Modern Tools for Noninvasive Analysis of Brainwaves

Applications in Assistive Technologies and Medical Diagnostics

Advances in Biomaterials and Medical Devices
Missouri Life Sciences Summit

Kansas City, March 8-9

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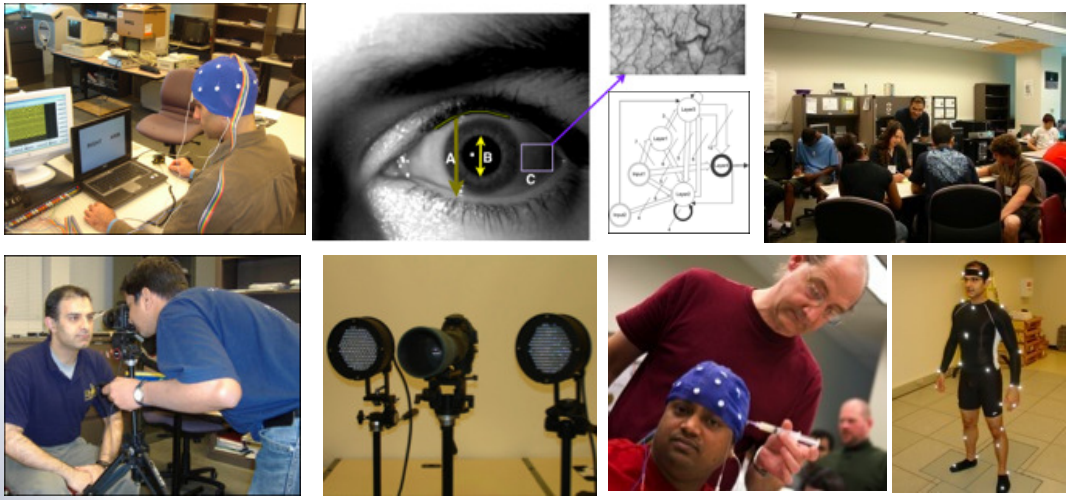
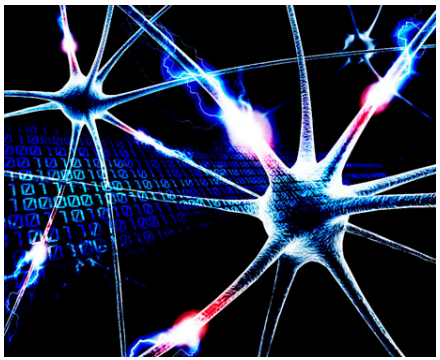


UMKC

Brain Signal Acquisition

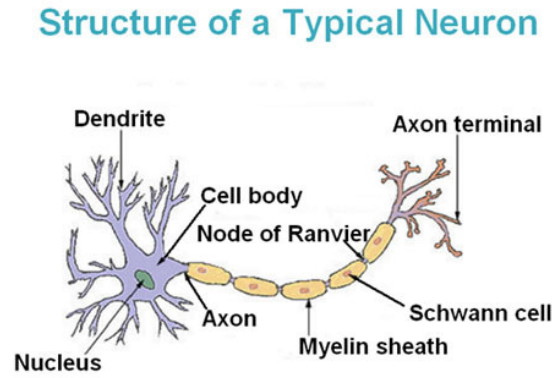
- Main modalities: Optical (NIRS), Electric (EEG), Magnetic (MEG)
  - Also nuclear, magnetic resonance, X-ray/CT, and ultrasound
- Our focus is noninvasive, portable, and affordable signal acquisition technologies amenable to bedside and remote medical monitoring, as well as assistive technologies

