  - *Keyboard* (finger/hand movements)
  - *Joystick* (hand/arm movements)
  - *Steering wheel, buttons, and pedals* (hand/arm/feet/leg movements)
- **Brain-Computer Interface (BCI)**: A device that utilizes brain activity for direct control of physical or virtual objects without using muscular activity or body movements.

Some Applications

- Improved communication and control for paralyzed and locked-in patients (e.g. stroke, ALS, spinal injury patients)
- Applications in health and safety
  - E.g. Early detection, diagnosis, and treatment of symptoms
  - E.g. Alertness monitoring in critical occupations (e.g. night drivers, pilots, railway "engineers")
- Computer-aided education and learning
  - E.g. Brain-activity based presentation of material?
- Augmented cognition (brain-body actuated control)
  - E.g. Air Force research using hybrid brain-body interfaces for speeding up responses during flight
- Entertainment and Security
  - E.g. Video games, TV/web browsing for patients,…
  - E.g. Better lie detection devices and "brain fingerprinting"?

BCIs in Sci-Fi



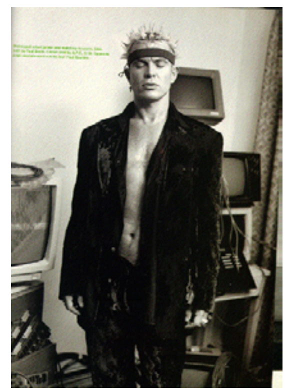
(Donovan's Brain, 1953)


(Johnny Mnemonic, 1995)

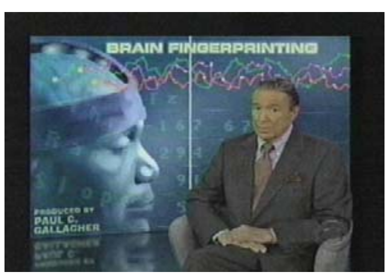

(The Matrix, 1999)

BCIs: The Hype

- Several commercial "BCI" systems exist
  - "Interactive Brainwave Visual Analyzer" (IBVA): "…trigger images, sounds, other software or almost any electronically addressable device…"
  - Cyberlink by Brain Actuated Technologies: "…operate computer software and any electrical device directly from the control center - *the mind*."
- Most are based on a *headband* with few sensors (typically 3)
- ***The Catch***: Control is more through eye movements and facial muscle activity than through brain activity



BCIs: More Hype

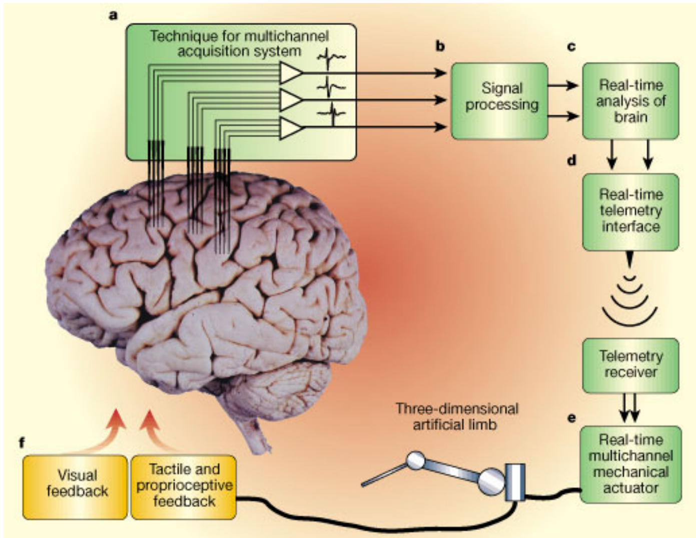


"Brain Fingerprinting"

http://www.brainwavescience.com/

"We use details that the person being tested would have encountered in the course of committing a crime. We can tell by the brainwave response if…a person has a record of the crime stored in his brain."

BCI: What is involved?



