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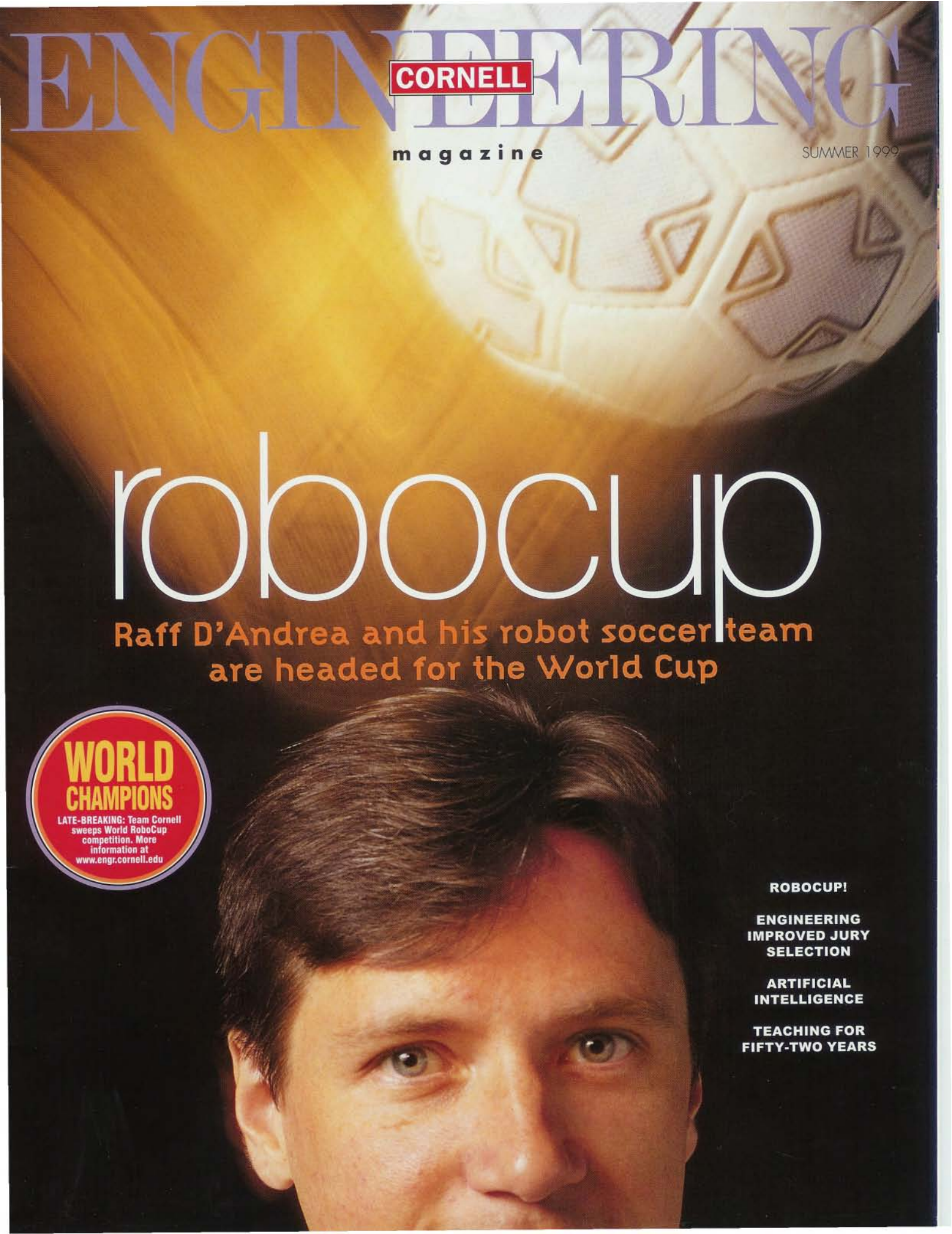
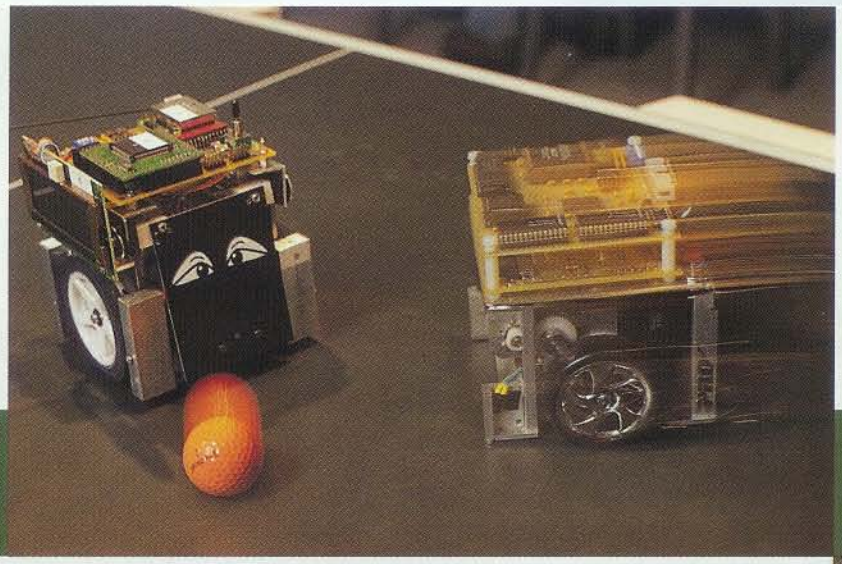
robocup

