Plan of Study

science / engineering

- IBIO 832 evolution of nervous systems (Spring 2019)
- IBIO 849 evolutionary biology (Spring 2018)

math / statistics

- MTH 881 Graph Theory (Spring 2019)
- STT 850 Applied Multivariate Statistical Methods (Spring 2019)

computer science

- CSE 822 parallel processing computer systems (Fall 2018)
- CSE 891 deep learning (Fall 2017)

Field of Interest and the Role of Computational Science

a. In terms a general audience would understand, describe an important, outstanding scientific or engineering challenge in your field of interest where computational science can play an important role. (1/3) b. Describe the particular science or engineering problem that you would like to pursue in your research. What would be the impact on the field and/or on science, engineering and/or society in general if this challenge could be successfully addressed? (2/3)

(Max characters is 2250)

Deep learning (DL) has provided computational means to address difficult problems such as image classification and automated language translation. Unfortunately, the extensive technical expertise required to manually design DL architectures (the pattern of connectivity between artificial neurons) has bottlenecked rollout of DL. Researchers at Google and Sentient have successfully used algorithms inspired by biological evolution to automate DL architecture design, reporting state-of-the-art performance. Unfortunately, Google and Sentient also report requiring on the order of hundreds of GPUs to perform these experiments. Such a computational burden is currently extremely prohibitive.

Inspiration from biology might enable more efficient and effective evolution of DL architecture. The theory of neuronal group selection (NGS) posits that development generates an excess of neural subnetworks, of which only those that successfully integrate into overall brain functionality are retained. In DL models, node and connection removal techniques mirroring NGS have been used to shrink

parameter count by an entire order of magnitude without incurring accuracy loss. I will investigate how NGS-inspired pruning, which has not been incorporated in existing architecture-evolution work, might make DL architecture evolution more efficient. I hope that accessible, automated methods to design DL architectures will empower a much broader range of researchers and entrepreneurs - especially those without a formal background in computing - to leverage DL to make new discoveries and build new real-world products that, in the end, benefit everyone. Additionally, my experiments will help to characterize the theoretical relationship between developmental plasticity and evolution. In particular, I am interested in understanding how developmental plasticity, in this case NGS-inspired pruning, might enable irregular refinements that are otherwise inhibited by the constrains of indirect genetic encoding. Answering this question will help biologists better understand the evolutionary history of the development process in biology and help engineers better harness evolution-inspired approaches to solve real-world problems.

Use of Computational Science in your research

In the research problem described in question 1, part b: a. How will you use high performance computing with modeling and simulation and/or large data analysis? (1/3) b. How will you use mathematics? (1/3) c. How will you demonstrate the success of your approach? (1/3)

(Max characters is 2250)

Using the MSU High Performance Computing Center, I will conduct computational experiments to evolve HyperNEAT ANN architectures that learn to address a variant of the bit mirroring problem. To simulate NGS, during training an evolved criterion based on activation and loss gradient will make a pruning decision for each artificial neuron. I will parallelize replicate evolutionary runs and, within individual runs, fitness evaluation of candidate architectures. Because these parallelized computations are wholly independent, significant speedups can be readily achieved.

My key objectives are (1) to develop an effective implementation of NGS and (2) to understand how developmental plasticity (ie NGS) enables irregular refinement. These objectives will require mathematical tools to quantify aspects of ANN phenotypic structure relevant to function. Graph theory and multivariate statistics, which are used to interpret and compare connectivity and activity in neuroscience, will fill out my toolkit. In addition, simulation stochasticity necessitates general statistical methods for significance testing.

My experiments will consider several variants of the NGS algorithm (timing of pruning passes, pruning nodes vs connections). I will assess variant effectiveness through performance of evolved architectures at solving the bit-mirroring problem and variant efficiency through average network size during training. Greater

performance of NGS variants relative to control at low problem regularity would confirm that NGS enables irregular refinement. I will investigate the structural basis of such refinements by comparing graph theoretic metrics between NGS and control architectures.

