Technologies and Foundations for Robust and Secure Networked Systems

CNS
Center for Networked Systems

Making MuSyC: Multi-scale Systems Center

Members of the Center for Networked Systems and researchers at nine other universities are part of a new research center charged with finding ways to improve the design of computing systems ranging from large data centers to tiny brain sensors. In its first three years, the Multi-Scale Systems Center (MuSyC) will focus on tackling a critical issue affecting multiple scales: energy efficiency.

"Energy is one of the key issues to be solved in order for systems to work more efficiently," said UC San Diego Jacobs School of Engineering professor Tajana Simunic Rosing (pictured), who is leading MuSyC's Large-Scale Systems effort. "At a very small scale such as a brain-machine interface, without energy you cannot do anything at all. At a very large scale such as a data center, if you are not efficient about how you deal with energy, you go bankrupt."

MuSyC is funded at a level of $3 million per year for three years by the Defense Advanced Research Projects Agency (DARPA) and industry members of the Semiconductor Research Corporation (SRC). Its kickoff meeting was held in mid-November.

According to the new research center, its multi-scale approach stems from recognition that "a new generation of applications is emerging that are destined to run in distributed form on a platform that meshes high-performance compute clusters with broad classes of mobiles, surrounded in turn by even larger swarms of sensors. The broad majority of these new applications can be classified as distributed sense and control systems that go substantially beyond the 'compute' or 'communicate' functions traditionally associated with information technology."

By focusing on energy, MuSyC aims to pave the way for 'energy smart' distributed systems that are deeply aware of the balance between energy availability and demand, and that can adjust their behavior through dynamic and adaptive optimization through all scales of design hierarchy.

New Associate Director
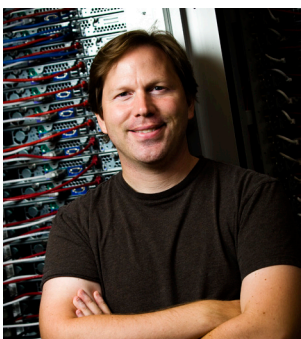
CNS recently announced the appointment of Jacobs School of Engineering professor Stefan Savage (at left) to fill a newly-created position of Associate Director. As CNS endeavors to grow over the next five years, the center identified Savage as someone who could assist with the duties of networking with industry collaborators and integrating a multitude of ongoing projects into a single, integrated research focus. Savage is an Associate Professor in the department of Computer Science and Engineering and his research includes the study of Internet security problems, high-availability Internet systems, intelligent network traffic analysis, and efficient self-configuring wireless networks. Professor Savage is a recognized leader in systems, networking and security research. He joined the CSE faculty in January 2001 and has been a faculty member of CNS since its inception.

CNS Members

AT&T · hp invent · Google · MOTOROLA · QUALCOMM · NetApp · Sun microsystems · CISCO

Four CNS Faculty Get Support from Yahoo!

This fall, Yahoo!, Inc. continued its track record of funding promising research projects at CNS when it provided three generous gifts to four CNS faculty members. CSE Associate Professor Alin Deutsch (pictured below) and CSE Project Scientist Ken Yocum received a joint gift to fund their work in the area of incremental workflow systems.

The second gift was provided to Professor Amin Vahdat in support of a project he is conducting to develop techniques which will allocate storage infrastructure to meet distributed application requirements. The third gift was awarded to CSE Associate Professor Stefan Savage in support of his work in computer security.
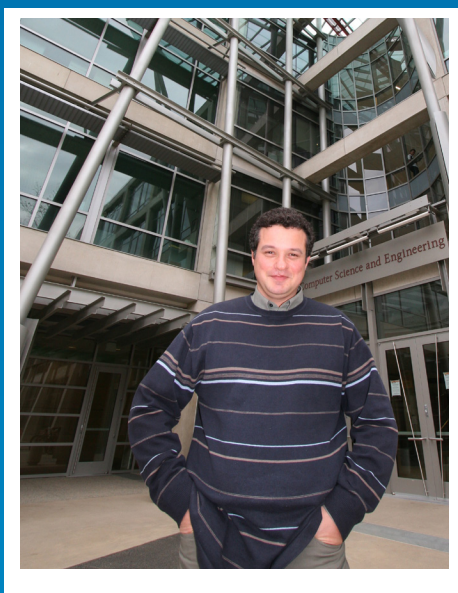
CNS Director Receives Engineering Leadership Award

