Alberto Testolin

MAIN TOPICS FOR RESEARCH PROJECTS

Project #01: Deep learning models of human numerical cognition and mathematical learning

Deep learning models can acquire perceptual and cognitive skills through statistical learning. However, it is not yet clear how these models can learn more structured knowledge, such as that underlying the manipulation of mathematical symbols. The main goal of this research line is to design and implement novel deep learning architectures that can simulate key phenomena observed in human numerical cognition (e.g., numerosity perception, approximate calculation…) and mathematical learning (e.g., acquisition of algorithmic procedures, generalization of arithmetic facts, learning and manipulation of symbolic mathematical notation…). This research topic is of theoretical interest for both AI research (out-of-distribution generalization, neuro-symbolic systems, etc.) and cognitive science (origins of human knowledge, simulation of neurocognitive development, etc.).

References: [1]–[7].

Target deep learning architectures: Self-supervised Models, Generative Models, Transformers, Recurrent Models, Deep Reinforcement Learning, Memory-Augmented Neural Networks, Large Language Models.

Project #02: Analysis of EEG time series from epileptic patients

Electroencephalography allows to record electrical activity from the human cortex, which can be used in healthcare applications to support diagnosis and build forecasting models. The main goal of this research line is to explore the application of machine learning / deep learning techniques to the analysis of EEG signals of epileptic patients to automatically extract useful features that can be used to predict upcoming epileptic events. A data set of EEG signals collected in collaboration with a local hospital will be used. This research topic is of interest for applied medical engineering but can also lead to theoretical insights on the electrophysiological nature of epileptic seizure.

References: [8], [9].

Target deep learning architectures: CNNs, Recurrent Models, Transformers, explainable machine learning models.

Project #03: Environmental soundscape monitoring

Artificial Intelligence techniques allow to build efficient and autonomous monitoring platforms, which can serve as a precious source of information to better understand our environment and take action to preserve biodiversity. The main goal of this research line is to implement a working prototype of an AI monitoring system based on intelligent microphones, which can be deployed in protected areas (forests) to identify and track over time the population of target avian species. Care should be taken to provide energy-efficient solutions that can be flexibly integrated into non-terrestrial telecommunication networks. This research topic promotes applications of AI for social good and it is of interest for applied AI research as well as to support scientific discovery in biology and ecology.

References: [10]–[12].

Target deep learning architectures: CNNs, Recurrent Models, Transformers, Mobile Networks, BIRDNet.

General notes

1. M.Sc. research projects usually requires 6 – 9 months to be completed (internship + thesis writing). Please note that some course degrees require the student to also carry out a separate external internship.
2. The student is expected to have a certain degree of independence and critical thinking: the idea is that you should explore the research topic and propose solutions to problems, rather than being told what to do step-by-step.
3. Advanced programming skills are required (Python with most popular deep learning frameworks, such as PyTorch / Tensorflow). Capability to implement code on cloud computing platforms is a plus.
4. Please read some relevant papers before scheduling a meeting to discuss the possibility of a M.Sc. thesis. Also, please mention student ID, M.Sc. degree and expected graduation period in your email.

References

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[3] S. Cognolato and A. Testolin, "Transformers discover an elementary calculation system exploiting local attention and grid-like problem representation," in *International Joint Conference on Neural Networks (IJCNN)*, Jul. 2022, vol. July, doi: 10.1109/IJCNN55064.2022.9892619.

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[5] F. Petruzzellis, A. Testolin, and A. Sperduti, "A Hybrid System for Systematic Generalization in Simple Arithmetic Problems," in *17th International Workshop on Neural-Symbolic Learning and Reasoning*, 2023, vol. 3432, pp. 289–301.

[6] A. Testolin, "Can neural networks do arithmetic? A survey on the elementary numerical skills of state-of-the-art deep learning models," Mar. 2023. [Online]. Available: https://arxiv.org/abs/2303.07735.

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[8] S. Shafiezadeh *et al.*, "Methodological Issues in Evaluating Machine Learning Models for EEG Seizure Prediction: Good Cross-Validation Accuracy Does Not Guarantee Generalization to New Patients," *Appl. Sci.*, vol. 13, no. 7, 2023, doi: 10.3390/app13074262.

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[10] B. Nur Korkmaz, R. Diamant, G. Danino, and A. Testolin, "Automated detection of dolphin whistles with convolutional networks and transfer learning," *Front. Artif. Intell.*, vol. 6, no. 2013, 2023, doi: 10.3389/frai.2023.1099022.

[11] P. Lauha *et al.*, "Domain-specific neural networks improve automated bird sound recognition already with small amount of local data," *Methods Ecol. Evol.*, vol. 13, no. 12, pp. 2799–2810, 2022, doi: 10.1111/2041-210X.14003.

[12] S. Kahl, C. M. Wood, M. Eibl, and H. Klinck, "BirdNET: A deep learning solution for avian diversity monitoring," *Ecol. Inform.*, vol. 61, no. January, p. 101236, 2021, doi: 10.1016/j.ecoinf.2021.101236.