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GRAD ED SPOTLIGHT

Search and discovery—Tips on getting involved in research

Craig Causer

Participation in research opportunities as both an undergraduate and graduate student often provides a wealth of both personal and professional benefits to prospective graduate students, including an increased knowledge base, the ability to work as a part of a team, and humility. This type of hands-on experience is invaluable, but how can undergrads go about finding the research opportunities that best match their interests and help launch them into a successful graduate program? What do students need to consider prior to applying to join a research project?

IEEE Potentials spoke with a number of current students and recent graduates regarding their research experiences and what they have learned from the process of finding and participating in research projects. Their voices are as diverse as their backgrounds—one graduate student serving as an intern prior to beginning his Ph.D. in the fall, three Ph.D. students, a postdoctoral fellow, and a senior research scientist each share their tips on how to secure research opportunities. These experiences may help prepare you for any surprises you encounter on your road to research.

Prepare to bear the grunt of the work

Name: Philip Guo
Status: Ph.D. student in the Computer Science Department at Stanford University in California.
Vitals: B.S. and M.E. in electrical engineering and computer science from the Massachusetts Institute of Technology (MIT).
The Tao of Guo: "…the apparent 'grunt work' is part of the learning process. Only by learning how to perform the more menial and grungy tasks can one truly become immersed in the actual depth of the research."

During his time at MIT, Guo took advantage of the institute's Undergraduate Research Opportunities Program (UROP), which was designed to make it easier for undergraduates to get involved in research projects. The UROP program paid the salaries of undergraduate researchers, Guo explains, so that professors do not have to spend money out of their own grants to fund undergraduates. This financial incentive made it much more appealing for professors and graduate students to "try out" undergrads in their research groups with very low risk; they simply needed to provide some guidance and mentorship. Guo sampled several UROPs before ultimately accepting one that he stuck with for over two years, which ultimately turned into his master's thesis project. He originally found out about that project from reading a departmental e-mail. He replied to the graduate student who posted the ad, they chatted on the phone and got along, and he was hired.

The research opportunity that Guo accepted involved working in the Program Analysis Group at MIT under the

Digital Object Identifier 10.1109/MPOT.2010.937456

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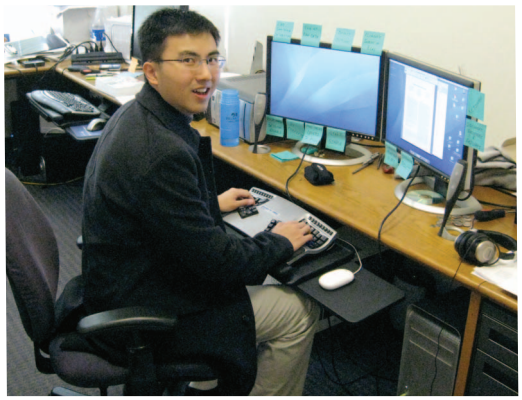
supervision of Prof. Michael Ernst. He was mentored by a Ph.D. student, Stephen McCamant, and met with Prof. Ernst several times per semester. His involvement in the research project was to build a new tool to analyze the run-time behavior of computer programs. It was a fairly big engineering task since he had to build that tool basically from scratch, Guo explains. McCamant and Guo held weekly meetings, where the Ph.D. student taught Guo the ropes about advanced programming and debugging techniques.



Guo working in his office in the Stanford Computer Science department.

"Like most undergraduates in research labs, I was doing a lot of engineering work and not so much involved in formulating novel research ideas, but I felt that this experience greatly benefited me in several ways," Guo says. "It exposed me to what life was like in an academic research lab, so that I could get a sense of what Ph.D. students did day to day. It helped me greatly improve my programming and debugging skills, which are extremely valuable when pursuing graduate-level research in my area. It greatly strengthened my Ph.D. and fellowship applications, since I was working as part of a cutting-edge research team and could write about the 'big-picture' topics of my research in my applications. It also helped me improve my technical writing and presentation skills, since it forced me to write papers and presentations."

The experience of getting involved in undergraduate research was embedded in the academic culture of MIT, Guo adds. Pretty much most of the people he knew were involved in some kind of UROP project, and he regularly monitored e-mail from various mailing lists where professors and grad students posted open positions.

