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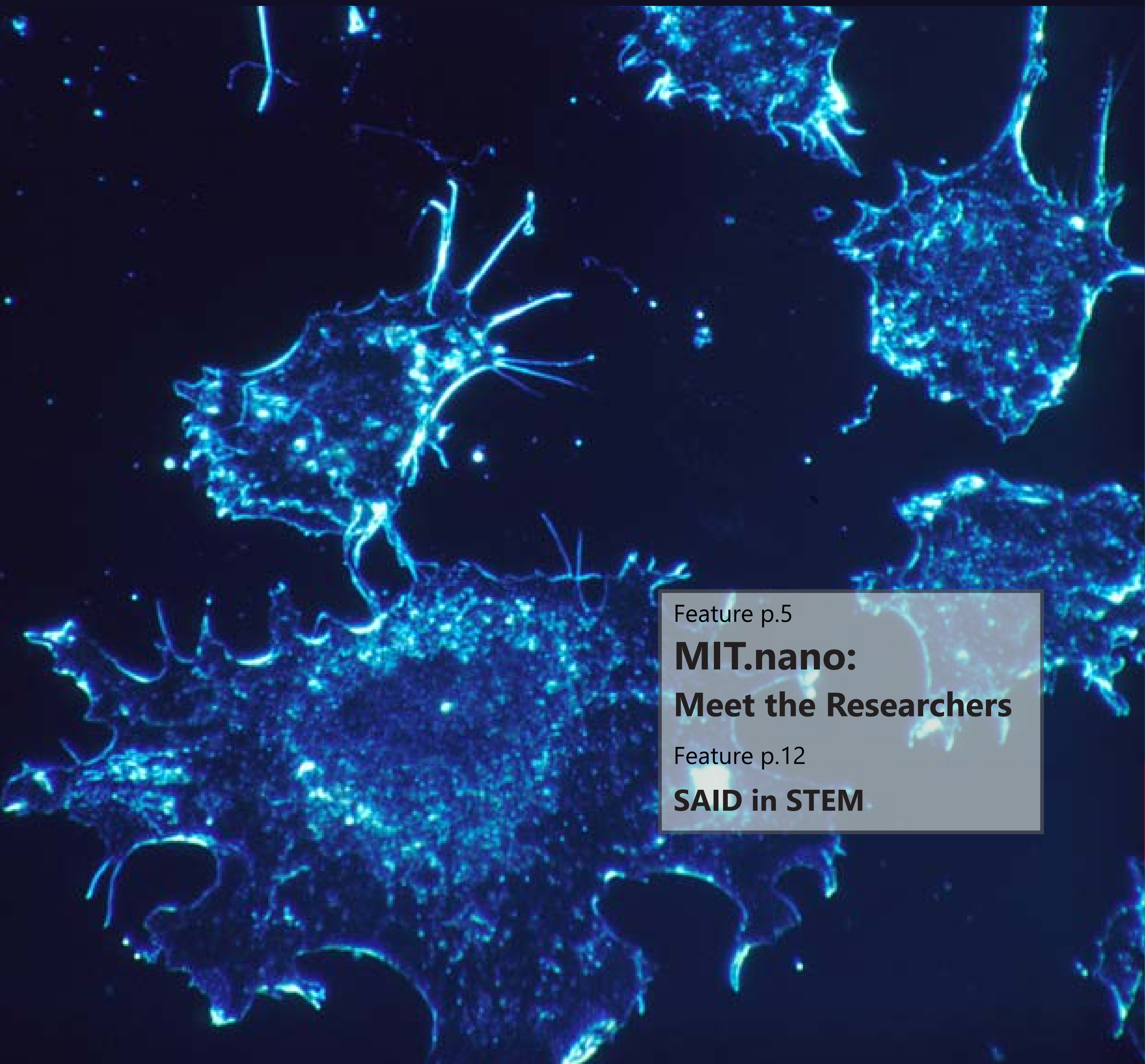
MURJ

Massachusetts Institute of Technology Undergraduate Research Journal



Feature p.5

MIT.nano: Meet the Researchers

Feature p.12

SAID in STEM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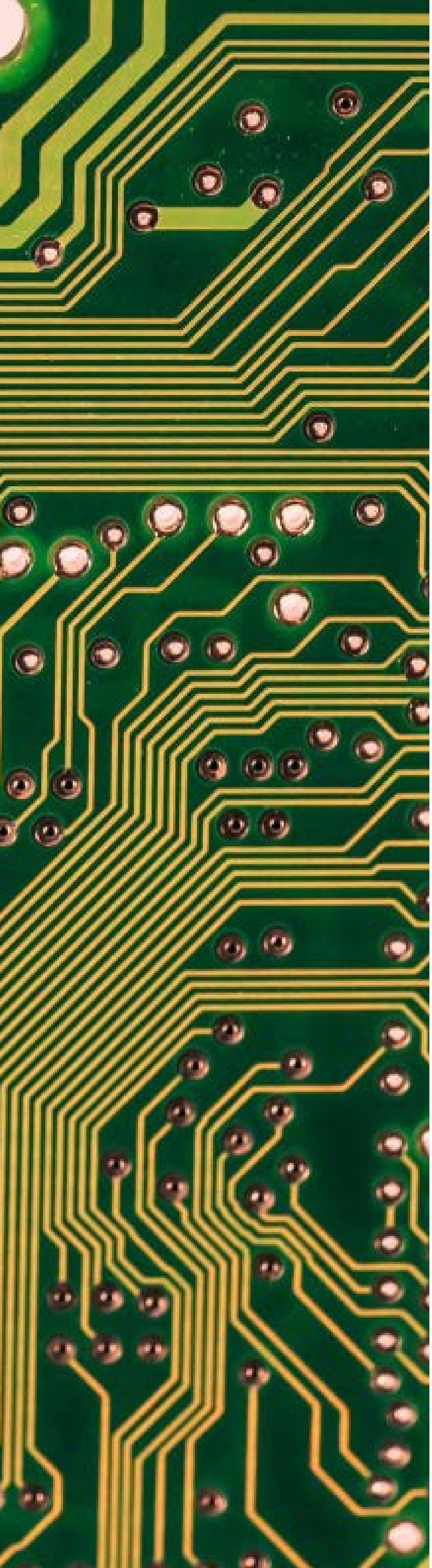

Contents

Introductory Letter

Features

Reports

Massachusetts Institute of Technology

UNDERGRADUATE
RESEARCH JOURNAL
Volume 37, Spring 2019

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MIT Undergraduate Research Journal

Massachusetts
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September 2019

Dear MIT community,

We are delighted to present the 37th issue of the MIT Undergraduate Research Journal, a biannual student-run publication that showcases undergraduate research on campus. The pages within contain student work on deep neural networks, post-disaster rebuilding legislation, and a tool for analyzing data from power plants.

This issue also features an interview with Mackenzie Lemieux, an MIT research technician and coordinator of the SAID in STEM lecture series. Held in the Brain and Cognitive Science Picower Institute, the lecture series aimed to raise awareness about inequality in the workplace and educate participants about biases and stereotypes affecting women and minorites in STEM.

Also included is feature exploring the new MIT.nano facility, including interviews with Nano researchers Vladimir Bulović, Jesus A. del Alamo, Catherine L. Drennan, and Timothy Manning Swager.