UMKC



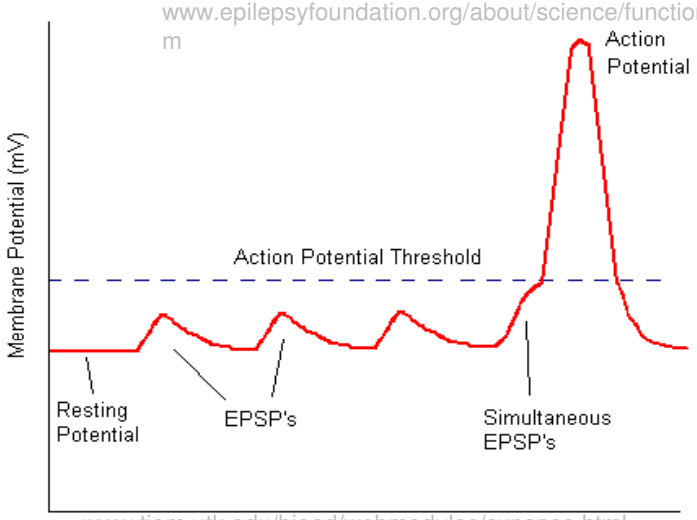
IEEE Spectrum, Nov 09

Eng-Brain 101

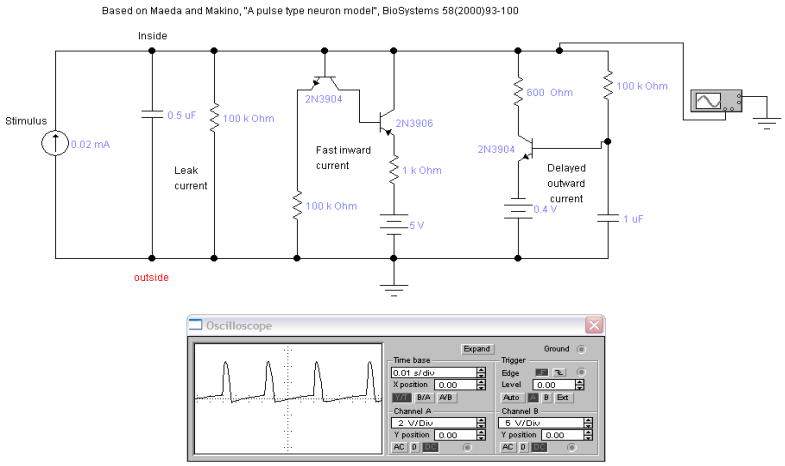


www.epilepsyfoundation.org/about/science/functions.cfm

- An electrical engineer's viewpoint
  - Brain: An extremely complicated electric circuit, made of many highly interconnected neurons
  - Neurons: electro-chemical signal processors
    - VCO/integrate and fire circuits?!



www.tiem.utk.edu/bioed/webmodules/synapse.html



www.nbb.cornell.edu/neurobio/land/PROJECTS/NeuralModels

What is EEG?

- EEG (electroencephalogram): collective signals originating from cerebral pyramidal cells; spontaneously or as evoked by auditory, verbal, visual, and motor activities.
- Billions of cells firing at the same time, a huge “cocktail party”, low amplitude noisy signal…

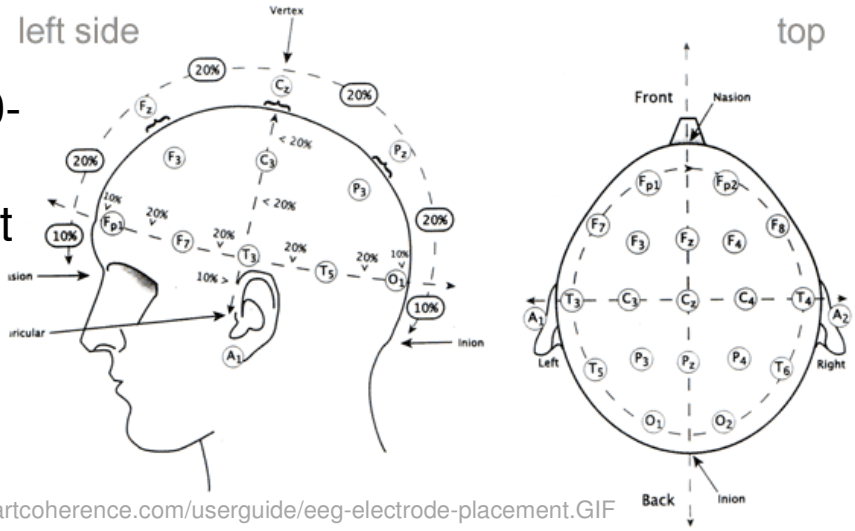
en.wikipedia.org/wiki/Electroencephalography

What is EEG?

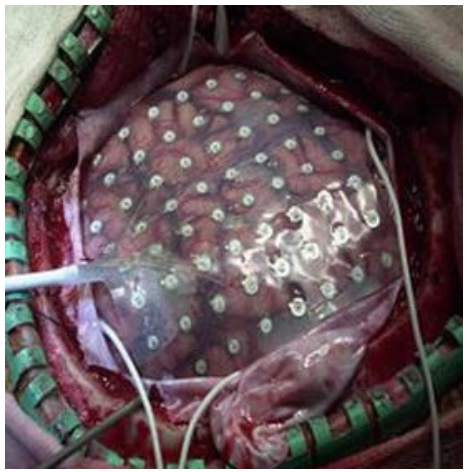
- Recorded noninvasively by surface electrodes connected to a bioamplifier, as opposed to invasive modalities such as Electrocorticogram (ECoG)
- Different modes of recording (number and placement of channels, reference potential, etc)

