Detecting Seizure Onset using Quantification of Stability of Fractional-Order System

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SHINE
Summer High School Intensive in Next-Generation Engineering

Introduction

- 1% of the world's population is affected by epilepsy
- ⅓ of epileptic patients are resistant to medication [1].

Therefore, improvements on neurostimulation devices remain crucial to aid epilepsy patients.

In Professor Bogdan's research project, we use fractional order dynamics to give new insight on spatial and temporal analysis of epilepsy ECoG (electrocorticography) data.

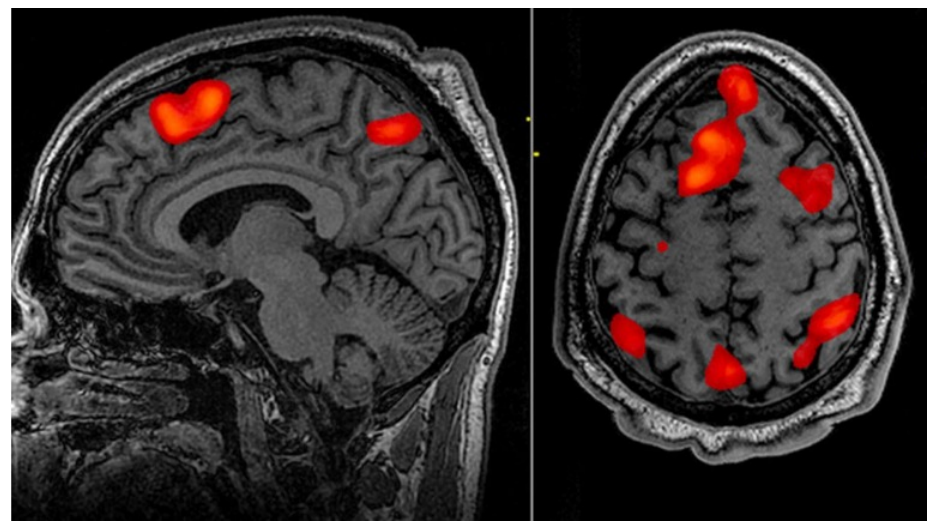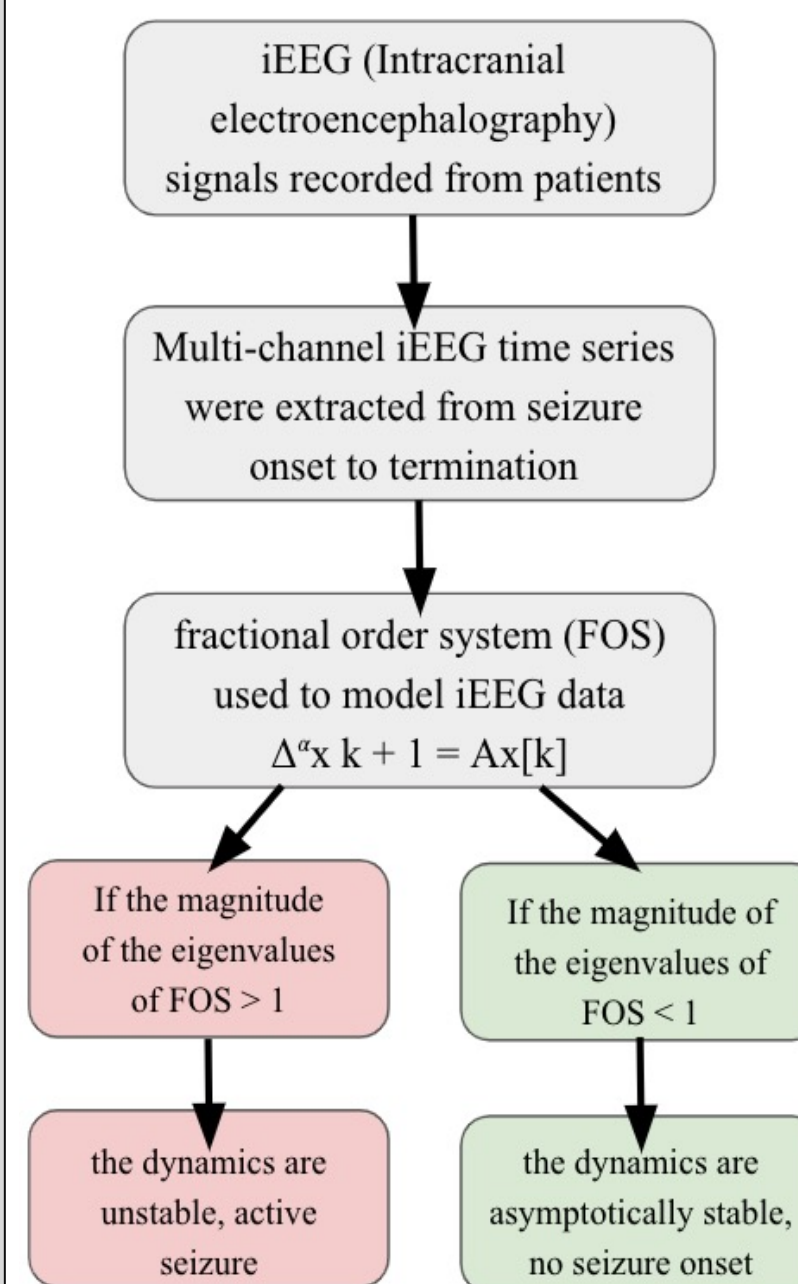- Help improve implantable devices and neurostimulation treatment

