Offer #2024-07315

PhD Position F/M Campagne doctorant 2024 - Emergence of mesoscale properties in neural networks

Contract type : Fixed-term contract

Level of qualifications required : Graduate degree or equivalent

Fonction : PhD Position

Context

This PhD project will be realized in the Inria NERV team, a research lab supported by the French institutions Inria, Inserm, CNRS, and Sorbonne University. The team is located in the Paris Brain Institute (ICM) within the Pitie-Salpetriere hospital.

The NERV team pursues a multidsciplinary research program at the intersection between biomedical engineering, complex systems and clinical neuroscience. NERV proposes new computational frameworks to analyze and model the spatiotemporal complexity of brain networks from multimodal and longitudinal neuroimaging data, and we design noninvasive intervention strategies based on brain-computer interfaces. Furthermore, the team ejoys a privileged position within a unique scientific and technological environment including comprehensive experimental core facilities (eg, neuroimaging, genetics, cellular), several animal models (eg, from nematodes to humans) and powerful centralized cluster computer system to realize big-data analysis and simulations.

Assignment

Context of the project

Artificial Intelligence (AI) and especially Deep Learning (DL) have undergone many successes in recent years in various domains of applications such as computer vision, speech recognition, language, domain recognition, decision-making, even outperforming the human capacities benchmark in most of them.

Those performances were mainly obtained by increasing scales : data augmentation and bigger models launched on GPUs and faster learning units. However many features of human ability described by cognitive sciences seem to remain completely out of reach for now. The main one being the generalizability beyond past experience, namely the adaptability to unknown contexts. Furthermore, deep learning algorithms always require a huge amount of data while adult brains can learn new tasks with a very few examples. So the question is how real brains came up with such e□cient versatility and what are the associated organizational features?

Recent developments in network science have provided fresh insights into the structure and dynamics of the brain organization from a system perspective [1, 2]. By modeling brains as graphs, with nodes accounting for brain regions and edges for anatomical/functional connections between them, a better understading of the organizational properties of the nervous system became possible [3]. Experimental evidence across disparate temporal and spatial scales indicated that brain networks tend to exhibit key topological features such as node centrality, modularity and efficiency. Notably, network modularity is a fundemental mesoscale property characterized by the presence of functionally specialized, yet interdependent modules, and o□ers several advantages such as functional factorization, adaptability to new tasks, and robustness against perturbations [4, 5]. Furthermore, brain network modularity is correlated to difference of performance across individuals [6, 7] and plays an important role in combining information from differently specialized modules to perform more complex tasks. In artificial networks, recent studies demonstrated that modular architectures could lead to improved performance in learning different compositional tasks [8, 9]. Thus, a crucial question is to understand why, where, and when mesoscale properties such as modularity emerge during the learning process [10].

Main activities

Objectives

The main goal of the PhD project is to elucidate the role of mesoscales network structures in generalizable artificial intelligence. Speci□cally, this project aims to:

□ + Conceive analytical network models that lead to the emergence of signi□cant mesoscale attributes, such as modularity, by integrating developmental insights. Provide a foundational understanding of the necessary conditions (eg, network size, topology, density) for such emergent properties.

 + Compare the results with those obtained from the brain wiring formation of di erent species (eg, nematode, humans). Finetune the model parameters based on the above mentioned biologically data and derive a neurophysiologically plausible interpretation.

 +Develop a novel training framework that takes into account the model architecture, the learning algorithm and the multimodal nature of real inputs. Evaluate the overall performance when confronted with unfamiliar scenarios, thereby evaluating their versatilty and robustness.

Main Activities

+ *Theoretical modeling*. The initial phase of this doctoral research involves the development of analytical models to understand the emergence and stability of significant mesoscale properties, such as modularity, within biological networks during developmental processes. It is posited that modularity manifests as a consistent outcome in neural networks influenced by a variety of parameters throughout the development of organisms. This investigation aims to elucidate the prerequisites for such emergent modularity across different species. Furthermore, the research will explore potential phase transitions towards modular networks in response to variations in these parameters.

