BINDERS: Brain-Inspired Developmental learning with Noise mEchanisms for Robust AI Systems

A Project to be potentially funded by NRF-TUBITAK (2523) jointly, 2026-2028

Project No: N/A

Fully funded M.S. and Ph.D. positions are available!

Project Description: This project investigates how human learning principles, specifically the role of biological noise and developmental processes, can enhance artificial intelligence (AI) and computer vision systems. The goal is to propose biomimetic training strategies for AI models that enable flexible and adaptive learning, mirroring the human brain's lifelong development. 1) Scientific/Technological Excellence: The project explores noise training based on developmental and lifelong learning principles, an area less explored than traditional engineering-driven noise injection. It builds on prior research demonstrating biological noise's crucial role in enhancing neural network robustness and recognition. The project aims to explain why noisy training for deep networks is effective by linking biological and computational approaches. It seeks to uncover generalizable principles of how temporally patterned neural noise contributes to robust AI recognition, inspiring new neurodevelopmentally grounded AI training strategies. The project also intends to investigate emergent behaviors in non-linear systems with noise, such as stochastic resonance. 2) Methodology: Deep learning models will serve as computational analogs of developing neural circuits to examine how neural noise's temporal trajectory influences sensory system robustness. Different training paradigms (clear-to-noisy, noisy-to-clear) will be compared on object recognition tasks. Our preliminary findings suggest superior robustness in models trained with the clear-to-noise paradigm. The approach will be expanded to include diverse noise profiles (e.g., Gaussian, Poisson, dropout-based), target various network architectures and layers, and incorporate more biologically plausible developmental noise trajectories. Robustness will be assessed using methods such as generalization under occlusion, transfer learning stability, and adversarial conditions. For lifelong learning, resting-state EEG signals from different age groups will monitor signal variability, complemented by task-evoked EEG during object recognition tasks with noisy stimuli. EEG experiments will be performed across three distinct developmental stages: younger children (7-12 years), older children (12-20 years), and adults (20-45 years), with a minimum of 10 participants per group. Detailed EEG recordings (32-64 channels) and signal processing will be used to bring a systematic approach to data collection and analysis on both sides. The project also plans to integrate developmental factors like limited visual acuity by manipulating input quality and internal processing constraints. 3) Project Management: The project is formed with the Korean side being predominantly responsible for investigating the neuroscientific underpinnings, neural noise processes in learning and computational model developments, and the Turkish side for information theory tools, biomimetic training strategies, model development and applications. 4) Importance of International Collaboration: The project title as well as the distinct research group responsibilities (Korean (Dr. Jang) and Turkish (Dr. Arslan) sides individually) implicitly indicates an international collaboration, expected to be rich, cross-cultural and fruitful. While specific benefits are not explicitly detailed, the interdisciplinary nature of the research, combining computational modeling with neuroscientific validation, significantly benefits from the diverse expertise and perspectives often provided by international partnerships. Such collaborations foster a richer understanding and broader applicability of findings across different scientific and cultural contexts. 5) Overall Impact: The project has several very timely and significant potential impacts. First

of all, it aims to enhance the robustness of AI models against real-world sensory perturbations (occlusion and adversarial noise), which is critical for safety-critical domains such as autonomous vehicles and medical diagnostics. The research is expected to improve AI model interpretability and human-likeness by promoting human-like recognition behaviors (e.g., shape bias over texture) and comparisons between model activations and human neural data across different ages. This will advance understanding of how biological and artificial systems converge in learning strategies. Insights into temporally structured internal noise could lead to AI models that learn more fluidly across time, potentially reducing catastrophic forgetting and enhancing transfer learning, providing a biologically motivated framework for lifelong learning. The computational framework could also offer novel tools for understanding atypical developmental trajectories and age-related cognitive changes, informing research on neurodevelopmental conditions (e.g., autism spectrum disorder) and age-related cognitive deficits. Finally, by embracing internal variability, the research may contribute to stochastic and neuromorphic computation, inspiring new designs for energy-efficient AI hardware that are both robust and computationally efficient, akin to biological brain mechanisms.

Project Management:

1. Prof. Hojin Jang (PI), Dept. of Brain and Cog. Eng. at Korea University.

2. Prof. Suayb S. Arslan (PI), Dept. of Comp. Engineering at Bogazici University and Research Affiliate, Brain and Cog. Sciences at MIT.

Applications and Compensations: Funding is available for M.S. and Ph.D. degrees.

1. Master of Science (M.S), 22,500TL + benefits

2. Philosophy of Doctorate (Ph.D), 37,780TL + benefits

All applicants are encouraged to contact the PI and Co-PIs of the project if there is any interest in engaging and contributing to this new exciting field. All questions about the logistics and official applications (A resume with previous project experience and publication record) should be directed to ***suayb.arslan@bogazici.edu.tr***. The available positions will be filled on a first-come, first-served basis upon successful fulfillment of project requirements.