Neuroscience

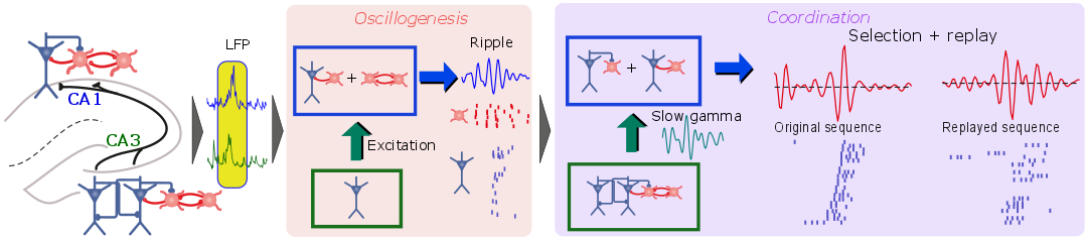

Figure 1.8: The mechanisms involved in replay of memory traces in the hippocampus. Left: connectivity of excitatory (blue) and inhibitory (red) cells in regions CA3 and CA1. Center: key circuits involved in generating synchronized neuronal activity. Right: circuits involved in generating replays of sequential activity of a sparse population encoding a memory trace. See [29].

Biological neural networks are characterized by a dense connectivity at multiple scales that makes it challenging to assess their organization and function, and generates complex and high dimensional dynamics. We develop machine learning and statistical tools to study the functional organization of these systems.

One illustration of the challenges brought by modern neuroscience is the diversity of functions and information encoded by neurons in higher level associative regions such as the prefrontal cortex (PFC) of non-human primates. In order to characterize the dominant activity patterns among large populations of recorded neurons in this region without prior assumptions, we exploit unsupervised learning tools such as Non-negative Matrix Factorization. This led to uncovering that a large proportion of cells in PFC exhibit general task monitoring activities, independently from the population representing the conscious content of visual percepts [27]. This finding is significant for the field, as such task monitoring activities represent a potential confounder when studying the neural basis of consciousness investigated in PFC.

Beyond characterizing neuronal responses in various contexts, a fundamental question is how networks self-organize in order to coordinate information processing among their units, thereby giving rise to reliable internal representations. One fascinating example is the organization of *episodic memory*, where evidence has shown that recollection of a particular event is associated with the precisely coordinated *replay* of sequences of spikes in hippocampal cell assemblies (see Figure). The mechanisms allowing the coordination of this phenomenon are still largely unknown and require accounting for detailed biophysical properties through computational modeling. Due to their intractable dynamics and high dimensionality, biologically realistic computational models do not provide immediate mechanistic knowledge of the underlying mechanisms of neural dynamics, but require sophisticated data analysis techniques to be interpreted. In order to investigate the replay of *memory traces* in the hippocampus of primates, we designed a detailed computational model able to reproduce a broad range of in-vivo experimental observations [29]. We established the key neural circuits underlying the reliable replay of memorized events with the help of supervised machine learning and interventions on the model. This led in particular to the discovery of the pivotal role played by *feedback inhibition* loops between excitatory and inhibitory neurons (see Figure), shaping the sparse sequential activity of neurons encoding a memory trace during replay.

Beyond these successful examples, our work is directed towards exploiting causality principles [152] to establish and exploit a synergy of machine learning with experimental and computational modeling approaches, and ultimately bridge the gap between the complexity of brain phenomena and their underlying biological mechanisms.

More information: https://ei.is.mpg.de/project/neuroscience