+ *Convergence with biological data*. In a second step we will test and fit those models on biological data over several species on the whole lifespan from the embryonic stage of development to the adult age. We will rst study small species for which the whole brain networks (i.e. the connectomes) are known. We will compare the mesoscale properties obtained in the synthetically-generated network models and those in the actual connectomes. Connectomes needed to experimentally validate network models are already available in the framework of different past and current research projects granted to the PIs team.

+ *Development of new artificial neural architectures*. The last phase of this research project will focus on leveraging biological insights to guide the design of artificial neural architectures, aiming to foster the emergence of highly effcient network properties such as functional specialization, since they have been shown as unable to achieve it [9]. Finally we also propose to explore how local learning algorithms for energy-based models could play a role in artificial networks mesoscale properties
emergence such as modularity [11].

Skills

Required skills

The ideal candidate should have a solid background in experimental physics, machine learning and data analysis, as well as experience in laboratory projects and simulations (Python, MATLAB). The ability and willingness to learn will do equally well.

Benefits package

- Subsidized meals
- Partial reimbursement of public transport costs (75%)
- Leave: 7 weeks of annual leave + 10 extra days off due to RTT (statutory reduction in working hours) + possibility of exceptional leave (sick children, moving home, etc.)
- Possibility of teleworking
- Flexible organization of working hours (after 12 months)
- Professional equipment available (videoconferencing, loan of computer equipment, etc.)
- Social, cultural and sports events and activities

Remuneration

According to civil service salary scales

General Information

- **Theme/Domain :** Computational Neuroscience and Medicine
  Biologie et santé, Sciences de la vie et de la terre (BAP A)
- **Town/city :** Paris
- **Inria Center :** Centre Inria de Paris
- **Starting date :** 2024-10-01
- **Duration of contract :** 3 years
- **Deadline to apply :** 2024-05-19

Contacts

- **Inria Team :** NERV
- **PhD Supervisor :**
  De Vico Fallani Fabrizio / fabrizio.de-vico-fallani@inria.fr

About Inria

Inria is the French national research institute dedicated to digital science and technology. It employs 2,600 people. Its 200 agile project teams, generally run jointly with academic partners, include more than 3,500 scientists and engineers working to meet the challenges of digital technology, often at the interface with other disciplines. The Institute also employs numerous talents in over forty different professions. 900 research support staff contribute to the preparation and development of scientific and entrepreneurial projects that have a worldwide impact.

The keys to success

Expected results and valorization

The expected results will shed light on the mesoscale network properties which are needed to achieve generalizable artificial intelligence. These will be evaluated with respect to those obtained with state-of-the-art approaches and interpreted from a theoretical and practical perspective. As such this project is expected to provide fresh knoweldge on the emergent structures of complex interconnected systems and their implication in biological and artificial scenarios, identifying at the same time the strong aspects and the weak points that can be addressed in the future. All the conducted research activity will be reported and shared with the PI's team and submitted for publications in peer-reviewed journals (eg, IEEE, APS) and/or presented in relevant international conferences (eg, NetSci, IEEE).

Warning : you must enter your e-mail address in order to save your application to Inria. Applications must be submitted online on the Inria website. Processing of applications sent from other channels is not guaranteed.

Instruction to apply

In your application (which can be in English or in French), please include:

- CV
- Letter of motivation
- Letters of recommendation
- Master's grades

Defence Security :
This position is likely to be situated in a restricted area (ZRR), as defined in Decree No. 2011-1425 relating to the protection of national scientific and technical potential (PPST).Authorisation to enter an area is granted by the director of the unit, following a favourable Ministerial decision, as defined in the decree of 3 July 2012 relating to the PPST. An unfavourable Ministerial decision in respect of a position situated in a ZRR would result in the cancellation of the appointment.

Recruitment Policy :
As part of its diversity policy, all Inria positions are accessible to people with disabilities.