

EECS Student Magazine

Works from Students at the University of Cincinnati



Contents:

- Forewords from Dr. Cahay, Dr. Fuchs, and Michael Santacroe
- Seven Articles from EECS Research, Projects, Classes, and Student Groups

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Foreword from Marc Cahay

Dr. Marc Cahay, *EECS, Department Head*

It is my great pleasure to write the foreword of the first edition of the *EECS Student Magazine*, an initiative taken by some of the EECS undergraduate students.

This is the pilot edition of the Magazine. This publication is not meant to be an academic journal, hence the name Magazine in the title. If you have some serious academic work, we recommend submitting to an academic journal.

Future editions are scheduled to appear twice a semester starting in the Fall of 2019 and are intended to highlight any work that our undergraduate students have done in the Department of Electrical Engineering and Computer Science (EECS) at UC besides their classwork. Undergraduate research work is highly encouraged, but any other projects, completed at school or home, are also acceptable. It could be a description of one of the numerous (close to 100) senior projects undertaken by our students in their final year of their BS programs. For another example, many of the 5000-6000 dual level classes culminate in a large final project, which would be great submissions. It could also be an account of some of the research projects carried by some of our junior undergraduate students participating in our Protégé program or involved in any REU project in some faculty lab (Research Experience for Undergraduate Students, including in the WISE program). This first edition gives a flavor of the type of articles which will appear in future editions.

The publication will be widely distributed using the EECS and College of Engineering and Applied Science (CEAS) newsletters. Our goal is to show how proud we are of our students and their accomplishments and open up many more Co-Op and job opportunities as well as opening doors to some of the best graduate schools in the country, even though we hope that many will stay at UC for that! We hope that other departments in CEAS will emulate this new initiative which, as I must reiterate, came from the students themselves. I wholeheartedly support their effort and join their excitement.

I hope you will join in this new venture by contributing to future editions, which I have no doubt will be a great success. Enjoy the pilot edition!

Foreword from Zachariah Fuchs

Dr. Zachariah Fuchs, *EECS, Assistant Professor*

SINCE joining the Electrical Engineering and Computer Science Department last fall, I have been impressed with the variety and quality of student projects that take place both inside and outside the classroom. I believe that engineers and programmers truly learn the theory we teach them while attempting to design, implement, and test a realizable system. It will never work perfectly the first time, and the resulting debugging process forces them to think about the engineering concepts from different perspectives which they may never have considered before. These experiences are invaluable, and the resulting skills cannot be acquired by simply reading a book, watching a video, or sitting through a lecture. That is why I was so pleased to see a student culture that not only embraces, but actively seeks out opportunities to get their hands dirty and actually build something.

However, I learned about most of these projects accidentally through word of mouth. Therefore, this publication, the EECS Student Magazine, provides an important opportunity for students to show off the results of their hard work and highlight some of the amazing things going on within our department. Perhaps more importantly, going through the writing and editing process for this publication is another opportunity to gain even more experience. Despite efforts to incorporate more writing and presentations into our curriculum, communication in general is often a weak point for many engineers and computer scientists. We believe the EECS Student Magazine provides our students an opportunity to write about a topic they are passionate about and will encourage them to develop a habit of publishing their work. Whether these students go into industry or continue on to grad school, the ability to present their work will make them more valuable future employees and researchers.

I look forward to working with the students on future editions of this magazine.

Foreword from IEEE at UC

Michael Santacroce, *M.Sc. Computer Engineering B.Sc. Computer Engineering*

WE have extremely high hopes for what might come from this initial issue; perhaps eventually sending future magazine issues to parents, alumni, or even employers. It is easy to envision the magazine becoming competitive and rewarding to publish in. Sponsorships, awards throughout the year for the best articles, highlighting some Co-Op and senior project submissions, maybe collaborations or partnerships with employers or student groups for special issues. Maybe scholarships! A host of possibilities exist.

We can imagine a world where this magazine has that kind of impact, however, we cannot make that happen on the first go. The magazine will take a large amount of love and dedication to become as fruitful as we hope it will be. My faith is in the future IEEE executive members to bring this goal to reality!

More than time or work, however, the magazine needs submissions to be successful. Submissions from **you**, from students at EECS. I have seen firsthand the extra mile, at times the extra marathon, that my peers will sprint through to achieve the highest quality work possible. They wake up at 5am to run the career fair, they work the hackathon for 24+ hours straight, they give their weekends to fix just one graph or run one more simulation, they Co-Op with companies like Apple and Google and Microsoft and NASA and many hundreds more, and they helped me make this magazine even though there is not much in it for them. They push themselves, constantly, in all aspects.

Our goal is simply to show off these efforts. I personally urge you to go that extra mile (within reason - there is such a thing as personal mental health, which many make the mistake of neglecting.) If you are doing so, or you have already, I then urge you to write up your experience and submit it here. Nationally and globally, the IEEE publishes many of the best journals and magazines around. Our local chapter would like to emulate this practice. Not only is it good to learn about what others are doing, but it can be a way to inspire students to achieve more, as the other editors have talked about in their forewords.

My peers do an extraordinary amount of great work. In the future, this magazine may be the place to see their talents showcased. As I have prepared to graduate this semester, I have experienced the strongest feelings of nostalgia, pride, sorrow, and excitement. I know what students here are capable of and I cannot wait to receive my copy of this magazine in the future!

Grace Hopper 2018 Reflection

Sydney O'Connor, 3rd Year M.Sc. Computer Engineering, B.Sc. Computer Engineering,
Mai Truong, 5th Year B.Sc. Computer Science, Laura Tebben, 5th Year B.Sc. Computer Science,
and Mansi Patel, 5th Year M.B.A, B.Sc. Computer Science,

Abstract—Grace Hopper was an extremely impactful time for all attendees and has left a lasting impression on how we, as females can succeed in this field. Below are accounts from the University of Cincinnati's GHC 2018 ACM-W attendees.

I. SYDNEY O'CONNOR

I had an amazing experience at the Grace Hopper Celebration this year. I am so thankful for UC for sponsoring me to be able to attend. It was truly a once in a lifetime experience and I know that the opportunities I got there will benefit me for years to come. The conference began with the keynote speaker, where all 20,000 attendees gathered to listen to some of the most influential women in tech today. Being surrounded by this many women in my field was unbelievably inspiring. The speakers not only empowered me to follow my dreams, but also gave great career and technical advice. The ending speakers and breakout sessions only built on this, and were all incredibly valuable.



While I loved the sessions, speakers, and networking opportunities, my favorite part of the conference was the career fair. The convention center was filled with hundreds of companies, all looking to hire women in technology. I have never had the opportunity to speak to so many companies before, much less the top companies in the world. I spoke with representatives from Google, Facebook, Microsoft, Amazon, IBM, and so many more. I even had the opportunity to interview with Facebook, Apple, Northrop Grumman, Texas Instruments and Tesla at the conference. Without the opportunity to attend Grace Hopper, my resume would never be noticed by these companies. Instead, I got the chance to not only be noticed, but be interviewed, and just get advice and learn from engineers at the top tech companies in the world. I even left the conference



with a job offer from Northrop Grumman, and advanced to the next stages of interviewing with multiple other companies.

