« Activity waves in the retina: a modelling study »

Project. You are running in the forest. There is wind. Everything is moving: your head, your body, the trees around you. Suddenly, a small bird crosses your visual field. You are immediately able to detect it even if your environment is so noisy. What makes our visual system so efficient ? What makes it able to perform so rapidly and efficiently the complex task of deciphering our ever-changing environment with a so weak energy consumption, largely outperforming all existing artificial devices ?

Part of this astonishing ability starts in the retina. This small membrane, at the back of our eyes, receives the light from the outside world and processes it in a very smart way [1], before sending the visual information to the brain in the form of spike trains. However, to extract essential information fast and efficiently the retina does not signal raw input features but follows a more efficient coding strategy: to predict its future input and only signal unpredicted or surprising events. In particular, a moving object induces a retinal wave of activity helping the brain not only to decipher but also to *anticipate* its trajectory [2,3,4]. In addition, short term plasticity allows the retina to respond to violations of its anticipation [5]. These overwhelming capacities are largely due to the complex network structure of the retina, better and better known thanks to striking advances in neuroscience. Yet, a theoretical description of the retinal network dynamics providing a global understanding of how it responds so efficiently to complex spatio-temporal visual stimuli is largely missing.

Our group has developed a formalism that allows us to mathematically characterise the different retina layers and their interactions in the realm of dynamical systems theory [6]. This has allowed us to propose mechanisms explaining developmental retinal waves propagation [7,8], retinal anticipation [4], the effect of drugs [9] or the role of short-term plasticity [5]. In parallel, we are developing a platform, Macular https://team.inria.fr/biovision/macular-software/, designed to simulate the retinal response to visual stimuli. The next step of our research is to better understand mathematically the links between the retinal network structure and its dynamics in response to spatio-temporal stimuli.

In this PhD, we intend to tackle this aspect on the basis of the models proposed in [4,6]. More precisely, we want to answer the following questions:

- How does the structure of the retinal network constraint and shape the wave characteristics (speed, spatial extension, latency) in response to a moving object ?
- Reciprocally, what can we learn about the retinal structure and dynamics from the observation of these motion-induced waves ?
- More generally, which type of spatio-temporal stimuli would allow to extract the maximal amount of information about the retinal network ?

The thesis will be at the interface between mathematical computations, numerical simulations performed and experimentations in collaboration with the University of Valparaiso (A. Palacios Lab).

Profile. We are seeking a student with a strong background either in physics, mathematics, biology or computer science, with strong interests in neuroscience, solid skills in mathematics (differential equations, linear algebra, probabilities) and programming (C++, Python).

References

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Team. The Biovision team's research revolves around the central theme biological vision and perception, and the impact of low vision conditions. Visual impairment affects some 285 million people in the world, mostly in developed countries: 85% have low vision, i.e., have remaining sight, and 15% are totally blind. It is predicted that the prevalence of visual disabilities will increase markedly during the next 20 years, owing largely to the aging. In this context, our strategy is based upon four cornerstones: To model, to assist diagnosis, to aid visual activities like reading, and to enable personalize content creation. We aim to develop fundamental research as well as technology transfer giving our team an original combination in expertise: neuroscience modelling, computer vision, Virtual Reality (VR) and Augmented Reality (AR), media analysis and media creation. Our research themes require strong interactions with experimental neuroscientists, modellers, ophtalmologists and patients, constituting a large network of national and international collaborators. Biovision is therefore a strongly multi-disciplinary team. Bruno Cessac, the head of the Biovision team, is a theoretical physicist, research director at INRIA, specialized in the modelling and analysis of neuronal models, especially, the retina.