In September CNS Director Amin Vahdat was awarded the Gordon Engineering Leadership Center's Gordon Fellows Medal in recognition of his accomplishments as a researcher in the areas of distributed systems and data center architecture and of his leadership in forging academic and corporate research partnerships as the Director of CNS.

The Gordon Center was established in January 2009 with the mission of educating and training effective engineering leaders who create new products and jobs that benefit society. In order to provide positive role models for students of engineering, the Gordon Center holds an annual awards ceremony to recognize exemplary engineers at the high school, undergraduate, graduate, and professional level. Recipients of the Gordon Fellows Medal not only must be outstanding engineers within their respective fields but must also have a proven record of leadership success. Professor Vahdat was one of three inaugural professionals to receive the Gordon Center's award.

Recent CNS Graduates

Mikhail Afanasyev graduated with a Ph.D. in Computer Science and is now a post-doctoral researcher at CSIRO in Brisbane, Australia. Afanasyev completed his dissertation, "Overhearing in 802.11 Mesh Networks," with the guidance of his advisor, Alex C. Snoeren.

Yuvraj Agarwal graduated with a Ph.D. in Computer Science after defending his dissertation, "Building Aggressively Duty-Cycled Platforms to Achieve Energy Efficiency." Agarwal continues to collaborate with his advisor, Rajesh Gupta, as a post-doctoral researcher for the CSE department at UC San Diego.

Mehran Bozorgi graduated with a M.S. in Computer Science after submitting a thesis proposing "A Machine Learning Framework for Classifying Vulnerabilities and Predicting Exploitability." His advisor was Lawrence Saul. Bozorgi is now a Software Engineer at Google.

Jerry Chou graduated with a Ph.D. in Computer Science after defending his dissertation, "A New Network Architecture for Future Optical Networks: Coarse Optical Circuit Switching by Default, Rerouting Over Circuits for Adaptation." His advisor was Bill Lin. He is now working as a Software Engineer at Lawrence Livermore National Labs.

Nicola Onose graduated with a Ph.D. in Computer Science after defending his dissertation "Uncovering the Full Potential of Data Services." Onose now holds a post-doctoral researcher position at UC Irvine. His advisor was Alin Deutsch.
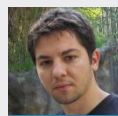
Todor Ristov graduated with an M.S. in Computer Science and is currently interning with CNS member company Motorola.

Making MuSyC: Scientists Explore Energy Efficiency in Multi-Scale Computing Systems

The new center's research agenda is initially structured to explore distributed sense and control systems (led by UC Berkeley's Alberto Sangiovanni-Vincentelli), large- scale systems (led by UC San Diego's Rosing), and small-scale systems led by Douglas Jones of the University of Illinois at Urbana-Champaign (UIUC). Another theme – exploring intermediate-scale systems such as mobile and portable devices – is foreseen, pending additional funding after MuSyC's first year of operation.

UC San Diego is taking the lead on large-scale systems because of existing expertise and projects underway within the Jacobs School's Computer Science and Engineering (CSE) department, the Center for Networked Systems (CNS), and the California Institute for Telecommunications and Information Technology (Calit2). The Calit2-based GreenLight project, funded by the National Science Foundation (NSF), will collaborate closely with MuSyC.

"One of the big attractions of having UCSD as a leading institution in this center is the infrastructure we bring to the table," said Rosing. "Part of that infrastructure is the NSF GreenLight project, which focuses on better understanding energy efficiency at the data-center scale. The GreenLight Instrument recently deployed on this campus [pictured below] will allow us to measure efficiency, quantify it, and help people design more efficient systems going forward."