ese.wustl.edu/~nehorai/eegmeg/eeg2.jpg

The international 10-20 standard of electrode placement (10%-20% placement between head landmarks):



www.heartcoherence.com/userguide/eeg-electrode-placement.GIF



www.gtec.at/products/g.BCIsys/bci.htm

←Emotive EPOC

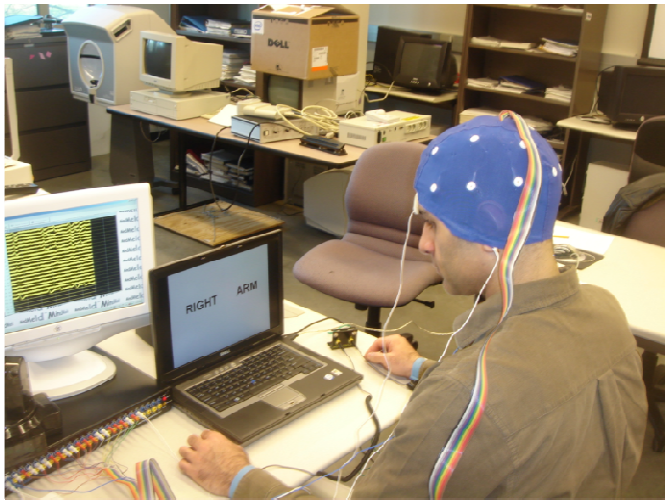
Advantages and Applications

- EEG carries affective and cognitive Information (but not at the level pre-cogs in minority report!)
- Cheap, portable, direct measure, well studied, good temporal resolution
- Some applications: medical diagnosis, assistive technologies/neuroprosthetics, operator aid, biofeedback for ADHD, stress and anxiety disorders, entertainment…

Engadget.com

www.gtec.at

Non-invasive Brain-Computer Interfacing (Thought Translation)



- Detection mental states, mostly intent to move limbs, from EEG
- Other applications: detection of stroke and geriatric balance problems
- Quality of life/AAC: thought sonification (with Dr Rudy, UMKC Conservatory)

http://www.youtube.com/watch?v=gq1xJIuDIV0

Kansas City Star, Front page, Dec 22 2008

Music is a new way to know the brain

Art meets science as graduate students at UMKC wire a mind in an effort to increase their understanding of how it works.

By STEVE PAUL
The Kansas City Star

The Brain sits quietly.

All around it there's commotion in the cramped college classroom as clumps of students peck on keyboards and stare at computer monitors. They're trying to make everything work for the class about to start.

But the Brain is patient and awaits its turn. The Brain belongs to Ramaraju Medisetty, and he will soon be the center of attention.

If everything goes as planned over the next two hours — and at the moment, that's not looking so solid — the Brain will soon be making music.

And in doing so, this class project may help open the door to further understanding of how the human brain operates.

