PhD proposal in BioElectronics

PhD thesis title: Study of the Observability and Controllability of Synchronization Models for Healthcare Applications
Starting date, duration and salary: the position starts from October 2025, for 36 months
Location: Bordeaux, France (IMS Laboratory, Building A31, 351 Cours de la Libération, 33405, Talence)
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Scientific context and objectives: Synchronization and desynchronization play a key role in various biological and medical fields, ranging from neuroscience to cardiology, as well as in glucose regulation and tumor growth. These phenomena open new biomedical perspectives, such as identifying biomarkers based on the synchronization state of cellular subpopulations or the controlled induction of specific dynamics for targeted therapeutic applications. Phase-coupled oscillator networks, such as the Kuramoto model [1], are widely used to understand the underlying mechanisms of these complex dynamics. They provide a robust theoretical framework for analyzing nonlinear interactions and network structures in real biological systems, enabling practical applications in neurology, oncology, and other disciplines [2].

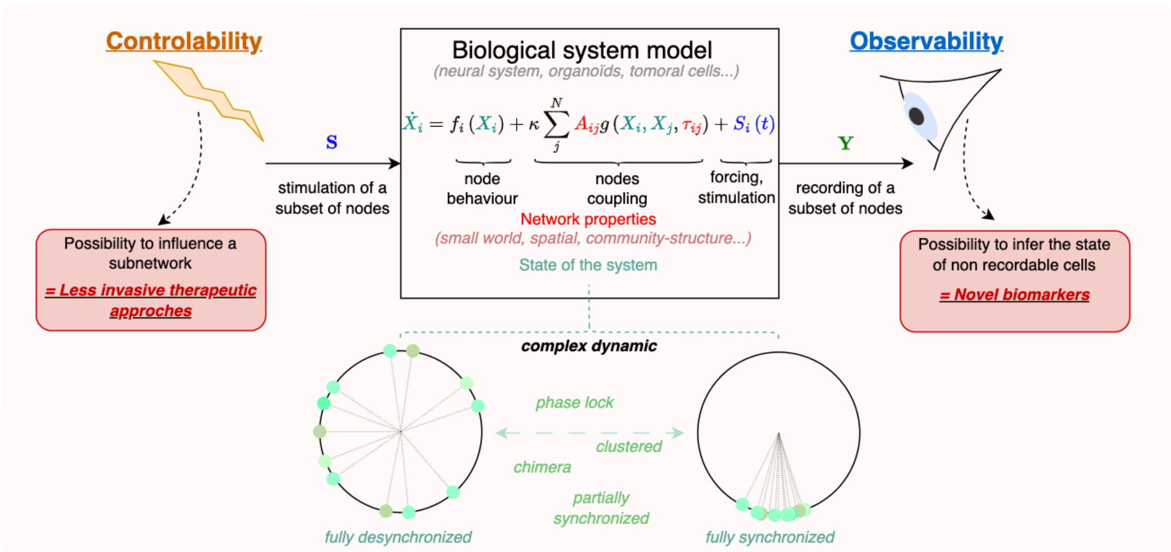

Figure 1: proposed approach at a glance - the main scientific direction is to study biological systems with synchronization models, exploring the properties of observability and controllability to propose future electroceuticals.

Among these models, Kuramoto equations stand out by modeling nodes with intrinsic frequencies and nonlinear couplings. Although initially developed for infinite networks, recent advancements have focused on finite networks and "small-world" architectures. These studies have explored how network density and structure influence synchronization and global dynamics, offering predictions applicable to real experimental contexts [3]. Thus, oscillator models provide valuable tools for understanding and controlling complex biological processes [4] while bridging theoretical approaches with experimental reality.

The aim of this thesis is to study phase-coupled oscillator models through the lens of observability and controllability, to explore the conditions necessary for developing new biomarkers and therapeutic strategies for network structures corresponding to biological systems. The proposed approach is twofold:

1. To develop a theoretical and computational method that incorporates the structure and nature of the network—considering its architecture, node properties, and couplings—integrating observability and controllability concerns from the earliest stages of defining the biological network.
2. To demonstrate the feasibility of this approach by reusing diverse application contexts and experimental means tied to ongoing and funded projects within the laboratory.

Expected outcome: The current PhD project aims at pushing the boundaries in designing novel electroceuticals in various and challenging contexts. We expect:

- Novel methods and computational tools for a modeling framework used in numerous scientific fields,
- Development of proof-of-concept experiments in neuroscience and cancer therapies, work with expert scientist in diverse projects
- Publications in high-impact scientific journals and conferences.

Expected skills: This PhD subject is highly transdisciplinary. We will consider applications from various backgrounds, from applied mathematics to engineering (control theory or electrical engineering). The candidate should have:

- Knowledge in system modeling (nonlinear systems, nonlinear ODE, computational simulation and numerical methods),
- Knowledge of programming in python/matlab, basic knowledge of C,
- Strong interest in biology and biomedical applications,
- Strong interest in team work and interaction, fluent communication in english.

Scientific references:

[1] Acebrón, J. A., Bonilla, L. L., Pérez Vicente, C. J., Ritort, F., & Spigler, R. (2005). The Kuramoto model: A simple paradigm for synchronization phenomena. *Reviews of modern physics*, *77*(1), 137-185. [2] Lodi, M., Panahi, S., Sorrentino, F., Torcini, A., & Storace, M. (2024). Patterns of synchronized clusters in adaptive networks. *Communications Physics*, *7*(1), 198. [3] Budzinski, R. C., Nguyen, T. T., Benigno, G. B., Đoàn, J., Mináč, J., Sejnowski, T. J., & Muller, L. E. (2023). Analytical prediction of specific spatiotemporal patterns in nonlinear oscillator networks with distance-dependent time delays. *Physical Review Research*, *5*(1), 013159. [4] Lynn, C. W., & Bassett, D. S. (2019). The physics of brain network structure, function and control. *Nature Reviews Physics*, *1*(5), 318-332.