The Large-Scale Systems team led by Rosing aims to develop a multi-scale energy management solution to monitor, model and manage energy across a spectrum of heterogeneous devices and hierarchy levels in large-scale data centers.

In addition to Rosing, three other UC San Diego researchers are involved in MuSyC. All have faculty appointments in the Jacobs School of Engineering's CSE department: CNS Director Amin Vahdat; Calit2 Associate Director Rajesh Gupta; and Allan Snavely, Associate Director at the San Diego Supercomputer Center (SDSC).

Gupta's work is focused on active duty-cycling, e.g., when a whole server is not needed, how to replicate some of its functionality in a low-power manner so the server can sleep while it still looks as if it is awake. Vahdat is developing a scalable network infrastructure that can be tested in a real-life data center, to measure and show how much faster and more energy efficient it is. SDSC's Snavely will look at how to characterize applications and machines, to better understand how much power and what kind of performance can be delivered for running a specific application on a specific machine. Rosing's lab will then figure out the right way to partition jobs and to control power and cooling within a data center such as the modular GreenLight Instrument on the UCSD campus.

"So it's a way to put together a bunch of different pieces that until now have been studied disjointly, and to show the benefits of doing this together," explained Rosing. "We're convinced that it is by doing cross-layer optimization that the biggest benefits can be obtained."
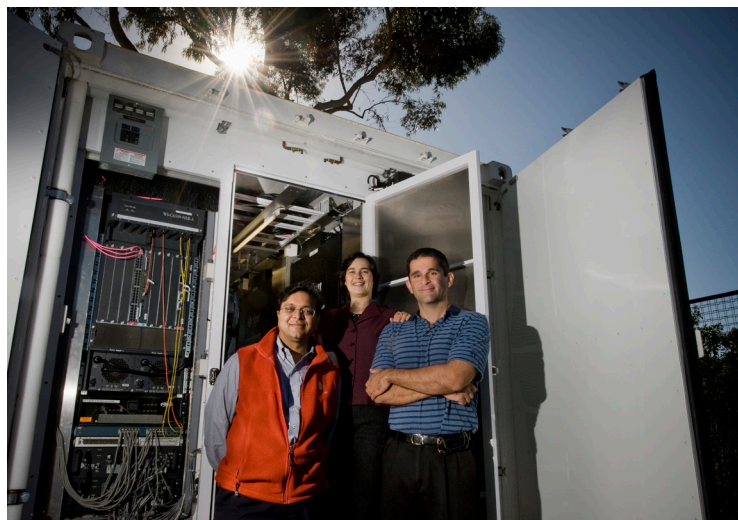
CNS and MuSyC investigators (l-r) Rajesh Gupta, Tajana Simunic Rosing and Amin Vahdat pose in front of the GreenLight Instrument modular data center.

Four other universities are part of the Large-Scale Systems research within MuSyC. At Stanford University, John Ousterhout will study novel memory architectures and software interfaces to those architectures, to better understand the energy implications of very high performance required by applications such as Facebook that could be done very, very fast and therefore more energy efficiently. UC Berkeley's Randy Katz will focus on the interface between the data center and the SmartGrid, i.e., scheduling of jobs across distributed data centers. At the University of Southern California, Jeff Draper and Bob Lucas are exploring resilience and reliability in applications such as video streaming where data recovery does not have to be 100 percent perfect. And Vivek Sarkar and Lin Zhong of Rice University are investigating the application layer – how to make managed runtimes more efficient.

Other academic institutions participating in MuSyC include Caltech, North Carolina State University, University of Maryland, University of Michigan, University of Pennsylvania, and UIUC.

According to UCSD's Rosing, MuSyC's Large-Scale Systems team has ambitious goals for its first year. "We want to gain a clear understanding of what the biggest sources of inefficiency are," she noted. "We also want to understand clearly the metrics for different classes of applications, to identify the workloads that make sense to run that would represent well what is out there in the real world, so we can benchmark and show our success. And finally, we hope to work on some initial deployments within the GreenLight infrastructure."

