

THE LINK

News from the School of Computer Science

Issue 6.1 / Summer 2011

OBAMA TOURS
NREC, P. 22

The Race is On!

NEARLY 30 TEAMS ARE TRYING TO PUT A LANDER ON THE MOON AND WIN GOOGLE'S LUNAR X PRIZE. HERE'S WHY A CMU SPINOFF HAS THE CLEAR LEAD.

ALSO INSIDE:

ZIV BAR-JOSEPH: RUNNING MAN

TRANSLATING LESS-COMMON LANGUAGES

CROWDSOURCING COMPLEX WORK

Carnegie Mellon University





The Link provides a mosaic of the School of Computer Science: presenting issues, analyzing problems, offering occasional answers, giving exposure to faculty, students, researchers, staff and interdisciplinary partners. The Link strives to encourage better understanding of, and involvement in, the computer science community.

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CALENDAR OF EVENTS

All events to be held at the Carnegie Mellon University campus in Pittsburgh, unless otherwise noted. Dates and locations are subject to change without notice. Visit calendar.cs.cmu.edu for a complete and current listing of events.

July 24
SCS and ECE Alumni and Student Cruise
Seattle, Wash.

Aug. 15–18
Graduate student orientation

Aug. 21–28
First-year student orientation

Aug. 29
Fall term begins

Sept. 5
Labor Day; no classes

Sept. 12
Add/drop deadline

Oct. 21
Mid-semester break; no classes

Oct. 27–30
"Cèilidh Weekend"
Homecoming and Family Weekend 2011

Nov. 14–18
Spring 2012 registration week

Nov. 23–25
Thanksgiving holiday; no classes

Dec. 9
Last day of classes

Dec. 12–20
Final exams

Jan. 16
Spring semester begins
Martin Luther King Day; no afternoon
or evening classes

March 5–7
Graduate Student Open House
Gates & Hillman Centers

Show Your Pride.

Unleash your CMU pride and be part of our exclusive recognition program, Loyal Scots. Stay informed about your alma mater, your friends and the Carnegie Mellon network.

- ✓ Stay Informed
- ✓ Give Back
- ✓ Get Involved
- ✓ Show Your Pride

**LOYAL
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PLAID TO THE BONE

cmu.edu/loyalscot

C O N T E N T S



10 / Cover Story: Astrobotic's Race to the Moon

Nearly 30 companies are vying for the Google Lunar X Prize—an award of up to \$25 million for the first privately funded team to land on the moon. Pittsburgh-based Astrobotic Technology has developed a commanding lead—their rover is built, the lander is ready and a rocket is standing by for a possible 2013 blast-off.

By Meghan Holohan



16 / Feature: Running Man

Marathon runner Ziv Bar-Joseph came to CMU in 2003 with a fascination for the biological world, and the idea that computer science could help make sense of the growing mountain of genetic data. Friends and colleagues say he's pulling ahead of the pack in more ways than one.

By Kenneth Chiacchia

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Less-commonly heard languages benefit from machine translation, too. Students in CMU's nascent ACM chapter are making contacts on- and off-campus. Should a robot tell jokes? Both Heather Knight and "Beetle Bailey" say yes. And a new performance test for supercomputers owes much to work done at SCS.

8 / In the Loop

His first Soviet-built computer couldn't save programs and overheated after three hours, but that didn't scare Alexei Efros away from computer science—it inspired him.

20 / Research Notebook

Crowdsourcing has become a powerful mechanism for distributing technical work online. Research conducted at SCS indicates that creative work—like writing articles—can be crowdsourced as well. Niki Kittur, Boris Smus and Bob Kraut explain.

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Not all of the Spring Carnival activity happens on the Midway and the Sweepstakes course.

Back Cover / Then and Now

There have been many prizes created to spur technological achievement, but 1980's Fredkin Prize looms large in the history of computer science at CMU. It led to IBM's chess-playing Deep Blue computer, which defeated Garry Kasparov in 1997.

On the Cover:

Astrobotic's Red Rover is being tested at several sites in the Pittsburgh area. If all goes as planned, in 2013 it will be traveling 500 meters across the surface of the moon to the site of one of NASA's Apollo landings.

Headed by William "Red" Whittaker, CMU's Fredkin Professor of Robotics, Astrobotic is one of 29 teams competing for the Google Lunar X Prize—an award of up to \$25 million for the first privately funded team to land on the moon.

Technology analyst and security consultant Michael Doornbos says Astrobotic is opening a lead over its competitors in most categories, but Whittaker cautions that the race is far from over.

Our story begins on page 10.

(Photo courtesy Astrobotic Technology Inc.)

I've recently had the opportunity to speak to groups of alumni, faculty and friends of the School of Computer Science about undergraduate admissions, and we've had many stimulating and thought-provoking conversations about the state of computer science education. I've also had the opportunity to share a few highlights pertaining to the incoming SCS Class of 2015.



Randal E. Bryant

We received 3,481 applications for admission this year. That's an all-time record for applicants, breaking the previous record set in 2001 at the peak of the dot-com boom. We admitted 385 students, the lowest number since 2005, but 152 students plan to enter the program—the highest number in the history of our undergraduate program.

The average SAT scores of the entering students are 729 reading, 769 math and 724 writing. (I'm not sure if I myself would have gotten admitted!)

Figure 1 shows the relative number of women and men in our incoming classes over the 18-year history of the undergraduate CS program. We had a remarkable period from 1999 to 2001 when women made up 36 to 40 percent of our entering classes (due in large part to efforts by Allan Fisher). In the aftermath of the dot-com bust, that percentage fell sharply; only people with a diehard passion for computing were choosing to major in computer science.

The upcoming class includes 48 women—roughly 32 percent. In my experience, when women make up at least one-quarter to one-third of a classroom, the women students no longer get the sense that they're in a minority. Simply by their presence, they help play an equal role to men in defining the attitudes and culture of the program.

Figure 2 shows the historical admissions statistics for the program. The blue bars show the total number of applicants to the program. These numbers vary a lot over the years, rising during the dot-com boom, falling after the bust, and climbing back again over the past several years. The red and yellow bars show the numbers of "admitted" and "entering" students—and those have remained fairly consistent. We're always looking for an incoming class of approximately 130 to 140 students.

As a comparison, Figure 3 shows the number of total new computer science majors in the United States and Canada, as measured by an annual survey of computer science programs known as the "Taulbee Survey." We can see that the number of CS majors increased rapidly during the dot-com boom, then fell off just as sharply during the bust. Since then, there has been a slight increase in enrollments, but they are still below their dot-com peak.

In Figure 4, I compared our numbers with the national trends. (I shifted the national numbers by one year, because at most schools, students declare their majors in the sophomore year, while at SCS, all of our undergraduate students are considered CS majors during their freshman year. I also divided the national numbers by 7.35 to put them on comparable scales. (For you statistics buffs, the ratio 7.35 yields the least-squares difference between the two data series.)

While interest in CS among undergraduate applicants has recovered somewhat across the United States and Canada, Carnegie Mellon is climbing out of the trough more clearly than other universities. I believe this is an indication of Carnegie Mellon's growing reputation as a "go-to" place for computer science, arising from both our research accomplishments and from the great successes of our alumni.

Randal E. Bryant
Dean and University Professor
School of Computer Science

UNDERGRADUATE PROGRAM ENROLLMENTS

Entering Undergraduate Majors By Gender

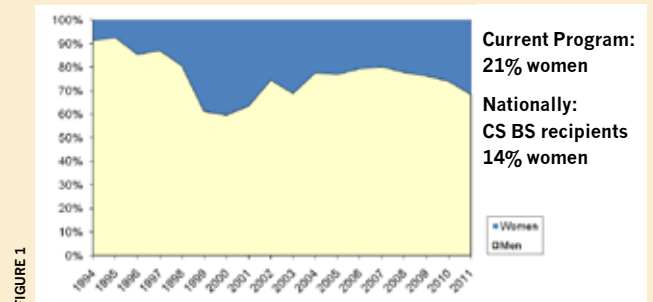


FIGURE 1

UNDERGRADUATE APPLICATION TRENDS

SCS Admissions for Fall 2011

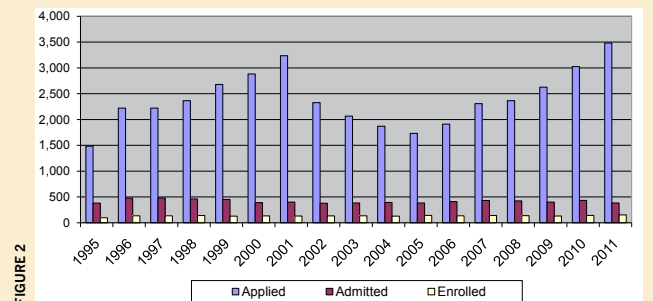


FIGURE 2

U.S. AND CANADA TRENDS

U.S. and Canada new CS Majors

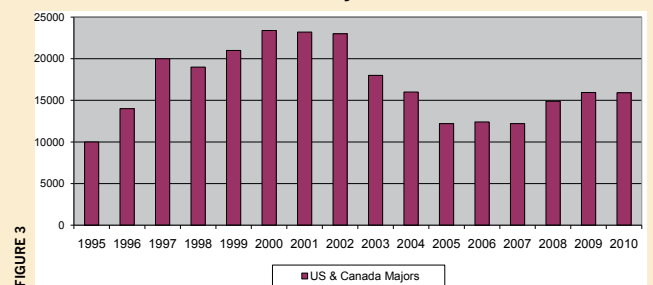


FIGURE 3

COMPARING SCS TO NATIONAL TRENDS

SCS Admissions: National Comparisons (shifted by one year)

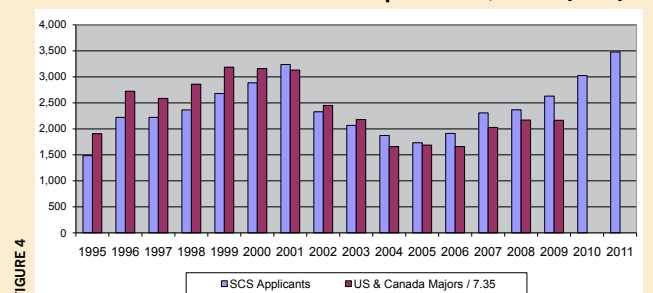


FIGURE 4

Finding the Right Words

CMU leads a multi-university effort to develop translation programs for less-common languages

> By Jason Togyer

About 12 million people worldwide are fluent in Kinyarwanda, an African dialect used in Rwanda and parts of neighboring Burundi and Uganda. It may sound like a lot—but consider that about 1.4 billion people speak Mandarin and 1.8 billion speak English. That makes it relatively simple to find someone who can translate English into Mandarin, but not so simple to find someone who can turn English into Kinyarwanda and back again.

The lack of translators for these less-commonly spoken languages becomes a serious problem when trouble—such as a natural disaster, or, in the case of Rwanda, civil war and genocide—erupts in a place where such languages are the native tongues. “Imagine setting up an army base or Red Cross tent,” says Jaime Carbonell, director of CMU’s Language Technologies Institute, “and people are coming to you for medical help—but you can’t speak their language.” Aid workers or peacekeepers then must rely on native translators who can be difficult to find, and in some cases are fellow victims (or even perpetrators) of the ongoing crisis.

While computerized translation systems for languages such as English, French, Mandarin, Spanish and other languages have flourished, less-commonly used languages have been largely left behind. A new five-year research project led by Carbonell and including colleagues from CMU and three other universities will try to close that gap. The research—valued at more than \$1 million per year—is being funded by the U.S. Army’s Multidisciplinary University Research Initiative, or MURI. Partner universities are MIT, the University of Southern California and the University of Texas at Austin.



U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT PHOTO

During crisis situations, human translators aren’t always available to help aid workers, and sometimes—like in this health clinic in Kinigi, Rwanda—their presence isn’t appropriate. Unfortunately, for less-commonly spoken languages, such as Kinyarwanda, machine translators aren’t often available, either. A five-year research project being led by Jaime Carbonell of CMU’s Language Technologies Institute is working to fill that void.

Researchers will develop machine translation models for Kinyarwanda and Malagasy, the national language of the island Republic of Madagascar, which is spoken by about 20 million people worldwide. Their broader goal is studying how a combination of computing power and human intelligence might create faster, better translation systems than either method alone.

“MURI is interested in examining languages in potential hot-spots in the world that are also less-commonly spoken languages,” Carbonell says. “Some of them are actually spoken by a lot of people, but there’s very little written data, and it’s difficult to map oral traditions onto computer models.”

Building translation systems for “resource-poor” languages isn’t simple. Early machine translation systems relied on grammar rules, but the practice went out of fashion because programming them took tens of thousands of person-hours, says Lori Levin, an associate research professor in the LTI. Since the early 1990s, most modern machine translation systems instead have been built on statistical models. Large bodies of parallel text in two or more languages—news articles or transcripts of United Nations or European Union proceedings—are analyzed and parallel words or phrases are matched based upon the frequency of their occurrence and the probability that they

have the same meanings. In the case of languages such as Spanish and English, there are “terabytes of data” to work with, Carbonell says.

Another member of the research team, Stephan Vogel, says many of the models being used were adapted from other disciplines such as electrical engineering, physics or computer science. “From a linguistics point of view, these models are fairly dumb, but from a practical point of view, they’re quite good,” says Vogel, an assistant research professor in the LTI. “It’s amazing how much machine translation has improved over the past 10 years.”

But with a language such as Malagasy or Kinyarwanda, there aren’t those collections of large, parallel texts with which to build statistical models. “If you have 10 million sentence pairs, you can build up a very good translation,” Vogel says. “In this case, we don’t have even 1 million sentence pairs. We may not have 100,000.”

Using a brute force method—paying people to hand-translate documents from Malagasy or Kinyarwanda into English, and then training machine-translation algorithms on those bodies of text—would be both slow and expensive, Carbonell says.

Instead, the team will use existing texts such as the Bible, Koran, government documents and >>>

Ace of Clubs

A student-run chapter of the Association for Computing Machinery is getting noticed both on- and off-campus

➤ By Jason Togyer

Chess. Water polo. Freestyle rapping. A cappella singing. Snowboarding. Swing dancing. Rowing. Baseball, foosball, racquetball and roller hockey.

More than 250 student organizations are competing for the attention of CMU undergraduates. Some focus on sports or hobbies; others celebrate ethnic heritage or encourage involvement in politics and activism.

This spring, another organization—the university’s three-year-old student chapter of the Association for Computing Machinery—waded into that crowded marketplace of ideas. For the first time, it participated in the campus’ Activities Fair, a semi-annual event where student-run organizations recruit new members.

