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 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 Berkeley

Berkeley's unique faculty concentration in neuro-inspired AI provides the ideal environment for my research goals.

Fascinated by **Dr. Bruno Olshausen's** invariant representation learning, I aim to unify the framework "An unsupervised algorithm for learning Lie group transformations" with factorization dynamics of "Compositional Factorization of Visual Scenes" by applying background in neural representation engineering. I propose investigating if encoding Lie operators into high-dimensional vectors allows Resonator Network's search-in-superposition to factorize objects and transformations more efficiently than gradient-based inference.

Intrigued by **Drs. Claire Tomlin's and Jack Gallant's** work emulating human cognitive processes, especially "A framework for evaluating human driver models using neuroimaging", I propose extending MPC to interactive scenarios using multi-agent game theory experience. Isolating strategic planner features, we could investigate if game-theoretic models explain variance in higher-order cognitive areas like the Prefrontal Cortex.

Drawn to **Dr. Sergey Levine**'s experiential learning research, particularly ViNG and ViKiNG's topological mental maps that decouple traversability from planning, I aim to leverage representation learning and offline RL background to augment ViKiNG's satellite-guided search. I propose developing learned heuristics re-weighting edges using text-observation alignment, investigating if this bias enables high-level planners to interpret abstract instructions.

I am eager to contribute my background in collaborative research and interdisciplinary curiosity to Berkeley's research community.

Brennen Hill - BrennenHill.com
CS PhD Applicant

Personal History Statement

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 Berkeley ecosystem. Seeing students explain concepts from their own disciplines solidified for me that this cross-pollination is essential. At Berkeley, I would formalize the curriculum I developed for the WNCNL into a DeCal Course that operationally connects findings from the Redwood Center for Theoretical Neuroscience with engineering challenges in the Berkeley Artificial Intelligence Research Lab. My lived experience of academic isolation is what drives me to mentor. I plan to serve as a mentor in the Student Mentoring and Research Teams program, guiding undergraduates through the challenges of interdisciplinary research. At Berkeley, I aim to be both a researcher and a community builder who ensures no student's passion exists in isolation.