CitiSense: Designing a Cell Phone-Based Air Pollution and Health Monitoring Network

You want to go for a run, but you don't want to run in polluted air that might aggravate your asthma. UC San Diego computer scientists are creating a network of environmental sensors that will help you avoid air pollution hot spots that exist exactly when you are planning your route. The system will provide up-to-the-minute information on outdoor and indoor air quality, based on environmental information collected by hundreds, and eventually thousands, of sensors attached to the backpacks, purses, jackets and board shorts of San Diegans going about daily life.

This is "CitiSense: Adaptive Services for Community-Driven Behavioral and Environmental Monitoring to Induce Change." The project is the vision of an interdisciplinary team which includes two Center for Networked Systems members, Hovav Shacham and Tajana Simunic Rosing, along with other researchers from the Jacobs School's Department of Computer Science and Engineering (CSE) and the California Institute for Telecommunications and Information Technology (Calit2). The group recently won a $1.5 million grant from the National Science Foundation to solve the many technical challenges that stand in the way of applications that merge the cyber and physical worlds. The award is funded under the American Recovery and Reinvestment Act of 2009 -- the so-called 'stimulus' funding.

"San Diego County has 3.1 million residents, 4,000 square miles, and only five official EPA air quality monitors. We know about the air quality in those exact spots but we know much less about the air quality in other places. Our goal is to give San Diegans up-to-the-minute environmental information about where they live, work and play—information that will empower anyone in the community to make healthier choices," said William Griswold, the principal investigator on the grant and a CSE professor in the UC San Diego Jacobs School of Engineering.

The goal of CitiSense is to build and deploy a wireless network in which hundreds or thousands of small environmental sensors carried by the public rely on cell phones to shuttle information to central computers where it will be analyzed, anonymized and reflected back out to individuals, public health agencies and San Diego at large. At the same time, the sensor-wearing public will have the option to also wear biological monitors that collect basic health information, such as heart rate. This combination of sensors will enable the team's medical team to run exacting health science research projects, such as investigating how particular environmental pollutants affect human health. UCSD School of Medicine professor Kevin Patrick, who directs Calit2's Center for Wireless and Population Health Systems (CWPHS), will lead the medical efforts.

Building a large-scale system that integrates sensors and other digital technologies into the physical world will require advances in a number of computer science areas including power management, privacy, security, artificial intelligence and software architecture. "It is a tremendous challenge to integrate a number of technologies and then deploy them outside—in the wild," said Griswold.

Capturing high quality data from sensors in uncontrolled environments is another challenge the computer scientists face. "Sensors will differ. Sensors will fail. People will breathe on them. And so there is the question of how you get good data in these conditions. We have to find a way to process the data to remove the noise," said Griswold, who noted that computer science professor Sanjoy Dasgupta and a team of student researchers is using statistical artificial intelligence (AI) to do just this.

Software architecture and cyberinfrastructure are additional areas in which breakthroughs will be needed. The computer scientists are developing new approaches to writing code for software systems that are open and flexible yet private and secure.

For example, if someone develops a new application for monitoring carbon dioxide, the computer scientists want to be able to drop the application into the system and have it not only work—but interact with existing systems in terms of data, power management and workflow. Computer science professors Ingolf Krueger and William Griswold are leading these efforts. In part, they are building on Krueger's previous work in service-oriented architecture, which can keep various components—like machine learning, power management and security code—much more separate than in traditional software systems, where functional elements are often so woven into the source code that it is difficult to quickly update any one aspect of the software.

