# SuperUROP

Advanced Undergraduate
Research Opportunities Program

## 2023–2024 Research Guide

MIT

SuperUROP tackles the most pressing challenges facing our world today and sets the stage for our students to pursue careers in research, industry, and beyond. Through a meaningful research experience and opportunities for interdisciplinary exploration, SuperUROP helps to shape how our students see the role of research in addressing challenges, regardless of their pursuits: earning advanced degrees at major research universities, making an impact in industry, or applying the lessons of their creative research within early-stage startups. SuperUROP uncovers a host of exciting new directions and possibilities.

—Anantha P. Chandrakasan
Dean, MIT School of Engineering
Vannevar Bush Professor of Electrical Engineering and Computer Science


Photo credit: Jake Belcher

As head of the MIT Department of Electrical Engineering and Computer Science, I'm pleased to report on the continued success of the Advanced Undergraduate Research Opportunities Program, better known as SuperUROP.

Since its debut in EECS in 2012, SuperUROP has equipped over 1,200 undergraduates with the research tools they need to tackle real-world problems by giving them the chance to engage in yearlong supervised research projects and complete a seminar that exposes them to the essentials of research in a supportive and structured environment. They learn to choose and develop research topics, design experiments, collaborate, write technical papers, and present their work. They also study entrepreneurship, ethics in engineering, and other critical topics. Some publish their research results in respected journals or present them at important conferences. SuperUROP alumni continue to thrive long after their time in the program has ended. Many go on to earn advanced degrees at top research universities, win major scholarships and fellowships, work for industry-leading companies, or join exciting new entrepreneurial ventures.

Hosted by the School of Engineering and administered by EECS, SuperUROP is a collaborative effort involving many other departments, both within the School of Engineering and beyond. This collaboration helps bridge the gap between the sciences and humanities through innovative, creative interdisciplinary research.

This program relies on generous support from EECS, alumni, corporations, foundations, and friends, all of whom are committed to growing SuperUROP and enhancing the student experience at MIT.

Once again, I wish to acknowledge Anantha Chandrakasan, Dean of the School of Engineering and Vannevar Bush Professor of Electrical Engineering and Computer Science. As EECS Department Head, he pioneered and oversaw SuperUROP for its first several years, and he remains among the program's strongest champions. I also wish to acknowledge the contributions of over 350 SuperUROP faculty supervisors over the years.

In the long term, I look forward to seeing where these bright young researchers go in their careers. They have already chosen challenging and difficult questions; I believe the flexibility and creativity they have displayed will carry them far. I invite you to discover more about the impressive research projects highlighted both within these pages and at superurop.mit.edu.

Sincerely,

Asu Ozdaglar
EECS Department Head
Deputy Dean of Academics, MIT Schwarzman College of Computing
MathWorks Professor of EECS

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Photo credit: Jake Belcher

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Shruti Garg, photographed by Randall Garnick

# Scholars

## Anthony Baez

**MIT EECS | Takeda Undergraduate Research and Innovation Scholar**

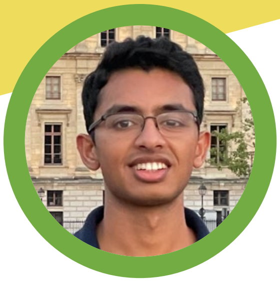
Enforcing Conservation Laws with a Projection Layer in a Physics-Informed Neural Network

***Supervisor: Luca Daniel***

Physics-informed neural networks (PINNs) are a powerful tool that can solve partial differential equations (PDEs) and effectively model complex physical systems from data while also being informed by physical laws. However, the solutions found by a PINN can violate conservation laws, which can prove to be unsafe if they are applied in a real-world setting. My research will investigate whether adding a projection layer that enforces a conservation invariant to the PINN will improve accuracy and conservation of some physical quantity.

> *I am participating in SuperUROP to learn how proper self-guided research is done. Over the past two summers, I have done ML and NLP research that have led me to seek a more formal and engaging research opportunity. I hope to continue to learn the skills that only come with doing real research in order to be more prepared if I decide to continue research and attend a graduate program.*


Max Burns, photographed by Randall Garnick



## Adithya Balachandran

**MIT EECS | Boeing Undergraduate Research and Innovation Scholar**
Swarm Algorithms for Dynamic Task Allocation in Unknown Environments
***Supervisor: Nancy A. Lynch***

Robot swarms, large groups of robots working together as a distributed system to reliably and efficiently accomplish tasks, have the potential to be uniquely useful in many areas such as natural disaster response, land mine detection, self-assembly, and inspection of spacecraft. These applications and others can be abstracted to the general problem of task allocation, in which tasks with possibly different demands are located across an environment, and robots must efficiently discover and assign themselves to these tasks. While several algorithms for task allocation have been proposed, most of them assume either prior knowledge of task locations or a fixed set of tasks at unknown locations. In this project, we wish to investigate dynamic task allocation strategies for robot swarms.

*Through this SuperUROP, I hope to gain experience in theoretical computer science research. I am interested in applying my knowledge from courses I have taken in algorithms and probability to develop and analyze distributed algorithms with several real-world applications.*

## Lasya Akila Balachandran

**MIT EECS | Advanced Micro Devices Undergraduate Research and Innovation Scholar**
Hardware Accelerator for Graph Machine Learning
***Supervisor: Arvind Mithal***

Graphs are increasingly being applied in machine learning for many domains, such as social network analysis, drug discovery, and financial fraud detection. The need to encode and find complex relationships within large datasets has led to the creation of specialized hardware to better support model-specific algorithm efficiency. However, current hardware accelerators for graph problems are often not scalable and tend to be optimized for a specific algorithm, such as graph random walks. By building on previous work related to a hardware and software co-design for a vector search algorithm, this project aims to design and implement an FPGA-based accelerator for a novel graph-based parallel vector search algorithm and extend the work to more general-purpose applicability.

*I am participating in SuperUROP because I am interested in gaining in-depth research experience related to high-performance computing architectures for artificial intelligence. I am looking forward to applying the skills I have learned through related coursework and prior research projects.*

# Eesha Banerjee

**Undergraduate Research and Innovation Scholar**

**Developing Machine-Learning-Based Preconditioners for Solving the Dirac Equation in Lattice Quantum Chromodynamic Theory**

***Supervisor: Phiala Shanahan***

To explore physics beyond the Standard Model and explain, for instance, the nature of dark matter, we need to probe the limits of our understanding of fundamental physics, which is based on quantum field theories such as quantum chromodynamics (QCD): high-precision and computationally expensive QCD calculations of physical observables are needed to provide predictions for experimental observations. Even lattice QCD calculations come with large computational costs. Dr. Shanahan's lab has made great strides using ML tools to tackle this problem, by using normalizing flows to more efficiently sample lattice quantum field distributions to generate field configurations (Abbott et al., 2022). Another computationally expensive side of the lattice QCD computational puzzle deals with calculations of physical observables over these configurations. My project uses neural-network-based preconditioners to increase the efficiency of these calculations by decreasing the iterations of the Dirac solvers.


**Photo credit: Jake Belcher**

## Franck Nongzanga Belemkoabga

**MIT EECS | Analog Devices Undergraduate Research and Innovation Scholar**

Next-Generation Electronic Nose

***Supervisor: Tomas A. Palacios***

Graphene has shown great promise as a biosensor for multiple chemical sensing applications. This project intends to build a robust electronic graphene-based sensing platform with at least 1000 sensing units with high-speed control electronics for accurate and efficient measurements. The platform enables real-time response for potassium, sodium, and calcium ions. With the help of machine learning inference, these measurements can be classified with the goal of monitoring human health and predicting certain types of diseases.

> *The SuperUROP is an incredible opportunity to help me go through the different steps of research from choosing a topic and presenting to writing a paper. This experience will help me develop valuable skills to become a better researcher and engineer.*

## Jean Ghislain Billa

**Undergraduate Research and Innovation Scholar**

Using User Modeling and Large Language Models for Critical Thinking Interventions

***Supervisor: Pattie Maes***

Large language models (LLMs), through AI agents, represent a great opportunity for modeling the priors that negatively impact humans' critical thinking and use this model to optimize the human-AI interaction loop. In this research project, we build upon the research on AI-enhanced reasoning by modeling a specific user's prior beliefs, facts, and behavioral trends and deduce how their personal heuristics negatively impact their critical thinking and decision-making. We aim to (1) test whether the AI system can accurately deduce information about these priors, (2) test if the AI system can accurately detect moments where the user might be vulnerable to these biases, and (3) test if awareness of these biases significantly impacts user decision-making processes.

> *This SuperUROP is an occasion for me to keep doing research in AI. My previous research experience both in UROPs and internships confirmed that I enjoyed the complexity and intricacies of research. I want to keep improving as a researcher, as I plan to pursue a career in AI research. I hope that my work this year will improve the understanding of the human-AI relationship and create more awareness about how AI can enhance the human experience.*

## Berkin Binbas

**MIT EECS | Analog Devices Undergraduate Research and Innovation Scholar**
Unraveling the Spectral Correlations for 2D Materials
***Supervisor: Jing Kong***

Photoluminescence is an essential property for optoelectronic and photonic applications. Notably, two-dimensional (2D) transitional metal dichalcogenides (TMDCs) exhibit intense and tunable PL as their thickness is reduced to monolayers. Among the prevalent characterization tools for 2D materials, Raman spectroscopy stands out as a fast and non-destructive technique capable of probing material crystallinities and perturbations such as doping and strain. The general aim of this project is to develop machine learning techniques that can learn about the structure of 2D materials from simpler spectroscopic experiments like Raman spectroscopy for tungsten diselenide (WSe2) and predict the results of more complicated experiments without having to perform them.

*This SuperUROP will help me explore the intersection of machine learning and physics. I have taken machine learning courses at MIT but haven't had the chance to apply them in a research project, and this field combined with the fundamental physics is pretty interesting to me. I also see this as an opportunity to decide where I would like to do my MEng, and whether I would like to pursue grad school in this field or not.*

## Max Joseph Burns

**MIT MechE | Undergraduate Research and Innovation Scholar**
Dynamic Gait Analysis with an Instrumented Walking Cane
***Supervisor: Neville Hogan***

Falls are a serious threat to the health and independence of older adults, and quantitative assessment of fall risk or standardized balance examinations are rare. In this project, we are using an instrumented walking cane to assess balance, by measuring the motion of the user's hand and the force they apply to the cane. We collected data from a cohort of people over 65, and are using these data to train regression models that predict the user's body sway. This device could provide a continuous, quantitative assessment of a patient's balance over long periods of time, informing physicians of changes in their patients' health and allowing them to prescribe interventions early.

*I am participating in the SuperUROP program because it will strengthen my capability as a researcher and provide invaluable project experience. I'm always learning new things about presenting my work and designing experiments, so I look forward to the guided format of the SuperUROP program. I am also excited to strengthen my communication skills and deepen my understanding of human balance by continuing to work with the MIT Newman Lab.*

## Cynthia X. Cao

**MIT AeroAstro | Undergraduate Research and Innovation Scholar**
Enabling Adaptive Depth-Sensing Capabilities on Energy-Constrained Robotics
***Supervisor: Sertac Karaman***

Power-constrained robots, either those with miniature form factors or long-duration requirements, spend a similar magnitude of energy on computational tasks as they spend actuating a movement, making traditional depth sensors such as LiDARS infeasible. As such, the first objective of my project is to enable perception on power-constrained robots in the LEAN Lab using a deep neural network (DNN) and single RGB camera; this entails producing depth images using the DNN and RGB images, estimating uncertainties of the DNN's predictions, and on-the-fly training of the DNN. The second phase will focus on adaptively adjusting the FPS at which an onboard sensing network runs, depending on the level of certainty regarding the environment, to conserve energy.

*Through this SuperUROP, I want to develop my research, communication, and writing skills, as well as experience what a more structured research process is like. Having done coursework as well as extracurriculars relating to robotics and controls, I'm excited to explore the field further in depth, especially with regards to path planning and energy efficiency, and contribute meaningfully to my group.*

## Benjamin Chen

**MIT EECS | Mason Undergraduate Research and Innovation Scholar**
Constructing Adversarial Datasets for Neural Network Training
***Supervisor: Aleksander Madry***

In computer vision, adversarial examples, images subtly altered to give an unexpected result when passed through a trained model, are a known phenomenon. However, they are often model-specific: they are usually created using information about a trained model, and thus an image that is adversarial for one trained model may not be adversarial for another. Our research aims to answer the question of whether it is possible to subtly alter a training dataset so that any model trained on it will exhibit some prespecified abnormal behavior on normal inputs.

*Through SuperUROP, I hope to improve my skills as a researcher, gain more experience conducting machine learning research, and work on an exciting problem. I've taken classes and have conducted research on machine learning in the past, and I hope to deepen my understanding of topics in the field through this project.*

## Jason Chen

**MIT MechE | Undergraduate Research and Innovation Scholar**
Modeling the Isentropic Compression of Non-Ideal Gas Mixtures
***Supervisor: John Lienhard***

Gas compression is commonly seen across multiple industries in the modern economy and has many applications like heat pumps and carbon capture. As industrial processes transition to electricity for power, gas compressors will play an increasingly important role as an energy storage source. Calculating this quantity requires accurate calculations of isentropic compressor work, which is straightforward for ideal gases, but more difficult to estimate for non-ideal gas mixtures. Many industrially relevant gas mixtures and process conditions do not follow the ideal gas assumption, so this project will develop a computational platform to efficiently calculate isentropic compression and expansion work using pressure-explicit cubic equations of state (EOSs) or multiparameter Helmholtz EOSs.