Due to this conference, I have accepted a co-op offer from Tesla. I am beyond excited to start working for this company and help bring back recruiters to UC.

The opportunities at Grace Hopper are simply unparalleled and I cannot wait to return to UC with the knowledge I have learned. I learned so much from the speakers and from talking to engineers and company reps at the career fair. I hope one day to be able to work for one of these amazing companies and encourage them to recruit other UC students. Not only was Grace Hopper an amazing professional development opportunity, it was also a ton of fun. It was great to have a chance to network and connect with my female peers, especially at UC, and build a support network. Each night after the conference, many companies sponsored events to continue networking. These events were so much fun, and attached is a picture of the UC student group and me at one of the Google events. I cannot express my gratitude enough, and I can't wait to see where my GHC experience takes me.

II. MAI TRUONG

Being able to attend Grace Hopper Celebration last week meant a lot to me. I made a lot of connections before, during, and after the conference. The connections were both professional and personal. Before the conference, I found out some groups on Facebook for people seeking tickets and accommodation. Even though ACM-W was able to provide me registration and accommodation, I still kept in touch and hang out with friends I've made there. Before the conference, I got 2 interviews from companies reaching out. I also found a recruiter's email on Twitter, reached out to her, and got another interview set up during the conference. It was also fun to share sign-up information about company events among friends.



At the career fairs, I was thrilled to see hundreds of tech companies, many of which I really want to be a part of, decorated their booths and talked to students. Some company staff members just collected resumes and told job seekers to apply online, while others actually looked at my resumes and asked questions. Two of those conversations resulted in interviews. Many companies separate resumes collected at Grace Hopper from applications submitted on other channels, so I spent the majority of my time checking in company booths and putting my resume in their GHC pile. Another exciting part of the conference is the fact that I am surrounded by so many confident and talented women, all the time. It feels very empowering for me since this is my first time going to a tech event where the majority of attendees are female. I tried to not leave a lot of space in my luggage for swags (free items with company logos), but I still ended up with a fair amount. I mostly got T-shirts, phone holders, stickers, etc. I found out that the president of the LLVM open source compiler project, Tanya Lattner, was representing LLVM. I never thought that I would be able to meet her in person. My favorite T-shirt from the collection of 10 T-shirts was the LLVM dragon T-shirt, and same goes for the dragon sticker.

The career fair was laborious in the morning and afternoon, but I had a lot of fun at the company events in the evening. Some events were popular and overcrowded, while other are less well-known but offered much more values for the time spent. On Tuesday before the conference started, I was still



hoping around from HubSpot to Lyft parties to get free food. During Wednesday at the career fair, I talked to a company I had interviews with before the conference and got invited to their private dinner. Even though it was a sit-down multi-course meal and I missed other company events happening at the same night, it was very relaxing to not have to stand in lines for everything like on Tuesday. The same thing happened on Thursday when I decided to go to Cisco Meraki dinner, skipping Facebook or Snapchat parties that many attendees were going to. It turned out to be a great choice. Not only did I get \$20 Lyft credits to go to the venue and back to the hotel, Cisco Meraki CEO Todd Nightingale happened to stop by the table where another girl and I were sitting. He talked to us for an hour, from how he started in the tech industry, what he had learned, networks security, to what a CEO actually does for a company. It was great talking to him and I learned a lot about what it's like being a real CEO of a big company. Friday were lighter since the career fair ended early and I could return to the hotel before going back to the convention center for the closing party.



In short, going to Grace Hopper Conference was an awesome experience for me. I connected with so many people that I would not be able to reach in my daily life. I felt the support that the

tech community is giving towards women in tech, evident by many executives stopping by their company's booth to interact with job seekers. The trip was exhausting but fun, and I hope more women in Engineering at UC would be given the chance to attend Grace Hopper Celebration.

III. LAURA TEBBEN

The Grace Hopper Celebration of Women in Computing was the most positive, empowering experience of my college



career. Being surrounded by so many intelligent, driven, and successful women was so inspiring and uplifting. As a woman in computer science at UC, 88% of my peers are men, which can be alienating and discouraging. To be able to attend this conference and meet so many women in my field was such a unique experience and was the first time since starting college that I was not the odd one out. I would highly recommend to every woman in tech that she attend GHC.

Even from a purely career-focused perspective, GHC was hugely rewarding. As a senior graduating in May and looking for full-time positions, the GHC career fair was very beneficial. In the month leading up to the conference, I had 10 interviews (all obtained by companies finding my resume in the resume database), and an additional 8 while at the conference itself. Before even leaving the conference, I got 3 offers! One from IBM, one from Capital One, and the last from Accenture. I am also still in the interview process with a couple other companies. This experience gave me the opportunity to network with companies that don't come to UC's career fair (like IBM, Capital One, Facebook, etc.) and make connections that I would not have otherwise been able to make.

After this conference, I accepted a full-time offer with IBM. I don't know if I would have ever connected with IBM if it weren't for this conference. I'm excited to start my career with this company and motivated to encourage recruiters to look at UC as a source for co-ops.

I am extremely grateful for the departments support in sending me to the conference. I think it was one of the most valuable opportunities that I have been given and I highly recommend continuing to send women in the future.

IV. MANSI PATEL

I have been extremely lucky to have attended Grace Hopper Celebration for the past 3 years, however this year, 2018 has been the most impactful. As a senior looking for full-time positions, attending GHC was crucial to finding companies that I might not otherwise at UCs career fair. Throughout the whole process, I had 13 interviews and received 13 offer letters from all companies. Prior to the conference, I had initial interviews both technical and behavioral. The conference provides an expedited interview and offer process which is unlike anything I've ever been a part of.

By the end of the three day conference, I had offer letters in my hand from top-tier companies such as Accenture, IBM, Microsoft, Cisco, GE, Deloitte, HMB, Ebay, PWC and more. I made a lot of contacts throughout the conference, and many of whom I still connect with on LinkedIn today. These women are leaders in the industry and many have reached out to me about recruiting activities with ACM-W. Betsy from Accenture is really looking to ramp up recruiting at UC and has been talking to me about how they can improve their interview process. Brittany from Cisco is looking into hiring co-ops in their Raleigh, NC office. I've connected her with co-op advisors to help her understand the process. Shunying from Microsoft is working with me and Deb from the co-op office to bring a bigger presence of Microsoft to the spring career fair. I am also working with Microsoft student partners, Tessa and Paul to help create an informational meeting and recruiting meetings.

I have officially accepted my full-time offer with Microsoft in Seattle. I honestly didn't know that I even had the potential of working with an amazing company like this until I attended GHC this year. I can't even begin to thank the department for



and I'm so grateful for Dr. Marc Cahay for recognizing the importance of this conference for females. I encourage the department to continue funding and send even more females to this conference and others like it. If I had attended this conference my freshman year, I know for a fact that the thought about dropping out of my major would have never crossed my mind. Attending this conference now as a senior has given me the platform to speak out and encourage more females to continue their journey in the technical field.

sending me and females like myself to this conference. You are opening doors that we didn't even know existed by sending us to conferences like Grace Hopper. You are giving us the confidence to realize that we belong in this field and that we can succeed. As females, we often face the impostor syndrome, but attending GHC has made me realize that I do have a huge support system and there are many, many opportunities for me to connect with other females.