Raff D'Andrea and his robot soccer team are headed for the World Cup

WORLD CHAMPIONS

LATE-BREAKING: Team Cornell sweeps World RoboCup competition. More information at www.engr.cornell.edu





Building a team of so
taste of real-world en

It's hot in here.

It's one of the first really warm days of spring, a Monday afternoon in mid-May, and several hundred people are crammed into Upson Hall lounge. As though the standing-room-only crowd didn't make the place stuffy enough, 1,000 watts of lighting has turned it into a steam bath—and open windows are strictly forbidden. To top it off, it's the beginning of the last week of classes, and exams and papers are stacking up like planes over O'Hare. But still the spectators are jammed in together 10-deep, and they seem content to stay all afternoon.

After all, it isn't every day you get to watch robots play soccer.

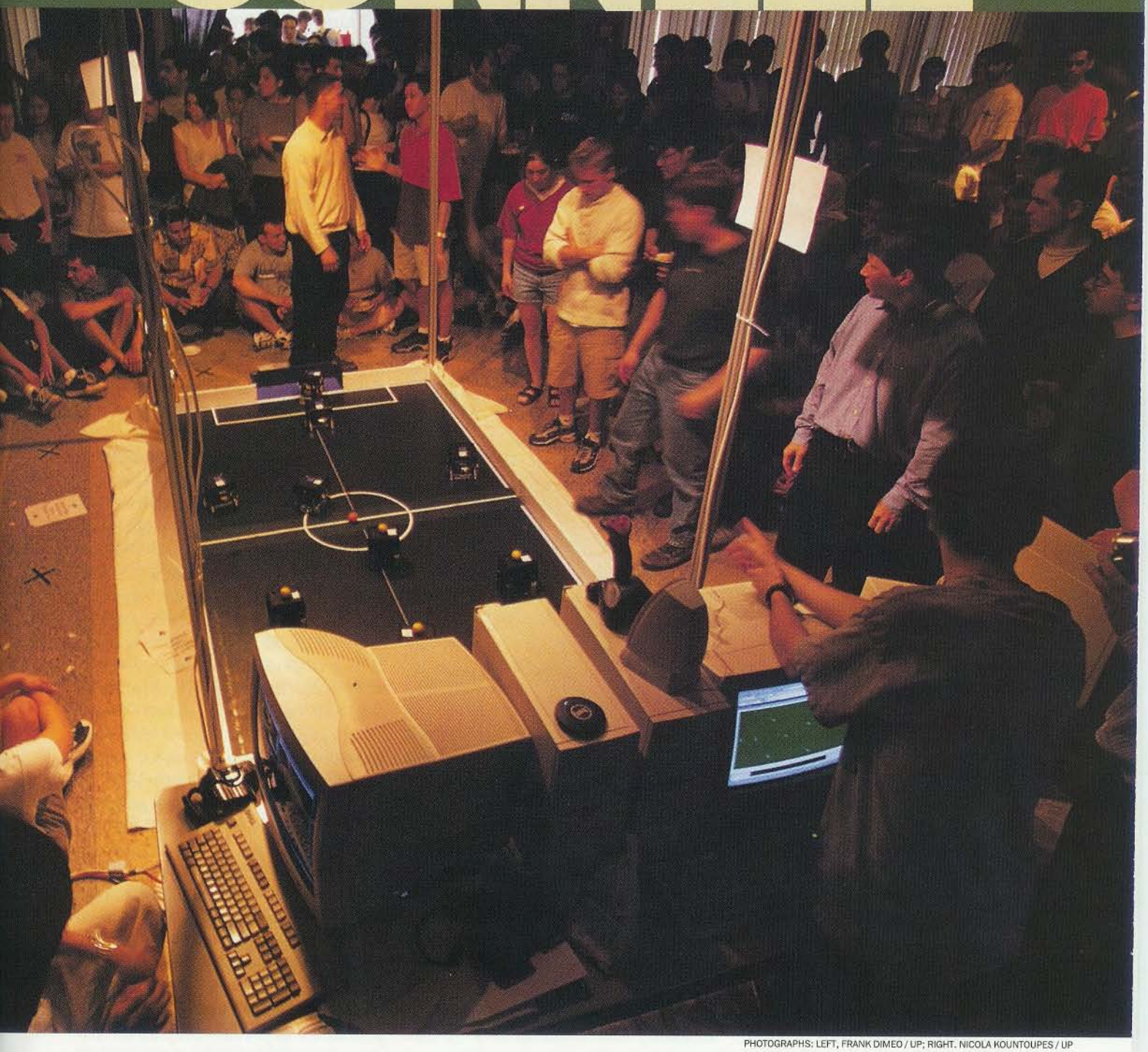
In the middle of the room sits a humble tabletop, a green-and-white rectangle topped by a metal frame; the bright lights and camera equipment suspended above give the contraption the look of a doll-sized movie studio. But this is truth, not fiction. In the next half-hour, 10 robots with names like Scoot, Sleepy, and Major Tom will be put through their paces in agility trials, control demonstrations, even an exhibition drag race. Then comes the main event: a real-time soccer match starring 10 autonomous robots, built from scratch by Cornell engineers.

The official name for this competition—at once Lilliputian and hugely ambitious—is the Robot World Cup Initiative, but everyone just calls it the RoboCup. For the past eight months, two dozen students have been working like mad, and it all comes down to 10 minutes of play to decide which of the two teams gets to go to Stockholm for the international tournament. And there, it will be Cornell versus the world.