Biannual publication of this journal is a collaborative undertaking by an extraordinary team of dedicated students. We would like to thank our editorial board and contributors for their time and hard work this semester. In addition, we would like to thank all the undergraduates who shared their research with us and the greater MIT community.

For previous issues of the MIT Undergraduate Research Journal, please visit our website at murj.mit.edu. If you are interested in contributing to future issues of the MIT Undergraduate Research

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MIT Undergraduate Research Journal

Journal, we invite you to join our team of authors and editors or submit your research for our Fall 2019 issue. Please contact murj-officers@mit.edu if you have any questions or comments.

Best,

Allison Huske
Nafisa Syed

Allison Huske
Nafisa Syed

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UNDERGRADUATE RESEARCH JOURNAL
Volume 37, Spring 2019

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MURJ Features

MIT.nano building will be a new center for nanotechnology research at MIT (Photo source: Wilson Architects)

MIT.nano

MIT Begins A New Era In Nanotechnology Research

By Shannon Weng

INTRODUCTION

After six years of diligent planning and construction, MIT's premier nanoscience building finally opened its doors for the 2018-2019 school year. The official MIT.nano launch, held on October 4, 2018, attracted hundreds of visitors from various institutions and companies around the country. As nanotechnology becomes more and more prevalent in our lives—showing its power in faster computers, lighter and more durable clothing, novel cancer treatments, and more—MIT.nano and its state of the art technology will become an ever more important part of the MIT community.

Among the new facilities are two clean rooms occupying the central space of the first to fourth floors. The clean rooms are designed to allow very precise nanoscale experiments to be done. This requires a full exchange of air 250 times per hour in order to ensure that no more than 100 large particles are present in each cubic foot of air in the room. To a nanoparticle, even a speck of dust is a large particle—being hit by dust is like being run over by a bulldozer, maybe even worse.

The basement of MIT.nano features three of the most advanced cryo-electron microscopes present at MIT. The largest is the $5 million Titan Krios, a cryo transmission electron microscope (cryo-TEM) that can be used to see structures of individual molecules. The rooms that house the microscopes are also specially

Clean room in the Nano facilities (Photo source: Wilson Architects) designed: vibration proof, humidity and temperature controlled, and shielded from electromagnetic waves. The microscopes are fully automated, meaning all data collected is transmitted and displayed directly on computers. In fact, researchers from all over the world can book time slots to use the microscopes remotely.

The facilities and equipment at MIT.nano are here to aid the research that will soon commence. Below, we highlight a few of the research projects that will be going on at MIT.nano and take a closer look at how the nano building will propel the research at MIT to new frontiers.

FEATURED RESEARCHERS

Vladimir Bulović

Professor Bulović is a Professor of Engineering and the director of MIT.nano. His lab develops the modern optoelectronic devices such as LEDs, solar cells, and lasers using nanomaterials.

What kind of nano research do you do, and how does this research influence our world?

Molecules, polymers, quantum dots, and other nano-structured solids open pathways to previously unimaginable technologies — from invisible solar cells to paper-thin LEDs to nano-scale lasers, from squeezable molecular switches to chemo-sensors for explosives and pheromones to strongly-coupled excitonic devices for new optical quantum computers. These are the technologies that my group imagines and pursues, guided by physical insights we first discovered at the nanoscale. Starting with a fundamental finding, we design and build a new device, then a prototype, and then often launch a new technology. Our alumni have grown our lab discoveries into companies that employ hundreds and make products now used by millions. With the expanding toolset of MIT.nano we will be able to accelerate the process of discovery and impact.

Vladimir Bulović will be the director of MIT.nano (Photo source OMICS International)

Jesus A. del Alamo is a Donner Professor and the director of the Microsystems Technology Laboratories (Photo source Microsystems Technology Laboratories)

Jesus A. del Alamo

Professor del Alamo is a Donner Professor and a Professor of Electrical Engineering. He is also the director of the Microsystems Technology Laboratories, the former micro and nanotechnology research center at MIT, now moving its equipment and personnel into MIT.nano. Prof. del Alamo's lab designs smaller transistors that will eventually lead to faster, more powerful electronics.

What kind of nano research are you doing, and how will the opening of MIT.nano affect that research?

In my group, we are exploring new semiconductor transistors to push Moore's Law [the empirical observation that the number of transistors needed in a dense integrated circuit doubles roughly every

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two years] beyond the point that silicon, the main stream semiconductor technology, can reach. So, my students fabricate extremely small transistors

Catherine L. Drennan is a Professor of Chemistry and Biology and investigator at the Howard Hughs Medical Institute (Photo source Kalman Zabarsky)

on exotic semiconductors such as InGaAs and InGaSb. My group [holds] many world records of transistor performance based on these materials. We heavily rely on the fabrication facilities of the Microsystems Technology Laboratories. We are very excited about the opening of MIT.nano and the opportunities that this is going to open to the nanotechnology community.

Catherine L. Drennan

Professor Drennan is a Professor of Chemistry and Biology as well as a professor and investigator of the Howard Hughes Medical Institute. Her lab works on determining the structures of metalloproteins and metalloenzymes. The development of cryo electron microscopy (cryo-EM) has allowed her lab to determine structures at a precision never attained before.

How will the opening of MIT.nano and its cryo-EM facility impact your research?

The opening of the cryo-EM facility is a game-changer for my research program. Obtaining time on state-of-the-art instruments has not been easy. We have waited six months or more and have had to travel across the country to collect cryo-EM data. With these instruments on campus, we will

Titan Krios cryo-TEM in the MIT.nano facility (Photo source Shannon Weng)

be able to move our projects along so much faster and we can take on new systems of study. There are so many structures of metalloproteins we want to get; structures that have been impossible to obtain by crystallography (the other main structural determination method). The advances in technology for cryo-EM are revolutionary and now MIT is part of the revolution!

Timothy Manning Swager

Professor Swager is a John D. MacArthur Professor of Chemistry and former head of the chemistry department. His lab works on designing carbon

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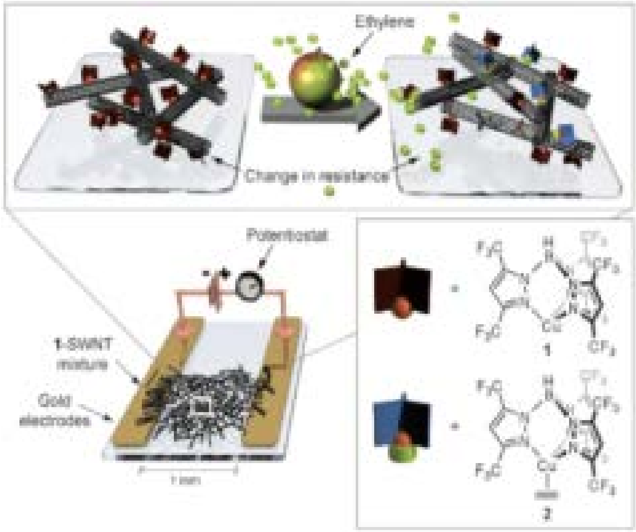
Timothy Manning Swager is a John D. MacArthur Profesor of Chemistry and former head of the chemistry department (Photo Source: Justin Knight)

nanotubes for various purposes, such as being a superb chemical sensor for ethylene, the molecule produced during fruit ripening. This new sensor can drastically reduce food waste, which is currently 30%-40% of all food produced in the U.S.

