Mathematical Modeling to Improve Neurostimulation

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SHINE
Summer High School Intensive in Next-Generation Engineering

Introduction

Approximately 1.2% of the people in the US have epilepsy, which amounts to ~ 3.4 M people nationwide, and 65 M+ globally [1].

- Although there are many treatments available with new advancements in medicine,
  - 1/3 of all epileptic patients are resistant to medication
  - Patients that undergo surgery only have a 40% chance of being seizure free.
- The innovation of an **implantable electrode** will help epileptic patients that are resistant.

Figure 1
The image above shows the implantable electrode (grey square) which measures electrical signaling to provide neurostimulation to the brain.

Learning Process + Skills Learned

In my first week of SHINE, I learned how to efficiently read research papers, which I then applied to the 3 papers my PhD mentor said were helpful.

- Compiled research and made a Literature Review + Slideshow for all notes
- Research Paper Analysis
- Matlab Training --> Learned how to code graphs / models

For the second and third weeks of SHINE, I attended the workshops hosted by Prof. Raghothaman, Prof. Hsu, and Eric Ewing. These workshops were challenging, as they were topics that I hadn't gone over before.
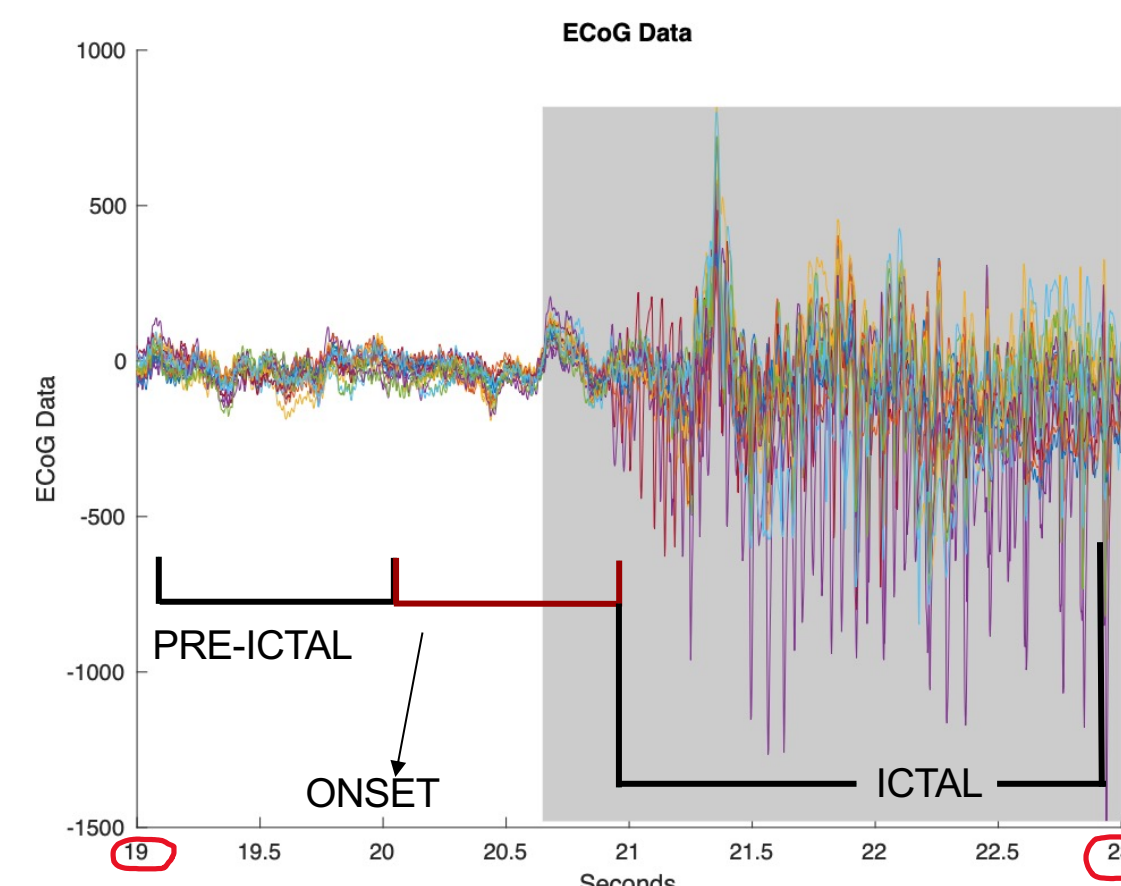
- Learned about Mathematical Modeling of Dataset
- Applied Physics and Calculus topics into my research, which will help in future classes.