A word to the wise

Guo's main piece of advice for undergraduates who want to get involved in research is to properly set expectations. Be prepared to learn and to execute, and don't stress out about doing something overly creative or original.

"I sometimes hear complaints from undergrads in research labs who say that they don't get to have enough creative input in their project, and that they're basically just doing 'grunt work'," Guo explains. "My response to them is that the apparent grunt work is part of the learning process. Only by learning how to perform the more menial and grungy tasks can one truly become immersed in the actual depth of the research. It's almost impossible for someone who is not experienced in a field to make a significant creative contribution. It takes many years of work experience, trial-and-error, and iteration to develop into a researcher who is capable of coming up with worthwhile and novel research ideas, so don't try to rush into it as an undergraduate. It takes most Ph.D. students four to six years to develop the ability to come up with and execute their own project. One should strive to learn from one's mentors (graduate students and professors) and gain hands-on, 'in-the-trenches' work experience. I think that being satisfied with one's project is all about setting and maintaining the proper expectations."

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Whether writing papers or creating presentations, Guo often visits the café for a change of scenery.

That being said, Guo adds that undergrads should not be afraid to quit and switch projects or labs if they are not happy with how the project is going. Students should not feel like they have somehow failed if a project did not go well. Research is often high risk and filled with dead-ends and apparent failures, so just because a project did not go as planned does not mean that it's a failure on your part, he says.

"More broadly, your main job as an undergraduate is to obtain enough class credits to graduate and simultaneously find time to do some extracurricular activities to broaden your social, cultural, and intellectual (horizons)," Guo advises. "Getting involved in research is one such extracurricular activity, but it is by no means your primary job, so don't stress out too much about it."

Learn and contribute together

Name: Kerri Cahoy
Status: NASA Postdoctoral Program Fellow at NASA Ames Research Center, Space Center and Astrobiology Division, at Moffett Field in California.
Vitals: B.S. in electrical engineering from Cornell University in Ithaca, New York. M.S. and Ph.D. in electrical engineering from Stanford University in California.
The Tao of Cahoy: "Research is all about people not knowing the answer and not knowing how to do something. It's all about learning together how to do something new and exciting."

Space and planetary exploration has always fascinated Cahoy, so she was excited to have a chance to get a little closer her goal of exploring our solar system and universe when, as an undergrad, she was offered the opportunity to help conduct research with Prof. Steven Squyres in the Space Science Department at Cornell University. Cahoy was part of a team that worked on supporting the twin Mars Rovers mission, now called Spirit and Opportunity. In the early stages of the mission, she helped to design the calibration target for the spectrometers on the APXS and Moessbauer rovers.

DOMINIC HART, NASA AMES RESEARCH CENTER

A research project at Cornell University was an early inspiration for Cahoy's current work at the NASA Ames Research Center.

As a NASA postdoctoral program fellow, she currently works to help design and simulate a new space mission to detect and characterize exoplanets, which are planets in star systems outside of our own solar system. The mission uses a telescope on a spacecraft that is put in orbit around the Sun. The space telescope has an instrument called a coronagraph on it, which is used to block out a target star's light so you can look very closely next to the star to see if there are any planets there. The coronagraph we are working on could potentially detect Earth-like planets around other stars.

Cahoy also codes and analyzes simulations of what the images of exoplanets from the instruments on the mission might look like. She also uses computers to simulate what the planets might look like if they are observed at different wavelengths of light (different colors). The relative changes in the colors can tell us about what gases are present in the exoplanet's atmosphere and whether it might be habitable, like Earth.

The folks at NASA Ames can thank the effectiveness of an old-fashioned bulletin board for fostering Cahoy's interest in space. "I was just walking through the hall of the electrical engineering building on campus and noticed that there was a flyer posted advertising for undergraduates to help with research on the Mars Rovers," she recalls. An e-mail to the contact person led to meeting with the principal investigator, Prof. Squyres, who was "very enthusiastic and team oriented," Cahoy says. As a result, she was accepted and spent a lot of time in the Space Sciences building, which she enjoyed immensely.