I am devoted to giving back to the University through the best way I know, which is to come back and recruit through my company. I'm more committed than ever to create a pipeline of talent that streams to Microsoft from University of Cincinnati. I know how capable and how well trained students from UC are through the co-op program and this is something that I have also brought to recruiters from Microsoft. They're incredibly impressed with the amount of experience UC students come with and that truly sets us apart from many other universities.



If I wasn't able to go to GHC this year, I don't think I would have been able to network with as many individuals as I did. They're so impressed with the talent we have at UC and are looking to come and make UC a prominent recruiting school. I have been able to accomplish every goal I had set for myself since freshman year and UC has provided me the opportunity to achieve more. I thank the department and UC for all of these opportunities and for truly giving me the opportunity to provide a better life for myself and my family. The opportunity to attend GHC my senior year has truly changed my life

Priority Hints: Resource Loading in Google Chrome

Dominic Farolino, 5th Year M.Eng. Computer Science, B.Sc. Computer Science

Abstract—Loading resources has historically been a critical and challenging task for web browsers, seeing as how low-friction and network-dependent the web platform is. Consequently, browsers have developed heuristics to determine, in a generic way, which resources should be prioritized above others, primarily based on resource type. The browser’s heuristics may work broadly across a slew of websites in the general case, but certainly there are instances in which the developer of a website knows that a certain resource on a page is high priority, when the browser would consider it low-priority. Priority Hints is a web standard that allows web developers to communicate the suggested priority of a resource to the browser to take into consideration.

I. STRATEGIES FOR PRIORITIZATION

HISTORICALLY, browsers follow a somewhat complicated predetermined set of heuristics to determine which discovered resources should be prioritized over others [2]. Since the IETF’s HTTP/1.1 protocol has no native support for indicating the priority of a requested resource to a server, this leaves room for browsers and web developers to innovate in this space.

A browser generally uses self-determined priorities to create a queue for low-priority resource requests to sit in while high-priority requests are being discovered and fetched. Once the high-priority requests are fetched, the low-priority requests can themselves be fetched and flushed from the queue. This queuing prevents bandwidth contention between low- and high-priority resources hosted on the same origin, especially when the low-priority resources are discovered before higher-priority ones.

*For the sake of brevity, the description of what is happening under-the-hood is a gross oversimplification, as clearly this naive solution could easily result in the starvation of low-priority resources for arbitrary amounts of time.

A. Non-native solutions to prioritization

In addition to the browser’s generic prioritization efforts, the web community has come together to form several library-level solutions (solutions that are inherently not made at the platform-level, but manifest themselves in open source libraries authored by web developers).

To mitigate some of the drawbacks incurred by native-only non-standard per-browser prioritization schemes, researchers out of MIT and the University of Michigan proposed and developed a solution for more effective and malleable request prioritization. Their solution is called VROOM, and is two-fold [4]. First, VROOM’s software must be installed on a server, making it VROOM-compliant. VROOM-compliant servers respond to HTML requests with:

- 1) The HTML response

- 2) A list of dependency URLs (sub-resources) the browser would inevitably discover when processing the HTML resource

The precise way in which VROOM-compliant servers compute the list of dependencies given a resource is omitted here for brevity. The idea behind delivering a list of dependency URLs the browser would eventually find on its own, is to speed up the discovery of these URLs, and their fetching.

"Without going into too much detail, the problem of browsers efficiently discovering all of the subresources a page has to offer is a deep one, very inherent to the web platform [9]."

To complement VROOM’s server-side software, a light-weight client-side VROOM JavaScript library is responsible for fetching the server’s list of early-discovered URLs, specifically in such a way that maximizes the usage of the client’s bandwidth and CPU [4]. VROOM, along with many other request scheduling libraries available to developers, provides impressive results in many situations. One of the biggest complaints with solutions like these, however, is that they are not made at the platform-level, and as such, are just band-aids to the real problems that could ultimately be fixed by some sort of prioritization standard.

II. HTTP/2 PRIORITIZATION

The IETF’s revision to HTTP, HTTP/2 [1] provides a way to natively express the priority of a request to a responding server, so that it can send high-priority resources to the client before low-priority ones, or at least prioritize sending their bytes over those belonging to low-priority resources when multiplexed over the same TCP connection.

HTTP/2 is well-explained in [6], and the reader is encouraged to check that resource out. Briefly put, the expression of priorities in HTTP/2 is carried out by creating a tree whose structure represents both the dependency relationship and priorities of the requests multiplexed over a TCP stream. This tree can mutate throughout the duration of the connection as resources are discovered and fetched by the browser.

HTTP/2-enabled servers are encouraged to take the priority information communicated via the HTTP/2 protocol into account when serving the various files. Given HTTP/2’s somewhat complicated prioritization system, and the fact that each browser can prioritize requests in any way it wants (while communicating its prioritization to servers via the protocol), it is reasonable to try and assess which browser is making the most of HTTP/2 prioritization, and if the current-best approach can be improved upon. In fact [5] does just that. Robin Marx et al. researched the very different ways in which Chrome, Firefox, and other browsers implement request prioritization on the web, in hopes to discern what strategy of priority-creation may work the best across the most sites.

They found that Firefox’s prioritization strategy, one that utilizes HTTP/2’s multiplexing far more than Chrome’s, is certainly the fastest. However, they concluded that to warrant a non-trivial page load time decrease across many sites, a web standard along the lines of Priority Hints [3] would likely be necessary to give the browser insight into the best prioritization scheme on a per-site basis.

III. PRIORITY HINTS

With all of the aforementioned solutions to aid the prioritization of resource requests on the web, and the platform-level adjustment made at the transfer protocol level, there still exists a lingering problem. Sometimes the browser gets priorities wrong. HTTP/2 is an improvement in terms of priorities, in that the browser can share self-determined priorities with servers, however these self-determined priorities are exactly that, the result of a generic set of heuristics browsers uniformly consult across all sites.

Priority Hints is a new web standard, adding the ‘importance’ content attribute to resource-fetching HTML elements such as `<script>`, ``, and `<link>`. The motivation for the standard is precisely the problem described above. There are many cases where the browser’s default prioritization is not as effective as it could be, so Priority Hints allows developers to hint the priority to the browser by describing the importance of a resource to the page, via three keywords:

- 1) auto (the default)
- 2) high
- 3) low

For example, the default loading priority for asynchronous script resources (a.k.a. `<script async src=...></script>`) is low. Developers often fetch scripts asynchronously to prevent the HTML parser from halting while the script loads, however the fact that they are fetched with low-priority means that many other resources discovered while the script request is either queued or loading, can effectively “jump ahead” of the script. For some performance-critical applications, it is desirable to load scripts asynchronously but with high-priority. This is a perfect example in which Priority Hints lets the developer give per-page prioritization preferences to the browser.

