HR EXCELLENCE IN RESEARCH

2023-06611 - PhD Position F/M PhD thesis: From Reservoir Transformers to BrainGPT

Contract type : Fixed-term contract
Level of qualifications required : Graduate degree or equivalent
Fonction : PhD Position

Context

This PhD thesis is part of the BrainGPT "Inria Exploratory Action" project. In the wake of the emergence of large-scale language models such as ChatGPT, the BrainGPT project is at the forefront of research in Artificial Intelligence and Computational Neuroscience. These models, although remarkably powerful, do not reflect the way in which our brains process and learn language. BrainGPT is rising to the challenge by focusing on the development of models that are more faithful to human cognitive functioning, inspired by data on brain activity during listening or reading. The ambition is to create more efficient models that are less dependent on intensive calculations and massive volumes of data. BrainGPT will open up new perspectives on our understanding of language and cognition.

Assignment

This PhD topic is at the intersection of Transformers and Reservoir Computing.

Transformers [1] are a type of model in machine learning, renowned for their use of self-attention mechanisms to discern contextual relationships in data. They form the cornerstone of many Large Language Models (LLMs) such as GPT and BERT. These LLMs utilize the Transformer's architecture to produce rich, context-aware representations of text, excelling in tasks like text generation, translation, and question answering. Consequently, Transformers have revolutionized the field of natural language processing.

On the other hand, Reservoir Computing is a well-established method that has been shown to outperform other techniques in complex tasks like chaotic time series prediction [2,3]. From the time of its inception, it has found widespread applications in numerous domains [4]. Despite its low computational demands and lesser reliance on massive training data compared to LSTM [5] or other methods, it is presently underexplored, overshadowed by the prevailing trend of deep learning. To bridge this gap, ReservoirPy [6], a new Python library, was recently developed by our team. This state-of-the-art tool enables the easy development of complex models [7], and already incorporates several advanced features derived from the literature. ReservoirPy is a user-friendly library built upon Python's scientific modules. It is currently the most popular and frequently updated Python library in the Reservoir Computing domain.

Reservoir Computing appears as a relevant alternative for several reasons:
- Reservoir computing can achieve equivalent performance with less data than traditional methods based on gradient backpropagation (e.g. LSTM) with a significant computation time saving [5];
- It has already been shown that deep neural networks like Transformers can have part of their connections random (untrained) and achieve comparable performance [8];
- Over the past fifteen years, studies have shown that the principle of reservoir computing could be applied to many physical mediums, ranging from the exploitation of lasers to the magnetic properties of magnets [9].

[1] Vaswani, A. et al. (2017) Attention is all you need. Advances in neural information processing systems.
[2] Jaeger, H., & Haas, H. (2004). Harnessing nonlinearity: Predicting chaotic systems and saving energy in wireless communication. science, 304(5667), 78-80.
[3] Vlachas, P. R., Pathak, J., Hunt, B. R., Sapsis, T. P., Girvan, M., Ott, E., & Koumoutsakos, P. (2020). Backpropagation algorithms and reservoir computing in recurrent neural networks for the forecasting of complex spatiotemporal dynamics. Neural Networks, 126, 191-217.
[4] Lukoševičius, M., & Jaeger, H. (2009). Reservoir computing approaches to recurrent neural network training. Computer Science Review, 3(3), 127-149.
[5] Trouvain N, Hinaut X (2021). Canary song decoder: Transduction and implicit segmentation with ESNs and LSTMs. International Conference on Artificial Neural Networks 71-82.
[6] Trouvain N, Pedrelli L, Dinh TT, Hinaut X (2020). Reservoirpy: an efficient and user-friendly library to design echo state networks. International Conference on Artificial Neural Networks, 494-505.
[7] Trouvain, N., Rougier, N. P., & Hinaut, X. (2022). Create Efficient and Complex Reservoir Computing Architectures with ReservoirPy. In FROM ANIMALS TO ANIMATS 16: The 16th International Conference on the Simulation of Adaptive Behavior (SAB2022).
[8] Shen, S. et al. (2020) Reservoir transformers. arXiv preprint arXiv:2012.15045.
[9] Tanaka, G. at al. (2019) Recent advances in physical reservoir computing: A review. Neural Networks, 115, 100-123.

