Statement of Purpose

Word Count: 412

Research Motivation and Background

My research is driven by the observation that while deep learning has achieved remarkable feats, it remains constrained by inefficiency and rigidity compared to biological intelligence. Standard backpropagation struggles with global error signals, and static architectures lack the plasticity required to prevent catastrophic forgetting or adapt to adversarial scenarios. My objective is to bridge this gap by investigating how biological principles, such as predictive coding and local plasticity, can be mathematically abstracted to create robust, adaptable learning systems.

My background is rooted in Computer Science, yet my research trajectory has consistently converged on neuroscience. As the founder and director of the **Wisconsin Neuromorphic Computing and NeuroAI Lab**, I have led interdisciplinary teams to translate biological theories into computational models. My work spans from **bio-inspired multi-agent reinforcement learning (MARL)**, where we utilized world models to improve task success from 12.2% to 96.5%, to implementing primate visual cortex architectures that outperformed state-of-the-art models while being significantly smaller. Additionally, my collaboration with **Dr. Michael Levin on active inference** demonstrated that principles of basal cognition could solve complex control tasks without explicit reward signals.

Why Oxford and the 1+3 Program

I am applying to the University of Oxford because the **DPhil in Neuroscience (1+3)** offers the specific structure I need to transition from a computer scientist to a computational neuroscientist. While I possess strong empirical skills in AI, I require the granular physiological knowledge provided by the MSc rotation year to rigorously ground my computational hypotheses.

The MSc modules in "Synapses and Transduction" and "Neuronal Cell and Molecular Biology" are essential for my development. They will enable me to move beyond biomimicry toward biologically grounded discovery. Furthermore, the opportunity to apply model-based RL to experimental settings during rotations will bridge the gap between my theoretical models and wet-lab data.

Research Interests and Future Goals

My research interests align closely with the work of **Dr. Rafal Bogacz**. I aim to contribute to his research on predictive coding, specifically investigating the biological implausibility of explicit error neurons. I would be interested in investigating **predictive dendrites** where compartments predict somatic activity, thereby internalizing error comparison. Additionally, I am eager to explore inhibitory plasticity rules to address the inefficiencies of Hebbian learning in excitatory-dominated cortices.

My long-term goal is to research at an institution like **DeepMind's neuroscience lab**. Conversations with Drs. Kim Stachenfeld and Matthew Botvinick have reinforced that the theoretical depth offered by an Oxford DPhil is the essential next step to achieving this ambition.

Extended Statement

Word Count: 991

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 NSF 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 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, outperformed 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.

Research Leadership and Mentoring

To create an interdisciplinary structure for this research at UW-Madison, **I founded and direct the Wisconsin Neuromorphic Computing and NeuroAI Lab**, securing formal funding, dedicated space, support from Dr. Akhilesh Jaiswal as advisor, and partnership with neuroAI startup FinalSpark. Through **nine graduate-level AI and neuroscience courses**, I gained technical foundations to lead this initiative. 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.

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 University of Oxford

I am applying to the University of Oxford because its unique concentration of faculty researching applications of neuroscience for AI provides the ideal environment to pursue my research goals.

To move from bio-mimicry to biologically grounded discovery, the 1+3 structure is ideal. The MSc training in "Synapses and Transduction" and "Neuronal Cell and Molecular Biology" provides the granular physiological knowledge required to ground my computational hypotheses. Through the program's rotations, I can apply AI, such as model-based RL, to experimental settings, bridging wet-lab data with computation. The program's past projects like "Extracting hierarchical structure from experience" directly parallel my interest in autonomous state-space emergence. This facilitates my transition from computer scientist to computational neuroscientist.

My research interests align with Dr. Rafal Bogacz, specifically regarding the biological implausibility of explicit error neurons. I aim to contribute to his work modelling predictive coding via predictive dendrites, where compartments predict somatic activity to internalize error comparison. Furthermore, addressing the inefficiency of standard Hebbian learning in excitatory-dominated cortices, I could model inhibitory plasticity rules. This would allow me to leverage my state-space modeling background to investigate how local plasticity generates emergent, brain-like dynamics.

I am eager to bring my unique background in collaborative research and interdisciplinary curiosity to the University of Oxford and to contribute to its research community.