From (Nicolelis, 2001)

Signal Acquisition: Current Approaches

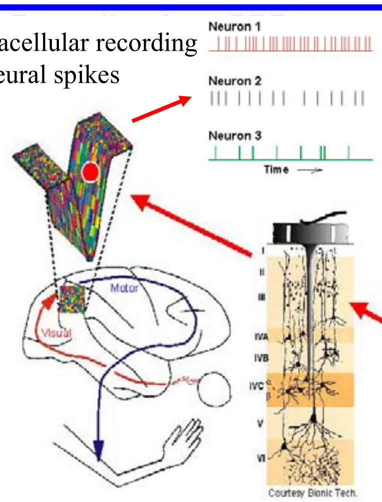
- Invasive Approaches:
  - Recording Activities of Neurons inside the Brain using Electrodes and Electrode Arrays
    - Typically only in animals (rats and monkeys)
  - Recording Electrical Activity from the Brain Surface (Electrocorticography or ECog)
    - In humans (patients scheduled for brain surgery)
  - Implants and Neural Stimulation
    - In animals and humans (e.g., Parkinson's patients)

Signal Acquisition: Current Approaches

- Non-Invasive Brain Imaging:
  1. fMRI (Functional Magnetic Resonance Imaging): Measures changes in blood flow due to increased brain activity
     - Good spatial resolution but too slow for real-time BCI
  2. MEG (MagnetoEncephaloGraphy): Measures changes in magnetic fields due to neural activity
     - Good spatiotemporal resolution but expensive and cumbersome
  3. EEG (ElectroEncephaloGraphy): Measures voltage changes at the scalp due to neural activity
     - Good temporal resolution but poor spatial resolution
     - Inexpensive and therefore most common in current BCIs

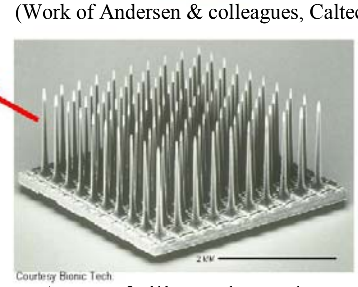
Invasive BCIs: Monitoring and Stimulating Neurons

Extracellular recording of neural spikes



Array is implanted in an area of the cerebral cortex

(Work of Andersen & colleagues, Caltech)



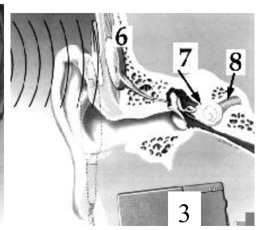
Array of silicon electrodes with platinum-plated tips

Invasive BCIs: A Commercial Example

Components of a *Cochlear Implant* (Electrode array (1) & receiver/stimulator (2) are implanted in the head)

- Has been implanted in over 30,000 hearing-impaired adults and children
- Many (but not all) have improved hearing ability

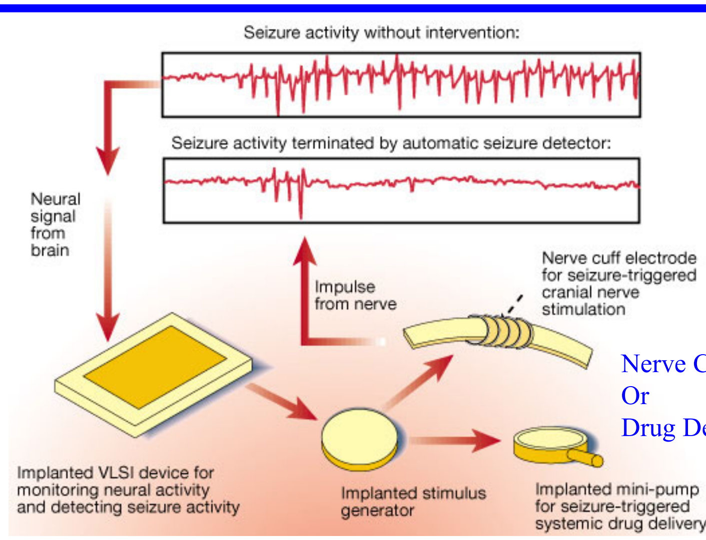
1. Microphone
2. Cable
3. Sound processor
4. Cable
5. FM radio transmitter