Prof. Swager describes his group's new ethylene sensor in his research paper:
"Our detection method has high selectivity towards ethylene and is simply prepared in few steps from commercially available materials. The sensing mechanism relies on the high sensitivity in resistance of single-walled carbon nanotubes (SWNTs) to changes in their electronic surroundings…. For the selective recognition of ethylene we employ a copper(I) complex [complex 1 in image]...which is able to interact with the surface of carbon nanotubes, thereby influencing their conductivity. Upon exposure to ethylene, [complex 1] binds to ethylene and forms complex 2, which has a decreased interaction with the SWNT surface. The result of this transformation is an increase in resistance of the SWNT network."



Copper (I) Complex used for selective recognition of ethylene in the Swager Group's rearch (Photo Source: Birgit Esser, Jan M. Schnorr, and Timothy M. Swager)

When asked about how the opening of MIT.nano will influence his research and the research at MIT in general, Prof. Swager said that MIT.nano will allow his research group and others to share equipment that all groups can benefit from. It is too costly for any single group to own all the equipment needed to conduct nano research. MIT.nano's imaging equipment and clean rooms will allow his group to see and manipulate molecules on a scale much smaller than was previously possible. Since no researcher has permanent offices at MIT.nano, all the facilities and equipment are shared for the good of the entire MIT community. ▪

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Mackenzie Lemieux (Photo source Mackenzie Lemieux)

SAID in STEM: An Interview with Mackenzie Lemieux

A discussion with the founder and coordinator of a seminar seiries dedicated to exploring inquealities, biases, and stereotypes in STEM

By Rachel Rock

INTRODUCTION

Students Advocating for Increased Diversity (SAID) in STEM was a seminar series held in the Brain and Cognitive Sciences (BCS) Picower Institute throughout the months of January and February. Through group discussions, critical analysis of journal articles, and talks from successful women in science, SAID aimed to raise student and faculty awareness of workplace inequalities. The series also sought to educate participants about the biases and stereotypes directly impacting behaviors and decreasing opportunities for women and minorities pursuing STEM careers, especially positions of leadership.

The series was highly successful and is aiming to expand further. This will involve launching in other locations and, likely, disciplines as well. Today, I got to interview SAID founder and coordinator, Mackenzie Lemieux, who, as a Tye Lab research technician, happens to be a woman in science herself.

INTERVIEW

Hello, Mackenzie, to start us off, I'm going to ask you if you could tell me a little bit more about what inspired you to start SAID in STEM?

So, initially, I was inspired to start a program like this for two reasons. Since I hope to be an physician-scientist in the future, I have presented my scientific research at many MD-PhD conferences. At these conferences there was always a talk or breakout session about the barriers women face in science and medicine, and there was often only one man attending each of these sessions. I thought to myself, Oh, this makes sense! It's a women and science talk, so only women go to these. At these sessions, students and speakers talked about their experiences in the clinic or in the lab with gender harassment and sexual harassment–really terrible stuff to hear. I just could not believe that this was happening. That this is happening. That it's 2018 or 2019 and these things happen to women in the clinic, and women in the lab.

> *"I think it's important to educate the community about the biases and stereotypes that are present and constantly shaping our behaviors and thoughts."*

And all I could think about was that if there were men in the room they'd likely feel upset and want to help! Plus, they're often in a position to help. So then, I started to think, If I could make a program that was attended by everyone in the scientific community, not just women, people could hear about these experiences and then hopefully feel motivated to advocate for women in STEM. This increased awareness would be really important to change the status quo.

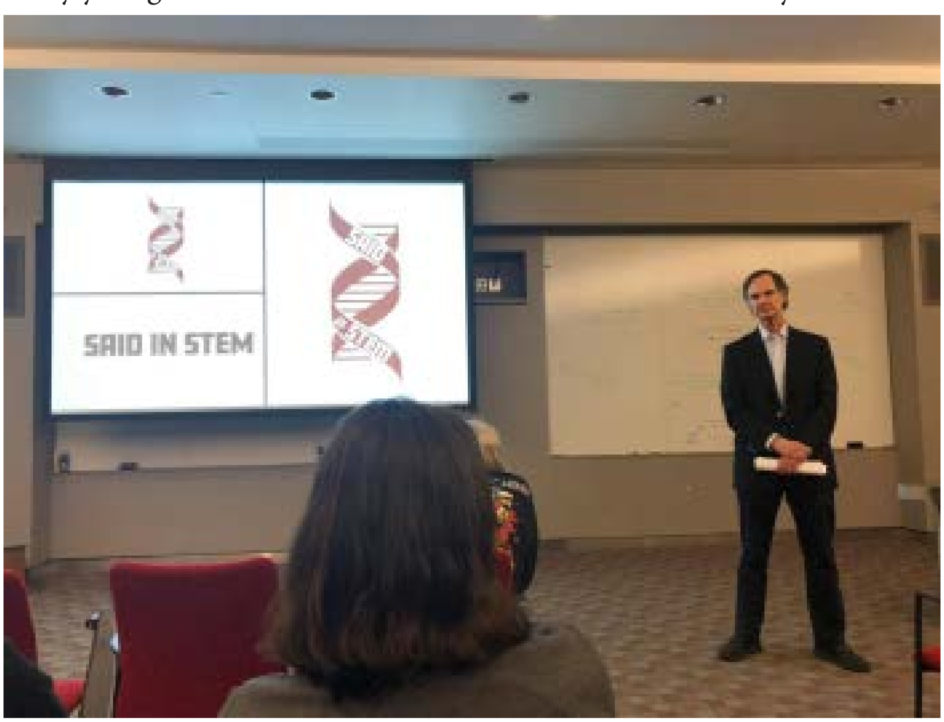
That was one factor. Also, some of my close mentors have faced gender harassment sexual harassment and also discrimination along their academic careers. This fact really motivated me; I was so frustrated that they had to deal with these things while trying to push the field of neuroscience to new levels.

So, those were the two main things that inspired me to do this. I, luckily, have not faced too much discrimination, though it's also the case that maybe I just don't always realize it happening. Actually, that might be the situation for a lot of women and minorities. Sometimes people think that's how a person like me should be treated in STEM..., which is pretty terrible in my opinion. At talks, I've noticed that speakers don't hold my questions to the same standard that they'd hold a males'–or an upper level females'–question to. This is a common complaint of many young women in STEM.

Could you tell me a little bit more about the structure of the seminars and how the course of the series sought to address these kinds of issues?

