Neuroscience Gateway Project

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UC San Diego
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NSG NEUROSCIENCE GATEWAY A Portal for Computational Neuroscience
NEURON for empirically-based simulations of neurons and networks of neurons

Abstract

For the last few decades, high performance computational software has been and continues to be very useful for scientists wanting to understand the workings and map of the brain, nervous system, and why humans behave the way that they do. The development of these technologies have also accelerated the evolution of neuroscience as a whole, leading to significant discoveries in the field that would have been almost impossible without it. Methods such as the Functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET) are what make modern neuroscience what it is today, with thousands of scientists in the field using them in their published works. Our research adapted these useful tools in helping us collect our findings and capturing any noticeable features in analyzing the data as well as simulating certain phenomena that are otherwise far too costly to perform real-life lab experiments with. Through our research, we seek to find links between performing a certain function and the corresponding brain signal as well as model neurons to understand the important processes that take places in the brain and throughout the human body.

Introduction

Our research involving supercomputers, EEG, and brain simulations explores how brain activity differs when a person is resting or sitting versus moving, using both invasive and noninvasive data collection methods. Our work is important for understanding brain function in health and disease, aiding in the diagnosis and treatment of disorders such as Parkinson's, epilepsy, blindness, and hearing loss.

Expanse

Supercomputer at SDSC

OpenMP

- Thread-based parallelism
- Threads share same resources and memory (master thread of execution)
- No message passing
- Shared data: single storage location
- Private data: multiple storage locations on individual threads

Both:

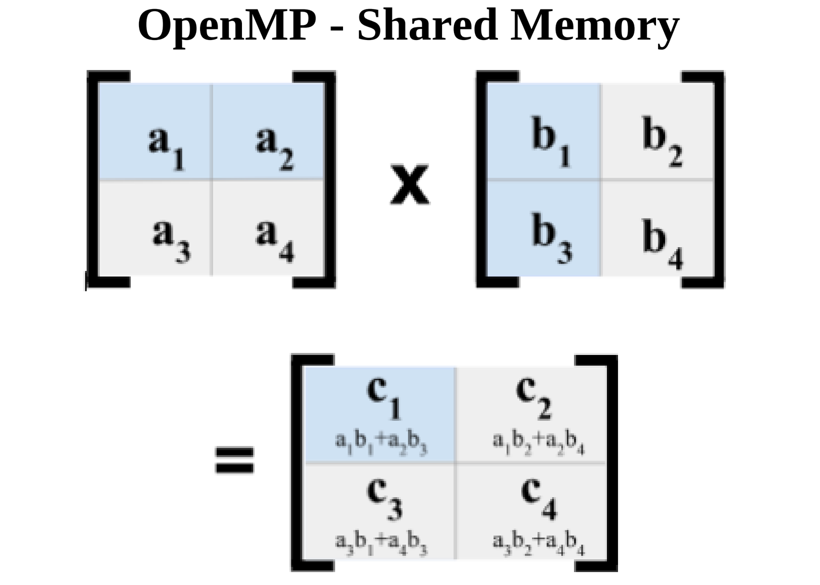
- Parallel computation

MPI

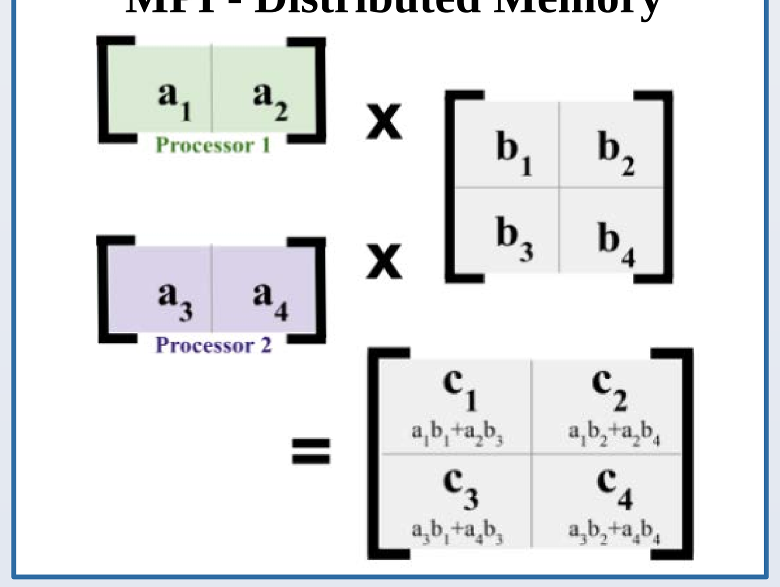
- Parallel computation for distributed memory
- Process-based parallelism
- Each process has own memory space, executes independently
- Processes execute by passing messages to each other