"We are addressing major problems of the day of tremendous social, environmental and economic importance. When you attach the science and engineering to the problems of the day, it drives the research in a very exciting
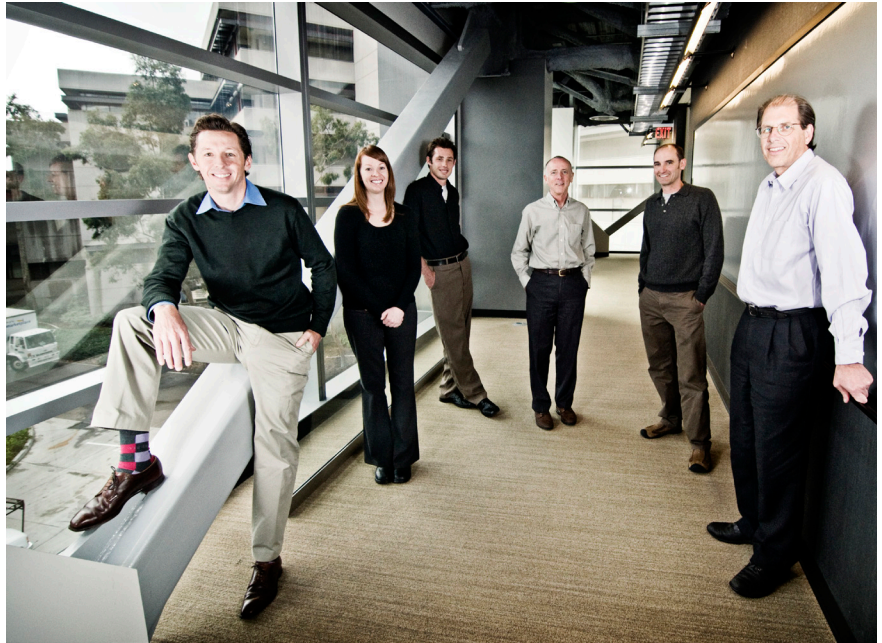
Dr. Kevin Patrick (center) with his team in Calit2's Center for Wireless and Population Health Systems, are working on the medical aspects of the CitiSense project.

way," said Griswold, who noted that Qualcomm, Inc., is donating funds for the cell phones needed by the project, and Seacoast Science, Inc., is providing expertise in chemical sensors.

The CitiSense project could lead to fundamental advances in modularity techniques for composable adaptive systems, adaptive power management, cryptographic methods for open systems, interaction design for the mobile context, and statistical interference under multiple sources of noise.

CNS Researchers Make CitiSense

Mobile phones and other handheld devices are traditionally designed to serve one person—the user. Including these electronics in advanced computing systems that have other priorities will require new power and workload management strategies. In the CitiSense project, computer science professor and CNS member Tajana Simunic Rosing and her graduate students are developing systems to ensure that the phones and other mobile devices serving as stepping stones between environmental sensors and the centralized computing infrastructure will not drop calls or suffer other hits to performance.

Rosing's team is also investigating how sensors fixed in the environment—rather than carried around by the general public—might be powered by solar, wind, or vibrational energy instead of batteries. In addition, the computer scientists are considering how these fixed sensors might rely on nearby handheld devices to send environmental information to central computers.

Another CNS researcher, computer science professor Hovav Shacham (pictured), will lead a team focused on security and privacy issues, which are particularly challenging given the limited computational power of sensors and other embedded devices.

Facebook CTO Shares Lessons Learned

The exponential pace of growth that has occurred within the last fifteen years at some technology companies has presented previously unknown design and scaling challenges that have demanded original and creative business and development solutions. What lessons have been learned and what models have been created about how to manage technologies that emerge at an exponential rate? In October CNS hosted a talk by Jeff Rothschild, Vice President of Technology at Facebook, who outlined what he has learned since arriving at Facebook four years ago to tackle novel problems posed by the social networking site's exponential growth and complex usage patterns.

Facebook began as a small project in the dorm room of two Harvard undergraduates and is one of the largest Web sites today – whether counting the number of users (more than 300 million active users), the amount of time spent on the site per user, the number of objects stored on the site, the rate at which these objects are accessed, or the number of connections made between users and objects. That growth poses significant challenges in design and hardware scalability.

