Learning Computer Science from Evolution: As a computer scientist, I am awed by the incredibly diverse algorithms encoded in biological organisms that have evolved for over four and a half billion years. Our genomes are filled with algorithms capable of fantastic feats, such as cellular homeostasis, multicellular development, and even human intelligence. Traditionally in computer science, algorithms are designed by humans from conception to implementation; I want to learn more about the algorithms found in our DNA that are generated, maintained, and improved upon by evolutionary processes. In a sense, evolution has been doing computer science for billions of years!

My fascination with evolution-produced algorithms has drawn me toward two questions: How do evolutionary processes develop the complex algorithms we see in nature? And, how do these algorithms work together to produce the immense biological diversity around us?

I am pursuing a dual doctoral degree in Computer Science and Ecology, Evolutionary Biology & Behavior at Michigan State University (MSU). I chose MSU because of the opportunity to join the National Science Foundation (NSF)-funded BEACON Center for the Study of Evolution in Action, which provides opportunities to study both computer science and evolutionary biology with support from interdisciplinary mentors. I want to transfer ideas between these fields in both directions: (1) using computational techniques to advance our understanding of evolutionary processes; and, (2) using a deeper understanding of evolutionary processes to develop new methods of computation. I am using graduate school as an opportunity to become both a computer scientist *and* an evolutionary biologist to be best equipped to reach these goals. When I arrived at MSU, I received a University Distinguished Fellowship to support my PhD work. I joined Dr. Charles Ofria's Digital Evolution Laboratory in my first semester where I collaborate with both biologists and computer scientists, using computational evolution to study evolutionary processes and the algorithms those processes develop.

Relevant Background: When I arrived at Mississippi State University as an undergraduate, I wanted to gain new perspectives, so I actively sought multidisciplinary experiences. First, I developed software for a group of astronomers led by Dr. Angelle Tanner in the Physics Department. Their goal was to discover and document unknown extrasolar planets, so I developed tools to automate data retrieval from the NASA Star and Exoplanet Database. This interdisciplinary experience provided me with the foundational skills to earn an internship at the Jet Propulsion Laboratory (JPL). There, I worked as a software developer on a team of optics engineers and geoscientists. I focused on modernizing their instrument calibration software for their Near-Nulling Radiometers, enabling the team to perform more efficient and reliable calibrations. During my time with Dr. Tanner and at JPL, I was often the only computer scientist, which taught me essential lessons in communicating my ideas across disciplinary boundaries.

In order to feed my desire for multidisciplinary perspectives and curious about how psychology and robotics fit together, I joined the Social, Therapeutic, and Robotic Systems (STaRS) Laboratory under the mentorship of Dr. Cindy Bethel. At first, I primarily helped to run human participant studies, which gave me first-hand experience with proper study design and execution. I then joined a research team working on the Robot Intent and Control Project, which aimed to improve how tactical teams interface with robot team members. When coordinating with an unmanned robot, it is critical for human team members to accurately perceive the robot's intended behavior and maintain the ability to alter that behavior if necessary. We designed a study to evaluate the usability of different types of robot-human interfaces on a coordination task that required human operators to maintain awareness of the robot's intentions and to periodically override the robot's intended behavior. As the project progressed, I took on a leadership role. I became responsible for study implementation, task distribution among team members, and ensuring the project moved forward on schedule. Our study showed users preferred a handheld touchscreen interface over gesture-based and audio-vocal interfaces. This result informed the design of a new interface for a tactical unmanned ground vehicle, which is currently being integrated into the training sessions of the Starkville P.D. S.W.A.T. team. I was first author of the peer-reviewed article that detailed our results at the IEEE Workshop on Advanced Robotics and its Social Impacts [1]. I formally presented our results at the workshop and at an undergraduate research poster competition at Mississippi State. This research revealed my passion for scientific inquiry, and I gained confidence in myself as a researcher.

Relative to animals, the robots I worked with in the STaRS Lab were less capable and inelegant, cultivating my interest in bio-inspired computing. Exploring this interest, I interned at the Laboratory for Autonomous Systems Research (LASR) in Washington D.C. I worked with cognitive scientists and image processing experts to research the effects of integrating contextual information (generated by a model of the way humans learn associations between concepts) to assist a robot's object recognition system. Because humans rely heavily on context to recognize objects, I hypothesized that contextual information would drastically improve the robot's object recognition system. I found contextual information to help in some situations; however, like humans, the robot became susceptible to self-fulfilling prophecy effects. With a taste of developing bio-inspired algorithms at LASR, I became completely focused on how nature develops algorithms: evolution. This interest led me to the work of Dr. Ofria at MSU.