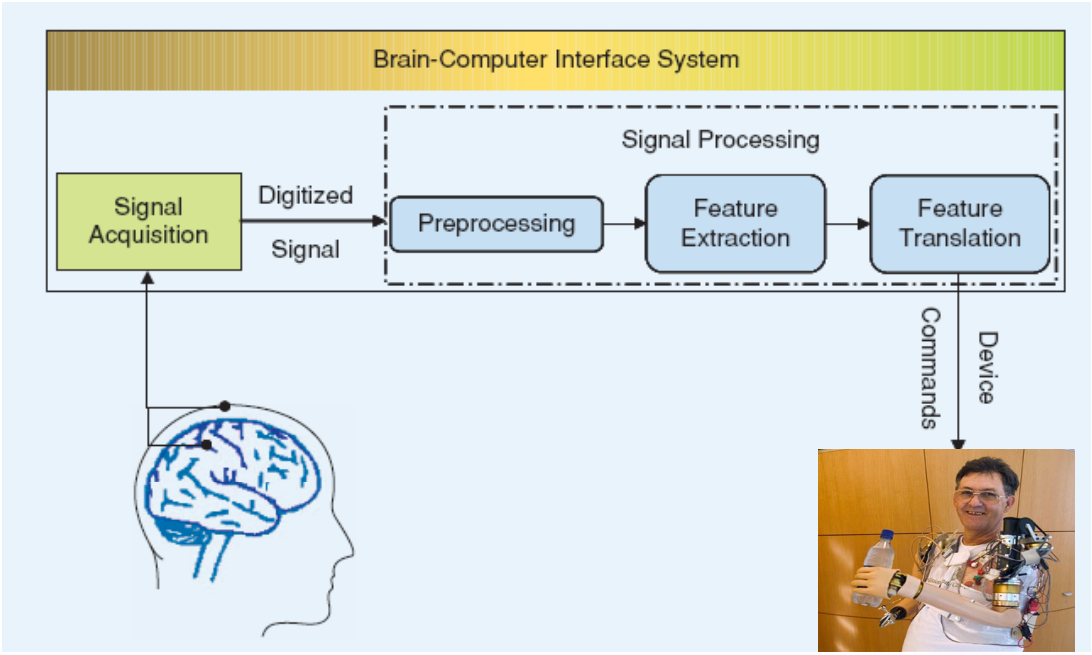
Welcome to the final class of the

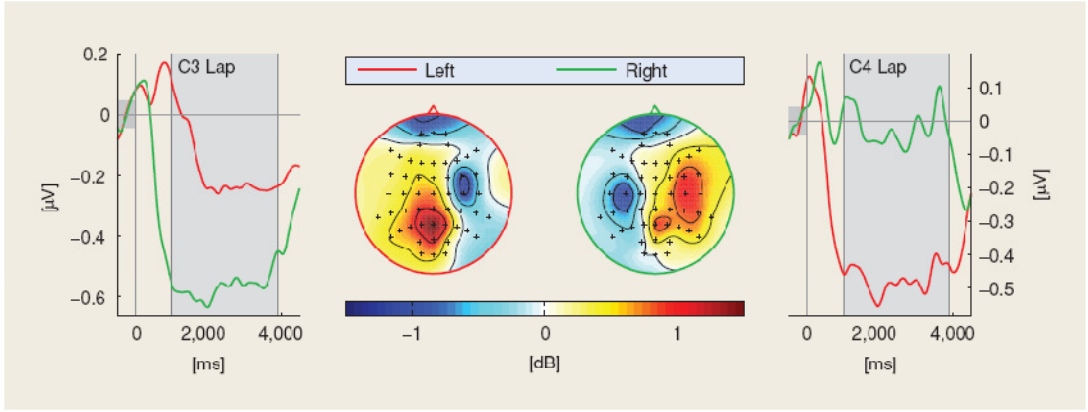
SEE CLASS | A4

KEITH MYERS | THE KANSAS CITY STAR

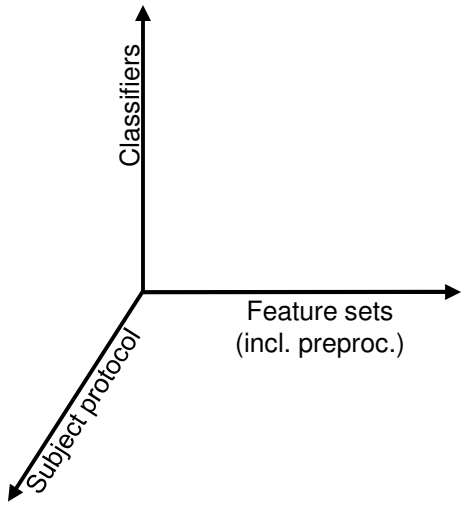
Graduate engineering student Ramaraju Medisetty offered his brain waves for study by his peers at UMKC.

qEEG: Signal Classification





[FIG2] Event-related desynchronization (ERD) during motor imagery of the left and the right hand. Raw EEG signals of one subject have been band-pass filtered between 9–13 Hz. For the time courses, the envelope of the signals has been calculated by Hilbert transform (see e.g., [9]) and averaged over segments of –500–4,500 ms relative to each cue for left or right hand motor imagery. ERD curves are shown for Laplace filtered channels at C3 and C4, i.e., over left and right primary motor cortex. The topographical maps of ERD were obtained by performing the same procedure for all (non-Laplace filtered) channels and averaging across the shaded time interval 1,000 to 4,000 ms.