What contributed to her satisfaction was that undergraduates were really able to get involved in the project. They participated in teleconferences with the instrument designers and makers, the other scientists, and the people doing the operations planning for the mission. Each of the undergraduates would track the progress and challenges for different instruments on the Rover, like the drill/brush on the arm, the panoramic camera, and the spectrometers. Occasionally, the undergrads even got to work with hardware or hardware prototypes such as with the design of a calibration target (rock and aluminum plate). The group worked with the on-campus machine shops and geology labs to get a prototype made and tested, including trying to drill rock samples for it. "We put the pieces together with epoxies that we hoped would survive the very cold and hot temperatures in space," Cahoy explains. "We put it in very, very cold freezers and in ovens and in vacuums to see if it would stay together. We also had to shake it like it would during launch."

One of the ancillary benefits from her undergraduate research was meeting people that she still works with today. "It is great to start building your network that early and to take advice from people who are doing what you dream of someday doing yourself," Cahoy says. "It definitely affected my desire to go to graduate school, and encouraged me to do so, so that I could continue to learn and specialize and make connections."

Droppin' science

When it comes to your professors, it helps to avoid viewing them simply as your teachers, Cahoy says. Many professors have a research group that does very interesting things. She advises students to look professors and their groups up online and then ask them about their research in person. Since professors and the researchers in their group are often extremely busy, be prepared to have to ask about it more than once, and prepare to have to be very flexible with your schedule. Also, don't be discouraged if they sound stressed sometimes. Usually professors are very excited to have young people involved in their work, she adds.

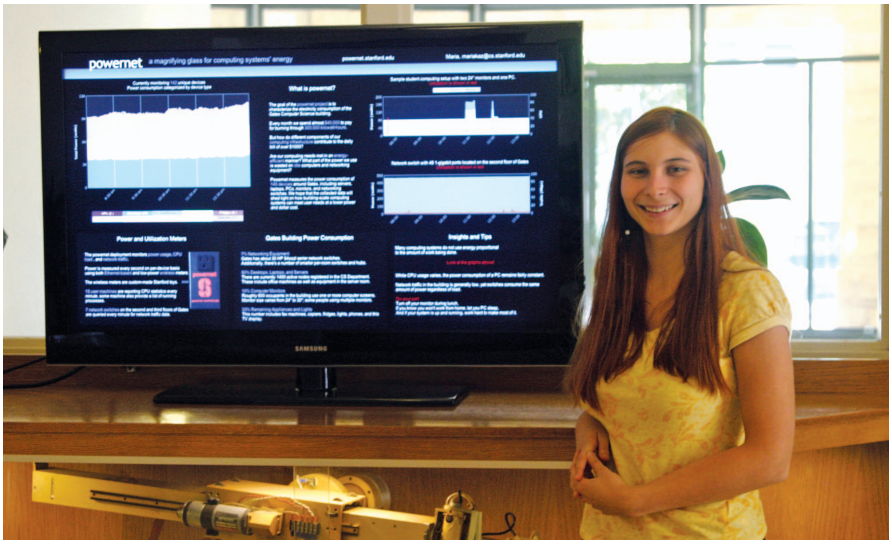
More importantly, don't be a slave to your youth. "Don't ever think you're too young or inexperienced to make a big contribution—you're not," Cahoy exhorts. "Research is all about people not knowing the answer and not knowing how to do something. It's all about learning together how to do something new and exciting. Everyone can contribute something."

Get over the feeling that you "know nothing"

Name: Maria Kazandjieva
Status: Ph.D. student in the Computer Science Department at Stanford University in California.
Vitals: B.A. in computer science (math minor) from Mount Holyoke College in South Hadley, Massachusetts. M.S. in computer science from Stanford University.
The Tao of Kazandjieva: "Once I embraced learning and stopped worrying about if I would get everything perfect, I was able to enjoy my time and grow as a researcher."