The Big Red's first-ever RoboCup entry is the brainchild of a man who knows a whole lot about systems engineering—and a whole lot about soccer, for that matter. Raffaello D'Andrea, an assistant professor of mechanical and aerospace engineering (MAE), started the RoboCup program last fall. His aim: to give students a taste of

ccer-playing robots gives students a
gineering experience. By Beth Saulnier

TEAM CORNELL



PHOTOGRAPHS: LEFT, FRANK DIMEO / UP; RIGHT. NICOLA KOUNTOUPES / UP

Assuming an annual salary of $60,000 plus benefits, the RoboCup would add up to a $1 million industrial project.

what they'll encounter in the real world, from deadlines and cost limitations to old-fashioned teamwork. "Students find that more and more, as they go into industry, they aren't just working on one thing. It's not just widgets anymore. It's big, complex systems," D'Andrea says. "I wanted to teach a class where they could work in multidisciplinary teams. In industry today, that's the norm."

With those goals in mind, D'Andrea convened the traditional engineering think tank: the student pizza party. After a night of brainstorming last spring, he settled on the idea of a robotic soccer game—and found out that it already existed, having been first played in Nagoya, Japan, in 1997. He decided Cornell should throw its virtual hat into the ring, and promptly got 60 applications for the 24 openings. "It's a real project," D'Andrea says of the course's appeal. "We're actually building something." A year later, D'Andrea and his RoboCup protégés are, quite literally, in the hot seat. "After eight months, Saturday night was the first time things worked the way they were supposed to, so we've spent the last 24 hours just fine-tuning," he says as the students sweat and scramble to finish setting up for the big game. "These guys have been working around the clock."