Yeah, totally! So my initial idea was to have some journal-club like meetings where we would look at some primary literature because as scientists, we like to know the facts and the data surrounding these issues. So, I first held two sessions on the primary literature showing that we all have implicit biases that are shaped by society and emerge very early in life. The literature also highlighted how these mental representations lead to a dearth of women and minorities in STEM. We focused on the work of two main researchers during these meetings. One was Dr. Ben Barres, who was a passionate advocate for women in STEM, and we focused on his article called "Does Gender Matter?". In the second journal club we looked at articles by Dr. Nilanjana Dasgupta. She is from UMass Amherst and her research focuses on what we can do to keep women in the STEM pipeline through targeted intervention at critical career junctures

Mackenzie Lemieux (left), introduces Professor Kay Tye for the final SAID in STEM Series 1 seminar (Photo source Mackenzie Lemieux)



Dr. Bertschinger speaks at SAID in STEM about institutional changes being made to improve diversity and inclusion (Photo source Mackenzie Lemieux)

After that, we had six different guest speakers attend SAID in STEM on different days, to talk about their scientific or medical career specialties and the obstacles they've faced throughout their career. We also had one speaker, Dr. Ed Bertschinger, the former Institute Community and Equity Officer at MIT who talked about what is being done at the institutional level to address the dearth of women and minorities in STEM. He also discussed his current research on the historical trends that lead to institutional change in diversity and inclusion.

Could you tell me a little bit more about some of the sessions that you found the most inspiring or informative, or that you found really taught people something?

The first session with Dr. Eve Marder's was very memorable. She was the President for the Society for Neuroscience in 2007 and is currently a Professor of Neuroscience at Brandeis University. Her presentation was impactul because she's a very confident and captivating speaker. She talked initially about her experience as a deputy editor for the Journal E-Life and how they try to address the issue of gender disparities in publishing. She also

Dr. Bertschinger and **Rozzeta**, visiting post-doctoral researcher from Malaysia (Photo source Mackenzie Lemieux)

gave advice for young people in (or entering) academia. I think her seminar addressed one of the goals that I first had for the seminar series: having successful women up on stage to talk about their experiences will provide a female role model/example and begin to build in people's minds a stronger association between woman and STEM. So, yes, she was a really powerful speaker, captivating, and very confident, plus had a lot of advice for us young scientists. The feedback forms support these conclusions. .

The other seminar that people enjoyed was Dr. Mary Montgomery's. She is a physician over at the Brigham and Women's Hospital and a Harvard Medical School Professor, specializing in infectious disease and LGBTQ health. She had a very nice structure to her presentation; she had some slides with more of a dialogue, but she first highlighted her career trajectory–why she decided to focus on infectious disease and be a doctor, not a scientist. Then she went on to discuss her experiences as an LGBTQ physician. She described her feelings of imposter syndrome, asking herself, "Do I really belong here?," showing the crowd that even the most qualified women can feel out of place and like they don't belong due to bias and the stereotypes people hold against women in science and medicine. She also talked about the marginalization of her patients; with HIV patients, there's so much stigma in society, and it's still there, still present. She showed us that you don't have to be a certain "type" of person to effect change; one's gender and sexuality do not limit their potential for success or impact.

Wow. That's a really empowering message, and it touches on something all too real at MIT. Many of my peers and myself at times have felt like, I shouldn't be here, or, I shouldn't be doing this, like, who am I? I don't deserve to be here...imposter-syndrome-type thoughts. Do you see this program as helping change those perspectives in the student body?

I really do. The moment that it hit me was during Dr. Kay Tye's talk. She spoke at the final seminar and she talked about the things that went through her mind as a junior faculty member and the things she thought about as she was moving forward in her career, and it really highlighted what I think many audience members felt or feel as junior faculty–it's your job as junior faculty "just to survive," as Dr. Kay Tye said. I think people often don't realize that other women and underrepresented minorities are also struggling; you're not alone. If someone as successful as Dr. Tye felt imposter syndrome, it is no wonder that young women in STEM also have these feelings as they progress through their careers.

I think that just having these powerful women in science stand up and talk about these issues, highlighting how real they are and that they are happening right now, is critical. It creates a space where people feel

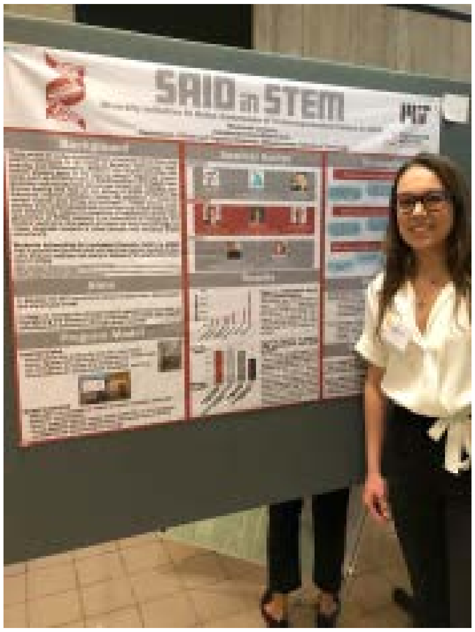
that they're not the only ones. Imposter syndrome is real. Successful people have felt it, and they pushed through these feelings by finding resources, advocates, and mentors which helped them to succeed and get to where they are today.

It's really powerful, the research that shows that people may prefer someone being more passive and less assertive if they're female. Then, that a woman being passive often leads her to being overlooked and not really being able to realize her potential...With SAID in STEM, you really get to see women and minorities and being successful in spite of these barriers. Putting that kind of image out there is powerful, and you've clearly attracted a good audience: at the session I attended, I saw a good mix of genders and ethnicities, and even a high school student. So this gets me thinking, where are you going from here, and how do you see the program evolving?

Regarding San Diego, I've been speaking to the Salk outreach program and they feel that SAID in STEM could really benefit the Heithoff-Brody Scholars program for high school students in the summer. This is a program where selected high school students come for the summer, join a lab, and get to experience hands-on lab work while learning both about scientific communication and how to apply for college. I think that having weekly or bi-weekly SAID in STEM sessions where the students can learn about the barriers that women and minorities face in STEM and how that impacts their ability to succeed will be important. These young scholars will be hearing from underrepresented minorities in the field, getting to train their brains to, for
example, associate, "female," or "black," with "science," or "neuroscience," or "immunology," or "cancer research..."

Hopefully, they'll feel inspired by some of these stories about women facing harassment or people facing discrimination in the workplace. This might motivate them to advocate at a young age. Then, when they become leaders in the field, they'll already have an edge thinking about these topics and hopefully keep their minds aware of their own biases. That's my idea for the summer high school program.

And regarding MIT, I talked to the Graduate Diversity Committee



Mackenzie Lemieux shares the results of SAID in STEM at American Association for Women in Science and Medicine Conference in New Orleans (Photo source Mackenzie Lemieux)

this week and showed them the results from the program. They were pretty excited, especially about its increase in size throughout the Winter, so they're working on contacting some other organizations/groups at MIT to get their support and to increase advertising for the program. I found that it was tricky as a research technician to advertise for SAID in STEM as I didn't have a huge network of students or any email lists to send my announcements out to. So I think that the Graduate Diversity Department helping me with advertising and connecting me with other organizations will really get the word out there and be huge for SAID in STEM.

Also, though this program had its roots in Brain and Cognitive Sciences, I do see it expanding to other disciplines, such as Mathematics and Engineering. It may possibly even go beyond STEM. Diversity issues really are pervasive across many disciplines. I think it's important to educate the community about the biases and stereotypes that are present and constantly shaping our behaviors and thoughts.

Thank you. Just another question: Is there anything that is a particularly good takeaway from the program? If you had to pick just one thing, what would it be? I know that's a hard thing to ask because there's just so much...

