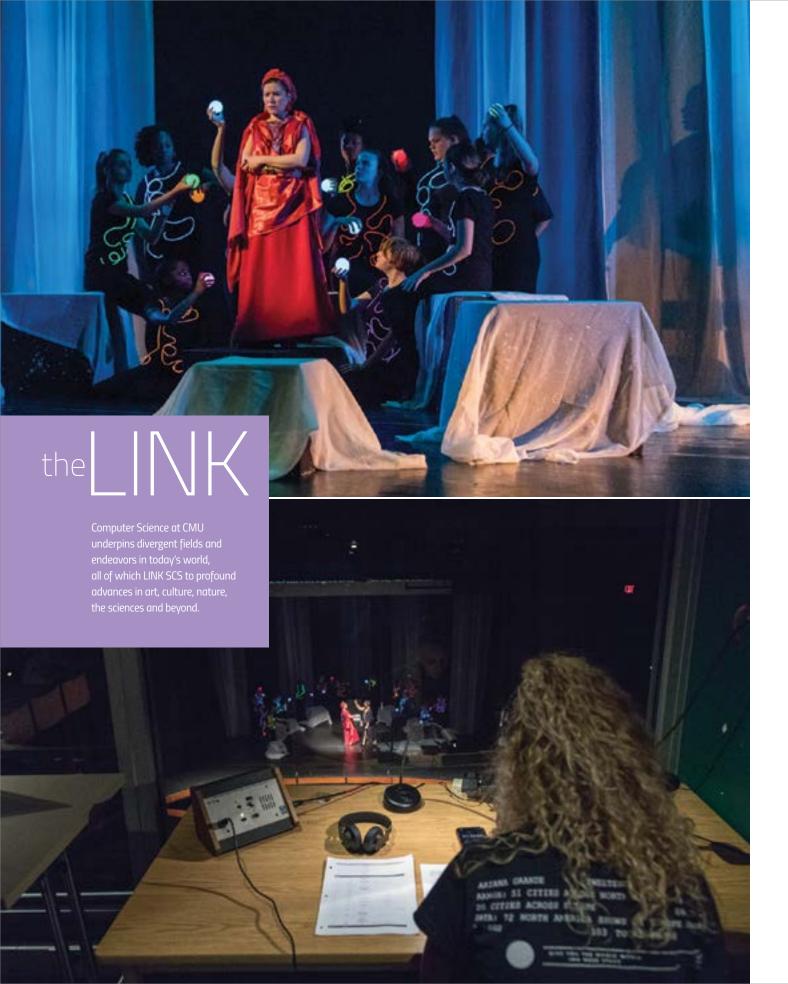


WINTER 2020 ISSUE 14.1



To see video of

The Mother of Fishes opera,

visit: http://bit.ly/tmofpgh

CMU Technology Powers Opera

Ah, the opera: powerful voices and live orchestra combine to tell dramatic and passionate human stories. What place is there here for computer science?

Well, the North American and **English premiere of the opera** The Mother of Fishes showcased not only the traditional elements of classic opera, but also made use of Soundcool, a free, open-source modular system for live sound performance. The performance, staged at Pittsburgh's CAPA creative and performing arts school, combined the voices of professional opera singers alongside CAPA students in the chorus. Roger Dannenberg, professor in the Computer **Science Department co-wrote** and produced the opera, and had a hand in the development of Soundcool as well.

The Soundcool software utilizes a tablet or phone touchscreen as a controlling interface for live sound processing. The Soundcool app connects via Wi-Fi to a computer, which hosts the sound files, allowing for remote manipulation. Under Dannenberg's guidance, CAPA students used Audacity, another open source audio editing software co-created by Dannenberg, to create and shape the sound effect files for live use.

For the opera performances, "Team Soundcool" students used four of Soundcool's sampler objects to start and stop a selection of 10 sound effects files, each with real-time volume and pitch control. From the back of the theater with their phones, the students produced and controlled an array of live sound effects for the show, all in sync with the professional orchestra and the voices on stage.



Photography

Contributing Writers

The Link

Publisher Martial Hebert

Editor Kevin O'Connell

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Owise Abuzaid, Rebecca Kiger, Anna Kuperberg, Elan Mizrahi

Cristina Rouvalis, Byron Spice

Susie Cribbs (DC 2000, 2006),

Niki Kapsambelis, Kevin O'Connell, Chris Quirk, Shilo Rea, Mark Roth,

Design

Vicki Crowley (A 1996)

Office of the Dean Gates Center for Computer Science Carnegie Mellon University 4902 Forbes Avenue Pittsburgh, PA 15213 cs.cmu.edu

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thelink@cs.cmu.edu





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Fighting Two Pandemics

ur world has changed a great deal since last semester. This note I write for each issue of *The Link* often contains previews of some of the interesting stories within, and perhaps a brief look forward. However, with all that has changed in the world at this time, there are pressing matters affecting the SCS community that I feel strongly about addressing.

The COVID-19 pandemic has wrought havoc throughout our world and altered our lives in profound ways. We have all adjusted to working from home, and SCS is no different. Campus this fall semester doesn't quite have the same bustle to it. We have adapted to hybrid distance learning — remote instruction, wearing masks, maintaining physical distancing and more — all to protect ourselves and one another. We have managed the formidable task of making SCS function given these circumstances.

I want to acknowledge the efforts the SCS community has undertaken to make this possible. While there have been bumps in the road, the achievements of our entire community are the foundation of our success, and even, at times, made it appear seamless. This has come about with much effort and teamwork. So, kudos to all.

The breadth of our research and a willingness to adapt it has allowed SCS to play a significant role in taking on the pandemic. The Delphi Project's COVIDcast work in pandemic data forecasting — adapted from influenza forecasting — continues to be impactful and widely utilized. Faculty have shifted their methods to produce 3D-printed personal protective equipment. We are looking closely into social media data to find bots spreading misinformation into our social feeds. Additionally, we are attempting to bridge the technology gap by broadening access to Wi-Fi for young people from traditionally disadvantaged communities. I could not be more proud of the response of SCS during these difficult times. There is much good work to come.

However, there is another pandemic affecting us all. The Black Lives Matter movement has laid bare the inequality and discrimination that endanger so many people in our country every day. We stand firm in our unequivocal support for the BLM movement and the diverse and equal community it stands to build.

This fall we published SCS' pledges on issues of diversity, equity and inclusiveness, along with regular updates of our progress. You can find a record of these at cs.cmu.edu/dei. This portal stands as an open invitation for idea generation and collaboration in our search for solutions to these difficult problems. As you will read in this issue, several SCS alumni across the country have taken up this problem and have begun to institute anti-racism curricula in the classrooms of their home school districts.

Going forward, we know we must continue our efforts to broaden the demographic makeup of our students. A more diverse college at all levels — among our students, staff and faculty — makes for better computer science, stronger research and more robust spinoff companies producing better products that work for more people. And, it will help to create a more just world to which we in SCS are committed.

I pledge, personally, to lead SCS to continue becoming a more diverse, welcoming and inclusive community. SCS will soon hire an associate dean for Diversity, Equity and Inclusion to oversee our college's hiring of a more diverse faculty and the recruitment of a more diverse student body. The university hiring a vice provost for Diversity, Equity and Inclusion will assist us in these efforts, as well as combating the biases inherent in college admissions tests.

It is important to remember that each of us has our role to play. We must continue to challenge ourselves to identify our blind spots and to correct and improve wherever we see opportunity.

It has always been during times of great difficulty that SCS and CMU shine the brightest. As we face these large-scale challenges, and those that the future will bring, let us tackle them head on, together. Let us lead toward a future that is more inclusive, safe, fair and just.

Martial Hebert Dean, School of Computer Science



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CMU Responds to COVID-19 With Innovation

Niki Kapsambelis

In January 2020, as news spread of the novel COVID-19 virus and its devastation on Wuhan, China, few Americans seemed to be paying rapt attention.

But Kathleen Carley was one of them. From her office more than 7,400 miles away, Carley — a professor in the Institute for Software Research — sensed a disturbance in the force, or at least the part of the force she studies: social media. As director of the Center for Computational Analysis of Social and Organizational Systems and the Center for Informed Democracy & Social-cybersecurity, Carley's focus rests squarely on the chatter that the rest of us take for granted.

And the chatter was pointing to China.

FALL/WINTER 2020



"A bot doesn't tell you how to think, but it can make you think that a lot of your friends are agreeing with your point of view."

 Kathleen Carley, professor in the Institute for Software Research

"When we saw what was going on in Wuhan in January," said Carley, "it was clear (that) even if it never left China, it was going to be a natural disaster health event." Carley specializes in applying multiple methods, including artificial intelligence, to identify bots in social media conversations.

Bots, or automated programs that behave convincingly as humans in social media channels, have the potential to sway public opinion to match a particular agenda. What that agenda might look like depends on who is behind the bot; Carley's research team hunts them down and presents its findings as an impartial third party.

From hunting down sources of misinformation to scaling up medical and protective equipment to helping schools bridge the technological divide, the School of Computer Science — and Carnegie Mellon — have responded to the COVID-19 pandemic with a characteristically innovative approach.

By late May, when it was clear that the virus was taking a severe toll on the U.S. economy, the bots were out in full force. Carley's research collected posts from Twitter, encompassing more than 200 million tweets discussing coronavirus or COVID-19; posts from Facebook, Reddit and YouTube were also included.

Of the top 50 influential retweeters, 82% were bots, Carley's group found.

"Usually a story appears first on a website from a human group, and the bots are used for amplification, for retweeting it, respreading it, or for redirecting it to another group," she said.

Some were spreading conspiracy theories; others were rebroadcasting information from the World Health Organization. But many also had a new message: the reopening of America.

A divisive and controversial topic, the question of whether and when to reopen businesses, public spaces or large-scale events has pitted people concerned about spreading the virus against people worried the economy will veer into territory from which it won't recover.

The fact that 2020 is a presidential election year only ups the ante, and Carley noted that bot traffic is about double its usual size, making her group's work even more challenging.

"It can get very exciting. It can also [be] wearying," she said. "It makes you think twice about a lot of how the world works."

For now, the group is trying to communicate its findings through journals, its website and case studies for government and industry. It's also trying to make sense of the campaign by better understanding who benefits.

Carley said the group is making headway in convincing the public that bot influence is a legitimate factor in swaying public opinion.

"A bot doesn't tell you how to think, but it can make you think that a lot of your friends are agreeing with your point of view," she said.

Ultimately, the research could help shed new light on how social media campaigns shape behavior that impacts public health.

"In whose interest are they acting?" she said, adding that the group is looking for a larger context, such as the end result of the bot's actions. "We're trying to get more and more of the 'So what? What are they really doing?'"

Forecasting a Pandemic

As the virus moved into the United States,

in response to a request from the U.S. Centers for Disease Control and Prevention, faculty from the School of Computer Science adapted a nationally recognized influenza forecasting system to predict the spread of COVID-19.

The Delphi group, led by Roni Rosenfeld, head of the Machine Learning Department, and Ryan Tibshirani, associate professor in the Department of Statistics and the Machine Learning Department, includes about 30 faculty members, students and other volunteers. Delphi has amassed years of expertise in accurately predicting flu outbreaks through a two-pronged approach that blends survey responses from volunteers and machine learning that recognizes patterns in data.

For COVID-19, Facebook invites users to answer a Carnegie Mellon-controlled survey about coronavirus symptoms they might experience. Individual responses are not shared with Facebook. The university also used Google surveys and information Google provides about user searches for COVID-19 related terms. Delphi combines this data with anonymous inpatient and outpatient

data for the coronavirus, and Quidel, a diagnostic test provider, contributes by sharing anonymized national lab test statistics.

The project then uses the data to build heat maps like the one below that offer real-time information on symptoms, doctor visits, medical tests and browser searches about COVID-19 as well as estimated disease activity at the county level.

Delphi's effort has been dubbed COVIDcast.

They intend for the project to help the public and policymakers alike monitor the virus around the country and anticipate hospitalizations and ICU admissions several weeks in advance. When COVIDcast launched in April, Tibshirani said the system offered a more realistic picture than what positive tests alone could provide due to factors such as limited test capacity and reporting delays.

