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Applicant for a PhD in Computer Science

RESEARCH MOTIVATION

I am captivated by the open challenges in machine learning that biology evolved to solve. Backpropagation can be inefficient due to global error signals while static architectures seem to lack the plasticity to prevent catastrophic forgetting. This rigidity in vision models appears to cause poor generalizability and vulnerability to adversarial attacks. Such fragilities in complex tasks can create intractable exploration spaces and unscalable communication. **I am motivated to research how integrating the principles of computation from biological substrates may reduce these limitations**.

SELECTED RESEARCH EXPERIENCES

My research with Drs. Hanna, Sala, and Berland has resulted in **eight first-author full-length papers: five peer-reviewed publications in NeurIPS** workshops (four in archival proceedings), one in BRAID, and two preprints under review.

World Models for MARL. My research began with exploring bio-inspired multi-agent reinforcement learning (MARL), contributing to my team's **first-place finish at RoboCup**, the international MARL robotics competition. Leading a group investigating inter-agent communication, we found that an emergent strategy, inspired by signaling in simple organisms, collapsed to 12.2% success at task allocation with partial observability despite stabilization. Pivoting to experiment with a **world-model based approach** improved to 96.5% success, revealing the value of an agent internally simulating the environment. This taught me to remain open to unexpected results and shift focus based on data.

Active Inference & Structural Plasticity. Inspired by theories of intelligence like the free energy principle and Dr. Michael Levin's work on basal cognition, I addressed the intractability of **active inference** by developing a novel approximation using **principles from RL**. After grounding this work in discussions with Dr. Josiah Hanna (RL) and Dr. Levin (biology), **Dr. Levin invited me to extend this research under his mentorship**. Without a reward, the model maintained 82% success in Cart Pole, forming a step towards computable active inference. This research strengthened my ability to navigate the intersection of theoretical biology and machine learning.

Visual-Cortex Architecture. Curious about macro-level perspectives, I led a team experimenting with **primate visual cortex architectures** for light field identification. We implemented biological features including **dual-stream processing and predictive coding**. Despite engineering challenges of integration, the model achieved 74.4% accuracy, outperforming the next-best by 2.3 percentage points while being 2.5 times smaller, and demonstrated the value of inductive bias through geometric neuroscience. I learned to manage complex component interactions essential to building brain-inspired systems.

Industry Embodied AI. Concurrently, I **lead state estimation research** at an industry AI R&D lab. State-of-the-art (SOTA) algorithms proved unsuited for our constrained hardware and low-accuracy sensors. This drove me to develop an algorithm reducing dimensionality by disentangling data manifolds. The algorithm achieved over 100x improvement in accuracy over SOTA. It is now **deployed on all company robots** and received extensive positive customer feedback. This experience taught me to navigate the entire research-to-deployment pipeline under real-world constraints.

SERVICE THROUGH RESEARCH LEADERSHIP AND MENTORING

I founded the Wisconsin Neuromorphic Computing and NeuroAI Lab (WNCNL) to create an interdisciplinary structure for this research and a learning community. I secured funding, dedicated space, support from Dr. Akhilesh Jaiswal as advisor, and an official partnership with the NeuroAI startup FinalSpark. My role involves **mentoring 15 undergraduate researchers**, providing advice to over 100 researchers, developing research proposals, organizing biweekly workshops, and lecturing on topics like spike-timing-dependent plasticity drawing **audiences of over 100 undergraduates, graduates, and professionals**.

My work with the WNCNL demonstrates my commitment to building scholarly community, a value I am eager to bring to Georgia Tech, such as by organizing a workshop series that operationally connects findings from the Institute for Neuroscience, Neurotechnology, and Society with engineering challenges at the Machine Learning Center. I aim to continue guiding undergraduates through the challenges of interdisciplinary research as a **mentor in the Opportunity Research Scholars' Program**,

Sample Research Extension

One fascinating direction building on my prior research investigates autonomous **emergence of state space** through predictive compression of high-dimensional sensory streams **during navigation**. While successor representations (SR) via spike timing-dependent plasticity are established, current models rely on pre-defined place cells or passive perception.

A **visual-cortex-based encoder** fuses with internal motion cues, and lateral inhibition encourages self-organization of sparse place cells. Distinctly, the model navigates to **minimize expected surprise** of its SR map. This research explores if such a bio-mimetic objective **stabilizes the online emergence of predictive maps**.

How a PhD Fits My Career Goals

Researching in industry, my development process was one of empirical iteration. I realized a deeper understanding of underlying mathematical theory may yield more efficient solutions. While I have strong practical skills, **I am driven to gain the theoretical depth to more rigorously devise novel algorithms**.

My long-term objective is conducting **research within a group like DeepMind's neuroscience lab**. Conversations with the current and previous lead, Drs. Kim Stachenfeld and Matthew Botvinick, solidified a PhD as the essential path to gain the theoretical depth and research freedom required. Receiving an **invitation from Dr. Karl Friston** to present my prospective doctoral research at his theoretical neurobiology group reinforced the value of a PhD for engaging with these ideas.

Why Georgia Institute of Technology

I am applying to Georgia Tech because its unique concentration of faculty researching applications of neuroscience for AI provides the ideal environment to pursue my research goals. **Dr. Santosh Vempala's** research bridging high-level cognitive algorithms and neuronal dynamics aligns with my research goals. Leveraging my background in biologically-plausible architectures, I propose integrating work in "Computation with Sequences of Assemblies in a Model of the Brain" with findings in "Brain Computation by Assemblies of Neurons" to incorporate probabilistic capabilities. I would investigate the emergence of probabilistic finite automata and graphical models within the assembly calculus. By modifying synaptic updates to encode transition probabilities, I aim to derive bounds for learning from stimulus streams and identify plasticity mechanisms for sampling future states, advancing the assembly hypothesis toward emergent statistical computation.

I am fascinated by **Dr. Constantine Dovrolis's** research on neuro-inspired architectural plasticity. I aim to investigate structural recycling within NICE to address its finite capacity. Drawing on my background in adaptive neural architectures, I propose researching a synaptic utility metric to identify low-distinctiveness frozen neurons and re-plasticize them to Age-0. This investigation would seek to formalize a computational equivalent of biological turnover to create a steady-state learner capable of indefinite operation.

Dr. Kuldeep Meel's research on scaling automated reasoning is captivating. Leveraging my experience engineering reasoning to address scalability challenges in "Scalable Counting of Minimal Trap Spaces and Fixed Points in Boolean Networks", I propose investigating a hybrid counting architecture bridging exact solvers (GANAK) and approximate counters (ApproxASP). I aim to research a structural decomposition framework that analyzes graph properties, such as treewidth, to partition networks for hybrid enumeration. This work would focus on formalizing a portfolio approach that establishes mathematical bounds to optimize runtime for high-dimensional biological systems. I am eager to bring my unique background in collaborative research and interdisciplinary curiosity to Georgia Tech and to contribute to its research community.