*By participating in SuperUROP, I'm hoping to gain insight into what it's like to complete the research process end-to-end, and explore more of my interest in computational work combining both my skills in mechanical engineering and computer science. I'm excited to learn more about how to model industrial processes, and hope to build a useful computational platform for others to use and contribute to further understanding of the field.*

## Sunmee Choi

**MIT EECS | Philips Undergraduate Research and Innovation Scholar**
Wireless Powering for Implantable Devices
***Supervisors: Anantha P. Chandrakasan & Giovanni Traverso***

Implantable sensor systems are used to report data collected within the human body to an external device. One of the major challenges with powering an implantable device is the dimensionality of the powering mechanism. Batteries are limited in capacity and take up significant volume, complicating delivery of the sensor into the body. With a wireless approach, only a certain range of frequencies can be used to ensure sufficient power delivery past the human skin within safe boundaries. For my project, I will be working on the simulation, prototyping, and iteration of a hardware system to wirelessly power, transmit, and receive data from an ingestible oxygen sensor. In addition to integrating the antenna network with the rest of the system, I will be optimizing the design to minimize losses.

*Through the SuperUROP program, I am looking to grow as a researcher through an intensive year-long research experience. Through transistor-based circuit courses, I have become interested in the design and applications of microelectronics, and I am excited by the interdisciplinary nature of medical devices. I am motivated by the idea of working on small devices that have the potential for tremendous impact on people's lives.*

## Sofie Chak-Riya Chung


**MIT EECS | Landsman Undergraduate Research and Innovation Scholar**


### Cue Production Profile


***Supervisor: Stefanie Shattuck-Hufnagel***


The surface articulation of an underlying phoneme commonly fluctuates depending on the context. For instance, the associated acoustic cues for a /t/ phoneme produced at the beginning of an utterance may be distinct from the acoustic cues of a /t/ phoneme that is preceded and followed by a vowel. Thus, for an individual speaker or speaker group, we can investigate what specific phonemic contexts result in the associated acoustic cues to be produced. An algorithm has been developed that matches a target phoneme to its corresponding acoustic cues. For a given database, we can recover all of the contexts in which a phoneme was produced and tabulate the various acoustic cue production patterns that arose. Lastly, we label these patterns by their speech production type (e.g., standard production, flapping, etc.) and produce an output in the form of a Cue Production Profile. As a result, this profile would allow for the association of a set of acoustic cues in specific phonemic contexts for an individual speaker or speaker group, such as speakers from a specific dialect region. The algorithm can also be expanded to include prosodic cues to account for how stress and intonation can affect phoneme production.

> *I am participating in this SuperUROP because I am eager to pursue research in an area that combines my two major interests–language and technology. I have been with the Speech Communication group for two years, so I am excited to continue working with them under this new research position. By the end of the program, I hope to publish a paper and present my results at a conference.*


**Photo credit: Jake Belcher**

## Bartlomiej Cieslar

**Undergraduate Research and Innovation Scholar**
**Sampling with Foresight for Task and Motion Planning**
***Supervisor: Tomas Lozano-Perez***

Integrated task and motion planning (TAMP) is an approach for solving robotics problems by conducting a two-level search over solutions, first over discrete actions and then over continuous commands to implement the robot movements. Recent approaches employ machine learning techniques to restrict the search space over continuous commands. Current methods do not account for future actions that the robot will need to execute to solve the overall task; for instance, if a robot is tasked with stacking books on a shelf, it would place the first books anywhere on the shelf and not consider leaving room for future books. My work will incorporate foresight into such learning-based methods to enable more efficient planning.

> *I am participating in the SuperUROP because I want to gain more experience in the research of robotics and machine learning. I have taken machine learning and robotics courses in the past and want to expand my experience in more cutting-edge technologies in those fields. I hope to publish a paper by the end of the SuperUROP, if I have meaningful results to display.*

## Thelonious Abraham Cooper

**The MIT Climate Grand Challenges Undergraduate Research and Innovation Scholar**
**Embedded-GPU Ensemble Approaches to Informative Estimation, Control, and Learning**
***Supervisor: Sai Ravela***

Our new approach to model-based estimation, control, and learning fuses ensemble simulations of state, parameter, and control input perturbations with the available measurements, labels, or performance variable precision to update parameters, states, inputs, and their uncertainties in an adjoint-free manner. Fully nonlinear black-box or gray-box models are admissible, and the quantified posterior uncertainties enable the maximization of information gain for efficient control, estimation, or learning. In this SuperUROP, we develop an embedded GPU-based solution for ensemble simulations for differential equations and apply the technique to real-time aircraft control. We anticipate that the computational core will support other applications in source localization and coordinated control.

> *I look forward to participating in SuperUROP because I have enjoyed my work thus far with ESSG on related projects. I am interested in signal processing and control, and the knowledge I will gain through this program will be invaluable to my continuing education in these areas. As a career, I would like to participate in industrial R&D and getting training in scientific communication through SuperUROP will help me thrive in such environments.*

## Omar Dahleh

**MIT Tang Family FinTech Undergraduate Research and Innovation Scholar**

**PrivateNLG: A System for Synthetic Data Generation for Mixed Data Types**

***Supervisor: Lalana Kagal***

In a world of increasingly ubiquitous machine learning tools and in particular large language models, the question of privacy in LLMs has become pressing and prevalent. Large language models are predicated on the usage of large swaths of training data. Privacy attacks that leak units of data, which are often private and confidential, have been more common in the advent of publicly available LLM tools such as ChatGPT and others. My research, a collaboration with Liberty Mutual Insurance, on their claims dataset, introduces a system for synthetic data generation for structured (tabular) and unstructured (free text) data that achieves both a high level of privacy and immunity to attacks, while maintaining the original attributes that make the data effective for generating LLMs.

## Gaurab Das

**MIT Tang Family FinTech Undergraduate Research and Innovation Scholar**

**Lightweight Cryptography for Energy-Efficient and Secure Deep Neural Network Accelerators**

***Supervisor: Anantha P. Chandrakasan***

Deep neural networks (DNNs) are increasingly deployed in security-critical embedded applications, such as autonomous driving and biometric authentication. However, security and privacy of those applications can be undermined by several attacks targeting hardware-level vulnerabilities. This motivates the need to encrypt the values stored in the chip, so that only the person with the right key will be able to access it, thus protecting the data stored in the memory of the chip (say parameters of the DNN like the weights and biases) from outside attackers.

Lightweight cryptographic (LWC) methods are of special interest because of low power consumption, and this project aims to implement and compare such methods to ensure that data remains secure within the chip in an efficient manner.

> *I am participating in this SuperUROP because I have always been fascinated by computer architecture, machine learning, and cryptography. While I had experience in these fields independently through classes or research, this is an opportunity to combine all of these seemingly interdisciplinary fields in an effort to develop energy-efficient accelerators. I am excited to learn more about ML accelerators and lightweight cryptography!*

# Joy Domingo-Kameenui

**MIT CEE | Undergraduate Research and Innovation Scholar**

Carbon Fluxes from Hydrologically Disturbed Peatlands

***Supervisor: Cesar Terrer***

Soil represents the largest terrestrial organic carbon pool, with a significant amount of carbon stored in peatlands. Peatlands, which are naturally waterlogged, can undergo various human- and climate-induced hydrological changes, from drainage for agriculture to seasonal drought. These can change water table levels, which can lead to significant carbon emissions through peat oxidation and wildfires. This project seeks to synthesize evidence for the relationship between water table depths and carbon emissions in boreal, temperate, and tropical peatlands. Our findings aim to inform improved peatland management techniques that minimize carbon losses.

*Ever since high school, I have been fascinated by soil science research. I believe this SuperUROP is the perfect opportunity for me to get experience in soil science research at MIT. I also like that this SuperUROP applies computer science and data analysis.*

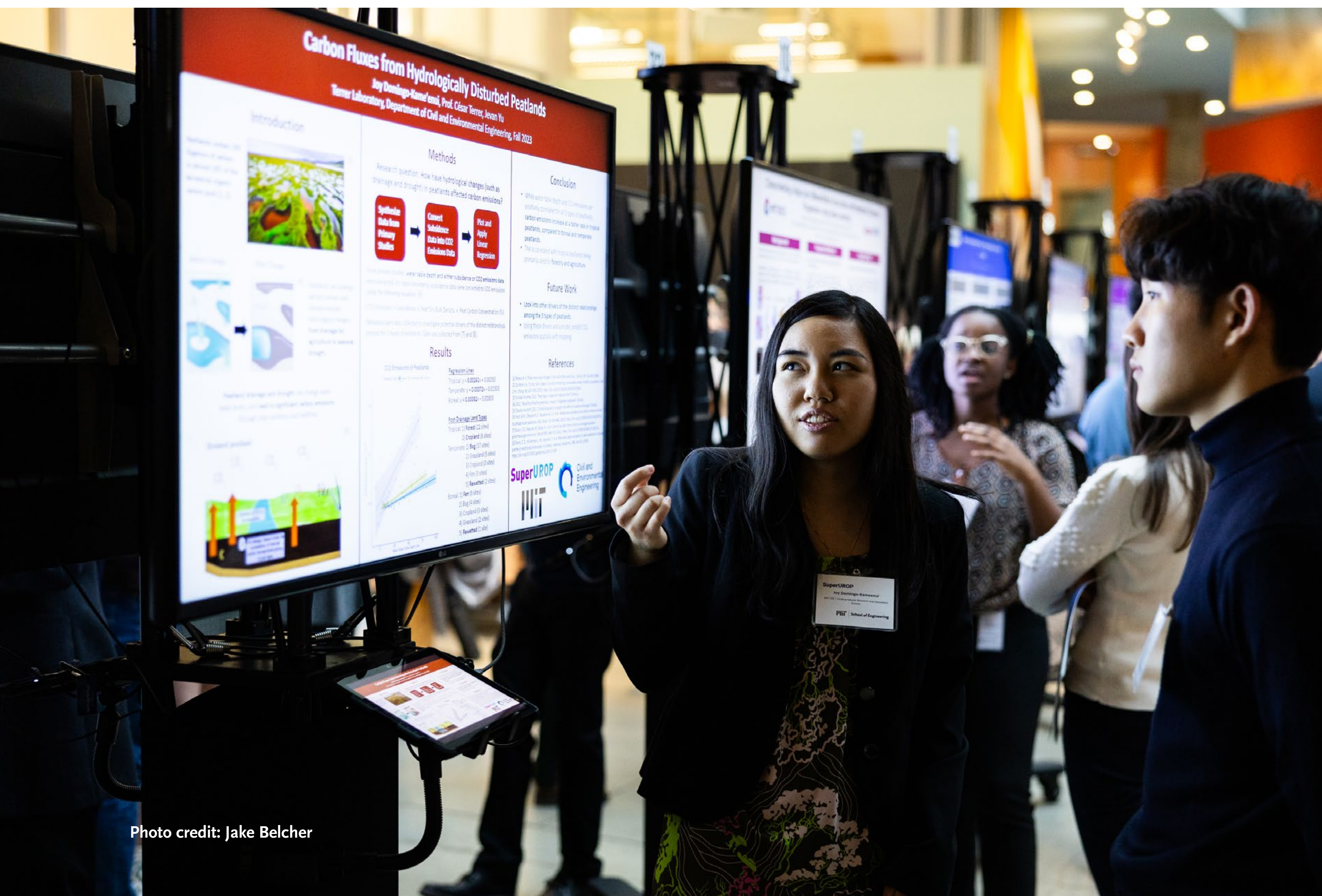



Photo credit: Jake Belcher

# Anna Duncan

**MIT MechE | Undergraduate Research and Innovation Scholar**

MIT HAUS Recycled Plastic Processing and Quality Improvement

***Supervisor: David Hardt***

Current large-scale additive manufacturing printers use pellets as their stock. Most printers use virgin plastic pellets but the MIT HAUS research group has proven that r-PET plastic pellets are just as mechanically viable for extrusion. R-PET pellets are made from re-extruded flakes of recycled plastic; this re-extrusion degrades the plastic material and decreases the mechanical properties of the plastic. The goal of this research is to test if flakes, and furthermore contaminated flakes, are a viable alternative for extruding recycled plastic. Flakes take less energy to create and have not undergone the degradation of re-extrusion, which makes them an attractive sustainable alternative to pellets. The flakes that will be tested are r-PET shards and strips of clean sorted PET plastic. The flakes are between 3mm and 10mm in size and vary in shape. The flakes for this round of testing are of high quality, and have gone through a rigorous sorting, washing, and shredding process that is both time and energy consuming. The flakes extrusion testing will be done by feeding them into the BAAM printer at Bates Laboratory and closely monitoring the extrusion output as well as testing several output strips for their mechanical properties compared to strips made by pellets. If it is proven that flakes are capable of being extruded on a large-scale printer called the BAAM then the focus will shift to using "dirty plastic." These plastic flakes will be contaminated with labels, granules of other types of plastic, bio-waste materials, and more. The goal of this research is to test if the recycling process for our r-PET stock needs to be as intensive. The contaminated flakes will be tested in a similar manner to the clean flakes but the testing will be done on a small-scale lab extruder and not the BAAM. It would greatly reduce cost and waste if it is discovered that the BAAM is capable of printing viable plastic structures using nothing but ground up dirty trash that can be found anywhere in the world.

> *I am joining SuperUROP to do meaningful research and to really dive into the work I have begun in my first two years at MIT. I truly believe in the mission of the MIT HAUS group and I would like to do my part in advancing their work. I hope to learn more about why we recycle plastics the way we do and if this process can be changed to be far more sustainable and economical.*

# Heidi Alba Durresi

**MIT EECS | Philips Undergraduate Research and Innovation Scholar**

Correlating Structure and Function in Neural Tissue

***Supervisor: Nir N. Shavit***

This project will investigate the existence and role of synchrony in the firing patterns of neurons presynaptic to the same neuron in biological neural networks. We have noticed such an effect of synchrony in the MICrONS Consortium's mouse visual cortex connectomics dataset, which contains both anatomical and functional data of tens of thousands of neurons. The first phase of the project involves further analysis of the functional data, and accounting for different factors that could affect synchrony, such as distance between neurons and different cell types. The second phase of the project involves modeling the system as an artificial spiking neural network, in order to provide insights on the possible effects of synchrony on the network, such as an increase in efficiency or robustness.