The students have had access to the Upson lounge for the past 28 hours. In that time, they've had to move everything down from the RoboCup lab on the floor above, rebuild the playing field (whose overhead grid required some juggling with the room's ceiling tiles), and make sure everything is still running right. But that's not as easy as it sounds. Both teams—one dubbed Italy, the other Brazil—rely on an overhead camera, the eye-in-the-sky of the so-called "global vision system" that tells the computers where the players are on the field. But that system has never been tried outside the lab, and the Upson lounge has windows. Big ones. And though Ithaca can usually be counted on for some comforting gloom, today it's blazingly sunny. "We've never tested it in here during the day," D'Andrea says as students climb onto chairs to tape dark material over the doors and windows. "Lighting is very critical. We need a constant source of light on the field, and it has to be uniform."

D'Andrea is standing between one sign that says NO FLASH PHOTOGRAPHY and another forbidding cellular phones. They aren't kidding. At a typical live stage performance, flashes are a distraction; here, they can be a disaster. "It'll make the robots spin uncontrollably," D'Andrea says with a grin that says he's seen it all before. As for cell phones? They can interfere with the wireless communication between player and computer, which, as he puts it, "may send the robots on a self-destruct course."

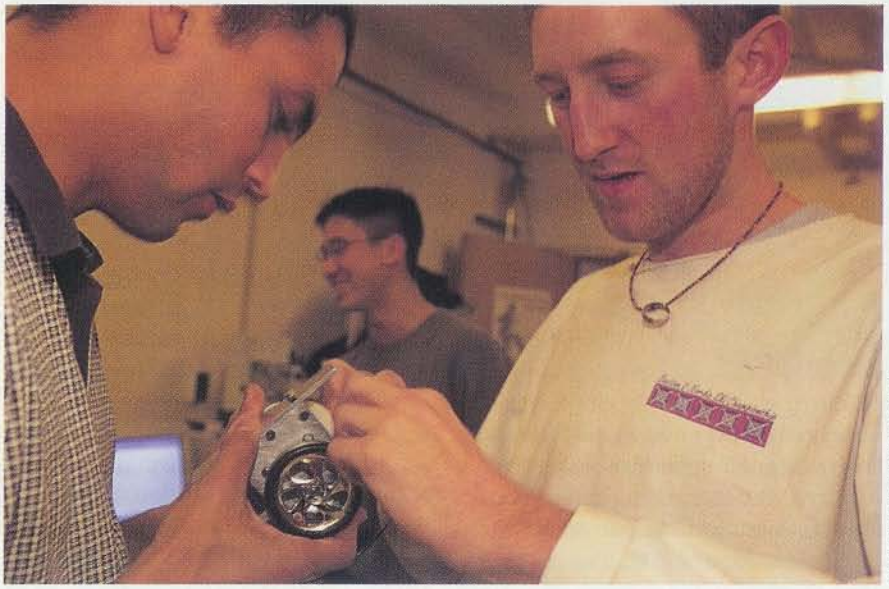
Along one wall, students are bent over keyboards and gazing into monitors. Even just a few minutes before the game, others are taking the "hats" off robotic competitors and giving their innards a final check. "I haven't really slept since Wednesday," says Scott Aaronson, a glassy-eyed computer science major from the Philadelphia area. "I think a lot of people here could say the same."

The RoboCup course, a year long, is open to all engineering and computer science students. The number of credits earned—eight—hardly reflects the time commitment involved. D'Andrea once calculated that each team put in 8,000 hours of work, for a total of about eight person-*years*. Assuming an annual salary of $60,000 plus benefits, the RoboCup would add up to a $1 million industrial project. "It's been fun—a lot of work, but fun," says Team Brazil's Alex Sepulveda, an M.Eng. candidate in mechanical engineering from Rio Piedras, Puerto Rico. "Sometimes things just kind of go nuts, but most of the time they work. I liked seeing other people doing what they do. It's more realistic, not just focusing on your own thing."