As graduate student working toward her Ph.D. in computer science at Stanford University, Kazandjieva conducts research into the energy efficiency of computing systems and works with wireless sensor networks. Her day-to-day tasks include reading research papers; designing, coding, and running experiments; analyzing energy consumption data; and generating new insights into how building computing infrastructures can use less energy. A number of research opportunities have helped shape her academic career thus far. She conducted research as an undergrad at Mount Holyoke College and completed

Attending graduate school in California has its perks. Kazandjieva spends time in the sun almost every weekend.



Kazandjieva erected a display that presents her research and shows real time data on power consumption in the computer science building at Stanford University.

two summer research internships, one at the University of Massachusetts (UMASS)-Amherst in 2005 and the other at Princeton University in 2006. She returned to Princeton for a six-month research position in 2007 after earning her bachelor's degree.

At Mount Holyoke she worked with her advisor, Prof. Sami Rollins, on ongoing research throughout the school year, during which time she analyzed discharge and recharge patterns of user laptops and how they can determine whether a machine has enough energy to perform background tasks such as file backup. The greatest benefit of this experience was teaching her the ropes of doing research—reading and writing papers, gathering data, and running experiments, Kazandjieva says. At UMASS-Amherst Kazandjieva worked with Prof. Lixin Gao on a Bluetooth project, where she learned about low-power wireless systems, which are still part of her research to this day. While at Princeton University, Kazandjieva teamed with Prof. Margaret Martonosi, spending nine months in her lab and working on pricing schemes for cell phone resources such as CPUs, storage, and cameras. She transitioned to helping define the architecture of a distributed system of cell phones that collaborate to accomplish a given task. Her time at Princeton prepared her for graduate school work, she adds, which included completing her first workshop research paper, working with a large team of students, and learning about student experiences.

"As an undergraduate I participated in the Computer Research Association's Committee on the Status of Women in Computing Research Distributed Mentor Project program (which has since been renamed the Distributed Research Experience for Undergraduates)," Kazandjieva explains. "The program targets women in computer science and matches them with female mentors at different schools. Another option for U.S. citizens is the National Science Foundation's Research Experiences for Undergraduates (REU) program."

Many schools also have funding for students who stay during the summer to engage in research. At Mount Holyoke College, Kazandjieva applied for such funding and worked with her advisor for a few weeks after the school year had ended. Kazandjieva cites faculty members as the best resource for research opportunities since they have the ability to point students to different REU projects as well as provide information about about local opportunities. Her six months at Princeton were a result of a more direct approach: Kazandjieva engaged her professor and directly asked if there was an interest in funding her research.

Advise and conquer

When it comes to looking into research opportunities, being proactive is the best approach, Kazandjieva advises. "Don't be afraid to ask professors in your department about opportunities, both outside and within the department. Oftentimes, they will be happy to have you work with them for the summer. Apart from that, REUs are the best source for organized research programs."

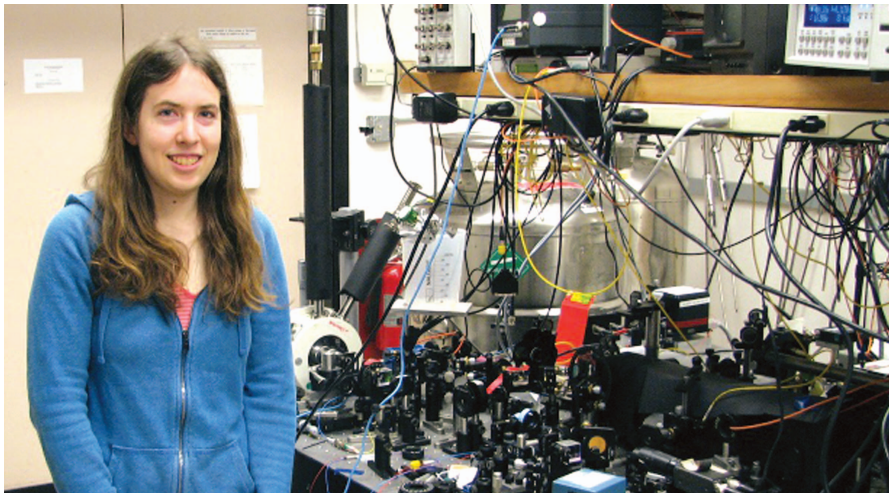
Undergraduates should also not go into projects feeling like they should know every aspect of the research. "Be prepared to feel like you know nothing," Kazandjieva bluntly explains. "That's how I felt every time I joined a different research group. Of course professors will know a lot more than you do—that's why you are there, to learn. Once I embraced learning and stopped worrying about if I would get everything perfect, I was able to enjoy my time and grow as a researcher."