At MSU, I decided to explore how evolution develops organismal control algorithms capable of effectively responding to uncertain conditions; in biology, this ability is known as phenotypic plasticity. While evolutionary biologists have a good understanding of the conditions necessary for plastic traits to evolve, the step-by-step process by which these traits evolve is less clear. Observing this process at a high resolution is often intractable in biological systems; however, computational evolution allows me to examine the evolution of plastic traits in populations of self-replicating computer programs. This requires that I first reproduce the conditions for the evolution of phenotypic plasticity in a computational system, then observe mutation-by-mutation how plasticity evolves.

I have found that traits first evolve to be statically expressed, not responding to environmental conditions. Next, imprecise forms of plasticity evolve before more precise forms of plasticity finally emerge. I also found that experimentally blocking any of these stages significantly reduces the chances for phenotypic plasticity to evolve. My results shed light on how evolutionary processes can generate plastic traits in nature, and inform situations in evolutionary computation where evolved solutions must be dynamic with respect to the environment. I was first author on a peer-reviewed article that I presented at the 2016 International Conference on the Synthesis and Simulation of Living Systems (ALife), which won the Best Student Paper award [2]. I also presented these results at the 2016 BEACON Congress and at MSU's Engineering Graduate Research Symposium. Additionally, I developed a publicly accessible, interactive web visualization tool that allows anyone to explore my data [3]. In the Spring of 2016, I won seed funding through BEACON to follow up this work. With this funding, I am beginning to look at how the underlying mechanisms for phenotypic plasticity affect the evolution of division of labor.

Broader Impacts: Growing up in the deep south of Mississippi, I have first-hand experience with how little exposure to the science of evolution K-12 students can receive because of anti-science cultural views and poorly supported science classrooms. Evolution was barely discussed in my elementary, middle, and high school science and biology classrooms and was often a taboo topic at family dinner tables. I would have discovered evolution's importance in understanding the natural world and its applications in computer science much sooner in life if I had better access to educational materials on evolution. I do not want students to miss out on learning science because of their socio-economic circumstances; thus, I am passionate about reaching out to students lacking access to science education through outreach and by creating tools that can be accessed and understood by anyone with an internet connection.

BEACON has given me a platform to help make science more accessible to K-12 students and the general public. I have authored several BEACON blog posts aimed at explaining concepts in evolutionary biology to a broad audience. I volunteer regularly at local elementary school science nights along with other BEACON scientists to teach students about evolution using interactive activities. Engaging in these hands-on demonstrations and activities allows students to experience evolutionary processes in action, making processes that normally operate on large timescales tractable and easier to comprehend.

In collaboration with the Digital Evolution Lab, I am working on a new, open source computational evolution platform capable of running interactively on the web. This software tool will allow anyone with an internet connection to replay actual experiments or to design and run their own, making it a powerful tool both for communicating research to a broad audience and for teaching students about evolution. Our goal is to make computational research tools for studying evolution widely accessible and easily usable. By prioritizing usability and accessibility, we will be able to reach a wider, more diverse audience than otherwise possible, giving underprivileged students who lack access to high quality science education the opportunity to learn about evolution using real research tools.

Because of my lack of exposure to evolution in K-12, I would not have made the connection between computer science and evolutionary biology without great mentors. Knowing how important my mentors have been for me, I make a point to be a mentor to less experienced students. As an undergraduate working in the STaRS Lab, I spent a significant amount of time training and mentoring new lab members. This past summer, I participated as a graduate student mentor in an REU program for students that are underrepresented in STEM. I guided an undergraduate student on a 10-week summer research project, and we are continuing to collaborate long-distance with the goal of the student preparing and submitting a manuscript to a peer-reviewed conference.

Future Goals: My goal for graduate school is to become both a computer scientist and an evolutionary biologist. This is an essential stepping stone in my pursuit of a lifelong career as research scientist at the frontier of both fields, linking ideas in both computer science and evolutionary biology. Receiving the NSF Graduate Research Fellowship ensures my ability to pursue these goals, giving me the flexibility and resources to simultaneously focus on making scientific advancements and improving the accessibility of evolution education.

References: **(1)** Lalejini *et al.* (2014) Evaluation of supervisory control interfaces for mobile robot integration with tactical teams. *Proc. ARSO 2014.* **(2)** Lalejini & Ofria (2016) The evolutionary origins of phenotypic plasticity. *Proc. ALife 2016.* **(3)** Lalejini (2016) Visualization: the evolutionary origins of phenotypic plasticity. (http://lalejini.com/plast_proj_lineage_visualization.html)