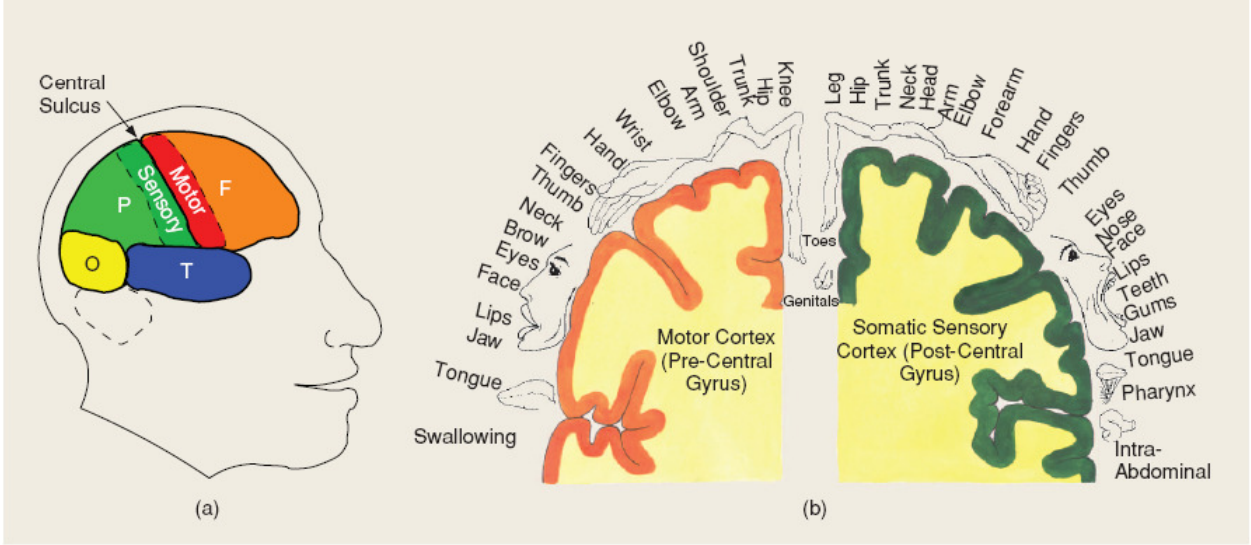


BCI Design Space

IEEE Signal Processing Magazine, Jan 08, BCI special issue (vol. 25, issue 1)

Preprocessing

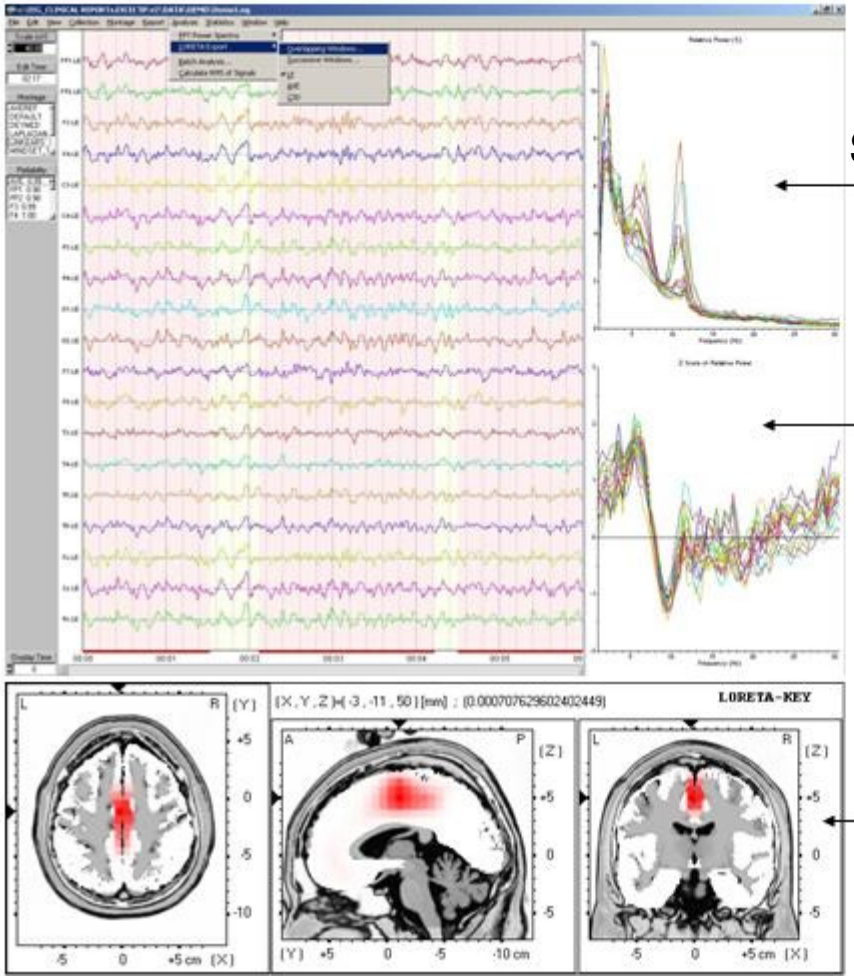
- Artifacts (line noise, blink, facial EMG, ECG, etc) and their removal
  - EG: level and frequency detection, ICA
- Spatial filtering



[FIG3] (a) Lobes of the brain: frontal, parietal, occipital, and temporal (named after the bones of the skull beneath which they are located). The central sulcus separates the frontal and parietal lobe. (b) Geometric mapping between body parts and motor/somatosensory cortex. The motor cortex and the somatosensory cortex are shown at the left and right part of the figure, respectively. Note that in each hemisphere there is one motor area (frontal to the central sulcus) and one sensori area (posterior to the central sulcus). The part which is not shown can be obtained by mirroring the figure folded at the center.