Yeah. I personally learned so much from the speakers and hearing about their experiences as well as hearing from Dr. Bertschinger at MIT about some of the actions underway to change culture. I think one major takeaway may be that more than one person is needed to change a culture at an institution.

"Class of 2019, you deserve to be here."

So you know there's this term, "outreach," but as Dr. Bertschinger said, it's better thought of as "inreach" in the scenario of advocacy: If you can get your group of scientists around you, your lab, your social network and allies to fight for one thing that's way more power than one person. Institutions don't often listen to just one person. I think that's something that I have learned, that the more people together, the better, then things will change. And that's happened at MIT: that's why the engineering department at MIT is 50/50 males, females. It's because people came together and spoke up.

That last point about the gender ratio–it's important. I'm thinking now about Pi Day now and how there will be all of these young female frosh coming to MIT in the fall. I'm in one sense afraid for them, as I remember this guy in high school grinning smugly as he told me, "Congratulations, Rachel. Great getting into MIT! Being first-generation college and female, your parents must be so proud of you." I didn't realize at the time...but it really hurt me. In an instant, I felt like I didn't deserve to be going to MIT. Like he should be there in my shoes because he was better at math, anyway. Do you have anything to say to young women and minorities entering MIT who may be hearing this sort of thing?

Class of 2019, you deserve to be here. I know this is hard to actually do in practice , but you should never feel like anything was merely "given" to you. You worked hard, and should be proud of the work that you've done to get to where you are today. You are no less qualified than any of your peers because you are a woman or because you are a person of colour. If anything, you have probably worked even harder than most of your peers to get to where you're at right now.

Don't be afraid to ask questions, to speak up, to say things during lectures. You deserve to be here and your voice needs to be heard to help progress the fields of science, technology, engineering, and mathematics. ▪

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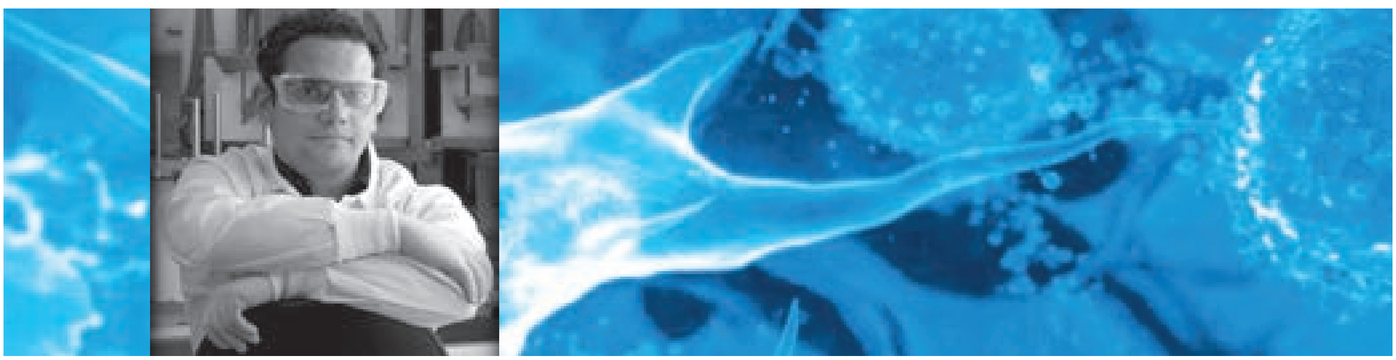

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MURJ Reports

Visualizing the Shape-Invariance of Deep Neural Networks

Elaheh Ahmadi[1], Alexa Jan[2], Xavier Boix[3]

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1. Overview

Deep neural networks (DNN) have achieved significant popularity in the machine learning community in the past few years. However, we still have much to investigate about DNN learning representations and computations. Recent research has shed some light on the intermediate operations of neural networks through layer visualization (Zeiler and Fergus, 2014). A deeper understanding of other dimensions, such as invariance, have not been prioritized, but would help increase transparency in DNN processes and uses.

Invariance is a property describing a set of images that all produce the same activation in a neural network. Understanding invariance could help gain insights on how to lower the number of samples needed to train a neural network (Gens et. al, 2014). This optimization comes from the fact that for every sample given, the network would be trained for all of that sample's invariances as well. Scale, transition, and clutter invariance have been explored in some depth, but other shape invariances still remain largely unexplored (Chen et. al, 2016).

Papers that do study invariance focus on identifying images with the same neuron activation within a given dataset (Cadena et. al, 2018). Furthermore, although there have been recent efforts to understand the representations of individual neuron units, much less is known about representations encoded in neuron populations, otherwise known as layers (Zhou et. al, 2017 and Zhou et. al, 2018). However, a layer's neural representations are known to be more general and expressive than individual units. Therefore, we intend to explore the entire neuron population within a layer. Additionally, our network generates natural invariant images for each layer, as opposed to manufacturing invariances within a dataset, which may not be relevant for DNN learning. Our proposed approach also allows us to investigate dimensions of invariant images currently unexplored, such as shape and geometric invariance.

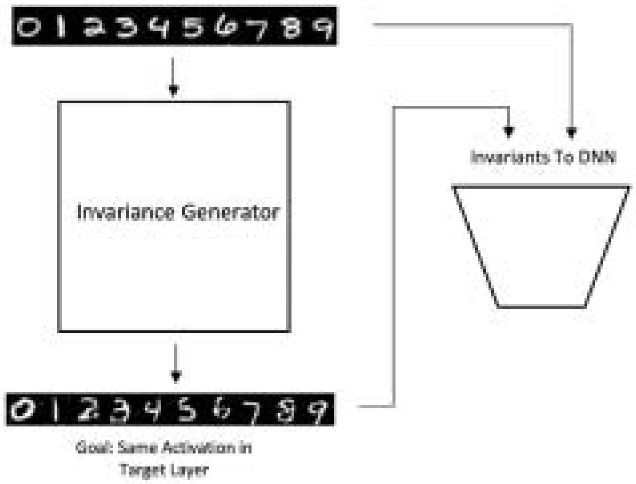

Figure 1: Overall layout of our invariance generator. The goal is to generate images with the same distribution as the input that are invariant to a target layer in the DNN under analysis.

2. Methods

We generate invariants with a network consisting of an InfoGAN and a DNN under analysis (Figure 1). The InfoGAN is a type of generative adversarial network, consisting of a generator and discriminator that optimize each other's performance (Chen et. al, 2016). This maximizes the mutual information between a subset of latent variables and observation data. These latent variables control the latent features that will ultimately generate unique invariances. The images are generated by minimizing the difference in activation between training images and generated images from a target layer in the DNN.

To achieve this minimization, we take the activation of training data from a layer in the DNN under analysis and feed it along with a vector of latent variables into the generator (Figure 2a). The inclusion of latent variables in our network allows us to identify the vector space of the data, as well as visualize the invariants specific to each DNN layer.

Next, we pass the generated images back to the DNN under analysis and calculate the activation difference (Figure 2b). Our optimization function seeks to minimize the activation difference and maximize the mutual information between the latent and the observed variables.

