Tiny wireless sensors and actuators — some costing under a dollar a piece — are driving the next revolution in computing. Networked to computers, connected to the Internet, and embedded in objects in our surroundings, these increasingly sophisticated devices provide the foundation for cyberphysical systems that have the potential to dramatically increase our ability to respond — automatically and in real time — to the world around us. If you drive a car, work in a factory, or own a smartphone, you already understand the power of cyber-physical systems.

Our department was present at the birth of this new technology, thanks to the pioneering work of Jack Stankovic, the BP America Professor of Computer Science. We now have one of the most influential research programs in the field.

As Stankovic points out, the potential of cyber-physical systems is vast. They will, for instance, allow us to realize significant savings in residential energy use, enable seniors to age in place and extend the working life of critical infrastructure. They also promise to usher in a new age of scientific discovery, while dramatically increasing manufacturing quality, output, and efficiency.

The research challenges are equally significant. In our department we are investigating many of the fundamental obstacles that must be addressed for cyber-physical systems to be widely deployed. Our faculty members are focusing on such issues as safety and security, network protocols, activity recognition, data mining, signal processing and programming and debugging. They are also developing prototype systems that they are testing in homes. Many undergraduates as well as graduate students are involved in this research.

Cyber-physical systems are inherently interdisciplinary. As a result, our work quite often takes us across Grounds and to other universities. We have collaborated with doctors, nurses, environmental scientists, control theory and signal processing experts, embedded systems designers, and hardware engineers, to name just a few. Together, we are moving toward a time when ubiquitous wireless sensors and actuators will shape the way we interact with our surroundings.

**READ MORE:** www.cs.virginia.edu/research
Ten years ago, the dot-com bubble drove a sharp increase in undergraduate enrollment in computer science programs, but when the bubble burst, the number of students majoring in the field fell off. Now enrollments are once more rising. They have doubled at U.Va. in the last year, but this time they are growing on a much more sustainable basis.

Computational techniques are now firmly embedded in virtually every field of endeavor, and the appetite for computation is only increasing. The demand for experts in such areas as computer security, mobile systems, high-performance computing and big data is on the rise. Engineering students are majoring in computer science because they foresee satisfying careers in the field.

The central importance of computation has also aroused interest across Grounds. Students in the College are signing up for the interdisciplinary B.A. in computer science in unprecedented numbers, and many of these students are double majors. These students understand — whether they're interested in business, biology, or art history — that fluency in computer science will position them to take on the most exciting challenges in their fields.

For the department, this increase in enrollment poses challenges — we simply don’t have the capacity now to meet the demand for the B.A. program — but it also creates opportunities. As we secure permission to add faculty in response to growing enrollment, we can add researchers selectively, strengthening established areas of excellence like security and gathering expertise in such emerging fields as big data. In doing so, we will collaborate with other departments and schools across Grounds, transforming a departmental strength into a University strength.

One area that already fits this paradigm of cross-University excellence is cyber-physical systems. We have one of the most prominent cyber-physical engineering groups in the nation. As you’ll read in this issue, we’re doing exciting interdisciplinary work in a field that promises to make computing part of the fabric of everyday life.

Kevin Skadron
Professor and Chair
“What music do I want to hear?” That’s often the first question smartphone users ask themselves after plugging in their earbuds. But instead of having to flick through their lists of albums and artists, they may soon be able to turn to Musical Heart, an app graduate student Shahriar Nirjon is developing. From songs already on the smartphone, Musical Heart generates a soundtrack that fits the moment.

Musical Heart illustrates the potential of cyberphysical systems to improve our quality of life by making the physical environment that much more responsive to our needs. Nirjon has developed a set of algorithms that combine the heartbeat and motion data generated by tiny infrared sensors and accelerometers in Musical Heart earphones with locational data from in-phone GPS receivers. The result is an in-the-moment, contextual profile of the user’s activity level.

Putting together this information, Musical Heart can determine if the listener is driving up a mountain pass in the Rockies or jogging around the local college track. Then, using a commercially available program to analyze the tempo, pitch and energy of available music, it selects the tracks that best suit the occasion.

“Whether I am traveling or relaxing, I could never find the appropriate music to listen to,” Nirjon says. “That’s why I decided to develop Musical Heart. The heart wants to hear something, but our music players don’t understand the need.”