"This forecasting problem is so complicated that we believe that a diversity of data and approaches is our best weapon," Tibshirani said.



Printing for Protection

For Zeynep Temel, an assistant professor at the Robotics Institute, her COVID-19 project originated with a sincere desire to help while sheltering in place. Before she left campus for home, she removed equipment from her lab and distributed it to her students. One 3D printer was unclaimed, so she took it home and set it up on a coffee table behind her desk.

Through social media, she learned of an organized effort in Pittsburgh by people with 3D printers to create face shields for first responders. She connected with two volunteer groups in her community, and using a file with a pattern that had been prepared for volunteers and raw materials purchased online, she started printing.

Each shield took between 90 minutes and two hours to create; later, Temel added ear savers, a strap that prevents ear irritation from prolonged

shield use. To date, she has printed nearly 200 of each; she then delivers them to a drop-off location organized by volunteers, who distribute them nationwide and track orders of requests to match them to available inventory.

Temel, who moved to Pittsburgh a year ago, was happy to put the spare printer to good use.

"It's part of my natural response. I wanted to help, but didn't know how to volunteer," she said. She had to train herself to use the particular model of printer that she'd taken home, and she even fixed it when it broke down.

Ordinarily, Temel researches small-scale, bioinspired robots. So fixing a broken 3D printer took little more than watching a YouTube video and reading a few tutorials.

"I'm a mechanical engineer. I figured it out," she said.



Zeynep Temel, assistant professor in the Robotics Institute

From a Crisis, a Path Toward Equity



Students in the AI4AII program, a summer camp free and open to students underrepresented in the field, as part of CMU's commitment to close the digital divide

Shortfalls in medical equipment aren't the only gaps addressed by the School of Computer Science. Disparities in access to technology — sometimes known as the "digital divide" — were magnified by the pandemic, which forced coursework online, regardless of whether students had adequate equipment at home to participate.

"The digital divide is a problem that COVID-19 is highlighting, not one that COVID-19 started. So we want to come up with a permanent solution," says Ashley Williams Patton, director of Carnegie Mellon's Computer Science Pathways program.

Together with Maggie Hannan, a learning scientist and associate director of Carnegie Mellon's Simon Initiative, Patton leads the university's partnership with Pittsburgh-based nonprofit Meta Mesh Wireless Communities to provide free access to Wi-Fi in underserved communities.

Hannan first became aware of the magnitude of the problem shortly after homeschooling began in earnest. To help educators attempting to navigate the online learning ramp-up, the Simon Initiative and collaborators held open office hours to learn where they were experiencing hardships so they could try to match the gaps with the appropriate expertise.

"Very quickly, within the first office hours session, we realized the access to technology was a huge equity issue," said Hannan.

Patton reached out to a contact at Meta Mesh, which offers free Wi-Fi by setting up an antenna that shoots out a signal similar to the way hot spots might work in a home, but on a larger scale. In the past, it has been used to widen a signal in a park, for example.

Meta Mesh agreed to try and repurpose the technology to bring reliable in-home wireless access to students who otherwise wouldn't have it, allowing them the upload and download speeds necessary for videoconferencing. A pilot project has been set up in Coraopolis, Pennsylvania as part of a partnership with the Cornell School District.

Patton and Hannan now plan to explore the feasibility of using ham radio towers to provide a broader swath of signal and possibly expanding to other Pittsburgh neighborhoods, including Homewood and New Kensington-Arnold.

They both hope that their project can serve as a model for other cities to expand broadband access.

"Internet is a necessity now; it's no longer a nice thing to have," Hannan said. "Kids without internet cannot access learning."

Patton agrees: "Access to the internet is a civic right," she said. "We are really ahead of the curve nationally in starting this conversation."

FORGING CHANGE

Three SCS Alumni Take Action Against Racial Inequality in Their Communities

Shilo Rea

The murder of George Floyd — a Black man brutally pinned to the ground by white police officers in Minneapolis, captured on video — sparked outrage and protests. It also renewed the world's attention on the Black Lives Matter movement, which included marches and demonstrations against racially motivated violence toward Black people.

"Collectively, the School of Computer Science must and does recognize this moment as a reckoning for the history of injustice against Black Americans," School of Computer Science Dean Martial Hebert wrote in June. "The time for systemic change is long overdue. Black lives matter at SCS and everywhere. And our voices and actions can create the change we so desperately need."

The movement simultaneously compelled three Carnegie Mellon University alumni to do just that — take action against racial inequalities in their own communities. Focusing on education — specifically fixing instruction and curriculum they believe to be missing — Maya Rau-Murthy (CS 2017), Eric Zhu (CS 2018) and Amal Nanavati (CS 2018) separately formed community groups, wrote and distributed petitions and outlined demands — and are already getting results.

Their activism illustrates how it is ingrained in the SCS culture to never shy away from a complex problem, but instead to develop creative solutions powered by data and science to improve the situation.



YORKTOWN, NEW YORK

Maya Rau-Murthy grew up in Yorktown, N.Y., a small town in Westchester County, and went to Yorktown High School with roughly 1,100 students. Attending Carnegie Mellon made Rau-Murthy realize there were significant gaps in her high school education concerning racism. Topics like redlining and police brutality were never covered.

"We wished we didn't have to wait until college to educate ourselves about racial inequality in the U.S.," Rau-Murthy said

Sad and angered, Rau-Murthy, a software engineer for Waymo, channeled her feelings into making a difference. When high school friend Lily Cao reached out during the protests that followed Floyd's death, the two shared ideas to improve racial education. Rau-Murthy helped Cao bring the movement to Yorktown Central School District.



Maya Rau-Murthy (CS 2017)

Rau-Murthy, Cao and five other high school friends, founded the Yorktown for Racial Justice Alumni and Students Coalition. The group has since grown to include more than 6,000 parents, teachers, alumni, students and local politicians from both the Democratic and Republican parties.

In their initial June petition and through subsequent activities, the coalition outlined key goals for the school district to adopt, including the formation of a diverse committee to oversee racial justice education, ensure racial equality in schools and serve as a liaison between the district and community. The group wants the district to revise and expand its K-12 antiracism curriculum to include racial identity, U.S. race relations after 1965 and ongoing institutional racial issues. Additionally, the petition demands that Yorktown Central High School publicly support Black and Indigenous People of Color when incidences of racial injustice occur, diversify the faculty and mandate extensive diversity, inclusion, sensitivity and unconscious bias training for all faculty and staff.

The coalition also diligently works to incorporate the community's needs, ideas and racial injustice stories by attending town hall meetings, speaking to elected officials and leveraging social media.

"The community needs to understand the gravity of the issue and that this is happening at home," said Rau-Murthy. "It's so important to educate from a young age and talk about things such as privilege and redlining."

The coalition received an overwhelming response to a call for personal experiences with racism, and Rau-Murthy said that reading through them was emotional.

"It's sad to read what is happening. It made us feel more strongly about what we are doing," she said.

Rau-Murthy has used the experience in Yorktown to make a national impact. She reached out to more than 10 districts in states from California to New Jersey, encouraging them to make comparable large-scale changes.



"We want them to understand that the issues are a lot deeper than saying you have anti-bias training and teach about the civil rights movement. It's not just history and English. There is a bigger conversation that needs to happen in schools."—Eric Zhu (CS 2018)

ALLENDALE, NEW JERSEY

Eric Zhu, a software engineer at Google, had been reflecting on his own high school education and its lack of teaching contemporary racial injustice when he learned through a group chat about Rau-Murthy's activities to change her hometown school district.

"Mass incarceration, redlining... they were never addressed explicitly or inexplicitly in high school," said Zhu, who attended Northern Highlands Regional High School in Allendale, N.J. "I've been learning more about lived realities in the U.S. ever since I got to CMU. Then, once my daily routine was interrupted by the pandemic, I was able to listen more intently to what Black and Indigenous People of Color activists were saying. And that compelled me to actually do something."

Zhu and 14 other high school alumni formed the Northern Highlands Alumni Action Committee to petition the school district, targeting curricula at the high school and middle school levels. They asked the district's Board of Education to ensure racial justice be regularly addressed in every classroom, provide quarterly extracurricular programming to educate students and teachers on racial bias and privilege, and establish a support system for Black and Indigenous People of Color.

"Our district is in the suburbs and is not racially diverse," Zhu said. "It was a good education learning

about history and the civil rights movement, but it stopped in the 1960s. It doesn't explain how things are today."

A big challenge Zhu and his group initially faced was persuading the school district that they needed to do more.

"We want them to understand that the issues are a lot deeper than saying you have anti-bias training and teach about the civil rights movement. It's not just history and English. There is a bigger conversation that needs to happen in schools," Zhu said.

Zhu also put the district's superintendent in touch with the NYU Metro Center's Center for Strategic Solutions.

"There's been a movement within education called #POCPD to get people of color to do professional development," he said. "The Center for Strategic Solutions could provide more tailored services that fit my high school's needs."

This isn't the first time Zhu has worked to change racial inequality at a school. While a CMU undergraduate, he was a member of the Student Senate and underscored the need for a diversity-inclusion presence on campus.

"CMU did not have a dedicated faculty, staff and student resource center for diversity and inclusion," said Zhu. "After I graduated, the faculty and administration created one, and that was an awesome moment—seeing that conversations do lead to something."



Amal Nanavati (CS 2018)

FREMONT, CALIFORNIA

Like Zhu, Amal Nanavati was inspired by Rau-Murthy's efforts in Yorktown.

"The idea clicked so well with me," Nanavati said. "I was trying to find ways to combat racism in my community, and education is a core way."

He had often wondered why his history classes stopped at the civil rights movement and why books he read in literature classes that covered Black experiences were written by white authors.

"I wasn't sure how to get started in my district. There are 35,000 students," Nanavati said.

Nanavati began with a small group of alumni, teachers and current students he thought would be interested. After a month of weekly meetings, research, brainstorming sessions and drafts, they created the FUSD: Anti-Racism Now petition for the Fremont Unified School District. They concentrated on improving three areas they felt perpetuate systemic racism: 1) diversifying the district's workforce and committing to social justice professional development, 2) rethinking the curricular content to include ethnic studies and anti-racist perspectives in all subjects and 3) reforming discipline procedures that often harshly impact students of color.

"The strength of our petition was that it focused on three topics that people often see as unrelated, all under the joint umbrella of anti-racism," Nanavati said. "The petition itself educated readers about the interconnected layers of racism."

There are many ways to teach students about how racism has affected our culture and to involve diversity in more grade levels and in subjects other than history and literature. One example would be to teach math students about the statistics of segregation, redlining, gerrymandering

and intergenerational wealth transfer. Science teachers could present information on why there is no scientific basis for race and teach about the exploitation of Black bodies during the history of medicine as well as current divisions in access to

Since they shared the original petition, Nanavati's group has achieved several victories: The school board created a task force to reevaluate their policy of having one police officer stationed in every high school. The district has drafted and shared an equity statement which Nanavati's group provided feedback on. The board also held a dedicated study session to discuss anti-racist reform and decided to keep it as a regular agenda item. Additionally, in mid-October, the Fremont Unified District Teachers Association voted almost unanimously to endorse the anti-racism petition.

"This is exciting because the teachers' union has seats on board committees and has considerable power to affect change in our district," said Nanavati.

Nanavati, who is pursuing his Ph.D. in computer science and engineering at the University of Washington, is also working to improve the environment there. He has helped plan, coordinate and lead anti-racism workshops, which encouraged researchers in the robotics program to learn more about racism and identify ways to further tackle the issues.

He credits this form of activism to his days at Carnegie Mellon when he co-founded Teknowledge, a student organization that develops and teaches computer science curricula to under-resourced middle and high schools in the Pittsburgh area.

"I have been fortunate to have great opportunities in life — especially in education — that have shaped me into the person I am," Nanavati said. "The fact that there are so many people in this nation who are denied these opportunities is sad and angering."

Beyond working to end injustices towards people of color, Rau-Murthy, Zhu and Nanavati also believe SCS to be uniquely positioned to fight technology bias, and for SCS students and alumni to consider the social implications of the technology they create.