3. Results

Current experiments focus on finding the invariances of an MNIST classifier with three fully-connected layers. The MNIST dataset, which contains labeled hand-drawn digits, is used because it is a benchmark dataset in the machine learning community. This neural network classifier was chosen because it serves as the standard starting point in deep learning and performs consistently well with GANs. Our preliminary results show a fully trained InfoGAN, with network losses consistently reaching zero and significant progress in experiments with the MNIST classifier

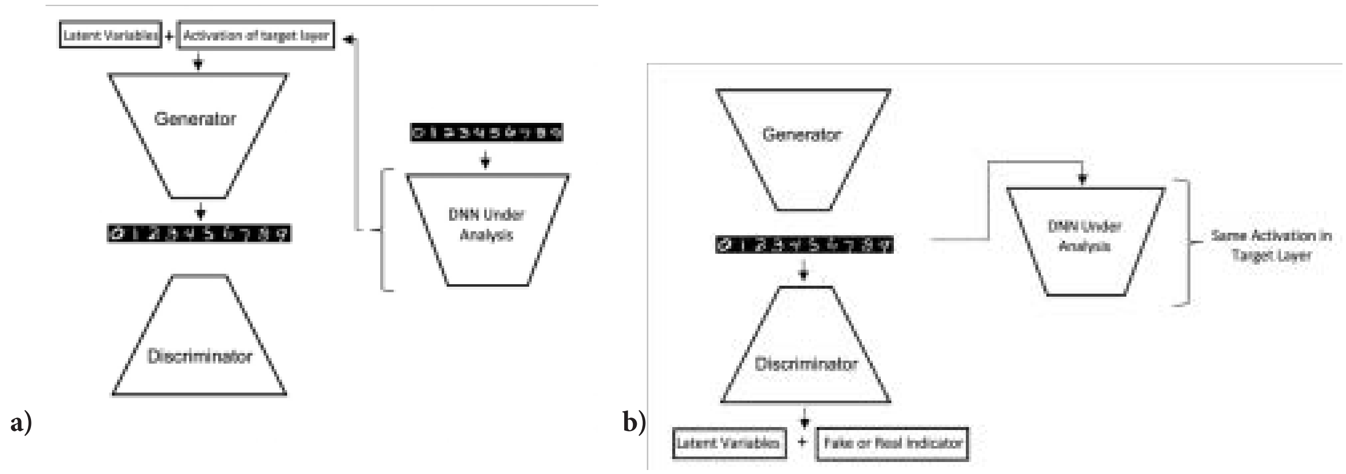

Figure 2a, b: Training steps in the Invariance Generator. a) The training data is fed into the DNN and the resulting activation of the target layer and latent variables are passed into the generator. b) The generated images from the generator are passed into the discriminator and DNN to minimize the activation difference and predict the latent variables.

Figure 3: A comparison of the MNIST training data and generated invariances. Above, we can see example samples of each number in the MNIST training dataset. Below, we have generated invariant images that produced the same activation in the last fully-connected layer of the MNIST classifier.

as the DNN under analysis. Chiefly, our invariance generator network has successfully generated invariances of the MNIST dataset, created from latent variable manipulation. These images all produce the same network layer activation in the MNIST classifier (Figure 3).

4. Conclusion

Next steps involve classifying our invariances quantitatively, as current work focuses on qualitative descriptions of invariances. This classification will entail plotting invariances on a coordinate space defined by the vector of latent variables to measure effects of its changes on dimensions of invariance. Future work also includes experimenting on other widely used neural network architectures to find patterns and generalizations to further optimize neural network training.

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Post-Disaster Housing and Rebuilding

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This UROP project includes providing analysis, insights, and recommendations into post-disaster housing solutions in the United States. Working alongside the Federal Emergency Management Agency (FEMA), as well as the National Association of Homebuilders, our work helps improve the experience of future disaster survivors by providing new insights and knowledge created for the benefit of emergency management officials, policy makers, political leaders, and the construction industry. We are in the process of writing an academic paper on our research on professional license reciprocity.

According to the Centre for Research on the Epidemiology of Disasters, 335 natural disasters in 2017 affected over 95.6 million people, killing an additional 9,697 and costing the U.S. over $335 billion in rebuilding and recovery (ReliefWeb 2018). While post-disaster construction capacity has been studied from a perspective of material availability, limited disaster-specific research has been done studying the impact of labor mobility on disaster rebuilding speed. Current policies like license reciprocity agreements may not fully utilize labor mobility for disaster rebuilding purposes (Diaz et al. 2014, Celentano et al. 2018). This study uses the occupations of electricians and plumbers as an entry point to understand labor mobility within the construction industry.

Our initial analysis includes tracking reciprocity laws for all 50 states and identifying trends for which states utilize certain reciprocity agreements, specifically for the professions of master and journeymen electricians and plumbers as there is data available for these professions. This data was compiled from two major sources: the U.S. Census Bureau and the National Center for Construction Education and Research (NNCER), particularly for state laws and reciprocity information about electrician and plumber legislation.

As we compiled individual state data and reciprocity legislature, we found that reciprocity rules varied widely from state to state. For ease of analysis, we divided state professional licensing laws into four categories: Locally Licensed (LL), State Licensed (SL), and State Licensed with Reciprocity laws (SLR). The states in each category are show in Figure 1 and 2 below for electricians and plumbers respectively. State Licensing is the most common for both professions, and states near the middle of the country tend to be more locally licensed than states on the coasts.

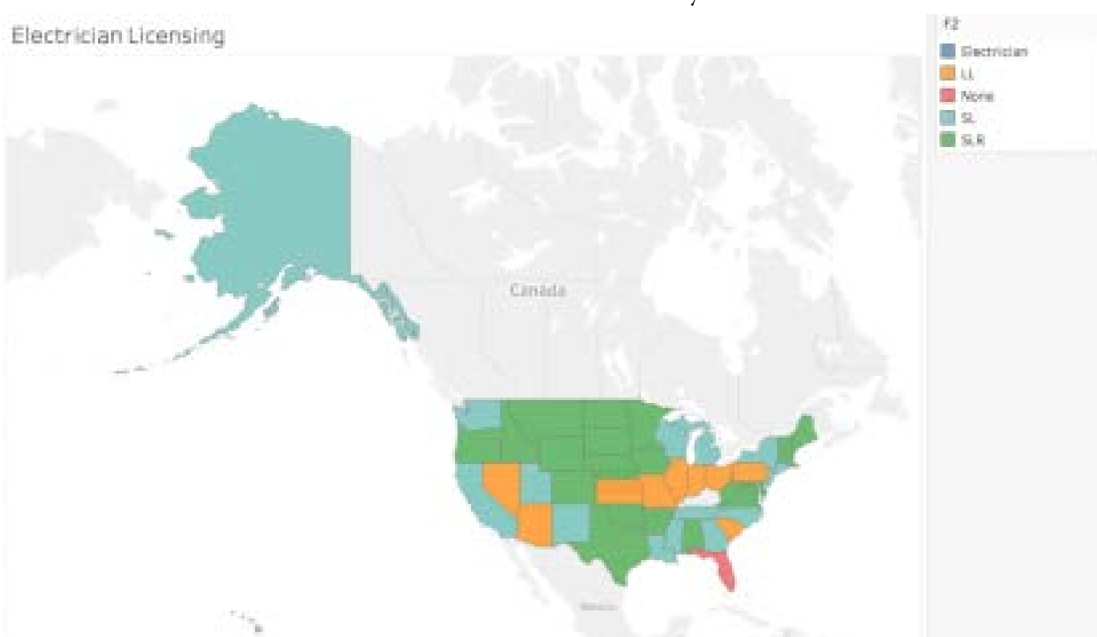

Figure 1: Electrician Licensing by State
Many states have reciprocity laws for electricians and can utilize them in disaster events.