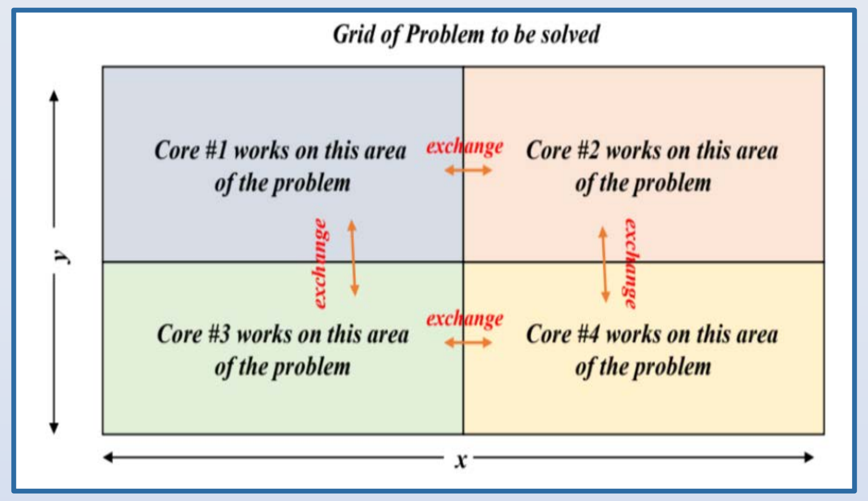
Matrices: two dimensional array of numbers - allow for efficient processing of large datasets on the SDSC Expanse Supercomputer.

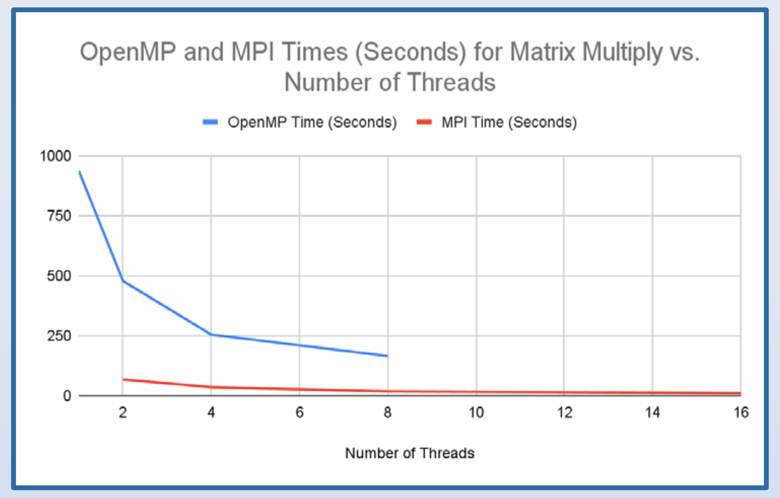
OpenMP - Shared Memory



MPI - Distributed Memory







Task Partitioning: Breaks up the computational tasks to complete into subsets so that it takes less time to finish (ex. assigning a set of books to workers)
Communication: Processors interact with one another, sharing and exchanging information (ex. passing of books to each other between subtasks)

EEG/Muse

Methods

- Used the MUSE headset along with the Mind Monitor app (with Bluetooth) to capture our brain waves in four different regions: AF7, AF8 (front) and TP9, TP10 (back)
  - One trial with eyes open, one trial with eyes closed (1 minute each)
- On Matlab and EEGLab, we graphed the spectra and maps displaying the location of the different channels and frequencies
- Spectra graphs showed the trends of different electrodes. Although the the graphs of each electrode had different values, they all generally followed a similar trend
- **EEGLab data Preprocessing Pathway**:
  - Collect high density data → Import into EEG → Import channel locations → Re-reference → High pass filter → Remove line noise → Identify/reject bad channels → PLOT

Delta - deep sleep (0.5-4 Hz)