"Technologists in the world today have a lot of power," Nanavati said. "Our work is not neutral, and we must confront how it influences power structures and is often used to further disempower the most marginalized among us."



GIVE TO THE **RAJ REDDY FUND FOR ARTIFICIAL INTELLIGENCE**

Raj Reddy's contributions to artificial intelligence cannot be overstated. As founding director of the Robotics Institute and a former dean of Carnegie Mellon University's School of Computer Science, he oversaw revolutionary developments in autonomous driving, computer vision and speech recognition (where he was personally a pioneer). The Raj Reddy Fund for Artificial Intelligence celebrates Raj's devotion to CMU, the School of Computer Science and AI in general.

BE A PART OF THE FUTURE OF AI

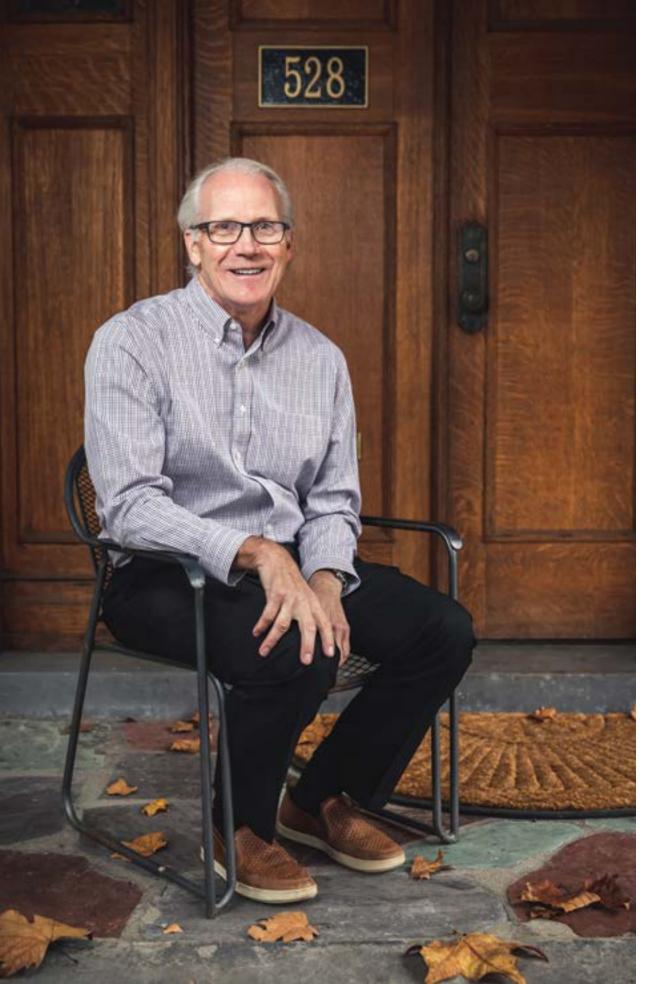
When you contribute to the Raj Reddy Al Fund, you acknowledge and celebrate the lasting impact Raj has made on the field. At the same time, you invest in the students, faculty and research that will change how humans and technology interact for generations to come.



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CONTACT Jenny Belardi, Chief Advancement Officer, School of Computer Science 412-268-8810 ■ jbelardi@andrew.cmu.edu

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Randy Bryant Taking the Next Step

Byron Spice

hen Randy Bryant took the helm of Carnegie Mellon's School of Computer Science in 2004, he quickly realized that SCS, despite its top ranking among computer science schools, had joined its peers in falling a bit behind the research curve.

It was a time when Google and Amazon used thousand-machine server farms to perform unimagined feats and develop new computational methods for solving problems. But academics had yet to embrace the power of big data.

"We were still thinking in terms of much smaller scale when we looked at data, and not all the things we could do with it," Bryant recalled recently. "So although good research was going on, universities were working at a much smaller scale than industry."

Under Bryant's leadership, SCS created a new emphasis on big data—an emphasis that then spread across the country. It was just one of many transformations in the school and discipline that bore Bryant's stamp during his 36-year CMU career.

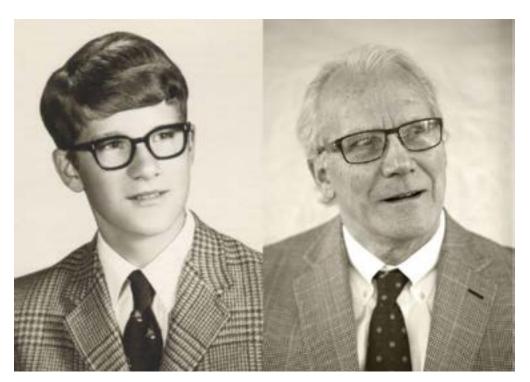
"As a dean, I feel like I just took what was already a great program with some great vision and helped move it along," said Bryant, who retired in June. "I was in a good place at a good time. I do feel like I was able to help the school move forward by recognizing both our own strengths and future trends and help foster that with the university."

Bryant, an MIT alum who spent three years on the Caltech faculty, arrived at Carnegie Mellon in 1984, joining an organization—the Computer Science Department (CSD)—that was smaller and more intimate than today's sprawling SCS. With a Ph.D. program and almost all of its funding coming from a large Department of Defense grant, "It was research all the time," he said.

In his case, research meant developing software to help computer chip makers design circuitry for then-new "computers on a chip." Between CSD and the Department of Electrical and Computer Engineering, CMU had lots of talent in these areas, and Bryant enjoyed the cross-boundary collaboration.

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"As a dean, I feel like I just took what was already a great program with some great vision and helped move it along."—Randy Bryant

As he worked on these design tools, his interests expanded into the field of formal verification. Finding bugs in hardware designs depended on simulation, and there were limits to how much simulation was possible. So Bryant began exploring formal verification — techniques that could prove a design was correct without doing endless testing. He began collaborating with Ed Clarke, who specialized in the field and would later win the Turing Award for his work on a type of verification called model checking.

Meanwhile, SCS launched in 1989 and with it came a new undergraduate computer science degree program. While CSD faculty had once focused almost exclusively on research, now they began to think about how best to prepare undergraduates. Bryant embraced this challenge, partnering with David O'Hallaron to create a new course

on computer systems — the one with the course number that's the same as CMU's Zip code, 15-213. They also wrote a textbook, now in its third edition.

"That really became a transformative part of my career," Bryant said. "To first create a course at CMU and then create a book we could use to export those ideas to the whole world and develop a community around this book at several hundred universities."

Jim Morris, then CSD head, saw administrative potential in Bryant and began coaching him for leadership. When Morris became SCS dean, Bryant became CSD head. And when Morris stepped down as dean in 2004, Bryant stepped up to replace him.

As dean, Bryant's vision of "big bets on big data" expanded as he visited companies and heard tales from the Language Technologies Institute about how Google had suddenly dislodged them and the other usual suspects in machine translation competitions. Suddenly, Google was making huge progress in translation by using machine learning to analyze

bilingual documents side by side. Unlike previous methods, Google's programs didn't understand language structure. They recognized patterns.

"Along with other people in the school, we formulated this theme of big data and made that a center point for SCS," Bryant said. "It turned out the timing was perfect and we had the right collection of people and the right resources to do it." He also promoted the idea at the national level, contributing to a paper that influenced the Obama transition team in 2008.

During his decade as dean, SCS also launched two new departments: the Machine Learning Department and the Computational Biology Department. In both cases, Bryant said, the new departments followed a CMU pattern: start small, hire young faculty, create bridges to related departments and build the programs carefully until they're ready to be departments.

Though new departments flourished, SCS also faced the so-called dot com bust during Bryant's tenure. Student applications, which had been on the rise, suddenly plummeted as high school students began to worry that no jobs were to be had in computer science, or that the jobs were boring, or that all of the jobs would be overseas.

"CMU lived through it because we had a big enough applicant pool that was still strong, even though it was shrinking," Bryant said.

But then things turned around. New grads started leaving SCS with tantalizing job offers and applications went off the charts.

"I describe that as the Mark Zuckerberg effect, because students went from saying, 'Oh, I don't want to spend my life in a cubicle turning out code' to 'Gee, I think I'm going to sit in my dorm room and write code all night.' Same thing, very different attitude," Bryant said.

When he stepped down as dean in 2014, Bryant opted to spend a sabbatical year at the Office of Science and Technology Policy (OSTP) in Washington, D.C. He spent much of that time promoting the National Strategic Computing Initiative — a unified plan to establish a highperformance computing infrastructure.

"It wasn't my main research area, but it gave me an opportunity to jump into the middle of a government initiative where a lot of good work had been done and that really just needed someone to keep the ball rolling," he recalled. Back at CMU after his year in D.C., Bryant returned to teaching and, inspired by his work on the computing initiative, decided to delve more deeply into parallel computing — one of the subjects he had tackled at the OSTP. Kayvon Fatahalian, who was then teaching the parallel computing course, agreed to have Bryant teach the course with him.

"Quite honestly, even though I was the more senior faculty member, I was very much the junior partner and I let him do most of the work. He developed the course," Bryant said. When Fatahalian left CMU two years later, though, Bryant suddenly found himself in charge.

"I was quite panicked," he said. "It was really stressful to do it for the first time." Three years later, he still taught the course, with Nathan Beckman as co-instructor, but in a much better position.

Now, Bryant has made one more transition: into retirement. Though he anticipates staying around CMU and is thinking about the fourth edition of his textbook with O'Hallaron, he said he plans to make it a real retirement, without the pressure of teaching huge classes. He's got grandkids to watch grow, travel plans — including a possible trip to Nepal — and music to enjoy as a member of the Bach Choir of Pittsburgh.

"One of the things my father used to say is, you should change your job every six years," Bryant said "And, in some ways, I've done that at CMU because I started as an assistant professor and then became a full professor and then a department head and then as a dean and now I'm post-dean. So I've fundamentally changed the nature of what I was doing every six years or so.

"And I've managed to do it without actually changing employers." ■





HELPING ROBOTS THINK

HENNY ADMONI

LIKE WEDO

 $Mark\,Roth$

The most successful home robot in the world does not resemble a science fiction android like C3PO, but a round rotating rambler that cleans your floors.

The widespread adoption of the Roomba holds an important lesson, said Henny Admoni, A. Nico Habermann Career Development Professor in Computer Science and head of the Human And Robot Partners (HARP) Lab.

The robots that she and other researchers are developing to help people with their daily tasks are more likely to be specialized devices especially suited to the jobs they perform. Unlike the Roomba, though, they will also increasingly possess another ability — predicting what their human partners want, and responding appropriately.

In her HARP lab, Admoni works to infuse artificial intelligence into a robotic arm to help people with disabilities feed themselves. She wants an arm that not only has excellent mechanical abilities, but can interpret what a human being wants it to do next.

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Henny Admoni, (center) working

with her team in the Human And Robot Partners (HARP) Lab.

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In one frequently viewed video of an experiment in her lab, people manipulate a joystick to get a robotic arm to spear marshmallows with a fork. While they work on the task, special glasses record where they are looking, a process known as eyegaze tracking.

Most of the time, their eyes bounce back and forth from the fork in the robotic gripper to the marshmallows on a plate. But if the robot arm gets out of position, their gaze concentrates on the part of the robot they need to reorient.

Eventually, Admoni hopes to develop algorithms that allow the robotic arm to take that eye gaze information and respond to it appropriately, picking up the food a person wants or changing its arm position to meet someone's needs without the person needing to use a controller.

Her groundbreaking work has earned widespread recognition. In April, she received a National Science Foundation Faculty Early Career Development Award, the organization's most prestigious honor for junior faculty members. Admoni's \$550,000 award covers a five-year period and fulfills the intention of providing younger scientists with stable funding for basic research.

Admoni recently had the rare opportunity to speak in January at the World Economic Forum in Davos, Switzerland, where Carnegie Mellon President Farnam Jahanian described her as "a rising star within the [School of Computer Science's] Robotics Institute, whose work aims to integrate technology into our lives in ways that enhance our humanity."

For Admoni, that starts with trying to give robots a skill we are all born with — understanding nonverbal behavior.

"There's a lot of nonverbal communication and coordination when people are working together, using things like eye gaze and gestures. My goal is to make robots capable of this kind of complex, nonverbal communication."

