<u>Motivation Letter:</u>

In recent decades, Machine Learning (ML) has transformed our approach towards tackling a problem through its widespread adaptation across entire aspects of scientific and technological breakthroughs. Learning generally refers to designing a machine architecture for extraction of a set of features from a given set of data (training data) such that the extracted features show the best representation of the underlying unknown generative process. However, besides the astounding success of the process and aside from observation that the extracted features are generally highly relevant in most cases to the training data, the question of why it works so well, remains an open question. In most cases, how relevant information is coded into data and can be learned from data is approached through mostly trial and error methods. Furthermore, this approach also led modern ML algorithms to be highly resource-consuming and susceptible to hidden biases in the training data [1]. As an example, it is quite easy even for a human child to recognize and associate digits regardless of whether it is printed as a white character with a black background or as a black character with white background. However, machine learning models, if trained with only one of such cases (e.g. white character with black background), generally show far inferior performance while testing with the color inverted version [2]. Therefore, going forward, we require two-pronged research into both basic learning methods which map the features to the relevant representations through the statistical structure of available data (especially if it's biased) and to the design of the new generations of resource-efficient machines capable of such learning process, both of which can be inspired by neural computations in Brain.
Recently, event-driven temporal computations and advances in local learning algorithms in spiking neural networks have shown tremendous promise towards achieving such goals. It has also been shown that local learning rules can be as efficient as traditional non-local learning algorithms [3,4]. Furthermore, a recently proposed model-free non-parametric statistical framework (based on frequency and degeneracy of distinguishable states for a given scale of compressed representation within range of supplied data) has shown huge potential towards designing optimal learning machines [5,6] or characterizing maximally informative (relevant) representations [7,8].

My postdoctoral research focuses on characterizing such Maximally Informative (Relevant) Neural spike trains and finding the time scale of their optimal coding to analyze their role in learning and in the development of neural circuits in the Hippocampal region. Our ongoing analysis shows the existence of such characteristic distribution of maximal information at different time scales. Continuing onward, I am interested in investigating such local learning rules in both neural data and spiking neural models which can generate maximally informative representations working from under-sampled data.

References
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Postdoctoral research:

A significant domain of neuroscientific research is focused on understanding neural correlates of external stimuli or behavior. Recorded neuronal activities in behaving animals are often used to show behavioral causality or non-causal correlation of specific neural circuits. Now a question arises that how does a neuron without direct access to external covariates "decide" on whom to "listen" to perform its role? An upstream neuron in a circuit may not have direct access to the external covariates and might have to depend only on incoming streams of spike-trains which might encode information in various time scales. Therefore, spike trains from different areas of a circuit must possess some form of statistical signature of its encoding and relevance for the receiver. Decoding such behavior of an upstream neuron for external covariates might be challenging and sometimes misrepresented if various time scales of encoding are not considered. My ongoing postdoctoral research focuses on characterizing Maximally Informative (Relevant) Neurons and finding the time scale of their optimal coding to analyze their role in the development of neural circuits in the Hippocampal regions.

Seizure Collaboration:

The emergence of collective behavior in subgroups of correlated oscillators is a key question in complex systems research. A specific type of cohesive behavior, known as synchronization, displays time-independent functional correlations between oscillators. However, such synchronized behavior can emerge partially in a complex system. Recently, such chimeric patterns have been reported with co-existing synchronous and asynchronous dynamics. Further, such chimera-like patterns have been found to emerge at the onset of epileptic seizures. However, our analysis shows the seizure dynamics may not always be captured by the instantaneous phases, typically used in seizure research by utilizing some form of phase synchronization measures. On one hand, the real-time estimation of the instantaneous phase of neural oscillators is still an open-ended problem, on the other only phase-based analysis may not truly represent seizure dynamics. In an ongoing collaboration, we are investigating the emergence of partial synchronization at the onset of a seizure and developing alternative non-phase-based features to measure seizure onset dynamics through chimera patterns.

Ph.D. Research:

Dynamics on the network represent the study of the temporal evolution of the state variables (quantities describing a system of interest) as a function of the initial state and the system's parameters where the system is modeled as a collection of nodes interacting through edges. A Synchronous (or coherent) state depicts a stable (time-independent), functional relationship between the state variables of the nodes in the network.

My doctoral research investigated the impact of multiple layers of interactions on the collective dynamical behavior in the context of a partially synchronous chimera state. Chimera refers to a hybrid state with co-existing synchrony and asynchrony in a multiplex network. A multiplex network is a layered representation of different types of interactions that exist between the same nodes. My thesis presents an extensive investigation of the system parameter space in which the chimera state emerges in multiplex networks and presents a control scheme to gain both qualitative- and quantitative control over it. My thesis, on one hand, demonstrates the emergence of chimera state in multiplex networks and how the interplay of system parameters like delay or inhibition or non-identical layers impede or expedite the appearance of chimera state, while on the other hand present a recipe for precise design of the appearance of chimera state. Additionally, revealing the impact of one layer on the dynamical behavior of another layer of the multiplex network, the thesis marks the importance of incorporating multiple layers of interaction while investigating collective dynamics in real-world complex systems which inherently possess such architecture.