6. Receiver & Stimulator
7. Electrode array stimulates auditory nerve fibers in cochlea
8. Auditory nerve

From: http://www.deafblind.com/cochlear.html

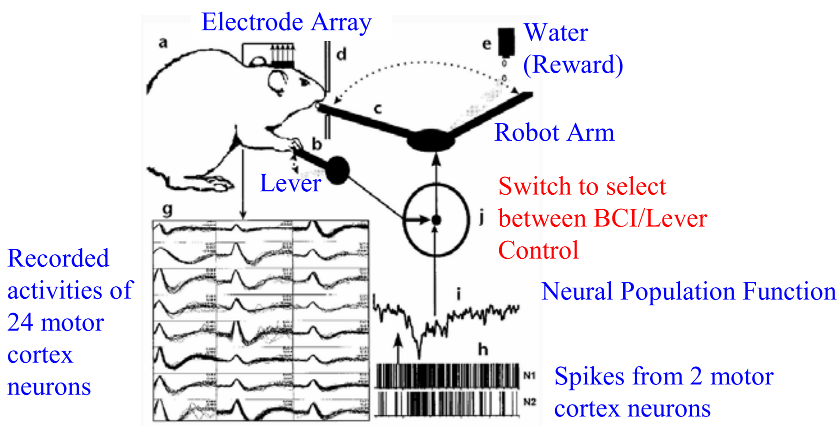
Treatment of Mental Diseases using Implants



Nerve Cuff
Or
Drug Delivery

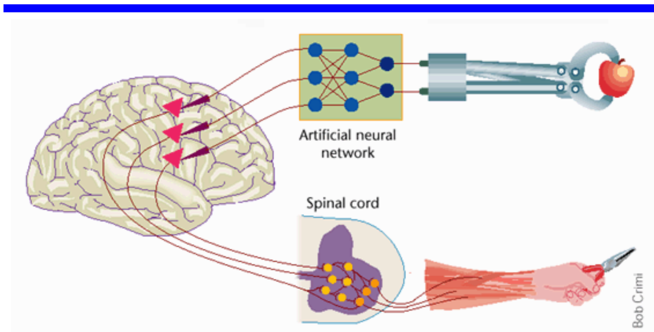
(Nicolelis, 2001)

BCI in a Rat: Rodent Telepathic Control



(Chapin et al., 1999)

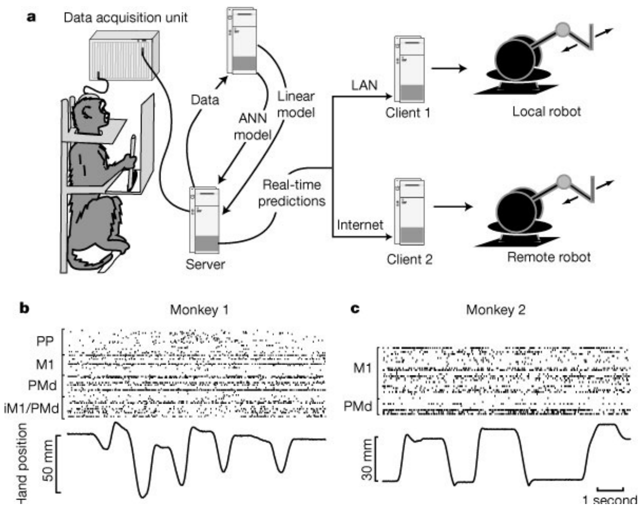
BCI in a Rat: Summary



Experiment by Chapin et al., 1999:

- Rat presses a lever to move a robotic arm to get reward
- Neural outputs from rat's *motor cortex* train an artificial neural network to control the robotic arm
- After training, several rats no longer used their own body movements but retrieved reward using their neural activity