Ultimately, she wants robots to be able to help people with everyday tasks like eating a meal or learning a new skill. To do that, robots need to know what kind of help people need at the precise moment they need it.

The same algorithms she develops for her robotic arm could one day help a bomb disposal expert defuse an explosive device or help astronauts control an arm outside a space vehicle. But for now, Admoni remains focused on people who don't have full use of their bodies.

"If I help someone teleoperate a robot arm, I'm helping them do their job better," she said, "but I'm not necessarily increasing their quality of life or giving them an increased capability at the same level that I am when I'm helping someone who has a motor impairment."

A Multitasker From the Beginning

Growing up in Long Island, Admoni originally wanted to be a journalist. It fit with her skills in English and psychology. But her high school also had a rigorous experimental science program, and Admoni learned how to design and conduct experiments, keep lab notebooks and prepare posters for top-level scientific competitions.

While attending Wesleyan University in Connecticut for her undergraduate work, she thought she might be able to combine her interests by majoring in neuroscience.

Then she ran into a major obstacle: Lab work in neuroscience required that she sacrifice animals in a laboratory, and she didn't want to do that.

Instead, she designed her own major: combining computer science, psychology and neuroscience. "I was trying to understand human behavior, human perception and human brains using computational techniques," she said.

After earning her bachelor's and master's at Wesleyan, she entered a Ph.D. program in computer science at Yale University. While there, her mentor, Brian Scassellati, introduced her to robots and the idea that they could be used to interact with people to provide physical, social and cognitive support.

Much of Scassellati's work centers on robots that interact with children who have autism, to



help the children communicate better with adults. In Admoni's case, she used a variety of robots to enhance understanding of how humans and robots communicate with each other.

One experiment asked people to take items handed to them by a robot and sort them into bins. The robot would turn its head to gaze at a particular bin before handing over the item, but many times, the humans would ignore the bin the robot was looking at.

"But when the robot would turn its head and then hold onto the object for a second too long before releasing it, all of a sudden people started looking more at the robot's face and placing the object in the bin the robot suggested. When the student in the experiment had to tug the object out of the robot's hand, all of a sudden the robot became a social agent."

Admoni is not trying to create robots that would replace human employees, but instead wants them to assist people in their work by making it more efficient and meaningful. For instance, if assistive robots can take over some of the feeding tasks for health care aides, then the workers can spend more time talking with their clients or helping them organize their medications.

No Fear of the Robot Apocalypse

Admoni knows that some people worry that robots one day might surpass human abilities.

"Media has portrayed robots both as incredibly helpful and incredibly scary," Admoni said. "But I think people focus on the scary part when they're thinking about the future of robotics.

"The only thing that makes me laugh is we are so far from *Terminator*. It's not even sensible to be afraid of it because it's such an outlandish fantasy."

Admoni speaking at the World Economic Forum in Davos, Switzerland.

Another initiative of Admoni's research uses robots to help boost creativity in young children. "We envision having children make some sort of digital art together with a robot, and the robot could push them, encourage them to use more creative colors, to try out new shapes."

Admoni is also working closely with Carnegie Mellon Research Professor Reid Simmons and Associate Research Professor Aaron Steinfeld on a project funded by the Office of Naval Research to use artificial intelligence to improve the ability of robots to tell humans the likelihood of the robots succeeding at a given task.

"We've had 10 years building these kind of black boxes, these systems that take in large numbers of examples and learn from them," Admoni said. "But when we open that black box, we don't know how they work and because of that we don't know when they're going to fail."

If a robot can tell its human partner the odds of whether it can successfully get past an obstacle or manipulate an object, it will make the two of them a better team. To communicate its chance of success, the robot needs to learn to think more like a person, Steinfeld said.

Take the task of helping a person with a physical disability get out of bed. "When you or I walk up to a person we're asked to help move," Steinfeld said, "one of the first things we think of is, 'Am I strong enough?' You might also think of the posture you have to get into ... and you're paying attention to your stability. The robot might need to do the same kind of thing." In this scenario, if a robot can give the human an idea of whether it thinks it can succeed at that task, it will greatly enhance the safety of the disabled person and the caregiver.

Admoni is especially well suited to these kinds of projects, Scassellati said.

"You have to be extremely technically competent; you need to be an exceptional computer scientist; you have to be an exceptional experimentalist to devise these clever experiments that demonstrate the one particular thing you need to test; and then you have to build something that is useful."

Henny Admoni excels in her ability to wear all these different hats. ■

From Video Signals to Bytes: Preserving the Legacy of CS at CMU



Cristina Rouvalis

The image from the videotape is blurry, deteriorated from the passage of time, but the professor is razor-sharp as he talks about the future. Herb Simon stands in front of a class at Carnegie Mellon University, musing about the difference between artificial and natural intelligence.

"So I suppose there are some respects in which it makes a difference whether we're talking about artificial or natural intelligence. When I'm in an airplane during a bad rainstorm, I always wonder which I'm being landed by," says Simon. The class laughs, and Simon, bespectacled and wearing a suit and tie, lets out a wry smile.

This is Herb Simon in September of 1971, before he won the Turing Award.
Before he won the Nobel Prize in Economic Sciences. Before he was widely heralded as a pioneer in artificial intelligence.







Emily Davis & Katherine Barbera of University Library Archives

hanks to the University Archives' renewed investment in audiovisual preservation, the public can watch a digital recording of that magical moment, one of many recorded at CMU between 1970 and

1993. Some 400 videotapes make up the Computer Science Videotape Collection, which capture the early, heady days of the field when a group of visionaries converged on a depressed steel town and through their research and collaboration, defined the very essence of modern life. These historic documents exude the sense of excitement and infinite possibilities during the formative years of the Computer Science Department and document the profound role of the School of Computer Science in defining the field.

To date, archivists have digitized 30 tapes, including recordings of Allen Newell, Raj Reddy, Alan Perlis and other SCS pioneers. A portion of these can be viewed on the University Archives' Vimeo Channel: https://vimeo.com/showcase/6834037. Other tapes highlight speakers and thought leaders from around the world who came to CMU to lecture or serve as visiting professors. Another 20 videos have been slated to be digitized by Preservation Technologies, a

Cranberry Township-based company. But the process is expensive, leaving approximately 350 videos vulnerable to deterioration. Each hour-long tape costs about \$250 to digitize, and the archivists hope to complete the project of digitizing them within the next three to four years.

"It's really important that we do this as soon as possible, before they degrade even further or it becomes too cost prohibitive," said Emily Davis, archivist at Carnegie Mellon. "Some of the tapes are so fragile and unstable. Some have mold that can eat away information on the tape."

One of the videotapes captures Allen Newell, a Turing award winner in 1975, giving his famous "Desires and Diversions" lecture about dealing with the distraction of life while still pursuing his passion for research. In the question and answer segment, Newell commands the classroom, speaking with remarkable dynamism and animation.

"I learned what a fabulous teacher Allen Newell was," said Katherine Barbera, archivist and oral historian at Carnegie Mellon. "He had this wonderful personality and a good sense of humor."

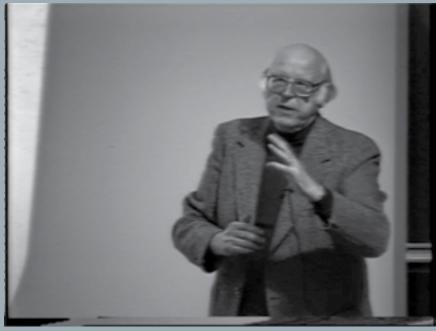
In another video, Mary Shaw, then a young Ph.D. student, introduces a lecture by Alan Perlis, the first winner of the Turing award in 1966 and head of the Computer Science Department. Shaw would go on to become a legend in her own right as founder of the Software Engineering Institute and now the A.J. Perlis Professor of Computer Science.

"These tapes bring history to life for current and future generations in a way that other archival materials, notes, letters, emails, code and even photographs simply can't," Barbera said. "The tapes really help the students grasp the legacy that they're inheriting."

Leaders within the Department of Computer Science, established in 1965, understood then the importance of documenting the innovative ideas contained within their lectures. They had the foresight not only to realize how far out in front of the field they stood, but to preserve CMU's role as visionaries in the emerging field as it was being formed. These videos are a treasure trove, which cement SCS's foundational legacy, allowing current and future generations to experience this history as it was being made.

"These tapes bring history to life for current and future generations in a way that other archival materials, notes, letters, emails, code and even photographs simply can't."

- Katherine Barbera



Allen Newell, a Turing award winner in 1975, giving his famous "Desires and Diversions" lecture about dealing with the distraction of life while still pursuing his passion for research.





Raj Reddy stands before an audience holding up a new Bally video game console.

"These videos represent the flesh and blood of the people who did the work, the camaraderie and the collegiality in what they were doing."

Ralph Guggenheim (DC 1974, MCS 1978), co-founder of Pixa

Making Films about Computers and Using Computers to Make Films

Raj Reddy stands before an audience holding up a new Bally video game console. It's October 1978, and in a few months, the game will become a popular Christmas gift.

"Basically you can play all kinds of games.
You can even do basic programming with it," he says. "So what I thought we would do today is just generally raise questions about how these are built and why they are built that way, and why they are so inexpensive. This is about \$50," says Reddy, who would go on to found Carnegie Mellon University's Institute for Software Research and also would become dean of SCS.

Reddy wanted to take the documentation a step further and produce 16 mm instructional films about scientific concepts to help him secure grant funding for research, just as he had while he was a professor at Stanford University. In the process, he helped launch the career of one of the pioneers of computer animation.

Ralph Guggenheim (DC 1974, MCS 1978) arrived at Carnegie Mellon in 1969 as a liberal arts major. But Guggenheim really wanted to be a filmmaker. After reading about the emerging field of computer animation, he decided to design his own master's degree in the Department of Computer Science, specializing in computer graphics and filmmaking. Raj Reddy was his advisor and mentor.

One day, the student went on a walk with Reddy, who told him about his idea to produce promotional films on research subjects such as voice recognition. "Looking back," Guggenheim said, "it was sort of like that closing scene in *Casablanca*—the beginning of a beautiful relationship."



Six months after graduation, while working at the New York Institute of Technology, Guggenheim received a phone call from Los Angeles about a job opportunity at Lucasfilm. The company had called Stanford, who recommended Reddy, who recommended his former student for the job. Several years later, Lucasfilm split off to form Pixar, with Guggenheim as co-founder and vice president. He produced the first feature-length computer animated movie, *Toy Story*.

"I wouldn't have done *Toy Story* without Raj Reddy," he said.

Today, Guggenheim wants to help preserve the thrilling history he lived through by helping to support the preservation of the Computer Science Videotape Collection.

"These videos [in the Computer Science Videotape Collection] represent more than just the dry research results. They represent the flesh and blood of the people who did the work, the camaraderie and the collegiality in what they were doing," said Guggenheim.

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"In my heart, I always knew they had to be saved."

-Catherine Copetas, Associate Dean of SCS

The Protectors of the Archives

For years, these videos multiplied by the dozens, while Catherine Copetas, the assistant dean for Industrial Relations, collected them. Without Copetas, the collection may have perished. She stored stacks on the shelves of her office in Wean Hall. The overflow tapes piled high in her storage closet. "The hoarding jokes were getting old," she quipped.

One day during winter break in the early 2000s, some of that history was nearly washed away. A graduate student in the office above Copetas had left the window open, the pipes by the window froze, and water flooded the office. Ceiling tiles came crashing down, the water soaking the walls. Luckily, the videotapes that were being stored there survived thanks to the quick work of two computer science professors — Dana Scott and Howard Wactlar, who rushed to salvage what they could from her office.

When the school moved to the Gates Hillman Center in 2009, some of the videotapes were scattered in storage rooms in Gates Hillman and Wean Hall, with the overflow to a storage unit on Penn Avenue. For years, the videos were "missing in plain sight," as Copetas puts it. "Playing the oldest ones wasn't possible. Technology shifted, original equipment broke and it was dangerous to even try to view for fear of destroying them." Even when it was nearly impossible to find a reliable player to view the old tapes, Copetas knew they were worth a cluttered office and storage closet.