To assess NGS as an applied machine learning technique, I will use CoDeepNEAT, a layer-based ANN encoding designed for DL, and benchmark datasets for computer vision (CIFAR) and language modeling (PTB). Through preexisting connections between my research group and Sentient Technologies, I will seek industrial collaboration to perform these larger GPU-intense experiments which will measure the effect of NGS on CoDeepNEAT benchmark performance and computational efficiency. I expect NGS efficiency and performance to meet or exceed state-of-the-art.

Program of Study

Describe how the courses listed in your planned program of study would help prepare you to address the challenges you have described in questions 1 and 2. Discuss your rationale for choosing these courses.

(Max characters is 2250)

My course of study will help me develop the technical skills I need to carry out my experiments. CSE 891 Deep Learning and CSE 848 Evolutionary Computation (EC) emphasize hands-on project work. From these courses, I learned the PyTorch DL framework and DEAP EC framework. These frameworks will allow me to build higher quality software for my experiments more quickly and in a manner that, eventually, will integrate more readily into real-world projects. Studying parallel computing–particularly, learning about performance profiling–will be key to writing efficient software that takes full advantage of the parallel processing power available through the MSU High Performance Computing Center.

My course of study will equip me to interpret my experiments, too. Coursework in graph theory (MTH 881) and applied multivariate statistics (STT 850) will help me select and understand the appropriate metrics to investigate how NGS algorithm affects network connectivity. Graph theoretic measures like connection density, in/outdegree, etc. in conjunction with multivariate statistical methods like discriminant, principal components, and cluster analyses are used to describe and compare connectivity in both biological and artificial neural networks. STT 850 will complement my previous statistical training in generalized linear model methodology through IBIO 851.

Finally, my course of study will help me bring biological inspiration and interpretation to my work. IBIO 832 surveys the evolutionary history of nervous systems. Learning how developmental processes interact with environmental

influences in nervous systems throughout natural history will help me ground my design and presentation of NGS-inspired algorithms in biological reality. IBIO 849 emphasizes class discussions of papers on foundational topics in the field of evolutionary biology. Discussing the model organisms, experimental designs, and ongoing debates that inform current thinking about the influence of plasticity on biological evolution will help me interpret and present my own work to a larger audience of evolutionary biologists in terms familiar–and of interest–to them.

Laboratory and Research Experience/Other Employment

Begin with current or most recent employment. Please include employer, dates employment started and ended, position, and nature of work.

Laboratory Experience example

Los Alamos National Laboratory, Summer 2016, Lab assistant, Research

Naval Research Laboratory, 5/2015–8/2015, Research Assistant, Immunosensor Research

Employment example

Michigan State University, Engineering Department, 12/2015 - 5/2016, Lab Technician, Research.

University of Pennsylvania, 5/2015 - 8/2016, Research Assistant, Developed stochastic models of neurons.

(Max characters is 4000)

Digital Evolution Laboratory at Michigan State university (Summer 2017 — present)

- Current projects include using autoencoder-based methods to automatically generate evolvable genetic encodings for evolutionary computing and developing a framework for experiments investigating fraternal major evolutionary transitions.
- Received additional fellowship funding for summer 2017 to continue undergraduate work with genetic regulatory network models investigating the relationship between plasticity and evolvability; presented findings at the 2018 BEACON Congress poster session.

Otis C. Chapman Honors Thesis at University of Puget Sound (Fall 2016, Spring 2017)

- Conducted a review of evolutionary computing literature and synthesize a theoretical analysis of evolvability in collaboration with advisor Dr. America Chambers and reader Dr. Adam Smith
- Performed computational experiments with Genetic Regulatory Network models to probe the relationship between phenotypic plasticity and evolvability.
- Prepared and delivered general-audience oral presentations at NW Honors Symposium and at the University of Puget Sound. Received Roderick MacArthur Award for an Outstanding Honors Thesis Presentation.