Another example revolves around images. In Chrome, images are fetched with low-priority unless they are in the viewport (a.k.a. visible) when initially discovered. Some sites however, may keep an image off-screen while it is loading and scroll it on-screen when it is finished. Such image may be critical to the purpose of the site, though Chrome’s heuristics will automatically assign a low-priority to the image request. This is another instance where the developer knows more about the specific importance a request plays to a site. The developer can adorn the `` element with `importance=high` to let the browser know that the image request’s HTTP/2 stream should be prioritized in relation to other in-progress requests. Priority Hints is a relatively nuanced feature, and is currently experimental in Chrome. The reader is advised to see [3], [7] for more information on the status of Priority Hints.

IV. CONCLUSION

Resource loading, and task scheduling in general, is a difficult and very nuanced problem. Efforts of late in the form of solutions to some of these problems vary from JavaScript libraries, to protocol changes, to new web standards aimed at opening up browser internals to be influenced by directives that web developers can control. Priority Hints is one of several ongoing attempts to let web developers pass on their per-page knowledge of prioritization to browser internals. It should be noted that the author of this paper was responsible for a significant portion of the web standard text in [3], and is the technical owner of the Priority Hints implementation in Google Chrome. Priority Hints is currently running as an Origin Trial [8] in Chrome, after which, the data collected will provide us a better idea as to whether the feature needs tweaked, completely changed, or if another approach altogether might be more effective.

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Review of RevolutionUC 2019

Noah Bass, *4th Year B.Sc. Computer Science*

Abstract—This write-up reviews the 2019 edition of RevolutionUC, the University of Cincinnati’s student hackathon, hosted by ACM@UC. On the 5th anniversary of the event this March, hundreds of students from around the midwest flocked to UC for 24 hours to build something awesome and learn something new. This write-up includes highlights of the winning hacks, why RevolutionUC is important to the campus community, the history of modern hackathons, and special thank-you’s from RevolutionUC.

I. INTRODUCTION

REVOLUTIONUC 2019 (<https://revolutionuc.com/>), the University of Cincinnati’s 24-hour student hackathon organized by ACM@UC (<https://acmatuc.org/>), was hosted on March 2nd and 3rd in Rhodes Hall. Students came together for 24 hours to build something awesome, learn new technologies, and grow the community at our university. With 385 hackers from 11 states and 35 majors, this year’s event was the largest ever hackathon hosted at our university and in Cincinnati. All students, regardless of major, are encouraged to participate at RevolutionUC. Thanks to the support of our sponsors, it’s free for all students to attend. Both software and hardware hacks were built and demoed at the hackathon with the support of free resources like Google Cloud Platform and Twilio credits and a hardware lab with free resources like Amazon Echo, DragonBoard, VR headsets, Arduino, and Raspberry Pi.

II. HACK HIGHLIGHTS

Polyglott, Figure 1 was one of our winning hacks at the event [2]. This team learned and utilized OpenCV at the hackathon to build a language and object detection system that teaches the user how to spell and say the word in many different languages. This tool could be useful for learning or traveling. First prize at RevolutionUC was awarded to MEME, Figure 2, a RPG built with Unity, a cross-platform game engine [1]. Our team of judges from academia and industry enjoyed their hack as it showed off knowledge that they learned at the hackathon. True to the spirit of the hackathon, this team taught themselves Unity and how to build 3D games. They leveraged their new knowledge to creating a fun, interactive experience that caught the eye of our judges. The team even wrote their own music and designed their own art for the game.

See <https://revuc-viii.devpост.com/submissions> for more information, including abstracts, on all the hacks submitted at RevolutionUC 2019.

III. ABOUT THE HACKATHON

Not only is RevolutionUC a fantastic environment for students across the mid-west to learn and build something new in 24 hours, it’s also a great place for talented students and

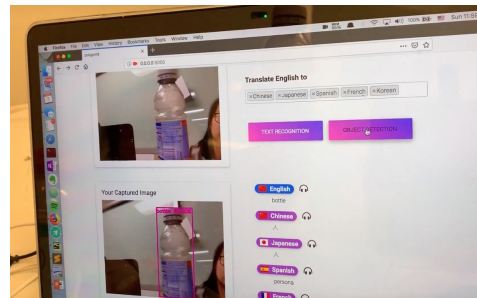


Fig. 1. Polyglott Demo at RevolutionUC

top Cincinnati-area employers to meet. This year, we had 16 sponsors, the most ever at a RevolutionUC event. Sponsors represented a diverse range from the technology industry, from 84.51° and Kroger Technology to GE Aviation and Wolfram. Engineers from our sponsors interacted with students in the form of mentorship for teams and presented technical workshops. Our annual hackathon wouldn’t be possible without the support of our sponsors.

RevolutionUC is completely student-run by ACM@UC (UC’s chapter of the ACM) with the advisement of Dr. John Franco and the support of Major League Hacking (MLH), a worldwide network of hackathons (<https://mlh.io/>). This semester marks five years of hackathons at UC. Since beginning in the Spring of 2014 with less than 100 hackers, RevolutionUC has turned into a significant and headlining event for the technology community at UC. The hackathon now attracts many hundreds of students to UC for a fun weekend of code, community, and self-improvement. We expect attendance at RevolutionUC to grow even more year over year.

The concept of a hackathon as we know it is relatively new. Hackathons began gaining widespread popularity only within the last decade. Since then, hackathon culture and community has exploded globally and MLH has played an important role in spreading the hackathon community. Last year, MLH reported that 71,000+ students attended 750+ different events around the world in 2017-2018 hackathon season alone [3], all organized by students from their respective schools with the support of MLH. Hackathons are designed to give students an all-inclusive space for students to learn something new and build something awesome. It doesn’t matter what technical skill level a student has, hackathons are open to students from all majors and backgrounds. With RevolutionUC, we’re bringing the hackathon culture to hundreds of students and building a better technology community in EECS, at UC, and in our midwest region.



Fig. 2. MEME_Demo

IV. CONCLUSION

Thank you to all of the students who attended this year. We're excited to have you again next Spring for RevolutionUC

2020! A special thanks to our guest judges from the university, Dr. John Franco, Dr. Chuck Zimmer, and Dr. Megan Lamkin, for lending their time to participate in the event. Finally, a big thank you to the RevolutionUC organizing team for their dedication in building and growing the computer science and technology community at UC and in the midwest.

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SHPE 2019 RLDC - EECS Student Experiences

Kristen Diaz, 5th Year B.Sc. Computer Engineering, Daniel Suarez, M.Sc. Electrical Engineering, Jeremy Torres, 1st Year B.Sc. Computer Engineering, and Laura Rodriguez, 1st Year B.Sc. Computer Science,

Abstract—The Society of Hispanic Professional Engineers (SHPE) at UC traveled to their second RLDC (Regional Leadership Development Conference) on April 17th-19th at the University of Minnesota campus. The RLDC is held every spring for Region 6 (the Midwest) at a different host city in the region. This year SHPE at UC brought 4 students from EECS amongst their group of 14 UC CEAS students to grow their professional development skills and network with local companies in the region. The group at large won two awards for chapter growth and group involvement in the region.