*I am participating in SuperUROP because I am excited to combine my interest in neuroscience with my computer science background and apply it to a long-term research project. I am also very excited to generally learn more about the research process, and hopefully get interesting results from my research.*

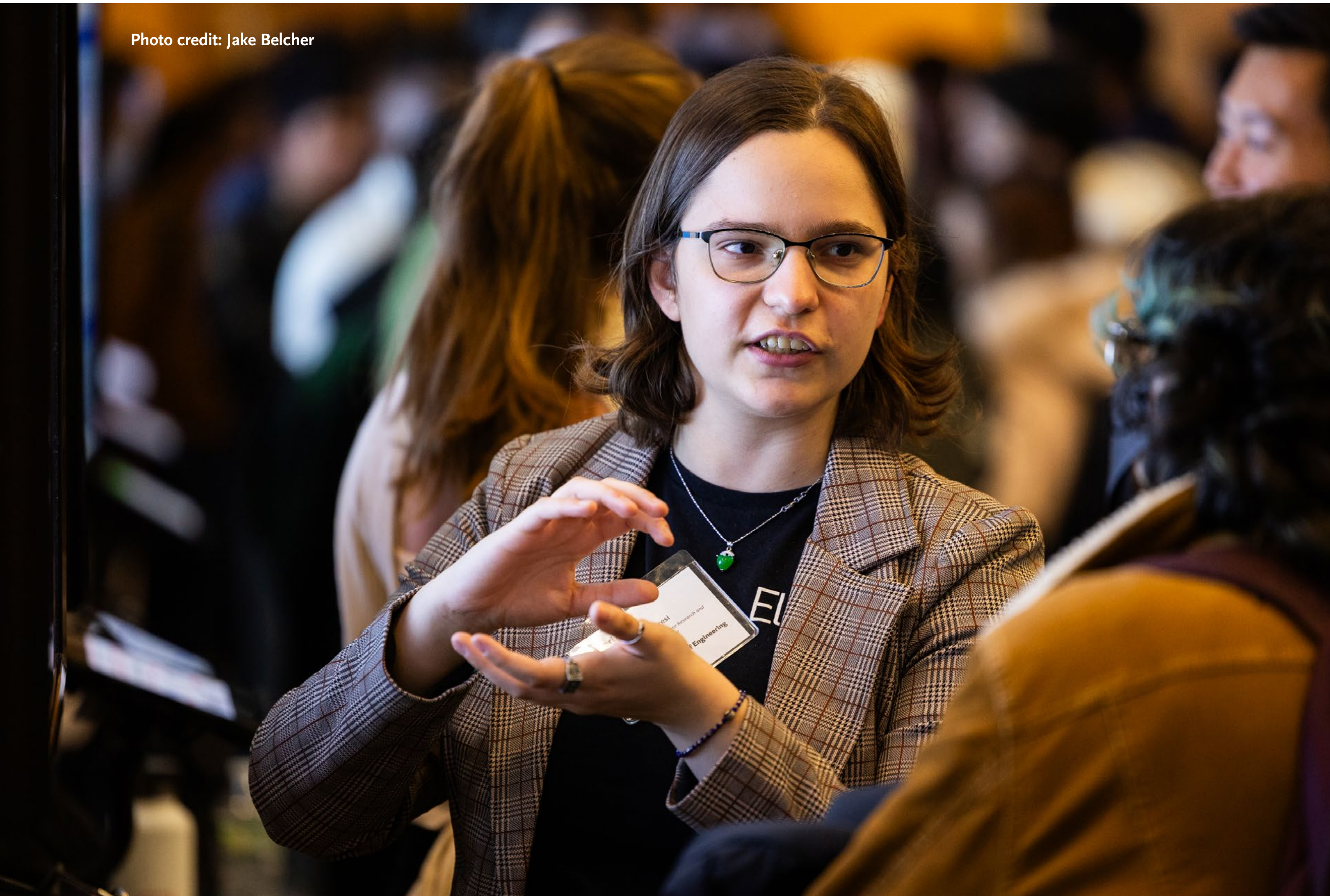


**Photo credit: Jake Belcher**

## Deniz Irem Erus

**MIT EECS | Analog Devices Undergraduate Research and Innovation Scholar**

Thermal Management in Advanced Semiconductor Devices

***Supervisor: Tomas A. Palacios***

Gallium Nitride (GaN) high-electron-mobility transistors (HEMTs) are a key element for the next generation of high-power and high-frequency electronics. However, the large power density in these devices induces harsh and localized self-heating in their conducting channel, which reduces device reliability. This self-heating is more pronounced in GaN-on-Silicon and GaN-on-SOI transistors. Even though these substrates enable wafer scaling, they have lower thermal conductivity than commonly used silicon carbide (SiC), making thermal management harder. This project focuses on researching thermal management in advanced semiconductor devices to find methods that decrease the peak channel temperature of GaN-on-Silicon and GaN-on-SOI HEMTs to that of GaN-on-SiC HEMTs.

*I am participating in SuperUROP because I want to gain more experience in advanced semiconductor devices. I have taken nanoelectronics classes and enjoyed learning about the interaction between semiconductor physics and electronic devices. I want to use that knowledge on a long-term research project. I am excited to apply my knowledge and interests to this project.*

## Eyan Forsythe

**MIT EECS | Analog Devices Undergraduate Research and Innovation Scholar**

Accuracy of Analog Neural Network Accelerators

***Supervisor: Joel Emer***

Deep neural networks are invaluable for the modeling and statistical inference of complex systems, but are often infeasible due to the prohibitive computational costs of matrix multiplication. Analog neural network accelerators have emerged as a strategy to reduce the computational requirements for these operations, but these accelerators trade off accuracy in the process. This project aims to quantify the accuracy lost from using analog accelerators to compute the output of deep neural networks. This project will evaluate how different accelerator architectures and multiplication techniques affect the accuracy of various neural networks. The goal of the project is to provide quantitative data that can inform the development of future analog accelerators.

*Through participating in SuperUROP, I would like to gain research experience beyond what a normal UROP can provide. I have taken courses on computer architecture, circuits, and machine learning, and I am interested in using low-level circuit elements to solve computational problems. I hope that this project will allow me to become more involved in research related to these interests.*

# Angela Gao

**Undergraduate Research and Innovation Scholar**

**Structure of the LINE1-ORF1-RNA Complex**

***Supervisor: Seychelle Vos***

The LINE-1 (L1) retrotransposon is a mobile genetic element that constitutes an estimated 17% of the human genome—significantly greater than the portion of the genome that is composed of protein coding genes. While the majority of L1s are inactive due to truncations or other mutations, a few retain their ability to propagate and insert into new regions of the genome via a "copy-and-paste" mechanism. This occurs through the activity of just two proteins, ORF1 and ORF2. ORF1 is an RNA-binding protein encoded by the L1 element that plays an essential but unknown role in L1 retrotransposition. This project will use cryo-electron microscopy and nucleic acid binding assays to characterize the function of ORF1. We will further investigate the interaction of ORF1 with Alu elements, a related transposable element that mobilizes by parasitizing L1 proteins. This work may inform preventative treatments for diseases linked to L1 retrotransposition.

*Having worked on this project throughout my time at MIT, I am excited by the opportunity to cumulate and present my research through the SuperUROP program. I'm interested in structural biology because of its ability to inform mechanistic details of biological processes, and I hope to use these tools to investigate transposon-driven diseases. I look forward to having the time and flexibility to dive deeper into my research this semester.*


Photo credit: Jake Belcher

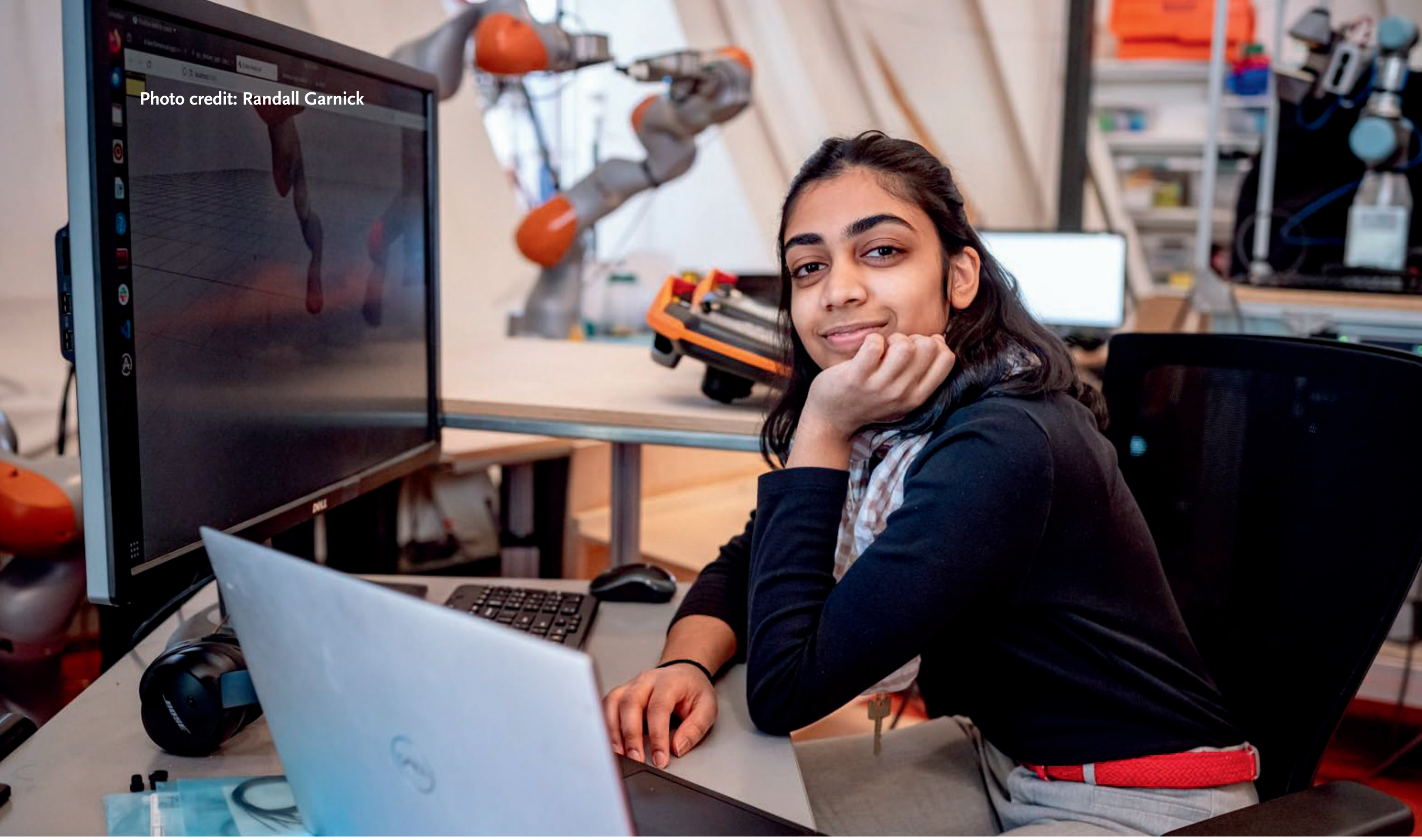


Photo credit: Randall Garnick

## Shruti Garg

**MIT EECS | Lincoln Laboratory Undergraduate Research and Innovation Scholar**

**Motion Planning for Bimanual Manipulation Using GCS**

***Supervisor: Russell L. Tedrake***

Bimanual robots often need to move both arms in conjunction. Planning for such motion deals with non-convex landscapes because of the nonlinear equality constraints between the end effectors. Trajectory optimizers are finicky with such constraints, needing good initializations for feasible solutions. Also, the valid configuration space is a measure-zero set, forcing sampling-based methods to rely on approximations or projections. A newer approach decomposes the planning space into convex sets. First we decide on a higher level the sequence of sets to move through. Then we find trajectories through each set, using convex optimization to guarantee a collision-free path if it exists. Working off this approach, my research will start with investigating approaches for optimizing over more complex objectives while maintaining feasibility guarantees. Ultimately, I aim to improve how we plan and execute motion in bimanual robots.

*I am very excited about working with the Robot Locomotion Group on research in a field of robotics I have only really taken (and enjoyed!) classes in before. Throughout the year, I hope to hone essential research and communication skills in the structured environment of SuperUROP and make publishable progress on my project. I am also looking to get a more structured introduction to what doing research means and how to approach it as I consider whether I want to work toward going to graduate school in the future.*

# Zoe Anne Gotthold

**Undergraduate Research and Innovation Scholar**

**Machine Learning Can Predict Translation Efficiency in Toxoplasma Gondii**

***Supervisor: Sebastian Lourido***

Toxoplasma gondii is a ubiquitous parasite among warm-blooded animals that can cause both acute and chronic infections (toxoplasmosis). Symptoms can be particularly severe in immunocompromised individuals. After an acute infection, Toxoplasma can differentiate into long-lasting stages known as bradyzoites. Previous research has noted the importance of translational regulation in this Toxoplasma life cycle: in particular, BFD1, the master regulator of Toxoplasma differentiation, is translationally, rather than transcriptionally, controlled.

