# Post-doc offer

**Supervisors: A. Chaillet and J. Auriol**

# 1 Context

Pôle Systèmes of L2S has been developing for around ten years control theory methodologies for neuroscience applications, particularly for the development of innovative closed-loop strategies for Deep Brain Stimulation in order to disrupt pathological brain oscillations related to Parkinsonian symptoms.

More precisely, using a mesoscopic model of the brain structures of interest (involving nonlinearities and delays), we have studied possible mechanisms of generation of these pathological oscillations [Haidar et al., 2014], and we have shown that a simple proportional control on the excitatory population is sufficient to disrupt them [Haidar et al., 2016]. These results have then been extended to spatio-temporal models of brain structures (delayed neural fields) [Detorakis et al., 2015, Chaillet et al., 2017].

In order to cope with the strong uncertainties affecting the models, to allow self-adaptation in case of evolution of the parameters involved (due, for instance, to disease progress or modification of the stimulating electrode impedance) and to limit energy consumption as much as possible, an adaptive control strategy has then been developed in which the proportional stimulation gain is automatically adjusted [Orłowski et al., 2018, Orłowski et al., 2021].

Although these strategies have not yet been assessed experimentally, they have been tested on a detailed numerical model of the brain structures involved in which every single neuron is represented by a conductance-based model whose parameters are tuned based on physiological evidence. This study demonstrated the efficiency of the adaptive control law to disrupt pathological oscillations, and to self-adapt to parameter changes [Fleming et al., 2020].

# 2 Post-doc objectives

## 2.1 Adaptive control in spatio-temporal models

A natural objective is to extend this adaptive stimulation to models accounting for spatial heterogeneity of the brain structures. In other words, the first objective of the post-doc will be to extend the results in [Orłowski et al., 2018, Orłowski et al., 2021] to delayed neural fields.

This first objective does not seem to be risky and will mostly be an opportunity for the recruited post-doc to get acquainted with our past developments.

## 2.2 Selective oscillations disruption

An essential limitation of the control strategies obtained so far is that they stabilize the whole neuronal network and thus impede the generation of any brain oscillations. Although some of these oscillations are related to Parkinsonian symptoms, some other types of brain oscillations (in other frequency bands) correspond to healthy brain functioning and might be needed in specific tasks. A more challenging objective of the post-doc is thus to derive control laws that disrupt oscillations in a targeted frequency band while limiting the impact on other frequencies.

To that aim, we envision using a network of interconnected Wilson-Cowan models, each of which generates oscillations in a given frequency band (etiher pathological or not). Each subsystem receives the same control input, which constitutes the main challenge for this objective. The second objective will be to derive control strategies that stabilize the "pathological subsystems" while leaving the "non-pathological" limit cycles unaltered. The envisionned strategy will request the robustness assessment of limit cycles, which is often a complicated task: we expect that results such as [Angeli and Efimov, 2015] and the relatively simple structure of the considered models will help us in that task.

### 2.3 Electrode placement for optimal measurement and actuation

Another challenging question is how one should place the electrode to optimize the impact of brain stimulation or get the best information on the brain structures. In particular, depending on the kernel that rules neuronal interconnection, one may wonder what information is needed to reconstruct the whole (spatiotemporal) state of a brain structure, or at least some significant spatial average of this state. This corresponds to a problem of observability of an infinite-dimensional system.

Two approaches are envisioned. The first one consists of projecting the kernel on a functional basis to rely on finite-dimensional systems conditions for observability: the main challenge is to guarantee that the neglected term does not compromise this observability for the original infinite-dimensional system [Morris, 2020] (spill-over effect). The second approach is more structural and consists of exploiting the particular structure of the considered kernel to provide intrinsic conditions for observability, in the spirit of the Hautus criterion (see, e.g., [Tucsnak and Weiss, 2009]). These conditions will allow the use of invertible integral transformations, thus simplifying the design of stabilizing control laws for the infinite-dimensional system.

## 3 L2S researchers involved

The post-doc will be supervised by both A. Chaillet and J. Auriol. Objectives 2.1 and 2.2 will be led by A. Chaillet, whereas J. Auriol will take the lead for Objective 2.3.

## 4 Sought profile

A PhD in control theory or applied mathematics is needed. The ideal candidate should have past experience in control of nonlinear systems (possibly through adaptive control) and in observability/controllability of infinite-dimensional systems.

## References


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