Control of a Robotic Arm by a Monkey



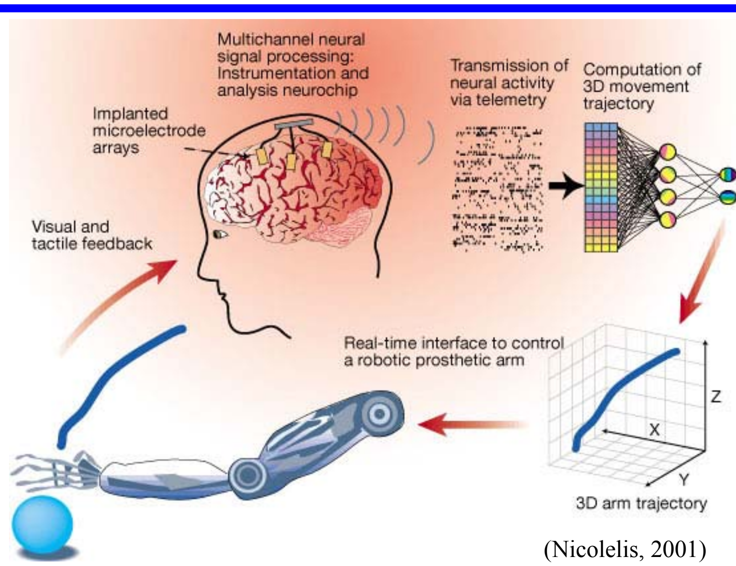
Experimental Set-Up

Spikes from neurons in several cortical areas in two monkeys

Hand Position

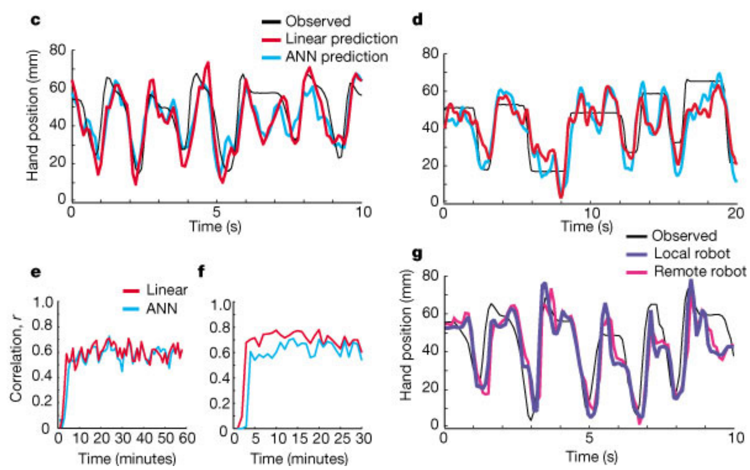
(Wessberg et al., 2000)

Neural Robotic Control: Methodology



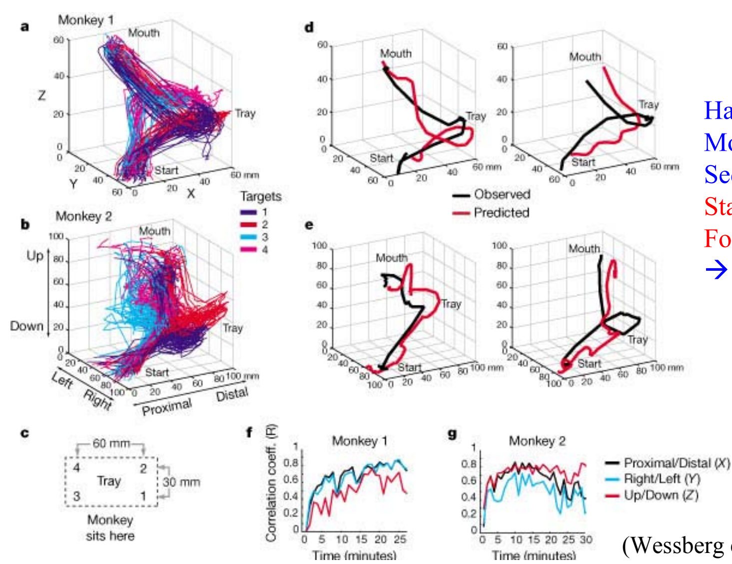
(Nicolelis, 2001)

Results from Monkey BCI – 1D Movements



(Wessberg et al., 2000)

Results from Monkey BCI – 3D Movements

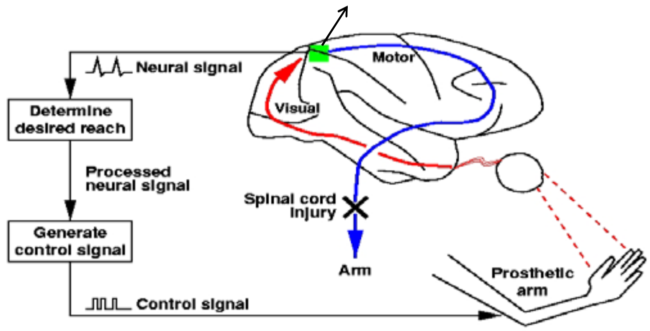


Hand Movement Sequence: Start → Food Tray → Mouth

(Wessberg et al., 2000)