And while the words “computing machinery” may not trigger the same visceral reaction as “snowboarding,” the event went well—with a few exceptions. Says Shashank Pradhan, an SCS senior, with a laugh: “With some people, as soon as you told them what ‘ACM’ stands for, they ran away.”

On the other hand, some also stayed because of what “ACM” stands for—the world’s first (founded in 1947) and largest (92,000 members) educational and professional society devoted to computing and computer technology. “Recruiters are impressed when they hear the letters ‘ACM’ because the reputation is so well known,” says Pradhan, who this year chaired the committee that publishes the student chapter’s newsletter, ACM Communications.

The CMU group was founded by Geeta Shroff (E’08, CS’08, ’10), who also served as its first president. It was chartered by the parent organization in 2008. One of more than 500 student ACM chapters around the world, the only requirements for membership in the chapter—informally known as ACM@CMU—are an interest in computing (not all of the members are affiliated with SCS), active participation >>>

UNITED NATIONS CARTOGRAPHIC SECTION MAP



Under a multi-university research initiative being funded by the U.S. Army, scientists will attempt to develop translation systems for Kinyarwanda (spoken in Rwanda and parts of neighboring Uganda and Burundi) and Malagasy (spoken on the island nation of Madagascar).

From page 3

other written works. In the case of Kinyarwanda, researchers also have access to translated testimonies given by the survivors of the Rwandan genocide. But those documents suffer from a problem called “domain specificity,” says team member Jason Baldrige, a computational linguist at UT–Austin. The genocide documentation hopefully doesn’t represent topics that native speakers of Kinyarwanda talk about in everyday life, he says, and formal works such as the Bible and Koran aren’t typical of modern speech patterns, either. (People don’t speak in sequences or “begats.”)

“We don’t have as much data to rely on,” adds another project researcher, Noah Smith, an assistant professor of language technologies and machine learning at CMU, “so we have to rely on deeper linguistic principles and squeeze more information out of the data we do have.”

To do that, the MURI initiative will experiment with hybrid translation systems that blend statistical models with language rules—a linguistic-core approach. “I think putting some linguistic knowledge back into the models is going to improve the quality of the translations,” Levin says. “Some of the statistical methods are beginning to be maxed out, and I think everybody knows that.”

Active-learning algorithms will then be used to explore the data being collected by the researchers and determine where statistical models alone are capable of devising accurate translation rules, and where linguistic and grammar rules written by humans will have a major impact. “Active learning is very good at determining what you don’t know that would make the biggest difference if you did know it,” Carbonell says. It’s too soon to say how much of a finished hybrid translation system will rely on probability models, and how much will rely on linguistics, he says: “This is a five-year project, and we’re only five months in. We’ve got a long way to go.”

Although a big test of the team’s work will be creating reliable translators for Malagasy and Kinyarwanda, the larger goal is learning how researchers can speed up the process of creating machine-translation systems for less-commonly used languages. “It’s no good if you respond to an emergency and a year later you say, ‘OK, now we have a system in place and we can translate,’” Vogel says. “Can you do it in three days?”

Jason Togyer is editor of *The Link*. Write to him at jt3y@cs.cmu.edu.

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in one of the chapter's committees, and regular attendance at weekly meetings. Underwriting from companies such as Lockheed Martin has enabled the student ACM chapter to defray many of its costs.

Will Zhang, a computer science junior who served as president during the 2010-11 academic year, says about 25 students regularly attend the chapter's meetings. Many of those meetings have featured lectures by people working in computer science—an April session, for instance, hosted Matt Maroon, founder of Blue Frog Gaming, which is developing applications for Facebook and other social networking sites.

Besides its lecture series, several outreach activities have helped raise the chapter's profile on campus. In February, student members of ACM presented a town hall-style discussion in the Rashid Auditorium where managers from five multinational banks—Barclays, Citibank, Credit Suisse, JPMorgan Chase and Macquarie—discussed the ways that global finance depends on technology. "The (theme) in our ACM chapter has been connecting with industry," Zhang says. Student ACM members also distributed résumé books from more than 150 SCS undergraduates



to corporate recruiters during the university's Technical Opportunities Conference.

ACM@CMU members credit Catherine Copetas, SCS assistant dean for industrial relations and director of special events, with arranging those industry connections and keeping students focused and motivated. "Catherine is amazing," Zhang says. "We would not be around if it weren't for her." Adds Jen Solyanik, another SCS junior and associate editor of ACM Communications, "Catherine helps us so much."

Though the professional aspects are important, there's time for fun as well. Besides obviously computer-oriented activities such as coding competitions and an end-of-semester Xbox gaming party that featured Microsoft's new Kinect technology, students are using the ACM chapter as an opportunity to make friends across class years and disciplines. "Some of the younger students have joined ACM to get an upperclassman's perspective on CMU," says Solyanik. ACM members share tips on which classes to take and how to balance campus life with a full CMU course load, she says. Jason MacDonald, an SCS junior who chaired the group's IT committee in 2010-11, says: "If you're a freshman, it's definitely a good resource, because

it's a good environment to come in and get advice from upperclassmen."

While interest levels were high at the end of the spring semester, student groups tend to wax and wane, and clubs that bustle one year can stagnate the next. Zhang says a lot of work remains to be done to make the chapter self-sufficient and self-sustaining. "People come in and out—it's inevitable," he says. "We just have to continue to be visible, continue to recruit members and keep on operating."

Luckily, the ACM chapter's newest members from the recent freshman class seem to have a lot of energy, says Solyanik, who headed the group's internal development committee in 2010-11, "and I expect them to be around for a while."

She notes that one of the traditional knocks on the undergraduate experience at Carnegie Mellon has been that there's too much work and not enough fun. "People sometimes feel like students aren't taking enough advantage of everything that CMU has to offer," Solyanik says, "and I think that ACM can really help with that."

Jason Togyer is editor of *The Link*. More information about ACM@CMU is available at the group's website, www.acm-cmu.org.

CEO: Unisys refocused on service, growth

The predecessors of today's Unisys Corp. pioneered some of the most amazing technological breakthroughs of the 20th century—the airplane auto-pilot, radar and microwave communications, and the first American-made commercially available computer, UNIVAC.

But by 2008, when J. Edward Coleman was recruited from Gateway to become Unisys' CEO, the company had gone from "king of the hill" to "run of the mill." Structured in the 1980s to take on IBM, 20 years later Unisys was top-heavy with management, embroiled in controversies, and losing both money and customers.

In 2009, Unisys turned its first profit in five years and ended 2010 with more cash than debt for the first time in memory. Coleman, who delivered a W.L. Mellon Lecture at CMU's Tepper School of Business in April, told students

that the road back to profitability required trimming away layers of management, cutting out expensive perks like corporate jets, creating a better work environment for employees and improving services for core clients in banking and government. (Unisys, based in eastern Pennsylvania, also has been drastically downsized over the years—from 120,000 employees to about 23,000—and has sold off several divisions.)

One growth area for Unisys has been creating secure government ID programs designed to combat global terrorism and other cross-border criminal activities, Coleman said. And while it continues to support its legacy systems, Unisys is also betting heavily on new cloud-computing technologies for its data-processing clients.

"Profits are up, cash is up, customer service is up," said Coleman, who was hosted by the School of



CHAD CROWELL PHOTO

Computer Science and met with several faculty members during his visit. "It's so refreshing—two years ago, customers were asking about our problems at Unisys. Now, we're talking about the clients and their problems."

—Jason Togyer

Machines With Charisma

Can robots tell jokes? If they want to be accepted by humans, they can—and should, says RI grad student Heather Knight

By Mary Lynn Mack

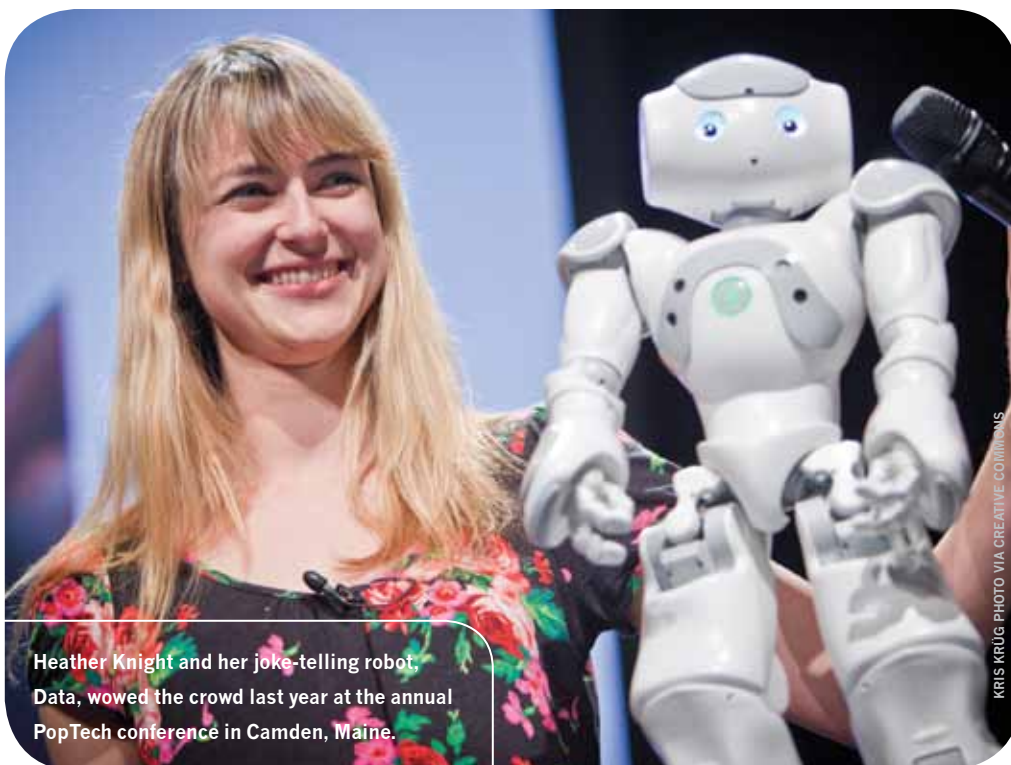
Sure, a person can be charismatic. But a robot?

Heather Knight thinks so. Currently a doctoral student in the Robotics Institute, Knight says that if we want human-robot interaction to be as seamless as human-human interaction, then we'd better make sure robots are more charismatic.

In fact, Knight says, the “icing on the cake” could be giving a robot a sense of humor. Adding humor and a sense of fun are important to creating the connection between human and machine, she says. “I think in the same way that we enjoy spending time with charismatic people, there will be different types of applications that will become open if we can make socially intelligent machines,” Knight says. “And it could do much to help us forgive them for their inevitable missteps—particularly if the humor’s self-deprecating.”

Knight’s interest in human-robot interaction was sparked when she was an undergraduate at the Massachusetts Institute of Technology and had an opportunity to work on a Cyberflora, an exhibit consisting of 20 individual robotic flowers that could sense and respond to the movements of nearby museum visitors and an instrumental soundtrack. The robotic flowers, which glowed brightly in shades of green, purple, blue and orange, would bend and stretch toward an oncoming visitor ... but if that visitor got too close or attempted to touch the flower, it would suddenly retreat, close up its floral bud and cool its colors.

Since then, Knight has continued to work on the development of several other robots, including The Huggable, a robot companion with affective, relational touch; Trisk, a robot that understands language by sensing its environment; and RoCo, a robotic computer for learning companion research. Knight’s current work, for which she recently earned a National Science Foundation graduate research fellowship, is with Data, a performance robot who not only does stand-up comedy, but also is learning to act in collaboration with other performers.



Heather Knight and her joke-telling robot, Data, wowed the crowd last year at the annual PopTech conference in Camden, Maine.

KRIS KRUG PHOTO VIA CREATIVE COMMONS

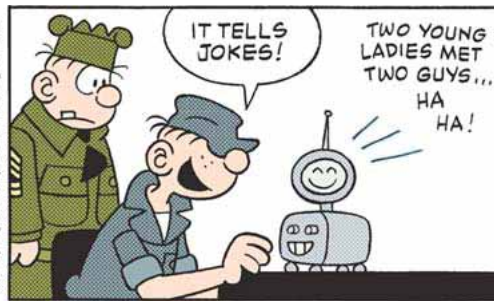
Data is an NAO humanoid robot, designed by Aldebaran Robotics. At just under two feet tall, his gestures may not be grand, but through his acting lessons with Matt Gray, an assistant professor in CMU’s School of Drama, Data is learning how a simple drop of the chin can convey shyness or how hand and arm movements can help accentuate a punch line. (In case you were wondering, Data is named after the Star Trek: The Next Generation character Data, who, through his desire to be more human, also explored the arts and acting.)

Gray says actors have to formalize the “process of being human” in order to be effective in their craft, adding that teaching this practice to Data has had many similarities in that he makes many of the same “elementary mistakes” as young actors do. One such example is that at times young or nervous actors will speak aloud text written into a script—such as stage directions or bracketed instructions from the writer—that was not supposed to be read.

Similarly, Data’s program does not differentiate between text to be spoken and punctuation, so while working on a line from Shakespeare, he once declaimed, “Woe woe woe is me, exclamation point.”

While on stage for his stand-up routine, Data uses real-time audio and visual feedback from the audience to adjust his performance. In a demonstration of the system at December’s first-ever TED Women conference, on-stage sensors measured the volume and duration of the audience’s ambient response in the form of laughter, applause or chatter. The initial version of the software assumed most feedback was positive, so it didn’t differentiate laughing and applause from heckling and booing. Knight says the tracking capabilities will be extended in the future, to allow deeper analysis of the performer-audience relationship.

During the first demo, visual feedback was given through the use of colored cards—green for “Yes” when asked a direct question or for a general “I am enjoying the performance” response and red for “no” or “I am not enjoying the performance.” At Data’s first live-audience performance, some jokes did better than others, and a few did flop (with almost complete silence from the audience once he reached the punch line). But when he asked the audience about his overall performance, he received almost all green cards and his loudest applause of the performance.



Heather Knight isn't the only one who understands the potential uses for a joke-telling robot. So does the star of "Beetle Bailey" in this comic strip that appeared in newspapers around the world back in January. (Reproduced with the permission of Mort Walker, www.mortwalker.com)

"There were some robots where the names reflected the function of the robot and some were just (called) a number, but the vast majority of the robots were actually named," she said.

After the initial Robot Census at Carnegie Mellon was complete, Knight opened the census to worldwide participation and would like to see census committees established at other large robotics campuses to see if there are conclusions that can be made about a campus from the types of robots in use there.

"As researchers, we might all call ourselves roboticians, but 'robot' is a diverse term," she says. "It will be interesting to examine how we think differently about robots, and have diverse cultures of robotics innovation across different institutions. The censuses will certainly start that conversation."

