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.

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 California, Santa Barbara

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

My interest in neuromemristive systems draws me to **Dr. Dmitri Strukov's** research and especially "NeoHebbian Synapses to Accelerate Online Training of Neuromorphic Hardware", which leverages ReRAM thermal dynamics for eligibility traces. However, thermal crosstalk limits scaling in dense $1T$-$1H$-$1M$ arrays. Drawing on my physics experience, I propose investigating active heat-routing architectures, integrating nanoscale thermal diodes within the back-end-of-line stack. This research aims to determine if directing heat flux vertically to maximize self-thermal coupling, while suppressing lateral diffusion, enables highly scalable, multi-physics neuromorphic hardware.

I am fascinated by **Dr. Peng Li's** work on memory-based continual learning, particularly the EMAR mechanism in "Continual Relation Learning via Episodic Memory Activation and Reconsolidation". Integrating this with "Adversarial Robust Memory-Based Continual Learner", and leveraging my background in natural language processing and adversarial machine learning, I propose addressing accelerated forgetting in relation extraction. I aim to investigate if relation prototypes offer a more stable regularization target against gradient obfuscation than standard replay buffers, and I could adapt Anti-Forgettable Logit Calibration to discrete textual perturbations to ensure prototype resilience.

Dr. Kerem Camsari's research on probabilistic computing aligns with my quantum computing background and I find compelling in "Training Deep Boltzmann Networks with Sparse Ising Machines" that sparse DBMs can match dense RBM accuracy. I propose extending this work by developing circuit-level interfaces to transition from FPGA emulation to native stochastic magnetic tunnel junction arrays. My investigation would focus on managing nanosecond fluctuations to scale throughput from ≈ 64 flips/ns to exceeding a million flips/ns.

I am eager to bring my unique background in collaborative research and interdisciplinary curiosity to UCSB and to contribute to its research community.

Fostering Intellectual Diversity and Community My research on neuroscience-inspired intelligent systems began with academic isolation. Professors in AI told me that researching the application of neuroscience for AI is uncommon. Noting I was the only engineer in his class, a neuroscience professor expressed a wish for research on building AI's neurons into hardware, independently envisioning neuromorphic computing, unheard of in his department. I had a passion for a field that, on my campus, did not seem to exist.

Driven by relentless curiosity, I searched for insights from textbooks and numerous papers outside of my coursework. I began to understand the active areas of research in this discipline and gain the skills required to work in them. I learned that the relevant subdisciplines were separated into distinct departments at UW-Madison, forming a systemic barrier to discovery. In my early studies, I sought a way to connect to others with similar interests, a mentor to teach me about neuroscience-inspired AI, or collaborators to help me start conducting relevant research. Yet I found none. To spare others that same isolation, I created the community I once sought.

I founded the Wisconsin Neuromorphic Computing and NeuroAI Lab (WNCNL) to create both an interdisciplinary research hub 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. I was delighted to see the collaborative nature of the lab: students from neuroscience explaining the biomechanics of a neuron to engineers and computer scientists explaining artificial neural networks to biologists.

To share my passion for learning and for this field, I give lectures on relevant topics and organize weekly meetings including biweekly workshops. When members run into challenges like low model performance, I give advice on how to resolve them. I also explain concepts, provide research proposals, point to relevant literature, and propose avenues for future research. For instance, explaining spiking neural networks' aptitude for sparse event-driven processing motivated one group to begin new research on meteor detection.

My work with the WNCNL demonstrates my commitment to building scholarly community, a value I am eager to scale within the UCSB ecosystem. Seeing students explain concepts from their own disciplines solidified for me that this cross-pollination is essential. I am keen to scale this model at UCSB, such as by organizing a workshop series that operationally connects findings from the Neuroscience

Research Institute with engineering challenges in the Institute for Energy Efficiency. My lived experience of academic isolation is what drives me to mentor. I plan to serve as a mentor in the UCSB Academic Research Consortium and Research Mentorship Program, guiding undergraduates and high school students through the challenges of interdisciplinary research. At UCSB, I aim to be both a researcher and a community builder who ensures no student's passion exists in isolation.

Cultural Empathy and Inclusive Support Systems My commitment to inclusivity is deepened by my experiences navigating cultural barriers. Seeking a global perspective on engineering, I studied abroad at the National University of Singapore. While the academic rigor was enriching, a transformative experience occurred outside the classroom. I contracted a severe illness and found myself navigating a foreign healthcare system alone. Wandering a mostly-empty hospital, spending the night in a waiting room, and being injected with an unknown fluid, the procedural barriers left me confused and voiceless.

This moment of vulnerability shifted my perspective on international education. I realized that the confusion I felt for one night is the daily reality for many international students navigating the US university system. This empathy now informs my approach to peer interaction. Whether it was bridging communication gaps for a Spanish-speaking classmate or in my prospective future role as a graduate student, I aim to support those who may be withdrawing socially due to cultural dissonance. At UCSB, I intend to proactively support international students by working as a tutor for Campus Learning Assistance Services and, if I reach candidacy, serving as a mentor in the Graduate Scholars Program.

Service to Underserved Populations Beyond academia, I am driven by a responsibility to address socioeconomic inequities in my community. Witnessing the severity of homelessness and food insecurity in Madison, I felt compelled to move beyond passive sympathy. Believing that access to food is a fundamental human right, I volunteered with Slow Food UW, an organization dedicated to providing pay-what-you-can meals to underserved populations.

To amplify this impact, I organized a group of thirty students to volunteer alongside me. Many of these peers expressed a desire to help the unhoused community but lacked the direction to begin; providing that pathway allowed us to scale our impact significantly. This experience reinforced my belief that engineering and academic leadership should not be divorced from civic responsibility. I am eager to bring this spirit of service to the UCSB community, volunteering with Doctors Without Walls to support disadvantaged populations in Santa Barbara.