Users can also turn to Musical Heart to select music that will optimize their heartbeat for a particular workout. Because it stores heart rate data and music from previous sessions, Musical Heart can build a playlist from songs that work best for individual users. “The app statistically rates the tracks based on how effective the tracks were in helping an individual reach a desired heart rate goal at a particular activity level,” says Nirjon. “We’ve designed Musical Heart to be convenient, noninvasive, low-cost and — above all — personalized.”

**THE SOUNDTRACK TO YOUR LIFE**

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**READ MORE:** about the Musical Heart at [www.news.virginia.edu/content/uva-computer-science-grad-student-develops-musical-heart](http://www.news.virginia.edu/content/uva-computer-science-grad-student-develops-musical-heart)
The limitations of current “smart” home systems are fairly evident to anyone who has spent time waving self-consciously at a motion detector to turn room lights back on. These systems suffer from having an inadequate number of sensors measuring the wrong things.

Associate Professor Kamin Whitehouse and colleagues in the Engineering School have a $2 million grant from the National Science Foundation to build novel sensing systems that extract meaningful information about a building’s inhabitants, enabling these systems to deliver services that accurately reflect the occupants’ true needs. Although targeted at heating and cooling systems, their system could equally be used for lighting and other energy-intensive services. “The problem with most smart homes,” says Whitehouse, “is that they’re just not that smart.”

The challenge that Whitehouse has set himself is twofold. He must deploy a robust sensor system, embedded in the home itself, that provides meaningful information about occupancy without intrusive microphones or cameras. And he must create analytics that go beyond establishing moment-to-moment presence to detect underlying patterns in the way occupants interact with their surroundings.

Whitehouse is addressing the first challenge by using ultrasonic and infrared sensors to track occupants’ movements and identify them by height, combined with off-the-shelf electric and water sensors that measure usage. He is tackling the second challenge by developing algorithms that extract the patterns of daily life and using them to judge the significance of real-time activities. For instance, if a person habitually rises early, it might make sense to heat the kitchen if they turn on the faucet at 6 a.m. If they turn on the tap at 3 a.m., it’s likely that they will return to bed after drinking a glass of water.

Currently, Whitehouse has designed and installed instruments for about 20 test homes. He plans to broaden his research agenda to commercial buildings once all of the necessary electrical systems are up and running in Rice Hall, the new 100,000-square-foot building that houses the computer science department. He will be undertaking this project with Trane Inc., which supplied Rice Hall’s heating, ventilating and air conditioning systems (HVAC). “The savings could be significant, based on our findings in residences,” Whitehouse says. “Preliminary results using data from eight homes indicate that our approach can save 28 percent of HVAC energy with only $25 in sensors.”

READ MORE: about CS at www.cs.virginia.edu/people/faculty/whitehouse.html
Given the choice, seniors by far prefer aging in familiar, comfortable surroundings to moving to an assisted living facility — but the drawback has always been safety. Even when surrounded by an attentive network of family, friends and professional caregivers, a fall or similar life-changing event can go undetected for hours, even days.

For Professor Jack Stankovic, the clear-cut solution is a robust cyberphysical system that, when thoughtfully deployed, can have the added advantage of keeping seniors healthier as well as safer. Working with a team of graduate students that includes Robert Dickerson and Enamul Hoque, he developed AlarmNet, a system that uses a variety of sensors — some wearable, some in the living space — to generate real-time data that can be used to analyze the health and well-being of a residence's inhabitants. “The goal is to use AlarmNet to give physicians a much richer picture of a patient’s health than they could gain during a typical office visit,” says Dickerson. “It could potentially help physicians detect changes in a person’s health early, when interventions can have the best effect.”

Dickerson and Hoque have been working with colleagues around the University to apply variations of AlarmNet in specific circumstances. For instance, they are working with Associate Professor Karen Rose in the School of Nursing on a National Institutes of Health-funded study trying to determine the relationship between incontinence and agitation in Alzheimer’s patients. Patients in the study wear a wrist actigraph at night — a device created by John Lach, a professor of electrical and computer engineering, that measures physical movement and agitation. Their mattresses are equipped with accelerometers, their diapers with wetness sensors, and there are microphones to record verbal agitation. The data will be analyzed to determine whether physical and verbal agitation precedes or follows bed-wetting, creating options for managing the disease more effectively. “We’re developing cyber-physical systems that, when used for research or in real life, can inexpensively produce the knowledge we need to make informed decisions,” Hoque says.