"In my heart, I always knew they had to be saved," she said. Then in 2017 Copetas met Barbera and Davis, who expressed interest in the collection. "I knew the tapes had found a good home in the University Archives and that the history contained in them would be restored." The videotapes she guarded form part of the history of both the university and the city. "Why CMU? Why Pittsburgh?" she said. "Why would this city become an intellectual powerhouse?"

"It's magical to get all these people here," she said. "When you have magic, you don't waste it."

The Power of Pioneers: Saving a Legacy

In June, some 150 alumni from around the country tuned into Zoom to watch short clips of Allen Newell, Herb Simon and Raj Reddy, as well as a brief presentation by Guggenheim who reflected back on the trajectory of his career. Others watched after a recording of the "The Power of Pioneers: Preserving CMU's CS video collection" was posted online.

Archivists also invited alumni to get in touch and share their personal stories of learning or working with these pioneers. One alumna inquired about the female computer scientists in the archives, and Emily Davis sent her a list of women and the dates they had given lectures.

"Everyone has been so excited," Davis said.
"A lot of alumni are saying, 'I was there. I was in that lecture." ■

If you would like more information on the project or would like to watch the recording of the webinar, visit: https://cmuaa.wistia.com/medias/pa345lm106# To make a donation to the preservation of the Computer Science Videotape Collection fund, please visit: https://give.cmu.edu/pmtx/giftselect?id=a412S0000015RnB&appeal=A7199





Mary Shaw, then a young Ph.D. student, introduces a lecture by Alan Perlis, the first winner of the Turing award in 1966 and head of the Computer Science Department.





Al and Work:

Relationship Status? It's Complicated

Chris Quirk

hen Google DeepMind's
AlphaGo computer program
beat Go grandmaster Lee
Sedol, an 18-time international
champion, in the first game of
their match in 2016, Sedol was
shocked. "I didn't think AlphaGo would play the
game in such a perfect manner," he said.

Game theorists widely consider Go to be the apex of board games in terms of complexity. Players must select from about seven times the number of possible moves from an average situation as compared to chess. And even though it had been nearly 20 years since Gary Kasparov lost to IBM's Deep Blue in the much-heralded chess match, experts remained steadfast in their predictions that it would take a great deal longer for AI to top the world's best at Go.

But AlphaGo took the five-game match, trouncing Sedol 4–1. "Don't Forget Humans Created the Computer Program that Can Beat Humans at Go," read an apologetic headline on FiveThirtyEight.com after Sedol's defeat. If AI could best the world's brightest in the most challenging games, the immediate question arose: What couldn't AI do better than humans? Wasn't it just a matter of time before AI replaced humans in all kinds of tasks? And, thus, what would that mean for workers?

Not Zero-Sum

The reality of how AI affects the way people work proves far more intricate and nuanced than a zero-sum game. At the forefront of examining the impact of AI on workers and society are the faculty at Carnegie Mellon's Human-Computer Interaction Institute (HCII). "The bleak view is that people will be put out of jobs," said Jodi Forlizzi, Charles M. Geschke Director and professor at the HCII. Forlizzi forecasts a dynamic future work environment, one that produces opportunities to go with the losses.

"A brighter casting of this is that work is going to shift. In some sectors, jobs won't exist anymore. And for as many jobs that will be eliminated, there will be other jobs created that interact with technology in new ways."

While the capacities of AI increase rapidly, the loss of jobs to technology is nothing new, points out Tom Mitchell, Founders University Professor of Machine Learning. "There are going to be positive and negative impacts of any powerful technology, including AI," he said. "Take toll booth operators as an example of a job being automated out of existence. It's bad news for a certain segment of people, unfortunately. It's better news for other people in terms of convenience and the general efficiency of the economy. You don't have to wait in line for 15 minutes anymore when you're driving on a popular toll road."

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Mitchell contends that we often overlook the fact that very few jobs comprise a single task — most are made up of a variety of tasks of varying complexities. Working with his colleague Erik Brynjolfsson of MIT, Mitchell examined the makeup of thousands of jobs for a 2017 study published in Science. "We found very, very few jobs where every task is likely to be automated. Instead of seeing a wholesale automation of many different jobs, we will more likely see jobs change rather than be eliminated."

While relatively few jobs are subject to fully automated replacements, Mitchell's work indicates that proving AI-enhanced technical support to workers in particular tasks using data, information or analysis could play a positive role. How that occurs is something John Zimmerman, Tang Family Professor of Artificial Intelligence and Human-Computer Interaction at HCII, has been researching. "I've created things like decisionsupport tools that help cardiologists decide when to implant a mechanical heart. It's not about making a decision for a doctor. Doctors are super confident and they know how to make decisions," said Zimmerman. "But can I give them a new resource at the right time and right place that is valuable to them in their decision-making process — something that makes them a better doctor, but that isn't doing the doctoring for them."

AI also shows great potential for supporting job tasks in the retail sector. For instance, AI could help inform customer service agents to personalize service and suggestions for customers in real time, and target a customer's need precisely, leading to greater customer satisfaction. "It's not high-end personal service for million-dollar customers. This is high-end personal service to every customer," Zimmerman said. "You're giving agents a resource that's not telling them what to do, but helping them be better at what they do."

Partnerships for the Gig Economy

The current gig economy has its drawbacks, but one distinct advantage is the low bar for entry for many jobs. This can mean quick access to earnings, instead of a protracted job search, hiring and onboarding process. For some jobs, a computer or car, or even simply a smartphone might be all you need. For someone out of work and in need of income quickly, this could be an attractive option. While getting a job as a cab driver involves licensing and training, drivers for Uber and Lyft report being approved to pick up fares in as little as a few days. "It's one of the positive impacts of AI and computer technology enabling these kinds of jobs," said Mitchell. "Without the sophisticated AI and software, we would never have Uber. Ideally, let's build better safety nets for people who lose their current jobs, so that they can do something while they're trying to retrain or look for a better job. I think the gig economy is one step in that direction."

Granted, when AI-powered jobs infringe on more traditional markets, conflicts will inevitably arise. Ride hailing apps take business from traditional cab drivers. Food delivery apps affect restaurant and hospitality workers. Recognizing this, Forlizzi and her colleagues work closely with UNITE HERE, the largest hospitality union in the country, to minimize the negative effects of new technology on workers. "UNITE HERE wants to assess new AI-driven technologies and to prepare and educate their workforce," said Forlizzi.

The problems that UNITE HERE and CMU partner on represent one small part of the broader relationship between technology and the societies in which it operates. "It's a very dynamic time in the workplace, and a lot of companies didn't have foresight about the kinds of changes that would take place," Forlizzi said. "The pattern we've seen unfortunately is things happen and then policy tries to rush to catch up."



"For as many jobs that will be eliminated, there will be other jobs created that interact with technology in new ways."

 Jodi Forlizzi, Charles M. Geschke Director and professor of the HCII

Finding the Balance

When societal concerns are left out of the conversation as technology is created and introduced, the chances for blowback rise, Zimmerman said. "My concern is that we design technology and policy as two separate processes, and typically policy is always done in reaction. We need to design technology and create policy together. The two are interwoven, and a lot of the potential harm that a new technology might do can be mediated by thinking of the policy at the same time."

While these concerns may seem esoteric at a glance, the nuts and bolts of how policy and technology are united will inevitably reverberate through society and affect the lives of individuals, some profoundly. "The challenge every time you make a simulation, whether on paper or on a computer screen, is that there's a ton of underlying assumptions," said Illah Nourbakhsh, K&L Gates Professor of Ethics and Computational Technologies in the Robotics Institute. "The hidden assumptions are critical to the functionality of the simulation or the model you're making. The only way to externalize those assumptions is to have all the different subject matter experts — all those disciplinary enthusiasts — in the room at the same time."

These design and policy debates among stakeholders will determine who benefits from the technological advances, and how much. "To the degree that technology lets us create more wealth, a bigger wealth pie, from the same amount of human effort, then we're growing the wealth pie. Who could possibly be against that?" said Mitchell. "On the other hand, the people who have control of that technology end up with a larger share of the wealth. I think that's the reality that we won't be able to escape unless we make some public policy choices. For example, we could choose a policy that says as the wealth pie grows, we'll do it in a way where nobody's piece of pie actually decreases."

Nourbakhsh concurs, asserting that ongoing multilateral cooperation between researchers, lawmakers and stakeholders is the way to achieve the right balance for society. "It's the only way to combat the natural tendency for the concentration of information and automation to exacerbate the divides between rich and poor," he said. "AI keeps changing every year, every month, and so we need a strategy for how we are going to renegotiate what the nature of labor is for people. We can't just make a decision, draw a line in the sand and then suggest that is going to work."



Leveraging Al to Give Voice to the Voiceless

Hate Speech Countered by Detecting, Highlighting "Help Speech"

Byron Spice

Complete
the following
sentence:
Rohingya refugees
should go to —

A. Pakistan.B. Bangladesh.C. Hell.

hese aren't good choices, but all are sentiments that have been expressed repeatedly on social media. The Rohingyas, who began fleeing Myanmar in 2017 to avoid ethnic cleansing, are ill-equipped to defend themselves from these online attacks, but innovations from Carnegie Mellon's Language Technologies Institute (LTI) could help counter the hate speech directed at them and other voiceless groups.

The LTI researchers have developed a system that leverages artificial intelligence to rapidly analyze hundreds of thousands of comments on social media and identify the fraction that defend or sympathize with disenfranchised minorities such as the Rohingya community. Human social media moderators, who couldn't possibly manually sift through so many comments, would then have the option to highlight this "help speech" in comment sections.

"Even if there's lots of hateful content, we can still find positive comments," said Ashiqur R. KhudaBukhsh, a post-doctoral researcher in the LTI who conducted the research with alumnus Shriphani Palakodety. Finding and highlighting these positive comments, they suggest, might do as much to make the internet a safer, healthier place as would detecting and eliminating hostile content or banning the trolls responsible.

Left to themselves, the Rohingyas are largely defenseless against online hate speech. Many of them have limited proficiency in global languages such as English, and they have little access to the internet. Most are too busy trying to stay alive to spend much time posting their own content, KhudaBukhsh said.

Jaime Carbonell, who served as the director of the Language Technologies Institute until his death in February 2020, was a co-author of the study.

To find relevant help speech, the researchers used their technique to search more than a quarter of a million comments from YouTube in what they believe is the first AI-focused analysis of the Rohingya refugee crisis. They presented their findings at the Association for the Advancement of Artificial Intelligence annual conference, in February in New York City.

Similarly, in a study presented at the European Conference on Artificial Intelligence in June, they used the technology to search for antiwar «hope speech» among almost a million YouTube comments surrounding the February 2019 Pulwama terror attack in Kashmir, which enflamed the longstanding India-Pakistan dispute over the region.

The ability to analyze such large quantities of text for content and opinion is possible because of recent major improvements in language models. These models learn from examples so they can predict what words are likely to occur in a given sequence and help machines understand what speakers and writers are trying to say.

But the CMU researchers developed a further innovation that made it possible to apply these models to short social media texts in South Asia, he added. Short bits of text, often with spelling and grammar mistakes, are difficult for machines to interpret. It's even harder in South Asian countries,

where people may speak several languages and tend to "code switch," combining bits of different languages and even different writing systems in the same statement.

Existing machine learning methods create representations of words, or word embeddings, so that all words with a similar meaning are represented in the same way. This technique makes it possible to compute the proximity of a word to others in a comment or post. To extend this technique to the challenging texts of South Asia, the CMU team obtained new embeddings that revealed language groupings or clusters. This language identification technique worked as well or better than commercially available solutions.

This innovation has become an enabling technology for computational analyses of social media in that region.

Samplings of the YouTube comments showed about 10% of the comments were positive. When the researchers used their method to search for help speech in the larger dataset, the results were 88% positive, indicating that the method could substantially reduce the manual effort necessary to find them, KhudaBukhsh said.

"No country is too small to take on refugees," said one text, while another argued "all the countries should take a stand for these people."

But detecting pro-Rohingya texts can be a double-edged sword: some texts can contain language that could be considered hate speech against their alleged persecutors, he added.