There isn't a set of instructions for research

Name: Kelley Rivoire
Status: Ph.D. student in the Electrical Engineering Department at Stanford University in California.
Vitals: B.S. in physics from the Massachusetts Institute of Technology. M.S. in electrical engineering from Stanford University.
The Tao of Rivoire: "Students who do successfully find a research opportunity should be prepared to speak up, ask a lot of questions, and be a little more independent."

Like Philip Guo, Rivoire attended MIT and was fortunate enough to have the Undergraduate Research Opportunities Program (UROP) as a resource. While professors and staff with specific needs for undergraduate researchers posted research descriptions through the program's Web site, Rivoire found the most success in matching her interests to a lab by simply e-mailing faculty to inquire about their labs. "In my experience, most faculty are enthusiastic about providing the opportunity for a young scientist to try real research, although persistence helps in setting up the initial meetings," Rivoire advises.

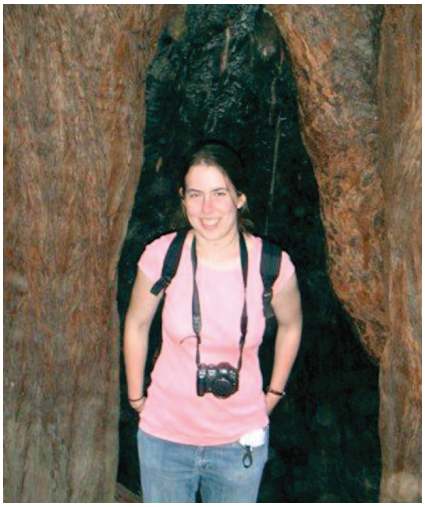
The summer following her freshman year at MIT, Rivoire spent time in a research program at MD Anderson Cancer Center in Houston, where she grew up. She had worked in the same lab the previous summer through a program she found out about at her high school. She then participated in two different research groups through MIT's program, one in her sophomore year, and another during her last year-and-a-half, including a senior physics thesis. The first experience, in an atomics physics lab, was her first experience creating experimental tools and helped her figure out what type of research tasks she enjoyed most, Rivoire says.



Rivoire takes a break in the optics lab at Stanford University.

That experience, along with additional coursework she picked up, allowed Rivoire to make what she deems "a great choice" for the next lab she joined, where she was able to make meaningful contributions to a project that matched her interests. The project, which was conducted by a group led by Prof. Marc Baldo, focused on enhancing the efficiency of organic light-emitting diodes. Rivoire fabricated and characterized devices and analyzed the results. That work eventually led to a paper in *Nature Materials*, on which she was third author. "Having a really great undergraduate research experience certainly influenced my decision to go to grad school, most notably in leading me to apply to electrical engineering and applied physics programs, rather than in physics, which was my major," she adds.

Each research project Rivoire worked on helped her to zero in on her interests and decide which field she found most interesting, as well as what balance of day-to-day work suited her best, she says. Now a Ph.D. student, Rivoire works on nanophotonic devices and spends most of her time in an optics lab, where she builds and runs experiments to test devices and study their behavior. She also fabricates devices using Stanford's nanofabrication facility, improves device designs using simulations that solve discretized Maxwell's equations, and analyzes data to evaluate the performance of devices and how closely they match theory. Her current work is in many ways a combination of what she liked best about each of her prior projects, she explains.



Rivoire spends some downtime hiking among the trees at Big Basin Redwoods State Park in Boulder Creek, California.

Help is on the way

Students looking to join a research group should assert themselves and take the initiative, Rivore says. "I think most faculty welcome undergraduate students in their labs. After all, part of their job description is training the next generation of scientists. So, students who want to do research shouldn't be afraid to ask for an opportunity or to be a bit persistent."