Of the 24 students in Cornell's RoboCup, 60 percent are M.Eng. candidates (the class satisfies the project requirement for those in the new systems engineering option). In choosing whom to admit, D'Andrea aimed for a mix of disciplines to reflect a real industrial team. Thus, 40 percent of the students are mechanical engineers, 40 percent electrical, and the rest from computer science and operations research and industrial engineering. And even after eight months of technical wrangling, that interaction among fields has made the biggest impression on the teammates. "It's been a really educational experience for me," says Aaronson, who worked on artificial intelligence for Team Italy. "Some of the biggest challenges have been communication—*human* communication. We're doing CS, but we can't operate in a vacuum. We need to know what's going on mechanically as well." Or, as Brazil team leader and M.Eng. student Dennis Huang '98 puts it: "The mechanical engineers and the double-Es have to *talk* to each other."

It's getting close to game time now, and Huang admits he and his teammates are feeling rushed. "We're not as ready as we'd like to be. But we're going to win, because our robots are well-built. They can dish out and take almost anything." But Huang's Team Italy counterpart—David Hsu, an M.Eng. student in systems engineering from San Mateo, California—jokes that his team will win for one simple reason: "We're better engineers." While Team Brazil concentrated on their robots and software, Italy pinned its hopes on complex electrical and mechanical systems, including

BELOW: JASON OVERSMITH, M.ENG. '99, IS AT THE CONTROLS, DESIGNING CIRCUITRY FOR TEAM BRAZIL'S ROBOTS. BOTTOM: HARRY CUADRADO, M.ENG. '99, AND LARS CREMEAN '99 ME ASSEMBLE TEAM ITALY'S ROBOTS.



PHOTOGRAPHS: FRANK DIMEO / UP

two different designs for the goalie and the field players. "We've worked with a really aggressive schedule and a really aggressive design," Hsu says, "and we pulled it off in the end."

If the RoboCup is the most complex project an undergrad or M.Eng. student is likely to encounter (unlike Cornell's, most teams are made up of doctoral candidates), the rules are relatively simple. Each team has five robots, including one goalie, who face off for possession of a bright orange golf ball on a soccer pitch consisting of a regulation Ping-Pong table. The robots must occupy a floor area no greater than 180 square centimeters, and be less than 15 centimeters tall. The goals are 50 centimeters wide—about a third of the length of the short end of the field—and are painted either bright yellow or blue. The games consist of two 10-minute halves, with a break in between.

To enter the third-annual RoboCup competition, Cornell had to submit a paper and video for approval; it was D'Andrea's idea to give the Big Red project a competitive flavor by forming two internal teams and letting them play for the right to go to Europe. But to ensure the strength of the Cornell squad as a whole, he created a canny list of student goals, in descending order. To wit:

1. Cornell wins RoboCup 1999.

2. Cornell wins RoboCup 2000 and beyond.

3. A student's own team wins the Cornell tournament.

Goal Number One puts the focus on the university as a whole rather than on the individual team, which inspired Brazil and Italy to collaborate on the global vision system. Practicing that vital kindergarten virtue—sharing—allowed both teams to develop the best possible system and devote more time and money to other parts of the project, like robotics and artificial intelligence. Goal Number Two encourages good documentation (since most of the present players will have graduated), as well as extra research into high-risk, high-payoff concepts that may not be used this year but could give Cornell a future edge. Goal Number Three—the question of whether Brazil or Italy will represent the university at Stockholm—comes in a not-so-distant third. "This was by far the most exciting class I've ever taken," says Team Italy member Lars Cremean, a senior in mechanical engineering from Wolcott, New York. "It's a pretty daunting task to get robots to do *anything* autonomously. I got a real sense of how to go about designing a system from the ground up."

The RoboCup was founded in 1997, a banner year for robotics and artificial intelligence. In May, IBM's Deep

BELOW, TOP: D'ANDREA (LEFT) AND ANDREW HOFFMAN '98 EE, M.ENG. '99, CONFER ON ROBOT DESIGN. BOTTOM: PROGRAMMED SIMULATIONS OF ROBO GAME ACTION AIDED IN THE DESIGN PROCESS.