Data Set
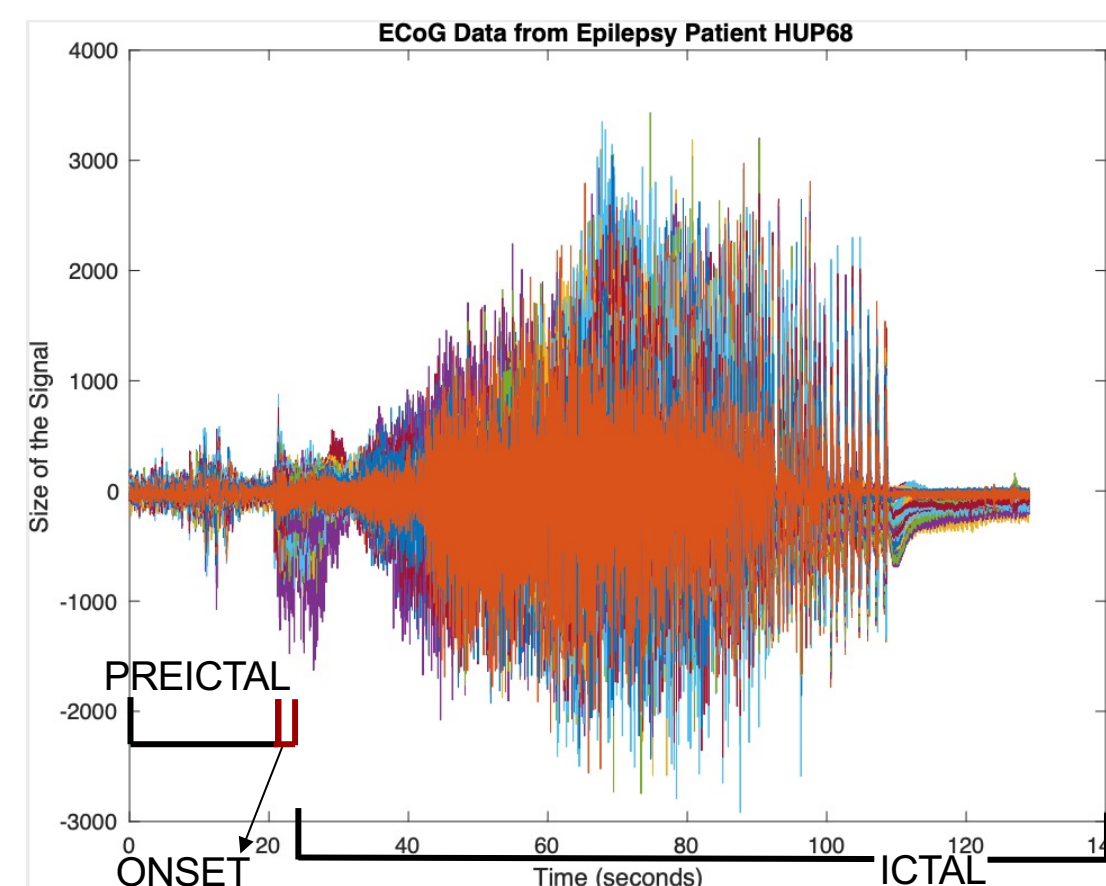
Figure 2
ECoG Data modeled from Patient HUP68
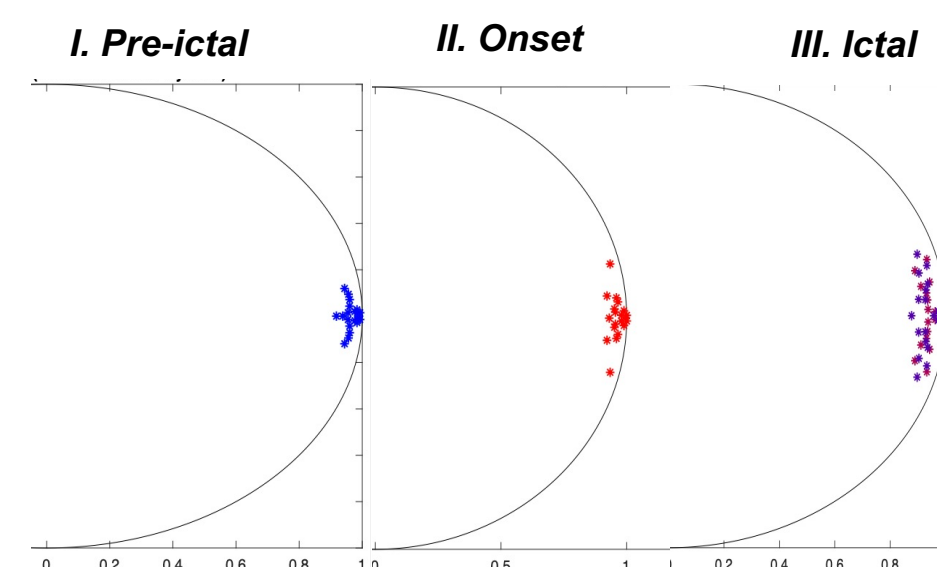
Figure 3
Snapshot of ECoG Data modeled from Patient HUP68, showing seizure onset stage

The different colors represent the different channels that the measurement is taken from. We can see throughout the model the normal brain activity **(pre-ictal)**, start of the seizure **(onset)**, and the duration of the seizure **(ictal)**.