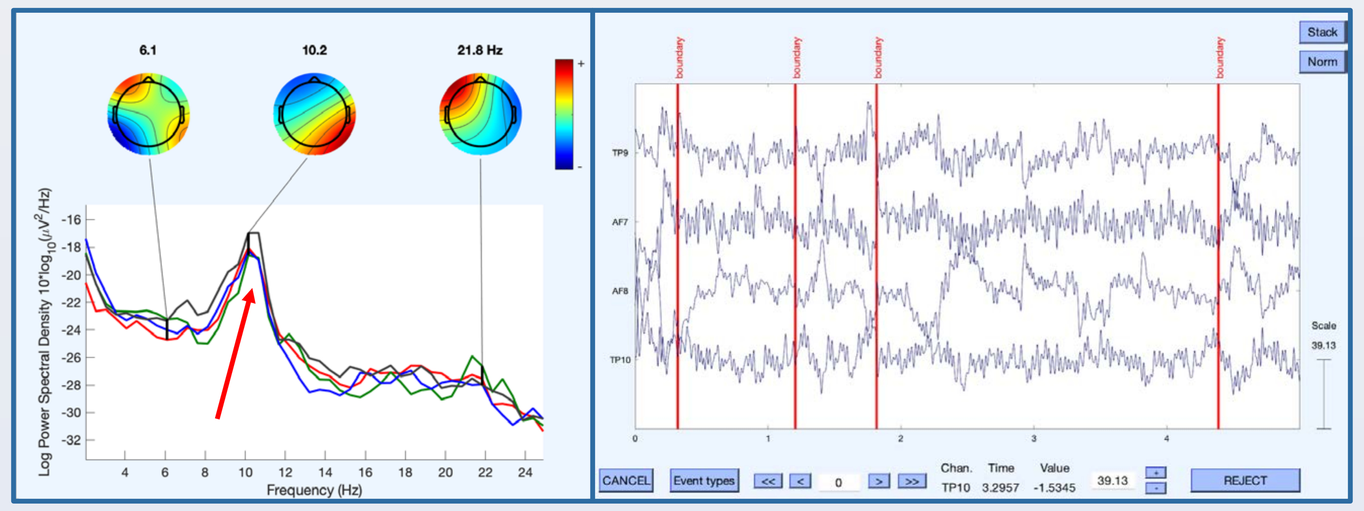
Theta - subconscious mind between sleep and wakefulness (4-8 Hz)

Alpha - restful state (8-12 Hz)

Beta - motor execution (12-30 Hz)

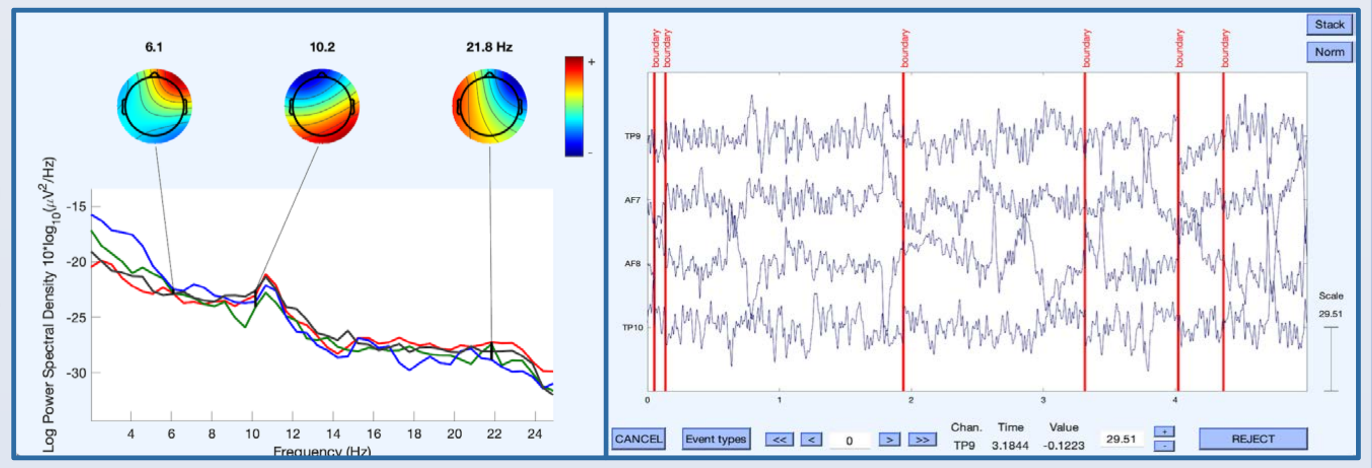
Gamma - very high frequency, intense focus (25-100 Hz)

Eyes Closed



Eyes closed: increase in alpha waves (peak between 8-12 Hz)

Eyes Open



Eyes open: slightly more dominant in beta waves (higher spectral density from 12-35 Hz)

Strengths and Limitations of EEG (Electroencephalogram)

Strengths	Limitations
- Good temporal resolution - Noninvasive (doesn't require dangerous surgery) - Can include a more diverse set of subjects - Ethical	- Poor spatial resolution - Can only read data from groups of neurons (not specifically targeting an area) - Very sensitive to noise

