1. Lecture 2.1 Underlying Brain Processes
   1. All BCIs have to operate on observable effects o fbrain activity
   2. Except for fMRI and fNIRS, they operate on effects of neural firing processes
   3. EEG, MEG and ECoG can only detect large-scale neural dynamics
      1. For example 50,000 neurons firing in near synchrony
   4. Underlying Neural Processes
      1. Largest contributors to the EEG are the pyramidal cells
      2. Radically oriented in the cortex (orthogonal to the surface)
         1. This leads to the neurons adding up and not canceling each other out
      3. Electromagnetic fields of co-aligned and co-activated neurons add up
   5. Large-scale Brain processes
      1. When would 50,000 neurons fire near-synchronously?
         1. An external event triggers a cascade of related neural processes
            1. In perception
            2. You saw something….
         2. An internal event triggers a cascade of related neural processes
            1. A sudden “aha!”

Realize something

* + - * 1. Gives rise to lots of dynamics

Might be able to pick up on a peak, might not know when to look

* + - 1. Neural populations enter a synchronized steady=state firing pattern
         1. Idle oscillations
         2. Many neurons firing at like every 10 Hz
         3. Happens when the brain enters an idle state
    1. Event-related Potentials (ERPs) and Oscillatory Processes are the two major BCI-detectable EEG/MEG phenomena
       1. These are the two biggest fields
  1. Signal Detectability
     1. Root cause might not be directly observable (e.g., dopaminergic system, deep brain structures, few neurons)
        1. You may not see the “aha” moment, just the cascade from it
     2. Widely scattered neural populations are unlikely to exhibit synchrony (unless connected by fiber tracts)
        1. Much more likely for a small compact group to fire together
        2. You will not see an impulse if the neurons do not fire in this small group
     3. Spatially compact populations are more likely to have coordinated timing
     4. Electromagnetic fields can cancel each other out