Mathematical Biosciences Institute (MBI) Research Experience for Undergraduates (Summer 2016)

- Designed and numerically evaluated an individual-based set of differential equations to model the foraging behavior of ants over uneven terrain, analyzed predictions of the model over various experimental conditions.
- Collaborated with advisors Dr. Jason Graham and Dr. Simon Garnier in the Swarm Lab at the New Jersey Institute of Technology to develop and execute project.
- Prepared and delivered oral and poster presentations at a capstone conference in Columbus, Ohio.
- Participated in seminars and workshops on mathematical biology coordinated by MBI at The Ohio State University.

NASA Undergraduate Research Scholarship at University of Puget Sound (Summer 2015)

- Designed, applied for grant funding, and carried out project to develop algorithms for automated extraction of mouse ultrasonic vocalizations from noisy recordings in collaboration with advisor Dr. Adam Smith.
- Developed and tested filtering algorithms inspired by the Sobel Edge detection method that, after being trained on human-annotated spectrograms of mouse vocalizations, distinguish between true mouse vocalization signals and background noise, achieving 75% accuracy at 25% recall.
- Presented results and methodology at a poster session on campus attended by faculty, summer research students, and other students.

US Department of Agriculture Horticultural Crops Research Unit (Jun. 2013 – Jun. 2017)

- As a Biological Science Aide, collected data for patent applications, performed plant propagation, and assisted with field maintenance.

Academic Awards and Honors

Include undergraduate and graduate honors (if applicable).

Academic Awards and Honors example

National Merit Scholar, 2014

Dean's List, U of Michigan, 2015, 2016, 2017

(Max characters is 4000)

Recipient of Blake and Mary Krueger University Distinguished Fellowship (institutional award; 0.2% acceptance rate; 2017)

Recipient of BEACON Science and Technology Center Top Up Fellowship (departmental award; 2017)

COMAP Mathematical Competition in Modeling Finalist (international award; 0.7% acceptance rate; 2017)

Recipient of National Science Foundation Graduate Research Fellowship Program Honorable Mention (national award; 2017)

Recipient of Edward Goman Outstanding Senior Award (departmental award, mathematics and computer science; 2017)

Recipient of Roderick MacArthur Award for an Outstanding Honors Thesis Presentation (departmental award; 2017)

Washington Consortium for the Liberal Arts College Essay Contest Campus Finalist (institutional award; 2017)

Recipient of Great Lakes National Scholarship Program Award (national scholarship in STEM; 2016-2017)

Recipient of James R. Slater Phi Beta Kappa Award (institutional award; 2016-2017)

Recipient of Puget Sound Association of Phi Beta Kappa Scholarship (regional essay competition; 2016-2017)

Recipient of Honors Alumni Scholarship (departmental award; 2015-2016, 2016-2017)

Recipient of Thomas and Hilda Jack (2014-2015), Sprenger (2015-2016, 2016-2017), and McKnight Memorial (2016-2017) Scholarships in chemistry (departmental awards)

Recipient of McGill Family (2015-2016), McKnight (2015-2016), and Thomas and Hilda Jack (2016-2017) Scholarships in mathematics (departmental awards)

Recipient of Beta Theta Pi Men of Principle Scholarship (institutional award; 2014-2015)

Recipient of University of Puget Sound Trustee Scholarship (institutional award; 2013-2017)

Dean's List (institutional award; Spring 2014-Present)

Member of Otis C. Chapman Honors Program (2013-Present)

Member Phi Beta Kappa, Pi Mu Epsilon, Phi Kappa Phi, Upsilon Pi Epsilon

Extracurricular Activities

Include technical societies and service organizations.