I. KRISTEN DIAZ

BEING able to go to the Society of Hispanic Professional Engineers' (SHPE's) 2019 RLDC (Regional Leadership Development Conference) was one of the most meaningful conferences I've been able to go to. The conference was only a couple days, however it took place in my hometown of Minneapolis and my post-graduation employer, 3M, was the premium sponsor of the conference. As a leader for SHPE I was able to be with some of my favorite fellow UC students as our University of Cincinnati chapter was recognized for two awards - best small chapter growth in the past year (we have more than doubled our numbers) & a Blue Chip Award for our success in activities as a group. During the conference I was able to meet and make personal connections with professionals from 3M before officially joining the company. My experience with our group & 3M has inspired me to join 3M's SHPE team to hopefully recruit more students from UC at SHPE's National Conference in the fall and help persuade 3M to come back and recruit at UC.

teams and managing projects. I felt the speakers were excellent and really encouraged people to pursue their goals and dreams. It is very important to be passionate about work. Many interesting topics were mentioned throughout the workshops. Some that caught my attention were Design Thinking, Project Management and Executive Presence. I believe that, regardless of the path that we choose as engineers, we always need to understand the importance of treating people with respect, knowing how to communicate our thoughts and ideas and learning about professional relationships.



II. DANIEL SUAREZ

The Regional Leadership Developed Conference 2019 hosted by SHPE and held in Minneapolis, Minnesota was a fantastic experience for me. I managed to attend interesting workshops that motivated me and allowed me to consider different approaches and strategies when it comes to leading



III. JEREMY TORRES

I had an amazing experience going to the regional SHPE conference these past few days. I learned so much from the workshops and events sessions that I believe will enable major success in my career in the future. I learned about how important it is to have a personal brand, that I have to be able to sell myself as the best me that I can be. People will buy me for me which not only would include my technical skills, but also my soft skills, for my personality, and for my effectiveness. On that note, another memorable lesson I

had learned at the conference was developing and having an executive presence. Having an executive presence is being able to have the presence that people can feel, giving you trust and believing that you can get them results. Having executive presence is important as it affects the first impression that a person has on you, even when you have not even met that person. Other helpful workshops such as the one about data analytics in the enterprise level, and one about innovations which act as disruptors gave me technical insight on how enterprises work, and where society is going as technologies and innovations in evolve. I am glad to experience for my own benefit, and for being able to experience this with the rest of my SHPE chapter members.



IV. LAURA RODRIGUEZ

The RLDC for Region 6 this year was a great opportunity to connect with wither SHPE members and companies in the region, while still participating in professional development events and learning more about the technical side of careers. For me, I learned quite a bit from a session about Data Analytics. The speaker spoke about the role of artificial intelligence in managing data, which is something I am very interested in. It was a great learning experience.



Summer at Max Planck Institute for Software Systems

Laura Stegner, 5th Year B.Sc. Electrical Engineering

Abstract—I was an intern at the Max-Planck Institute for Software Systems this past summer working on building a simulation environment to test autonomous vehicle controllers. In addition to my work, I had the opportunity to explore Europe and expand my understanding of world culture and politics.

I. INTRODUCTION

I spent this past summer living and researching in Kaiserslautern, Germany a part of the RISE Germany scholars program, funded by the Deutscher Akademischer Austauschdienst (DAAD). This program pairs high-achieving US and Canadian undergraduates with PhD students in top German institutes for summer internships. The goal of this exchange is to bring more research scholars into Germany while allowing them to experience German culture.

II. THE RESEARCH

We created a reactive language to write test scenarios for autonomous driving systems. Several simulation environments have already been developed, but the problem is that each one has to be hand-made through a drag-and-drop interface, making rapid creation/testing a challenge.

Our system allows the user to write a script to build road networks and add environmental components. A driving scenario, Figure 1 can be tested rapidly through a sweep of different weather conditions and environmental settings. An example of this is to test to see how much fog it takes to interfere with the autonomous controller’s accuracy. My contribution focused on developing the simulation environment using the Unity gaming engine and C# scripting. The full write-up of the project is published here: [1]

III. LIFE IN GERMANY

Germany Living in Germany brought many new perspectives to research. MPI-SWS is a research institute, not a

university lab, so I did not know what to expect. It was also my first experience in a software lab. Instead of reporting to professors, labs were run by Directors and Research Area leaders. Even though MPI is not a university and therefore unable to issue degrees, a handful of PhD students work through the local university to complete their dissertations with research funded by the institute. None of the directors had to teach classes, so all their time was devoted to their research. I thought it was really helpful, especially getting started, because we were able to meet almost every day to get the project figured out.

The culture at MPI was extremely welcoming. I faced several obstacles moving to Germany (primarily not speaking German), but my co-workers were always willing to help me. Only a few people at the institute were German, and the rest were from all over: Croatia, Pakistan, Greece, Canada, Turkey, Iran, Nigeria, Madagascar, Netherlands, UK, China, India, Russia, Spain, Switzerland. With such a mix of cultures, there was never a shortage of discussion. I had to learn to use the metric system for everyday purposes, because nobody understands Fahrenheit or miles or pounds outside of the USA. My understanding of world politics and cultures expanded immensely. I think it’s a really unique opportunity to mix so many open-minded people in one place.

On the weekends, I was able to travel around different parts of Europe, including Amsterdam, Stockholm, Strasbourg, Barcelona, and Vienna, Berlin, Cologne, and Munich. While I loved seeing all these iconic cities, my favorite memories are traveling to see some sites recommended by the locals of Kaiserslautern. I spent many weekends hiking through German wine country or sitting in a beer garden enjoying the summer weather.

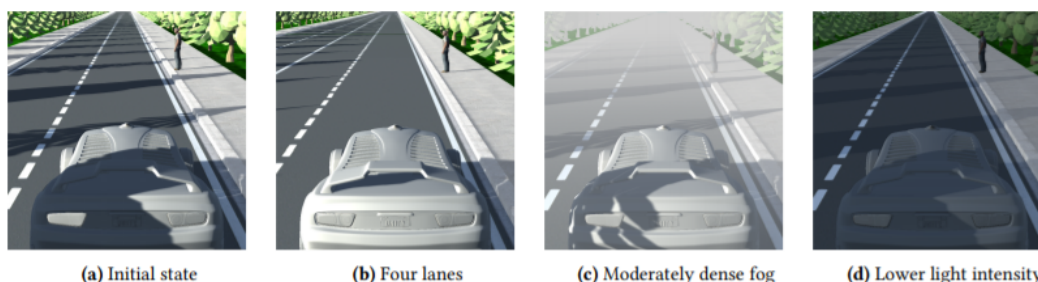


Fig. 1. Examples of different environment conditions for a given driving scenario [1]

IV. CONCLUSION

My experience in Germany was one of a kind; I got the opportunity to work at a world-class research institute and assimilate myself into German life. The DAAD RISE program was a great way to combine my academic and travel interests. Experiencing life in another culture is something I would

recommend to everyone.

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UC SASE Reflection for the South Central Regional Conference

Chris Huynh, *5th Year B.Sc. Computer Engineering*, Melanie Mai, *1st Year B.Sc. Computer Science*, and Lynzie Romero, *2nd Year B.Sc. Electrical Engineering*,

Abstract—SASE (The Society of Asian Scientists) is an organization that is focused around developing scientists and engineers of Asian descent for the professional work environment. Such opportunities for professional development occurs at regional conferences. This year the UC chapter of SASE went down to Austin, TX for SCRC (South Central Regional Conference) where we were presented the opportunities to network with others, attend workshops, and reflect on not only how to better prepare ourselves for the workplace, but also help others within our community do the same.