IEEE Signal Processing Magazine, Jan 08, BCI special issue (vol. 25, issue 1)

EEG Signal Features



http://www.biof.com/images/Dynamic_EEG-LORETA.jpg

Spectral features

Z-scores

Approximate point location (LORETA)

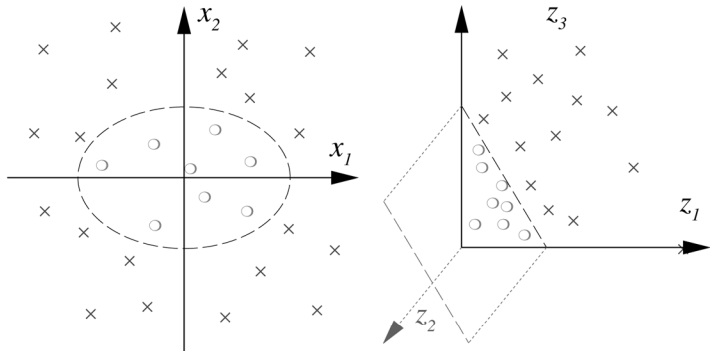
0.5-4 Hz: δ, deep sleep, overlaps with head muscle artifacts
4-8 Hz: θ, drowsy or deep meditation, larger in children
8-13 Hz: α, relaxed awareness, shut eyes
13-30 Hz: β, active thinking and attention
30-45Hz: γ, conscious perception

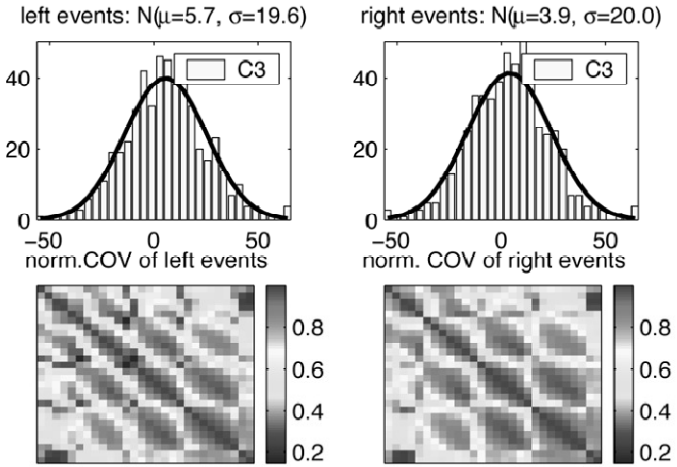
Features: Spatial, spectral, temporal (e.g. LPC), or a combination of the above (e.g. wavelets)

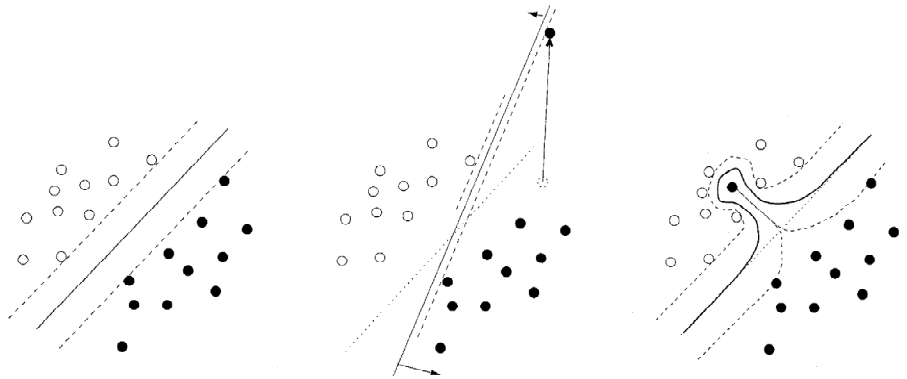
$$LPC: \quad x[n] = \sum_{i=1}^{p} a_i x[n-i]$$

Classification

- Traditional vs. data-driven
- Linear vs. Nonlinear
  - E.g. Fisher vs. SVM
- Ensemble & multimodal







