PhD studentship: Developing new computational frameworks for high-dimensional neural data

Principal Investigator: Dr. Shabnam Kadir

New developments in experimental technology have led to petabytes of raw data being produced by experimental neuroscientists, which are increasingly publicly available, e.g. Allen Institute data `http://www.brain-map.org/`. In particular, we are in the realm where population recordings of tens of thousands of neurons are feasible thanks to, e.g. a new generation of large dense probes for electrophysiological recordings [BGY, RPQ], imaging using 2-photon microscopy coupled with calcium fluorescent sensors [SGHK]. Large scale neuronal recordings require novel approaches for both processing and quantitative analysis. This has set major new challenges in the development of algorithms and methods of data analysis which has already resulted in a new generation of spike sorting algorithms [KGH, PSKCH]. We aim in this project to go beyond spike sorting and develop new tools and computational frameworks which would help interpret high-dimensional, often noisy data and interrogate how information is being processed by the brain, e.g. How are sensory stimuli (location in environment, visual and auditory stimuli) encoded? How can we characterise the neural activity associated with memory, attention, decision making, and motor control?

As well as using techniques from high dimensional statistics, machine learning, information theory, we aim to explore new approaches from mathematical fields outside statistics, such as algebraic topology. The study of networks is a particularly important topic in neuroscience: neurons communicate with each other electrically via synapses, forming intricate networks. These networks can be studied using techniques from computational topology (e.g. persistent homology [CI, SMISCR], clique topology [GPCI]). These could be used to extract information about subnetworks and assemblies, both from large scale recordings, and via connectomics derived from simulations (Blue Brain Project [M]) and experiments.

New techniques of topological data analysis [ELZ, ZC, CI] have been used to explore the relationship between the geometric/topological structure of the stimulus space and neural activity and to investigate questions such as how the former can be derived from the latter without having to 'recruit a middle man', namely, to perform standard operation of constructing dictionaries between the two, e.g. stimulus response functions such as place cells [OD]. This is a very important question from a biological perspective, as the brain itself is clearly able to infer properties of the environment in real time via neural activity alone, without having to perform experiments on its own response to the environment.

The neural code is sufficiently spatially and temporally smooth with respect to neural activity to enable meaningful neuroscientific recording on a large, coarse whole-brain scale, such as fMRI and EEG. We shall investigate the structural and functional connectome on publicly available datasets such as the Human Connectome project [H]. We also aim develop methods for exploring dynamic functional connectomics which enables analysis and the derivation of brain states from single recordings and single trial experiment [K]. This will aid us in a broad range of questions such as the nature of brain disorders such as schizophrenia (differences in the white matter structural connectome) [DMSK], and neural correlates of the visual perception and appreciation of art [K2].

We shall be collaborating with labs at Imperial, Pennsylvania State University, Brown University, UCL, Edinburgh, University of Warsaw.

We are looking for candidates with the following profile:

- Strong first degree in a quantitative field such as mathematics, physics, computer science, engineering, computational neuroscience.
- Strong programming skills (e.g. Python, MATLAB, C++, Julia).
- Interest in neuroscience and biology would be helpful.

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[K] S.N. Kadir *ICERM talk: Musings of mesoscale structures, brain states, and visual art, through a topological lens* `https://icerm.brown.edu/video_archive/?play=3416`

[K2] S.N.Kadir *Perceiving Art: Physics Principles and Research Challenges*, `https://www.ihp.fr/en/news-research-activities/perceiving-art-physics-principles-research-challenges`

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