I. CHRIS HUYNH

AS the president and founder of the UC Chapter of SASE, I would like to express my gratitude towards the EECS department for supporting us by sending us to the South Central Regional Conference in Austin, TX. Since we are such a newly founded chapter, it's a risk to support us in this endeavor, however I believe that it was a rewarding and beneficial experience for us to be sent to this conference.

Before attending this conference, I had no concept of what this conference entailed or even how other SASE chapters operated. I was also intimidated at the fact that I knew nobody else at this conference, except for those being sent with me. These fears I had turned out to be a blessing in disguise, because what little expectations I had were quickly subverted and I was amazed at how much I gained out of this conference. To elaborate even more, the fact that nobody else knew who I was turned out to be a great thing for me, because I was already out of my comfort zone. With that in mind, I decide to embrace that and took risks by approaching others and thought of each interaction as a learning opportunity on how to network, be more confident, or even learn more about how other chapters are ran. Although not every interaction was a success or went as smoothly as I liked, I believe that it was empowering that these new interactions were encouraged and that it was more than okay to fail at these. With that being said, I did get more comfortable with the idea of failing not being a completely negative event, but rather a great learning opportunity. This idea was further ingrained, because the conference provided a safe environment for all of us to take risks.

Not only did I make new connections with other attendees, but I also made connections with the company representatives present at the conference too. This was further empowering to me, because it showed me that it only takes a small risk in order to gain a new connection. I was scared at first to ask a few company representatives to sit at my table for lunch, but I am proud of myself for doing so, because I believe that they

are more inclined to reach out to the UC chapter in order to present or even recruit talent from our members. This could potentially lead them into recruiting at UC in events like the career fair too.

I also appreciated the fact that everyone in attendance at the conference not only accepted me for my title and what I was, but also who I was. That they even embraced the weird quirks in my personality and accepted me for all of me. I believe that once I got comfortable with that fact, I was also able to reciprocate and do the same for other attendees and even embrace my personality by showcasing it in the networking workshops. This kept me engaged throughout all of the conference and I genuinely believe that I got the more out of them because of the environment of this conference. This is something that I will try to impart onto my chapter before I graduate, because I truly do think that to flourish as an individual, there must be an environment that accepts everyone as they are and facilitates growth at the same time.

Despite graduating in a few weeks, this conference also revitalized me and makes me want to continue to give back to the UC community even after I leave. It was refreshing to see so many other Asian scientists and engineers in the same environment trying to reach the same goal. Learn. I think this was impactful on me because I noticed that I got swept up in the momentum and honestly learned a lot more than I could have imagined by attending this conference. With that being said, one of my last remarks that I would like to make is that Austin was a great city to go to, but the attendees, company representatives, and environment established by the conference was what made it a truly unforgettable and empowering experience that it was.

Although I was not able to capture everything that I gained in this reflection, it is clear that I gained a lot from this conference. Once again, I would like to reiterate that I am truly grateful for the department's support and would like for members in the future to continue to be sent to conferences like this. If future attendees get a fraction of what I got from this conference, then I think it is invaluable to send them to these conferences and the growth that the experience will be insurmountable. Whether the department chooses to send members to the Midwest Regional Conference or any other region is at the discretion of the department. I would love to see the department's continued support in helping Asian students of the EECS department grow not only as engineers, but also as leaders.

II. MELANIE MAI

I was able to attend my very first Society of Asian Scientists and Engineers (SASE) conference in Austin, Texas. I didn't know what to expect, but after experiencing it first-hand, I can say the SASE conference was one of the most inspirational and empowering experiences so far of my college career. As an Asian woman at UC majoring in computer science, I am constantly surrounded by males which can be at times, discouraging and alienating. At the conference, I was not only able to meet such positive and driven Asians that were men, but such highly-skilled, driven, and confident Asian women that were pursuing computer science as well. To be able to communicate and relate to a broader spectrum of women pursuing the same passion and goals was a unique experience and something I can and will never forget.

Not only did the SASE conference allow me to open up and meet new scientists and engineers, but from a career-focused perspective, SASE was able to give so many rewarding opportunities to network and reach out to different companies. Being able to have representatives from different companies give breakout sessions on how to improve yourself not only as a scientist or engineer, but as a person as well, and getting to know what kind of intern they're looking for, what kind of positions are open, how to be a better scientist or engineer is a rewarding experience. I've learned how to be more confident, how to better network with others, and many other things from each company and I was able to make connections I wouldn't have been able to make if I hadn't had the opportunity to go to the conference.

I am grateful for the department's support in sending me to the conference as it was one of the most rewarding and valuable opportunities I have been given in my college career. I highly recommend any Asian men and women in attending any future conferences.

III. LYNZIE ROMERO

Attending the SASE South Central Regional Conference helped me learn how to network with different companies while being surrounded by peers like me. It was great to not only see other Asians who have the same passion as me but to also see a lot of other Asian women who want to diversify the engineering field.

Throughout the conference, we had the opportunity to attend workshops from different companies such as how to successfully network, how to stand out in a large company, and how to be more confident in the workplace. Whenever we had time at the end of the workshops, we had the opportunity to talk to those companies more about advice on how to be successful in the workplace. I was able to talk to a representative from Sandia Labs about being the only women in the workplace and she gave great advice on how I can fit myself into the work culture.

We also had the opportunity to talk to representatives from a number of successful companies such as P&G, Baker Hughes, Lockheed Martin, the FBI and more. I wanted to improve on my networking skills so I pushed myself to talk to those different companies as well as trying to network with the other

attendees at the conference. I talked to a representative from the FBI and I was able to learn more about what kind of work that both their engineers and their interns do. I expressed my interest in them and was able to get more information about their intern program both in Austin and in Cincinnati.

I am very grateful for the department's support in funding for our trip to send us to this conference. I highly recommend this opportunity for any other Asian engineers to not only get to network with other engineers like us but to also have the opportunity to explore different career paths.



Fig. 1. From left to right: Lynzie Romero, Chris Huynh, Melanie Ma

Waste Energy Reclamation in Data Centers

Joshua Mayersky, *PhD., Electrical Engineering*

Abstract—Room temperature thermoelectric modules are designed for operation in computing data centers. Design parameters are simulated to calculate the maximum power output and efficiency at the designed module dimensions, reported, and discussed. A power generation per unit area of $0.083282W/m^2$ at an efficiency of 0.12735% was achieved with the designed TEM.

I. INTRODUCTION

DATA centers are the hub of the computing world; from information storage to data processing, they serve as the backbone of the cloud. Users in both the public and private sectors all rely on the services offered from cloud computing and storage providers like Google, Amazon, Oracle, etc. Just last year, 1,120 exabytes of information were stored in data centers [1]. Consumers and customers of these servers rely on 24/7/365 access, requiring the data centers to be powered up and running with near 100% uptime. Even slight downtime can dramatically affect customers and performance, as was seen in the hour-long outage of YouTube on Oct 17, 2018. This 24/7/365 data center uptime ends up consuming large amounts of energy, and as a result, generates a lot of waste heat as a byproduct. More power is then consumed to cool the servers so that they are operating efficiently and effectively. Data centers were forecasted to consume around 70 billion kilowatt-hours of electricity in 2018 [2], and at an average price of 11.02 cents per kilowatt-hour in July of 2018 [3], the cost of continuous uptime is ever rising. Here an avenue may exist for the use of thermoelectrics to offset the cost of powering and cooling server units in data centers by making use of temperature differentials in the data center between the hot exhaust air and the ambient air used to cool the servers.