Rothschild cited Facebook's photo service to illustrate the unusual challenges created by the site's complexity. Over 20 billion photos are currently stored on Facebook at four different resolutions and two billion are uploaded every month. However, unlike with other photo album sites, Facebook photos overlay a lattice of social connections and notifications that make the management of these objects far more complex. The challenge of managing Facebook is not only in storing and organizing the raw data entered into it – such as the 20 billion photos with two billion being uploaded every month – but also in managing the relationships between all of the individual pieces of data.

Facebook adopted commercial or open-source solutions, then devoted the company's engineering resources to optimizing and

Facebook CTO Jeff Rothschild (right) with UCSD alum Taner Halicioglu, Class of '96, Revelle College

customizing these off-the-shelf technologies for Facebook's specific needs. Only in extremis are engineering resources used to create original applications or tools, according to Rothschild, pointing to the unique coding challenges involved with the development of Facebook's Web interface. Though the architecture of the Facebook site resembles that of others on the Web, its social networking aspects as well as the massive size and rate of growth of the site presented a number of novel development conundrums. PHP was chosen as the scripting language to implement Facebook's Web interface because it is a simple language to learn, write, read and debug. However, PHP has its liabilities, not all of which were known when it was chosen as the Web interface language. Using available open-source applications, Facebook engineers developed optimizations to work around these shortcomings, such as making APC improvements (lazy loading, cache priming, and more efficient locking semantics for variable caching), custom extensions (memcache client extension and asynchronous event-handling mechanism), and a compiler that compiles PHP to C++ and then generates a native executable.

Facebook considers its dedication to participation in the open-source community to be a key to

continued viability. For all of the applications it has used, it has also created and given back many more. In his talk, Rothschild noted that any competitive advantages conferred by keeping improvements proprietary are outweighed by the quality of the improvements made by the open-source community.

"We will win when other people gain value from this software because they are going to make it stronger and better," said Rothschild. "We could never have built Facebook without PHP, without MySQL, without memcache – all technologies which we were able to adopt from other companies, and we benefited from their decision to open source. So we've open-sourced many of our projects today, pretty much anything we think other people would find useful."

Going forward, Facebook sees research challenges that include load balancing, balancing programmer productivity with machine efficiency, graph-based caching and storage systems, object discovery and ranking, and many others. No shortage of challenges, said Rothschild, and that means no shortage of jobs: he noted that despite the slow economy, Facebook is actively recruiting to expand its engineering development team.

New Faces at CNS

The Center for Networked Systems continues to grow and attract new researchers – while also reinforcing the involvement of current CNS members in the leadership of the center. Among them:

YY ZHOU
CNS Welcomes Its Newest Faculty Member

CNS is excited to welcome Yuanyuan (YY) Zhou as its newest faculty member.

Professor Zhou joined her home department, Computer Science and Engineering, this fall as the department's first holder of the Jacobs School's Qualcomm Endowed Chair in Mobile Computing. Her research covers three distinct sub-disciplines: computer systems; programming languages/software engineering; and computer architecture. Professor Zhou has pioneered new techniques for tolerating certain errors in programmer code, allowing developers to forego the currently impractical task of eradicating all coding errors. Professor Zhou brings a software engineering and systems focus to her computer architecture research. Some of her recent architecture work has focused on the difficult problem of identifying potential concurrency-related bugs.

GEORGE PORTER
New Post-doctoral Researcher Hired by CNS

Dr. George Porter joins CNS as a post-doctoral researcher after working as a Principal Investigator in the Big Data Research Group at Sun Microsystems Labs. Dr. Porter's research interests include distributed systems, operating systems, networking, and data intensive computing.

He is currently collaborating with Professor Amin Vahdat's research team on issues related to data center architecture.

CNS Advisory Board Votes to Fund Seven New Projects

The CNS Advisory Board, comprised of representatives from CNS industry members, met this past summer at the July 2009 Research Review and voted to fund seven new projects for the 2009-2011 support cycle. The projects span a wide spectrum of current hot topics in systems and networking research: security in cloud computing; routing in wireless networks; data management; data center switch architecture; and the fine-grained measurement of bandwidth usage.