Mary Lynn Mack is a Washington, Pa.-based freelance writer who has worked in Pittsburgh's high-technology sector for most of her career. This is her first Link byline.

Editor's Note: More information about Knight, her research and her robot theater company can be found on her website www.marilynmonrobot.com.

Knight had considered adding "stalling capabilities" to the routine, where Data would pretend to drop something or smoke a cigarette in order to allow for more time for audience feedback and for Data to process the information. But after feedback from the crowd at TED Women, she suspects the best modification would be to have the robot more directly acknowledge the audience, maybe with another joke: "You guys didn't like that one? I'll try a Steelers joke next."

While not all robots are charismatic, Knight is—and it's hard not to catch the enthusiasm she has for her research. Among her role models, she lists Carnegie Mellon's Manuela Veloso; MIT's Cynthia Breazeal, a mentor and a pioneer in social robotics and human-robot interaction; and former boss Bruno Maissonier, the founder of Aldebaran. Knight also cites the work of Jane McGonigal as an influence. McGonigal is a game designer, games

researcher and author, specializing in pervasive gaming and alternate reality games.

Last year, Knight made a splash in the mainstream media with her Robot Census. An attempt to count every robot residing in the university's labs, the form designed by Knight and her friend, Los Angeles-based graphic designer Chris Becker, was also a parody of the U.S. Census form. (Sample instructions: "Use blue or black pen. No Binary." and "Do not count any robots that were in a robot nursing home, jail, detention facility, etc., on September 8, 2010.")

In the end, 547 robots were counted on the Carnegie Mellon campus—more than double the number that RI staff had predicted. Included in her findings were that 60 to 70 percent of the robots on campus have been assigned a gender and most have been given a name.

Speed Test

A new measurement standard for supercomputers owes a debt to the work of CMU's Christos Faloutsos

> By Jennifer Bails

If you were shopping for a new car, you'd want to know more than just how long it takes for the vehicle to accelerate from zero to 60 mph at full throttle. A savvy buyer would also want some information about fuel economy, handling, braking and other performance metrics.

When you're comparison shopping for supercomputers, you also need performance metrics—but you can't exactly flip through Consumer Reports for the answers.

Traditionally, supercomputers have been ranked on a list known as the TOP500, a biannual worldwide competition based on the Linpack benchmark. The benchmark measures how fast these computers can solve a dense system of linear equations, and results are reported in the units of billions of floating point operations per second, or "flops." Last fall, China's Tianhe-1A took the TOP500 crown by reaching processing speeds of 2,507 petaflops—or 2,507 trillion calculations each second.

But just as you wouldn't buy a car based on its zero to 60 mph test alone, a supercomputer's floating-point rate of execution doesn't tell you everything you need to know about its performance. That's especially true now that supercomputing problems increasingly demand more than basic number crunching; they require deep processing of vast datasets. For many real supercomputing applications, the Linpack test has become meaningless.

"Much of supercomputing has focused on computation-intensive applications for 3D physics simulations," says David A. Bader, professor in the School of Computational Science and Engineering and College of Computing at Georgia Institute of Technology. "But as we move toward more data-intensive supercomputing problems, we need a way to measure how machines will perform on these other kinds of workloads."

Bader is a member of the steering committee of a new effort called Graph 500, which is creating a measurement to rank supercomputers in a way that's meaningful for data-intensive applications. This new yardstick will help guide the design of next-generation hardware architectures and software systems, according to Richard Murphy, a principal member of the technical staff at Sandia National Laboratories in New Mexico, who led the founding of Graph 500. "To quote Lord Kelvin, 'If you cannot measure it, you cannot improve it,'" Murphy says. >>>

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Graph 500 is a grassroots collaboration between industry, academic and government experts that began over a dinner conversation at the Supercomputing 2009 conference in Portland, Ore. As its name suggests, the benchmark ranks computers by how large of a graph they can build, and then how quickly they can sift through these data. Graphs are an ideal way to explain the complicated relationships between individual elements in large datasets, such as those between people on Facebook and Twitter; physical links between locations on transportation routes; patterns of disease outbreak; computer network topologies; and neuronal networks in the human brain. Computers increasingly are being used to analyze pathways through these graphs to find the shortest connection between two nodes. The information gleaned by “traversing” (stepping through) such graphs can help an immunologist understand how viruses spread, or allow financial experts to spot fraudulent transactions.

But although these graphs are everywhere, many of the most challenging large-scale graphs—the kinds that computers are analyzing in real-world situations—are those that have been created by major corporations or government agencies, and they’re off-limits to researchers, says Christos Faloutsos, Carnegie Mellon computer science professor. “People would love to analyze these graphs, but companies often cannot give them out for privacy and competitive reasons,” he says. It’s not enough to anonymize the data, either, because if even a single node is identified, the integrity of an entire graph can be compromised.

So with most real graphs off limits, researchers needed to generate realistic models—and that turned out to be quite a difficult mathematical problem.

“It’s extremely hard to model these graphs, let alone have a generator to use that could help us design supercomputers,” Bader says.

In 2004, Faloutsos and his colleagues published a paper in the proceedings from a data mining conference in which they described a recursive matrix—or R-MAT—model for graph generation based on fractal geometry. The R-MAT generator, Faloutsos says, is the first to simulate large-scale graphs with an unlimited number of nodes in a way that’s consistent with most properties of real graphs.

“There’s no limit to the size of the graph the generator can handle. You just have to specify how many nodes you want—a billion, a trillion, whatever is next after that—and the generator creates a graph that is highly realistic,” says Faloutsos, a data mining expert who has been at the university since

1997 and recently completed a year-long sabbatical at Google. In 2010, he was named an Association for Computing Machinery fellow in recognition of this and other fundamental contributions to computer science.

The Graph 500 steering committee also took notice, realizing the important gap Faloutsos’ technology could fill in their effort. Specifically, the benchmark they developed ranks a supercomputer on the size of the R-MAT graph it can generate and how fast it can search that graph as measured in gigateps, or billions of traversed “edges” per second. Edges are connections on a graph between two data points—for example, the items that an Amazon.com customer has bought that might predict her next purchase.

“Christos’ work has really let us turn a corner and allowed us to create something realistic with similar characteristics to actual data sets,” Bader says. “It has been instrumental in making the Graph 500 benchmark a success.”

The first-ever Graph 500 list was unveiled this past fall at the Supercomputing 2010 meeting in New Orleans, and there aren’t yet 500 computers on the list. In fact, only nine supercomputers clocked in at gigatep speed, with the U.S. Department of Energy’s IBM BlueGene-based Intrepid system coming out on top—using 8,192 of its 40,960 nodes to leap from one node to another on an artificially generated graph 6.6 billion times a second.

The newest Graph 500 was announced in June at the International Supercomputing Conference in Hamburg, Germany. Murphy and his colleagues aim to improve the benchmark and expand the size of the rankings list. While “500” is an ambitious figure, they say it’s probably not out of the question in coming years as more and more supercomputers are created to tackle data-intensive applications in everything from cybersecurity to medical informatics.

“Many of us on the Graph 500 steering committee believe that these applications will grow to be bigger than ‘traditional HPC’ over the next decade or so,” Murphy says.

Faloutsos is delighted to see his research play a role to help bring about this coming revolution. “People building supercomputers are very happy with our graph generator,” he says. “And that makes us very happy and proud.”

Jennifer Bails (www.jenniferbails.com) is a Pittsburgh-based freelance writer. Her work has appeared in *Carnegie Mellon Today*, the *Philadelphia Inquirer* and other publications.

Alexei Efros

Alexei (Alyosha) Efros is an associate professor of robotics and computer science at CMU and last year received a Finmeccanica Career Development Chair. A native of St. Petersburg, Russia, Efros came to the United States in 1989, earning his bachelor’s degree from the University of Utah and his master’s and Ph.D. from the University of California at Berkeley.

A member of the CMU faculty since 2004, he is a recipient of the CVPR Best Paper Award, a National Science Foundation CAREER award, Sloan and Guggenheim fellowships, and a SIGGRAPH Significant New Researcher Award.

Efros recently spoke to Link Editor Jason Togyer about his early computing experience, his career path and his current research in computer vision.

Your father is a physicist. Growing up, did you feel pressure to go into a scientific career?

My father did put pressure on me in one way. He said, “Don’t become a physicist!” (Laughs.) Science was certainly the preferred path. When I was growing up in the Soviet Union it was already the time of perestroika, but there was still a feeling that it was better to go into a technical field, because there was freedom for people to be independent of the authorities, which was very difficult to do in the arts or humanities. I think that’s one of the reasons the Soviet Union produced so many great scientists—other paths were so constrained.

What was your first computer programming experience?

Through my father, when I was 13, I got one of the first Soviet personal computers, called the Elektronika BK-0010. It was kind of like a Commodore, but with 32K of RAM.

My biggest stroke of luck was that the computer needed a tape recorder to load or store programs, and I didn’t have a tape recorder. I say “luck” because that meant I didn’t have any games that I could play, and I didn’t have any software, so I had to write my own. Even more “lucky” was that the computer would overheat after three hours! I couldn’t just write a game and keep

playing it, because it would die after three hours. I learned to code very quickly, and I think that pushed me in the direction of computer science. If I had started by playing games, I don't know that I would have had the perseverance to become a programmer.

I eventually developed an interest in artificial intelligence—creating computers that would not just do a bunch of things really fast, but that could reason and understand.

Why did you specialize in computer vision instead?

As I got older, I realized artificial intelligence was a very difficult problem, and the idea that computers would some day reason or write poetry seemed like such a big leap that I might not achieve realistic results in my lifetime.

In computer vision, we're creating computers that understand and recognize objects and scenes. While that's still an extremely hard problem, it's also the kind of problem where you can see very immediate results. By running your algorithm on a new image, you can immediately see if it's working or not. This can be very frustrating, but also very satisfying when things actually work.

Is computer vision a problem more of detection or processing?

Computer vision is really two fields—measurement and understanding. Computer vision as measurement means using cameras to sense something objective about the world, such as light intensity or the distance to an object. That's a very precise, well-defined problem, where increasing the resolution of a camera, for instance, will immediately give you impact in terms of better results.

Computer vision as understanding is a much less well-defined problem—most of the digital cameras now on the market already have better resolution than the human eye, but that's not really helping us in terms of understanding.

Understanding in terms of what?

In terms of telling a computer to look at a picture and “find a car on this street,” or “find a cup on this table,” or “find a chair in this room.” Those



questions require you first to define, “What is a cup?” or a car or a chair. You know one when you see one, but to come up with a visual definition of a chair—which may come in many different shapes and sizes—is very hard to do.

In a way, it's a question of psychology and philosophy. You cannot separate the questions from the fact that humans are asking these questions. It's humans, not computers, who are interested in the physical world—cups and cars and chairs.

Is it a problem of putting things into categories?

In some sense. But the problem is that old ideas of categorization, taxonomies, and so forth, going back to Aristotle and Socrates, don't seem to model the real world terribly well. Wittgenstein, for instance, said that while we all understand the idea of “games” as a category, it appears to be impossible to come up with a list of properties that would apply to all games. In this case, the categories aren't formal definitions, but rather groups of examples within a particular context.

Then how can we come up with a model that computers can use to understand the visual world?

We may not be able to come up with a good intrinsic model, but with all of the data we can collect, we may be able to come up with a phenomenological model so that a computer

might be able to predict, for instance, “what's going to happen next” within a given context. Humans, of course, do this all the time—we are amazingly good future tellers in terms of, “Can I cross the street now, or will I be hit by a car?”

I believe the answer lies in using huge amounts of visual data to build connections between these examples and their visual context. One of my areas of focus is trying to use a large amount of visual data to allow computers to discover their own understanding of the visual world, without any human help.

So we're trying to move away from linguistic definitions and more into direct ways of describing things, in terms of their relationships with

their environment and with a particular task. After all, vision, unlike language, is common to almost all animals. A mouse doesn't need to know that something is called a “cat,” but it better be able to predict what that something is going to do next!

Are you inventing a new visual language?

It's not that grandiose, but yes, it's a kind of non-verbal vocabulary—trying to understand the world in terms of vision and action instead of verbally, connecting things visually in much the same way that we now connect things with words.

And who knows what that's going to be useful for? If it works, it would get us closer to a visual understanding of the physical world that could aid in the navigation of autonomous vehicles, or in finding photos of something on the Web by doing a visual query.

Have you circled back to your original interest—building computers that reason?

I don't expressly say that, but I've always had in the back of my mind this grand goal. You might say I'm a cognitive scientist who happens to be working in a School of Computer Science because I want to build a computational model of how the brain works. We'll see how well that goes!

Astrobotic's Race to the Moon



> By Meghan Holohan

CMU's Planetary Robotics Lab is a cavernous room that resembles the service bay at a busy car dealership, full of tools and equipment and activity. James Lee, a senior in electrical and com-

puter engineering, walks past something that looks like a pool table with ATV wheels to a small pyramid-like structure covered with a mosaic of black tiles. It's a robotic rover, and one of its panels is open, revealing its guts—wires and microprocessors.



ASTROBOTIC TECHNOLOGY PHOTO

“Others have plans. Others have dreams. We’ve got a launch agreement.

This is the juice and the opportunity.”

William “Red” Whittaker, Astrobotic CEO and CMU’s Fredkin Professor of Robotics

Lee and other students call it “Red Rover.” If all goes as planned, Red Rover in 2013 will be traveling 500 meters across the moon to the site of one of NASA’s Apollo landings.

Lee is one of several Carnegie Mellon University students who are helping Astrobotic Technology Inc. visit the moon. Headed by William “Red” Whittaker, CMU’s Fredkin Professor of Robotics, Astrobotic is one of 29 teams competing for the Google Lunar X Prize—an award of up to \$25 million in combined prizes and bonuses for the first privately funded team to land on the moon and travel 500 meters, sending data and video to Earth. The rover is built. By the time you read this story, the lander will be ready, too.

Growing up, Lee found himself fascinated by outer space. Even though humans hadn’t been on the moon during his lifetime, he couldn’t stop dreaming about space travel. It amazed him to think that humans launched something that traveled more than 240,000 miles to the moon’s gray surface. He fondly recalls visits to NASA’s Johnson Space Center in Houston, wondering if he’d ever have an opportunity to work on a space launch.

Few, if any, humans now alive will have the opportunity to travel to the moon. But Lee’s contribution to Red Rover could enable him to get to the moon by proxy. “If you go to the moon before you’re 30, what else is there to do?” he says.

