Researching symmetry and asymmetry in brain connectomes:

Animal brains are mirror symmetric: each hemisphere looks like the other but flipped sidewise. But symmetry also appears broken at some points—e.g. human language is lateralized, implemented mostly by centers at the left side. Symmetry and asymmetry are very difficult to measure in brains—for example, because it can be unclear when certain regions start, as the neural tissue can look continuous and homogeneous. Because of this, it has been very challenging to test hypotheses that, nevertheless, are present since the beginnings of neuroscience. A prominent such hypothesis is that more complex cognition leads to more asymmetric brains [1]. This project aims at measuring brain symmetry and asymmetry in an innovative way. Specifically, our goal is to study the topological asymmetry of brain connectomes. Connectomes are networks that summarize relationships between different parts of the brain (either because they function in coordination or because there are fibers carrying signals from one region to another). The topology of a network or a graph refers to qualitative features of its structure—e.g. if it contains loops and how large they are, if nodes are connected to other nodes that look similar to or different from themselves, if it is easy or difficult to reach one part of the network from another, etc. When we build a brain connectome, the local graph around one region might look similar or dissimilar to the contralateral opposite—but this has not been measured yet, partly because we did not have the appropriate network-theoretical tools. Using new methods developed in our group, we aim at measuring symmetry in brain connectomes. The project is open to several variations, such as comparing topological asymmetry across connectomes of different animals (aiming at validating the hypothesis mentioned above, and studying how neural duplicates have evolved [2]), or using only human connectomes and investigating relationships between (i) symmetry and asymmetry and (ii) function and pathology. Alternatively, symmetry and symmetry breaking are key aspects in statistical physics and appear connected to phase transitions and criticality. Following earlier work from the research group [3, 4], an alternative proposal is to study symmetry and asymmetry in connectomes from a more theoretical perspective.

[1] Seoane LF. Optimality pressures towards lateralization of complex brain functions. *Phys. Rev. X*. In press (2023).
[2] Seoane LF. Fate of Duplicated Neural Structures. *Entropy* **22**(9), p.928 (2020).
[3] Seoane LF, Solé R. Modeling brain reorganization after hemispherectomy. *bioRxiv*, (2020).
[4] Carballo-Castro A, Seoane LF. Phase transitions in a simple model of focal stroke imitate recovery and suggest neurorehabilitation strategies. *bioRxiv*, (2022).

This research would be supervised by Luís F Seoane, junior researcher at Centro Nacional de Biotecnología (CNB) where he is part of the Evolutionary Biology group within the Systems Biology department, and where he is starting his own group, the BIT-Lab (Brain, Intelligence, Topology-Lab). Both are part of a wider network of collaborators around topics in evolutionary biology and complex systems, including network theory, computational neuroscience, machine learning, linguistics, ecology, or the theory of Darwinian evolution. We hold regular, wide ranging seminars of relevance to the research project which are also a unique formative opportunity.

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