Figure 1 ECoG data scan. Red areas depict high oxygen concentration in RBC, indicating high neural activity and electrical signals. [2]

Skills Learned

- Read and analyze research papers
- Conduct computational research
- Use Matlab: plot patient data, read/write code
- Understand linear order system vs. fractional order system
- Understand eigenvalues and eigenvectors conceptually
- view video overview of eigenvectors and eigenvalues:

Future Steps

- Learn/participate in research at the intersection of biology, mathematics, and technology
- Learn about racial biases in artificial intelligence
- Learn more about machine learning

Methodology

iEEG (Intracranial electroencephalography) signals recorded from patients

↓

Multi-channel iEEG time series were extracted from seizure onset to termination

↓

fractional order system (FOS) used to model iEEG data
$$\Delta^{\alpha} x\,k+1 = Ax[k]$$

↓

If the magnitude of the eigenvalues of FOS > 1 → the dynamics are unstable, active seizure

If the magnitude of the eigenvalues of FOS < 1 → the dynamics are asymptotically stable, no seizure onset

Data Processing

A.

Sample ECoG Data From Epileptic Patient — Seizure onset

B.

α of the Sample Channels
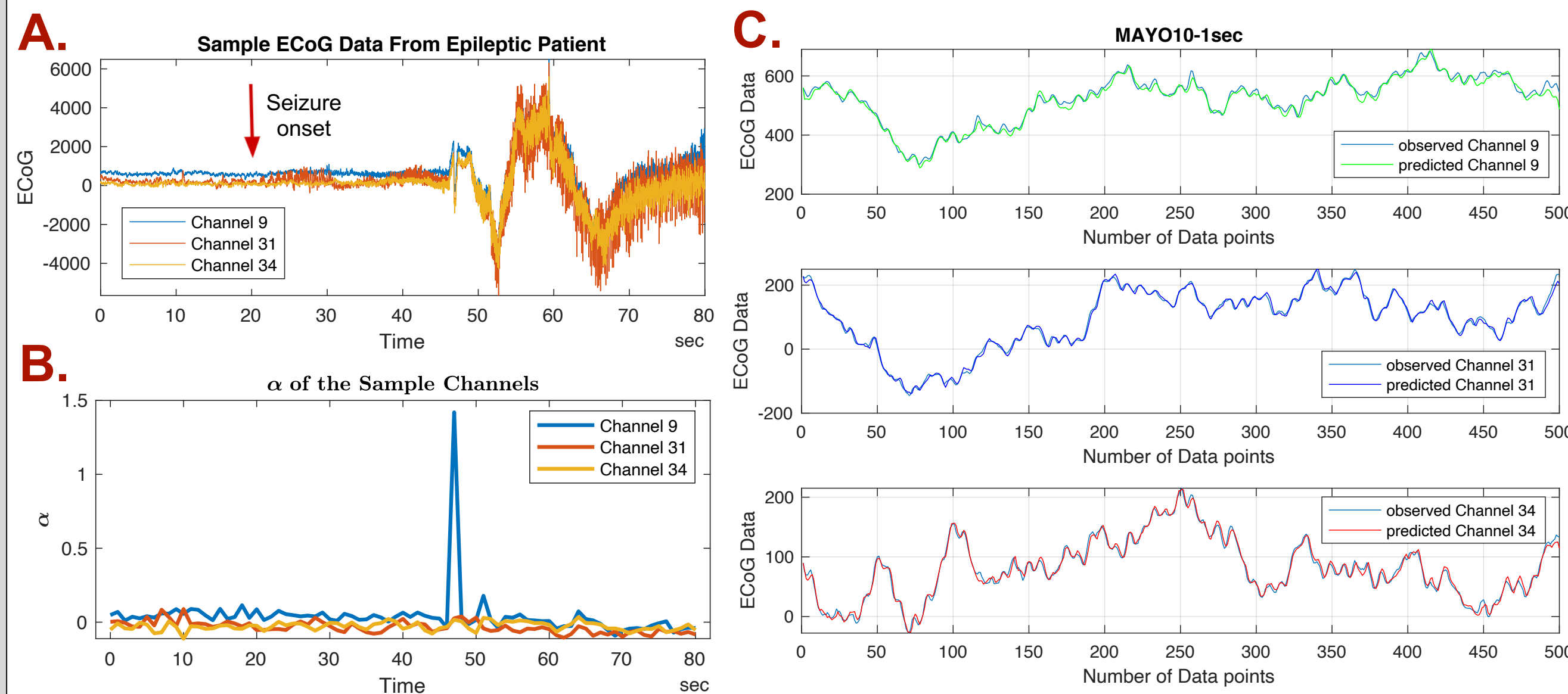
C.