Our research focuses on understanding translational control in Toxoplasma through the creation of machine learning models. Using ribosome profiling, we analyzed the specific RNAs bound by ribosomes, known as ribosome footprints. Normalizing the number of ribosome footprints to the total number of mRNAs provides a quantitative measure of translation efficiency for each gene. Using a random-forest model trained on several parameters, including coding sequence length, upstream start codon data, GC content, and UTR lengths, we were able to generate a model of translation efficiency (on unseen data, $R2 = 0.42$, Pearson's correlation = 0.65). Interestingly, this model is much less predictive in human data sets ($R2 = 0.21$) since a model trained on human fibroblasts places higher importance on GC content and 5′ UTR length than the Toxoplasma model. This could indicate the unique role of the 5′ UTRs in Toxoplasma, where specific UTR features might matter more than 5′ UTR length.

We also trained several more unsupervised machine learning models on only the sequences of Toxoplasma transcripts. Classifying each gene as "high" or "low" in terms of translation efficiency, we were able to train an effective LSTM (long short-term memory) network on sequence and length data alone (AUC = 0.76). These models will allow us to better understand the translational level of genetic regulation, a regulation that seems to be critical for parasite persistence in the host.

*I took SuperUROP because I am looking to develop my computational skills. As someone who plans to study infectious diseases, I believe that it is important to learn how we can use computational power to enhance research. We are in an evolutionary arms race with pathogens, and one tool we have that they do not is the ability to code: we should use it!*


Photo credit: Jake Belcher

## Michael Dimitrov Hadjiivanov

**MIT Tang Family FinTech Undergraduate Research and Innovation Scholar**

Graph Machine Learning for Financial Security

***Supervisor: Arvind Mithal***

This research is focused on developing techniques for subgraph representation learning. This task was prompted by a large financial dataset provided by an industry partner for the purpose of detecting illicit behavior in transaction networks. This is a challenging problem since it requires multitudes of relationships inside and outside the subgraph to be captured in a single vector. This research aims to build a model that is able to achieve state-of-the-art performance on subgraph representation tasks, and more specifically, is able to perform well on the financial dataset. Model development is currently based on a pre-train then prompt framework, and the bulk of the research will be focused on developing specific subgraph prompting methods, which have yet to be explored in the community.

> *I am participating in the SuperUROP program to better prepare myself for graduate school. I have done UROPs in the past, but often felt that I needed a stronger commitment to produce meaningful results. I hope to contribute significantly to the field of graph learning, and in that pursuit, become a better researcher and hacker. What excites me most about my project is its potential to be implemented in real-life financial security systems.*

## Kaivalya Hariharan

**MIT Tang Family FinTech Undergraduate Research and Innovation Scholar**
Investigating Internal Signatures of Neural Network Failure Modes
***Supervisor: Nir N. Shavit***

Neural nets are often easy to trick, whether through restricted perturbations of the input (Lp Adversarial Examples), or through prompt injections (LLM jailbreaks). These failures are often studied while treating models as a black boxes; this has yielded some results, but we remain far from using these insights to build robust models. Instead, we study neural network failures by investigating model internal computation. By using mechanistic interpretability techniques (e.g., path patching, dictionary learning) and examining model internal statistics, we aim to produce theories of neural network failures that are grounded in phenomena that can be observed in the internal computations of DNNs. We hope that such theories can inspire novel approaches for building robust models.

*Through this SuperUROP, I want to gain experience understanding neural network failures by opening up model black boxes and studying their internals. I am looking forward to applying both my prior experience researching adversarial examples in CNNs, and my math background to this project. I am most excited about treating studying deep learning as a systematic science, and figuring out the techniques best suited for understanding these models.*

## Preston Hess

**MIT EECS | Philips Undergraduate Research and Innovation Scholar**
Modeling Auditory Attention with Machine Learning
***Supervisor: Josh McDermott***

Attentional selection allows humans to recognize communication signals amid concurrent sound sources (the cocktail party problem). Although attentional abilities have been characterized to some extent in humans, we lack quantitative models that can account for attention-mediated behavior, explain the conditions in which attentional selection should succeed or fail, and reveal how attention should influence neural representations to enable selective listening. Inspired by neurophysiological observations of attention, we will develop a model of auditory attention by equipping a neural network with stimulus-dependent gains. We will optimize the model to perform a recognition task on spatialized audio signals, reporting the words or the location of a cued talker in a multi-source mixture.

*I will use my time in the SuperUROP program to dive more deeply into the research that I have pursued at MIT. I hope to use the time in the program to prepare myself for graduate school through presentations, posters, and hopefully a publication at the end of my time. The project will allow me to expand my understanding of both cognitive and computer science as I apply for programs in their intersection.*

## Giorgos Iacovides

**Undergraduate Research and Innovation Scholar**

Ensemble Machine Learning for Optimized Electric Vehicle Charging Under User Behaviour Uncertainty

***Supervisor: Mardavij Roozbehani***

My project focuses on managing the electricity demand from a highly concentrated number of Electric Vehicles (EVs), in order to reduce the stress on electricity distribution networks. The first phase involves developing a number of statistical and deep learning models to estimate the charging parameters of EV owners using limited information such as past arrival time and consumption patterns. Ensemble methods will then be applied to obtain better predictive performance. In the second phase, we will build on the existing predictive models by developing pricing and incentive algorithms to shape the aggregate response from the fleet of EVs, to reduce the stress on the grid and maximize consumer welfare.

*I am participating in SuperUROP because I am very interested in applying my machine learning and reinforcement learning knowledge (from 6.3900 and 6.7940 respectively) and mathematical background to a longer-term research project. I am excited to expand my knowledge and skills in these areas through a project with real-life practical applications. I hope to have meaningful results to display by the end of the SuperUROP and publish a paper.*

## Aaron Alvarado Kristanto Julistiono

**MIT Tang Family FinTech Undergraduate Research and Innovation Scholar**

Optimization Path for Stochastic Mirror Descent on Attention Mechanisms

***Supervisor: Navid Azizan***

Deep learning models have enjoyed enormous success in many tasks, such as natural language processing and computer vision, among others. While deep learning has demonstrably enabled breakthroughs in a wide variety of tasks, we often cannot easily understand what the model is truly learning. To alleviate that, this project investigates how the weight parameters of a deep learning model change throughout training, and by doing so we can show what the model actually learns. Specifically, we investigate the Mirror Descent algorithm, which is an important generalization of the well-known Gradient Descent algorithm, along with the attention model, which has opened up a world of possibilities in many areas of machine learning.

*I am currently a junior in the Computer Science and Engineering (6-3) major and the Mathematics (18) major of MIT. I am excited to continue this project and make it into a SuperUROP with the goal of preparing myself for a PhD. Using the knowledge I gained in the classroom, such as machine learning, statistics, and algorithms, I hope to successfully complete this SuperUROP by the end of the year.*

## Amirabbas Kazeminia

**Eric and Wendy Schmidt Center Funded Research and Innovation Scholar**
**Exploring Target-Based Antibiotic Discovery Using Deep Learning**
***Supervisor: Caroline Uhler***

Deep learning is becoming prominent in the realm of drug discovery. However, even though there is a significantly large, diverse dataset of protein binding, the models trained on these datasets tend to lack generalization. We expect that when a model is trained on a dataset that has different types of proteins and ligands, it should be able to generalize better. One goal of this project is to study this problem and discover a solution to tackle this.

*Through this SuperUROP, I want to strengthen my research skills, expand my knowledge in the application of AI in medical science, and prepare myself for PhD programs.*

## Dong Young Kim

**MIT EECS | Landsman Undergraduate Research and Innovation Scholar**
**Fairness in Computer Vision: Concept Bottleneck Model**
***Supervisor: Lalana Kagal***

Image classification models using computer vision techniques have seen tremendous expansion in the past few decades. Many of these models, however, have been shown to produce biased results. For example, COMPAS, which predicts criminals' likelihood of reoffending, has produced racially biased results. In our project, I will focus on the fairness aspect of biases and aim to develop a tool to improve fairness in the image classification domain. I hope to achieve this by using the Concept Bottleneck Model (CBM), under which each image first gets mapped into higher-level concepts (binary per concept) and then used as input for classification. With the recent development of tools like CLIP, the process of mapping images to concepts could be a more scalable and accurate process than before.

*Knowledge with no application will disappear; work with no impact has limited meaning. I decided to participate in SuperUROP this year because I wanted to apply my skills and knowledge to produce tangible results. Moreover, I am extremely excited as my research will be at the intersection of technology and ethics. I hope to publish a paper by the end of the year and further the current understanding of this field by an inch and a half.*

## Song Eun Kim

**MIT EECS | Analog Devices Undergraduate Research and Innovation Scholar**
Using E(3)-Equivariant Features for Autoregressive Transition Metal Complex Generation
***Supervisor: Tess Smidt***

Molecular generative models can help navigate the enormous space of chemical compounds for applications in medicine, energy storage, and industrial catalysis. We develop an E(3)-equivariant autoregressive model to generate transition metal complexes, aiming to predict the ligand positions for a given central metal atom. Euclidean symmetry-equivariant neural networks (E(3)NNs) like this one are particularly well suited to handling the data types used to describe atomic structures because they account for the Euclidean symmetries found in 3D space: 3D rotation, translation, and inversion. This is part of our ongoing project to predict metal-organic chalcogenide assemblies (MOChAs), crystals containing low-dimensional transition metal chalcogenide structures scaffolded by organic ligands.

*The intersection of machine learning and physics is fascinating to me, and I look forward to more deeply exploring this area in general, and molecular generative models in particular, over the course of this SuperUROP. As part of Prof. Smidt's group, I have had the opportunity to make progress on a generative model for small molecules, and I am excited to continue developing this model for more targeted forms of material design.*

## Lisa Kondrich

**MIT EECS | Lincoln Laboratory Undergraduate Research and Innovation Scholar**
Autonomous Sea Turtle Robot
***Supervisor: Daniela L. Rus***

As a part of developing unobtrusive wildlife observation, this project aims to deploy an autonomous sea turtle robot to study the behaviors of sea turtles in the wild. My role in this project focuses on developing the software needed to allow the robot to detect and track other turtles. Using custom turtle datasets I compile, I will fine-tune and compress turtle detection machine learning models that run efficiently on the Raspberry Pi that controls the robot. Further development will include adding machine-learning-assisted depth perception to determine the robot's distance from the turtle it is tracking, to allow the robot to follow and continue observing the targeted turtle.

*Through this SuperUROP, I hope to learn a lot about robotics by fully immersing myself in the process of creating a robot by directly working on computer vision software and learning how to apply machine learning to a real-world scenario. I also hope to gain more insight into what being a researcher is like, and work on a paper to publish my results.*

## Audrey Lee

**MIT EECS | Nadar Foundation Undergraduate Research and Innovation Scholar**

Fast Path Planning Through Collision-Free Convex Polytopes

***Supervisor: Russell L. Tedrake***

Collision-avoidance algorithms are crucial for safe, reliable motion planning. Although most existing algorithms require considerable computation time to randomly generate and verify potential paths, my project will focus on a newly developed and optimized real-time method that generates known collision-free regions and achieves collision avoidance by finding paths only within these "safe" regions. Until now, this method has relied on axis-aligned bounding boxes as the safe regions in order to take advantage of their simple geometric constraints for faster computation. Our research will evaluate the time efficiency of expanding this method to work with more general convex polytopes, which would enable it to be used in a greater variety of environments as well as in the configuration space.

*I have really enjoyed the constant learning and discovery that has come with doing UROPs in the past, so I am excited to add to those experiences with the structure and mentorship of the SuperUROP program. I look forward to exploring a different facet of robotics research with the Robot Locomotion Group and hope to gain both publishable results and a more complete understanding of the academic research cycle.*

## Daniel Anda Li

**MIT Tang Family FinTech Undergraduate Research and Innovation Scholar**

Large-Scale Dynamic Program Analysis Using Machine Learning

***Supervisor: Armando Solar-Lezama***

This project focuses on predicting part of the behavior of a computer program without having to run the program. Most of the previous works in this area involve analyzing code statically by using a model trained on a dataset of code without a lot of runtime information, while this project aims to perform dynamic analysis on large-scale real-world programs on the web. I will use a dataset that involves dynamic runtime data of JavaScript programs used on real websites. I will make a machine learning model trained on the dataset to perform the task. The model will take code as input and generate an output used for a query and an output used as context for other lines of code. The query part of the model will take as input the previous output and a query and output a yes/no answer.

*I am participating in SuperUROP to get research experience in computer science and machine learning. I have taken machine learning courses and worked on a UROP involving machine learning. I hope to publish a paper and get additional research experience by the end of this SuperUROP.*

## Zhening Li

**MIT EECS | CS+HASS Undergraduate Research and Innovation Scholar**

When Do Skills Help Reinforcement Learning? A Theoretical Analysis of Temporal Abstractions

***Supervisor: Armando Solar-Lezama***

Skills are temporal abstractions that intend to improve reinforcement learning (RL) performance through hierarchical RL. Despite our intuition about the properties of an environment that make skills useful, a precise characterization has been absent. We provide the first such characterization, focusing on the utility of deterministic skills in deterministic sparse-reward environments with finite action spaces. We show theoretically and empirically that RL performance gain from skills is worse in environments where solutions to states are less compressible. Other theoretical results suggest that skills benefit exploration more than they benefit learning from existing experience, and that using unexpressive skills such as macroactions may worsen RL performance. We hope our findings can guide research on automatic skill discovery and help RL practitioners better decide when and how to use skills.