‘Others have plans ... we’ve got a launch agreement’

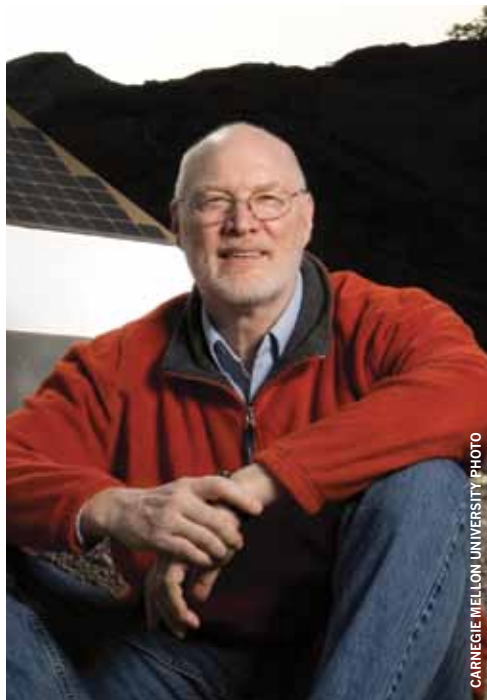
Red Whittaker serves as Astrobotic’s CEO and chief technology officer. One of the world’s leading experts in autonomous navigation, Whittaker has long believed that robots would be capable of traveling around the moon’s surface and readying it for a permanent station. “The biggest challenge isn’t driving around the moon’s surface,” he says. “The greatest challenge is getting there.”

Left: The road to the moon goes through West Mifflin, Pa., for Astrobotic’s “Red Rover,” which is getting a workout at a steel mill slag pile.

And unlike any of Astrobotic’s closest competitors for the Lunar X Prize, the team has a launch vehicle and a lander. “Others have plans,” Whittaker says. “Others have dreams. We’ve got a launch agreement ... This is the juice and the opportunity.”

In February, Astrobotic announced that it had booked a flight with SpaceX, the private space exploration company headed by PayPal co-founder Elon Musk, to have its rover and lander launched to the moon using one of SpaceX’s Falcon 9 rockets. “We are building the spacecraft, hardware and software to reach the moon,” Whittaker says.

The mission could blast off as early as December 2013. That’s the earliest that any team has planned a launch, and could lock up the prize for Astrobotic—if all goes well.



There’s no room for failure, says Red Whittaker, because Astrobotic’s business model “only works if (we) win.”

A tradition of technology prizes

The Google Lunar X Prize follows in a tradition of great technology prizes that spurred the transformation of entire industries. But some of these successes came at great risk. Perhaps the most famous contest—the Orteig Prize—originated in 1919, when hotelier Raymond Orteig offered \$25,000 for the first pilot to cross the Atlantic Ocean without stopping. Orteig hoped to encourage the commercialization of air travel.

For years, pilots attempted the flight—and many met their deaths. In 1926, a young, unknown airmail pilot arrived at New York City’s Roosevelt Field with a monoplane, claiming he’d be the first to cross the Atlantic, and that he’d do it alone. Many expert fliers scoffed at his aircraft, believing it wouldn’t be able to complete the trip. But on May 21, 1927, Charles Lindbergh arrived in France, a little more than 33 hours after leaving New York.

Orteig’s prize spurred the growth of commercial air travel and Lindbergh’s flight inspired generations of pilots. Since Lindbergh’s flight, several other prizes have sparked innovation, though most carried much less danger. In 1980, for instance, artificial intelligence pioneer Edward Fredkin—then a professor of computer science at CMU, and now a visiting research professor—offered a prize of \$100,000 to the developer of the first computer that could beat a chess grandmaster. That led to IBM’s Deep Blue, which defeated Garry Kasparov in 1997.

In 1996, entrepreneur Peter Diamandis created the X Foundation. His first prize—created with fellow entrepreneurs Anousheh and Amir Ansari—offered \$10 million to any non-governmental group or agency that by 2004 could successfully launch a reusable manned spacecraft into space twice within two weeks. The spacecraft had to reach an altitude of at least 100 kilometers and carry a pilot and a weight equal to two passengers. Burt Rutan won the \$10 million prize and began working with Richard Branson’s Virgin Galactic to make commercial space travel a reality. >>>

In 2007, Google joined the X Foundation to create the Google Lunar X Prize. Under the terms of the contest, to win the prize, the winning team must land on the moon, drive 500 meters, and send data back to Earth. The purse decreases if the teams don't arrive by 2015, or if a government agency arrives before a private group. Ninety percent of the teams' funding must be private.

The prize is the just the beginning

But the \$20 million grand prize, \$5 million second-place prize and some \$5 million in bonus prizes are really the beginning, not the destination. While the money covers some of the development costs of creating and launching the rover—and of course, everyone wants to be first—the Google X Prize is about more than money and fame. It's about creating a model for private space exploration.

"The prize provides the kick start," says Julian Ranger, founder of the British defense contractor STASYS and Astrobotic's angel investor. "I think if you were focused purely on winning the prize, you might win it, but where do you go from there?"

When Astrobotic joined the contest in 2008, Whittaker and the Tartan Racing team were fresh off a victory at the 2007 DARPA Grand

Challenge. Boss, their unmanned Chevy Tahoe, successfully navigated a simulated urban obstacle course—the Urban Challenge—with an average speed of 14 mph to beat five other teams for the \$2 million prize.

Winning the Urban Challenge emboldened Whittaker and his students, providing them with the confidence they could tackle another major contest and win. Providing the financing that could back up their knowledge became the job of David Gump.

Gump, a serial entrepreneur, in 1989 founded LunaCorp with the stated goal of putting a privately funded satellite into orbit around the moon. After Gump met Whittaker in 1995 at the Space Studies Institute in Princeton, N.J., the two began collaborating on a lunar rover. Lack of funding forced LunaCorp to be dissolved in 2003, but not before Gump got attention from high-profile clients, including RadioShack Corp., which signed on as an early sponsor of the company's rover. LunaCorp even arranged for a RadioShack TV commercial to be filmed aboard the International Space Station.

Gump says the same technology that drove Boss to victory in the DARPA Grand Challenge—the ability to spot obstacles and rapidly recalculate

its path—will guide Astrobotic's lander to a safe arrival on the lunar surface.

And from the beginning, Whittaker and Gump have never left any room for doubt—they have to win, they say, because there's no room for failure.

"There is only one winner. It only works out if you win," Whittaker says.

That confidence, combined with Whittaker's proven ability to build successful autonomous robots, has contributed heavily to Astrobotic's ability to raise funds—one of the most important resources needed to win the Google Lunar X Prize.

Slightly crazy—but 'second to none'

"When I first got involved in 2008, I looked at (Astrobotic) and thought it was slightly crazy as an investment, but the people involved are frankly incredible all the way down the line," says Ranger, who built STASYS from a handful of employees into a 17 million U.K. pounds sterling business before its acquisition in 2005 by Lockheed Martin.

"Red Whittaker's expertise in automated robots is second to none," Ranger says. "It's a remarkably good technical team and it's also the only team that has a plan for multiple visits to the moon."

Technology analyst and security consultant Michael Doornbos has been following all 29 Google Lunar X Prize teams, ranking them on various metrics such as funding, innovation, connections, progress, rover quality and "inspiration." In most categories, Astrobotic leads the field, according to the Google Lunar X Prize scorecard posted on Doornbos' website, Evadot.com. He estimates the team is about four months ahead of its closest competitors.

Yet Doornbos is hesitant to declare any team a "winner" until the rover is strapped on a launch vehicle, heading to the moon. And while he considers Astrobotic's leadership and funding to be two important reasons why the team is leading so many categories, he believes any of the top eight teams have a chance of claiming first prize.

"The difference between first place and eighth place is just a few points," Doornbos says. "The top eight teams have a clear shot at launching something."

To arrive at his rankings, Doornbos interviewed the teams, evaluating their plans, some of which they must make public as part of the contest rules.

"I think (success) has a lot to do with the leadership," he says. Astrobotic's leaders "believe in the importance of the prize and the mission."

"Red Whittaker's expertise in automated robots is second to none. It's a remarkably good technical team and it's also the only team that has a plan for multiple visits to the moon."

Julian Ranger

Astrobotic's biggest asset might be the power of Carnegie Mellon students—shown here testing the rover in Pittsburgh's Hazelwood neighborhood—who have been involved with every aspect of the design and testing.



ASTROBOTIC TECHNOLOGY PHOTO

David Gump (right and inset, below) is a serial entrepreneur who's been involved in several privately funded space exploration ventures, and in 2001 arranged for a TV commercial to be filmed aboard the International Space Station. He's currently raising money to fuel Astrobotic's race to the moon.



ASTROBOTIC TECHNOLOGY PHOTO

If any of the top eight teams received a huge influx of cash, it could help catapult that team past Astrobotic, Doornbos says. And that's something that Astrobotic doesn't take lightly. "We understand that it is a race, and any one of those teams that come into enough money to solve their weaknesses could start sprinting," Gump says.

But Astrobotic has designed a business plan that Gump and Whittaker say will help secure steady funding and create a sustainable business model. The spacecraft can carry an additional payload besides the rover, so Astrobotic is offering other companies the chance to ride to the moon. Numerous researchers are trying to deliver scientific experiments to the moon, but without any means of getting there, their research has languished.

Astrobotic is also selling sponsorships and naming rights, and may offer exclusive video and other content to raise revenue, Gump says. "You have to have the cash to do the exploration," he says, before quoting *The Right Stuff*: "No bucks, no Buck Rogers."

Biggest asset might be CMU's students

While money is one of the challenges to winning the Google Lunar X Prize, the other difficulty is finding experts with the technical know-how to build a lander and a rover. And here's where Astrobotic may have its greatest asset—its partnership with the Robotics Institute and its Field Robotics Center, headed by Whittaker.

In fact, Ranger argues that Astrobotic's biggest advantage over the other teams is the power of Carnegie Mellon and its students. "There is a certain sort of innovation freshness that you get with youngsters," he says. "Those students are picking up an enormous amount working on this project, and it will help them in their careers."

In fact, students are playing hands-on roles in every aspect of the design and testing of the rover and the lander. Kevin Peterson, a Ph.D. student in the Robotics Institute who was also part of the Boss team, is working on the systems that will control the lander's descent to the moon's surface. He says the engineering is at a "much higher level" than Boss. "Thousands of things can go wrong and end the mission," Peterson says. For one thing, he says, testing for a land vehicle is easier. "Earth's gravity is six times as strong as the moon's," he says. "If we want to test the rover you have to offset gravity and you use a pulley (to do so). It's very difficult."

As a young boy, Peterson regularly visited CMU where his father, Jeffrey, is a professor in the Physics Department and a member of its Astrophysics and Cosmology research group. While Kevin Peterson (E'02,'04, CS'09) did occasionally help his dad tinker with telescopes, he didn't dream of space exploration. Rather, he found himself enamored with solving tough engineering problems. When he worked on the Urban Challenge, he found that fixing complexities invigorated him—like understanding why Boss didn't recognize pedestrians and drove right toward them. As he considered Ph.D. dissertation topics, he realized

the Google Lunar X Prize team presented a unique combination of technological challenges.

For example, NASA's Apollo missions only had to land in a very general spot on the moon, but a grant awarded to Astrobotic by NASA requires its lander to touch down within a specified 100-meter area. The Apollo missions used radar to calculate the distance from orbit to the moon's surface, but Peterson says Astrobotic will "take advantage of computer vision technology and lasers and use the new technology to land very, very softly."

Designing the lander for a soft landing also means it won't need a large, heavy engineered structure to absorb a severe impact, which leaves more room in the spacecraft for scientific payloads, according to Heather Jones, doctoral student in the Robotics Institute. "We've gone through a lot of iterations of the lander (before) we got to the point of doing detailed analysis and designing of the parts," she says.

Made primarily of aluminum donated by Pittsburgh-based Alcoa, Astrobotic's lander is a squarish platform with four tanks for fuel on it. The rover rests in the middle, and after the lander descends to the moon, a ramp will lower, allowing the rover to roll gently to the moon's surface and begin its trek. The legs on the lander must be able to withstand impact velocity. And if something fails during the landing, the team wants the rover to still be able to get off the landing vehicle.

Once on the surface, the rover will traverse the surface of the moon during lunar noon, when temperatures go well above 100 degrees >>>



Astrobotic's publicity campaign—designed to excite school-age children and their parents as well as potential investors—has included a series of open houses at CMU's Planetary Robotics Lab. Here, a group of preschoolers from CMU's Cyert Center for Early Education gets hands-on lessons in space exploration and robotics.



ASTROBOTIC TECHNOLOGY PHOTOS

Celsius—hot enough to boil water on Earth. Figuring out how to draw heat away from the electrical components has been one of Jones' tasks.

In a personal computer, a fan can be used to draw air away from heated components. With no atmosphere, a cooling fan won't work on the moon. When Jones joined the team after taking a course with Whittaker as a graduate student, she started building thermal models of the rover and lander, to analyze how excess heat can be channeled away from the onboard electronics. The rover is asymmetric, with solar panels on one side to provide power, and a large radiator on the other side to dump heat.

While the solar panels on the rover's angled face will provide power, they'll also direct heat away from the rover's electronics.

Before grad school, Jones worked on a NASA project for nearly three years, running simulations to see what would happen if something went wrong with the mechanical docking arm on the International Space Station. Ideally, Jones' calculations for the ISS would never be used as long as the docking arm worked correctly. But when it comes to her work on Red Rover, every calculation is necessary.

"It's a little scary, but pretty exciting," Jones says. "This is a very exciting project to work on and we're definitely moving forward."

Exciting, exhilarating, overwhelming

Building a successful autonomous vehicle means the designers must anticipate any possible problems. Consider the consistency of the moon dust. It's not soft and powdery; compared to Earth's dirt, it's sharp and rough, and jagged rocks cover the moon's surface. Motors must be protected within the rover's body, instead of the wheel hubs as on Mars rovers.

Steering the rover is another roadblock. It might seem easy to drive a rover using a joystick from the ground, but Lee, who leads the software development and vision systems for the rover, says there's a three-second delay in communication between Earth and the moon, meaning Earth-side controllers can't see barriers in the rover's path in real time. "In three seconds, the rover goes 15 centimeters," Lee says. "If you're 15 centimeters away from a crater, you'll crash."

Instead, controllers will give general directions to the rover, which will steer itself with the help of stereo cameras and 3D topographic maps of the

moon. Lee calls it "supervised autonomy." Controllers will click on a point on the 3D map and the rover will roll in that direction, calculating its distance from obstacles and steering itself around them. (As another way to generate public interest, Astrobotic plans on sponsoring a contest—the winner will be allowed to steer the rover on the moon.)

As Lee describes the rover's navigation systems, his excitement is palpable. Like the rest of the team members, he finds the idea of sending something into space both exhilarating and overwhelming. While Astrobotic's team members are living and breathing the mission, many people—even many people at CMU—are only vaguely aware of the project. But to everyone connected with Astrobotic, the Google Lunar X Prize is more than a mission—it's a real step toward making commercial space exploration an ongoing reality.