Figure 2: Plumber Licensing by State
Plumbers tend to have more local licensing than electricians and overall fewer reciprocity laws.

Our work is important for two main reasons. First, the inconsistency of licensing across states makes it extremely difficult to rebuild in an efficient manner after a disaster event - some states may not allow electricians or plumbers in other states to work on projects in a different state from which they are licensed in. Second, our study is the first to identify the nuanced differences between professional licensing laws and how this might affect how reciprocity actually works in action. We aim to quantify the surge capacity that a given state could have if reciprocal states sent them, for example, all of their electricians, to help rebuild after a disaster. Ultimately, we hope to continue our reciprocity research to determine how labor pool reciprocity may be useful in post-disaster rebuilding and in understanding overall construction capacity in the United States.

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Data Analysis of U.S. Power Plants

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Electricity generated by wind and solar is intermittent (i.e. fluctuates on short time frames), and the demand does not respond significantly over a comparable period. If the difference between supply and demand is sufficiently large, the resulting change in AC frequency can damage the grid and connected electronics (Brendan Kirby et al., 2002). Intermittency is one of the reasons for the strong interest in grid-scale energy storage, and of the available options, batteries are a primary candidate. Extensive battery research and development is happening, but battery costs are still not low enough to see grid-wide installations (Rylan Dmello et al., 2016).

In the absence of grid-scale energy storage, the power output from fossil fuel power plants is being adjusted in real-time to ensure supply matches demand. However, fossil fuel power plants were designed and built to run at a relatively constant power output for maximum efficiency (Debra Lew et al., 2013). The Energy Systems Modeling Group is testing the hypothesis that in the process of responding to intermittent renewable electricity generation, fossil fuel plants emit more carbon per unit energy than before the introduction of renewables, accounting for general technology improvements over time. The hypothesis is based on the thermal and mechanical inertia that the power plant equipment must overcome and operational changes in emissions controls during startup (Lew et al., 2013). The results of this analysis could support changes in power plant operation and government regulations.

Power plants are a collection of units, which are themselves aggregations of individual generators.[1] The Energy Systems Modeling Group is creating an analysis tool written in MATLAB, that uses hourly unit-level data published by the EPA to answer that hypothesis and other questions. For each unit in a state at every hour, the EPA's dataset records the on-time of the unit, quantity of electricity produced, heat rate which can be used to compute thermal efficiency, and emissions of CO2, SO¬2, and NOX. These gases are contributors to global warming and local pollution through events such as acid rain and smog.

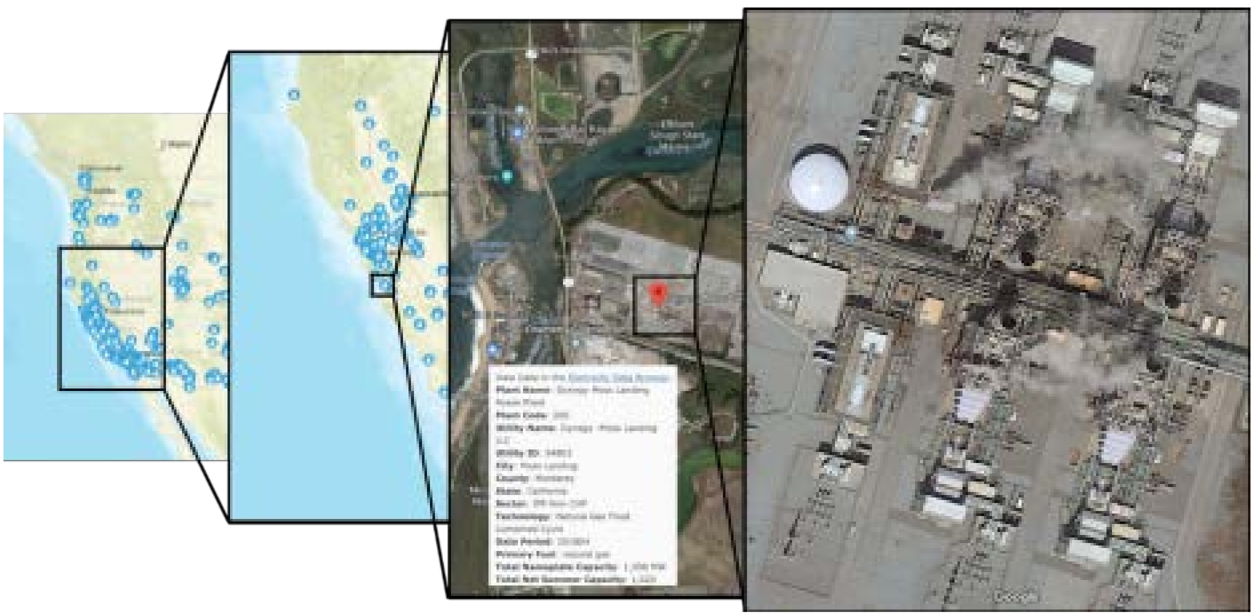

Figure 1: The tool can perform regional analysis and drill down to a specific power plant (Emre Gencer, 2019).

Before performing the analysis, the EPA data is formatted for faster retrieval and cleared of units that are not listed in the EPA's Emissions & Generation Resource Integrated Database (eGRID).

1 Two types of power cycles are simple and combined. A simple cycle is a standalone gas or steam turbine. In a combined cycle, hot exhaust gas from a gas turbine is used to heat water and power a steam turbine. A unit is a fossil fuel combustion device. For a simple cycle gas turbine, the generator and unit describe the same thing. In a combined cycle, the steam and gas turbine are separate generators within one unit. Some power plants have complicated generator to unit groupings.

eGRID provides information including power plant location, number and type of generators (gas or steam), age of generators, and what fuel is used (e.g. natural gas, subbituminous coal, or petroleum coke).

Although eGRID provides useful, detailed information, it is does not include how generators are organized into units at each power plant. Since units have varying configurations, a mapping between units and generators allows for robust comparative analysis. This deeper analysis could identify specific turbine models that provide a better response to changing loads on the grid. Thus, a generator-to-unit mapping for the PJM region was made. This step involves was done manually since some mappings are unintuitive. Still, the bulk of the work is repetitive, so future work includes creating a rule-based classification system to partially automate this step.

The primary focus during the fall semester was rewriting MATLAB code to employ vectorization in the formatting and cleaning steps. Vectorization is a programming technique to apply operations onto entire arrays instead of individual elements. Combined with other changes, the new version reduced the computation time from 5 days to a few hours to process data for the Pennsylvania-New Jersey-Maryland (PJM) regional transmission organization. They service regions of 13 states and the District of Columbia. These preliminary steps would enable later analysis with the granularity represented in figure 1.