*My previous UROP projects helped me discover my research interests in AI for science and neurosymbolic learning. Since these projects focused on experimental evaluation of ML models and algorithms, I wanted to explore ML theory through the SuperUROP program. One of my previous UROP projects studied symbolic RL skills for neurosymbolic reasoning, which was the inspiration for my SuperUROP project on theoretically characterizing the utility of skills for RL.*

## Yong Yan (Crystal) Liang

**MIT EECS | Nadar Foundation Undergraduate Research and Innovation Scholar**

Programmable Smart Devices for Gastrointestinal Steering and Health Monitoring

***Supervisors: Joel Voldman & Giovanni Traverso***

The focus of this project is to design a steering system with low driving voltage (< 2.5V), medium actuation frequency (< 2Hz), and miniaturized space requirement (diameter < 500 um) that enables effective energy saving with ideal controllability for an intravascular steering and drug delivery device. This will provide an unprecedented solution for a miniaturized, controllable steering and drug delivery system that will have huge translational impacts on therapies for Parkinson's disease and Crohn's disease. I will be assisting in the design and fabrication of the PCB and mechanical parts of the proposed gastrointestinal steering and monitoring device that will help ensure that the medicine needed for the patient gets delivered properly.

*Through my SuperUROP project, I aim to gain more experience working with medical devices in diagnosing and treating diseases. I hope to apply my skills in PCB and bio-mechanical design from 6.9000 and 6.4840. I have always been passionate about the BioEECS field, especially artificial organs and related mechanical systems in healthcare. I am super excited to pursue this research opportunity and will strive to publish a paper at the end of it.*

# Elaine Liu

**MIT EECS | Lincoln Laboratory Undergraduate Research and Innovation Scholar**

**Coordinated Multi-Layered Optimization for Electrical Vehicle Charging**

***Supervisor: Marija Ilic***

Recent years have seen a significant rise in the popularity of electrical vehicles. However, the new technology lacks regulation, and most EV projects are handled on a case-by-case basis. The lack of coordination creates many challenges in grid stability, demand satisfaction, and energy equity—each of interest to different stakeholders. The goal of my project is to design incentives in a competitive market to encourage market participant coordination. My work explores what market structure encourages communication between electricity market participants such to optimize market and energy efficiency, and how to minimize the price of anarchy under this coordination scheme. I hope results of my project situated in power systems will lend insight into facility location and pricing problems more broadly.

> *I'm taking 6.UAR to develop good research habits and learn how to approach difficult questions and uncertainties in research. I'm hoping to apply my background in math to a longer-term project and work on something I'm potentially interested in doing in grad school.*

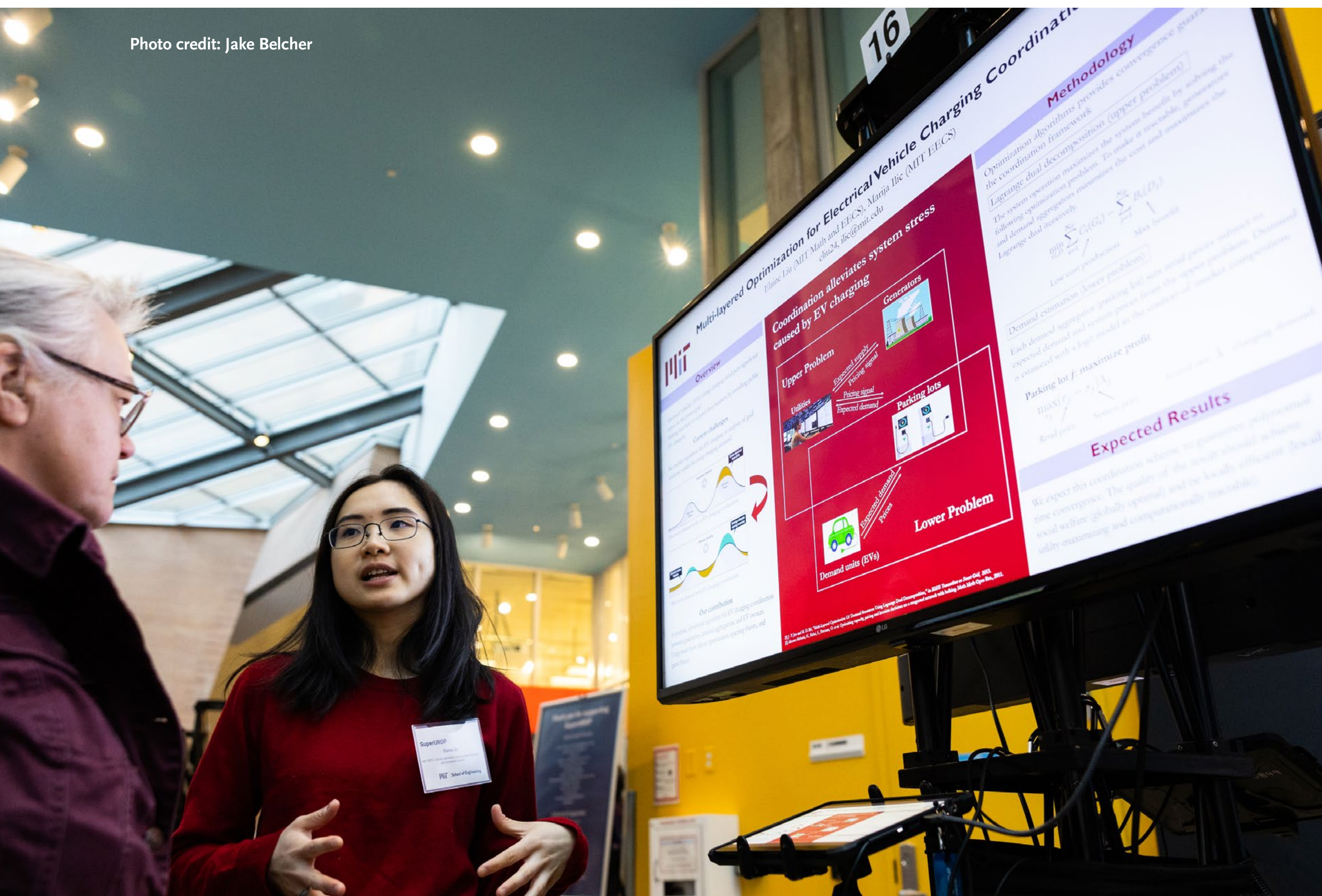


Photo credit: Jake Belcher

## Maggie Liu

**MIT ChemE | Raj V. Tahil (1981) Research and Innovation Scholar**

Optimizing Copper Nanoparticle Faceting for Carbon Dioxide Electroreduction

***Supervisor: Ariel Furst***

50 gigatons of CO2 are expected to be released into the air in the next few decades. To alleviate the harmful environmental impact of CO2, we can recycle CO2 into valuable chemical products through electrocatalysis using copper nanoparticles. By controlling the exposed facets in the nanoparticle, we can control the desired product. The goal of the project is to optimize the efficiency of the process by attaining size control of the particles, improve the product selectivity and faradaic efficiency of the electrocatalyst reactions, and achieve a scale-up of the synthesis while ensuring consistent catalyst quality.

> *I want to use the opportunity given by this SuperUROP to expand my project by using the skills I have learned as a chemE and past research experiences. I want to learn more about electrocatalysis as well as new characterization and analytical techniques. I hope that I can produce valuable results and be able to present my work to a larger audience beyond my lab.*

## Ashley Margetts

**MIT MechE | Undergraduate Research and Innovation Scholar**

Artificial Reef Design Optimization

***Supervisor: Faez Ahmed***

More than 60 percent of the world's reefs are under a direct threat from local sources such as overfishing, coastal development, and pollution. There have been efforts to replicate these reefs, but designs are often not optimal for reef fish development or for coastal protections. This is a high-risk design task that considers factors such as shape, size, water flow, temperature, and water carbon content. This level of complexity and risk combined with the high number of potential design iterations makes reef design a viable candidate for topology optimization techniques. My work will apply multi-objective functions to the existing artificial reef topology optimization work, optimizing coral reefs for performance in cultivating marine life and sheltering shorelines from storms and erosion.

> *I am very excited at the opportunity to develop my own project that I feel will make a unique and tangible contribution to the research space. I hope to gain technical experience in optimization methods as well as learn how to conduct a research project and present my findings.*

## Ashley Marie Martin

**MIT EECS | Philips Undergraduate Research and Innovation Scholar**

**Deploying a Joy-Based Brain-Computer Interface (BCI) for Regulating Emotional Activity in the Prefrontal Cortex**

***Supervisor: Manolis Kellis***

We designed Joie, a joy-based EEG brain-computer interface (BCI) where users imagine joyful thoughts that alter their prefrontal asymmetries. Mental health is crucial; 32.3% of U.S. adults (100+ million) reported anxiety or depression symptoms in 2023, peaking at 45.4% for ages 18–29. Prefrontal neurofeedback training has been shown to improve anxious and depressive symptoms. However, these systems are typically confined to the laboratory and fail to prioritize usability and engagement. We have run placebo-controlled studies to demonstrate that joyous thoughts can activate prefrontal symmetries connected to improved depressive symptoms and have created a wearable EEG headband suitable for home environments. In this project, we investigate the usability, engagement, and transfer of Joie.

> *This year, I am continuing my previous research in the field of brain-computer interfaces. I have been pursuing a career in BCIs for several years, and I hope to learn more about the field and research environment as a whole. I am participating in SuperUROP in order to improve my skill set and get feedback on my research practices. I am excited to continue the project and discover what improvements can be made.*


**Photo credit: Jake Belcher**

## Hector Xavier Martinez

**MIT EECS | Lincoln Laboratory Undergraduate Research and Innovation Scholar**
Autonomous Vehicles in Challenging Driving Scenarios: Dynamic Safety Constraints
***Supervisor: Daniela L. Rus***

This research project proposal aims to enhance the capabilities of autonomous vehicles in challenging driving scenarios by developing innovative algorithms that dynamically incorporate safety constraints. The focus is on merging real-world safety considerations with theoretical models and testing them on physical robotic platforms. The study employs a combination of supervised and self-supervised learning techniques to improve perception algorithms, enabling autonomous vehicles to navigate complex and uncertain environments more effectively. By advancing autonomous driving technology, the research seeks to enhance safety, accessibility, and efficiency while addressing issues related to human error and variable driving contexts.

*I am engaging in a SuperUROP to apply creative problem-solving skills to cutting-edge research in my field. My previous work with AVs at NVIDIA (backend) and at the Autonomous University of Barcelona (research on mono-ocular depth perception) has prepared me for this project. I hope to gain a deeper understanding of interconnected machine learning systems and am most excited to gain a better intuition with self-driving vehicles.*

## Cesar Meza

**MIT AeroAstro | Undergraduate Research and Innovation Scholar**
Lunar Soil Beneficiation for Molten Regolith Electrolysis Reactors
***Supervisor: Jeff Hoffman***

Molten regolith electrolysis (MRE) is a technique for extracting water and iron from lunar soil (regolith), resources that can be used to create steel for space-exploration infrastructure and support human activity respectively. Increasing the metal content of regolith before smelting (beneficiation) would increase MRE reactor output. This project aims to develop a prototype for a lunar soil beneficiation system in three stages: identifying an optimal combination of techniques, validating results from literature through testing, and designing a compact module combining the selected methods. Testing the prototype's output involves feeding the system with lunar regolith simulant inside a vacuum chamber and analyzing a sample's mineral content with energy-dispersive X-ray spectroscopy.

*Inspired by the dream of returning people to the moon, I have conducted space systems engineering research for three years. I wish to apply my skills in a SuperUROP to help develop technologies that will support the goal of lunar-based manufacturing. With global interest in establishing a permanent human presence on the lunar surface, I believe in-space manufacturing's importance will only increase, and I cannot wait to contribute to the field.*

## Edgar Morfin

**MIT EECS | CS+HASS Undergraduate Research and Innovation Scholar**

Designing an Algorithm for Automatic Detection and Labeling of English and Spanish Glides

***Supervisor: Stefanie Shattuck-Hufnagel***

I will be working on the creation of an algorithm designed to automatically detect and label glides in the English and Spanish languages. Glides are a specific acoustic cue, which are one of the fundamental features in phonetics, the study of human speech. In doing so, it will help to streamline the preprocessing of data for future research in phonetics, and will also contribute greatly to the process of creating a unified system of acoustics for the Spanish language, which will also allow for more research in the field to be done for this language.

*I am doing the program to allow myself the amazing opportunity to explore doing research in a field of interest. I hope that in doing so, I will begin to discover a great passion for research, which will push me to do more in the future. I also believe that this program is a great opportunity for me to connect with others that will then enable me to make a real, positive impact for my community.*

## Kairo Tiere Morton

**MIT EECS | Lincoln Laboratory Undergraduate Research and Innovation Scholar**

3D Self-Supervised Representation Learning

***Supervisor: Vincent Sitzmann***

Building systems that can interpret and reason about the 3D world is a fundamental problem of computer vision research. In order to achieve this goal, these systems must first learn to encode the geometry and semantic content of the world through limited 2D observations. In this project we hope to explore methods that can learn scene representations of this kind in a completely self-supervised fashion. Specifically, our goal is to develop models that with a few 2D image observations of a 3D scene can produce a representation that encodes useful information (semantic, geometric, etc.) while still modeling uncertainty accurately. Finally, we will design techniques for evaluating the effectiveness of these learned representations on a variety of downstream tasks.

*Through this SuperUROP, I hope to continue my work with the CSAIL Scene Representation Group in developing vision systems that can understand and reason about the physical world. In the past few years, I have taken multiple machine learning classes and have completed two summer research internships at Google. With this preparation in mind, I am excited to take on this challenge in order to further my research and technical abilities.*

## Abutalib Namazov

**MIT EECS Undergraduate Research and Innovation Scholar**
Generating Web Applications from Conceptual Designs
***Supervisor: Daniel N. Jackson***

The fast-paced evolution of web apps and their growing complexity highlights the need for a fresh approach to software modularity that goes beyond today's microservices. Microservices have their drawbacks, like tangled dependencies and not being modular enough, which hold back the full potential of software flexibility, reusability, and adaptability. This research project is driven by the desire to discover a new architectural method that overcomes these limitations, making it possible to develop highly adaptable and efficient web applications. By investigating the idea of services as concepts and using parallel synchronization, this project aims to reshape the way web apps are designed, developed, and maintained.