Antagonists of the Rohingya are "really kind of like animals not like human beings so that's why they genocide innocent people," said one such text. Though the method reduces manual efforts, comments such as this indicate the continuing need for human judgment and for further research, the scientists concluded.

Harlene Samra Earns Inaugural Krulcik Scholarship

Susie Cribbs

chool of Computer Science junior
Harlene Samra has so many doubts
about whether she belongs in SCS that
she's slapped an "imposter" sticker on
her laptop. After all, when other people
are pulling all-nighters, she's keeping a
healthy sleep schedule. She binges TV shows. She
works all weekend on assignments that might take
someone else all of two hours.

But her peers, professors and other admirers in SCS have no such doubts. In fact, they're so certain of her place in SCS that they've named her the inaugural recipient of the Scott Robert Krulcik Scholarship in Computer Science.

Established by the Krulcik family to honor their son after his untimely death last winter, the merit-based Krulcik Scholarship acknowledges and rewards a current SCS undergraduate who clearly demonstrates the core traits, attitude and approach that Scott (CS 2018) embodied: a leader with a positive attitude, an insightful and compassionate scholar, an innovative contributor to the SCS community, and an inspiring peer mentor.

Samra won't admit it, but she's all of those things.

The Stamford, Connecticut, native didn't know she wanted to major in computer science until she was a senior in high school, took AP computer science and realized she "kind of liked it." She'd visited CMU the previous summer and was hooked. "The tour guides I met were really nice. I don't know. I just got here and I felt that vibe. I knew it was where I should be," she said.

Trying desperately not to raise her own hopes, she launched a "Hail Mary" (her words) and applied to computer science schools — SCS as her top choice. "When I got in, I was so shocked that I fell out of bed," she recounts. But she had to be sure, so another campus visit ensued, during which she met Krulcik, who was then an SCS tour guide, as well as a host of other impressive students. It sealed the deal. She turned Tartan and joined the SCS community in 2017.

Since then, Samra has done what she modestly calls "quite a few things." She was a tour guide for CMU's Office of Undergraduate Admission the summer after her freshman year, and now works as an SCS tour guide. She's been a teaching assistant (TA) for 15:151: Mathematical Concepts for Computer Science the past two fall semesters, and she TA'd 15:150: Functional Programming last spring.



SCS junior Harlene Samra

"I really like the idea of being a TA for someone who just came to college, because I think it's important that they have someone who is there for them at the beginning," Samra said. "And getting to know everyone in SCS is really easy when you're a TA because you learn all the students and the other TAs and there's a network."

Beyond TAing, Samra participates in the club Teknowledge, of which she's president this year. The organization sends student volunteers into local middle schools to teach the Python programming language. In the same vein, she's also part of the CMU CS Academy, which has created an online high school computer programming curriculum that's free for any teacher who wants to use it. She joined the team the summer after her freshman year — while she was also a campus tour guide - and helped create content for the first class, a one-year Python course. She later started working on the organization's AP Computer Science Principles curriculum and currently belongs to the team developing a class that applies computer science to subjects like art and music.

Samra says helping is simply in her nature.

"I didn't realize it until recently, but everything I do is educating and helping other people. It's a good feeling when you help someone else understand something. That moment of clarity is a huge thing for me," she said. "Plus, I learn things in the process. I feel like by helping others — it's almost selfish — you're helping yourself in the end."

That drive to help is what brought her to the scholarship committee's attention.

"Having been Scott's academic advisor, I was especially attuned to nominating an outstanding student for this inaugural award," said Mark Stehlik, teaching professor, assistant dean for Outreach and co-founder of CMU CS Academy. "That wasn't easy, as we have so many great students. But Harlene closely mirrors what Scott brought to this place: a warm, sunny, positive disposition, and always willing to help. She's been an integral part of our CS Academy outreach project, echoing Scott's own contributions to that program."

Even knowing that she's received the award hasn't really tamed Samra's imposter syndrome, though.

"I'm not going to lie: I was kind of like 'Why me?' There are a lot of people who probably could have gotten this. But I am really grateful, because Scott was such an amazing person," she said. "It's wonderful to know that these professors saw in me what they saw in him. It gives you a little bit of a boost to know that something you're doing matters."



CMU Mourns Loss of Jaime Carbonell

Distinguished Professor Founded CMU's Language Technologies Institute

Byron Spice

aime Carbonell foresaw a world where people could freely communicate with each other, no matter what language they spoke. He knew that making this dream a reality would require automation, so he spent his career building machines that could understand human language.

He knew full well that earlier attempts at machine translation had largely come to naught. Nevertheless, as a young computer science professor at CMU in 1985, Carbonell persuaded his superiors to let him start a Center for Machine Translation. For the next 35 years, he and his colleagues would create pioneering translation systems and expand the horizons of artificial intelligence.

Carbonell, 66, died on February 28, 2020, following an extended illness. He was the Allen Newell Professor of Computer Science and had earned the distinction of University Professor, the highest academic accolade CMU faculty can attain.

Machine translation, which was high-risk research when Carbonell first championed it, is big business today, dominated by tech giants such as Google, Microsoft and Amazon. And the research center he launched would expand in 1996 to become the Language Technologies Institute (LTI), one of seven academic units in CMU's top-ranked School of Computer Science.

Under Carbonell's direction, the LTI became the largest and best-known organization of its kind. It has been a leader in areas including natural language processing, question-answering systems, and speech recognition and synthesis, and now boasts five graduate degree programs.

"He's kind of the godfather of language technologies," said Raj Reddy, the Moza Bint Nasser University Professor of Computer Science and Robotics and former SCS dean. Carbonell advised more than 60 Ph.D. recipients who continue to spread his influence through academia and industry.

But his influence extended well beyond language technologies. Carbonell made many contributions to the field of machine learning, said Tom Mitchell, Founders University Professor of Computer Science.

"He played an important and influential role in the early days of machine learning in pulling together researchers working in this area, helping to create an international research community," Mitchell said. His contributions included methods that allowed computers to reason by analogy, developing algorithms that could actively query a teacher to more efficiently learn new concepts, and applying machine learning to diverse real-world applications, ranging from information retrieval and search to protein folding.

"Jaime always had astounding levels of energy and creativity," said Robert Frederking, a student of Carbonell's who is now SCS associate dean of doctoral programs. "I have never understood how he could advise maybe a dozen Ph.D. students, run the LTI, personally be the principal investigator on several research projects, teach regularly and travel to D.C. frequently to work with funding agencies.

"And with all that going on," he added, "if you ran a new technical problem by him, he would usually come up with three good suggestions for solution paths to investigate."

Carbonell also advised Manuela Veloso, University Professor of Computer Science at CMU, now on leave while she directs AI research at financial services giant J.P. Morgan. She remembers him as an amazing educator and mentor.

"With Jaime I learned a lot of AI, but I also learned how to advise," she recalled. "I became a faculty member at Carnegie Mellon and I embraced a lot of what I learned from Jaime. Even now, I still look at Jaime as my advisor, and throughout my career have turned to him for different types of advice. As of now, I have graduated 40 Ph.D. students. I will always thank Jaime for having graduated me."

Carbonell grew up in Spanish-speaking Uruguay before his family moved to Boston when he was nine. He earned bachelor's degrees in mathematics and physics at the Massachusetts Institute of Technology and his master's degree and Ph.D. in computer science at Yale University.

While studying at MIT, Carbonell worked parttime translating computer manuals into Spanish and developed machine-translation tools to speed up the process. Thus began a fascination with machine translation that would become the focus of his AI research.

"We are living in a globalized society, and I think automation has to be the way to overcome language differences," he told the Boston Globe in 1996.

Carbonell, who joined CMU in 1979, led teams that developed knowledge-based machine translation of text as well as speech-to-speech translation. He invented a number of well-known algorithms and methods, including maximal marginal relevance (MMR) for summarizing text and a type of machine learning called proactive learning.

"Getting the right information to the right people at the right time in the right language in the right medium with the right level of detail" became his mantra.

Carbonell played a key role in establishing language technologies as an industry in the Pittsburgh region.

"Dr. Carbonell launched, spearheaded and provided expert advice and support to numerous commercial enterprises, ranging from small startups to Fortune 100 companies," said Alon Lavie, a longtime LTI faculty member who is now vice president of language technologies at Unbabel. Locally, those companies included his own spinoffs, such as Carnegie Speech, Carnegie Group and Wisdom Technologies, and those he advised, such as Vivisimo and Lycos — one of the first successful search engines. Lavie's own spinoff, Safaba Translation Technologies, was acquired by Amazon and became the core of that company's Pittsburgh office.

Carbonell created the university's Ph.D. program in language technologies, and is co-creator of the Universal Library and its Million Book Project, which scanned and digitized books and made them available for free online.

Carbonell also led a project to apply machine learning techniques to data generated by the aerospace industry and explore how this might improve aircraft maintenance, operating efficiency and reliability.

When Carbonell wasn't working, he indulged a lifetime passion for chess.

Due to COVID-19, a memorial on campus has been postponed. \blacksquare



Negotiating a socially-distanced SCS

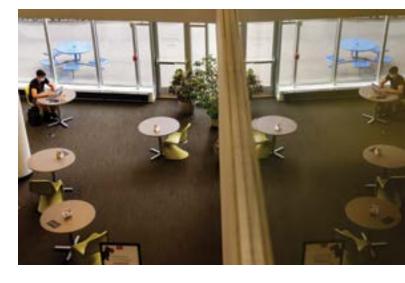












Getting creative in work and play







2020 Donor Recognition

July 1, 2019 - June 30, 2020

With 2020 soon coming to a close, we offer special thanks to our donors for their time, engagement with CMU and the School of Computer Science, volunteerism and donations to SCS-related funds during fiscal year 2020. We've enjoyed connecting and reconnecting with many of you, and we sincerely appreciate your ongoing or first-time support.

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Heather Felix & Peter Felix ■■

Kangwei Feng CS'16 ■

Yuanyuan Feng 🛭 Richard Dean Fennell CS'75 15 Kenrick Fernandes CMU'14 **❸** ■ Avin James Fernando CS'02, S'02 Adam Christopher Ferrall-Nunge CS'04 & Elizabeth Ferrall-Nunge CS'07 Raymond Alan Ferrer CS'94 6 Joan Ficca Mehmet Fidanboylu CS'02 Nathaniel W. Filardo CMU'06, CS'07 @ Allison M. Fisher CS'17 Jessica Fong & Carleton Lee Kingsford ■ Lawrence Fontaine **⊕** Jodi L. Forlizzi A'97, CS'07 🚯 🔳 Mike Formica ■ Camille F. Fournier CS'01 & Christian Kaiserlian 🕦 🔳 Asa K. Frank CS'15 6 Edward H. Frank CS'85 & Sarah Gay Ratchye A'83 @ Alexander M. Franz DC'95 & Keiko Horiguchi DC'93 🛭 💶 Robert E. Frederking CS'87 6 Dan Patrick Freeman CS'11 Peter Anthony Freeman CS'70 2 Eduardo Gustavo Frias CS'94 6 Ann Phyllis Friauf CMU'04 Liora Friedberg ■ Carol Frieze DC'89, CS'07 & Alan M. Frieze David M. Frucht & Alexia RC Gospodinoff Earl Fry & Joy Fry 6 Ping Fu CS'94 & Yifan Tang **❸** ■ Wenjie Fu CS'08 ● Talia Fukuroe CS'97 1 Eli Gabriel & Tara Loughran J. Elias Gabriel James C. Gabriel CS'16 & Shuyue He € Jeyhun Gafarov INI'20 Benjamin Gafford ■ Rajeswari Ganesan & Anish Kumar 🛭 Jingkun Gao E'14, CS'16, E'17 🚯 Lili Gao TPR'13, CS'16, TPR'16 & Tianjiao Dai 6 Tan Gao E'12 🚯 Weijia Gao E'19 ■ Elmer Garduno CS'12 Anjuli Garg CS'03 & Aseem Vikas Garg CS'03, DC'03 3 Janet Garrand ■ Charles S. Garrod CS'06, CS'08 David Thomas Gauthier CS'99 (B)