1. Lecture 2.2 Spatial Characteristics
   1. Can assign certain parts of the brain to areas because there are certain nervers ending there, and if this is where the nerve ends then the neurons that are around the ending are most likely going to be dealing with handing that input
   2. Some notable large-scale brain features are the hemispheres, lobes, gyri and suci (brain atlas)
      1. Prefrontal lobe
      2. Frontal lobe
         1. No nerve coming from the body
         2. Literature goes all over the place for this section
      3. Temporal lobe
      4. Precentral Gyrus (motor cortex)
      5. Central culcus
      6. Postcentral gyrus (somatosensory cortext
      7. Parietal lobe
      8. Occipital lobe
      9. Visual Cortex
         1. The nerves from the eyes end at the back of the head
         2. The neurons here are most likely to be processing visual
   3. Volume Conduction
      1. Neural activity is conducted through the brain volume to the scalp and sensors by Volume Conduction
      2. Volume Conduction is linear
      3. Each sensor measures a (weighted) sum of each neuron’s activity
      4. The point-spread function from a source patch to the scalp is extremely broad
   4. Measurement Sites
      1. Standardized location system (10-20 system)
      2. Saves a lot of hassle vs. custom labels
      3. Can use a digitizer to ensure proper placement
      4. Don’t need to worry about placement of cap with machine learning
   5. Equivalent Dipole Model
      1. Electromagnetic field sustained by a compact collection of neurons (e.g., 1 cm2) can be modeled as a single equivalent dipole
      2. This facilitates localization of the field source
      3. A way to localize points
   6. Dipole Modeling Problems
      1. High-quality fits are hard to achieve
         1. Requires knowledge about sensor locations
         2. Requires assumptions about conductivities of scalp, skull, cerebrospinal fluid (CSF), brain tissure
         3. Requires knowledge of the folding of the cortext (candidate dipoles) unless simplistic spherical model is used
         4. Some brain tissue has anisotropic conductance (white matter)
         5. Scalp maps are usually not perfect (arise from data processing) – fit accuracy suffers
         6. Scalp maps can be a sum of multiple dipole sources – requires a distributed source model
   7. Distributed Source Modeling
      1. Allow to recover and image distributed cortical support of given scalp maps
      2. Wide range of methodologies and underlying assumptions (sLORETA, Beamforming, Sparse Bayesian Learning, …)
      3. Prone to finding only locally optimal solutions
      4. Sparse Bayesian Learning is the best we think
2. Lecture 2.3 Temporal Characteristics
   1. Neural vs. Scalp Activity
      1. Neurons typically spike and resonate
         1. May be a type of encoding
      2. Typical Signal measured at a scalp site
         1. Never will be able to measure a certain neuron
         2. Might be able to pick up some stuff at higher frequencies
         3. Average of millions of neurons
         4. Sensor noise
   2. Event-Related Potentials (ERPs)
      1. Averaging EEG activity relative to an event results in primarily event-induced activity (trial-to-trial variability averaged out)
      2. Can use many many trials to remove the noise
   3. Oscillatory Processes
      1. EEG is permeated by oscillatory processes, such as the alpha rhythm
      2. Standard names for such rhythms:
         1. Delta
            1. 0-4 Hz
            2. Low frequencies
         2. Theta
            1. 4-7 Hz
            2. Known to occur in “bursts” relative to events in certain brain areas (e.g. frontal midline, lateral frontal)
         3. Alpha
            1. 8-13 Hz
            2. Sensory areas (visual cortex, auditory cortex) and Motor areas (motor cortex) exhibit strong alpha-band oscillations when “idle” in most subjects
         4. Beta
            1. 12-30 Hz
            2. Motor cortex often generates also beta-band oscillations
         5. Gamma
            1. 25 – 100 Hz
            2. Crossover from low gamma to high gamma is about 45 Hz
3. Lecture 2.4 EEG Phenomena
   1. Higher-order phenomena
      1. Event-Related Coherence between two signal components
      2. Sometimes signals are phase locked, sometimes they are out of sync and sometimes they are off by 90 degrees
   2. Effective Connectivity
      1. Sophisticated measure of interaction between multiple signals (“information flow”)
      2. Tim Mullen’s toolbox sift
      3. One source driving other sources
      4. Looking at if one source predicts the firing of another source, if so then draw an arrow from it
4. Lecture 2.5 Non-Brain Artifacts
   1. Non-Brain Artifacts
      1. Often far outscale the brain processes in the EEG (when present)
         1. Larger in amplitude because they are from muscles and not tiny neurons
      2. Internally Generated
         1. Neck, face and eye muscles, eye dipoles, heart activity
         2. Neck muscles are the dominate ones
         3. The eyes themselves are dipoles
            1. When they turn the projection changes
            2. They give off an electromagnetic source
      3. Externally Generated
         1. 50/60 Hz line noise, EM spikes from equipment
         2. If you know it in one, you can subtract it from all of them
      4. Sensor-related
         1. DC offset drifts, cable sway, thermal noise, quantization noise
   2. Muscle Artifacts
      1. High-frequency / broadband, large amplitude
         1. There are some algorithms to remove these
      2. Scalp projections are spatially stereotyped
         1. If you design a BCI and you throw machine learning at the problem, you might actually pick up a muscle artifact because the person was excited or something
   3. Eye Blinks
      1. Large low-frequency peak and rebound, mainly frontal
         1. Dominate in the frontal channels
      2. Can also incurs non-linear effects in occipital cortex
5. Lecture 2.6 Sensing and Acquisition
   1. EEG Sensor Designs
      1. Most EEG systems are gel-based
         1. Salty, electrolyte solution
      2. Nowadays mostly using active electrodes
         1. Have a little amplifier on the electrode them self
         2. Artificats are much lower
         3. Much worse impedances
            1. The resistance between the electrode and the skin
      3. Passive
         1. No electronics with it
      4. Dry (gel-free) systems are emerging quickly
         1. Pins (g.SAHARA)
         2. Spring-loaded pins (NCTU)
         3. Foam-based sensors (NCTU)
            1. For the forehead where there is no hair
         4. Pins
            1. Used to get through the hair
            2. Distribute the force through multiple sites
            3. Rounded tips (so they don’t hurt or puncture)
            4. Only need a couple to make contact
      5. Recent Prototypes (look here?)
         1. Bristle Sensors
            1. Grozea et al., 2011
            2. Little britles like a tooth brush
         2. Epidermal Electronics
            1. Kim et al., 2011
            2. Full circuit printed on skin
   2. Digitization
      1. After amplification (e.g., 50000x), signal is low-pass filtered using an analog filter, then digitally sampled at a fixed rate
      2. Can give the illusion that the output is a step function, don’t believe it
         1. Gives the illusion that it is interpreted as a step function
      3. There is a highest frequency you want to deal with, you filter right above that, and digitize at twice the rate and you are absolutely fine
         1. Nyquist-Shannon sampling theorem
   3. Sampling Theorem
      1. If the signal is band-limited below the Nyquist frequency B (i.e., contains no higher frequency than B), it can be exactly reconstructed using the interpolation function
      2. The Nyquist Frequency is ½ sampling rate
      3. Good article here
         1. <https://en.wikipedia.org/wiki/Nyquist–Shannon_sampling_theorem>
         2. All you need to really apply is that if you band limit a signal, you can perfectly reconstruct it
         3. Essentially if you are only taking a sample every time factor you might loose useful data during each time interval because you might measure the same sampled sequences by chance creating an alias and not the actual sample you wanted…
   4. Computer-based Access
      1. That data is made accessible through
         1. Vendor-specific recording programs
            1. BrainVision Recorder, ActiView, g.Recorder
         2. Vendor-Specific system drivers
            1. Emotive SDK, BioSemi Driver
         3. Generic system interfces
            1. Bluetooth serial port, A/D cards, TCP
      2. Almost all EEG systems support real-time signal access (except for some gadgets)