A. James Clark School of Engineering

ECE 7
Neural Model of Working Memory

College of Computer, Mathematical, & Natural Sciences

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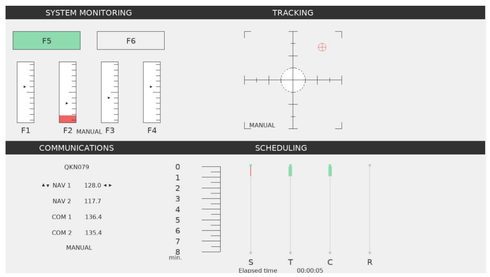
Background

- The brain's ability to store and manipulate short-term information (**working memory**) is important for:
  - Multi-tasking (**context switching**)
  - Cognitive performance under load
- The **Multi-Attribute Task Battery** (MATB), designed by NASA, is a tool for testing cognitive performance under load.



- **Limitations of current MATB research:**
  - **Exclusively performed on human participants**
    - Small sample sizes
    - Fatigue, stress, anxiety sway results
    - Months to complete a study

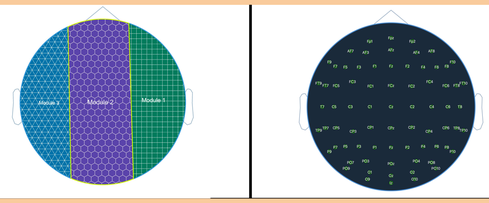
Objective & Solution

- **Objective:** Allow researchers the ability to test countless runs of the MATB, to further research into the brain's working memory
- **Solution:** A biologically plausible neural network visualization and simulation software for neurology researchers that:
  - **Supports creation** of highly customizable neural architecture
  - **Simulates** the MATB being performed
  - **Visualizes** real-time neural activity via configurable sensors on the brain model

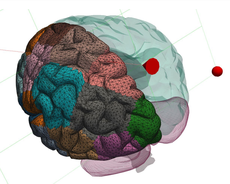
Software Design

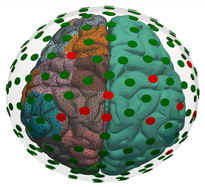
- **neural2 User Interface:**
  - **Create** a virtual brain model in **2D** or **3D** with:
    - **Modules** (cerebral regions)
    - **Nodes** (clusters of neurons)
      - **Lattice patterns** to simulate real neural layout
    - **Edges** (neural pathways)
    - **Sensors** (EEG electrodes)
      - Import custom templates or use common headcap layouts

2D User Interface

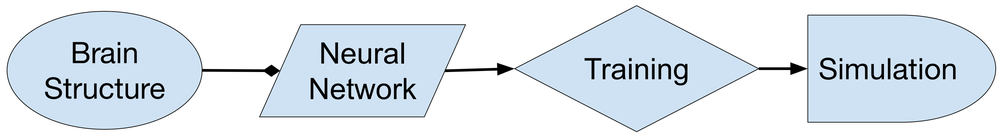


3D User Interface

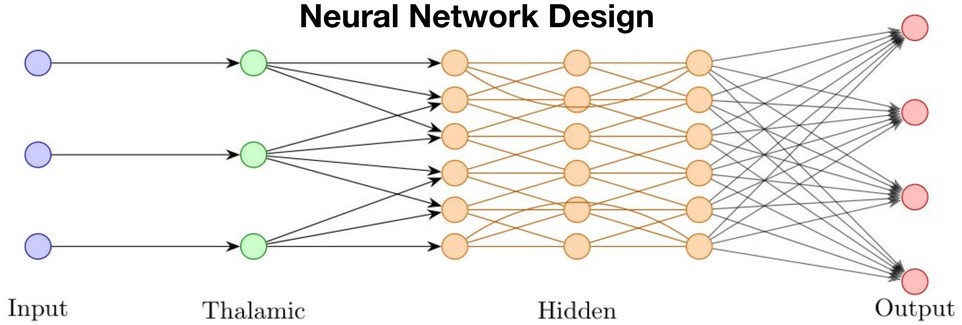




User Workflow



Neural Network Design



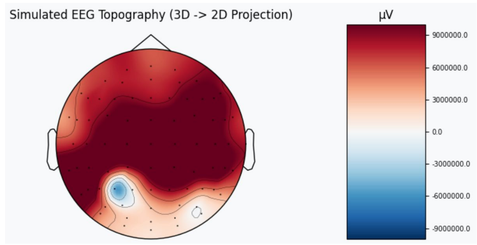
- **Thalamic Layer** used to model **context switching** by suppressing winner's associated inputs and boosting runners-up
- **Recurrent Hidden Layer** enables **working memory**: Neurons feed back to themselves, maintaining task context across time

- **Train** the neural network:
  - Select activation (e.g. tanh) and loss (e.g. log loss) functions
  - Apply **Hebbian learning** to update hidden→output edge weights

- **Simulate** the brain completing any combination of three of these MATB's subtasks:
  - System Monitoring
  - Tracking
  - Communications

Results

- **Visualize** a variety of simulated brain activity metrics in real time:
  - EEG Trace History
  - Power Spectral Density
  - EEG Heatmap



- **Export** post-simulation info:
  - Neural Network information
  - MATB parameters
  - Training results
  - Simulation results
    - Anomalies, Accuracy

Conclusion

- User parameters can greatly vary model results (as desired), but some models were able to reach up to **80% accuracy**
- As a result of context switching and ease of task, the models perform the **best** on the **system monitoring** subtask
- By giving users freedom in the model and simulation's structure and parameters, we are able to control specific variables and see how they affect task performance

References

- Garra, J. (n.d.). Juliencegarra/OpenMATB: OpenMATB: A multi-attribute task battery promoting task customization, software extendability and experiment replicability. GitHub. https://github.com/juliencegarra/OpenMATB
- Liebe, S., Niediek, J., Pals, M., Reber, T. P., Faber, J., Boström, J., Elger, C. E., Macke, J. H., & Mormann, F. (2025, March 24). Phase of firing does not reflect temporal order in sequence memory of humans and recurrent neural networks. Nature News. https://www.nature.com/articles/s41593-025-01893-7