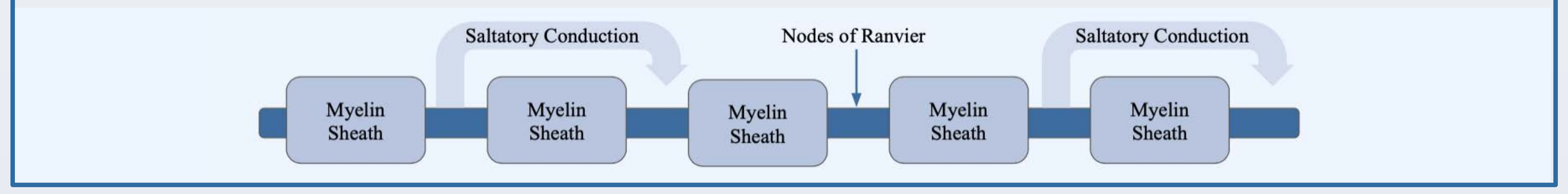
Neuron Simulation

Anatomy/Physiology of a Neuron

- **Internal resistance**: Resistance within the axon (inversely proportional to axon diameter)
- **Membrane resistance**: Prevents current from leaking (proportional to length constant)
- **Input resistance**: Factor which electrode current is decreased by in axon
- **Length constant**: Distance over which the potential falls to 37% of its max value
- **Time constant**: Time it takes for the potential to rise to 63% of its final value
- **Capacitance**: Amount of charge accumulated for each volt of potential applied to it (causes a delay)
- **Voltage**: Difference in electrical potential between two points

Myelinate Axons & Saltatory Conduction

- Made of proteins and fat (Schwann cells)
- Increases membrane resistance; Decreases internal resistance; Increases capacitance
- Has Nodes of Ranvier (exposed axon with cluster of sodium channels → quick depolarization)
- Current jumps from node to node (**saltatory conduction**) → increases current velocity

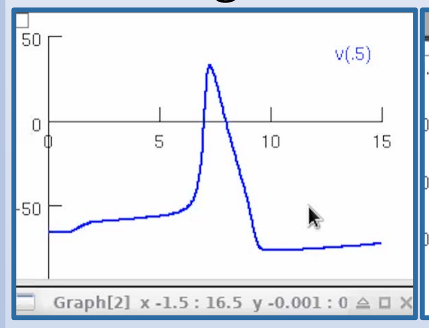


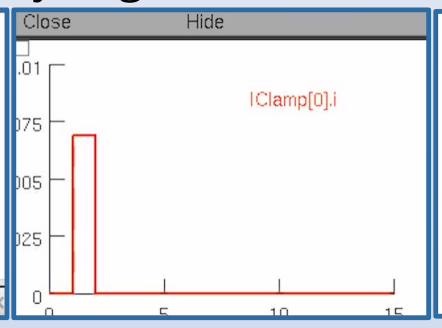
Invasive/noninvasive methods learned

- **Noninvasive**: EEGs use metal electrodes are placed on the test subject's scalp and differential amplification is used to detect the voltage difference between the electrode and postsynaptic potentials in the brain **see EEG/Muse section*
- **Invasive**: EES, DBS, SCS involve electrode implants

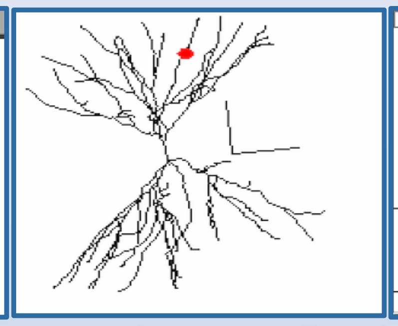
Epidural Electrical Stimulation (EES)	Deep Brain Stimulation (DBS)	Spinal Cord Stimulation (SCS)
- Creates monopolar potentials at the point of contact - Promotes stepping movements in lower limbs and grasping, reaching, and pulling movements in upper limbs - Region and frequency specific - Potentially therapeutic	- Treatment for treatment resistant depression (TRD) and movement disorders - Activates specific axon pathways in the cortico-striato-thalamo-cortical (CSTC) networks - Specific mechanisms/optimal targets not well-defined	- Mostly used for pain control as a form of neuromodulation (affecting nerve signals) - Still no clear understanding in why SCS works so well for pain control

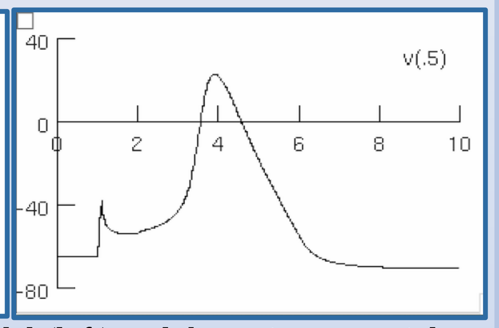
Modeling and Analyzing Nerve Cells with NEURON





Action potential (left) caused by 0.0069 nA (right)





Complex nerve cell model (left) and the action potential (right) caused by currents from an electrode placed at the red dot