This year the Advisory Board selected the following seven proposals as beneficiaries of the grants program:

- Data Center Switch Architecture
  Principal Investigator: Amin Vahdat

- Future is Cloudy: Security and Availability Issues in Outsourced Computing Infrastructure
  PIs: Hovav Shacham and Stefan Savage

- Measuring and Allocating Bandwidth at Fine Time Scales
  PIs: George Varghese and Amin Vahdat

- Opportunistic Routing for Mesh Wireless Networks
  PIs: Tara Javidi (at right), Per Johanssen, Anders Nilsson, Abhijeet Bhorkar

- Proactive Endpoint Risk Management Meets Byzantine Fault Tolerance
  PI: Keith Marzullo

- SeaWall: Managing the Derived Data Deluge
  PI: Ken Yocum

- Understanding Failure Patterns in Real Networks
  PIs: Alex C. Snoeren, Kirill Levchenko and Stefan Savage

Every summer CNS accepts proposals for the CNS Research Grants Program. CNS research grants generally run for two years and are awarded to support cutting-edge research in the area of systems and networking. This program is the core of CNS's research activity, with the work of many past projects resulting in the further awarding of large federal grants, groundbreaking publications in top conferences, Ph.D. dissertations and best-paper awards. Researchers are invited to present their proposals at the July review, and then the CNS Advisory Board meets to vote on which of the proposals will receive funding.

CNS Lecture Series

CNS Lectures feature key players in the research and development of systems and networking technology and are free and open to the public. Summer and fall lectures included:

• **Rich Wolski**, Professor at UC, Santa Barbara and CTO of Eucalyptus Systems, Inc. presented "Eucalyptus: An Open Source Infrastructure for Cloud Computing" on June 16, 2009.

• **Z. Morley Mao**, Professor of the department of Electrical Engineering and Computer Science at the University of Michigan, Ann Arbor spoke August 10, 2009 on "Intelligent Network Measurement for Diagnosis and Attack Defenses."

• **Jeff Rothschild**, Vice President of Technology at Facebook spoke October 8, 2009 on "High Performance at Massive Scale: Lessons learned at Facebook." (see page 7)

• **Wenn-Han Wang**, Vice President, Intel Labs and Director of Systems and Circuits Research spoke November 6, 2009 on "Powering Future Systems Innovations."

• **Sharad Agarwal** of Microsoft Research presented "Volley: Automated Data Placement for Geo-Distributed Cloud Services" on November 15, 2009.

To view webcasts of our past lectures, visit the Lectures Archives page under the "News and Events" tab on the CNS Web site.

Upcoming Events

January 20-21, 2010
CNS Winter Research Review

The winter Research Review will feature keynote speaker Stan Williams, HP Senior Fellow and Director of the Information and Quantum Systems Lab at HP Labs. Also on the agenda: talks by two of our industry affiliates, a roundtable panel hosted by our member companies to discuss their top current research concerns, progress reports from recipients of the CNS Research Grants Program, a graduate student research poster session and reception, and numerous opportunities for informal interactions with CNS faculty, researchers and graduate students.

Attendance at the Winter 2010 Research Review is limited to industry sponsors and invited guests.
For more information, please contact *kkrane@ucsd.edu* or call 858-822-5964.

Mission and Objectives of CNS

The mission of CNS is to develop key technologies and frameworks for networked systems. By combining our research talents and strengths in partnership with industrial leaders, CNS achieves critical mass and relevant focus, accelerating research progress and creating key technologies, frameworks and systems understanding for robust, secure networked systems and innovative new applications. CNS also works to educate the next generation of top students with a perspective on industry-relevant research and to train students on how to continue their leadership throughout their careers. This is accomplished by bringing together leading faculty, students, and companies to investigate the most challenging, interesting and important problems in computer networks.

If you are interested in joining the Center, please contact Director Amin Vahdat at vahdat@cs.ucsd.edu.