Analysis

SWITCHED LINEAR MODEL
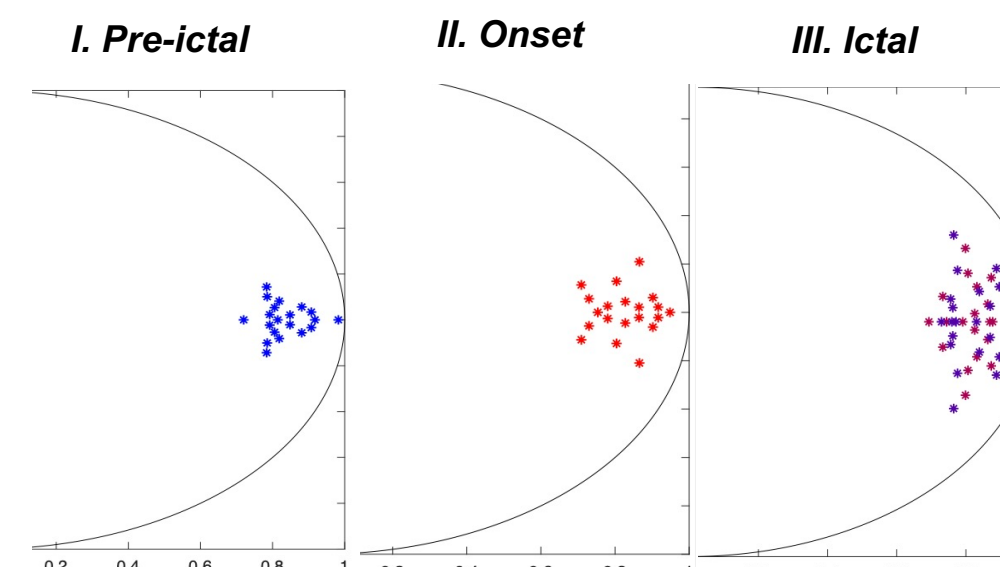
$$x[t + 1] = A_k x[t]$$

I. Pre-ictal   *II. Onset*   *III. Ictal*

Figure 4 [3]
Eigenvalues modeled by switched linear equation

FRACTIONAL-ORDER MODEL

$$\Delta^\alpha x[t + 1] = A_k x[t]$$

I. Pre-ictal   *II. Onset*   *III. Ictal*

Figure 5
From left to right, eigenvalues from Pre-ictal, Onset, and Ictal modeled by fractional order equation

These eigenvalues can show us when the system is stable / unstable, and classify the start, middle, and end of seizure. As the eigenvalues move out of the unit circle, the system becomes more and more unstable, showing us the start and duration of the seizure. The fractional-order equation shown to the right has memory, meaning it uses all past measurements to predict future ones. Using this equation, we found eigenvalues (Figure 5), which we want to compare to the switched linear eigenvalues (Figure 4). We compare the two equations to see which would better represent our data.

Conclusion

After modeling our dataset for patient HUP68, and analyzing the various graphs, we can use the implantable electrode to better predict when a seizure will happen. As the system becomes more unstable (Figure 4), the electrode knows that a seizure is occurring, and can step in to mitigate the seizure. This ties back to our overall motivation for this project. We want to help epileptic patients that are resistant to treatments, such as medication and surgery, by using an implantable electrode.

Next Steps

I want to learn more about making my own algorithms to model datasets and apply the knowledge I learned here at SHINE to analyze other datasets. Furthermore, I want to research on other projects that are at the intersection of health and technology.

Acknowledgements

[1] Holland, Kimberly. "Epilepsy: Facts, Statistics, and You." *Healthline*, Healthline Media, 14 May 2019, www.healthline.com/health/epilepsy/facts-statistics-infographic.

[2] Chatterjee, Sarthak, et al. "Fractional-order model predictive control as a framework for electrical neurostimulation in epilepsy." *Journal of Neural Engineering* 17.6 (2020): 066017.

[3] Ashourvan, Arian, et al. "Model-based design for seizure control by stimulation." *Journal of neural engineering* 17.2 (2020): 026009.

[4] Bassett, Danielle S., and Olaf Sporns. "Network neuroscience." *Nature neuroscience* 20.3 (2017): 353-364.