*My research motivation springs from a deep passion for software engineering and design. Having firsthand experience with the challenges of web development, I am convinced that it is necessary to find a fresh approach to modularity in order to create innovation and meet digital demands. I also aspire to enhance software education, simplifying the implementation of web apps. My aim is to create a groundbreaking paradigm and a platform that overcomes current limitations and allows software to be easily built.*

## Jakin S. Ng

**MIT EECS | Lincoln Laboratory Undergraduate Research and Innovation Scholar**
Learned Initializers for Iterative PDE Solvers
***Supervisor: Justin Solomon***

Partial differential equations (PDEs) are ubiquitous throughout science, describing fundamental physical phenomena. Designing efficient and accurate numerical solvers is crucial but highly non-trivial. We propose using Fourier neural operators (FNOs), which learn the solution mapping for a family of PDEs, as learned initializers for iterative PDE solvers. By initializing close to the actual solution, the number of iterations required for the solver to converge is reduced, while achieving at least equivalent convergence and accuracy guarantees. Advantages include reduced computational cost for an entire family of PDEs, as well as equivalent accuracy to the original numerical solver.

*During the SuperUROP program, I am looking forward to experiencing the full research process, as well as learning to communicate and present my results more effectively. I'm most excited to work on integrating ML and numerical methods to solve PDEs quickly and accurately.*

# Melissa Nie

**MIT CEE | Undergraduate Research and Innovation Scholar**

**Quorum Sensing Analysis for Marine Microbial Communities**

***Supervisor: Otto Cordero***

Microbes live in a noisy world, sensing and integrating information from countless chemical cues in their environments to optimize growth. One way bacteria gain knowledge about their surroundings is quorum sensing (QS). Through sensing the concentrations of specific, diffusible QS signals, bacteria can regulate behavior in response to fluctuating population sizes, rendering the collective more powerful than the individual. Though well-studied in the lab, QS in natural environments remains poorly understood. In this project, I will characterize signals produced by wild bacteria isolates that act as carbon digesters of the ocean, exploring how QS impacts ecological interactions between these strains and what it can tell us about the role of QS in the carbon cycle.

*This SuperUROP is a continuation of work I've done since IAP 2023, and I'm grateful that I've had the chance to get a more hands-on research approach and gain experience with wet lab techniques. I want to apply what I've learned from my computer science courses to the bioinformatics aspects of this project, which will help me gain more experience in a field I hope to join after graduation.*


**Photo credit: Jake Belcher**

Photo credit: Jake Belcher

## Divya Vani Nori

**Eric and Wendy Schmidt Center Funded Research and Innovation Scholar**

RNAFlow: RNA Structure & Sequence Co-design via Inverse Folding-Based Flow Matching

***Supervisor: Caroline Uhler***

The growing significance of RNA engineering in diverse biological applications has spurred interest in developing AI methods for structure-based RNA design. While diffusion models have excelled in protein design, adapting them for RNA presents new challenges due to RNA's conformational flexibility and the computational cost of fine-tuning large structure prediction models. To this end, we propose RNAFlow, a flow matching model for protein-conditioned RNA sequence-structure co-design. Its denoising network integrates an RNA inverse folding model and a pre-trained RosettaFold2NA network for simultaneous generation of RNA sequences and structures. The integration of inverse folding in the structure denoising process allows us to simplify training by fixing the structure prediction network. We further enhance the inverse folding model by conditioning it on inferred conformational ensembles to model dynamic RNA conformations. Evaluation on protein-conditioned RNA structure and sequence generation tasks demonstrates RNAFlow's advantage over existing RNA design methods.

*Through SuperUROP, I hope to gain experience with methods development for computational biology. My past research projects have given me a strong grasp of machine learning fundamentals, especially in the context of molecules and proteins. Building on that, I'm excited about building methods for the challenging setting of nucleic acid structure prediction. Learning from my mentors, I hope to balance thorough experimentation with creativity.*

## Eddy Onyango

**Eric and Wendy Schmidt Center Funded Research and Innovation Scholar**

Evaluation of Neural Networks for Object Segmentation in Biological Images

***Supervisor: Caroline Uhler***

Many researchers can gain valuable insights into their research using AI models but only a few are familiar with their inner workings to use them efficiently. This presents a usability problem that could perhaps be solved with a decent easy-to-understand interface, but training and inference for large models tend to be compute-heavy. This makes it difficult for the biologist, our target user, to use these progressive tools. We propose Piximi, an object segmentation tool for biological images that would bring an intuitive interface coupled with models running on the browser without a server; this would mean efficient transfer learning and machine learning workflows that allow for varied model adaptability, without leaving the browser.

> *I am interested in the dual areas of computer systems and optimization and machine learning. This project exists in this beautiful intersection and I believe that by bringing my joint experience in both fields, I might have interesting ideas that will take us steps closer to our goal. I am also motivated to make this work since it's very important in democratizing artificial intelligence.*

## Edwin Otieno Ouko

**MIT EECS | Landsman Undergraduate Research and Innovation Scholar**

Digital Phenotyping for Mental Wellness

***Supervisor: Richard Fletcher***

The use of data gathered from smartphones and wearables is increasingly prevalent in identifying early indications of illnesses, allowing medical professionals to evaluate a patient's well-being from a distance, or even better, automating the process. Nevertheless, accurately forecasting a patient's emotional state using this data remains a formidable task. As part of my research, I integrate sensor and user interaction data to enhance the precision of predicting individuals' stress levels.

> *This SuperUROP has given me a chance to do research at the intersection of machine learning and healthcare and to see how machine learning could change disease diagnostic processes.*

# Lara Ozkan

**Eric and Wendy Schmidt Center Funded Research and Innovation Scholar**

**Sex-Specific Differences for Alzheimer's Disease**

***Supervisor: Manolis Kellis***

Alzheimer's Disease (AD) is a progressive neurodegenerative disorder that can severely impact an individual's memory, behavior, and thinking. There have been great advancements in the understanding and research of AD molecular mechanisms in the scientific community. These studies have also introduced that a patient's sex may contribute to differences in severity, risk factors, and disease progression. The focus of this study is to delve into these sex-specific variations based on region and cell-type-specific molecular studies. This project leverages the large-scale transcriptional (changes in gene expression) and epigenomic profiles of individuals with AD to create and understand single-cell RNA-sequencing maps across mouse and human samples. This will allow for an analysis across sex, age, and genetic risk parameters to better understand the causal mechanisms for the sex-related differences. The overall goal is to understand the full scope of this disease by capturing the sex-specific variability and using this information to ultimately develop personalized therapeutic approaches for AD.

*I am excited about SuperUROP because it gives me the unique opportunity to conduct in-depth, high-level research and also be an effective communicator. I have always been fascinated with the applications of computer science to solve our world's most challenging biological problems, so I am grateful to have this hands-on experience to both learn about the scientific research process and also contribute to our understanding of Alzheimer's Disease.*

**Photo credit: Jake Belcher**

## Tuong Phung

**MIT EECS | Analog Devices Undergraduate Research and Innovation Scholar**

**Designing New Metal-Organic Chalcogenide Assemblies Using Genetic Algorithms**

***Supervisor: Tess Smidt***

Metal-organic chalcogenide assemblies (MOChAs) are hybrid crystals exhibiting unique electronic properties due to the confinement of electrons. This project aims to better understand the geometry of MOChAs in order to design new ones. In particular, spectra will be used as a descriptor of the local environments of silver atoms bonded to sulfur, selenium, or tellurium, using data from the Cambridge Structural Database and the Materials Project. The insights derived from analyzing these geometries will serve as a fitness function for a genetic algorithm, an approach that emulates the evolutionary process of natural selection, to generate new potential MOChAs.

*As an aspiring researcher, I am looking forward to gaining more research experience through the SuperUROP program. I am interested in the applications of AI for science and also enjoyed taking 6.S966 (Symmetry and Its Application to Machine Learning) last spring. This SuperUROP provides the perfect opportunity to apply what I learned in that course to an interesting problem at the intersection of AI and computational chemistry/materials science.*

## John Jairo Posada

**MIT AeroAstro | Undergraduate Research and Innovation Scholar**

**Development of Energy-Efficient Algorithms for Pose Estimation, Mapping, and Activity Planning Onboard Small Robots and Groups of Robots**

***Supervisor: Sertac Karaman***

Miniature robots have incredible potential for long-duration missions in fields such as environmental monitoring, search and rescue, space robotics, and medicine. In order for these robots to be capable of those missions, they have to be extremely energy-efficient to preserve their energy as long as possible. In these cases, the energy they spend on running algorithms that enable them to be autonomous is non-negligible and comparable to the energy they spend moving around. This research will focus on the intersection of mapping, planning, and path execution, all under low power constraints. The work will develop and analyze algorithms that best balance robotic performance and energy efficiency, and lead to demonstrations with three small autonomous robots: a car, a boat, and a blimp.

*This SuperUROP offers me the opportunity to delve into algorithms for autonomy and what really makes robots work. My main experience is with robot dynamics and control, but I'm excited to explore visual navigation, activity planning, robot communication—the works. Beyond just studying the cutting edge of robotics research, I'm hoping to bring this project to fruition and go from just ideas to concrete, publishable work.*

Photo credit: Jake Belcher

## Steven Raphael

**MIT EECS | Hudson River Trading Undergraduate Research and Innovation Scholar**

High-Performance Subgraph Computations for Anomaly Detection

***Supervisor: Julian Shun***

Efficient and accurate clustering algorithms have a wide range of applications, such as financial time series analysis. In this project, I will implement a framework for dynamically clustering time series data. This project started over the summer, where I improved the performance of a static clustering algorithm, and will continue through this year. I will implement heuristics to extend the static algorithm to dynamic time series and apply the algorithm to real-world data. Additionally, I compare other algorithms in the dynamic framework, and I will attempt to modify the static algorithm to increase performance in a dynamic setting.

> *I am interested in doing this UROP because I want to gain experience in constructing large projects and getting results. I want to get a better understanding of how to create and implement algorithms.*

## Brian Joseph Robinson

**MIT AeroAstro | Undergraduate Research and Innovation Scholar**
Megawatt-Class High-Speed Electrical Machine Demonstrator
***Supervisor: Zoltán S. Spakovszky***

Despite the growing interest in turbo-electric propulsion systems, all hypothesized benefits require considerable technological improvement from the current state of the art. There is limited research demonstrating how turbo-electric propulsion systems could output the necessary energy levels on a megawatt scale to prove useful in aerospace applications. Given this, the MIT Gas Turbine Lab is pursuing a demonstration of a 1MW-class integrated motor-generator power system. We are working on a damper tuning experimental test for rotodynamic characterization of the 1MW demonstrator drive shaft. The goal of my project is to focus on the design and development of an experiment to tune the dampers of the bearing housing with the shaft that will be used in the final demonstrator.

> *Through this SuperUROP, I am able to contribute toward research that has a high applicability toward what is going on in industry right now. I intend to rely on the fundamentals from Course 16's Unified Engineering and on my experience with CAD and FEA analysis. I hope to further my knowledge via real-world engineering challenges and learn from the incredible colleagues around me!*

## Jonah Romero

**MIT Tang Family FinTech Undergraduate Research and Innovation Scholar**
Exploring Security Vulnerabilities in Modern Processors
***Supervisor: Mengjia Yan***

Modern processors have been aggressively optimized for performance and energy efficiency. However, recent attacks, such as high-profile Spectre and Meltdown attacks, have shown how vulnerable modern computer hardware is. This project is to explore various side channel vulnerabilities in modern processors. We are going to study potential security problems in those micro-architecture structures, which have not been fully understood by the community, such as buffers and directories in the memory hierarchy and network-on-chip. The project will involve reverse engineering commercial processors, developing end-to-end attacks, and breaking privacy of modern applications, including crypto libraries and ML applications.

> *Conducting research at a world-class institution like MIT has always been a goal for me. My interest in low-level systems led me to take Computer Architecture and Secure Hardware Design, both central to my SuperUROP. I aim to learn as much as possible from my UROP team, utilizing the knowledge from my classes to contribute effectively. Above all, I'm thrilled to start hands-on testing with physical hardware and, hopefully, break it.*

# Dinuri Rupasinghe

**MIT AeroAstro | Undergraduate Research and Innovation Scholar**

**Analysis of Fuel Sloshing and Controls of In-Space Wax Propulsion System**

***Supervisor: Danielle Wood***

Wax propulsion has the opportunity to be a significant green, non-toxic, and low-cost fuel used as a deorbit thruster in space, which can be used to deorbit satellite debris. In order for wax propulsion to come to fruition, research is being completed on the feasibility of generating wax fuel grains in space, since the prospect of on-earth manufacturing and launch to space will likely be too fragile. The accepted method of wax fuel grain generation is called centrifugal casting, where chunks of wax are melted to a liquid state, spun up in a tube, and cooled down in an annulus configuration. The work will focus on modeling the controls required for this process. The work will analyze the reaction wheel supports required for successful performance of centrifugal casting on a LEO satellite that is released from the International Space Station. The goal of the research is to perform an analysis of liquid sloshing on melted wax undergoing centrifugal casting, create and test the hardware required for the analysis of a preliminary wax system on the NASA Jet Propulsion Laboratory Small Satellite Dynamics Testbed, and conduct an optimization of sizing and material selection for the satellite based on propulsion and control parameters.