BCI based on Cortical "Reach" Neurons

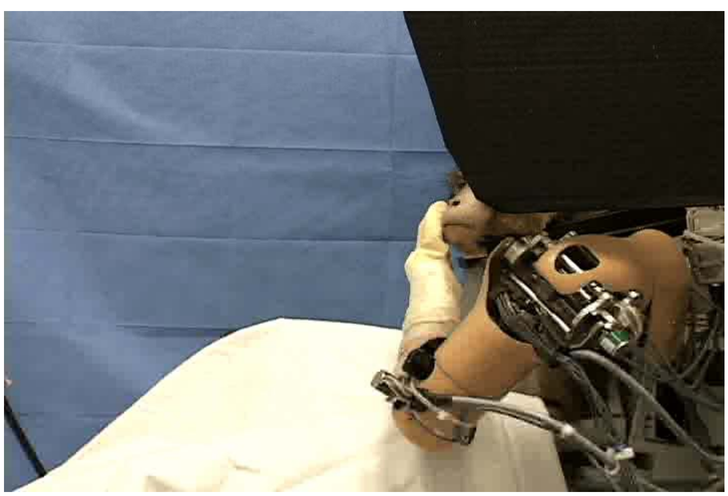
"Reach" Area in Parietal Cortex



(Work by Andersen and colleagues, Caltech)

- Neural activity predicts intended location of a reach movement by the monkey
- Might be easier to translate into robot commands than raw motor activity as in previous slides

Video: Monkey controlling a Robotic Arm

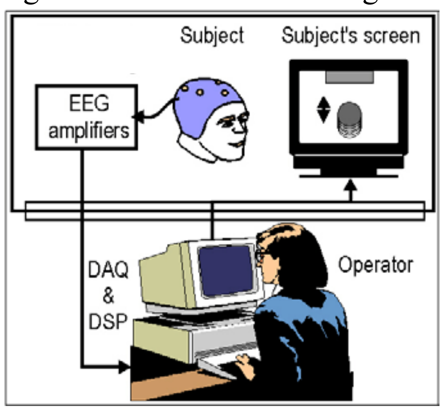


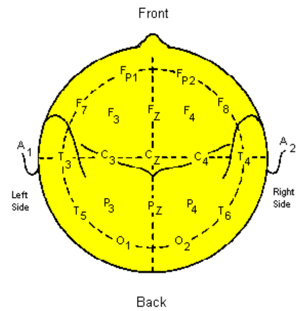
(Work by Schwartz and colleagues, U. Pittsburgh)

http://motorlab.neurobio.pitt.edu/Motorlab/download_movies/download_movies.html

Non-Invasive BCIs: EEG-based Systems

- EEG signals: Acquired from a cap of electrodes that contact scalp through a gel
  - Recent progress: Active electrodes and dry electrodes.
- Signals are in *microvolts* range → need to be amplified

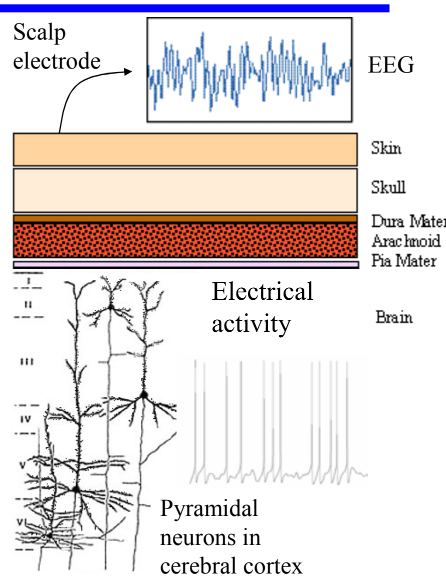




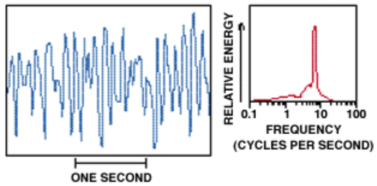
"10-20" arrangement of scalp electrodes

What is EEG?

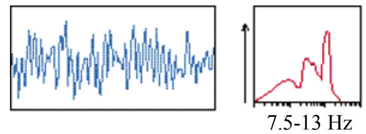
- Voltage fluctuations at the scalp due to activities of *large populations of neurons* in the cerebral cortex
- Input potentials and activities of neurons get attenuated and summated due to passage through meninges, cerebrospinal fluid, skull, and scalp.