Ranger, who once thought his investment was crazy, now finds himself energized by its potential. Astrobotic has "the technical expertise and plan," he says, to create "a sustainable space future."

The year 2013, he predicts, "will be the start of a new space race."

Pittsburgh-based freelance writer Meghan Holohan is a regular contributor to mentalfloss.com and has written for [Geek Monthly](http://GeekMonthly.com), [ComputerWorld](http://ComputerWorld.com) and asylum.com.

Completed lander got shakedown in June



Red Whittaker with Astrobotic's completed lander. The half-ton aluminum structure was shipped in June to a California lab for "shake testing."

ASTROBOTIC TECHNOLOGY PHOTO

The landing craft that will deliver Red Rover to the moon got its initial shakedown—literally—in June.

Structural assembly of the lunar landing craft was completed June 13, and the half-ton aluminum structure was shipped to a lab in California for "shake testing." The procedure was designed to confirm the craft's soundness and its compatibility with the SpaceX Falcon 9 launch vehicle.

Astrobotic plans to land the spacecraft, carrying both the robot and a commercial payload, on the moon's Sea of Tranquility or on the Marius Hills next to a recently discovered "skylight" leading down into a volcanic cave. The solar-powered Red Rover will broadcast high-definition video to Earth as the four-wheeled robot explores the moon.

"This lunar lander will be a key part of our initial moon mission and we expect to re-use this design for a series of missions that will establish Astrobotic Technology as an ongoing, exploration enterprise," Red Whittaker says. "It's an amazing piece of technology and it's gratifying to know that so much of it was invented and crafted here in Western Pennsylvania."

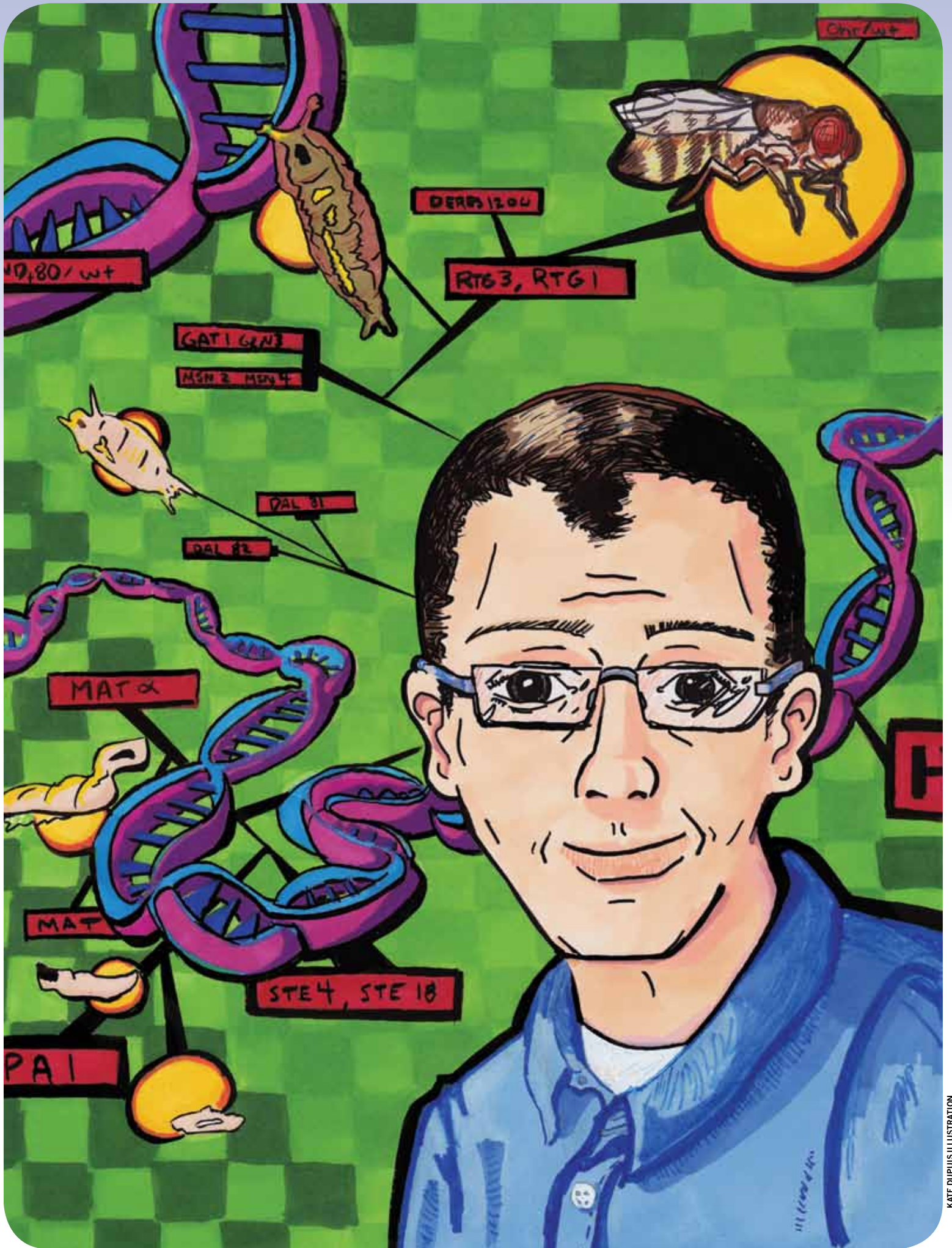
The team used engineering simulation software provided by ANSYS Inc. of Canonsburg, Pa., to calculate the design's strength and stiffness. Pittsburgh-based Alcoa provided technical expertise, the aluminum used to create the structure of the lunar lander, and the fasteners that hold the lander together. Its largest component is a 10-foot-diameter, 1-inch-thick deck made from two slabs of solid aluminum joined by Concurrent Technologies Corp. in Johnstown, Pa., and machined by Edgar Industries in New Kensington, Pa.

Assembly took place in the Planetary Robotics Lab in Carnegie Mellon's Gates and Hillman Centers.

When the craft is completed, the deck will support four spherical fuel tanks capable of carrying almost two tons of propellant. A single main engine controlling the lander's descent will sit below the deck and eight thrusters on the deck's periphery will provide stability. A cone-shaped structure atop the deck will connect to the 173-pound Red Rover. The lander also can carry up to 242 pounds of commercial payload and will have rechargeable batteries and solar panels capable of providing 500 watts of power during daylight.

In addition to Carnegie Mellon, industrial partners such as International Rectifier Corporation and corporate sponsors such as Caterpillar Inc. support the mission.

—Byron Spice



KATE DUPUIS ILLUSTRATION

Running Man

> By Kenneth Chiacchia

When Ziv Bar-Joseph talks about his research, he's precise, but rapid-fire. It's as if language can't keep up with him; as if the ideas have to come out more quickly than verbal communication can allow.

That's not surprising, perhaps, given the nature of his work at Carnegie Mellon University: bridging the biological and computational worlds in a way that allows us to finally understand a tremendous volume of built-up data.

Thanks to technologies that allow genetic information to be rapidly decoded, vanishingly small traces of DNA to be expanded to any quantity needed, and thousands of proteins to be identified and analyzed in parallel, biologists have recently been able to amass a vast amount of information about how living creatures develop, live, grow sick and even die.

Yet the complexity of interactions between biomolecules—coupled with the very volume of the data—has threatened to overwhelm the painstaking, point-by-point methods of wet-lab analysis and interpretation.

Enter Bar-Joseph, who came to CMU in 2003 and is now an associate professor with joint appointments in machine learning and computational biology. Bar-Joseph carried out his Ph.D. studies at the Massachusetts Institute of Technology after earning a master's degree in computer science at Hebrew University in Jerusalem in 1999. He brought to the United States a fascination with the biological world, and the conviction that computer science could make it possible to understand the mountain of data then beginning to emerge from biological laboratories.

"The end of my master's and beginning of my Ph.D. ... really coincided with the rapid advances that were taking place in biological sequencing capacity," he says. "I [watched] some lectures, and it just seemed like there were a lot of things going

on. I thought it would require a lot of computational ideas ... to understand it."

The problem—and the opportunity—both stemmed in part from the successful first sequencing of the human genome. The Human Genome Project cost billions of dollars in an international collaboration to produce the first sequence of human DNA. Along the way, the effort spurred more efficient methods of sequencing. But if gene sequencing was like writing, then it was producing many, many books in a strange language that biologists could only read on a word-by-word basis. They couldn't understand the syntax, the stories or any higher themes.

"[The genome project] actually did pay off in terms of research, but it's clear now that it's not enough to have the sequence," Bar-Joseph says. "Heart and lung cells all have the same sequence information, but they do different things because they're using different parts of that sequence."

Understanding which part of the genetic information in a cell is being used at any given time is only one part of the puzzle. Equally important is understanding how the proteins that are expressed are used by cells, and how those uses change as the proteins interact with one another.

One example of his work at MIT, in the laboratory of David Gifford, was a 2003 article in the journal *Nature Biotechnology*. Bar-Joseph and his collaborators used a novel computer algorithm to identify groups of genes that work together to perform biologically relevant tasks, such as respiration, protein synthesis and response to external stress.

In many ways, the work set the tone for his later career, in that it explained a biological system using a new computer tool that iteratively analyzed large amounts of data—but, importantly, also pulled in data sources not utilized by previous researchers.

In the 2003 paper, those new data consisted of measurements of the ability of proteins synthesized by given genes to bind to the DNA sequences of possible target genes. It's a mainstay of genetic interaction: regulatory genes direct the production of proteins that in turn modify the activity of other genes, which can include both functional and other regulatory genes.

"[The genome project] actually did pay off in terms of research, but it's clear now that it's not enough to have the sequence. Heart and lung cells all have the same sequence information, but they do different things because they're using different parts of that sequence."

Ziv Bar-Joseph

Previous work had consisted largely of measuring statistical correlation between the expression of genes, assuming that those expressed contemporaneously are likely to be interacting. By adding the binding data, Bar-Joseph and his colleagues were able to discriminate between genes involved in the same genetic module, and those involved in different modules that just happen to be activated at the same time. >>>



Ziv Bar-Joseph (above) is a “prototypical example” of someone who can develop new tools to solve problems, says Tom Mitchell, head of CMU’s Machine Learning Department.

Bar-Joseph is a “prototypical example” of someone who has the skill set of developing new tools while examining novel problems, says Tom Mitchell, the CMU’s Fredkin Professor of Computer Science and Machine Learning and head of the Machine Learning Department.

One example Mitchell gives concerns Bar-Joseph’s work on understanding the cycle of cell division—the process that transforms a resting cell into two daughter cells containing identical copies of the genetic information.

In order to divide successfully, a cell must duplicate its DNA, segregate the two copies perfectly, and then divvy up the other cell components so that, when the two daughter cells split, they each have a fully functional genetic and cellular complement. The process takes precise coordination, synchronization and communication between thousands of genes.

The problem, says Mitchell, is that the cells in a given experiment “are not dividing at exactly the same time. They’re dividing on their own asynchronous schedules. Now, the question is, how can you deal with the different timing of those different cells?”

Bar-Joseph solved the problem by building a new algorithm, which he designed to accommodate the asynchrony-generated noise in the data.

What makes Bar-Joseph really special, Mitchell says, is something else, though—it’s his ability to bridge two vital specialties via a deep focus on both.

“We wrote a paper together that had to do, again, with time series of gene expression data,” Mitchell says. “What was fun was just working with Ziv” to frame the problem as a machine learning problem, he says: “It became very clear to me in that process just what an advantage Ziv had over me and most people ... he really understood the biology and really understood the machine learning.”

“Many people have diverse interests, and they dabble in things,” Mitchell adds. “Ziv does more than dabble—he goes to work in a wet lab,” referring to a yearlong sabbatical Bar-Joseph took in a laboratory studying the development of the fly nervous system. “He doesn’t just jog, he runs marathons.”

That last bit is not a metaphor: Bar-Joseph is a running enthusiast, and by any measure but his own, is a formidable competitor.

“In Boston, I ran with a group,” Bar-Joseph says. “Here, I run on my own.” Initially, when he moved to Pittsburgh in 2003 to take up his duties at CMU, he did run with a group: “But they were much too strong for me.”

One tends to take that statement with a bit of a grain of salt, upon hearing of a recent milestone he achieved: a three-hour marathon, something relatively few amateurs achieve. (Of more than 4,000 competitors in the 2010 Pittsburgh Marathon, for instance, only 59 clocked in at less than three hours.)

“Since I came here, I’ve improved dramatically,” he admits.

Bar-Joseph the runner has fallen in love with Pittsburgh’s rolling hills and river valleys, which give him varying challenges.

“I run a lot in Schenley Park,” he says. “Once a week I run between 15 and 20 miles. The nice thing about Pittsburgh is you can find 15 or 20 miles that are flat next to the rivers—or, if you want hills, you have that.”

The driven nature of a marathon runner came through in Bar-Joseph's recent project with colleagues including Yehuda Afek at Tel-Aviv University and Naama Barkai, a molecular geneticist at the Weizmann Institute of Science in Israel. The work resulted in a high-profile paper for the journal *Science* in January 2011, on how the fly's nervous system self-organizes as it develops; it was the project for which he took his wet-lab sabbatical.

The work was a little atypical for Bar-Joseph, as it took a biological observation and used it to derive lessons for organizing distributed networks, rather than using computer technology to derive lessons for understanding a biological system.

The insight that the investigators gleaned came from the simplicity of the fly system. In order for a network to form, some nodes in the network must become leaders; but leaders must be spaced apart from each other in the network for efficiency. In traditional, computer-science derived self-organization, in order to decide whether to become a leader a node must know how many direct neighbors it has and receive information from these neighbors that scales with the network's size. What the collaborators discovered was that the fly's neurons could decide whether to become leaders even without knowing the size of their neighborhood, and using only one-bit messages from their immediate neighbors. The lesson from this carbon-based network immediately suggested better ways of forming silicon networks.

"The one thing for which the credit goes entirely to Ziv Bar-Joseph is that he realized [the fly system] was behaving as a distributed algorithm," Afek says. But as with the cell-cycle work with Mitchell, his greatest value to the work possibly lay in his ability to form connections.

"He's very energetic; he was really the leader," Afek says. "His mind keeps working all the time. He would send an email in the middle of the night with a new idea: 'Let's try to analyze this idea, how about trying this kind of algorithm.'"