> *I am participating in the SuperUROP program because I love the research process. It is intriguing how engineering research can contribute to a real product in the future. I have been working with the Space Enabled Research Group at MIT Media Lab since my first year at MIT, and I wanted the opportunity to contribute to a significant portion of research for wax propulsion. To be able to conduct spacecraft dynamics and controls research in an environment where I can learn more about proper research is exciting and engaging.*


**Photo credit: Jake Belcher**

## Dhruv Saraff

**Undergraduate Research and Innovation Scholar**
NetBlocks
***Supervisor: Saman P. Amarasinghe***

Various domains of computer science have vastly different properties and hence require very different network protocols. For example, RPC in data centres transfer minimal data but require strong reliability and checks against corruption, whereas video streaming applications need to transfer a lot of data with low latency, but some packets can be dropped or corrupted. As a developer aiming to design a network stack, you could use an off-the-shelf solution like TCP/IP, which will probably have everything you need but also unnecessary latency caused by many features you do not need. Otherwise, you could use a network library like PicoTCP, but libraries are generally not configurable enough and suffer performance penalties caused by the modularity they offer. NetBlocks takes the compilers approach to generate network stacks, providing users with full flexibility on how they want to design their protocols, and gets rid of all performance penalties put forward by the offered flexibility during code compilation.

*I am participating in SuperUROP because I want to apply my knowledge of compilers and networks to a longer-term research project.*

## Fareed Sheriff

**Eric and Wendy Schmidt Center Funded Research and Innovation Scholar**
Causal Inference and Reinforcement Learning
***Supervisor: Caroline Uhler***

In many applications the end goal of causal inference is not necessarily to learn the underlying causal system but to infer the best interventions in order to push the underlying system toward a desired state. This is the case for example when studying reprogramming, where the goal is to determine the best interventions (e.g., over-expression of particular transcription factors) to push a differentiated cell toward the stem cell state. In this project, the goal is to build on methods in active learning, RL, and causal inference to obtain methods for selecting the best interventions in order to push the system toward a desired state.

*I'm participating in this SuperUROP because I am interested in statistics and inference research. I would like to obtain more experience with inference while learning about causal inference, which is applicable to many fields including economics, the social sciences, and biology. I hope to learn relevant background on existing problems and solutions in causal inference and hopefully produce work worth publishing.*

# Ron Shprints

**MIT EECS | Takeda Undergraduate Research and Innovation Scholar**

**Substrate Metric Learning: Contrastive Learning for Molecular Representations**

***Supervisor: Connor Coley***

Learning molecular representation is a critical step in molecular machine learning that significantly influences modeling success, particularly in data-scarce situations. The concept of broadly pre-training neural networks has advanced fields such as computer vision, natural language processing, and protein engineering. However, similar approaches for small organic molecules have not achieved comparable success. In this work, we introduce a novel pre-training strategy, substrate scope contrastive learning, which learns atomic representations tailored to chemical reactivity. This method considers the grouping of substrates and their yields in published substrate scope tables as a measure of their similarity or dissimilarity in terms of chemical reactivity. We validate our pre-training approach through both intuitive visualizations and comparisons to traditional reactivity descriptors and physical organic chemistry principles. This work not only presents a chemistry-tailored neural network pre-training strategy to learn reactivity-aligned atomic representations, but also marks a first-of-its-kind approach to benefit from the human bias in substrate scope design.

*SuperUROP is a fantastic opportunity to engage in research, which is something I started doing in my freshman year. Then, I became interested in using statistics to solve problems in drug discovery. I believe that theoretical and applied research are often closely related and through this project, I'd like to deepen my understanding of both. I'm looking forward to designing explainable machine learning models to facilitate molecular discovery.*

Photo credit: Jake Belcher

## Anahita Srinivasan

**MIT EECS | Nadar Foundation Undergraduate Research and Innovation Scholar**

Guardrails for LLMs Supporting Security

***Supervisor: Una-May O'Reilly***

Improving the accuracy of results generated by large language models (LLMs) has been a major focus in recent generative artificial intelligence research. This project focuses on connecting LLMs with BRON, a collation of data sources that bridges many different databases in the cybersecurity domain. By doing so, the generative power of LLMs can be harnessed with the verified facts and inherent structure of BRON to produce higher-quality query results. This method of guarded query and retrieval will be tested on three different applications: generating cyber domain PDDL (planning domain definition language) files, directly generating the plans that would be the result of running the aforementioned PDDL files through a classical planner, and retrieving general cyber information.

> *I am participating in this SuperUROP because I want to apply my skills and interest in generative artificial intelligence to a more long-term research project. My previous UROPs and my coursework in machine learning have provided me with a foundation in this area, and I am excited to explore cutting-edge techniques and collaborate with the lab. I hope to learn more about the technology behind large language models.*

## Ashwini Suriyaprakash

**Eric and Wendy Schmidt Center Funded Research and Innovation Scholar**

Building the Gene Regulatory Network Using Deep Learning

***Supervisor: Manolis Kellis***

The expression of genes is controlled by gene regulatory networks, which capture the interactions between genes, non-coding regulatory elements, and transcription factor proteins. Understanding gene regulatory networks has wide applications in disease treatment since many disease-related mutations occur in non-coding regions and indirectly alter gene expression.

Though we understand how some pairs of regulatory elements and genes interact, many interactions still remain unknown. The goal of this project is to discover these interactions by architecting a transformer-based deep learning method.

> *Having taken algorithms and machine learning courses, I am interested in the applications of computer science in human health. I believe this SuperUROP is an excellent opportunity to investigate a fundamental problem in genetic mechanisms using computational methods. While learning about regulatory networks, I am excited to gain more experience in breaking problems into subproblems, handling ambiguity, and communicating my work to others.*

## Gianni J. Tipan

**MIT EECS | Mason Undergraduate Research and Innovation Scholar**
Inferring and Manipulating Object-Level Models from Visual Inputs via Segment Anything (SAM) and NeRF
***Supervisor: Frederic P. Durand***

This project aims to derive 3D object models from visual inputs like single-view videos or multi-angle photos. By segmenting 3D scenes into individual objects, we can enhance AR/VR asset acquisition, 3D editing, and robotics. Using known segmentation and object categories aids in understanding their geometry and appearance. We'll leverage current computer vision segmentation models and novel-view synthesis techniques such as NeRFs and triplane representations. Our primary tool will be the Segment Anything Model (SAM) for monocular segmentations and NeRF Shop prototypes, aiming to highlight and manipulate objects within scenes and make them movable. Additional objectives encompass determining objects' physical attributes including geometry, appearance, and lighting.

*I'm very excited to partake in a long-term research project through this SuperUROP. I've enjoyed editing videos and images before, and it's been thrilling to observe the evolving capacity of editing throughout years. I hope to further my knowledge of rising computer vision tools and computer vision's nuances, alongside contributing to this field.*

## Ella Tubbs

**MIT EECS | Philips Undergraduate Research and Innovation Scholar**
A Module for Automatic Analysis of Burst Spectra for Consonant Place Detection
***Supervisor: Stefanie Shattuck-Hufnagel***

Acoustic cues are defined as physical features that profile various speech production events. A cue of particular interest is the Spectral Burst (SB), which can be leveraged to predict the place of articulation of a consonant sound in the vocal tract. In turn, accurately classifying Spectral Bursts can create more robust Automatic Speech Recognition (ASR) that is reliable cross-linguistically. In this project, I will develop a statistical machine learning model that detects Spectral Bursts in phonologically complex settings. Then, I will test this model to see if it processes speech in accordance with known human perceptual benchmarks. This requires understanding both the low-level phonetic decomposition and high-level probabilistic approaches necessary to analyze speech psycholinguistically. This model can then be applied to fields such as speech disorder diagnostics, emotion recognition, and interactive voice systems.

*I am participating in SuperUROP to experience end-to-end research in a field of interest, speech processing. My project will utilize theory from some of my favorite courses at MIT: 9.35 (Perception), 6.390 (ML), and 24.900 (Linguistics), alongside skills and interests such as signal processing and acoustic phonetics. I ultimately hope to produce research that is both computationally robust and aligned with underlying psycholinguistic theory.*

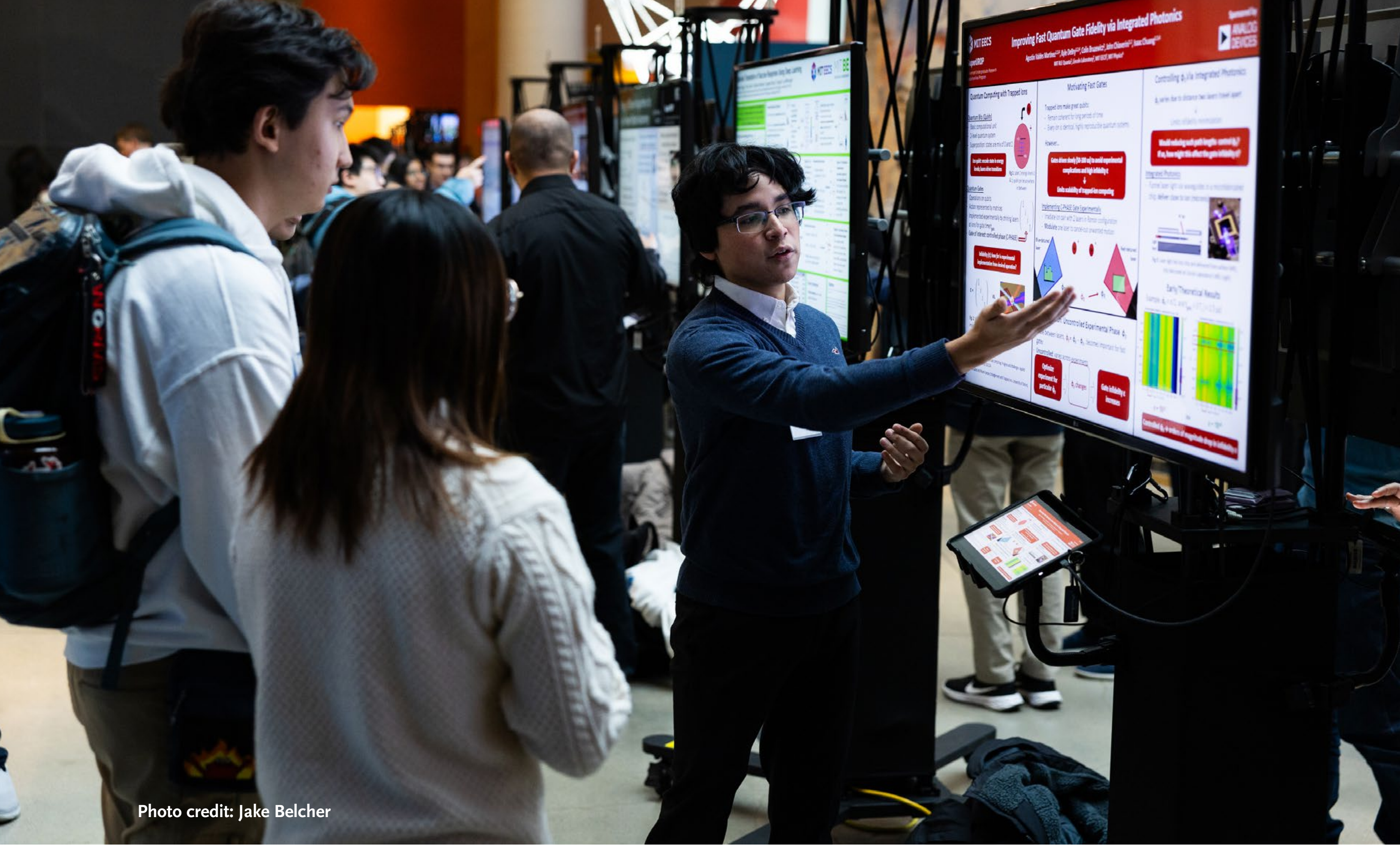



Photo credit: Jake Belcher

## Agustin G. Valdes Martinez

**MIT EECS | Analog Devices Undergraduate Research and Innovation Scholar**

**Improving Raman Gate Fidelity via Pulse Shaping and Integrated Photonics for Trapped Ion Quantum Computing**

***Supervisor: Isaac L. Chuang***

For this SuperUROP project, we are interested in actualizing a two-qubit gate using Raman transitions in a pair of calcium ions. In particular, we will investigate how laser-pulse-shaped sequences and integrated photonic beam delivery affect gate fidelity at high speeds. We expect that by smoothing out the pulses used to realize the two-qubit gate, we will be able to mitigate the infidelity that arises when said gates are driven quickly. Additionally, by delivering the Raman beams through wave guides in a micro-fabricated ion trap, we may be able to control the optical phase between the beams, resulting in possibly higher fidelities. Through these improvements to the Raman laser pulses and beam delivery method, we hope to demonstrate a quantum gate at record speeds and fidelities.

*After working in the Quanta Lab on projects related to lab automation, pulse shaping, and the theory of two-qubit gates, I am eager to take my research contributions to the next level via SuperUROP. I am especially excited to have the structure of this program insofar as learning about research techniques and presentation, whilst also having the liberty to explore questions at the intersection of atomic physics and electrical engineering.*


Photo credit: Jake Belcher

## Audrey Vargas

**Eric and Wendy Schmidt Center Funded Research and Innovation Scholar**

Species Translation of Vaccine Response Using Deep Learning

***Supervisor: Sangeeta Bhatia***

Non-human primates (NHPs) are used in the late-stage vaccine development for many infectious diseases, including HIV. This is because of the similarities that NHPs have with humans; for example, NHPs do not experience sickness with HIV but rather with SIV (a similar but different virus). Vaccines stimulate the body to create antibodies. Antibodies, holding specific structure and features, are responsible for recognizing antigens. Antibody feature data may be leveraged from NHPs to make predictions for feature importance in humans. My project uses deep learning techniques to identify important antibody features that correlate with viral protection in non-human primates. Understanding antibody responses in NHPs may help us design future vaccines.