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Michael L. Horowitz CS'88

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Michael Steven Kahn CS'12 **③** ■

Joshua P. Kalapos CS'20 2

Mari Kalapos & Thomas L. Kalapos 🗨 Jacob G. Kalberer CS'06 Barb Kalina Dirk Lee Kalp S'73 ● Chitra Malini Kalyanaraman CS'04 Tanav Kamat ■ Guosheng Kang & Qing Luo ■ Hongwen Kang CS'09, CS'12 & Xiaolan Shu Sing Bing Kang CS'92, CS'94 1 Yijin Kang CS'19 🛭 Joshua D. Kangas CS'13 🛛 🔳 Poornima Kaniarasu CS'13 & Sathish Kumar Deivasigamani Joel Kanter & Ricki Kanter 🕒 Grace E. Kao CS'19 Padmani Katharani & Michael Khan 🛭 🔳 Michael Makihiko Kato S'91, S'92■■ Divyansh Kaushik CS'19 🚯 Michael L. Kazar CS'85 & Rebecca Foster @ Robert K. Kedoin CS'87 Michele L. Kee CS'87 🚯 Kimberly Kristine Keeton E'91 Patrick Gage Kelley CS'09, CS'13 ■ John Ronald Kender CS'80 2 Karen Key **②**■ Marc J. Khadpe CS'00 (Afshan R. Khan TPR'91 & Mohammed Abdul Rahman Khan 🛭 💶 Sanjay Khanna CS'93 Sara Kiesler ■ Jonathan Daniel Kilgallin CS'10 🗨 🔳 Stephen Killourhy Calvin Bok-Ro Kim CS'96 3 Chang Hyuk Kim CS'96 Heui K. Kim & Sang Y. Kim Janet C. Kim CS'08 6 Jin Seop Kim CS'12 **1** ■ Myung Soo Kim CS'12 € Se Young Kim ■ TJ Kim CS'01 **⚠** ■ Michael Kimmett CMU'06 & Jennifer Kimmett ® Nick Kindberg CS'13 **ⓑ** ■ Jennifer E. King CS'04, CS'15, CS'16 & Anne C. Bock 2 Hemanth B. Kini CS'16 Adam Kirsch ■ Latika Kirtane CS'06■■ James Jay Kistler CS'93 **₽**■ Brian Kjersten Timothy D. Klemm S'90 1 Carey Kevin Kloss E'95, E'97

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Tan Li CS'18 CS'19 **3** ■

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Xiyuan Liu CS'17 ■

Yancheng Liu CS'16

Yi Liu & Shaling Zhou ■

Xudong Liu E'19

Yandong Liu CS'11

Youbang Liu & Yubing Tang 6 Yufeng Liu S'99, CS'03, S'03 & Yiping Zhan CS'03, S'04 6 Yulin Liu CS'18 🚯 Yuxiang Liu CS'06 ■ Zhuoran Liu DC'18, CS'19 Michael T. Livanos CS'04 & Jessica Livanos Ian Lo CS'19 Doug Locke CS'86 & Kathy Locke ® Elliot Aryeh Lockerman CS'17 Stuart Renwick Locklear CS'99 1 Amir R. Lodhi CS'09 ■ Yee Chuan Loh CS'03, TPR'05 Ralph Leslie London S'60, S'64 @ William G. Long DC'01, CS'02 William James Lovas CS'10 Daniel Edward Lovinger CS'95 Jia Han Charles Low ■ Yucheng Low CS'08, CS'10, CS'13 David Y. Lu CS'18 @ Lynda Lu & Yuan Zhuang 2 Rachel Anne Lucas CS'14 Peter John Lund CS'14 Allen William Luniewski S'74 Angela Marie Lusk 🛭 🔳 Christopher Lynch ■ Kevin Michael Lynch CS'96 & Yuko Lvnch Hannah D. Lyness E'16, CS'17 1 Geoffrey Lyon **3**■ Janice Lyons & Michael Lyons ■ Boxiang Lyu DC'18, CS'19 Jian Ma & Hong Shen ■ Jun Ma CS'14 & Chialing Tsai ■ Shunzhe Ma 🛭 Weiman Ma TPR'14 2 Yifei Ma CS'13, CS'17 **3** ■ Zhengkun Ma & Kehai Zhang Christine Mackey & John Fletcher Mackey James F. Maclean E'14, CS'14 Hari Madala ■ Kenneth John Magnes CS'93 Aravindh Mahendran CS'14 1 Austin Patrick Maher CS'85 Khalid Mahmood & Safia Mahmood @ Daniel Eliot Mahr CS'18 Kai Zhen Mai CMU'05 & Shuai Quan 3 Emily A. Maitin & Donald Shepard 15 Rangan Majumder E'02, CS'02

& Beth E. Wilion TPR'04 2

Mun-Thye Mak CS'09 **1** ■

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Catherine Dianne McCollum CS'81 & Robert McCollum Janet McConville & Michael McConville Pamela McCorduck 3 Ian Makemson McCullough A'00, MET'01 **№** ■ Luke W. McCullough CS'00 & Jodi M. Kurtz DC'99 ■ Carol McDowell & Francis McDowell @ Patrick F. McGehearty CS'80 David M. McKeown Kristofer Robert McQueen CS'96 **②**■ Maija E. Mednieks CS'14 1 Carl N. Meister CS'00 Andrew O. Mellinger CS'10 & Susan Mellinger 🕡 Fang Meng CS'14 Shini Unnikrishnan Menon CS'06 & Anadi Bhardwaj Michael Grey Merideth CS'05, CS'09 Jonathan G. Merrin CS'18 ■ The Anne Hevman & Seth Merrin Family Fund 2 Nichole C. Merritt 🗨 🔳 Kent Edward Meyer CS'91 2 Jiangbo Miao CS'05 & Nan Zhao 🔞 Kerry Michaels & Margaret Michaels 2 Phillip Daniel Michalak CS'98 Victor Joseph Milenkovic CS'88 Lauren Violet Milisits E'13, CS'14 ■ Ashley McKnight Miller CS'04 (8) Courtney Miller ■ Jason C. Miller DC'97 & Hyewon Miller 🕸 💶 Kevin C. Miller CS'01 & Rebecca Leigh Miller E'04 Lori J. Miller CS'00 & Scott Miller Paul P. Miller BCSA'13 2 Roberta N. Miller Tilee Miller Danielle M. Millett CS'09 Edward A. Miner CS'88 Edwin Miranda E'10 🕕 Joan Mitchell & Tom M. Mitchell 2 Andrew P. Mittereder CS'14 **⑤** ■ Roman W. Mitz CS'00 & Kelli Ireland 🕕 Kenneth Edward Mixter CS'98 & Michele C. Mixter E'01

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Adil Nathani & Nandini Nathani 6

Celeste Neary E'17 ●
Katharine Needham 🕖 🔳
Adrienne Neithardt ■
Adam Steven Nemitoff CS'92 2
James Hiram Nesbitt A'91 ■
Karen Nesbitt 3 ■
Leonardo Ribas Machado
das Neves CS'16
David J. Neville CS'10 🕙 🔳
James Neville & Virginia Neville ❸■
Noel Marie Newell ⊕ ■
Emily P. Newman CS'19
Gail L. Newton CS'87
Rob Newton ■
Jiang Ni CS'04, CS'07 ①
Ping Ni & Qiming Zhang ■
Wode Ni ■
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Maya Nigrosh CS'03, A'07
Tanachat Nilanon CS'12 2
Frances Jen-Fung Ning E'02, CS'02,
E'03 1
Yuke Ning CS'18 ■
Alex Nizhner CS'01, INI'05 ⊕
Andrew Noh E'11, CS'11, E'12 1
Michael J. Nollen CS'04 ⊕
Robert Louis Nord CS'92 9 ■
Charles Avery Noren ■
Donna Norling ⑤ ■
Carol Lucile Novak CS'92 1
Steven Michael Novick CS'09, TPR'10
& Ariel Gold Novick 🗗 🔳
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William O'Brien ② ■
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Annette O'Neill & Vince O'Neill ■
Arsa Oemar CS'05, TPR'10 ⑤ ■
Paul Taylor Ogilvie CS'03, CS'10 ③ ■
Kyung Chul Oh CS'03, CS'06 ⑤ ■
Ronald Bert Ohlander CS'75 5
Koustubh D. Oka 俄■
Yogesh K. Oka CS'04
& Ripple Sharma ⊕ ■■
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Jennifer Kaitlyn Olsen DC'10, CS'15,
CS'17 ⑤ ■
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Melody A. Olvera CS'20 3
Abbas A. Omais & Nadia A. Omais
Steven J. Onorato E'04, CS'04 🐠
Ejike C. Onyeador & Linda C. Onyeador
Bree Orner
Marcel Oyuela-Bonzani CS'18

Clifford D. Platt CS'98 Daniel J. Paciulan CS'01 1 Roger Packer & Tiffany P. Platt E'01 1 Cheryl N. Platz CS'02 (18 🔳 Giridhar Padmanabh CMU'05 Andre Platzer 🔁 🔳 Preetha Padmanabhan David C. Plaut CS'91 Venkata Rama Karthik Paga CS'18 2 & Marlene Behrmann 2 Anthony Paiva & Laura Paiva Scott Pakin CS'92 1 Vahe V. Poladyan CS'04, CS'08 & Heather Poladian 🛭 🔳 Mark M. Palatucci CS'08, CS'11 Thad Anderson Polk CS'92 Shijia Pan E'18 🛭 & Norma S. Polk A'89 🖪 Sashank Mitra Pandem CS'18 2 Mark D. Pollard CS'96 @ Stanislav Panev 🛭 Peter Foon-Wang Pong CS'09 2 Michael Konstantinos Papamichael CS'15 **G** Andres Pons **⑤** ■ Michael D. Poole E'99, CS'99 Rebecca L. Paren CS'15 🚯 🔳 & Erika Eve Poole E'00 🕦 Asit Kumar Parida CS'19 Ankur Prashant Parikh CS'12, CS'15 Cameron A. Pope CS'97 ■ Jean-Luc Hoon Park CS'94, DC'94, Geoffrey Pope ■ Tyler W. Porten BHA'15, CS'15 TPR'98 🕕 🔳 Mark R. Power 6 Scott M. Parker CS'01 Douglas Pratt & Laura Pratt 2 Bryan Jeffrey Parno E'05, E'10 & Diana Kalyana B. Prattipati CS'98 Marwick Seymour Parno S'06, S'11 ■ Elena Pascal George Walter Price Greg Price CS'06 & Margaret Barusch Alkeshkumar Maganbhai Patel CS'14 Keith Edward Price CS'77 ⊕■ Brad James Patton MET'07 William Robert Price CS'74 € & Ashlev Williams Patton Kevin Primm MET'13 ■ Jonathan J. Paulson CS'13 & Amy Mija Kelly Prokop ■ Catalina Quispe CS'13 🕖 John Edward Peabody CS'11 1 Robert Prokop 🛭 John M. Przyborski CS'14 🚯 Linda Pearce ■ Kadambari Pulivarthy Brian T. Peck 🗗 & Venkata Pulivarthy 2 Jorgen David Pedersen E'95, CS'98 Veronica Peet **❸** ■ Robert J. Punkunus CS'01 1 Alwal Reddy Putta E'13 Qunjia Peng & Lihong Tao ■ Thomas B. Puzak CS'03, S'03 Adam G. Pennington CS'01, E'03 1 & Gita N. Coupal DC'03, S'03 Crispin Stone Perdue CS'77 ① Jie James Qi CS'09, S'09 2 ■ Francisco Machado Aires Pereira CS'07 **1** Liangsheng Qian CS'04 & Kevin Rim @ Jinpei Qiang E'17 Suzanne Perla ■ Jining Qin DC'14, CS'18, DC'19 Adele C. Peterson CS'03 Long Qin CS'13, CS'13 & Carl Robert Peterson E'03, DC'03 6 & Yanan Chen 🕙 🔳 Marko Petkovsek CS'91 Zachary Pezzementi Xinxi Qin TPR'10 & Wenjing Xiao 4 Andreas Robert Pfenning CS'06 Xianghua Qu & Heying Yang 2 Yan Qu DC'94, CS'01 & Mary Cooper Siong Kar Quek CS'00, TPR'00 Carol Phillips & Timothy Phillips Mariena E. Quintanilla CS'05 Margaret Phillips **3**■ Todd E. Phillips S'02, CS'09 & Jose Quintanilla 🕙 🔳 Thomas R. Quisel CS'07 Satidchoke Phosaard CMU'03 Sameer Qureshi CS'01 ■ Patrick Piemonte CS'07 ■ Paul Raff CS'04, S'04, S'05 David R. Pierce CS'93 **5** & Audria C. Stubna S'06 🚯 Joao Luis Pinto Da Fonseca Dos Reis CS'18 Omar Rahman CS'16 ■