The analysis required to investigate the hypothesis about increasing emissions per unit energy is still ongoing. In addition, current efforts are directed towards improving a user interface, pictured in figure 2. A UI allows non-technical users to benefit from publicly available data which is unapproachable as-is. The target users are strategic decision makers at businesses and government agencies. This tool is intended to inform decisions such as power plant design for generation flexibility and policies such as energy storage subsidies to more accurately incorporate the value of managing renewable energy intermittency.

The analysis of nationwide thermal electricity generation is one effort within the Energy Systems Modeling Group led by Emre Gencer. The team's goal is to create Sustainable Energy Systems Analysis and Modeling Environment (SESAME). This tool will combine techno-economic and life-cycle analysis of electric power, transportation, and industrial sectors to model the United States' power system response to decarbonization.

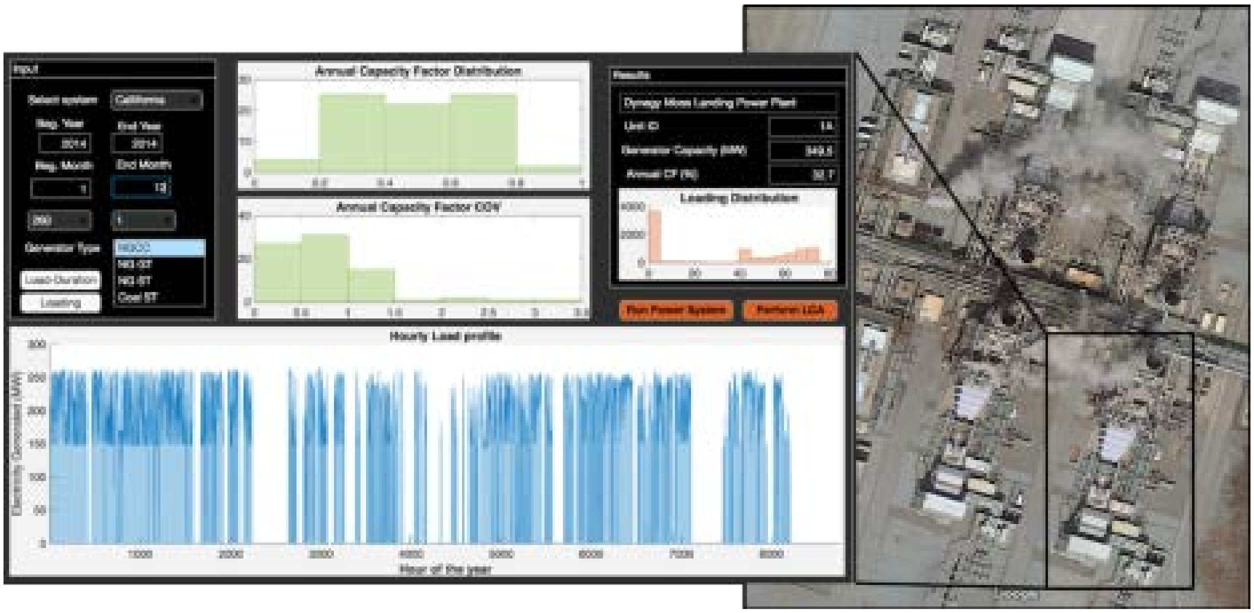

Figure 2: User interface to analyze data and view results, ranging from the scale of regions to the unit level which is emphasized by the boxed section (Emre Gencer, 2019). The simple UI empowers decision makers without requiring programming expertise.

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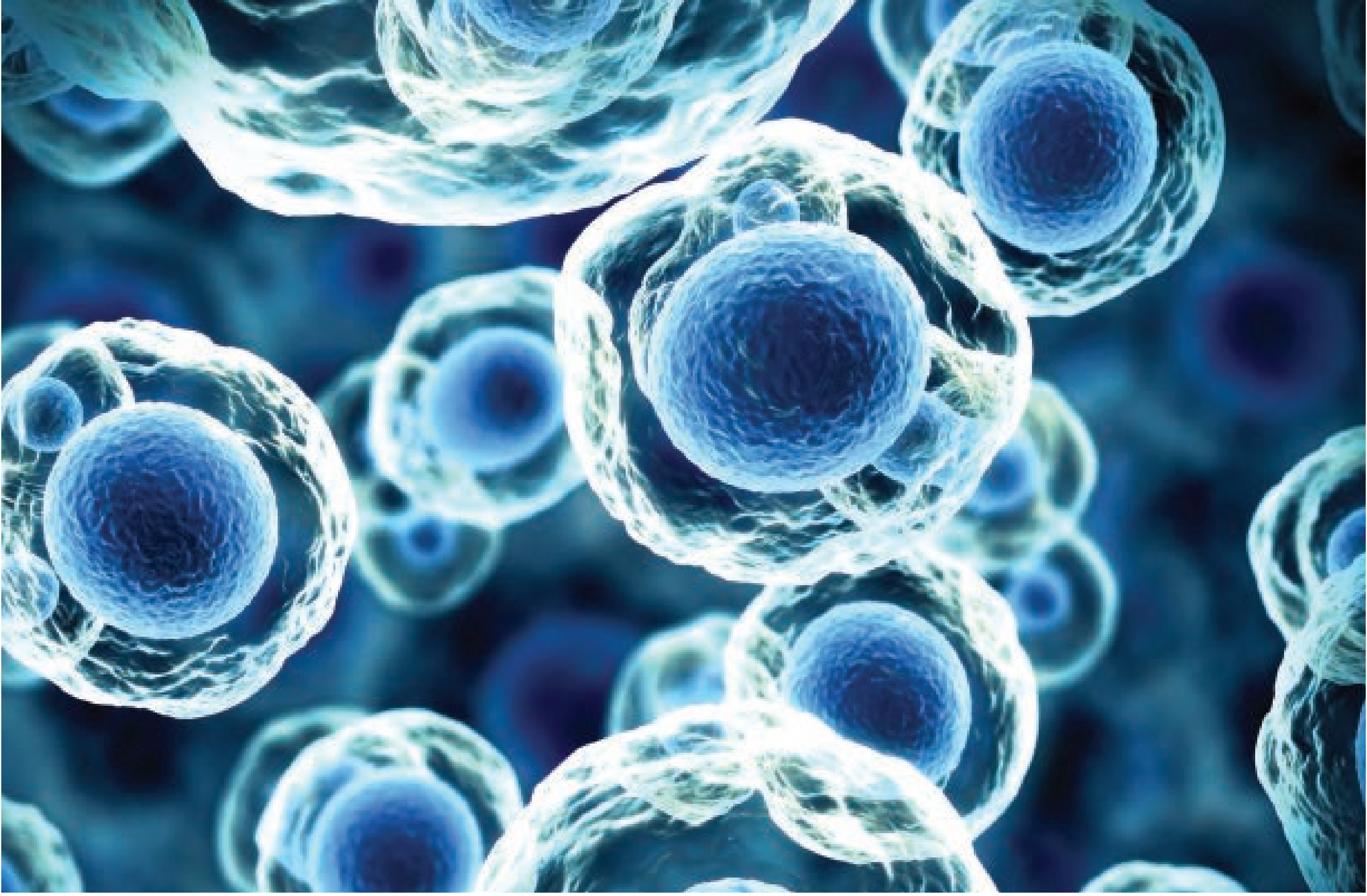

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