Data-driven mechanisms of cortical memory networks in cognition

Matin Jafarian
Delft University of Technology
Email: m.jafarian@tudelft.nl

1 Introduction

The importance of understanding human memory functioning is evident from its central role in cognitive processes and its influence on the development of artificial memory networks. Simply put, memory is acquired information that is stored, processed, recalled, or forgotten. Its dynamics range from the connection of two cells [1] to networks of integrated cells and populations across spatial and temporal scales, including short-term and long-term processes [2–5].

The neuronal dynamics of memory have been understood via detailed bio-physical, or phenomenological, abstract [2] or purely data-driven approaches. While detailed biophysical models are mainly relevant to the cell level [1] and networks of cells, they are less useful in cortical representations. They simply have too much parameters to be identified, rapidly scale in complexity and being computationally demanding.

Cortical memory dynamics of human brain are relevant in studying the process of memory consolidation as well as the interplay of memory with higher order cognitive tasks, such as attention regulation, decision making, and the interplay with emotions. To reveal these mechanisms, mainly data analysis techniques have been employed, and partly phenomenological models. In addition to mechanistic understanding, regulation and control is a new focus in brain science owing to the advancement of measuring and intervention technology.

In this talk, we present some examples of our recent work on data-driven mechanistic understanding of memory, discuss the challenges, contributions, and perspectives.

2 Identification of memory dynamics

We focus on data-driven modeling, informing the models with no or with only some high-level biological hypotheses. We consider two experiments using fMRI and MEG recordings of several brain regions whose states are stacked in vector $\mathbf{x} \in \mathrm{R}^n$. In the fMRI study, we consider an associate memory encoding task in which the interplay of emotions and memory was examined. We consider a geneal nonlinear dynamics with inputs, in the form,

$$\dot{\mathbf{x}} = f(\mathbf{x}, u, \theta),$$

where the function f, its relation with the exogenous input u, and its corresponding parameters are to be identified. Using the dynamic casual modeling framework, we show that a stochastic bilinear model best describes the data [4].

In the MEG study, we consider a task of working memory in which the interplay of attention and memory was examined. We propose the following oscillatory network model [5]

$$\dot{\mathbf{x}} = f(\mathbf{x}, \theta_f) + \lambda g(\mathbf{x}),$$

where the function f is assumed known with unknown parameters, function g which represents the attention mechanism, $\lambda \in \{0,1\}$, is to be identified. For the latter, We use universal differential equations (UDEs) [5].

3 Results and Discussion

Our focus will be devoted to the identified dynamics, their level of complexity compared with biophysical and abstract models. We discuss the results, their utilization in neuroscience and medical research. We also discuss how analytical tools from systems and control theory could enhance revealing, analyzing and regulating these mechanisms.

References

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