PHOTOGRAPHS: FRANK DIMEO / UP

Blue beat world chess champion Gary Kasparov; on Independence Day, NASA deployed the first autonomous robotic lander, Sojourner, as part of its Mars Pathfinder mission. The idea of robotic soccer had been first mentioned in 1992 by Alan Mackworth, a professor at the University of British Columbia; meanwhile, similar discussions were going on in Japan. The first RoboCup was announced in 1995 and played two years later in Nagoya, with more than 40 teams competing before 5,000 spectators. It grew to nearly 100 teams the following year, and more are expected in Stockholm.

But RoboCup organizers don't plan to settle for watching miniature robots play soccer. The ultimate goal is to have a team of fully autonomous humanoid robots capable of beating human players—and not just any humans, but the most recent winners of the World Cup. Target date: sometime in the mid-21st century. "This goal may sound overly ambitious given state-of-the-art technology today," says the organization's official website, <www.robocup.org>. "Nevertheless, we believe it is important that such a long-range goal be claimed and pursued. It only took 50 years from the Wright brothers' first aircraft to the Apollo mission . . . [and] from the invention of the digital computer to Deep Blue." It's a heady prospect—and, incidentally, one D'Andrea doubts will ever be realized. "It will be a long, long time, if ever, before machines can match what a human being can do athletically," he says.

At this year's tournament, all eyes will be on Carnegie Mellon University, which has taken home the title two years running. "They have by far the best artificial intelligence," D'Andrea says of the top-seeded squad. "Our strength is our integrated approach—and our robots are by far the best." The RoboCup is a round-robin tournament with quarters, semis, and a final. Before each match, a coin toss decides which team gets to put up its global-vision camera first. Player substitutions are allowed—teams can bring an unlimited number of spares—and a human referee oversees the action, which has been known to include robots spinning uncontrollably and parts flying every which way. The ref blows the whistle, D'Andrea says, "if the robots get out of hand."

The professor gave his team a competitive edge by videotaping last year's RoboCup final in Paris, so Cornell students could see what they'd be up against. Further proof of his mettle: when French muggers attacked him with pepper spray and stole his briefcase, he managed to hold onto his camera with one hand—and use the other hand to whack them with his laptop. Says Brazil team member Aris Samad-Yahaya: "Professor D'Andrea's pretty intense."

D'Andrea was born near Venice of parents who had little formal education, but adventurous spirits and a yen for travel. After the death of his father, his mother moved to Toronto with her two sons in tow and all of $500 in her purse. (There's just the faintest trace of an Italian accent in D'Andrea's voice, along with a healthy dose of Canadian in his *outs* and *abouts*.) The future RoboCup mentor earned an undergraduate degree in engineering physics from the University of Toronto (where he met his wife, Leanna), followed by a Ph.D. in electrical engineering from Cal Tech. He came to Cornell in January 1997 and now focuses his research on the field of feedback control.

D'Andrea fell in love with soccer as a toddler and kept playing—for an engineers team in college, a club at Cal Tech, a co-ed squad at Cornell called The Rovers. At the RoboCup game in Upson, a spectator (Mike Coleman, Ph.D. '98, an MAE lecturer and fellow soccer fanatic) asks him if knowing a lot about the game gives a RoboCup team an advantage. "Truthfully, no," D'Andrea grins back at him. "But I think if you play sports, you have a competitive nature."

Cornell's RoboCup system is composed of three elements: robots, global control, and computer vision. (Like most teams, the Big Red squad opted for an

overhead camera, which tracks the colored Ping-Pong balls mounted atop the robots, but participants are also free to design a "local" system, with cameras on each robot.) If the robots are the players and the vision system their senses, then global control is the coach—the mind that puts all the game factors together and formulates a strategy using data fed to the camera 60 times per second. The goalie, for example, constantly runs an optimization program to see how close the ball is, and whether to move accordingly. "The key point is that it's fully autonomous," D'Andrea says. "There's no human interaction."