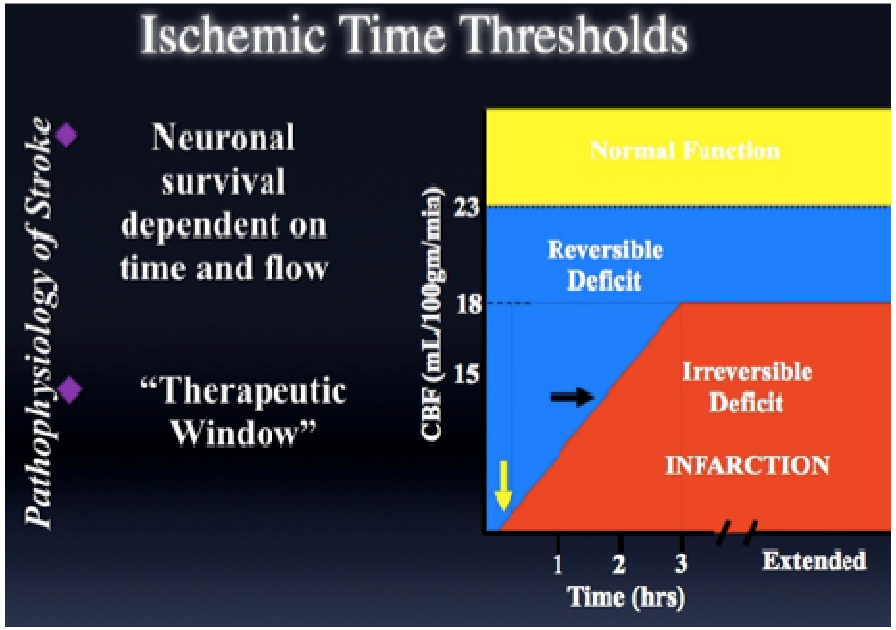
Linear and Nonlinear Methods for Brain–Computer Interfaces
Klaus-Robert Müller, Charles W. Anderson, and Gary E. Birch,
IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING, VOL. 11, NO. 2, JUNE 2003.

BCI Challenges

- Many, including:
  - Low SNR
  - Highly contaminated by various artifacts (blink and other facial EMG, ECG)
  - Nonlinear, low pass filtering of the head volume (skull and other tissue)
  - Chatter from other brain circuits (cocktail party problem)
  - Low spatial resolution
  - Variance: Same parson (long and short term)
  - Variance: Person to person
    - E.g: physical peculiarities of different brains (congenital or inflicted)
    - *Subject independence (one size fits all, SIBCI)?*
  - Discipline gap:
    - Medicine: Highly focused on linear analysis and vanilla statistics, but rich in domain-specific physiology
    - Engineering: The opposite!

qEEG and Ischemia

- With Dr Paul Camarata (St Luke's/UMKC), and Muhammed Banday and Meenakshi Mishra (UMKC)
- EEG is sensitive to decreased cerebral perfusion
- Applications: detection and monitoring of ischemic stroke and carotid endarterectomy (clamping of the internal carotid artery)



qEEG and Ischemia

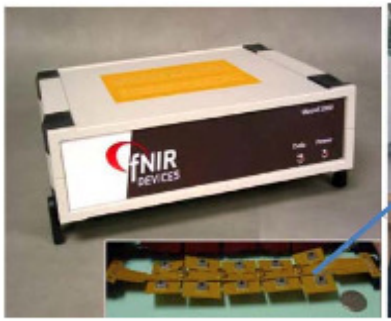
- During operations, EEG is manually monitored to determine weather selected shunting is required to avoid clamp-induced ischemia.
  - Selective shunting carries complication risks, and its administration depends on surgeon's judgment aided by visual assessment of the intraoperative EEG
  - For objective assessment of ipsilateral ischemia, qEEG methods such as Brain Symmetry Index (BSI) have been suggested recently

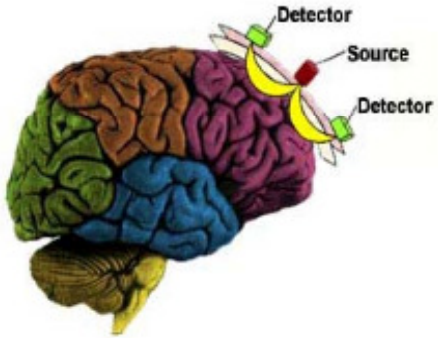
$$sBSI = \frac{1}{N}\sum_{i=1}^{N}\left\|\frac{1}{M}\sum_{j=1}^{M}\frac{R_{i,j}-L_{i,j}}{R_{i,j}+L_{i,j}}\right\| \qquad tBSI' = \frac{1}{N}\sum_{i=1}^{N}\left\|\frac{1}{K}\sum_{j=1}^{K}\frac{S_{i,j}-S_{ref\,i,j}}{S_{i,j}+S_{ref\,i,j}}\right\| \qquad tBSI = \frac{2tBSI'-sBSI}{2}$$