With such an intense focus on work, it may come as a surprise how much time Bar-Joseph spends with his family. A man of deep faith who's involved in Pittsburgh's Orthodox Jewish community, he spends Saturdays with his wife, daughter and two sons in strict religious observance, not performing any work in honor of the Sabbath—including using the car. On other days, they'll take an extended break to places near Pittsburgh, farther afield, or to Israel to visit family.

As his children grow up—his oldest, a boy, is 11—they're also developing individual interests that he's had fun helping to shape and join. Hiking and camping, in places like Ohiopyle State Park, ap-

"It became very clear to me in that process just what an advantage Ziv had over me and most people ... he really understood the biology and really understood the machine learning."

Tom Mitchell, Machine Learning Department chair

peal to him and his kids—though "my wife doesn't really like it," he says, a little sheepishly. He plays basketball with his 11-year-old; his eight-year-old daughter has gotten interested in running.

"My hope is to run a half-marathon with her some day," he says, smiling. "By that time, she'll beat me."

Today, Bar-Joseph's research group carries out three main avenues of research. One explores computational methods to understand the dynamics of systems that change over time—for example, the cell cycle, or epidemics. Another is the study of cross-species analysis; though the biological literature brims with experiments performed on hundreds of species of biomedical and wider biological interest, they take place in organisms and cells in different life stages, health conditions and environments. The complex comparisons lend themselves to Bar-Joseph's machine-learning approach. The third direction for the lab uses biology to understand and build better computer systems and networks, like the fly nervous system development work with Afek.

While Bar-Joseph's work spans varied topics and disciplines, it's not exactly surprising, according to his other boss—Robert Murphy, the Ray and Stephanie Lane Professor and director of the Lane Center for Computational Biology. It's more or less a job description.

"That's what we exist for," Murphy says about the Lane Center. "The key is combining expertises to solve problems." He particularly cites "Ziv's work within system biology ... trying to integrate information on a genomic scale, to be able to build models of cell behavior or of biological behavior ... It's precisely the scale of the problem that makes it the most interesting computationally."

Murphy has published two papers with Bar-Joseph and together they supervised a Ph.D. student. "Ziv's a great practitioner of computational biology and a tremendous contributor to our department," he says. "We're very pleased and lucky to have him here at Carnegie Mellon."

"He's a no-nonsense guy," Mitchell agrees. "Once he decides to solve a problem, he's going to solve the problem. Every time we met [to discuss the cell-cycle work], he was on top of the question ... Over the next decade, the leaders in the field are going to be people like Ziv."

For his part, Ziv Bar-Joseph loves both his job and his adopted home. "In Israel, they're much more focused on the theory. Here, application is at least as important. Since I work a lot on applications, I like it."

Coming to Pittsburgh "proved to be the right decision," he adds. "The students that I was fortunate to have since coming here were great. If I've had any success in my career, I owe it to my students and the post-docs ... The fact that [at CMU] you can attract the best students from around the world is really key."

Freelance author Ken Chiacchia won a Golden Quill Award this year from the Press Club of Western Pennsylvania for his reporting on WYEP-FM's "The Allegheny Front." He lives in Harmony, Pa.

An avid runner, Bar-Joseph ran his first sub-three hour marathon in Columbus, Ohio, on Oct. 17.



MARATHON PHOTO/ EVENT PHOTOGRAPHY GROUP, USED WITH PERMISSION

CrowdForge: Crowdsourcing Complex Work

> By Aniket Kittur, Boris Smus and Robert Kraut

Introduction

Crowdsourcing has become a powerful mechanism for accomplishing work online. Hundreds of thousands of volunteers have completed tasks including classifying craters on planetary surfaces (clickworkers.arc.nasa.gov), deciphering scanned text (recaptcha.net), and discovering new galaxies (galaxyzoo.org). Crowdsourcing has succeeded as a commercial strategy for accomplishing work as well, with companies accomplishing work ranging from crowdsourcing t-shirt designs (Threadless) to research and development (Innocentive).

One of the most interesting developments is the creation of general-purpose markets for crowdsourcing diverse tasks [1]. For example, in Amazon's Mechanical Turk (MTurk), tasks range from labeling images with keywords to judging the relevance of search results to transcribing podcasts. Such "micro-task" markets typically involve short tasks (ranging from a few seconds to a few minutes) which users self-select and complete for monetary gain (typically from 1–10 cents per task). These markets represent the potential for accomplishing work in a fraction of the time and money required by more traditional methods.

However, the types of tasks accomplished through MTurk have mostly been limited to those that are low complexity, independent and require little time or cognitive effort to complete. In contrast to the typical tasks posted on Mechanical Turk, much of the work required in many real-world work organizations and even many temporary employment assignments is often more complex and interdependent, and requires significant time and cognitive effort. These tasks require substantially more coordination among co-workers than do the simple tasks typically seen on micro-task markets.

The impact of micro-task markets would be substantially greater if they could also be applied to these more complex and interdependent tasks. Here we describe a framework for extending micro-task markets to support complex, interdependent tasks.

Consider for example the task of writing an article about a locale for a public relations campaign, a newspaper, a travel guide or an encyclopedia. This is a complex and highly interrelated task that involves many subtasks, such as deciding on

Micro-task markets such as Amazon's Mechanical Turk represent a new paradigm for accomplishing work, in which employers can tap into a large population of workers around the globe to accomplish tasks in a fraction of the time and money of more traditional methods. However, such markets typically support only simple, independent tasks, such as labeling an image or judging the relevance of a search result. Here we present a general-purpose framework for micro-task markets that provides scaffolding for more complex human computation tasks that require coordination among many individuals, such as writing an article.

the scope and structure of the article, finding and collecting relevant information, writing the narrative, taking pictures, laying out the document and editing the final copy. Furthermore, if more than one person is involved in the task, each person needs to coordinate in order to avoid redundant work and to make the final product coherent. Many kinds of tasks—ranging from researching where to go on vacation to planning a new consumer product to writing software—share the properties of being complex and highly interdependent, requiring substantial effort from individual contributors.

Approach

Our goal is to support the coordination dependencies involved in complex work through micro-task markets. As previously mentioned, most tasks on these markets are simple and self-contained with no challenging coordination dependencies.

The audio transcription tasks posted by Castingwords.com are a rare exception to the typical MTurk task. Castingwords breaks up an audio stream into overlapping segments, and workers are employed to generate transcriptions from each audio segment. These transcriptions are then verified by other workers, whose work is later automatically put together into a complete transcription. Unlike the standard micro-market task, the disaggregation of an audio file into smaller transcription tasks and the use of a sec-

ond wave of workers to verify the work done by the transcriptionists involves the producer/consumer dependency and others of the dependencies identified in the previous section.

It also provides a simple model for many of the elements of our approach. For example, the transcription task can be broken up into the following elements:

- A pre-specified partition that breaks up the audio into smaller subtasks;
- A flow that controls the sequencing of the tasks and transfer of information between them;
- A quality control phase that involves verification of one task by another worker; and
- Automatic aggregation of the results

The TurKit toolkit for MTurk [2] extends some of these elements by enabling task designers to specify iterative flows. Little and colleagues use as an example a text identification in which the results of multiple workers' outputs are voted on and the best sent to new workers, whose work is then voted on, and so forth. Our goal is to generalize these elements into a framework that supports the crowdsourcing of highly complex work. Specifically, our framework aims to support:

- Multi-level partitions in which a task can be broken up by more than one partition;
- Dynamic partitioning so that workers themselves can decide how to partition a task, with

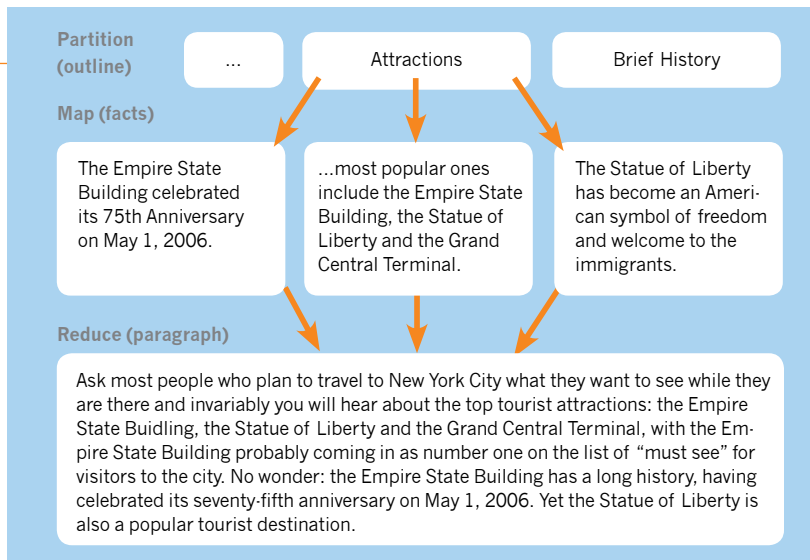


Figure 1: Partial results of a collaborative writing task.

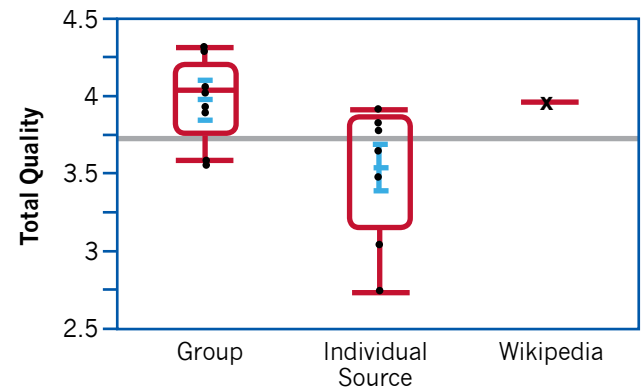


Figure 2: Rated quality of articles produced by workers acting individually or as a group compared to the rated quality of the same article on the Simple English Wikipedia

their results generating new subtasks during the flow (rather than the task designer needing to fully specify partitioning beforehand);

- Complex flows involving many tasks and many workers; and
- A simple method for specifying and managing tasks and flows between tasks

Our approach builds on the general approach to simplified distributed computing exemplified by systems such as MapReduce [3] of breaking down a complex problem into a sequence of simpler subtasks using a small set of subtask types (e.g., “maps” and “reduces”). We define three types of subtasks:

1. Partition tasks, in which a larger task is broken down into discrete subtasks
2. Map tasks, in which one or more workers process a specified task
3. Reduce tasks, in which the results of multiple workers’ tasks are merged into a single output

CrowdForge abstracts away many of the programming details of creating and managing subtasks by treating partition-map-reduce steps as the basic building blocks for distributed process flows, enabling complex tasks to be broken up systematically and dynamically into sequential and parallelizable subtasks.

In partition tasks, workers are asked to create a high level partitioning of the problem, such as creating an outline of an article with section headings

or a list of criteria for buying a new car. In our system the partitioning is made an explicit part of the task itself, with subtasks dynamically created based on the results of the partition step. Importantly, this means that the task designer does not have to know beforehand all of the subtasks that will be generated: defining the division of labor and subtask design is shifted to the market itself.

In map tasks, a specified processing step is applied to each item in the partition. These tasks are ideally simple enough to be answerable by a single worker in a short amount of time. For example, a map task for article writing could ask a worker to collect one fact on a given topic in the article’s outline. Multiple instances of map tasks could be created, or instantiated, for each partition; e.g., multiple workers could be asked to collect one fact each on a topic in parallel.

Finally, reduce tasks take all the results from a given map task and consolidate them, typically into a single result. In the article writing example, a reduce step might take facts collected for a given topic by many workers and have a worker turn them into a paragraph.

Any of these steps can be iterative. For example, the topic for an article section defined in a first partition can itself be partitioned into subsections. Similarly, the paragraphs returned from one reduction step can in turn be reordered through a second reduction step.

Case studies

We explored as a case study the complex task of writing an encyclopedia article. Writing an article is a challenging and interdependent task that involves many different subtasks: planning the scope of the article, how it should be structured, finding and filtering information to include, writing up that information, finding and fixing grammar and spelling, and making the article coherent. These characteristics make article writing a challenging but representative test case for our approach.

To solve this problem we created a simple flow consisting of partition, map and reduce steps. The partition step asked workers to create an article outline, represented as an array of section headings such as “History” and “Geography.”

In an environment where workers would complete high effort tasks, the next step might be to have someone write a paragraph for each section. However, the difficulty and time involved in finding the information and writing a complete paragraph for a heading is a mismatch to the low work capacity of micro-task markets. Thus we broke the task up even further, separating the information collection and writing subtasks. Specifically, each section heading from the partition was used to generate map tasks in which multiple workers were asked to submit a single fact about the section (workers were also asked to submit a URL reference to the source of the fact to encourage high quality fact collection). >>>

Next, the reduction step asked other workers to create a paragraph for each section based on the facts collected in the map step. By separating the collection of information and writing into two stages we could significantly decrease the cost of each stage, making the task more suitable for micro-task workers. In addition, we benefit from other effects such as being able to collect more and more diverse information when more workers were involved. Finally, since the sections of encyclopedic articles are relatively independent, the resulting paragraphs were themselves reduced into an article by simply concatenating them.

We used this approach to create five articles about New York City. Articles cost an average of \$3.26 to produce, and required an average of 36 subtasks or HITs, each performed by an individual worker. Partition-workers identified 5.3 topics per article in the partition step. The average article ended with 658 words. A fragment of a typical article is shown in Figure 1; this article consisted of 955 words and seven sections: brief history, getting there, basic layout, neighborhoods, getting around, attractions and ethnic diversity. It was completed via 36 different HITs for a total cost of \$3.15.

To verify the quality of these collaboratively written articles, we compared them to articles written individually by workers and to the entry from the Simple English Wikipedia on New York City. To produce a comparison group of individually written articles, we created eight HITs, which each requested one worker to write the full article. To control for motivations associated with reward, we paid these individuals \$3.05, approximately the same amount as the average group payment. The resulting articles consisted of an average of 393 words, approximately 60 percent of the length of the collaborative written articles.

We then evaluated the quality of all articles by asking a new set of workers to each rate a single article based on four dimensions: use of facts, spelling and grammar, article structure and personal preference. Fifteen workers rated each article on five-point scales. We averaged the ratings of the 15 raters across the four dimensions to get an overall quality score for each article.

On average, the articles produced by the group were of higher quality than those produced individually (see Figure 3: mean quality for group-written articles = 4.01 versus 3.75 for individually-written ones, $t(11)=2.17, p=.05$). The average quality for the group-written articles was roughly the same as the Simple English

Wikipedia article (Wikipedia quality=3.95). Not only was the average quality of the group articles higher than the individually written ones, but the variability was lower as well ($t(11)=-2.43, p=.03$), with a lower proportion of poor articles.