But there's been plenty of human interaction over the past eight months, as the team members assigned to five different aspects of the project—electrical and mechanical engineering, artificial intelligence, vision, and R&D—worked together. As the students building the robots set to their task, programmers developed a simulation (complete with collisions, friction, delays, and noise) that would allow them to test the software, which included 10,000 lines of code for the AI system alone. The actual robots came into play only in the final month.

Meanwhile, each team designed its own circuit boards and sent them out for manufacture, then installed and tested the components. D'Andrea's role was more coach than team owner; for instance, although he advised Team Italy against a complex electronic design, they went ahead with it anyway. "The students have a lot of pride, and they're very creative," he says. "They were able to do it, but *man* did they work hard." Mechanically, the two teams also took different approaches. For example, Brazil decided to make its robotic wheels out of mousepad material (friction being a vital factor in the robots' ability to stop, turn, and kick) while Italy opted for hobby wheels; Brazil's kicking mechanism used a wind-up spring, while Italy's used electromagnets.

The robots are protected by a layer of foam padding, which may seem superfluous for what's not supposed to be a contact sport—until you see them in action. Each robot weighs in at 1.7 kilograms, and they move like lightning, with a maximum velocity of 2.5 meters per second, or 9 kilometers (5.6 miles) per hour. "These guys are power hogs," D'Andrea says of the robots, which run on a 9.6-volt nickel cadmium battery. "We'd really like to find batteries that will power them for the duration of the game." The rules allow "accidental" contact—the players aren't supposed to turn their soccer match into a hockey brawl—but defense can turn into offense faster than you can say Pele. "Definitely a big part of the game is putting yourself in front of another robot," D'Andrea says. Or, as he put it in his introduction to the Brazil vs. Italy match: "I'm 100 percent sure you're going to see collisions."

He was right. Just over a minute into the 10-minute game (D'Andrea had decided they'd only play one half), Brazil scored—and Italy's goalie seemed to take it hard. "Whoa! Whoa!" somebody yelled. "The goalie's going crazy!" He spun out of control, bashing into side walls and other robots, and by the time Team Italy got him under control, he had to be taken off the field. Without a backup, all the Italy squad could do was sit a spare field robot in the goal with its power switched off, and Brazil racked up two more goals in quick succession.

The score was 3-0. Then, out of a sense of fair play, Brazil decided to shut off its goalie as well—and promptly scored again. Final tally: Brazil 4, Italy 0. Still, there were no hard feelings. "I thought the play was pretty impressive," says Cremean. "It went so much smoother than I've ever seen it go." He chalks up the goalie's problem to human error—a soldering mistake that caused a short between the robot's two boards—and adds that Italy's system made great strides in the project's home stretch. "A few weeks ago, the obstacle avoidance algorithm was pretty primitive," he says. "Negotiating the walls was a big thing. The robots just ran into them and tried to keep going."

Aaronson, one of two juniors on the RoboCup squad, plans to come back for more in the fall. "This year, we haven't had the opportunity to do a lot of higher-level AI," he says. "But very simple things took a lot of math and a lot of twiddling to get to work. When you start interacting with the robot and you realize how difficult it is to get them to do simple things, a lot of your dreams about what's feasible start to change."

After the match, D'Andrea hosted a barbecue, where the RoboCup players came to an unexpected decision: the Brazil and Italy systems will be integrated, and the best of both sent to Stockholm. The class has been more about collaboration than competition, the students say—further proof that they've been following D'Andrea's number-one goal all along. "The win was great and all, but it wasn't the win that made us feel really good," says Samad-Yahaya, a senior electrical engineer from Malaysia. "It was seeing the system work—the feeling that we managed to get it all running pretty well."

For Samad-Yahaya, the RoboCup turned out to be a life-changer. His experience doing original research on trajectory generation for Brazil's AI team convinced him to pursue a Ph.D., which he will begin in the fall of 2000 after taking a year off. "It was a real eye-opener to me," he says. "It was really exciting to figure out a new way of doing things, to discover new science. We created something truly remarkable."

Beth Saulnier is associate editor of Cornell Magazine.