**READ MORE:** about John Stankovic’s research at [www.cs.virginia.edu/people/faculty/stankovic.html](http://www.cs.virginia.edu/people/faculty/stankovic.html)
Miles Gordenker’s drive to optimize his mental and physical performance led him to maximize the quality and minimize the duration of his sleep. Using a sleep-tracking device called a Zeo, he adopted a polyphasic sleep pattern that combines three hours of core sleep with several short naps.

But Gordenker knew that people suffering from sleep deficiencies would also benefit from accurate information about the quality of their sleep and customized feedback to help them improve it. Working with Professor Jack Stankovic, he is writing programs for the Fitbit wireless sensing platform — which has an open API — to help people understand the intersection of specific environmental and behavioral factors like ambient light and temperature and sound, restorative sleep.

Gordenker, a fourth-year BA Major in the College, is currently developing a user interface for his program and will be beta testing it this spring. “I just want to develop cool software,” he says, “and helping people get the sleep they need is a satisfying way to harness that passion.”

READ MORE: about the BA Major in the College at: www.cs.virginia.edu/acad/ba/about.html
Graduate Research Spotlight

ERIN GRIFFITHS—ENERGY-EFFICIENT HOMES

As Erin Griffiths sees it, there are a number of ways to conserve energy and cut household energy bills. You can take a passive approach, investing in new windows, better insulation and energy-efficient appliances, or you can take a dynamic approach, building a sensor network that turns services on and off as occupants move from room to room.

Griffiths, a master’s degree student, is helping Associate Professor Kamin Whitehouse test a prototype of a dynamic system in a series of homes. Griffiths and Whitehouse detect occupancy by placing inexpensive ultrasound and infrared sensors at the threshold of each room. These sensors provide information about the height — and therefore the identity — of individuals passing through them, as well as their direction of movement.

Griffiths has been building the sensors and their enclosures, addressing interference from other wireless networks in the homes, writing scripts to process data and doing signal processing to identify events.

The challenge, as Griffiths, has discovered, is matching data with human behavior. “People don’t always act simply,” she notes. “They might stand in a doorway, neither entering a room or moving away. It’s been fun trying to find the best way to identify specific activities.”

READ MORE: about CS research at: www.cs.virginia.edu/research/

Alumni Spotlight

CHENYANG LU

A professor of computer science and engineering at Washington University in St. Louis, Chenyang Lu has emerged as one of the leaders in cyberphysical systems since earning his Ph.D. at U.Va. in 2001. He is now editor in chief of Association for Computer Machinery’s Transactions on Sensor Networks, one of the leading publications in the field, and is also chairing the ACM/IEEE International Conference on Cyber-Physical Systems, the flagship conference in the field.

Lu maintains an extensive research program. For instance, he has a grant from the National Science Foundation to develop advanced wireless monitoring and control systems for civil infrastructure. One use of this system is to help buildings and bridges respond to earthquakes. A challenge is designing the network architecture to optimize performance and longevity. With support from the National Institutes of Health, Lu has also conducted a series of clinical trials of a sensor network that collects vital signs from patients at Barnes-Jewish Hospital in St. Louis. This system is a way to extend the level of monitoring found in intensive care units to clinical wards.

“I was very fortunate to have been at U.Va.,” he says. “Jack Stankovic and his colleagues were at the forefront of developing sensor network technology. They set the standard for the kind of mentorship and research environment I wanted to create.”

TIAN HE

As a researcher, Tian He (CS ’04) is driven by the desire to create practical solutions to real-world problems, solutions that both advance the state of the art and improve the lives of others. He has a number of research interests, ranging from integrated sensor systems such as VigilNet, which he first encountered as a Ph.D. student of Jack Stankovic, to wireless systems, vehicular networks, and distributed and real-time systems in general.

His work has been well received and cited more than 10,000 times. As an associate professor at the University of Minnesota, He earned an NSF CAREER Award as well as a series of best paper awards from the top journals in his field. His university has also named He its McKnight Land-Grant Professor.

He credits his colleagues and mentors at U.Va. for giving him the tools he needed to launch a productive career. “In addition to providing an opportunity to develop my technical skills, U.Va. gave me valuable experience in leadership and management,” He says. “I was very lucky to be a graduate student at U.Va.”

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