Overall, we found that using the CrowdForge approach to crowdsource the complex and interdependent task of article writing worked surprisingly well. Despite the coordination requirements involved in managing and integrating the work of dozens of workers, each contributing only a small amount of work, the group-produced articles were rated higher and had lower variability than individual-produced articles—even though individuals were paid the same amount as the whole group and did not have to deal with coordination challenges—and similar in quality to corresponding Simple Wikipedia articles.

We are currently exploring the application of CrowdForge to other kinds of writing, including crowdsourcing scientific journalism and poetry translation, as well as other kinds of tasks—such as writing software code—that involve high coordination costs.

Understanding the opportunities and limitations of crowd work will be an important research area for the future, and here we present one step along the road towards that goal.

Bob Kraut is Herbert A. Simon Professor of Human-Computer Interaction at Carnegie Mellon University. Niki Kittur is an assistant professor in CMU's Human-Computer Interaction Institute. Boris Smus earned his master's degree in Human-Computer Interaction at CMU in 2011, and works at Google as developer programs engineer for the Chrome browser.

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President:

There's no plan for a robot uprising at Carnegie Mellon University. Not yet, anyway.

That pronouncement comes directly from the United States Commander-in-Chief—President Obama, who visited the Robotics Institute's National Robotics Engineering Center in Pittsburgh's Lawrenceville neighborhood on June 24.

Obama came to NREC to launch a major initiative designed to boost high-tech manufacturing in the United States, but joked that he was really in town to “keep an eye” on CMU's robots. “I'm pleased to report that the robots you manufacture here seem peaceful—at least for now,” Obama told CMU faculty, staff and students and local and federal officials.

Kidding aside, robotics forms a key component of the new manufacturing initiative announced by the president during his visit to NREC.

The new Advanced Manufacturing Partnership is a national effort bringing together industry, universities and government to invest in emerging technologies, create sustainable new businesses, and enhance U.S. competitiveness. “If we want a robust, growing economy, we need a robust, growing manufacturing sector,” Obama said. “That's why we told the auto industry two years ago that if they were willing to adapt, we'd stand by them. Today, they're profitable, they're creating jobs and they're repaying taxpayers ahead of schedule.”

Carnegie Mellon and five other research universities are partners in the Advanced Manufacturing Partnership along with such manufacturers as Johnson & Johnson, Honeywell and Pittsburgh-based Allegheny Technologies. Under a proposed National Robotics Initiative, the National Science Foundation, NASA, the National Institutes of Health and the U.S. Department of Agriculture will make \$70 million available to support research in next-generation robots.

'Cutting edge ideas' will spur new jobs



During a tour of CMU's National Robotics Engineering Center, President Obama unveiled a major initiative designed to boost American manufacturing. In the background is Sensabot, a remotely-operated mobile robot that can perform inspections in hazardous or toxic environments.

Inset: The president autographed Sensabot for NREC personnel.

The federal grant money is necessary, Obama said, to fund research that brings “new, cutting-edge ideas” to market, keeps American manufacturers competitive, and grows the middle-class, ensuring America’s future economic prosperity. “We have not run out of stuff to make,” he said. “We’ve just got to reinvigorate our manufacturing sector so that it leads the world the way it always has—from paper and steel and cars to new products that we haven’t even dreamed up yet. That’s how we’re going to strengthen existing industries—that’s how we’re going to spark new ones.”

June’s visit was Obama’s third to CMU, and his second since taking office. In 2008, then-Sen. Barack Obama visited the campus to host a summit on the role of educators, entrepreneurs and community leaders in boosting America’s global competitiveness. Two years later, the president made a national address from the campus’

Wiegand Gymnasium on his administration’s efforts to shore up the sagging economic recovery.

“Carnegie Mellon is a great example of what it means to move forward,” Obama said. “At its founding, no one would have imagined that a trade school for the sons and daughters of steelworkers would one day become . . . one of the region’s largest employers and a global research university. And yet, innovations led by your professors and your students have created more than 300 companies and 9,000 jobs over the past 15 years—companies like Carnegie Robotics.”

Prior to addressing an invited audience of about 150 people, the president saw demonstrations of several technologies, including the sewer and water pipe inspection robot developed by Robotics Institute spin-off RedZone Robotics. Obama also taped his weekly video and radio address during his visit to NREC.

Carnegie Mellon President Jared Cohon said the Obama administration’s proposal has the potential to spur development of the U.S. robotics industry and create good-paying jobs for Americans. “Robotics is at the heart of the race for 21st century global economic leadership, as current and emerging robotic innovations will become increasingly vital to keeping us healthy, safe and prosperous in the next decade and beyond,” Cohon said. “Now, more than ever, it’s important that industry, academia and government work together to ensure our economic security and global competitiveness.”

Video of Obama’s address is available on the Carnegie Mellon website. Visit the School of Computer Science homepage at www.cs.cmu.edu for links and details. —Jason Togyer



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 School of Computer Science
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Above and Beyond

I've often talked about how gifts of time are important, and how being a volunteer can make an impact.

In Mark Dorgan's article on the next page, you'll read about a group of volunteers—the Alumni Advisory Board—and how their gifts have impacted the School of Computer Science. As the board nears its 10th anniversary, I'd like to share just a few thoughts about what this dedicated alumni group has meant to me.

Our first meeting was in October 2001. I remember it well. There were only 12 members of what was then called the Young Alumni Advisory Council, and we gathered in the lower level (fondly remembered as “the basement”) of the Sheraton Palo Alto. Essentially, we were launching a “start-up” (familiar territory for many in the room). The board was created as part of a new effort to build a school-wide alumni relations program—a job I was hired for in March 2000.

By the spring meeting, a name change was in the works. The group's acronym—YAAC—was a source of lively discussions (there was a reference to “Mr. Yuk” at one point). We renamed the group the “Alumni Advisory Board,” and we laid out our goals and mission: we would work on initiatives to help us strengthen the valuable relationships among the school, its students and alumni.

Today, there are 26 members of the board. Although each member officially serves one three-year term, most stay on for several more years. In fact, six of the founding members remain on the board today, and nearly all the student representatives ask to stay on after graduation.

Through the years, this group has generously shared ideas, expertise, wisdom, successes and failures. Their work is always done with energy and enthusiasm, but even more importantly with a sense of humor.

They serve as SCS's greatest ambassadors, champions and cheerleaders to the world at large. They've dedicated countless hours to helping various outreach initiatives; many have been successful, and a few weren't quite so. Those are the growing pains of a start-up. Time after time, they come back and ask, “How can we help?” And believe me, they are not shy about voicing their opinions when given a chance.

To all my AAB members, thank you for your extraordinary dedication, continued support and insight provided through the years. It's a privilege to work with you. My job certainly would not be as rewarding without your generous gifts of time, energy and enthusiasm.

Tina M. Carr

Alumni Award Winner



Congratulations to Ram Raghunathan (CS'11), winner of the ninth-annual SCS Alumni Award for Undergraduate Excellence in Computer Science. Justin Weisz (CS'03,'07,'09), alumni award committee member, made the presentation to Ram (on right) during the SCS diploma ceremony in Pittsburgh on May 15.

Ram was honored for his thesis “Design and Implementation of a Power-Aware Load Balancer.” His advisor was Mor Harchol-Balter, associate professor of computer science.

Established in 2003, the alumni award recognizes technical excellence in research and development by a graduating senior participating in the thesis research program. An alumni committee reviews student theses and oral and poster presentations, judging each work on factors such as originality, technical excellence, potential societal impact, accessibility and general excitement among the alumni community participating in the process.

“Ram's work was selected not only because of his technical quality but also because of the impact that it has on the state of the art and practice,” says Grace Lewis (CS'01), who chaired the award committee. “In his work, Ram proposes a set of simple but effective algorithms for load balancing and for turning machines on and off in order to preserve energy. The results he shows are very promising and the applicability of his work for data centers and server farms looking to reduce power consumption and costs is very clear.”

Ram will be joining our vibrant alumni base in New York City to work as an infrastructure developer at Tower Financial Capital.

Members of the Alumni Advisory Board gathered for a group portrait during Spring Carnival festivities in April.

Back row: Andrew Widdowson (CS'05); Philip L. Lehman (CS'78,'84), SCS associate dean for strategic initiatives; Tina M. Carr (HNZ'02) SCS alumni relations director; Jonathan T. Betz (CS'99); Boris Sofman (E'05, CS'05,'07,'10); David M. Steier (CS'86,'89); Justin D. Wesiz (CS'03,'07,'09) and Michael T. Livanos (CS'04)

Front row: Grace A. Lewis (CS'01), Christopher M. Maeda (CS'92,'97), Monte Zweben (CS'85), Sriram J. Gollapalli (CS'02, CMU'03), M. Bernardine Dias (CS'00,'04) and Anita A. Taylor (CS'07)

Not pictured: Phil L. Bronner (CS'92), Eric A. Daimler (HS'94, CS'10), Andrew Dubois (CS'03), Jennifer Li Dubois (CS'04), Kayvon Fatahalian (CS'03), Jonathan S. Goldick (S'88, E'89), Sesh Iyer (CS'96), Ajay N. Jain (CS'91,'92), Amy J. Matzke (CS'07), Raul Medina-Mora (CS'79,'82), John A. Mount (CS'91,'95), David I. Murray (CS'06, A'06) and Wil E. Paredes (CS'01, CMU'01)



Giving Back: SCS Alumni Advisory Board

> By Mark Dorgan

They have diverse backgrounds. Some are working in high-tech startups, while others are at well-known established corporations, and a few are educators or researchers. Some attended the School of Computer Science as undergraduates, while others came here to earn their graduate degrees. But no matter how they became connected to SCS or where their career paths have taken them since, all of the members of the SCS Alumni Advisory Board share a passion for the School of Computer Science.

The board was established in 2001. Its 26 members provide feedback and guidance to the dean and the director of alumni relations, and serve as direct connections between the school and the SCS alumni network. The AAB keeps SCS alumni informed and involved, building awareness of the school's research and academic initiatives, and helping the school build an engaged, active alumni community.

Tina Carr, director of alumni relations for SCS, works closely with the board throughout the year, and assists in guiding their activities and involvement. Members of the board meet twice a year to

discuss ongoing initiatives designed to build SCS alumni involvement. And throughout the year, they participate in a variety of alumni activities, from hosting events to meeting with students. Members of the AAB also personally provide annual support to the School of Computer Science in the form of gifts of time and money.

In fact, during the construction of the Gates and Hillman Centers, the AAB decided together to support naming a space in one of the buildings. Their combined gifts were so generous that they actually supported three offices on the fourth floor of the Gates Center. Together these spaces are known as the Alumni Advisory Board Offices, and they were dedicated at a ribbon-cutting ceremony in the spring of 2010.

In addition, during the fundraising drive to complete the Gates and Hillman Centers, several members of the AAB made additional individual gifts to support programs with which they were involved as students, or to name seats in the Rashid Auditorium or other spaces in the Gates Center.

The AAB provides critical annual support and gives generously of its time and talent, helping advance the mission of the school as well as CMU. Each of its members is an outstanding example of ways that alumni can give back to the School of Computer Science. (For more information about the board and to view a list of the current members, visit www.cs.cmu.edu/alumni.)

The AAB's gifts were made as a part of Carnegie Mellon's "Inspire Innovation" campaign. As of May, that campaign had raised \$709 million. To find out how you can help the School of Computer Science through scholarships, fellowships, faculty support or gifts to the Gates and Hillman Centers, please contact me at mdorgan@cmu.edu or call me at 412-268-8576. You can also learn more about the Inspire Innovation campaign by visiting www.cmu.edu/campaign.

Mark Dorgan is executive director of major gifts and development liaison for the School of Computer Science.

Alumni Snapshots

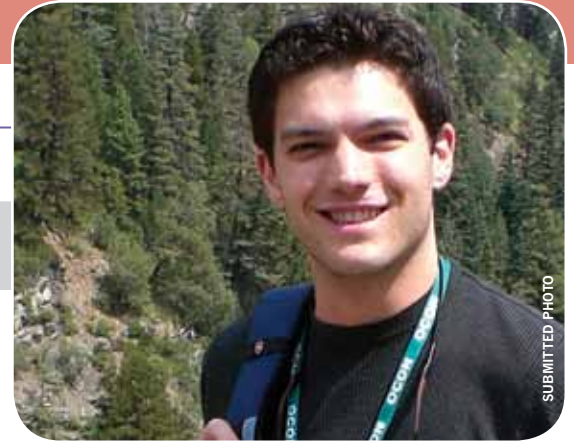
Jason Crawford • B.S., computer science, Carnegie Mellon University, 2001

As someone who worked for more than two years for the world's largest online retailer—Amazon.com—Jason Crawford might not seem like a friend to traditional stores. But that's not true at all. Crawford likes brick-and-mortar retailers: "Stores have one big advantage that the Web will never have—you can pick something up and take it out of the store the same day."

In fact, Crawford wants to help brick-and-mortar retailers compete using social networking and mobile computing. In 2010, he and fellow SCS alumnus Blake Scholl (CS'01) founded San Francisco's Kima Labs to develop iPhone and iPad apps that can help drive traffic into retail locations. "If brick-and-mortar stores take advantage of the Web in ways that mobile technology offers, they can find new ways to compete," he says.

Kima's first app, Barcode Hero, turns shopping into a game, allowing users to scan UPC codes while they're shopping and share their recommendations with Facebook friends. Player-shoppers earn points for every item they scan, and those with the most points in various categories become the "kings" or "queens" of areas. TechCrunch and other websites have called Barcode Hero "addictive" and "awesome."

Because shopping via the Web requires a lot of searching, Kima's newest app, Deal Flow, does much of the work for the user. Released July 8, Deal Flow draws data from nearly 100 consumer and coupon Web sites to alert users to bargains at restaurants, stores and attractions in their immediate areas. The app helps users "find things you didn't necessarily know were even out there," Crawford says.



A native of D.C.'s Maryland suburbs, Crawford says he was attracted to CMU by faculty and students who really seemed to live the motto, "My heart is in the work."

"People seemed to be happy in what they were doing and excited about what they were working on," Crawford says. These days, his heart and much of his time are invested in Kima Labs, but in his off hours, he enjoys swing dancing and rock climbing.

—Jason Togyer (HS'96)



Santosh Mathan • M.H.C.I., human-computer interaction, Carnegie Mellon University, 1996 • M.A., instructional science, CMU, 2000 • Ph.D., human-computer interaction, CMU, 2004

ing attention, and manipulating physical objects. Imagine, for instance, if a brain-wave sensor could tell a monitoring system that an air-traffic controller was getting fatigued, or if it could enable someone who's lost the use of her limbs to maneuver a wheelchair through a crowded room.