Students who do successfully find a research opportunity should be prepared to speak up, ask a lot of questions, and be a little more independent. Flexibility is a key trait as well. "There isn't a set of instructions for research," Rivoire reveals, "so it's important to think and learn independently, as well as learn how to ask for help."

Make friends and influence people

Name: Kamakshi Sivaramakrishnan
Status: Senior research scientist at Admob Inc., in San Mateo, California.
Vitals: B.E. in electronics engineering from the University of Mumbai, India. M.S. in electrical engineering from Boston University in Massachusetts. Ph.D. in electrical engineering from Stanford University in California.
The Tao of Sivaramakrishnan: "Pursue research opportunities in the form of internships with industry research labs. This helps forge relationships with industry researchers and engineers which eventually helps in defining your own career, be it in academia or industry."

Sivaramakrishnan is a senior research scientist at Admob Inc. (recently acquired by Google), where she drives the algorithmic, machine learning techniques agenda for ad optimization and selection. She develops statistical models that capture responses to advertisement impressions on mobile devices so as to maximize the user experience of the most relevant ads being shown to them. As a part of her undergraduate curriculum, she took an advanced class in digital signal processing during her senior year that exposed her to a highly mathematical discipline in electronics engineering.

Sivaramakrishnan is currently driving the efforts around algorithmic optimization of in application display ad performance on smartphones.

"I particularly enjoyed the material for both its mathematical components and a wide array of practical applications around it," Sivaramakrishnan explains. "This motivated me to seek a deeper, more advanced grasp on the subject, leading to the pursuit of graduate school at Boston University. As a part of my application to the graduate program, I received a teaching assistantship to teach the undergraduate class in digital signal processing, which introduced me to faculty members conducting research in the area. I pursued the research opportunity by attending research group meetings of these faculty members and quickly zeroed in the professor whose research topics interested me the most."

The following semester, Sivaramakrishnan committed to a research assistantship conducting research in video compression techniques using wavelet transforms. It was the beginning of a

Become familiar with the Ph.Dos and Ph.Don'ts

Making decisions regarding research opportunities can be time-consuming but then toss on top of that having to select the Ph.D. program that is right for you. Andreas Koltes is currently working as an intern at Diehl Stiftung in Nuremburg, Germany, which is involved with metal products, defense technology, and aircraft equipment. Koltes is using his internship to bridge the gap between the end of his university program at the end of 2009 and the start of his Ph.D. program in the fall of 2010.

As of the printing of this issue of *IEEE Potentials*, Koltes has not yet accepted an offer from a Ph.D. program and is currently involved in the selection process. He says he selected the universities to which he applied according to multiple criteria. First, he would like to use the time as a Ph.D. student to gather additional insight into both state-of-the-art technologies in his special field of interest (reconfigurable computing and computer architechture) as well as into research methodology. Gathering additional international experience is another facet that is very important to him. Therefore, working toward his Ph.D. in Germany was not an option. Koltes also would prefer to earn his Ph.D. at a university that enjoys an excellent international reputation in the field of computer engineering, so that he may work with and learn from world-class researchers and enhance his professional network.

Koltes (second from the right) attended the dinner at the 2008 IEEE Region 8 Student Branch Congress in London.

According to Koltes, before thinking about the specific universities and departments to which you may apply, students should ask themselves the following questions:

- Why do you want to earn a Ph.D.? What do you want to use it for (e.g., are you planning an academic or an industrial career)?
- What is the maximum duration of a Ph.D. program that is acceptable to you (e.g., how old will you be when you actually start your career)?
- In which subject area do you want to earn a Ph.D.? Do you want to specialize in the same subject you have already studied or do you want to broaden your education by choosing a related subject?
- In which country do you want to do earn a Ph.D.?

Working through the actual application processes of the various universities and doing the necessary qualification tests—the Test of English as a Foreign Language and the Graduate Record Examination in his case—took significantly more time than was expected at the beginning, Koltes recalls. "Especially assembling the various application documents required by the individual departments takes a lot of time. Do not expect to be able to just prepare one application and to submit it to all the places you are interested in. Every department adds its own very special bit of magic to its application process, which makes it very time-consuming to submit a strong application."