Varun Rajpurohit CMU'17

Karthik Kumar Ramachandran TPR'03 ■

Mel Pirchesky TPR'92 ❷■

Hunter Alexander Pitelka CS'11 1

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Shirley Roper Ronald Rosenfeld CS'91, CS'94 & Ilana Diamond Ethan Miles Rosenthal Michael Hayden Rosenthal CS'97 Hillary Ross ■ Manuel A. Rosso-Llopart CS'92 & Catherine A. Llopart @ Patricia A. Rote 🚯 🔳 Isaac P. Rothenbaum CS'12 David Christian Rothenberger CS'93, CS'96 M Han Hong Rovins 🛭 Carolee Rowley & Eric Rowley Deanna Rubin DC'98 Steven Michael Rubin S'74, CS'76, CS'78 🚯 Dawn Rucker 🚯 🔳 Peter Ruess Matthew Michael Ruffalo ■ Charles Andrew Ruhland CS'09 John Joseph Rusnak S'90, S'90, E'09 Paul Martin Russo CS'86 & Allison G. Russo AM'88 Olatunii O. Ruwase CS'13 ■ Laurel Ryan 🛭 Michael David Rychener CS'77 Brooke A. Sachs CS'18 Gabrielle Sade ■ Norman M. Sadeh-Koniecpol CS'91 & Patricia deFaro Sadeh-Koniecpol **(1)** Linda Sadej ❷■ Andrew D. Sager CS'20 Engin Cinar Sahin CS'06, CS'08 & Duygu Basaran Sahin 1 Sabesan Saidapet Pachai CS'06 Merline Saintil CMU'05 Maid F. Sakr & Nisrine Sakr 🚯 Phillip Arthur Saltzman MET'06 **1** Darshana Salvi ■ Selva Samuel ■ Erica F. Sandbothe CS'09 & Evan C. Wright INI'08 Jeffrey Stuart Sander CS'09 Qingzi Sang ■ Akkarit Sangpetch E'05, CS'05, E'10, E'13 & Orathai Sangpetch E'05, E'05, E'13 🛭 🔳 Abulhair Saparov CS'17 Yumi Sato ■ Mahadev Satyanarayanan CS'79, CS'83 & Deborah C. Kelly HNZ'94 @ Steven Saviano Li Shao ■

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Hideki Shima CS'06, CS'15
& Mie Shima 🚯 🔳
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& Gregory Kipp Shrack E'94 🛛 🔳
Zifang Shu & Xiaoyong Yi ■
Jefferey Allen Shufelt S'90, CS'93, CS'96
& Stacey Lynne Jacobs TPR'90,
TPR'93 🛭
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Heung-Yeung Shum CS'96
Heung-Yeung Shum CS'96 & Ka Yan Chan ① ■
& Ka Yan Chan 🕦 🔳
& Ka Yan Chan ❶ ■ Rhonda Shumate ■
& Ka Yan Chan ① ■ Rhonda Shumate ■ Lisa Shumate-Willsey
& Ka Yan Chan ❶■ Rhonda Shumate■ Lisa Shumate-Willsey & Robert Max Willsey ②■
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& Ka Yan Chan Rhonda Shumate ■ Lisa Shumate-Willsey & Robert Max Willsey ■ Emmin Shung & Alexis Voulgaris ■ Vincent Siao CS'14 & Stephanie Yeung CS'14 David Sidwell & Lynda Sidwell ■ Yingli Y. Sieh CS'19, DC'19 ■ Robert J. Siemborski CS'03 & Jennifer Kathryn Smith CS'03, MET'05 ■ Mark Brian Silverman CS'97 ■ Alexander Gardner Silverstein CS'10 ■ Melanie Simko ■ Reid Gordon Simmons ■ David Anthony Simon E'87, CS'93, CS'97 ■ Clement & Erlinda Singarajah ■
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& Ka Yan Chan Rhonda Shumate ■ Lisa Shumate-Willsey & Robert Max Willsey ■ Emmin Shung & Alexis Voulgaris ■ Vincent Siao CS'14 & Stephanie Yeung CS'14 David Sidwell & Lynda Sidwell ■ Yingli Y. Sieh CS'19, DC'19 ■ Robert J. Siemborski CS'03 & Jennifer Kathryn Smith CS'03, MET'05 ■ Mark Brian Silverman CS'97 ■ Alexander Gardner Silverstein CS'10 ■ Melanie Simko ■ Reid Gordon Simmons ■ David Anthony Simon E'87, CS'93, CS'97 ■ Clement & Erlinda Singarajah ■ Kirielle F. Singarajah CS'20, CS'20 ● Ayman Jot Singh CS'11 ■
& Ka Yan Chan Rhonda Shumate ■ Lisa Shumate-Willsey & Robert Max Willsey ■ Emmin Shung & Alexis Voulgaris ■ Vincent Siao CS'14 & Stephanie Yeung CS'14 David Sidwell & Lynda Sidwell ■ Yingli Y. Sieh CS'19, DC'19 ■ Robert J. Siemborski CS'03 & Jennifer Kathryn Smith CS'03, MET'05 ■ Mark Brian Silverman CS'97 ■ Alexander Gardner Silverstein CS'10 ■ Melanie Simko ■ Reid Gordon Simmons ■ David Anthony Simon E'87, CS'93, CS'97 ■ Clement & Erlinda Singarajah ■ Kirielle F. Singarajah CS'20, CS'20 ● Ayman Jot Singh CS'11 ■ Sandeep Singh & Suma Singh ●
& Ka Yan Chan Rhonda Shumate ■ Lisa Shumate-Willsey & Robert Max Willsey ■ Emmin Shung & Alexis Voulgaris ■ Vincent Siao CS'14 & Stephanie Yeung CS'14 David Sidwell & Lynda Sidwell ■ Yingli Y. Sieh CS'19, DC'19 ■ Robert J. Siemborski CS'03 & Jennifer Kathryn Smith CS'03, MET'05 ■ Mark Brian Silverman CS'97 ■ Alexander Gardner Silverstein CS'10 ■ Melanie Simko ■ Reid Gordon Simmons ■ Reid Gordon Simmons ● Clement & Erlinda Singarajah ● Kirielle F. Singarajah CS'20, CS'20 ● Ayman Jot Singh CS'11 ■ Sandeep Singh & Suma Singh ● Manal Kumar Sinha E'18
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Ryan Sit CS'14

Kenneth Kin-Shing Siu CMU'04,

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Lauren Snow & Michael Snow

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TPR'04 🕢 🔳

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Stephanie Smith

CS'10

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Miguel Sousa CS'09 1

Alfred Z. Spector **(b)**

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Stephen Staresinic

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Michael A. Stevens CS'07

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Kathryn Louise Spear S'86

Alexandra Enid Snoy CS'17 ■

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Boris Sofman E'05, CS'05, CS'07,

Selvamraju Somalraju CS'13 🕡 🔳

& Zhanwu Liu DC'07 2

DC'91

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Walter Van Roggen CS'82 6

Harold Raymond Van Zoeren S'55 **⊕**

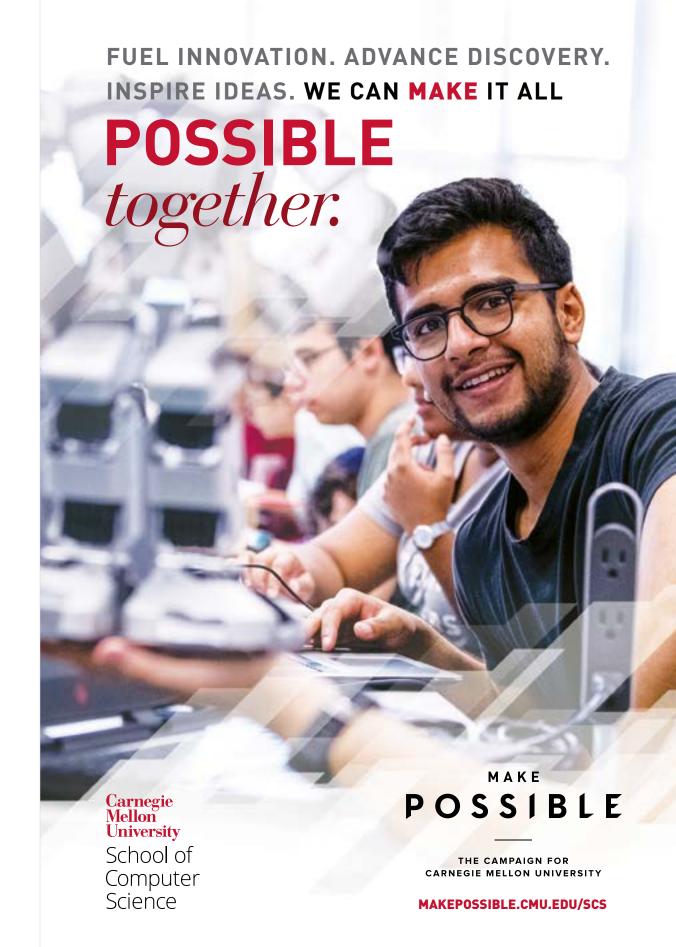
Shivam Vats■ Vignan Velivela CS'18 🛭 💵 Maria Manuela Veloso CS'89, CS'92 & Jose M.F. Moura 🗗 🔳 Anantha Vemulapati & Murali Vemulapati Shweta Venkateswaran CS'15 Mark Andre Ver CS'97 **●** Kyle E. Verrier CS'13 6 Alison Vesco & Paul Vesco ■ Jean-Philippe Vidal CS'89 **❸** ■ Jose Villegas ■ Rina Vinetz Subansiri Vishnubhatla & Suresh Vishnubhatla Jorge L. Vittes CS'04 **1** ■ Karthik Vivekanandan CMU'05 Mauricio Vives CS'98 & Holly Vives DC'97 **❷**■ Katherine Vogt CS'14 Robert Irwin Voigtmann CS'09, TPR'10 & Janice Lee Voigtmann E'13 🕕 🔳 Tom Vu CS'12■ Krishna Vudata CS'12 Brian A. Wachowicz CS'16 & Skye C. Toor DC'17 3 Jeff Wagner TPR'97, HNZ'00 & Barbara Johns Alexander Waibel E'81, CS'86 & Naomi Aoki Waibel CS'95, CS'97 **3** ■ Aaron Wald CS'98 & Ann Wald CS'98 Kevin Rathbun Walker CS'96, CS'00 **②**■ Timothy A. Wall CS'17 2 Eugene S. Wan & Hui Boon Wan 🐠 🔳 Bo Wang & Tao Yang 🛭 🔳 Carl Wang CS'06 (B) Cheng Wang E'16 Guo-Shiuan Wang CS'07 Haovu Wang CS'15 🚯 Hua Wang & Weisong Xu ■ Jianwei Wang & Lin Wu 🛭 Jim Wang CS'01, CMU'03 & Martha Ottenberg Wang E'04 Jing Wang E'10 Jinghang Wang CS'20 Jingtao Wang ■ Jue Wang CS'05 (B) Ken Wang TPR'15 2 ■■ Lie Wang & Yan Zhou ■ Peng Wang & Yuhong Zhao ■ Robert Y. Wang CS'04 1 Shengze Wang CS'18 Sibo Wang CS'16 Sihan Wang CS'18 (2)

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Qichen Zhang E'17

Carnegie Mellon University School of Computer Science

OFFICE OF THE DEAN 5000 FORBES AVENUE PITTSBURGH PA 15213-3890





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