Algorithmic Foundations of Biomimetic Training: Regret-Optimal Curriculum Learning for Robust and Generalizable AI

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Project No: N/A

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

Project Description: Biological visual systems develop through a stereotyped *coarse-to-fine* trajectory, beginning with low spatial resolution and gradually incorporating fine detail. Recent findings in neuroscience and machine learning demonstrate that training neural networks with similar biomimetic curricula leads to substantially improved robustness and generalization. Despite this empirical success, there is still no principled algorithmic explanation for *why* such training strategies emerge as optimal, nor under what conditions they should be expected.

This project proposes a unified theoretical and computational framework that explains biomimetic coarse-to-fine training as a *regret-minimizing solution to adaptive curriculum learning under uncertainty*. Curriculum selection is formulated as a nonstationary online decision problem in which the learner dynamically allocates training effort across data regimes (e.g., blurred versus high-resolution inputs) based solely on partial feedback in the form of learning progress. Using tools from multi-armed bandit theory, we show that early preference for coarse, low-variance inputs naturally arises as a near-optimal strategy for maximizing long-horizon learning progress and robustness. As internal representations stabilize, the same framework predicts a principled transition toward fine-grained detail.

The project integrates theoretical analysis, simplified dynamical models, and controlled deep neural network experiments to validate this account. Robustness to noise, blur, adversarial perturbations, and distribution shift will serve as primary evaluation criteria.

Objectives:

1. To provide a theoretical foundation for biomimetic training by casting curriculum learning as a regret-minimization problem in nonstationary online learning.
2. To design adaptive curriculum algorithms based on learning-progress rewards that do not rely on predefined training stages or hand-crafted schedules.
3. To validate the proposed theory computationally using simplified models and deep neural networks trained under adaptive coarse-to-fine curricula.
4. To quantify robustness and generalization gains relative to conventional and fixed-curriculum baselines across multiple perturbation settings.

Project Management:

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

Applications: 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.