Extracurricular Activities example

Men's Fencing Captain, 2016

Volunteer for Habitat for Humanity

American Physical Society

(Max characters is 4000)

Macdonald Middle School, mathematics classroom assistant (2017-2018)

- Worked four hours weekly in a sixth grade geometry classroom and a seventh grade math intervention classroom.
- Worked one-on-one and with small groups of students outside of the classroom to help students keep up with class material or cover new topics.
- In the classroom, assisted students with questions and worked one-on-one to keep students engaged with class material.

Elementary Science Nights outreach at Marble, Whitlehills, and Glencairn Elementary Schools (2017-2018)

- Along with other NSF BEACON members, led hands-on activities to engage kids with key evolutionary ideas like natural selection and natural history.

COMAP Mathematical Contest in Modeling (2015, 2016, 2017)

- Collaborated in a small team of three students for four days to develop a mathematical model in response to a prompt.
- Communicated results in a journal-style paper describing our model and outlining recommendations to policy makers.
- In 2017, developed a model of vehicular traffic in the greater Seattle area to assess the impact of self-driving cars on commuter travel delays. Our model predicted that, in certain areas, designating lanes for exclusive use of autonomous would become advantageous once these vehicles constitute approximately 5% of traffic volume. Our team received a "Finalist" designation in the competition, ranking among the top 11 of 1,527 participating teams.

- In 2016, developed a model of satellite fragmentation events and the subsequent disbursement of debris in orbit to investigate the feasibility of quick-response efforts to neutralize debris generated by satellite explosions and collisions; our model suggested that, although technically feasible, such efforts would be economically impractical without a significant reduction in launch costs. Our team received received an "Honorable Mention" designation in the competition.
- In 2015, developed an epidemiological model to investigate the spread of Ebola virus disease and make recommendations on vaccine distribution; our model suggested that regional travel restrictions would not significantly curb the Ebola epidemic in West Africa and that efficient distribution of any vaccination should be prioritized over uniform or widespread distribution.

University of Puget Sound, computer science departmental mentoring program co-coordinator (2017)

- Recruited upperclassmen mentors to lead small groups of underclassmen in computer science activities.
- Planned and led social, brain teaser, and coding activities.
- Publicized program through classroom visits.

University of Puget Sound Center for Writing, Learning, & Teaching, Tutor and Academic Consultant (2015-2017)

- Helped mathematics students work through assignments, led study sessions to prepare students for examinations, and provided a safe and supportive environment to discuss frustrations and build self-confidence.
- Conducted academic advising appointments, working with students develop organization, communication, and time-management skills, particularly in the context of executive function or other impairments.
- Liaised with faculty members to discuss coursework and support students.
- Developed, led, and participated in professional development activities for student staff.

University of Puget Sound Access Services, access coach for Tuesday Night Tutoring (2016)

- Met with local middle and high school students for two hours weekly in an informal helproom setting on the University of Puget Sound campus.
- Tutored homework material, shared study skills, and worked to make higher education feel approachable by building relationships with students and discussing college life.

Oakland High School, volunteer (2016)

- Worked with Communities in Schools for two hours weekly at a credit-recovery-focused alternative high school in Tacoma, WA.
- Co-led an after-school Homework Club, aiming to help students complete assignments and feel more connected to the school.

- Served as a classroom assistant, answering student questions and keeping students engaged with class material.

Puget Sound Youth Wind Ensemble, coach (2015-2016)

- Played alongside local high school oboists in ensemble rehearsal for two hours weekly.
- Planned and led weekly sectional rehearsals, working to develop individual technique, section coordination, and social connections.

Programming Languages and programming models

List (four at most) the programming languages and programming models with which you have experience. Provide a sentence that describes how you use them. (Max characters is 200)

Example

Programming Languages: C++, Python, and MATLAB

Programming Models: CUDA, OpenMP, and OpenCL

Programming Language/model

Imperative, object-oriented, low level programming (C/C++/Java)

Description

I use this programming model to write performance-critical programs where greater manual control (e.g. memory management) is justified by a payoff for greater computational efficiency.