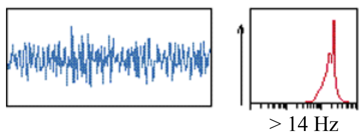
Types of EEG Waves



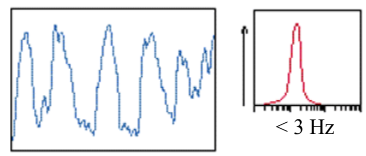
Mu waves: Associated with movements or intention to move



Alpha waves: Associated with unfocusing attention (relaxation)



Beta waves: Associated with alertness and heightened mental activity



Delta waves: Associated with deep sleep

(Images from Scientific American, 1996)

Some Achievements of EEG-based BCIs

- Typing words by flashing letters (Farwell & Donchin, 1988)
  - Select a character (out of 36) in 26 seconds with 95% accuracy
- Move a cursor towards a target on a screen by training subjects to control the amplitude of their Mu waves (Wolpaw et al., 1991; Pfurtscheller et al., 1993)
  - 10-29 hits/min and 80-95% accuracy after 12 45-min sessions
- Moving a joystick in 1 of 4 directions by classifying EEG patterns during mental tasks using artificial neural networks (Hiraiwa et al., 1993; Anderson & Sijercic, 1996)

Example Videos of EEG-Based BCI
(from the Wadsworth Group)

- An individual uses the mu rhythm to select from 6 choices in a target task
- An individual spells a word using P300 evoked potentials
- BCI2000 in Online Operation: A user spells a word and selects from icons (mu rhythm control, 64 channel EEG, 160 Hz)

EEG-based Systems: Challenges and Limitations

- Electrode placement is cumbersome and set-up time is typically long (up to ½ hour based on number of electrodes)
- Results of training and learning may not be transferable from one day to the next due to shifts in electrode locations, noisy contacts with scalp, etc.
- Low signal-to-noise ratio and on-line adaptation in subjects necessitate powerful amplifiers as well as efficient machine learning and signal processing algorithms
- Signal attenuation and summation between the brain and the scalp, together with sparse sampling of activity, limits the range of useful control signals that can be extracted

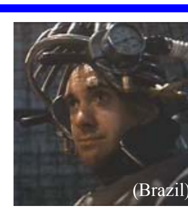
BCI Research: Current Problems and Challenges

- Signal Acquisition (Hardware): Need better technology to record activities of several thousands of neurons with high signal-to-noise ratio
  - Non-Invasive BCIs: Need physicists to discover better methods of brain imaging than EEG/MRI
  - Invasive: Need biocompatible implantable chips for recording and/or stimulating large groups of neurons
  - Need better instrumentation for amplification and telemetry
- Signal Processing (Software):
  - Current approaches use: Fourier analysis, classical neural networks, linear function approximators
  - Need more robust and adaptive algorithms for learning the mapping between brain activity and desired outputs

BCI Research: Moral and Ethical Issues


(The Matrix)


(Terminator 2)


(Brazil)

- "Where does the human end and the machine begin?"
- Privacy, safety, and health issues with wireless implants
  - What if someone sends a "virus" to receiver? ("brainwashing"?)
- Abuse of technology (in law, war, crime, and terrorism)
  - E.g. Misuse of "Brain fingerprinting" methods in criminal cases
- Societal impacts: The new haves and have-nots
  - Possession and control of BCIs to augment mental/physical capabilities may significantly alter balance of power in society

Conclusions

- Significant advances are being made in the development of both non-invasive and invasive BCIs
- Invasive systems in rats and monkeys have allowed these animals to control robotic arms in real time for simple tasks
- The most popular non-invasive systems, based on EEG, allow reasonably accurate but slow control of cursors and selection of letters
- In the rest of the quarter, we will delve into these systems in more detail:
  - What are the brain signals and behaviors being used?
  - What are the feature extraction and machine learning methods that underlie these systems?
  - What are their strengths and weaknesses?

Next Class: Lecture by Pradeep on
Machine Learning for BCI
& Sign-Up for Paper Presentations

Don't forget to browse the class website, look over the papers, and sign up for the mailing list…