MAYO10-1sec

Figure 2 System Identification. *Fig. 2A* Shows sample data from MAYO10 patient exhibits seizure onset at 20 sec. *Fig. 2B* The order of the systems are fractional orders, and they demonstrates significant difference from 0. *Fig. 2C* One-step prediction for ECoG data for one second shows that the fractional order system can accurately predict data. *PC: Julia G.

Data Analysis
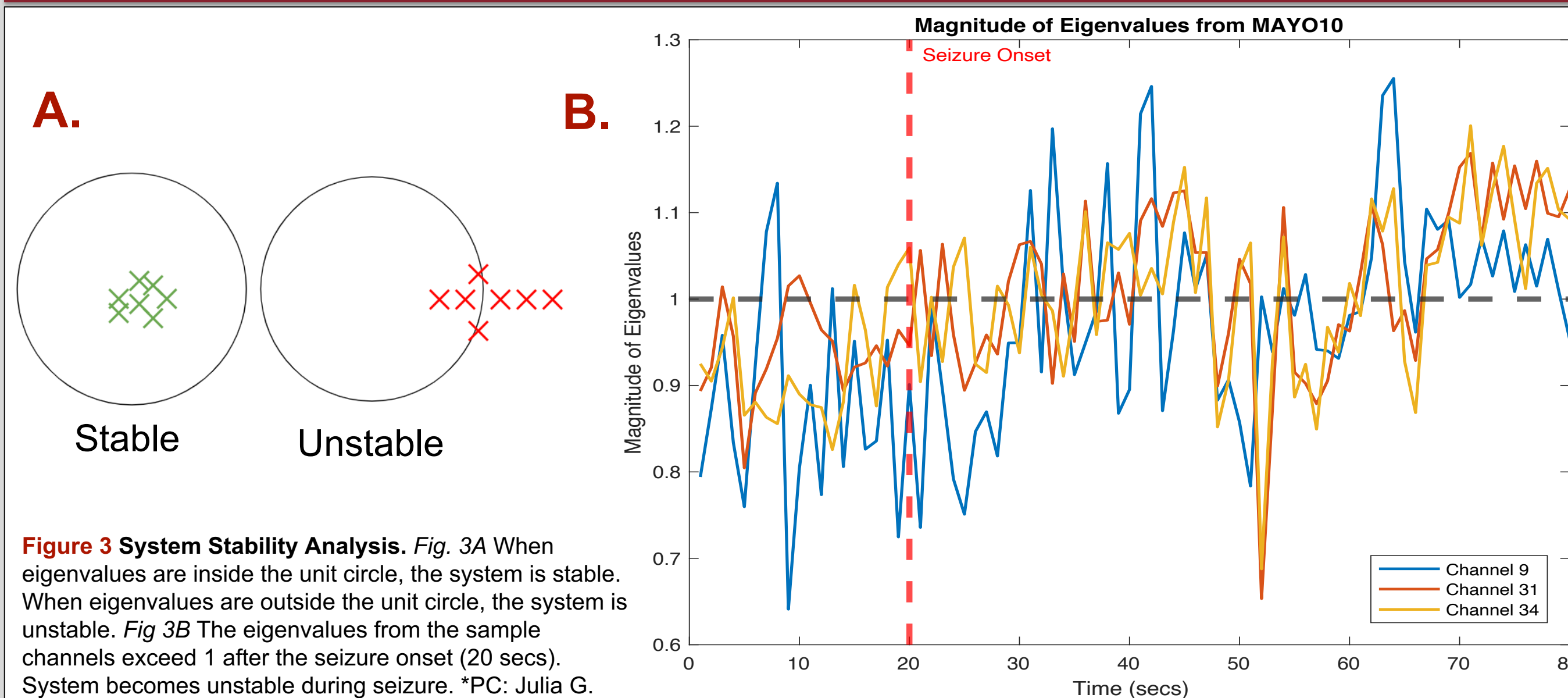
A.

Stable   Unstable

Figure 3 System Stability Analysis. *Fig. 3A* When eigenvalues are inside the unit circle, the system is stable. When eigenvalues are outside the unit circle, the system is unstable. *Fig 3B* The eigenvalues from the sample channels exceed 1 after the seizure onset (20 secs). System becomes unstable during seizure. *PC: Julia G.

B.

Magnitude of Eigenvalues from MAYO10 — Seizure Onset

Acknowledgements

1. Ashourvan A, Pequito S, Khambhati AN, Mikhail F, Baldassano SN, Davis KA, Lucas TH, Vettel JM, Litt B, Pappas GJ, Bassett DS. Model-based design for seizure control by stimulation. J Neural Eng. 2020 Mar 26;17(2):026009. doi: 10.1088/1741-2552/ab7a4e. PMID: 32103826; PMCID: PMC8341467.
2. T. Pedersen, "All About Functional Magnetic Resonance Imaging (fMRI)," *Psych Central*, 13-Dec-2021. [Online]. Available: https://psychcentral.com/lib/what-is-functional-magnetic-resonance-imaging-fmri#definition. [Accessed: 18-Jul-2022].