If there is a particular research group you would like to work with, try to contact them in advance and mention the group and some potential supervisors in your statement of purpose. Since many prestigious departments receive more than 1,000 Ph.D. applications per year, you should make sure that the people with whom you are trying to communicate really notice your application, Koltes adds.

A vital part of your application will be the recommendation letters you send in along with your application. Koltes advises to take some time to think about who knows you and your abilities best and speak to them early. The person making the recommendation will not be able to just send out exactly the same letter to all places to which you apply, so keep in mind that it will take them quite some time to prepare these documents. Remember that those who are writing letters for you have other duties as well, so you should make their work as easy as possible and allow them time to process them to ensure that you will get strong references, he adds.

Try it out

The first time Koltes experienced university research was when he was employed as a student research assistant at the Chair of Computer Networks and Computer Communication at the University of Passau in Germany. Although his work there was limited to smaller support tasks, it sparked his interest in academic research.

When Koltes studied abroad as an exchange student in Scotland, he got in contact with a research project at the University of Glasgow in the scope of a fourth-year project. Koltes recalls that the project was originally intended as a preparative project for a grant proposal to the British National Science Foundation related to reconfigurable computing. The project went well and was developed further into a larger scale precursor project for an intended National Science Foundation proposal. Following his exchange scholarship from Glasgow, he prolonged his stay in the United Kingdom for three months, joining another research project at the department in the same research area.

These undergrad research activities were a great opportunity to "try out" academic research before actually entering a Ph.D. program, Koltes says. In the scope of the research project, he had the opportunity to coauthor multiple publications, which bolstered his applications to Ph.D. programs.

Assessing the potential for long-term collaboration is essential in identifying research opportunities, Sivaramakrishnan says.

research career that has eventually led her to many successful publications in statistics, signal processing, and machine learning.

Her primary research engagement during the last few years has been her thesis work titled, "Universal Schemes for Denoising Discrete-Time Continuous-Amplitude Signals." She pursued her thesis work with Prof. Tsachy Weissman in the area of information theory with a focus on universal techniques for signal processing problems like denoising. In keeping with her previous research interests, Sivaramakrishnan's area of research was statistical signal processing and information theory. One of the significant highlights of her graduate research work was her involvement in the NASA mission to the outer planetary system called New Horizons, she says. Sivaramakrishnan worked on the communication system for an onboard critical radioscience scientific experiment, REX.

"My thesis work prepared me very well for a research career in machine learning and data mining," Sivaramakrishnan adds. "With the explosion of data driven methods in a wide range of disciplines like digital advertising, social networks, Web applications, crowd sourcing, quantitative finance to name a few, I am uniquely positioned with respect to my research having applications in a variety of different fields."

Pointers in the right direction

When a student has decided to actively pursue his or her research interests, it is essential that they work to engage faculty members, peers, and industry, Sivaramakrishnan counsels. Communicate with faculty members whose research areas are of interest to you for potential opportunities of research in their group, she says. Even if immediate opportunities are not available, it helps to pursue the communication by attending their group meetings. This helps you follow the various projects that might of interest to you and an early start on the research assistantship.

Students should also attend conferences if they have results to publish from their undergraduate or master's research program. This gives you visibility to the research community and helps makes the initial contacts to faculty members conducting research in potential areas of interest. Pursue research opportunities in the form of internships with industry research labs, she adds. This can forge relationships with industry researchers and engineers that eventually help in defining your own career, be it in academia or industry.

"Most universities offer research credits as a part of the curriculum," Sivaramakrishnan continues. "It could help to initially embark on a research opportunity taking these credits with a professor you might be interested in pursuing research with. This gives both you and the professor an opportunity to get to know each other better and assess the potential of a long-term collaboration."

Concerning students pursuing a doctorate program, Sivaramakrishnan advises to work on relevant, cutting-edge problems with maximum impact to technological advances. "Lack of focus on this critical aspect to defining your thesis topic might lead to the years of research not being particularly relevant to opportunities both in academia and industry," she says.

—Craig Causer is the managing editor of *IEEE Potentials*.