**Reproducing the evolutionary path to human-level intelligence**

**Introduction**

Since the beginning of my research career, my research goals have been guided by my passion for creating a true general Artificial Intelligence (AI) that would be capable of benefitting humankind and changing society, as we know it, for the better. As a half-Computer Scientist/half-Neurobiologist, I have pursued an unconventional route to solving the problem of AI: instead of trying to hard-code intelligence into the computer, I am attempting to reproduce the evolutionary path that our ancestors followed to evolve human-level intelligence. The research projects described below are two small steps along a long and winding path to understanding how to evolve an AI in a computer.

**Evolving an artificial brain for a biped robot**

For my undergraduate thesis, I completed a project seeking to evolve an artificial brain for controlling the gait of a two-legged robot, which has been a notoriously difficult problem for robotics researchers1. Adaptive, digital robotic controllers have important applications in robotics, Artificial Intelligence, and video games & animation (e.g., EA’s Madden NFL). With the guidance of my undergraduate advisor, I completed the project on my own and learned many skills important to independent research: how to solve unexpected problems, how to come up with new solutions to problems, and most of all, how to stay motivated when the research project is not working as planned. Additionally, I learned much of my core computational skillset during this project, such as how to design experiments, test for errors, create digital models of evolution, gather, manage, and statistically analyze data, and extend projects started by other researchers.

At the conclusion of the project, I discovered that the state-of-the-art artificial brain model was insufficient to evolve a stable controller for two-legged robots. Furthermore, I suggested that the artificial brains had to be able to modify themselves during the lifetime of the two-legged robot to be capable of balancing while walking forward. As a result, my colleagues and I are attempting to create adaptive artificial brains in my current lab. This research project solidified my interest in evolved Artificial Intelligence, and motivated me to pursue this passion in my graduate studies.

**Testing the *confusion effect* hypothesis in an evolving digital system**

During my first year of graduate studies, I joined a research project studying collective animal behavior. Biologists have spent decades studying collective animal behavior due to its important implications for social intelligence, collective cognition, and its potential applications in automated control of distributed systems2. Swarming behavior is one of the most striking examples of such collective animal behavior. These decades of research have produced numerous hypotheses about the selective benefits of swarming behavior, such as increased mating success or improved defense against predators (reviewed in 3). However, due to the long generation times in swarming animals, studying the evolution of swarming behavior has often proven difficult4. To overcome this difficulty, I developed a computational model that simulates digital organisms with evolving behaviors to examine which of the proposed selective benefits favor the evolution of swarming5. Digital systems have previously been used to provide key insights into core evolutionary processes6, and several well-known studies have adopted digital systems as a method to study swarm behavior (e.g., 7). With my computational model, I determined that the *confusion* *effect*, where swarming prey confuse and thereby reduce the attack efficiency of their predators, provides a sufficient (but not necessary) selective advantage to evolve and maintain swarming behavior in prey.

Throughout this project, I further refined my research skills by learning how to design experiments to test biologically relevant hypotheses, collaborate in ongoing research projects, use a new artificial brain model developed in the lab, and learning about responsible conduct of research in academia. Additionally, I gained a great amount of experience giving presentations and poster presentations at conferences (listed in my application) and local meetings sharing the results of this project. Moreover, I was able to apply what I learned about evolving artificial brains from my undergraduate research project to improve the artificial brain model in my current lab.

Most notably, this project resulted in a new method for testing hypotheses about the evolution of animal behavior. As a result, data and methods from this project are being included in a grant proposal to the NSF this year. Due to this project’s success, I am proposing a direct extension of this project in my Proposed Research statement.

**Intellectual Merit**

My previous research experiences have helped me develop the essential skills for responsible graduate research by providing projects in which I participated in the majority of the research process: constructing the hypotheses, designing the experiment to test the hypotheses, executing the experiment, analyzing the results, then repeating this process until repeatable, publishable results are achieved. Beyond research skills, I have learned a great breadth of knowledge about the evolutionary and neurobiological processes guiding the evolution of animal behavior, which will directly aid me in my proposed doctoral research. Ultimately, these skills will enable me to achieve my goal of reproducing the evolutionary path to human-level intelligence.

**Broader Impacts**

The experience I gained in my previous research projects has enabled me to share my passion for science, evolution, and the field of Artificial Intelligence with the public. I have regularly participated in outreach efforts to educate the public about these topics via blog posts on NSF BEACON’s web site, museum events, and local science fairs. From the numerous presentations I have given about my work, I have developed the confidence to share and discuss my research with professionals in my field, and the ability to relate my research to other researcher’s work in a meaningful way. As a result, I have been able to establish numerous collaborations bridging computational research and biology, leading to yet more projects that will broaden our understanding of the evolution of animal behavior.

**References**

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