II. DATA CENTER DESIGN

Data center design varies widely based on the desired computing power, available space, energy requirements, computing cost, and many other design variables. Due to these shifting requirements, a design was chosen to be representative of an industry standard. In a typical data center, computing stacks are separated by an aisle through the center, with walls isolating and funneling the hot exhaust air from the computing stacks back to a computing room air conditioner (CRAC). Air flows from the CRAC underneath a raised floor, and back into the cold aisle and into the intake of the computing stacks. It is imperative that this raised floor is kept airtight, to force the airflow solely through the perforated tiles in the isolated cold aisle. Figure 1 shows the layout and air flow in this typical data center.

The cold intake temperature of $T_C = 12.8^\circ\text{C}$ and the hot exhaust temperature of $T_H = 24^\circ\text{C}$ are typical for a 2kW computing stack as found in Suhas Patankar’s paper, Airflow

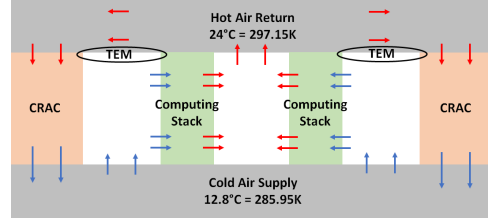


Fig. 1. Typical Data center layout

and Cooling in a Data Center [4]. Here the CRACs provide a rated airflow of $5m^3/s$. After the air flows into the cold air vents and through the perforated air tiles in the cold aisle, this airflow is reduced to $0.15m^3/s$ [4]. The standard size for these tiles is 2ft by 2ft, so an air velocity of $0.403m/s$ can be calculated. Using this velocity, a heat transfer coefficient, $h_c = 16.3997W/m^2K$ can be calculated using the empirical equation below [5].

$$h_c = 10.45 - v + 10\sqrt{v} \quad (1)$$

This heat transfer coefficient is assumed to be valid for both the cold air supply aisle and the hot air return aisle as in this model data center, the air duct for the hot air return is the same size as the cold aisle inlet tiles, 2ft by 2ft. In addition, it is assumed that the internal fans for the computing stacks maintain the same airflow as the CRAC, supplying an air velocity of $0.403m/s$ through the hot air return ducts. Table I details the parameters used in the simulations.

Parameter	Value
$h_{c,hot\ side}(W/m^2K)$	16.3997
$h_{c,cold\ side}(W/m^2K)$	16.3997
$T_H(K)$	297.15
$T_C(K)$	285.95

TABLE I
HEAT TRANSFER COEFFICIENTS AND TEMPERATURES

One of the last things to consider is the placement and physical size of the thermoelectric modules. Ideally, the module should be placed at an interface with the largest ΔT . In this design, the interface of the bottom of the hot air return ducts and the ceiling of the cold air supply aisle serves as this location, although higher ΔT may be achieved by placing the TEM closer to the main sources of heat (processors, memory in the computing stacks).

Datacenter product supplier SubZero sells a standard containment panel product with a thickness of 4mm [6]. For this project, a thermoelectric generator (TEG) leg length (L) of 4mm was treated as the desired design value. This allowed for the heatsink of the TEM to be immersed in the cold air flow, as well as allowing the hot side of the TEM to sit just inside

the hot air exhaust. As the available area for TEMs is largely dependent on the size of the data center and the availability of the ΔT interface, a total area of 100mm²-500mm² was chosen in order to analyze the effects of scaling on the power output of the TEM.

III. THERMOELECTRIC MODULE DESIGN

For the TEM design, a key consideration was the material selection. Considering the relatively low temperature range of operation, n-type and p-type materials with high ZTs around room temperature were greatly desired. For this work, alloys of n-type BiTeSe and p-type BiSbTe were selected for use because of their well-known performance as room temperature thermoelectrics [7]. The values for the n-type material properties were taken from [8], and the values for the p-type material properties were taken from [9]. Table II details said material parameters at a temperature of 300K.

Material Parameter (@300K)	n-type Bi ₂ Te _{2.7} Se _{0.3}	p-type Bi _{0.5} Sb _{1.5} Te ₃
S(μ V/K)	-182.05	184.141
σ	956.158	1174.06
$\kappa(w/m * K)$	1.15093	1.07308
ZT	0.826	1.113

TABLE II
MATERIAL PROPERTIES USED IN SIMULATIONS

The design process for finding the maximum power output of the TEM was as follows. First a value for the cross sectional area of the n-type thermoelectric leg (A_n) was selected. The cross sectional area of the p-type thermoelectric leg (A_p) was then calculated using Equation 2. Here, σ is the electrical conductivity and κ is the thermal conductivity for each leg.

$$A_p = A_n * \sqrt{\frac{\sigma_n * \kappa_n}{\sigma_p * \kappa_p}} \quad (2)$$

Having selected A_n and A_p , several fill factors (F) were then selected. For each combination of A_n , A_p , and F , the output power vs. L was calculated and plotted (the resistance load matching condition was used for these simulations). The previous steps were then repeated for a different set of A_n and A_p . After finding the A_n , A_p , and F that maximized the output power, the load resistance (R_L) was adjusted to values around the calculated internal resistance (R_i) to further maximize the output power. R_i can be calculated from Equation 3. Here, N is the number of $n - p$ leg pairs.

$$R_i = N * \left(\frac{\frac{1}{\sigma_n} * L_n}{A_n} + \frac{\frac{1}{\sigma_p} * L_p}{A_p} \right) \quad (3)$$

Table III details the values for each parameter simulated.

The gap filler in the TEM was assumed to be air at an average temperature of $\frac{1}{2}(T_H + T_C)$. This resulted in a gap filler thermal conductivity of $\kappa_{\text{gap}} = 0.02575\text{W/mK}$ [10].

IV. SIMULATION RESULTS

All simulations were performed using the Advanced Thermoelectric Power Generation Simulator for Waste Heat Recovery and Energy Harvesting tool located on nanohub.org

A_{total} (mm ²)	A_n (mm ²)	A_p (mm ²)	F
100*	0.05*	0.04673*	0.01
200	0.15	0.14019	0.03*
300	0.25	0.23365	0.05
400	0.35	0.32712	0.1
500	0.45	0.42057	0.3

TABLE III
DESIGN PARAMETERS USED IN SIMULATIONS (*DESIGN PARAMETERS USED FOR MAXIMUM POWER OUTPUT)

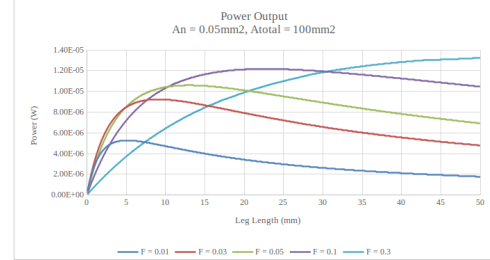


Fig. 2. Power outputs at a fixed A_n and A_{total} for different fill factors

[11]. This powerful tool allows for the simulation of temperature dependent material properties used in thermoelectrics. Simulations were run using the material properties specified in Table II, controlling different properties in each simulation according to Table III. A total of 126 simulations were run to fully test the five A_{total} values with every combination of each set of A_n/A_p and each F . The independent variable in these simulations was L , while the dependent variable was the power output of the TEM. The final simulation run tested different R_L values to maximize the power output and efficiency of the TEM.