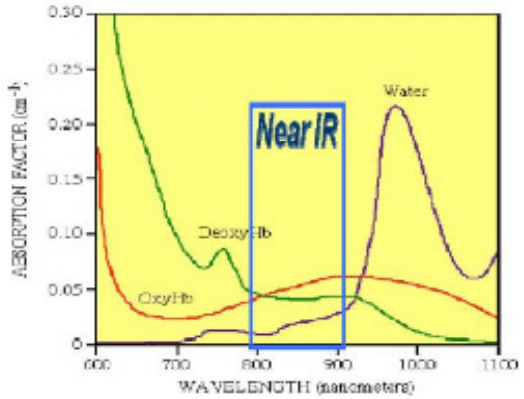
  - We are developing new machine learning techniques for intelligent qEEG analysis with better performance
  - Example: using Laplacian Montage, Fisher LDA, and ROC AUC feature selection, we improved 19% over tBSI and 54% over sBSI (one minute post clamp, 27 non-shunt patients, 9 fold cross validation)

Upcoming Technologies and Trends

- Near infrared spectroscopy (NIRS)
- Based on the absorption of NIR by Oxy/Deoxy hemoglobin, which correlates with tissue metabolic rate/activation
- Combining temporal resolution of EEG with spatial resolution of NIRS?





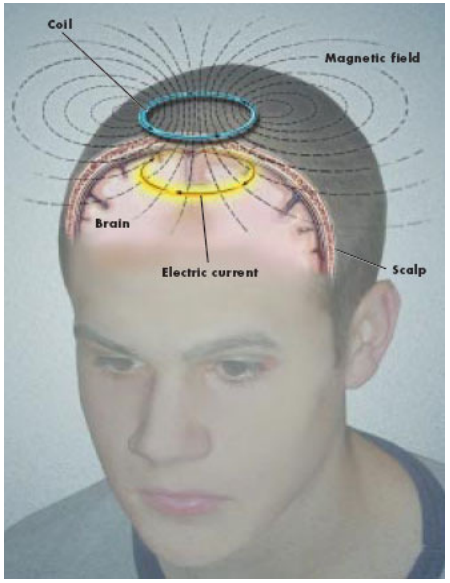


Images Courtesy of BIOPAC Systems

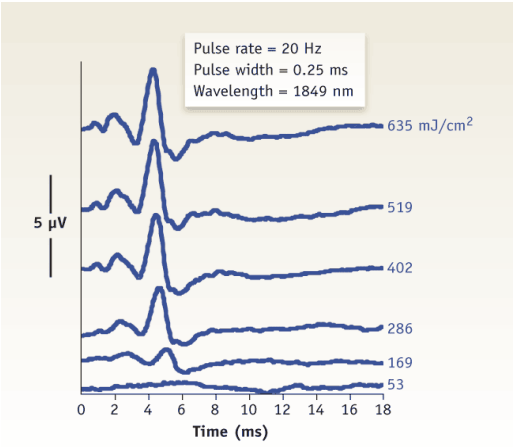
- My vision: a stand-alone, economical, helmet-shaped opto-electric system with spring-loaded electrodes; publicly accessible like automatic defibrillators; and used for early screening, telemedicine, assistive technologies,…

Upcoming Technologies and Trends

- EEG/NIRS are one way communication (read only), but how about writing back into the brain circuits, directly but noninvasively?
  - Transcranial Electromagnetic Stimulation (TMS)
    - Neurological/psychiatric treatments
    - Wide focal area
  - Infrared Nerve Stimulation (INS)
    - CNS tissue stimulation, e.g. peripheral nerves as in cochlear implants
    - Higher spatial resolution



Top: www.sfn.org/skins/main/images/brainbriefings/bb_summer2006_large.jpg
Bottom: www.optoiq.com/index/biophotonics/display/bow-article-display/345216



Hearing via light: direct IR stimulation of cochlear nucleus in the brainstem causes auditory response

www.aculight.com

For Further Exploration

- Papers:
  - IEEE Signal Processing Magazine, Jan 08, BCI special issue (vol. 25, issue 1)
  - Wolpaw J. , Birbaumer N., McFarland J., Pfurtscheller G., and Vaughan T. (2002) “Brain–computer interfaces for communication and control Clinical Neurophysiology, 113, pp767–791.
  - Izzetoglu, M., Bunce, S.C., Izzetoglu, K., Onaral, B., Pourrezaei, K.: Functional brain im- aging using near-infrared technology. IEEE Eng. Med. Biol. Mag. 26, 38–46 (2007)

- Commercial Educational Resource
  - g.tec http://www.gtec.at
- BCI Videos:
  - Invasive: www.youtube.com/watch?v=NIG47YgndP8
  - Non-invasive: www.youtube.com/watch?v=QnztNhCGch4
- Our web resources
  - www1.sce.umkc.edu/~derakhshanir
  - www1.sce.umkc.edu/cibit