> *I am grateful to have been working with this project since my freshman year at MIT. I feel that doing a SuperUROP in this lab is a nice culmination to my experience in academia thus far. I also am looking forward to getting more experience with deep learning techniques throughout the school year with this project.*

# Ellie Anna Vaserman

**MIT CEE | Professor Wilson H. Tang (1966) Research and Innovation Scholar**

**Insights into Ancient Roman Construction Utilizing Multiscale Characterization of Pompeiian Materials**

***Supervisor: Admir Masic***

Ancient Roman concrete is known for its longevity and strength, although the composition and production methods of this material remain unknown. Recent research suggests that quicklime ($CaO$) was directly added to Roman mortar and that the concrete was prepared on site utilizing hot mixing as the quicklime, water, pozzolana, aggregates, and other components reacted, resulting in a material that can heal cracks in itself over time. The eruption of Mount Vesuvius in 79 CE resulted in the preservation of the ancient Roman city of Pompeii as it was buried under volcanic ash. Prior to the eruption, earthquakes damaged structures in the region, leaving homes and frescoes in the stages of being repaired. Recent excavations have recovered preserved building materials, pre-mixed dry mortars, and tools from these sites. It is theorized that gypsum was used in the fresco mortar and that quicklime was used in structural mortar, but evidence of this has not been found. To determine whether this theory is supported, multi-method microstructure characterization will be performed on the excavated construction materials to determine particle size, elemental composition, and degree of crystallinity. This study serves as a preliminary look into the potential for multi-scale characterization techniques to preserve cultural heritage sites and reveal details about resilient ancient engineering practices.

*The reason I am participating in SuperUROP is to prepare me to pursue academia in the future. The part of my project that I am most excited about is that it takes the old adage of listening to your elders literally, and applies it to science. My hope is that by leveraging modern technologies to extend studies into past civilizations, we could learn more about what we must do for a sustainable future, especially in the construction industry.*

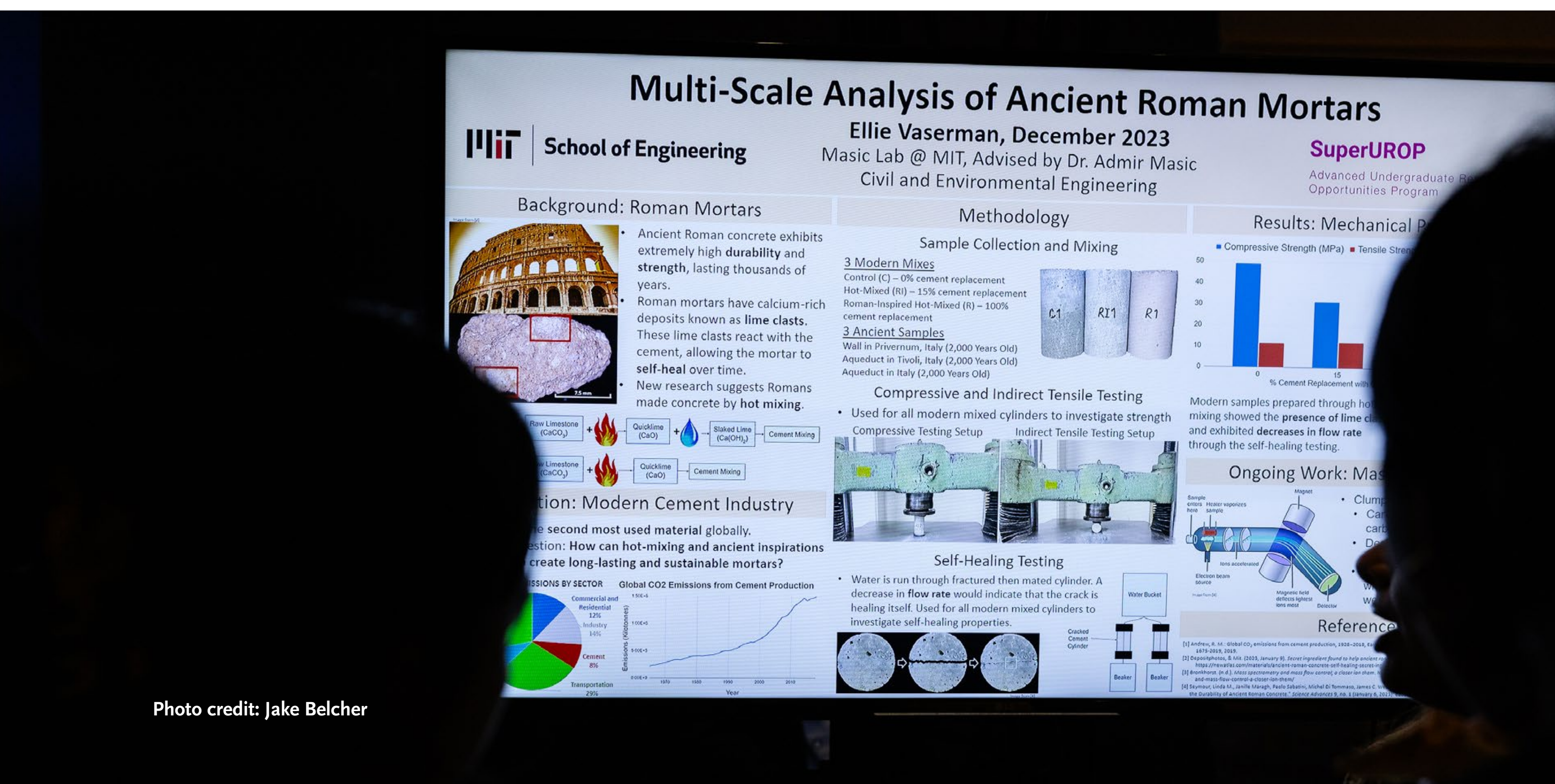



**Photo credit: Jake Belcher**

## Vetri S. Vel

**MIT EECS | Analog Devices Undergraduate Research and Innovation Scholar**
Multiphysics Simulations for High-Throughput Screening in 2D Material Synthesis
***Supervisor: Jing Kong***

Developing 2D materials by chemical vapor deposition (CVD) through high-throughput screening using real processes is time-consuming and expensive. Computational models can serve as a surrogate for CVD environments, enabling high-throughput 2D material synthesis. Multiphysics simulations can capture the relationships between growth conditions, morphology, and material properties. We aim to simulate CVD graphene growth using the open-source multiphysics modules developed by the Idaho National Lab, called MOOSE. The model will integrate multiple modules for physical equations, including heat transfer, gas flow, chemical reaction, and phase field. The project has the potential to serve as a framework for studying growth mechanisms and accelerating the development of 2D materials.

> *I am participating in SuperUROP because of the extra structure that the program provides in presenting my work. I think that my physics and computer science classes like 8.04 and 8.044, as well as 6.046, have prepared me well for this project. I hope to learn about what physics simulations can do.*

## Ryan Welch

**Eric and Wendy Schmidt Center Funded Research and Innovation Scholar**
Causal Disentanglement of Nonlinear Additive Noise Models
***Supervisor: Caroline Uhler***

Causal disentanglement aims to learn representations of causally related latent variables, wherein the data pertaining to the variables of interest are observable only through an unknown linear transformation. This project studies how we can perform causal disentanglement from the score of the observed data distribution in non-linear additive Gaussian noise models without interventional data. Both general methods for causal disentanglement and the use of score-matching for causal discovery have been at the forefront of recent causal inference research, yet a method of using score-matching for causal disentanglement without strong assumptions on the presence of interventional data has yet to be discovered. The algorithm developed in this project will be the first of its kind and can be applied to learning casual representations with latent variables in numerous settings such as economics and computational biology.

> *I am participating in SuperUROP to gain experience in performing theoretical research. All of my prior research experiences have been very high level, and I have always been interested in diving deeper into the theoretical models that drive many machine learning applications. I hope to contribute significantly to the field of causal representation learning this year and pave the way for a successful future in this line of research.*

Photo credit: Jake Belcher

## Victory M. Yinka-Banjo

**Eric and Wendy Schmidt Center Funded Research and Innovation Scholar**

Elucidating Cardiometabolic Disease Pathways & Biomarkers Using Deep Learning

***Supervisor: Caroline Uhler***

The development of therapeutics for diseases is contingent upon a thorough understanding of the disease's root causes. Diseases like Alzheimer's and cancer are intricately linked to physical changes in affected cells, as well as genetic and transcriptomic alterations. While researchers have made strides in integrating these aspects to identify potential therapeutic targets, they encounter limitations due to the diversity and limited nature of biological datasets. To address this challenge, a promising approach involves adapting successful methodologies for a given disease dataset and applying them to analogous datasets with similar structures. This approach can yield new insights and discoveries. Drawing inspiration from the success of STACI, a computational framework used to analyze Alzheimer's disease, my research focuses on creating and applying similar methods to a dataset (with both imaging and transcriptomic details) related to cardiometabolic diseases. My work will aim to provide valuable and potentially therapeutic-inspiring diagnostic information for a range of such cardiometabolic health conditions, ranging from heart attacks to obesity.

*I am pursing this project because I am passionate about using computational tools (especially AI) to solve biological problems. I also want to learn more about the process of research so I can learn what kind of work I want to commit to in graduate school. I am excited to apply my knowledge from cancer research in industry, biology classes, and 6.036 to this project. I hope that by the end of this SuperUROP, I can publish a paper on my findings.*

## Alice Zehner

**MIT CEE | Undergraduate Research and Innovation Scholar**

Piezo-Raman Analysis of Geological and Biogenic Calcite

***Supervisor: Admir Masic***

This study focuses on shell material from Australian pearl oyster (Pinctada maxima) and Pen shell (Pinna bicolor) and the biogenic calcite that composes their outer shell. Previous work on biogenic calcite has established its mechanically superior properties to geological calcite, but does not sufficiently model stress dissipation and toughening on the intercrystalline scale.

Through piezo-Raman and microindentation techniques, this study visualizes and quantifies the plastic deformation and toughening mechanisms present in biogenic calcite forms. We establish a linear applied stress-vibrational mode shift relationship for geological, P. maxima, and P. bicolor calcite. We then apply these relationships to the Raman maps of depressions made with a microindenter to create correlative maps of residual stress for each tested material. These maps demonstrate that biogenic calcite structures are able to store comparatively high energy and resist cracking with several toughening mechanisms.

> *I am participating in SuperUROP for the opportunity to develop my independent research skills and to create a body of work that is my own. I look forward to applying the skills I've learned in this lab and in my material science coursework to advance the understanding of biological materials.*

## Zachary Tangbei Zhang

**MIT EECS Undergraduate Research and Innovation Scholar**

Communicating Human Priors to Neural Logic Machines

***Supervisor: Leslie P. Kaelbling***

Given a set of base predicates, Neural Logic Machines (NLMs) sequentially apply first-order rules to draw conclusions. NLMs are powerful because they can recover a set of lifted rules, which allow for more effective generalization to scenarios that are larger than those in the training dataset, deal with higher-rarity relational data and quantifiers, and effectively scale up with the complexity of given rules (Dong, 2019). My project investigates how to communicate human priors to an NLM in order to improve its performance, mimicking how humans rarely learn new tasks with a completely random or structureless approach. Investigating these improvements is crucial because we ultimately want to build robots that are highly data efficient and can make precise decisions quickly with limited information.

> *I am participating in SuperUROP because I am interested in having a structured environment to dive deep into my research. Prior to SuperUROP, I was a UROP student at the Koch Institute working on differentiating cells based on mass, stiffness, and density. I am excited to gain the skills to drive my own research in the future and to discover efficient ways for human knowledge and thought processes to be communicated to machines.*

## Kristine Zheng

**MIT EECS | CS+HASS Undergraduate Research and Innovation Scholar**

Experiments and Modeling to Identify Curricula for Faster Locomotor Adaptation

***Supervisor: Nidhi Seethapathi***

The learning mechanisms underlying the rapid and energy-efficient adaptation of human locomotion to varying environmental and physical conditions are not well understood. Our goal is to model locomotion adaptation using a feedback controller, reinforcement learning component, and memory mechanism for curriculum learning tasks such as sequences of split-belt treadmill and exoskeleton, and temporal credit assignment. Next steps also include incorporating hip and ankle exoskeleton dynamics and control to the current model and converting existing work for open-source distribution. With a more robust model of human motor learning, we can better understand locomotion learning disorders, improve rehabilitation methods, and design more supportive robots.

*I am participating in SuperUROP because I want to gain meaningful long-term research experience in the motor control field. I've previously taken courses in reinforcement learning, machine learning, and robotics and can expand this knowledge toward real-world applications. Additionally, I'm excited to collaborate with and learn from members of the lab and contribute toward open-source science and neuromotor rehabilitation.*

## Yan Zheng

**MIT ChemE | Raj V. Tahil (1981) Research and Innovation Scholar**

Electrocatalytic Carbon Dioxide Reduction

***Supervisor: Ariel Furst***

The emission of carbon dioxide into the atmosphere is about 40 billion metric tons per year, and tens of gigatons of carbon dioxide are anticipated to be generated in the next few decades. To effectively mitigate negative environmental impact, a feasible method of recycling carbon dioxide can be developed. The goal of this project is to directly reduce carbon dioxide to value-added products using copper nanoparticles (CuNPs) as an electrocatalyst. To accomplish the goal, I need to establish a synthetic method for shape and size control of the CuNPs, optimize the product selectivity of the electrocatalyst reactions, and scale up the synthesis method with consistent catalyst quality.

*I am participating in SuperUROP because I want to engage academically with my interest in the field of electrocatalysis and nanotechnology, and apply what I have learned in class as a chemical engineer. Through this opportunity, I would like to enhance my problem-solving skills, learn characterization techniques, and expand my knowledge on the fields of interest. Regarding the project, I am most excited to see what nano-sized particles can accomplish.*

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