

Training program in *Computational Biophysics*

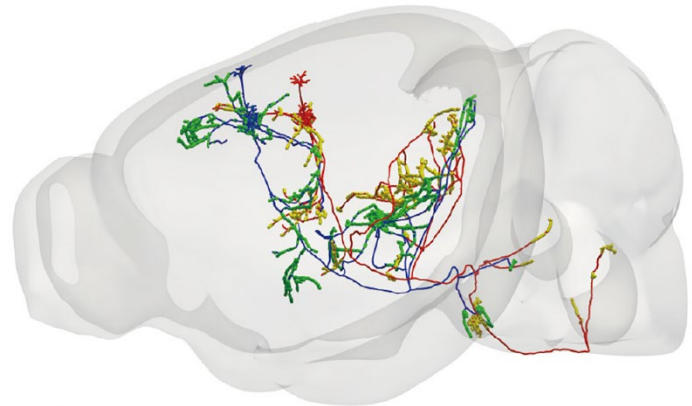
TFE proposal

Bridging Biological and Artificial Intelligence through Network Architecture

Brains are biological systems that evolved to allow fast interaction with our environment. Recent worldwide collaborative efforts are allowing to map brain network architecture at the single neuron level [1,2]. The data obtained allows us to infer graph connectivity of biological neuronal networks [3].

In this basic science project, we will explore the impact of network architecture on cognitive task performance (e.g. visual, language, executive function, ...). We will measure task performance by implementing Artificial Neural Networks, both including feedforward and recurrent neural networks using classical backpropagation, and bio-inspired learning rules. We expect to learn why specific network architectures have evolved to optimize specific task performance.

The obtained knowledge will be relevant for both optimization of current artificial intelligence (AI) models, and may have implications also on robotics and network management.



Two mouse cortical pyramidal neurons (red and green) with their full projection axons. Yellow and green dots indicate axonal botons, indicative of synaptic connections.
<https://doi.org/10.1016/j.celrep.2024.113871>

References:

- [1] Peng, H., Xie, P., Liu, L., Kuang, X., Wang, Y., Qu, L., ... & Zeng, H. (2021). Morphological diversity of single neurons in molecularly defined cell types. *Nature*, 598(7879), 174-181.
- [2] The MICrONS Consortium (2025) Functional connectomics spanning multiple areas of mouse visual cortex. *Nature* 640(8058), 435-447.
- [3] Qian, P., Manubens-Gil, L., Jiang, S., & Peng, H. (2024). Non-homogenous axonal bouton distribution in whole-brain single-cell neuronal networks. *Cell Reports*, 43(3).

Project details

Objectives

Investigate the relationship between brain-inspired network architecture and cognitive task performance using Artificial Neural Networks (ANNs).

Compare classical and bio-inspired learning algorithms (e.g., backpropagation vs. Hebbian/plasticity-based rules) across different network architectures.

Identify which architectural features (e.g., modularity, recurrence, depth) enhance performance in specific cognitive domains (e.g., vision, language).

Translate insights from biological circuits into artificial models to guide future AI development.

Disseminate findings via a peer-reviewed publication in the NeuroAI domain.

Activities

- Review connectomics data and extract key features of biological network architecture (e.g., hierarchy, small-world properties, hub nodes).
- Design and implement artificial neural networks that emulate these architectural features (using PyTorch, TensorFlow, or similar).
- Simulate cognitive tasks (e.g., classification, sequence prediction, working memory) using both feedforward and recurrent models.
- Analyze which architectural properties correlate with better task performance, drawing parallels to known brain function specializations (e.g., visual cortex, prefrontal cortex).
- Visualize and interpret the learned representations, especially in relation to biological principles (e.g., receptive fields, sparsity, modularity).
- Project on the interface between AI and computational neuroscience.

Supervisors and host research groups

- Linus Manubens-Gil linus.manubens@upc.edu
BIOCOM-SC <https://biocomsc.upc.edu/en>

Valued characteristics of the candidates

- Programming knowledge, especially PyTorch and R
- Knowledge in statistics and visualisation tools
- 4th course student of Engineering Physics, Data Science and Engineering, Biosystems Engineering, or Mathematics.

Practical information

Financial opportunities: The selected student will be considered as a candidate for an INIREC fellowship (<https://talenthub.upc.edu/en/jobs/r0-predocutorial>, awarded subject to the availability of funds).

Application: Send CV and a motivational letter to Linus Manubens-Gil (linus.manubens@upc.edu) .

Further information: You can contact Linus Manubens-Gil linus.manubens@upc.edu to ask for more details.