The first set of simulations analyzed the power output of a TEM for different A_n and A_p , and F for each set of cross sectional areas. Figure 2 shows the simulated power outputs for the 100mm² TEM at a fixed A_n of 0.05mm², for the five different fill factors. As expected at the desired L value of 4mm, the output power initially increases, then decreases as the open circuit voltage (V_{OC}) of the TEM decreases with further increased N . This is due to the increased heat input and the decreased thermal resistance of the TEM, which results in a lower ΔT , and therefore a lower V_{OC} . It is also expected that for a fixed fill factor, the output power initially increases with increasing leg length because the V_{OC} increases, but then reaches a maximum value and starts to decrease due to the increasing electrical resistance of the TEG legs. This increasing resistance is directly proportional to the leg length as seen in Equation 3.

This exact same trend for the power output vs. L at different F existed for every tested A_n and A_p combination, as well as for every A_{total} simulated. Table IV summarizes the results from these simulations for the 100mm² TEM showing what the absolute maximum output power was, and the A_n , F , and L necessary to generate it. Given that in this table we are looking at the absolute maximum, the largest F generated the highest power, as the L boundary of the simulation includes its maximum as well. It should be noted though that for further increasing F , the simulation boundary would have to

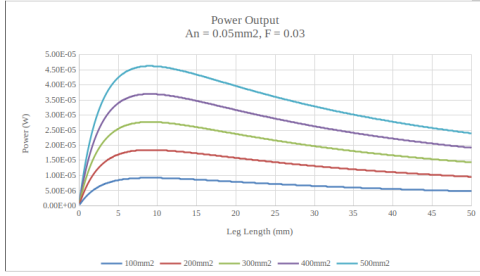


Fig. 3. Power outputs at a fixed A_n and F , for different A_{total}

be increased to include every maximum value.

A_n (mm ²)	Max Power Output (μW)	Fat Max Power Output	L at Max Power Output (mm)
0.05	13.2392	0.3	49.6
0.15	13.2466	0.3	49.6
0.25*	13.2895*	0.3*	49.6*
0.35	13.2064	0.3	49.6
0.45	13.1206	0.3	49.6

TABLE IV

MAXIMUM POWER OUTPUT FOR ALL CROSS SECTIONAL AREAS AND FILL FACTORS (*MAXIMUM VALUE)

Table V details the maximum power outputs, and the F necessary for said power at the desired dimension of $L = 4\text{mm}$ for each A_n and A_p pair for the 100mm^2 TEM. Here we see a decrease in the power output with an increase in A_n and A_p , which was expected as for an increasing A_n and A_p , the number of TEG leg pairs that can fit in the TEM at a given F decreases.

A_n (mm ²)	Max Power Output at $L = 4\text{mm}$ (μW)	Fat Max Power Output
0.05*	7.86262*	0.03*
0.15	7.63767	0.03
0.25	7.60877	0.03
0.35	7.33813	0.03
0.45	6.84788	0.03

TABLE V

MAXIMUM POWER OUTPUT AT A FIXED TEG LEG LENGTH FOR DIFFERENT CROSS SECTIONAL AREAS (*MAXIMUM VALUE)

Figure 3 details the output power at a fixed fill factor for the increasing A_{total} values. As expected, with increasing area, the power output increases due to the increased V_{OC} from the TEM.

Figure 4 details the exact trend for the increase in power output with increasing TEM area. The trend line R^2 values for $F = 0.01, 0.03, 0.05, 0.1, \text{ and } 0.3$ were $0.9997, 1, 1, 1, \text{ and } 1$ respectively, conclusively showing a linear trend for power vs. area.

Having selected the individual leg cross sectional areas, leg lengths, fill factor and total area for the TEM, the last step in maximizing the power output of the module was to tune the load resistance. This was done by first calculating the internal resistance R_i of the module, then varying the load resistance R_L around that value. R_i was calculated to be 48.54Ω using

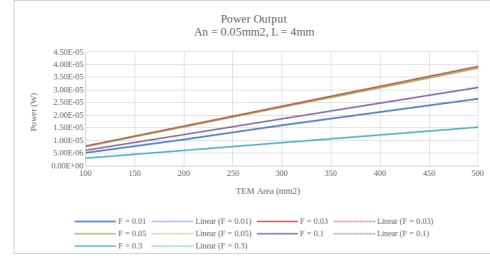


Fig. 4. Trends of increasing TEM A_{total} vs. power output

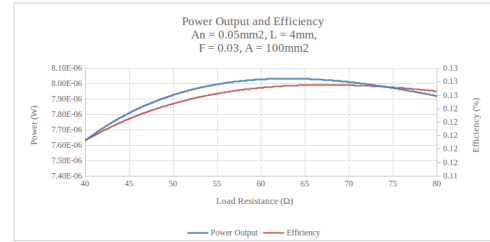


Fig. 5. Load resistance tuning

Equation 3. By fixing the listed parameters to be the previously found values of $A_n = 0.05\text{mm}^2$, $A_p = 0.0467\text{mm}^2$, $L = 4\text{mm}$, $F = 0.03$, $A_{total} = 100\text{mm}^2$, and varying R_L to values around the calculated R_i , the maximum power output and efficiency for the module were found. These values are listed in Table VI, and the simulated values are plotted in Figure 5.

Load Resistance (Ω)	Power (μW)	Efficiency (%)
62.5	8.03282*	0.12735
66.7	8.02638	0.12753*

TABLE VI

MAXIMUM POWER AND EFFICIENCY (*MAXIMUM VALUE)

V. CONCLUSION

At the design for the maximum power output at the desired dimensions, the power per unit area is $0.083282\mu W/\text{mm}^2$ or in standard units: $0.083282\text{W}/\text{m}^2$. To generate $1\text{kW}\cdot\text{hr}$ of energy with this design, a TEM with a total area of 12.448km^2 would have to run for 1 hour, resulting in a savings of 11.02 cents.

This result renders this design is entirely unfeasible for implementation, as the area required is far too vast, and the power generated per unit area far too small. To make energy reclamation in data centers viable in any measure, the TEM power output needs to be elevated by multiple orders of magnitude. In order to achieve that, the ΔT needs to be greatly increased. The problem this introduces is that if the T_C is lowered, this introduces extra energy and money costs via the CRAC, and if the T_H is raised, it costs energy and therefore money through the computing stacks. It may be possible to move the TEMs closer to the main heat generation sources (processors and memory of computing stacks), but doing this will drastically limit the room available for the TEMs, as well as increase the T_C . Further ways to improve this TEM include increasing the heat coefficients at both the hot and cold sides,

as well as reducing the thermal conductivity of the gap filler in order to better thermally isolate the TEG legs.

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