Main activities

The rapid rise in performance of language models, as demonstrated by the recent appeal of ChatGPT, is undeniable. However, the computational cost and environmental impact associated with such models are often overlooked [1]. These models rely on

General Information

- **Theme/Domain :** Computational Neuroscience and Medicine Statistics (Big data) (BAP E)
- **Town/city :** Bordeaux
- **Inria Center :** Centre Inria de l'université de Bordeaux
- **Starting date :** 2023-10-01
- **Duration of contract :** 3 years
- **Deadline to apply :** 2023-08-31

Contacts

- **Inria Team :** MNEMOSYNE
- **PhD Supervisor :** Hinaut Xavier / xavier.hinaut@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

We are looking for a skilled and passionate profile in machine learning, bio-inspired computing and neuroscience. If you master Python and demonstrate an interest for advancing the fields of Transformers and Reservoir Computing, we invite you to explore this opportunity with us. Our ideal candidate is not just interested in using existing machine learning methods, but also excited about innovating and creating new ones.

Please send an informal email quickly for any questions to Xavier dot Hinaut at inria dot fr.

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.

Transformers [2], which facilitate unsupervised learning on a large volume of data. These same models are used to predict brain activity from functional magnetic resonance imaging (fMRI) or magnetoencephalography (MEG), an application our team also exploits [3].

The main ambition of the BrainGPT project is to combine the explainability of mechanistic models with the predictive power of Transformers to analyze brain imaging data. Today, on the one hand we have explanatory but less predictive mechanistic models, such as those based on Reservoir Computing, and on the other hand, high-performance predictive models, but not explanatory, like Transformers. Our goal is to combine the best of these two approaches, to develop more efficient ("sample efficient") models inspired by Transformers, which more faithfully reflect the how the brain works, while improving the predictive power of mechanistic models.

Towards this ambition, the BrainGPT project seeks to identify the key mechanisms that allow Transformers to predict brain activity. Furthermore, our project strives to build models that are more biologically plausible than Transformers, incorporating the most relevant components for predicting brain activity, while integrating constraints derived from human cognition studies.

The long-term objectives of the BrainGPT project are as follows:
- Making Transformers more biologically plausible, which could improve the prediction of brain activity by imaging (fMRI, MEG, etc.).
- Proposing new perspectives and computing paradigms that do not rely exclusively on gradient backpropagation, given its high computational and energy cost.
- Reducing the energy footprint of Transformers by minimizing the computational costs associated with their learning.

In summary, the thesis will mainly consist of developing new bio-inspired models inspired by the mechanisms, learning methods, and emerging behaviors of Large Language Models (LLMs) and Transformers. Subsequently, in collaboration with our collaborators, these models will be tested to assess their ability to predict brain activity from imaging data.

[1] Bender, E. M., Gebru, T., McMillan-Major, A., & Shmitchell, S. (2021, March). On the dangers of stochastic parrots: Can language models be too big? In Proc. of the 2021 ACM conference on fairness, accountability, and transparency (pp. 610-623).
[2] Vaswani, A. et al. (2017) Attention is all you need. In Proc. of Advances in neural information processing systems.
[3] Oota, S. R., Trouvain, N., Alexandre, F., & Hinaut, X. (2023, August). MEG Encoding using Word Context Semantics in Listening Stories. In Proc. of INTERSPEECH 2023.

Skills

Ideal Candidate Profile:
- Holds an engineering or scientific degree and/or a PhD in digital sciences (computer science, automation, signal processing).
- Has a first professional experience (6 months of internship or more) in Machine Learning and Python development. Especially in one or more of the following: Recurrent Neural Networks (in particular Reservoir Computing), Transformers, Large Language Models.
- Possesses strong expertise in the scientific Python software and scientific stack (numpy/scipy).
- Demonstrates a solid grasp of linear algebra concepts.
- Proficiency in technical English is crucial, as it enables efficient collaboration with our international partners and effective presentations at conferences.
- Has proven experience with version management, familiarity with Git, and proficiency in using the GitHub platform.

We are also looking for someone with the following general abilities:
- Ability to work in a multidisciplinary team.
- Ability to adapt to the project context.
- Knows how to establish a relationship of trust with their interlocutors.
- Is autonomous in personal organization and reporting.
- Has good written and oral communication skills in English.
- Masters technical and scientific English.

Benefits package

- Subsidized meals
- Partial reimbursement of public transport costs
- Possibility of teleworking and flexible organization of working hours
- Professional equipment available (videoconferencing, loan of computer equipment, etc.)
- Social, cultural and sports events and activities
- Access to vocational training
- Social security coverage

Remuneration

2051€ / month (before taxs) during the first 2 years, 2158€ / month (before taxs) during the third year.

Instruction to apply

Thank you to send:
- CV
- Cover letter
- Master marks and ranking
- Support letter(s)

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.