"EEG has been around as a clinical tool for psychological research for decades," Mathan says. "We're trying to take some of that research out of the lab and into practical settings. Areas of application that we are working on are broad—from tools for assessing cognitive function following traumatic brain injury, to games, to hands-free robotic controls."

There are several challenges. Neural signals are very weak, and older-style EEG sensors were placed on the skin using a conductive gel that's "inconvenient and unpleasant," Mathan says. Dry electrodes developed by Mathan's research collaborators show considerable promise, and the algorithms developed by his lab can reliably detect signals associated with working memory load, attention, and perceptual judgments—

in real time. Honeywell is already field-testing some of the technology. "Most of it is still lab work—but it's fairly advanced lab work—in collaboration with universities and companies around the world. We have validated this technology among pilots, intelligence analysts, soldiers and people recovering from brain trauma," Mathan says.

Mathan was attracted to Honeywell because of the company's long history in aerospace technology, including design and manufacture of aircraft navigation systems and engines. A pilot since 1992, Mathan has a "huge passion" for flying and wanted to apply his computer science knowledge to the aviation industry.

Besides flying occasionally from Seattle's Boeing Field, Mathan, his wife Reny, and daughters Sara and Miriam enjoy outdoor activities such as sailing and kayaking in Seattle's Lake Union. "We also enjoy good food, and the Seattle area is a great place for that," he says.

—Jason Togyer (HS'96)

Santosh Mathan's research includes monitoring and interpreting neurophysiological (brain and nervous system) signals using body-worn sensors. But he doesn't have one of those crazy helmets used by mad scientists in old movies, he says, laughing.

"Many of the systems we use are like baseball caps with embedded sensors," says Mathan, principal scientist at Honeywell Research Laboratories in Seattle. "Very low profile. The technology has evolved quite a bit."

Mathan is investigating ways that brain activity—detected using electroencephalography, or EEG—can be used for tasks such as managing workload, estimat-

Researchers: Self-driving systems can be proved safe



Passenger cars with automatic steering, braking and speed-control devices could help ease traffic congestion and prevent accidents—if they're safe.

A team led by Andre Platzer, assistant professor of computer science, has demonstrated that it's possible to verify the safety of these highly complex systems.

"The system we created is in many ways one of the most complicated cyber-physical systems that has ever been fully verified formally," says Platzer, whose research team presented its findings June 22 at the International Symposium on Formal Methods in Ireland.

Platzer is a leader in developing new techniques to verify complex computer-controlled devices that must interact with the physical world. He and Ph.D. students Sarah M. Loos and Ligia Nistor developed a model of a distributed car-control system in which computers and sensors in each car combine to control acceleration, braking and lane changes, as well as entering and exiting the highway.

They then used the same formal verification methods used to find bugs in computer software to verify that the system design would keep cars from crashing into each other.

Platzer, Loos and Nistor showed that they could verify the safety of their adaptive cruise control system by breaking the problem into modular pieces and organizing the pieces in a hierarchy. The smallest piece consists of just two cars in a single lane. They eventually were able to prove the system's safety for arbitrary numbers of cars and lanes of traffic.

Their proof has a major limitation—it only applies to straight highways—but future work will include curved lanes and other complications, Platzer says. "Any implementation of a distributed car control system would be more complicated than the model we developed. But now at least we know that these future systems aren't so complex that we can't verify their safety."

The research was supported by the National Science Foundation and the Office of Naval Research.



Andre Platzer

Shaw Named University Professor

Mary Shaw (CS'72) is one of four members of the Carnegie Mellon faculty who this year were awarded the title "University Professor"—the highest academic accolade CMU bestows on its educators.

Shaw, a faculty member since 1972, is the Alan J. Perlis Professor of Computer Science at CMU and a leader in software engineering research.

Her work on software architecture—the large-scale structure of software systems—helped establish it as a recognized discipline.

Besides her long research and education career at CMU, Shaw also holds the distinction of being among Carnegie Mellon's first Ph.D. graduates in computer science.

"Mary Shaw has played many important and unique roles at Carnegie Mellon," says Randy Bryant, SCS dean. "Especially significant are her efforts to create a strong foundation for software engineering education and in identifying the overall organization of a software system—its 'architecture'—as a key element in its design."

Shaw holds faculty appointments in the Institute for Software Research, the Computer Science Department and the Human-Computer Interaction Institute. She has served as chief scientist of CMU's Software Engineering Institute and as associate dean for professional education.

Earlier this year, Shaw was a co-recipient, along with David Garlan, of the Outstanding Research Award from the Association for Computing Machinery's Special Interest Group on Software Engineering for contributions to software architecture (SIGSOFT).

Last year, she was the first recipient of the Distinguished Educator Award presented by the IEEE Computer Society's Technical Council on Software Engineering.

Shaw is a fellow of the ACM, the IEEE and the American Association for the Advancement of Science.

Other CMU faculty honored this year as University Professors are Lorenz (Larry) T. Biegler, the Bayer Professor of Chemical Engineering; John P. Lehoczky, dean of the College of Humanities and Social Sciences; and George Loewenstein, the Herbert A. Simon Professor of Economics and Psychology.



Mary Shaw

Ph.D. student takes top ACM prize

Swapnil Patil, a Ph.D. student in computer science, took first place in the graduate student category of the Association for Computing Machinery Student Research Competition Grand Finals.

Patil received the award June 4 at the ACM Awards Banquet in San Jose, Calif., for his development of a file system director service that scales to millions of files, which he presented at SC10, the international conference for high performance computing, networking, storage and analysis.

ACM's Student Research Program is sponsored by Microsoft Research to encourage students to pursue careers in computer science research, and to ensure the future of scientific discovery and innovation.

The competitions, held at 13 major ACM Special Interest Group conferences within the last year, featured research projects produced by an international array of computer science graduate and undergraduate students. Winners from each of the SIG competitions were then eligible to compete in the Grand Finals.

Four honored by ACM SIGMETRICS



Adam Wierman

An SCS alumnus was honored last month with the SIGMETRICS “Rising Star Researcher Award,” while an SCS professor and two other alumni received the “Test of Time Award” for a paper they published in 2000.

Adam Wierman (CS '01,'04,'07), now an assistant professor at the California Institute of Technology, was honored for his research into resource allocation and scheduling decisions in computer systems and services. Currently a member of CalTech's Rigorous Systems Research Group, Wierman's work focuses on developing analytic techniques and applying them to energy-efficient computing, networks and the electricity grid.

While at CMU, Wierman received the Alan J. Perlis School of Computer Science teaching award in 2005 and the Carnegie Mellon Graduate Student Teaching Award in 2006. His advisor was Mor Harchol-Balder.

SCS associate professor of computer science Hui Zhang, Yang-hua Chu (CS'05) and Sanjay Rao (CS'00,'04) were honored for their paper “A Case for End System Multicast,” published in the Proceedings of ACM SIGMETRICS in 2000.

Currently on leave from CMU, Zhang is the co-founder and chief scientist of the online streaming video company Conviva. Rao is an assistant professor of electrical and computer engineering at Purdue, while Chu is with Google.

Student programming team goes to world finals

The Dragons, Carnegie Mellon's team in the Association for Computing Machinery International Collegiate Programming Contest, tied for 13th overall among 105 competitors and second among the 18 U.S. teams at the World Finals in Orlando, Fla., May 27 through 31.

China's Zhejiang University took first place in the competition, with the University of Michigan finishing second. The complete results are available online.

The team, composed of computer science majors Nathaniel Barshay, Tom Conerly and Si Young Oh, was coached by Danny Sleator, professor of computer science, along with Eugene Fink, senior systems scientist, and Ph.D. students Richard Peng and Kevin Waugh.

The Dragons qualified for the World Finals by placing second in ACM-ICPC East Central North American regional contest in Cincinnati last October. More than 8,300 teams worldwide sought a place in the annual “Battle of the Brains.” Only the 105 top teams qualified for the finals.

Fink said Sleator “put a lot of work in training the students to solve hard algorithmic problems, which gave our team an edge.” Travel and all other team expenses were paid for by IMC Financial Markets of Chicago.

CMU's teams have done well in recent years, earning a bronze medal two years ago and finishing just outside of medal contention last year.

Conference at CMU marks Reynolds' 75th birthday

Friends and colleagues paid tribute to longtime professor of computer science John Reynolds on his 75th birthday.

A special session in Reynolds' honor was held during the 27th Conference on the Mathematical Foundations of Programming Semantics, hosted at CMU in May.

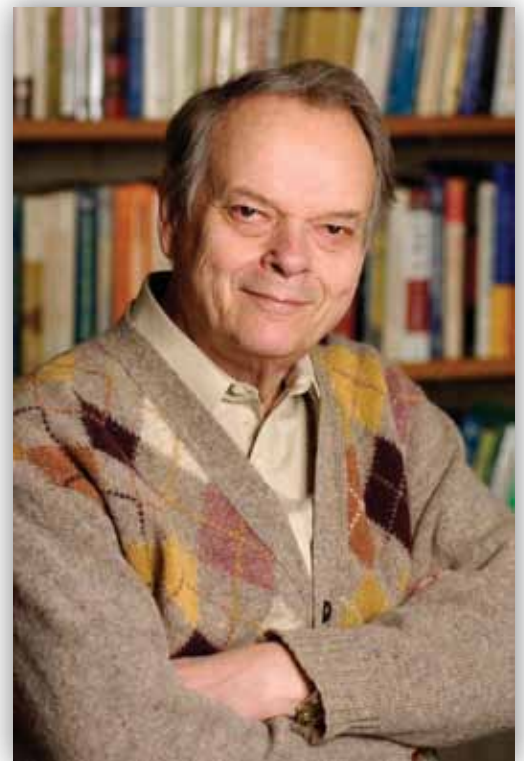
“His work has been enormously influential in shaping the field and has been the source of inspiration for many researchers,” says Stephen Brookes, CMU professor of computer science and one of the conference organizers.

Reynolds, a graduate of Purdue and Harvard universities, joined the CMU faculty in 1986. His work has focused on the use of mathematics and logic for designing and defining programming, and methods for proving that programs meet their specifications.

Brookes says that Reynolds has been a “major contributor” to the MFPS series since “forever.”

Reynolds, Brookes and the U.K.'s Peter O'Hearn collaborated on the development of separation logic, which began as way of reasoning about sequential programs and has grown into a significant research area with applications in automated software analysis and program verification.

About 50 people attended the conference. Edmund Clarke, professor of computer science, was the speaker at a special session on systems biology.



John Reynolds

SCREEN SHOTS

Not all of the action at CMU's annual Spring Carnival happens on the midway or along the Sweepstakes course.

One of the oldest School of Computer Science traditions during Carnival is the MOBOT—"mobile robot"—race in front of Wean Hall.

Now in its 17th year, MOBOTs are required to self-navigate a winding downhill slalom course through a series of 14 "gates" (they look a little like croquet hoops), steering themselves by following the line painted on the course. The MOBOT that travels the furthest the fastest wins a \$1,000 prize.

Unfortunately, bright, glaring sun and some recent sidewalk repairs played havoc with MOBOTs this year, and none of the competitors completed the course. The winner in the undergraduate category was Kwabena Agyeman, a junior majoring in electrical and computer engineering, whose "StingRay" navigated eight gates in about 97 seconds. Second prize went to seniors Kyle Neblett (ECE), Aaron Jaech (math/CS) and Diana Hu (ECE), while third prize went to ECE sophomore James Wahawisan.

One MOBOT—"Johnny 0.5," owned by Eli Richter of HackPittsburgh—did complete the course during an exhibition run. Below right, Richter talks with MOBOT commentator Greg Armstrong, senior research technician in the Robotics Institute. (For more information and photos from MOBOT, visit www.cs.cmu.edu/mobot.)



Off the Midway



WADE H. MASSIE PHOTOS

Some activities during Spring Carnival aren't weather-dependent. Near the Rashid Auditorium in the Hillman Center, CMU's Game Creation Society hosted a three-day free arcade to showcase video games written by club members.

The GCS is "extremely interdisciplinary," says Connor Fallon, an H&SS senior and club president. "All of the games were made in our free time, and everyone in the club is really passionate."

Above are Evan Shimizu, a sophomore majoring in computer science and art, and Fallon. Visit www.gamecreation.org to learn more—and to download some of the games created by the club's members. —Jason Togyer



ADDRESS CORRECTION REQUESTED

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Then and Now

No other prize in the long history of technology prizes (see p. 11) has as many connections to Carnegie Mellon as the Fredkin Prize.

Edward Fredkin—currently a visiting career professor of computer science at CMU—threw down the gauntlet in 1980. A pioneer in artificial intelligence and inventor of the Fredkin quantum logic gate, the trie data structure and other hardware and software innovations, Fredkin promised \$100,000 to the designers of the first computer that could beat a world chess champion.

Carnegie Tech and Carnegie Mellon had a long history in computer chess, dating back to Herb Simon, Allen Newell and Cliff Shaw's 1950s development of the first chess program able to beat a human player. Naturally, CMU was chosen to award the new Fredkin Prize.

The first team to get close was at Bell Laboratories, where in 1981, a chess computer achieved master status. (The designers shared a \$5,000 Fredkin award for their work.) Then, in 1988, five CMU grad students—Thomas Anantharaman (CS'86,'90), Michael Browne (CS'86,'89), Murray Campbell (CS'87), Feng-hsiung Hsu (CS'90) and Andreas Nowatzyk (CS'90)—received a \$10,000 Fredkin award for designing a machine that reached international master status.

They named it “Deep Thought” after the computer that knew the answer to the meaning of “life, the universe and everything” in Douglas Adams’ “The Hitchhiker’s Guide to the Galaxy.”

Eight years later at IBM, Campbell, Hsu and colleagues unveiled their ultimate chess-playing computer—Deep Blue, a 30-node parallel-processing machine with but one purpose: playing chess, and playing it fast, evaluating up to 200 million possible positions every second.

At the time, the world’s reigning champion was Garry Kasparov, who had defeated Deep Thought in a two-game match in 1989. Now, in February 1996, Kasparov took on Deep Blue in Philadelphia. The computer won the first game, but Kasparov won the overall tournament.

More than a year later, in May 1997, Kasparov and a much-improved Deep Blue faced off again, this time in New York City. Kasparov won the

first match. Deep Blue won the second, and the next three games were draws.

The sixth was a decisive win for Deep Blue and the IBM team. Kasparov, who claimed to have seen “human intelligence” in Deep Blue’s moves, demanded a rematch. IBM declined.

That June, Hsu, Campbell and IBM researcher A. Joseph Hoane Jr. received the \$100,000 Fredkin Prize during the AAAI’s annual meeting in Providence, R.I. “There has never been any doubt in my mind that a computer would ultimately beat a reigning world chess champion,” Fredkin told reporters. “The question has always been when.”

—Jason Togyer



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