Programming Language/model

Functional Programming Techniques (Python, Scalable Concurrent Operations in Python)

Description

I use this approach to tackle problems composed of a large set of independent subtasks where a functional interface to parallelism (eg parallel map) provides significant speedup for negligible effort.

Programming Language/model

Deep learning framework (PyTorch)

Description

With this approach, I use reliable plug-and-play components to define sophisticated deep learning models and deploy these models to GPU hardware for compute-intensive training.

Programming Language/model

Numerical differential equation solvers (Matlab)

Description

I use this approach to harness sophisticated, pre-built numerical methods to approximate solutions to sets of differential equations.

Papers

Rex Cole, Valera Peremyslov, Savanah Van Why, Ibrahim Moussaoui, Ann Ketter, Rene Cool, Matthew Andres Moreno, Zuzana Velupkova, Valerian Dolja, and John E. Fowler. \textit{A Broadly-Conserved NERD Interacts With The Exocyst To Affect Root Growth And Cell Expansion.} Journal of Experimental Botany. Manuscript submitted for publication.

Talks

Matthew Moreno. Investigating the Relationship Between Plasticity and Evolvability in a Genetic Regulatory Network Model. Math/CS Day, University of Puget Sound. April 2017.

Jordan Fonseca, Jesse Jenks, and Matthew Moreno. MCM: Impact of Autonomous Vehicles on Seattle Traffic. Math/CS Day, University of Puget Sound. April 2017.

Matthew Moreno. COMAP Mathematical Competition in Modeling 2017. Spring Experiential Learning Symposium, University of Puget Sound. April 2017.

Matthew Moreno. Modeling the Collective Behavior of Ants on Uneven Terrain. Phi Sigma Undergraduate Research Symposium, University of Puget Sound. April 2017.

Matthew Moreno. Evolvability: What Is It and How Do We Get It?. Otis C. Chapman Honors Program Thesis Presentation, University of Puget Sound. March 2017.

Matthew Moreno. Modeling the Collective Behavior of Ants on Uneven Terrain. Joint Mathematics Meetings, Atlanta, GA. January 2017.

Matthew Moreno. Evolvability in Evolving Artificial Neural Networks. NW Honors Research Symposium, Seattle Pacific University. November 2016.

Matthew Moreno. Modeling the Collective Behavior of Ants on Uneven Terrain. Undergraduate Capstone Conference, Mathematical Biosciences Institute at The Ohio State University. August 2016.

Matthew Moreno and Becky Hanscam. Relieving the Space Jam: Assessment of a Quick-Response Satellite Mission to Neutralize Debris from Orbital Fragmentation Events. Math/CS Day, University of Puget Sound. April 2016.

Matthew Moreno. Mathematical Contest in Modeling: Eradicating Ebola. Math/CS Day, University of Puget Sound. May 2015.

Posters

Matthew Andres Moreno. \textit{Plasticity and Evolvability in a Genetic Regulatory Network Model}. BEACON Congress Poster Session, East Lansing, MI. August 2017.

Matthew Moreno. \textit{Evolvability and Plasticity in a Genetic Regulatory Network Model}. Math & Computer Science Department Seminar Series, University of Puget Sound. April 2017.

Matthew Moreno. \textit{Modeling Ant Foraging on Uneven Terrain}. Elements Science Magazine, University of Puget Sound. December 2016.

Matthew Moreno. \textit{Modeling the Collective Behavior of Ants on Uneven Terrain}. Fall Poster Symposium, University of Puget Sound. September 2016.

Matthew Moreno. \textit{Modeling the Collective Behavior of Ants on Uneven Terrain}. Undergraduate Capstone Conference Poster Session, Mathematical Biosciences Institute at The Ohio State University. August 2016.

Matthew Moreno. \textit{Automated Extraction of Mouse Vocalizations from Noisy Recordings}. Fall Poster Symposium, University of Puget Sound. September 2015.